

Mashkiiziibii Sea Lamprey Stewardship Plan



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Acronyms

GLFC	Great Lakes Fishery Commission
MLC	Minimum lethal concentration
MNRD	Mashkiiziibii Natural Resources Department
PE	Population estimate
SLCP	Sea Lamprey Control Program
SMRT	Sterile Male Release Technique
SOP	Standard Operating Procedures
TFM	Lampricide - 3-trifluoromethyl-4-nitrophenol
USFWS	United States Fish and Wildlife Service
YOY	Young of year

Executive Summary

The Bad River, a highly productive Lake Superior tributary, drains approximately 659,000 acres and provides more than 391 miles of cold and cool-water fish habitat. Since the discovery of the first sea lamprey in the Bad River during 1955, the river has developed into the largest sea lamprey producing tributary on the south shore of Lake Superior. Over the past six decades, control of sea lampreys in the river has been maintained primarily through lampricide treatments. The U.S. Fish and Wildlife Service (Service), in partnership with the Great Lakes Fishery Commission (GLFC), controls sea lamprey populations in the Great Lakes. Vision statements included in the Bad River Band of Lake Superior Chippewa Indians (Band) *Integrated Resource Management Plan and the GLFC Strategic Vision* address protecting the environment by reducing the use of chemicals in the river. The GLFC continues to investigate and develop alternatives to chemical control of sea lampreys. Barriers are currently the only viable alternative to lampricide treatments. A suite of experimental removal options may also be considered as supplemental methods of control. The goal of the *Mashkiiziibii Sea Lamprey Stewardship Plan* is intended to eventually reduce the use of lampricide in the Bad River by providing an effective and dynamic integrated plan based on good science and the vision statements of the Bad River Band and the Great Lakes Fishery Commission.

Mashkiizibii Sea Lamprey Stewardship Plan Goal

The goal of the *Mashkiizibii Sea Lamprey Stewardship Plan* (Plan) is to provide an effective and dynamic integrated plan based on the best available knowledge and the vision statements of the Band, the GLFC, and the Service.

Looking forward to the Seventh Generation, the Band hopes to achieve the following vision of the Bad River Indian Reservation:

Our vision is of a Reservation where all living things are in natural balance and are no longer threatened with negative anthropogenic (human-made) impacts; where all individuals and institutions value the gifts of Mother Earth and willingly choose to act in a manner which ensures achievement of sustainable environmental and economic goals; where every Bad River member, young and old, shares in the benefits of a healthy environment; where each Bad River member maintains the traditional cultural values necessary to live harmoniously with the natural world; where every Bad River member accepts the personal responsibility and challenge of pollution prevention in his or her daily life, and is committed to moving from a consumer-oriented society to a conservation-minded society; where the Bad River Band gives high priority to the protection of its environment, its natural resource base, and the functions of the natural systems on which all life depends; where the majority of the Bad River Band's subsistence needs are provided for by the local community (Elias, 2001).

The vision statement on integrated sea lamprey control contained in the *Strategic Vision of the Great Lakes Fishery Commission (2021-2025)* (GLFC 2001):

The GLFC will suppress sea lamprey populations to levels that permit achievement of fish community objectives for each Great Lake and to continue investment in research and development of supplemental methods to augment the traditional sea lamprey control program.

The vision statement of the Service:

We will continue to be a leader and trusted partner in fish and wildlife conservation, known for our scientific excellence, stewardship of lands and natural resources, dedicated professionals, and commitment to public service.

Description of the Bad River and its Fishery

The Bad River system provides more than 391 miles of cold and cool-water fish habitat and drains approximately 659,000 acres. Major cold-water tributaries to the Bad River include the Potato, Tyler Forks, Brunsweller, White, and Marengo rivers. Within the exterior boundaries of the Bad River Reservation (Figure 1), the Bad River system is composed of approximately 200 miles of stream.

The main stem of the Bad River (Figure 2), downstream from the confluence with the Marengo River, supports a diverse fish community which includes lake sturgeon/namé (*Acipenser fulvescens*) and walleye/Ogaa (*Sander vitreus*). Both species are anadromous, although resident populations exist in the river. Other anadromous fishes found in the lower Bad River include white (*Catostomus commersoni*), longnose (*Catostomus catostomus*), silver (*Moxostoma anisurum*), and shorthead redhorse (*Moxostoma macrolepidotum*) suckers/Namebin.

Resident fishes in the lower Bad River include northern pike/Ginoozhe (*Esox lucius*), muskellunge/Maashkinoozhe (*Esox masquinongy*), yellow perch/Asaawe (*Perca flavescens*), smallmouth bass/Noosa'owesi (*Micropterus dolomieu*), rock bass/Ashigan (*Ambloplites rupestris*), and a variety of forage and minnow species. In addition, at least five nonindigenous fish species reside in this portion of the Bad River including the sea lamprey (*Petromyzon marinus*), white perch (*Morone americana*), rainbow smelt (*Osmerus mordax*), carp (*Cyprinus carpio*), and Eurasian ruffe (*Gymnocephalus cernuus*).

Upstream from the confluence with Marengo River, the Bad River and its major tributaries support resident brook/maazhmegoons (*Salvelinus fontinalis*) and brown (*Salmo trutta*) trout and provide spawning and nursery areas for anadromous coho (*Oncorhynchus kisutch*), chinook (*Oncorhynchus tshawytscha*) and pink (*Oncorhynchus gorbuscha*) salmon/miskwemeg wag, and rainbow/namegoshens (*Oncorhynchus mykiss*) and brown trout. Of these salmonids, only the brook trout is native to these tributaries. Forage fish (minnows, darters, and dace) are also present, but a comprehensive species inventory has not been conducted. Sea lampreys, rainbow smelt, and perhaps other non-native fish species inhabit some of these waters.

The White River also provides spawning habitat for walleye and a variety of sucker species (longnose and white suckers, and shorthead and silver redhorse) that migrate into this system from Lake Superior. Lake sturgeons have been documented downstream of the White River hydroelectric dam and it is likely that spawning occurs in the system (Mattes 2001). While the dam is a barrier to fish migration, prior to dam construction a waterfall at this site prevented upstream fish migration.

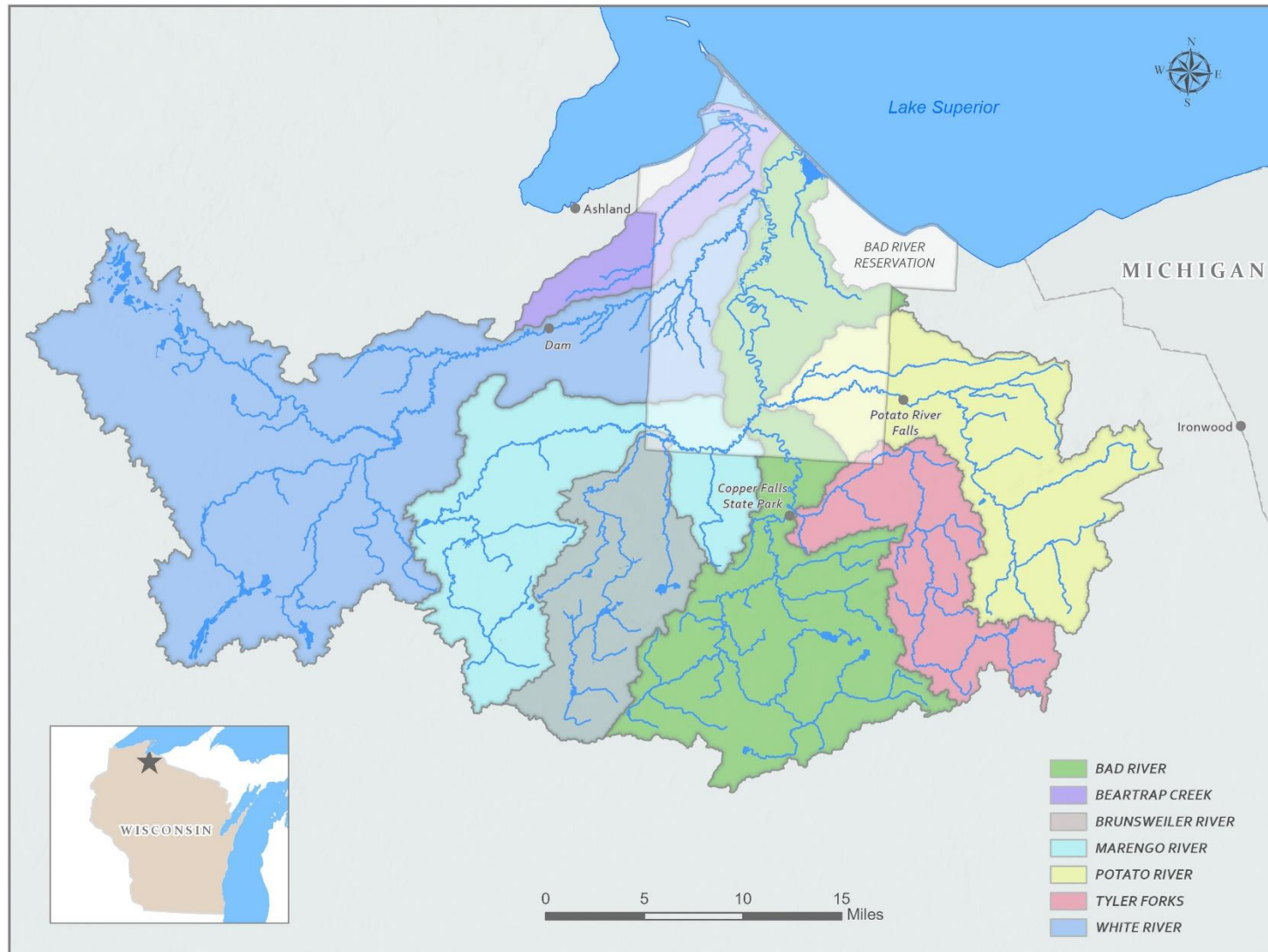


Figure 1. Exterior boundaries of the Bad River watershed and sub-watersheds.

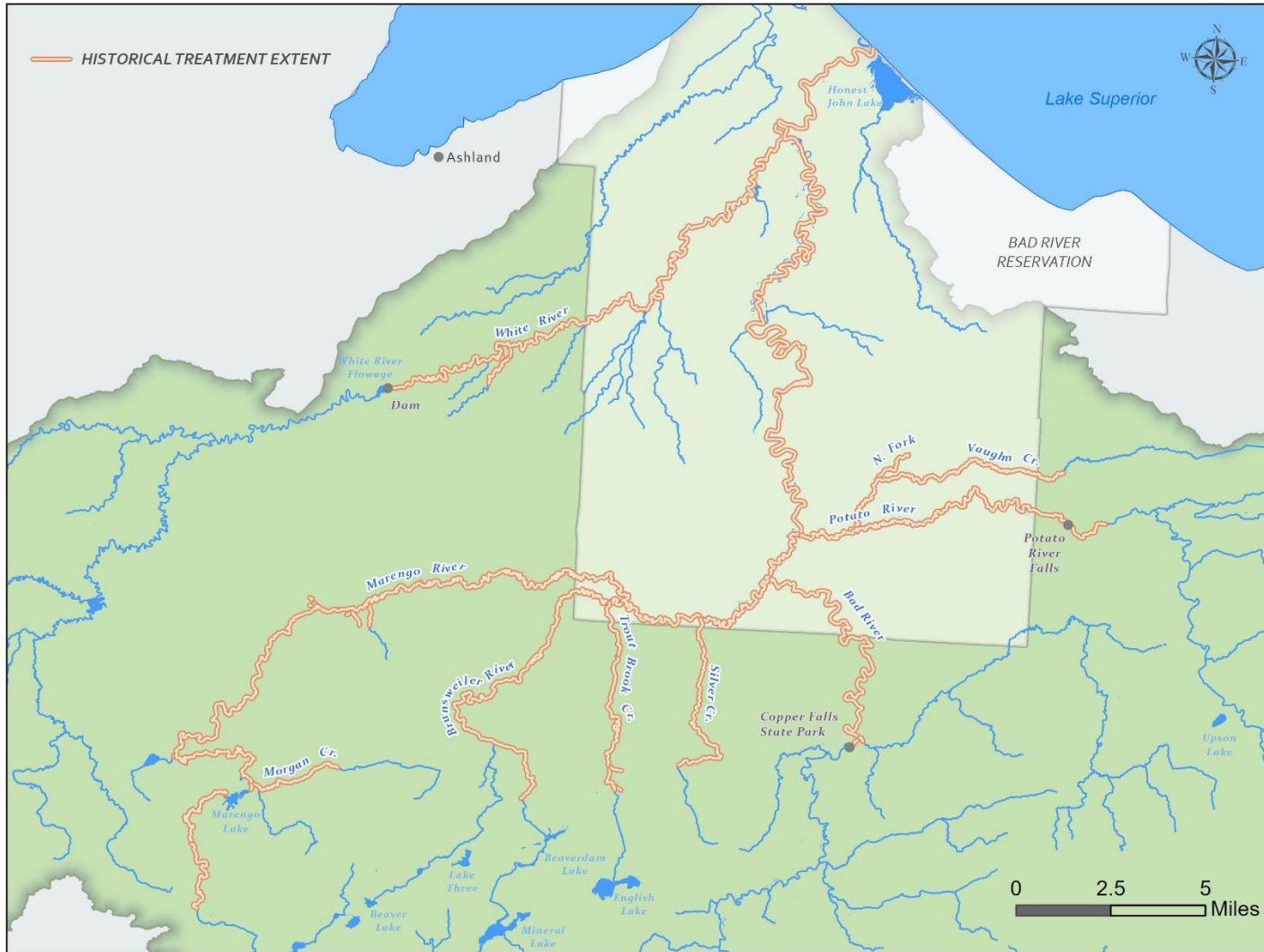


Figure 2. Mainstream and major tributaries of the Bad River watershed including historical treatment extent.

Sea Lamprey

Native to the North Atlantic Ocean, sea lampreys entered the Great Lakes during the 1800s and were first recorded in Lake Superior in 1938. In the Atlantic, sea lampreys live in saltwater, feed on large ocean host fish, and migrate to freshwater streams to spawn. Sea Lampreys found in the Great Lakes have adapted to live their life entirely in freshwater.

Sea lampreys are parasitic on other fishes. The mouth of a sea lamprey consists of a tooth-lined sucking disc, which enables the lamprey to attach to its host. The lamprey rasps a hole in the side of its host with its rough tongue and secretes an anticoagulant to keep the blood from clotting and the wound open. A lamprey may remain attached to its host for hours, days, or even weeks, while it feeds on blood and other body tissue fluids. A sea lamprey kills approximately 40 pounds of fish during its lifetime and sea lampreys in the Great Lakes annually kill significant numbers of trout, salmon, whitefish, and other host fish.

The Bad River produces more larval sea lampreys than any other U.S. tributary of Lake Superior, contributing 20-30% of the parasitic sea lamprey population (Schleen et al. 1996). This high productivity of parasites threatens Lake Superior fisheries. A sea lamprey stewardship plan is beneficial to all resource users and will maintain and enhance the fishery of the Bad River system and help protect the fishery in Lake Superior.

Sea lamprey populations in the Great Lakes have been reduced by approximately 90% of pre-control levels primarily through the application of the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) to streams which targets the removal of sea lampreys during their larval phase. The reduction of sea lampreys has allowed fish populations to rebound (Bronte et al. 2004). Despite this success, continuous control is required because a sufficient number of larval sea lampreys remain after treatments and cause high mortality of fishes in Lake Superior (e.g., the combined loss of lake trout/Namegos (*Salvelinus namaycush*)). Spawning adult sea lampreys continue to reproduce annually in the system and repopulate the river.

While lampricide treatments have proven to be an effective control technique, reducing the dependence on lampricides continues to be important to the Band, Service, and GLFC. Currently, barriers are the only alternative control method to lampricides. Future alternative control methods include the development and application of pheromone technologies and other experimental removal options that are being investigated to determine their feasibility for implementation.

The Band is committed to control of sea lamprey populations through an integrated approach that works toward a goal of minimizing and eventually eliminating the use of TFM in the Bad River watershed and actively engaging and involving community members in the process. Tribal leaders and the Mashkiziibii Natural Resources Department (MNRD) have expressed strong interest in the use of alternative and supplemental controls for sea lampreys in the watershed to assist in the reduction of lampricide use.

The History of Sea Lamprey Activities in the Bad River Watershed

Larval Assessment

Assessment activities in the Bad River began during 1952 when Service crews identified the system as having significant potential to produce larval sea lampreys. The Service verified the presence of sea lampreys in the Bad River system during 1955. Personnel from the Service's Marquette Biological Station continue to conduct sea lamprey assessments in the Bad River with assistance from MNRD. These assessments include surveys to determine numbers of larvae, document larval distribution, prepare for lampricide treatments, assess the success of the previous treatment, monitor re-established populations, and search for new infestations. Data from assessments are used to document habitat characteristics of sea lamprey-producing streams, estimate larval populations, and provide information on sea lamprey production, growth, and survival.

The population of larval sea lampreys in the Bad River watershed (including the White, Marengo, Brunswiler, and Potato rivers) was collaboratively estimated by GLIFWC, MNRD, and the Service during 1991, prior to lampricide treatment. A post-treatment estimate was made during 1992 that measured a 96% reduction in the larval sea lamprey population (from 951,735 prior to treatment to 38,056 after treatment; Schleen et al. 1996). Since that time, the population of sea lamprey larvae in the river has remained significantly high by the third year after treatment with a mean larval population estimate (PE) of 1,269,000.

Electric Barriers

Sea lamprey control activities in the system began during 1956 when Service crews installed electrical barriers on the Bad and White rivers. While the electrical barriers were targeted to control lampreys, they also served to provide information on the abundance of spawning-phase sea lampreys that were captured in traps at the electrical weir sites. The electric barriers were in operation through the 1960 season. They proved ineffective as control structures because during high water periods the barriers were easily negotiated by sea lampreys or became non-functional due to damage from debris and high water. Lampricide treatments became the primary means of controlling lampreys in the Great Lakes.

Lampricide Control

The Service first used TFM in Lake Superior tributaries during 1958 and in the Bad River during 1960. During 1962, after the first round of treatments in Lake Superior tributaries was complete, the lake-wide lamprey population was reduced by 84%. Since then, portions of the Bad River watershed have been treated by the Service on 25 occasions. A review of sea lamprey control activities and a biological inventory of non-target organisms (organisms other than sea lampreys) collected during these activities can be found in the Service document, *Background Information on Sea Lamprey Control in the Bad River (October 13, 1994)*, and in an appendix to that document (May 5, 1997), both available at MNRD. In addition, non-target mortality was monitored by MNRD in treatments beginning in 1997 and are documented in internal MNRD and Service reports.

Adult Assessment

The assessment of adult (spawning-phase) populations of sea lampreys is used to gauge the success of the sea lamprey control program. The Bad River adult sea lamprey PE is important because this river along with other Lake Superior stream populations are used to calculate the total number of spawning sea lampreys in Lake Superior. The estimate is obtained using portable assessment traps that are set at the lower falls in the Bad River and monitored by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) personnel working in partnership with the Service. About 10 percent of the spawning-phase sea lampreys captured in the traps in the river are marked and transported downstream for release. Some of these are later recaptured in the traps as they migrate back upstream and are then removed from the river. The number of lampreys captured, marked, released, and recaptured is used to estimate the total number of adult sea lampreys spawning in the river.

An annual index of adult Sea Lamprey abundance has been estimated in Lake Superior from 1986 to present. The adult index is derived by summing individual population estimates from traps operated in a specific suite of streams (index streams) during spring and early summer. Mark-recapture estimates are attempted in each index stream; however, in the absence of an estimate due to an insufficient number of marked or recaptured Sea Lampreys, abundance is estimated using the annual pattern of adult abundance observed in all streams and years and adjusted to the stream-specific average abundance estimate in the time series. The three-year (2020-2022) average adult index estimate in Lake Superior was 23,000 (PE: 106,724) and has been holding steady over the past five years (Figure 3).

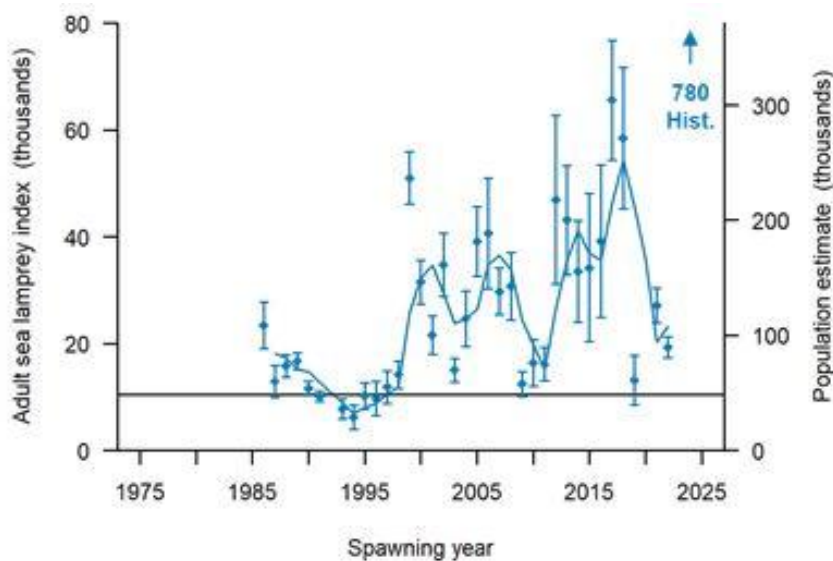


Figure 3. Index estimates with 95% confidence intervals (vertical bars) of Lake Superior adult sea lampreys, including historic pre-control abundance (as a population estimate) and the three-year moving average (line). The PE scale (right vertical axis) is based on the index-to-PE conversion factor of 4.64. The adult index in 2022 was 19,000 (95% CI 17,000-21,000). The three-year (2020-2022) average of 23,000 was above the target of 10,000. The index target was estimated as the mean of indices during a period with acceptable marking rates (1994-1998).

The Service has estimated the number of adult sea lampreys in the Bad River watershed annually since 1986 (Appendix 1). The average Bad River adult sea lamprey PE during the last 36 years has comprised about 33 percent of the total Lake Superior adult abundance.

The target sea lamprey population for Lake Superior is based on the fish community objective to *Suppress Sea lampreys to population levels that cause only insignificant mortality on spawning-phase lake trout* (Horns et al. 2003).

The GLFC's Lake Superior Committee agreed that an annual abundance of 46,400 (based on data through 2022) adult sea lampreys should lead to the target of 5 wounds per 100 lake trout and achievement of the fish community objective for Lake Superior. The target number and range were calculated from the average number of adult sea lampreys estimated for the five-year period (1994-1998) when wounding rates were closest to 5 marks per 100 lake trout. Wounding rates of less than 5 per 100 lake trout indicated that sea lampreys were inflicting less than 5% mortality on lake trout.

Memorandum of Stipulations

A Memorandum of Stipulations signed by the Band, Service and GLFC has facilitated efforts to control sea lampreys and address concerns of the Band. The first set of stipulations was drawn up prior to the 2001 lampricide treatment and has been updated for each subsequent treatment. The Memorandum of Stipulations for the 2021 treatment is included in Appendix 2. A current version will be developed for each future treatment.

Non-target Organisms

Mortality of non-target organisms during lampricide treatments has been a concern of fish managers since the implementation of the sea lamprey control program. The Service and other agencies have conducted studies to determine short-term and long-term effects of TFM on fish and other aquatic organisms. These studies have shown that TFM is a selective toxicant (i.e., TFM is relatively specific to sea lampreys), and when used according to label specifications, is acutely toxic to sea lampreys.

Some non-target organisms including burrowing mayflies (*Hexagenia spp.*), native lampreys, juvenile lake sturgeons (<100mm) in high alkalinity water, and tadpole madtoms (*Noturus gyrinus*) are sensitive to TFM at concentrations close to those applied during treatment. Once these sensitive species are identified in a river, the Service takes special precautions to reduce or avoid stress to the organisms.

Lake Sturgeon (Namé)

An example of an effort to reduce TFM induced stress on non-target organisms is ensuring treatments are scheduled when a species is least sensitive. Streams that have reports of spawning lake sturgeon are treated after August 1 to allow young-of-year lake (YOY) sturgeons to grow to a size where they are less sensitive to TFM. Since 1995, treatments of the Bad River have

been conducted during September after the manoomin harvest and when YOY lake sturgeon are less vulnerable to TFM.

Wild Rice (Manoomin)

Manoomin is culturally important to the Ojibwe as it is a part of their origin story. During their migration, the Ojibwe people would know they were at their final destination by the presence of food growing on water (manoomin). Manoomin is present in the lower Bad River near the mouth and is harvested by community members. Because the effects of TFM on manoomin is unknown, lampricide treatments are scheduled after the fall harvest. Additionally, TFM is not applied below US HWY 2 which allows the lampricide to dilute down through the drowned river mouth. Recently, Bad River elders requested data on the duration of time that TFM is detectable in manoomin areas. MNRD and Service staff conducted a study during 2021. Water and sediment samples were collected before (control), during, and after the treatment to determine lampricide concentrations. Results show that TFM concentrations quickly dropped below detection limits in both water and sediment and would not pose a significant risk to manoomin (Solomon et al. 2022). This is supported by other studies (Thingvold and Lee 1981 and McConnell et al. 2017) that demonstrated that TFM does not bioaccumulate and is degraded by sunlight within a few days depending on amount of photolysis and microbial organisms that breakdown the lampricide.

Mussels

During the September 1995 treatment of the Bad River, tests were conducted to determine the toxicity of TFM to the green frog tadpole (*Rana clamitans*), eastern ellipto freshwater mussel (*Eliptio complanata*), river club dragonfly (*Stylurus amicola*), and sea lamprey larvae in the White River. The non-target species were found to be less sensitive to TFM than sea lamprey larvae. No mortality occurred at TFM concentrations that were used to kill sea lampreys (Approximately 2.7 mg/l) in the Bad and White Rivers.

During 1996, a team of investigators from the U.S. Geological Survey, Service, and MNRD evaluated the effects of TFM treatments on adults and juveniles of two freshwater mussel taxa in the White River. No mussels were killed at treatment concentrations or at concentrations as high as 1.6 x Minimum Lethal Concentration (MLC) of TFM to kill larval sea lampreys. During 1997, this research group measured effects of the combination of TFM and niclosamine (another lampricide) on freshwater mussels during a twelve-hour exposure. This lampricide combination is more toxic to sea lampreys than TFM alone. Again, no mussel mortality occurred at concentrations greater than those used in sea lamprey treatments. Growth and mortality rates of mussels were not reduced when exposed to TFM at treatment concentrations during 1998 (Waller et al., 2003). Non-target mortality was monitored by MNRD during the 1997-2017 treatments and was documented in internal reports, which were forwarded to the Service.

Cultural impacts caused by sea lamprey attacks on native fish

Lake trout/Namegos (*Salvelinus namaycush*), lake whitefish/Adikameg (*Coregonus clupeaformis*), and other fish mortality in Lake Superior caused by sea lampreys impacts

cultural and economic opportunities of the Bad River Band. By allowing native fishes to thrive, sea lamprey control in the Bad River provides a direct benefit to Bad River members and other user groups who fish Lake Superior for commercial or subsistence purposes. This, in turn, aids in the re-establishment of a balanced ecosystem.

TFM in fish tissues

Bad River community members and others eat fish from the Bad River and are concerned about the safety of eating fish that have been through a treatment. Numerous studies have been conducted on fish tissues after exposure to treatment concentrations of TFM and have determined that TFM residues in fish tissue decreases rapidly, falls below detection limits within 6-24 hours after exposure (Hubert et al. 2005 and Vue et al. 2002), and poses no apparent risk to consuming fish after a treatment.

Testing for impurities in lampricide

During the late 1980's, dioxin-like impurities were detected in TFM. To test for these impurities, the Service collected walleye, white suckers, and sediment samples from the river. The samples were analyzed by private laboratories. Results showed that while dioxin-like impurities were found in the TFM formulations, no dioxins or dioxin-like impurities were found in fishes or sediment samples. The manufacturing process was changed to eliminate the contaminant. The MNRD listed the dioxin-like contaminant as a concern for the 1995, 1998, 2002, and 2005 treatments, however, no dioxin-like impurities were detected in TFM prior to treatment in these years. Because dioxin-like impurities have not been detected in TFM in over 30 years and the manufacturing process has not changed, the service asks to discontinue future testing of TFM used for treatments unless the manufacturing process changes. At some point in the future, testing may be discontinued or the length of time between testing further increased if agreed to by all parties.

Mercury in sea lampreys

Sea lampreys affect fish in the open waters of Lake Superior and the faunal elements of its associated watersheds. This occurs when elevated methyl mercury burden in the parasitic stage sea lampreys provides bio-available mercury to Great Lakes watersheds exposed to spawning runs of sea lampreys. The exposure to the food chain in the watersheds is exacerbated, when adult sea lampreys die in the stream after spawning, further increasing the availability of mercury to the food chain (Moses et al. 2018). Adult bald eagles/migizi (*Haliaeetus leucocephalus*) have been observed feeding eaglets sea lampreys, and the Band had initiated a food habits study in an area that has high concentrations of spawning sea lampreys and poor eagle productivity. In the Bad River falls study area, one nest has produced two young in eight years. Other Lake Superior bald eagle nests have records of sea lamprey remains in nests as prey items (Papp, Pers. Comm., 2007)

Treatment planning

The Sea Lamprey Control Program strives to apply lampricide to the Bad River to remove larval sea lamprey without negatively affecting non-target organisms. Effective stream treatments require knowledge of the chemical and physical characteristics of a stream. Pre-treatment studies typically include application of an inert vegetable-based dye (rhodamine)

to monitor the flow of water, stream discharge measurements, and analysis of water chemistry (pH and alkalinity) to determine variables that may influence treatment effectiveness. When needed, onsite toxicity tests are conducted by the Service to determine the specific concentration of lampricide required to kill sea lampreys without harming non-target organisms. The Service applies lampricides to a river only when the results of preliminary studies indicate that a successful TFM treatment will result. During application, TFM is metered into the stream for about 12 hours. The treated water is analyzed periodically at several locations along the stream course and application rates are adjusted to ensure proper concentration (GLFC-SOP 2021).

Although TFM is applied at minimal effective concentrations, a few species of fish have tolerance levels only slightly greater than those of sea lampreys, and occasionally some of these fishes are killed. Fishes are most sensitive to TFM during spawning; consequently, TFM treatments are routinely scheduled to avoid spawning periods of sensitive organisms.

The Service has strived to reduce the amount of TFM used during treatments to further protect non-target organisms. For example, during the 1995 treatment, the use of TFM was reduced by 31% from the 1991 treatment. This reduction was due to 1) the entire Bad River system treated at one time rather than in multiple stages, and 2) TFM was applied closer to MLC required to kill sea lamprey larvae but utilized more application sites.

Options for Supplemental Controls

The GLFC is committed to reductions in TFM use through the implementation of alternative and supplemental controls. While lampricides target the removal of sea lampreys during their larval phase, supplemental controls to barriers and/or lampricide treatments, can further reduce sea lampreys (Johnson et al. 2020). The focus is on reducing reproduction of lampreys during their spawning-phase and includes trapping, electrical barriers and guidance systems, sterile-male release, pheromone applications, and other experimental removal options.

Supplemental technologies that strive to reduce reproduction by targeting actions during the sea lamprey spawning-phase can work, but they are subject to variability in effectiveness. Jones et al. (2003) and Dawson (2007) observed a significant positive relationship between spawning density and recruitment, but they also observed considerable density independent variation in the relationship. However, when spawning populations are low, reducing reproduction by trapping or other means should result in lower recruitment on average. Two subsequent studies (Young 2005, Velez- Espino et al. 2008) observed similar patterns in lake-wide modeling studies. In addition, reduction in reproduction in scenarios where lamprey populations were already low or suppressed through lampricides resulted in further suppression of lamprey abundance but had little effect when spawning densities were relatively large.

Trapping

Technologies currently employed to capture spawning phase sea lampreys are passive systems that exploit the strong urge of sea lampreys to find passage around stream-borne obstacles during their migration. When a barrier to migration is encountered, a sea lamprey will follow

its edge and aggressively probe for passage, seeking any indication of flow that may guide it past the obstacle. In this manner, traps with funnels placed against a barrier (natural or manmade) with an attractant flow of water and a lead (such as the face of a dam) has proven to be very effective at capturing sea lampreys. Sites without these characteristics or with extreme flows can be challenging to trap. Trapping devices used to capture adult sea lampreys generally fall into one of four categories:

Nets – These are fyke or modified hoop nets (D-ring) that are often used in shallow sections of streams where barriers are absent. Long leads or wings are used extending downstream to guide the lampreys to the net opening. As much of the river width is covered as practical. Nets are labor intensive, require frequent cleaning, are susceptible to floods and debris and typically have a low efficiency.

Portable assessment traps - These are rectangular sheet mesh cages hung from a structure or placed on the stream bottom in shallow waters during the period of the sea lamprey run and removed afterward (Schuldt and Heinrich 1982). Their portability allows fine-scale adjustment in a variety of locations. High velocities and high flows can dislodge the traps and make them unserviceable. Portable traps are often less effective on very large rivers.

Permanent traps – These are structures that have been engineered to provide consistent and optimal operating characteristics at specific sites. They are usually made of concrete or steel, square or rectangular in shape, and are built into a permanent barrier or a trap-and-sort fishway. Most have a method of providing attractant water through the trap either by a pump, pipe, or physical structures that direct the flow of water in the desired direction. Operating efficiencies for these traps are usually higher and less variable than for portables.

Semi-permanent traps – These are structures that have many of the same operating advantages of permanent traps, but have seasonal parts (leads, wings, screens) that usually require more annual setup. Like permanent traps, they typically have large square or rectangular traps and tend to be more efficient than portables or nets.

Traps have been used in the Bad River and have consisted of a network of portable traps fished at the lower falls cooperatively by GLIFWC and Service staff. The efficiency of the trapping network is low and averages about seven percent. This is due to the physical nature of the trap site, challenging flow conditions and the lack of a barrier to congregate and lead lampreys into a trap. While the efficiency of traps fished at the lower falls is low, the information from trapping is important in assessing the population in both the river and Lake Superior.

A permanent or semi-permanent trap may have potential to increase trapping effectiveness in the river. Possible locations include sites near the upper falls (Brownstone Falls) of the mainstream Bad River or in conjunction with a barrier in the Marengo River. If pheromones are demonstrated to increase trap efficiency, they could be used in conjunction with the development of this type of trap.

Barriers

Typical sea lamprey barriers consist of a fixed-crest low-head structure that maintains at least an 18-inch drop. Sea lamprey barriers have an overhanging metal plate at the crest of the barrier that, in combination with the drop, prevents sea lampreys from moving upstream. While barriers block upstream sea lamprey migrations, streams with barriers may still require treatment downstream from the barrier if the area downstream supports spawning and larval habitat.

It is recognized that extreme flows during the lamprey migration period may result in sea lamprey recruitment upstream of the barrier that cannot be mitigated in low-head barrier design due to practicality of barrier height. As such, a barrier does not have to block 100% of the lampreys 100% of the time to be considered successful. However, it is expected to block often enough that it at least reduces the need for treatment. Barriers may be designed with an option of increasing barrier height during high water using removable stoplogs or a periodically activated electrical field.

A barrier may be possible on the Marengo River below its confluence with the Brunsweler River, but this is not known without a comprehensive analysis of a proposed site. Treatment of the Bad River watershed costs an estimated \$470,000 of which an estimated \$184,000 is spent on treating the Marengo River. This does not include larval and spawning-phase assessments in the watershed between treatments. Estimated cumulative costs of a treatment every three years and annual adult and larval phase surveys and treatments would be about \$700,000 (USFWS, 2022). A barrier on the Marengo River would result in: 1) less of the Bad River watershed being regularly exposed to lampricide; 2) a decrease in habitat available to sea lampreys for reproduction and infestation; and 3) a decrease in mortality of lake trout, whitefish, and other host fish in Lake Superior. During recent treatments, about 126 miles of the Bad River system were exposed to lampricide including the main stem of the Bad River, lower White River, Potato River, and Marengo River. A proposed barrier site on the Marengo River would reduce 44 miles of stream requiring treatment.

To date, there has been no suitable site identified for a sea lamprey barrier on the mainstream of the Bad River. This option was explored in depth at the Elmhoist Bridge, the upper, and the lower falls. Due to cultural and environmental issues (passage of desirable fishes, aesthetic value of a free-flowing river, sensitive cultural properties, and extreme fluctuations in flow), these sites were eliminated from further study and development during 2002.

Experimental barrier designs including some seasonal, electrical or velocity barriers have not demonstrated consistent reduction in the need for lampricide treatments. Therefore, they are not pursued as a feasible option for new barriers, but they could be tested as supplemental controls.

Sterile-Male-Release Technique

The sterile-male-release technique (SMRT) was implemented experimentally in Lake Superior and the St. Marys River during 1991-1996 (Bergstedt et al. 2003) and exclusively in the St. Marys River during 1997-2011. Evaluation of the technique had been challenging given the long-life cycle of sea lampreys and lack of an experimental control for the large-scale experiment. Nevertheless, several evaluations suggest the technique can contribute cost effective suppression and reduction in reproduction in smaller river systems (Siefkes et al. 2021).

Experimental releases into Lake Superior occurred during 1991-1996 with 96,670 sterilized male sea lampreys released into 33 tributaries. Of these, approximately 14,500 sterile male sea lampreys were released into the Bad River during 1992-1997 (Table 1). The technique in Lake Superior was discontinued in 1996 to focus the effort and limited supply of males in the St. Marys River. Releases continued in the Bad River in 1997 as part of an agreement with the Band to continue alternative controls in the river. However, revelations about mercury contamination (Madenjian et al. 2014) in sea lamprey flesh caused the Band to request cessation of further releases after 1997.

Table 1. The estimated population of male sea lampreys in the Bad River, the number of sterile male sea lampreys released, the estimated ratio of sterile to normal males, and the predicted percent reduction in larval production for the years 1992-1997.

Year	Estimated male population	Sterile males released	Sterile:normal male ratio	Predicted reduction (%)
1992	1,404	3,170	2.3:1	70
1993	1,231	3,927	3.2:1	76
1994	1,129	3,500	3.1:1	76
1995	1,152	2,151	1.9:1	66
1996	4,108	1,669	0.4:1	29
1997	1,875	1,500	0.8:1	45

Expansion of the sterile-male-release technique to areas other than the St. Marys River (i.e., Bad River) is limited by the supply of male sea lampreys. For the SMRT to again be considered for the Bad River, a source of male sea lampreys would need to be identified and the technique would need to be coupled with other aggressive efforts to reduce reproduction. The most likely scenario would first involve a more rigorous lampricide treatment frequency to reduce spawner densities to very low levels. Given the Band's interest in options that reduce lampricide treatments, lack of effective trapping in the river, limited supply of source males and a continued concern with mercury levels in spawning-phase sea lampreys, this method is not a feasible option in the Bad River at this time.

Experimental Removal Options

Exploration of new technologies to remove spawning-phase sea lampreys is underway and has the potential to capture lampreys in difficult locations such as large rivers and sites without barriers. Recently attempted or proposed technologies include the following:

- *Mashkiiziibing Sea Lamprey Project* –Buckner et al. (2020) crafted a project proposal designed to be implemented for a minimum of 7 years. The project vision is to serve as a model for culturally aligned non-native species stewardship that enriches and preserves our shared human and ecological communities for fellow Native Nations within the Laurentian Great Lakes and beyond. The project tasks MNRD to contact Pacific Northwest (PN) tribes

to connect on traditional methods of harvesting Sea Lamprey. After finding a contact within a PN tribe, MNRD would contract that contact as a mentor for Bad River (BR) tribal members. After a few BR tribal members have been fully trained in the art of capturing Sea Lamprey these members will become mentors of other BR tribal members. After enough tribal members are trained enough to capture lamprey a full implementation of the traditional capture methods will commence. After 3-years of traditional capture methods are complete, an assessment of Sea Lamprey population will occur. The measure of success of this project is to delay treatment of the Bad River watershed. If the capture method is a success the lamprey population would be low enough to not need treatment after the first 3 years of this method. This project expresses support for a barrier or multiple barriers on the Bad River and its tributaries if the experimental method is not successful enough to delay treatment.

- *Pheromones* - A suite of pheromone compounds have been identified that are instrumental in drawing sea lampreys to suitable spawning environments and mates. Researchers continue to evaluate additional pheromone components and trapping scenarios (Li et al. 2007). Pheromones are likely to be most useful in the short-term to enhance trap captures, but other longer-term strategies may include a variety of disruptions to spawning success. Research into pheromones, antagonists, and other chemical cues is ongoing and has shown some success (Fisette et al. 2021).
- *Tube traps* - Tube traps (also called bucket traps) are cylindrical tubes with funnels at both ends that are placed in the river for spawning-phase lampreys to use for daytime refuge. They target early run lampreys in the lower reaches of rivers in deeper slack water. Placement in appropriate substrate and stream environment is critical to their success. They have not contributed substantially to lamprey captures to date.
- *Fishwheels* - A fishwheel uses river current to turn baskets on an axle, captures upstream migrating spawning-phase lampreys in the baskets, and deposits them into a live holding cage. Fishwheels may provide trapping opportunities in rivers without barriers or where velocities are too high to fish traditionally. Fishwheels can be cumbersome to deploy but are relatively easy to operate and service once in place. Sufficient velocity and depth are critical, and the nets need to sweep very close to the bottom to be effective.
- *Manual removal* – This technique relies on a person walking a length of stream, removing observed spawning-phase lampreys from nests and evacuating eggs from nests where reproduction has occurred. It is applicable in wadable streams but is labor intensive. Anecdotal information suggests that this technique has been successful in a limited setting.
- *Downstream trapping of metamorphosing-phase sea lampreys* – This method captures metamorphosing-phase lampreys on their downstream migrations to the lake to begin their parasitic-phase. Recent investigations with a rotary screw trap and nets have shown promise for capturing substantial numbers of migrating sea lampreys in certain

environments. The feasibility of trapping downstream migrants continues to be evaluated for control as well as to meet population assessment needs. The approach may be useful in streams that have been delayed from treatment but is not a substitute for lampricide treatments. GLIFWC partners with the USFWS to trap juvenile lampreys on their downstream migration to Lake Superior in the fall.

Manual removal of spawning-phase sea lampreys and their eggs from nests and downstream trapping of metamorphosing-phase sea lampreys may have applicability in some areas of the Bad River system. However, it is important to evaluate and quantify the potential of these experimental options to determine the level of reduction they can contribute. Reductions would have to be significant and cost-effective enough to reduce the need for lampricide treatments.

Additional portable traps, nets and fishwheels are not recommended for the Bad River because they are not capable of removing enough spawning-phase lampreys to elicit a level of control that would reduce the need for lampricide treatment.

Summary and Recommendations

The Bad River is widely recognized as the largest producer of sea lampreys on the south shore of Lake Superior, contributing between 20-30% of the parasitic sea lampreys in the U.S. waters of Lake Superior. It is imperative that the larval population in the river be effectively controlled on a regular basis to allow fish populations in Lake Superior to thrive.

The Band would like the use of lampricides and other chemicals to be reduced and eventually eliminated. Tribal leaders and the MNRD have expressed interest in barriers to block sea lamprey spawning migration and supplemental control methods. However, the use of TFM is currently the only proven effective method of sea lamprey control in the Bad River. Supplemental control options currently available may not eliminate the need for lampricide treatments although new technologies are continually researched and tested. The GLFC is committed to the development of effective alternative and supplemental control techniques to reduce sea lampreys. Options to enhance lampricide control in the Bad River watershed include trapping and barriers. Options under development that may be further investigated include the use of pheromones, antagonist chemosensory cues, manual removal, and downstream trapping of metamorphosing-phase sea lampreys. In the future, additional options may arise as the GLFC continues with its commitment to develop alternative sea lamprey control techniques.

Recommendations for a fully implemented integrated sea lamprey control plan in the Bad River are:

1. Lampricide treatment during 2024 and then every three years thereafter prior to metamorphosis and outmigration of the oldest year class. If a lampricide treatment is ineffective and the larval sea lamprey population requires a follow-up treatment, one will be scheduled within the 3-year treatment cycle. Until alternative and supplemental controls can reliably and effectively be used to control sea lampreys in the Bad River, lampricide treatments will be required.

2. Collaboratively conduct larval assessments to delineate distribution of larval sea lampreys in the river, monitor the effectiveness of treatments, and other larval phase surveys as needed.
3. Test TFM used for treatments of the Bad River for dioxin-like compounds when a new manufacturing process occurs.
4. Continue to schedule lampricide treatments of the Bad River after the tribal harvest of wild rice on the reservation, which typically occurs in early September.
5. Continue of use of portable assessment traps to assess the abundance of spawning-phase sea lampreys at the lower falls.
6. Consider the implementation of the following alternative and supplemental controls methods:
 - a. Investigate feasibility of constructing a barrier with trap on the Marengo River downstream of the confluence of the Brunsweler River or at another location that would reduce the miles requiring a lampricide treatment.
 - b. Investigate feasibility of constructing permanent trap(s) at the upper falls.
 - c. Investigate feasibility of manual removal and downstream trapping to reduce the need for lampricide treatments in applicable sections of the river.
 - d. When available, use novel trapping technologies that do not rely on barriers and are proven effective to capture sea lampreys.
 - e. When available, use pheromones as part of an integrated control strategy to reduce lamprey reproduction, in concert with other supplemental control methods when such techniques have been field-proven and cost effective.
 - f. Consider re-implementation of the sterile-male-release technique once mercury-free lampreys and effective trapping are available, and there is a sufficient supply of adult male lampreys to meet all program needs.

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Appendices

Appendix 1.

Bad River adult sea lamprey trap catch and estimated populations in the Bad River and Lake Superior from 1986-2022. Data are collected by the Service and GLIFWC.

Year	Bad River Total Catch	Bad River Spawner PE	Lake Superior Spawner PE
1986	184	NA	108,593
1987	439	22,212	59,927
1988	972	35,143	73,364
1989	684	22,787	77,582
1990	465	13,980	53,902
1991	121	2,960	46,853
1992	236	NA	NA
1993	NA	36,037	1993
1994	110	10,728	28,699
1995	237	15,535	47,355
1996	313	23,307	45,089
1997	272	21,771	54,882
1998	460	17,507	65,750
1999	607	41,973	236,728
2000	283	22,750	146,313
2001	536	39,036	100,048
2002	1,039	60,793	161,286
2003	1,372	41,709	69,725
2004	811	57,805	114,529
2005	1,090	78,611	181,591
2006	1,603	116,186	188,741
2007	1,987	59,888	138,091
2008	2,111	80,156	142,499
2009	1,203	26,211	57,702
2010	964	40,298	76,154
2011	256	NA	75,001
2012	732	98,837	217,918
2013	286	27,678	200,098
2014	642	63,304	155,482
2015	55	NA	158,790
2016	129	14,407	181,675
2017	731	37,217	304,356
2018	710	52,435	271,289
2019	318	20,105	60,939
2020	NA	NA	NA
2021	719	54,404	126,085
2022	174	8,431	89,612

Appendix 2.

**Memorandum of Stipulations
Among the Bad River Band of Lake Superior Tribe of Chippewa Indians, Great Lakes Fishery
Commission, and U.S. Fish and Wildlife Service**

This Memorandum of Stipulations among the Bad River Band of Lake Superior Tribe of Chippewa Indians (Band), the Great Lakes Fishery Commission (Commission), and the U.S. Fish and Wildlife Service (Service) as agent for the Commission, is intended to facilitate efforts to control sea lamprey (*Petromyzon marinus*) in waters within the Bad River Reservation and to address concerns of the Band.

Concern 1. Need to identify and utilize only the best available batch of TFM.

Response: A very minute amount of a dioxin-like compound was discovered in TFM as a contaminant in the 1980s. Once discovered, the manufacturer redesigned their process to eliminate the dioxin-like contaminant from the TFM. The Bad River Natural Resource Department, now referred to as Mashkiiziibii Natural Resource Department (MNRD), listed the contaminant as a concern for past treatments occurring in 1995, 1998, 2002, 2005, 2008, 2011, and 2017. TFM was tested prior to treatment in these years and the dioxin-like compound was not present so it appears that the manufacturer was successful in removing this compound from the TFM manufacturing process. Testing for dioxin-like impurities is an expensive process and the parties have agreed that TFM only needs to be tested every other treatment or when the manufacturing process or manufacturer is changed. This agreement to test TFM every other treatment occurred during 2011. TFM was tested during 2017 prior to treatment to satisfy the requirements of testing every other treatment. No dioxin-like compounds were present. Testing for these compounds is not scheduled to be conducted during 2021.

Concern 2. Need to identify and implement a custody process to ensure that the integrity of best available batch is not compromised during storage, transportation, and/or application.

Response: The Service provided a revised copy of its "Standard Operating Procedures for Application of Lampricides in the Great Lakes Fishery Commission Integrated Management of Sea Lamprey (*Petromyzon marinus*) Control Program" to the MNRD. The quality control protocol for the safe handling and storage of lampricide will be followed and is included in that document under AOP: 008.0.

Concern 3. Need to identify a process and funding mechanism for tribal participation, including the fisheries specialist, throughout preliminary studies, bioassay procedures, application of TFM and observations for non-target mortality.

Response: The Commission, through the Service and based on the availability of funds, will provide \$6,000.00 under a cooperative agreement to the MNRD to secure the temporary services of three tribal employees to assist with larval sea lamprey surveys and observing and documenting non-target mortality during the TFM treatment of the Bad River. The MNRD will provide the Service with a written report documenting non-target mortality observed during the treatment.

Concern 4. Need to provide an annual summary report describing all treatment and assessment activities on the Bad River Reservation and all related sampling, inventory, and bioassay procedures to the MNRD by December 31 of each year.

Response: The Service will provide an annual summary report of treatment and assessment activities on the Bad River Reservation to the MNRD by December 31 of each year.

Concern 5. Work towards the goal of continuing to reduce and eventually eliminate TFM use within the Bad River needs to continue.

Response: The Commission and the Service have coordinated with the MNRD and the Bad River Tribal Council to develop the "Integrated Management Plan for Controlling Sea Lampreys in the Bad River" which recommends methods to investigate the feasibility and implementation of all alternative methods to block, capture and remove sea lampreys in the Bad River and its tributaries.

Concern 6. Treatment shall not be permitted prior to the completion of the wild rice harvest within the Bad River System.

Response: The Commission and the Service agree to not initiate a sea lamprey control treatment in the Bad River system prior to September 11, 2021.

Concern 7. If permission is granted for the application of TFM by the Bad River Tribal Council, the Commission, Service and the MNRD shall hold a public information meeting prior to the treatment to discuss the treatment plans.

Response: The Commission and the Service agree to participate with the MNRD in a public information meeting that shall be conducted prior to the treatment.

Concern 8. Need to verify that all treatments will be conducted according to the "Standard Operating Procedures for Application of Lampricides in the Great Lakes Fishery Commission Integrated Management of Sea Lamprey Control Program," which include strict procedures designed to protect non-target fish species.

Response: The Commission and the Service affirm that all treatment activities on the Bad River will be conducted according to the "Standard Operating Procedures for Application of Lampricides in the Great Lakes Fishery Commission Integrated Management of Sea Lamprey (*Petromyzon marinus*) Control Program." <http://www.glf.org/sop.php>

Concern 9. Assurance of application of best available science and control methods after the "Integrated Management Plan for Controlling Sea Lampreys in the Bad River" is completed. This includes exploring the feasibility, implementation, and evaluation of all alternative (non-lampricide) techniques identified in the plan.

Response: The Commission and the Service support the concept of "application of best available science and control methods" as identified in the "Integrated Management Plan for Controlling Sea Lampreys in the Bad River." This applies to implementation and evaluation of all alternative sea lamprey control techniques identified in the plan.