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Commentary

Co-production of knowledge and co-innovation of solutions for contaminated sediments in the Detroit and Rouge Rivers

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ABSTRACT

Contaminated sediments continue to limit ecological recovery of the Detroit and Rouge River Areas of Concern. Co-production of knowledge and co-innovation of solutions for contaminated sediments have been underway since the remedial action plan program began in 1985 and are accelerating with increased investment in remediation. In the Detroit River, up to 5.1 million m^3 of contaminated sediments on the U.S. side require remediation. On the Canadian side, no further sediment remediation is required beyond one completed project in Turkey Creek. An estimated 350,000 m^3 of contaminated sediment require remediation in the Rouge River (Michigan). Co-innovation of solutions, including collaborative funding, has estimated a $100 million shortfall in non-federal match funding necessary to secure Great Lakes Legacy Act funds. All stakeholders and rightsholders must have a sense of urgency to address this shortfall because, as of 2023, only three years remain of Legacy Act funding. If this window of opportunity is missed, there is no guarantee that comparable federal money will be available in the future. We recommend: ensuring environmental justice is a priority; completing all necessary sediment remediation in the U.S. portion of the Detroit River and lower Rouge River; recruiting partners, including the State of Michigan, to help meet necessary non-federal match requirements; exploring creative financing like environmental, social, and governance and sustainability-linked investment opportunities; and developing a compelling ecosystem vision that is carried in the hearts and minds of all watershed denizens, coupled with a complementary investment thesis to help make these watersheds more investable.

1. Introduction

Detroit, Michigan and Windsor, Ontario are well known as the automobile capitals of the United States and Canada, respectively, and both are considered part of the Rust Belt – a region that has experienced industrial decline (Hartig and Graham, 2022; Hartig, 2019). The defining geographic feature of this region is the 51-km Detroit River, a shared water resource between Detroit and Windsor that was vitally intertwined with industry and development (Fig. 1). The 202-km Rouge River is a major Michigan tributary of the Detroit River with a similar history. As industry expanded along the shores of these rivers and as these watersheds grew into major metropolitan areas, the health of these rivers precipitously declined and both were identified as Great Lakes Areas of Concern by the International Joint Commission in 1985 (Great Lakes Water Quality Board, 1985; Hartig and Thomas, 1988).

During the 1960s, the Detroit River was considered one of the most polluted aquatic ecosystems in the United States and the Rouge River was considered one of the most polluted streams in Michigan (U.S. Department of Health, Education, and Welfare, 1962; Hartig, 2019; Hartig and Wallace, 2015). Examples of pollution and resource degradation from the 1960s include oil spills; the Rouge River catching fire from unabated oil discharges; discharges from industries and municipalities that were not adequately regulated; wastewater treatment plants only providing primary treatment with disinfection; and Detroit's regional combined storm and sanitary sewer system discharging more than 117.3 billion liters of untreated wastewater per year from

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combined sewer overflows. Those stressors led to waterfowl die-offs resulting from oil pollution; the macrobenthic invertebrate community being highly degraded throughout large portions of the river; no bald eagles, peregrine falcons, or osprey reproducing in the watershed; and lake sturgeon and lake whitefish not spawning in the river (Hartig et al., 2020a; Hartig et al., 2021).

Starting in the 1960s and growing in the 1970s, public outcry over pollution culminated in the enactment of many important environmental laws and a binational agreement, including the Canada Water Act of 1970, the U.S. National Environmental Policy Act of 1970, the Canada-U.S. Great Lakes Water Quality Agreement of 1972, the U.S. Clean Water Act of 1972, the U.S. Endangered Species Act of 1973, and the U.S. Toxic Substances Control Act of 1976 (Hartig et al., 2021). These laws, the Agreement, and supporting state, provincial, and local programs such as Remedial Action Plans initiated in 1985 to restore Great Lakes Areas of Concern, provided the framework and impetus for investing billions of dollars in pollution prevention and restoration over the last 50 years (United States and Canada, 2022; Hartig et al., 2021).

Monitoring has now documented that the pollution prevention and control programs, and ecological rehabilitation efforts like habitat enhancement, have improved water quality in the Detroit River since the 1960s resulting in the return of bald eagles, peregrine falcons, osprey, lake sturgeon, lake whitefish, walleye, beaver, and river otter (Hartig et al., 2020a; Hartig et al., 2021). However, despite this recovery, further improvements in aquatic ecosystem health are limited by legacy pollution, specifically contaminated sediments from industrial chemicals and wastes that remain in the ecosystem long after they were first introduced, resulting in detrimental effects on flora, fauna, and humans (Ellison et al., 2020; McPhedran et al., 2017; Drouillard et al., 2006). This manuscript will review the history and current status of contaminated sediments in the Detroit and Rouge Rivers and share conference steering committee recommendations for completing necessary contaminated sediment remediation. Those recommendations are based on the conference papers and panel discussion at the 2022 State of the Strait (SOS) Conference. With the U.S. Great Lakes Legacy Act (i.e., a federal act that provides funding to accelerate contaminated sediment remediation in Areas of Concern) set to expire in three years, there is a sense of urgency to take advantage of the federal government providing up to 65 % of the cost of sediment remediation.

2. SOS conference methodology

The SOS is a Canada-U.S. forum held every two years that brings together natural resource managers, researchers, students, business representatives, members of environmental and conservation organizations, and concerned citizens to assess ecosystem status and provide advice to improve research, monitoring, and management programs for the Detroit River and western Lake Erie. The Conference now has a 25-year history of documenting and supporting transboundary cooperation to better inform ecosystem-based management of these shared waterways. Reports and publications from these conferences are archived online at https://scholar.uwindsor.ca/softs/. The theme of the 2022 conference was contaminated sediment remediation in the Detroit and Rouge Rivers. This theme emerged from the previous conference and

Fig. 1. Map depicting the Detroit and Rouge Rivers.

report, held in 2019 (Hartig et al., 2020), which highlighted the need for additional sediment remediation in the Detroit and Rouge Rivers.

Both the Detroit River and the Rouge River are good examples of the co-production of knowledge and co-innovation of solutions to contaminated sediment problems. Co-production of knowledge is a collaborative and inclusive form of learning where knowledge, information, or data are generated through a shared research process that involves different levels and backgrounds of people (Muir et al., 2023). Quantifying the remaining needs for remediation, assessing benefits that have occurred to date, and envisioning a future after the completion of remediation requires co-production of knowledge across federal, provincial, state, and local governments in the U.S. and Canada, community-based groups, and other partners. Under the auspices of the Detroit River remedial action plan (RAP) that started in 1985, federal, state, and provincial governments have worked with the University of Windsor's Great Lakes Institute for Environmental Research (GLIER); environmental consulting firms; nongovernmental organizations like Detroit River Canadian Cleanup, Friends of the Detroit River, and Detroit River Public Advisory Council; and industries to identify the severity and geographic extent of contaminated sediments. Similarly, under the auspices of the Rouge River RAP that started in 1985, state and federal governments have worked with environmental consulting firms, nongovernmental organizations like Friends of the Rouge and Alliance of Rouge Communities, and industries to do the same.

Co-innovation of solutions happens when two or more organizations purposely work together to solve an environmental problem (Vereijssen et al., 2017). In the Detroit River, federal, state, and provincial governments have worked with industries, environmental consulting firms, the University of Windsor's GLIER, and nongovernmental organizations to identify and review contaminated sediment remedial options and select preferred ones. In the Rouge River, state and federal governments are working with industries, environmental consulting firms, and nongovernmental organizations to do the same. It should be noted that SOS is an example of expanding co-production of knowledge and co-innovation of solutions by further evaluating the severity and geographic extent of sediment contamination, proposed sediment remedial options, and collaborative and creative financing in a binational context.

This 2022 conference was framed by three questions: "Where have we come from?", "Where are we now?", and "Where do we want to be in the future?" The conference included a series of technical papers and a panel discussion on creative financing (i.e., innovative use of environmental or green bonds to accomplish environmental cleanup or restoration) to help answer the above three questions to address this legacy pollution. Conference findings and recommendations were developed by a writing team (i.e., the co-authors) based on the conference papers and discussions and reviewed and approved by the conference steering committee. More information about the conference program is available from Hartig et al. (2023).

3. Where have we come from?

Detroit has a long history of industrialization dating back to 1760 when the British began building armed naval vessels and commercial sailing craft (Hartig, 2019). By the 1890s, more ships were built along the Detroit River than in any other city in America (Hartig, 2019). Metropolitan Detroit's long history and expertise in building steam engines for ships and manufacturing coaches and carriages aided it in becoming a leader in automobile manufacturing. By 1913, the industry grew to the point where there were 43 different automobile companies operating in the Detroit area. Henry Ford's Rouge Plant is probably the most well-known factory, all housed on 810 ha on the banks of the Rouge River, just upstream of the confluence with the Detroit River. Automobile manufacturing would soon dominate the economy of the Detroit area; it became the Motor City and one of the largest industrial manufacturing centers in the world (Holli, 1976). During World War II, the region responded to the "Arsenal of Democracy" paradigm shift by tapping into its manufacturing capability and technical expertise to produce about $29 billion of military output between 1942 and 1945, significantly helping the military contribute to an Allied victory (Pringle, 2023; Hartig, 2019).

There were no major environmental regulations during this period of growth. One of the major unintended consequences was contaminated sediments in the Detroit and lower Rouge Rivers. Prior to 1985 when the Remedial Action Plan program started, there were also no comprehensive federal, state, or provincial programs to remediate contaminated sediments (Tuchman et al., 2021). It should be noted that dredging for navigational purposes, to keep shipping channels open, resulted in a secondary benefit of removing some contaminated sediments. To address this deficiency, the U.S. Environmental Protection Agency (EPA) initiated the Assessment and Remediation of Contaminated Sediment (ARCS) Program in the early 1990s to evaluate the severity and extent of sediment contamination in Areas of Concern, recommend approaches to measure the effects of these contaminants on aquatic life, recommend approaches to assess risks to wildlife and human health posed by the contaminants, and test technologies that might be used to clean up these contaminated sediments (Tuchman et al., 2021). In Canada, a Canada-Ontario Agreement Sediment Committee was also formed in 1989 to provide guidance and funding to Remedial Action Plan teams for sediment assessment in AOCs (Richman and George, 2021). Soon after, the Canadian federal government created the Contaminated Sediment Removal and Contaminated Sediment Treatment Technology Programs to assist Remedial Action Plan teams with addressing contaminated sediment by demonstrating new technologies.

4. Where are we now?

Over the past several decades, legislation and pollution prevention and control programs have been enacted on both the Canadian and U.S. sides of the Detroit River to reduce the amount of contaminants entering these waters. As a result, improvements are being measured in sediment quality, particularly on the Canadian side (Serran and Drouillard, 2023). Where "severe effects levels" contamination exists, it is localized in nature, indicating that severe widespread biological impairment, due to contaminated sediment on the Canadian side of the river, is unlikely (Serran and Drouillard, 2023). Therefore, there have been no sediment remediation projects in the Canadian waters of the Detroit River to remove contaminated sediment.

There has been one sediment remediation project in Turkey Creek – a subwatershed of the Detroit River on the Ontario side. In 2008, 975 m^3 of sediments contaminated with heavy metals and polychlorinated biphenyl (PCBs) were excavated to a target total PCB concentration of less than 1 μg/g in the Grand Marais Drain upstream of Walker Road (Serran and Drouillard, 2023). This resulted in reduced PCB concentrations in sediments and water that decreased bioavailability. Further, a 2012 study conducted to determine the success of the sediment remediation found reduced metal concentrations in sediment in the Turkey Creek Grand Marais Drain. A decline in contaminants and toxicity in sediments in the Canadian portion of the Detroit River has also resulted in the improvement of benthic invertebrate communities and, as of 2020, "Degradation of Benthos" is no longer considered a use impairment (Serran and Drouillard, 2023).

In contrast to the Canadian side of the Detroit River, the legacy of industrial and municipal effluents persists on the U.S. side in the form of contaminated sediment in the Detroit and Rouge Rivers. In order to identify remediation sites, the Detroit River Public Advisory Council and the Friends of the Detroit River partnered with the University of Windsor, U.S. EPA, Michigan Department of Environment, Great Lakes, and Energy (EGLE), and others in 2012 to gather and review all the existing data on Detroit River sediment, some dating back 40 years (Noffke, 2023). These data were used to create hazard index maps to show the risk factor for the three most concerning contaminants in the

river: mercury, polycyclic aromatic hydrocarbons (PAHs), and PCBs (Fig. 2; Szalinska et al., 2013). These hazard index maps were used to develop a weight-of-evidence approach to identify areas for characterization in the Detroit River (Noffke, 2023).

Beginning in 2013, the U.S. EPA and EGLE conducted a series of sediment characterization investigations which were completed in 2018 (Noffke, 2023). These surveys characterized nearly the entire western shoreline of the Detroit River for contaminants, including PCBs, PAHs, and metals. Information gained from these sampling efforts was used to delineate known areas of contaminated sediment, referred to as sediment remediation targeted areas (Fig. 3). A total of six sediment remediation targeted areas were identified and explored with additional sampling to further refine areas that may require remediation. These sediment remediation targeted areas, from upstream to downstream, have been designated as: Harbortown Upstream, Harbortown, Riverbend, River Rouge-Ecorse Shoreline, Trenton Channel (i.e., Monguagon Creek, former McLouth Steel site, and Elizabeth Park), and the Celeron Island/Gibraltar canals.

Following the analysis of the field data, each hot spot was evaluated using a set of criteria that included several factors: chemical

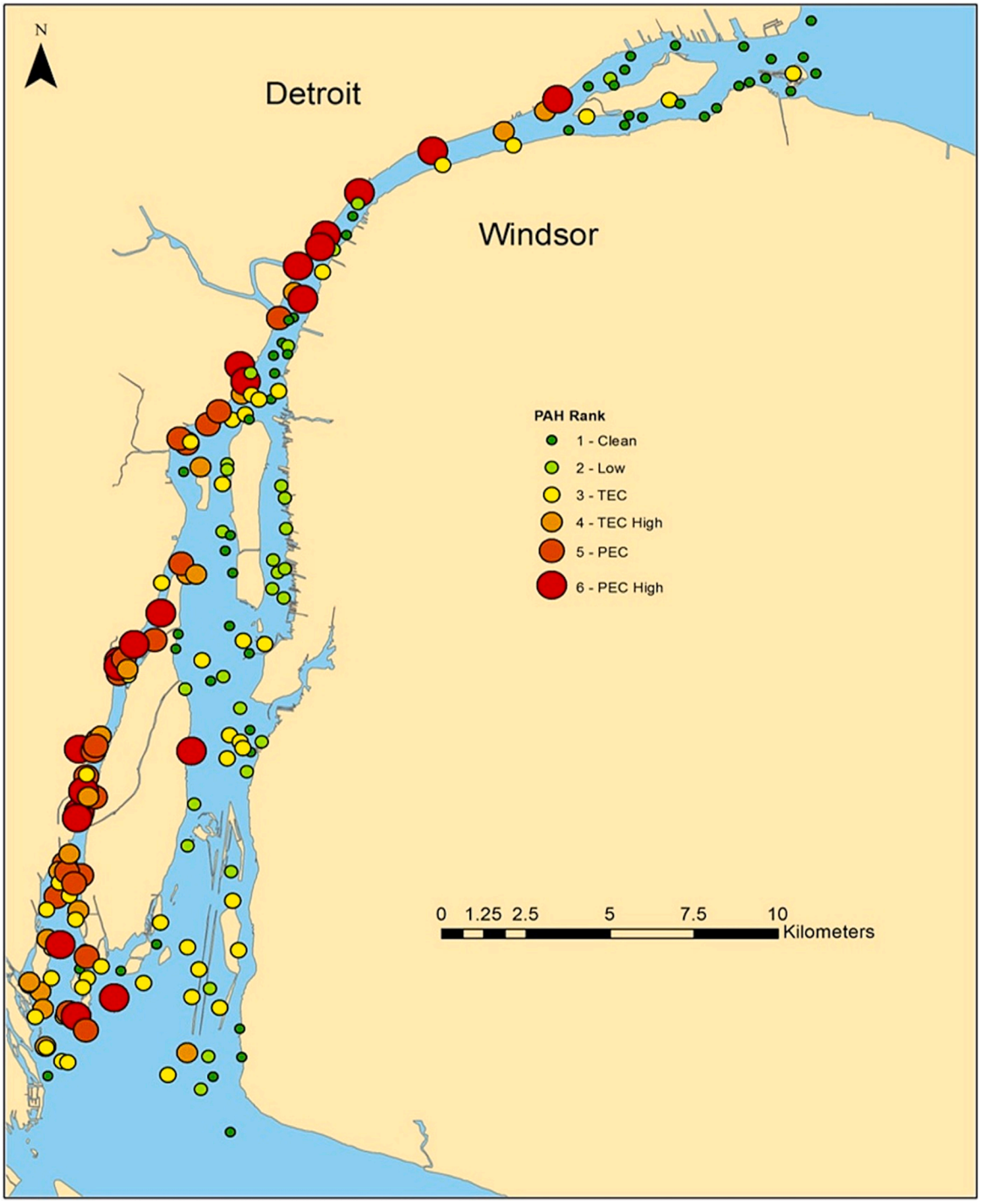

Fig. 2. Polycyclic Aromatic Hydrocarbon (PAH) Hazard Categories developed by the University of Windsor, from Detroit River Public Advisory Committee, EGLE pass through grant (hazard map generated by A. Grigicak-Mannion of University of Windsor's Great Lakes Institute for Environmental Research using data reported by Szalinska et al., 2013).

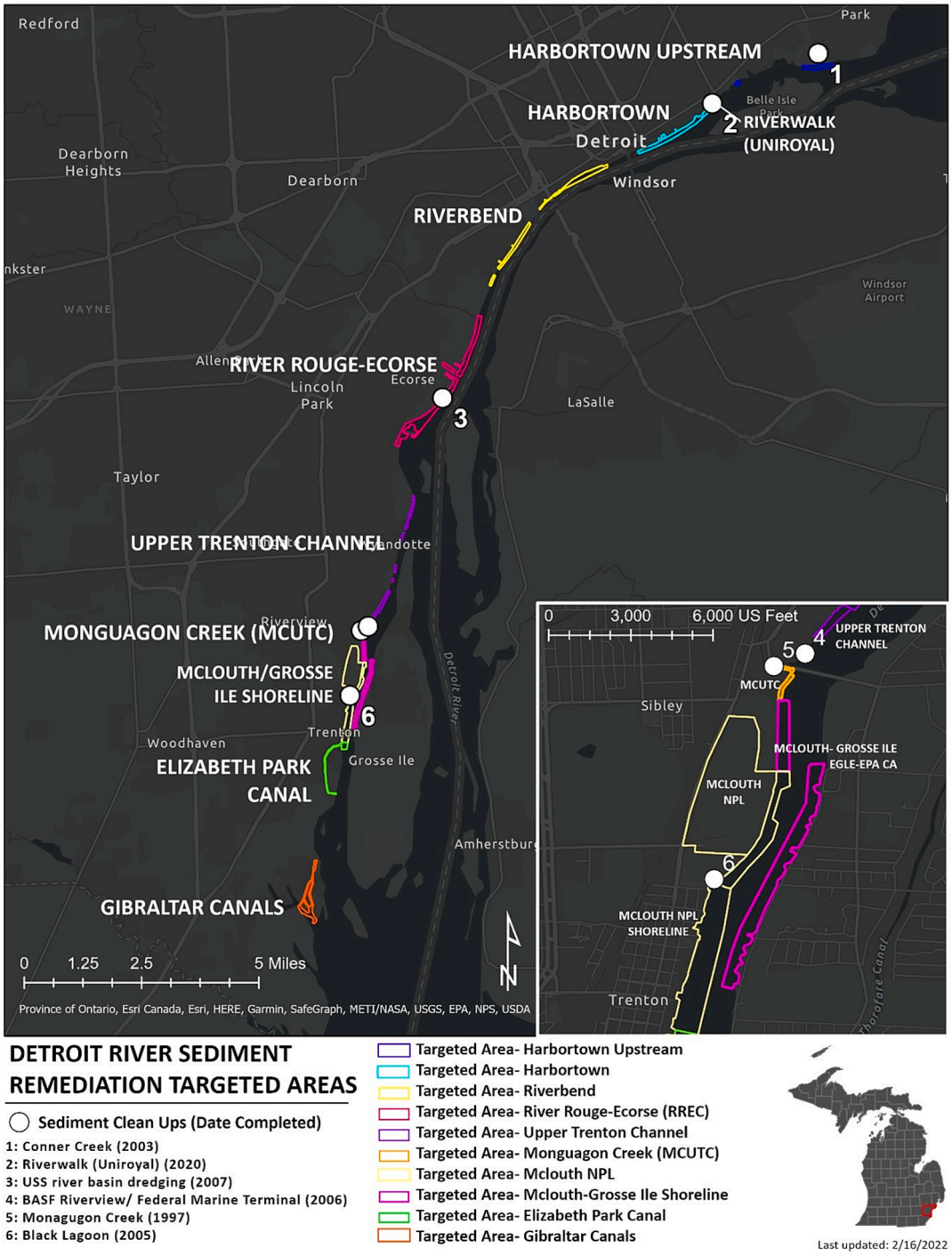

Fig. 3. Map of Detroit River sediment remediation target areas.

concentration, potential toxicity, presence of bioaccumulative chemicals, and estimated volume of contaminated sediments. These factors were scored and evaluated within each targeted area. The sites were then discussed with the Detroit River Public Advisory Committee as well as with other experts from the U.S. EPA, EGLE, and the University of Windsor. These targeted sediment remediation sites were approved by this committee as sites for future remedial investigation. Additional sediment investigations by EGLE and U.S. EPA during 2021 and 2022 focused on the former McLouth Steel and Grosse Ile shoreline segments within the Mid-Lower Trenton Channel target area, Harbortown Upstream, and Riverbend.

During 1993–2020 there were eight sediment remediation projects in the Detroit River addressing about 274,000 m^3 of contaminated sediment at a cost of approximately US$40 million (Table 1; Ellison, 2023). There are an additional three Detroit River projects currently underway that will address another 218,000 m^3 of contaminated sediment: one in the Riverbend target area (i.e., Ralph C. Wilson, Jr. Park) and two in the Trenton Channel target area (i.e., Upper Trenton Channel and Monguagon Creek/Upper Trenton Channel). Future sediment remediation projects in the Detroit River include investigations into Harbortown Upstream, Harbortown Shoreline area, Riverbend Shoreline area, River Rouge/Ecorse Shoreline area, Elizabeth Park Canal area, and the Gibraltar Canals area. In total, up to 5.1 million m^3 of contaminated sediments on the U.S. side of the Detroit River have been

Table 1
Contaminated sediment remediation in the U.S. portion of the Detroit River, 1993–2020. Note all funds are in U.S. dollars.

Location or Site	Nature of Project	Volume of Sediment	Year	Estimated Cost
Elizabeth Park Marina	Dredging and disposal	3100 m^3	1993	$1.3 million
Monguagon Creek – Riverview	Dredging and disposal	19,300 m^3	1997	$3 million
Conner Creek	Dredging and disposal	111,630 m^3	2004	$4 million
Black Lagoon – Trenton Channel	Dredging and disposal	88,440 m^3	2004–2005	$9 million
U.S. Steel	River basin dredging and disposal	11,500 m^3	2007	Unknown
BASF Riverview	Removal of contaminated soils, creation of an on-site disposal cell with an inward hydraulic gradient, removal and disposal of contaminated sediments, and creation of shoreline habitat and 0.4-ha of fish spawning habitat	30,000 m^3	2007–2008	$19.5 million
Refuge Gateway's Monguagon Creek – Trenton	Dredging and disposal	70 m^3	2008	$0.15 million
Old Uniroyal Site near MacArthur Bridge	Capping	Approximately 9940 m^3 of sediment along 640 m of shoreline (isolate, stabilize, and cap with clean material)	2020	$2.9 million
Ralph C. Wilson, Jr. Centennial Park	Capping contaminated sediments and creation of shoreline habitat	Approximately 23,000 m^3 of river sediments	2022–2023	$17 million

targeted for remediation.

Between 1986 and 2020 there has been 396,800 m^3 of contaminated sediment removed in the lower Rouge River at a cost of US$62.75 million (Table 2; Ellison, 2023). A cooperative agreement has been signed between the U.S. EPA and EGLE to complete the necessary remedial investigation work on the Lower Rouge River Main Stem. It is estimated that 350,000 m^3 of contaminated sediment requiring remediation remains in this portion of the Rouge River. Much of that volume and area of contaminated sediments will ultimately be remediated through removal and disposal, but other options such as capping can help achieve the results at a potentially lower cost or logistical complexity compared to dredging.

It should also be noted that removal and confined disposal of contaminated sediments began in the 1980s and accelerated during the 1990s and early 2000s. Some of this activity was performed solely for remediation, but a substantial portion of this sediment removal, particularly in the Rouge River, was performed to maintain navigable depths in shipping routes (Luke, 2023). The cost and extent of sediment removal for remediation tends to be higher than for navigational dredging.

5. Where do we want to be in the future?

There is broad agreement among stakeholders that contaminated sediment remediation should be a priority so that impairments of beneficial uses (i.e., changes in the physical, chemical, and biological integrity of the Great Lakes which cause restrictions on fish and wildlife consumption, fish tumors or other deformities, degradation of benthos, restrictions on dredging activities, etc.) can be eliminated and should allow for expanded public access for other uses like recreation, riverwalks, kayak landings, etc. Further, the 2022 SOS Conference participants noted that there is an urgent need for the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws and policies – environmental justice (Lewis-Patrick, 2023). Communities like Southwest Detroit, River Rouge, and Ecorse have been waiting for decades for consequential responses to long-standing issues of poor air quality, contaminated sediments, contamination associated with industrial brownfields, noise pollution from truck traffic, and water inequity (Lewis-Patrick, 2023). These underserved residents deserve meaningful action and improvement in their ecosystems, communities, and lives, and to see movement toward a more sustainable and just society. Through efforts to remediate contaminated sediment, managers need to make sure that meaningful progress is made toward environmental justice as well.

Table 2
Contaminated sediment remediation in the Rouge River, 1986–2020. Note all funds are in U.S. dollars.

Location or Site	Nature of Project	Volume of Sediment	Year	Cost
Lower River near Double Eagle Steel	Dredging and disposal	30,000 m^3	1986	$1 million
Evans Products ditch	Dredging and disposal	7300 m^3	1997	$750,000
Newburgh Lake	Dredging and disposal	306,000 m^3	1997–1998	$11 million
Lower River – Old Channel	Dredging and disposal	53,500 m^3	2019-present	$50 million

Clearly, the State of Michigan faces enormous challenges with the need to remediate up to 5.1 million m^3 of contaminated sediment on the U.S. side of the Detroit River and an estimated 350,000 m^3 of contaminated sediment in the lower Rouge River mainstem. No additional contaminated sediment remediation is needed on the Canadian side of the Detroit River, beyond the one project completed in the Turkey Creek subwatershed.

For the U.S. side of the Detroit River and the lower Rouge River, the federal Great Lakes Legacy Act can fund up to 65 % of the cost (Tuchman et al., 2021). Nonfederal partners must contribute 35 % or more to fulfill legislative match requirements. If there are no known potentially responsible industries and the contaminated sediment area is considered an orphan site, then the Great Lakes Legacy Act will provide 65 % of the cost and the remaining must come from non-federal sponsors like the state, a county, a city, or other non-federal entity. In general, if there is a willing industrial partner, then the cost share is often 50 % federal and 50 % from industry or industries with some known potential liability for the site. U.S. EPA's Great Lakes National Program Office typically determines the appropriate cost share for industrial partners.

For the Detroit River, U.S. EPA and EGLE staff have estimated a total sediment remediation project cost of approximately US$900 million (Electronic Supplementary Material (ESM) Appendix S1). Of that total project cost, sediment managers are hopeful that over $580 million could be covered by the U.S. EPA through the Great Lakes Legacy Act and $245 million covered by industrial partners. That leaves approximately $75 million needed to cover all the likely orphan sites in the Detroit River and this could potentially be covered with state funds

(ESM Appendix S1). For the Rouge River, U.S. EPA and EGLE staff have estimated a total project cost of approximately US$480 million. Of that total, sediment managers are hopeful that approximately $255 million will be covered by the U.S. EPA through the Great Lakes Legacy Act and $200 million could be covered by industrial partners. A consortium of industrial partners is already meeting to complete mapping out the severity and extent of sediment contamination in the lower Rouge River mainstem and explore collaborative funding to make the non-federal match requirements. That leaves approximately $25 million needed to cover all the likely orphan sites in the Rouge River and this could potentially be covered with state funds (ESM Appendix S1). Therefore, the State of Michigan would need approximately $100 million to be able to provide the 35 % cost share for the known orphan sites in the Detroit and Rouge Rivers. These cost estimates may increase or decrease significantly as more information is gathered. While securing the non-federal match is a significant challenge at any scale, there are good examples of collaborative funding success. For example, Minnesota used state funds to match Great Lakes Legacy Act funds for sediment remediation in the St. Louis River Area of Concern in Duluth. In 2008, Minnesota's voters passed the Clean Water, Land, and Legacy Amendment to the Minnesota Constitution to protect drinking water, protect and restore habitats, preserve arts and culture, support parks and trails, and protect and restore surface and groundwater. During 2010–2018, over $19 million in Minnesota Water, Land, and Legacy funding was used to help make a match on contaminated sediment remediation in this Area of Concern (French et al., 2021).

In 1998, Michigan voters authorized the state to borrow $675 million for the Clean Michigan Initiative. This initiative helped clean up and redevelop contaminated sites, clean up contaminated sediments in rivers and lakes, protect and improve water quality, prevent pollution, abate lead contamination, reclaim and revitalize community waterfronts, and enhance recreational opportunities. A good example of the benefits of the Clean Michigan Initiative was the cleanup of the former Black Lagoon on the Detroit River's Trenton Channel. In 2004 and 2005, the U.S. EPA and the Michigan Department of Environmental Quality (now EGLE) removed 88,000 m^3 of severely contaminated sediment from Black Lagoon at a cost of $9.3 million (Tuchman et al., 2021). Sixty-five percent of the funds came from the Great Lakes Legacy Act and 35 % from the Clean Michigan Initiative. This was the first fully funded Great Lakes Legacy Act project in the Great Lakes and was considered a major success in removing environmental blight from the Downriver area. Upon completion of this project, the Black Lagoon was renamed Ellias Cove in honor of the family who donated the adjacent land to Trenton which became Meyer-Ellias Park (Tuchman et al., 2021). However, as funds in the Clean Michigan Initiative were depleted, no new funding was appropriated and this program ceased to be a viable funding mechanism.

In 2019, the Renew Michigan fund was created within the Michigan Department of Treasury to promote the cleanup of contaminated sites, waste management, and recycling. Initially, it received $69 million. A good example of how the Renew Michigan fund has helped make the match requirements on contaminated sediment remediation projects in the Detroit River is the Ralph C. Wilson, Jr. Centennial Park under construction on the Detroit RiverWalk. The Detroit Riverfront Conservancy has received a $1 million grant from the Renew Michigan fund to help make the match on a nearly $30 million project to remediate contaminated sediment, restore habitats, and create a water garden that will be the centerpiece of the park. U.S. EPA is providing about $19 million through the Great Lakes Legacy Act and the Great Lakes Restoration Initiative. The balance of the funds is being provided by the Detroit Riverfront Conservancy, with $1 million being provided by the Renew Michigan fund. However, the Renew Michigan fund is not adequately funded to meet the estimated $100 million non-federal match requirements for the remaining sediment remediation in both the Detroit and Rouge Rivers. One way of doing this in Michigan would be to secure a "special appropriation" for EGLE to meet the necessary match on this much-needed contaminated sediment remediation. In early 2023, the Michigan Environmental Council prepared a sign-on letter to the Michigan Governor, key Michigan legislators, and the Michigan Budget Director calling for a special appropriation of $100 million to make the non-federal match requirements on known contaminated sediment orphan sites in the Detroit and Rouge Rivers. In total, 61 different individuals from universities, nongovernmental organizations, communities, and businesses signed the letter (ESM Appendix S1), but this effort was ultimately not successful. However, the letter did raise awareness of this urgent need and opened the door for going back to the State of Michigan next year to secure these funds through the budget process.

At the SOS Conference, Cieniawski (2023) noted that managers need to explore every opportunity to make up the 35 % non-federal match requirements on future sediment remediation projects, including acts/projects that are already underway and can be included as in-kind support (e.g., green stormwater infrastructure, habitat rehabilitation, combined sewer overflows, and other related water quality improvements at the local and regional level). Further, if managers are only looking for traditional funding partners (federal, state, philanthropic, and corporate) to remediate contaminated sediments and not exploring creative financing that considers a wider range of related investment and financing instruments (e.g., green or impact bonds) that achieve additional community and economic benefits, then they are missing a broad swath of capital resources that have been developed under the umbrella of conservation, green financing, and social impact (Hartig et al., 2023). For example, in 2021 the Buffalo Sewer Authority issued a US$54 million environmental impact bond to incentivize installation of green infrastructure throughout the city. Proceeds from this bond will fund the design and installation of green infrastructure (Higgins et al., 2021). This type of creative financing could also be used to remediate contaminated sediment.

6. Concluding remarks and recommendations

The control of contaminants at their source remains the primary imperative for action (Zarull et al., 2001). Experience has shown that pollution prevention is much more ecologically sound and cost-effective than environmental remediation (Hartig et al., 2023).

Contaminated sediment remediation on the U.S. side of the Detroit River and in the lower Rouge River is essential to fully realize the goals of Remedial Action Plans for these Areas of Concern, the Great Lakes Legacy Act, the U.S. Clean Water Act, and the U.S.-Canada Great Lakes Water Quality Agreement, and to help catalyze waterfront development and community revitalization. Co-production of knowledge and co-innovation of solutions (including collaborative funding) have been shown to be effective strategies for advancing contaminated sediment remediation in Great Lakes Areas of Concern (French et al., 2021; Pickard et al., 2021; Hartig et al., 2020b). Continued priority must also be placed on co-production/co-innovation/collaborative financing to strengthen science-policy-management linkages for resolving this legacy pollution problem.

Clearly, there must be a sense of urgency to raise the non-federal match dollars because there are only about three years remaining of federal Great Lakes Legacy Act funding. If this window of opportunity is missed, there is no guarantee that comparable federal money will be available in the future. This is a long-standing problem in the Detroit metropolitan region, and stakeholders have a once-in-a-century opportunity to address it for both present and future generations.

Conference steering committee recommendations include:

1. That environmental justice become a key priority in the process of remediating contaminated sediments in the Detroit and Rouge Rivers, including making sure that there is meaningful action and improvement in the ecosystem, community, and lives of underserved

residents of Detroit, River Rouge, and Ecorse toward a more sustainable and just society;
2. That a high priority be placed on full remediation of the up to 5.1 million m^3 of contaminated sediment in the Detroit River and the Lower Rouge River Main Stem (turning basin to cut-off channel) and Old Channel through the Great Lakes Legacy Act;
3. That all relevant stakeholders of the Detroit and Rouge River watersheds work with a deep sense of urgency to recruit partners to help make the necessary 35 % non-federal match on sediment remediation projects;
4. That the State of Michigan either fund the Renew Michigan Fund (designed to help fund environmental cleanup and redevelopment) at an adequate level or provide a special appropriation ($100 million identified above) to help meet the non-federal match requirements;
5. That Detroit and Rouge River stakeholders pursue both collaborative funding and creative financing – moving beyond federal and philanthropic grants, including environmental, social, and governance and sustainability-linked investment opportunities (e.g., green or impact bonds) to address contaminated sediment remediation in the Detroit and Rouge Rivers that achieves associated social and economic benefits; and
6. That Detroit and Rouge River stakeholders and communities develop a unified bold and compelling vision for their watersheds that is carried in the hearts and minds of all watershed denizens and that this is coupled with a complementary investment thesis to help make these watersheds more investable.

These recommendations amount to an aggressive acceleration of actions that are underway (recommendations 2, 3), adoption of innovative approaches and partnerships for sediment remediation in the Detroit and Rouge Rivers that have proven successful in other Areas of Concern (recommendations 1, 4, 5), and a long-view aspiration for the simultaneous restoration of natural ecosystems and human communities that would make the Strait an example for sustainability (recommendations 1, 6). The intended recipient of these recommendations is not a single State or Federal agency, but rather the full suite of partners that will be required to execute and achieve these goals.

CRediT authorship contribution statement

John H. Hartig: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Roles/Writing - original draft, and Writing - review & editing. **Casey M. Godwin:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Roles/Writing - original draft, and Writing - review & editing. **Brianna Ellis:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Roles/Writing - original draft, and Writing - review & editing. **Jon W. Allan:** Conceptualization, Formal analysis, Investigation, Methodology, Roles/Writing - original draft, and Writing - review & editing. **Sanjiv K. Sinha:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Roles/Writing - original draft, and Writing - review & editing. **Tracy S. Hall:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, and Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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