Title: Ecological challenges and potential mitigations for an ultra-large pumped storage hydropower system connecting Lake Ontario to Lake Erie

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North America has the potential to host the World's largest pumped hydro energy storage system by leveraging the immense volumes of water in Lake Ontario and Lake Erie and the very large 325-foot elevation difference between them. Such a system is unique in two major beneficial ways:

(i) it does not require construction of a new reservoir or submergence of any land area, and

(ii) it enables daily energy storage of up to 2740 gigawatt-hours (GWh) which will represent the World's largest pumped hydro storage system, with such an ultra-large design sized to enable America to reach its aspirational goal of 100% renewable electricity by 2035.

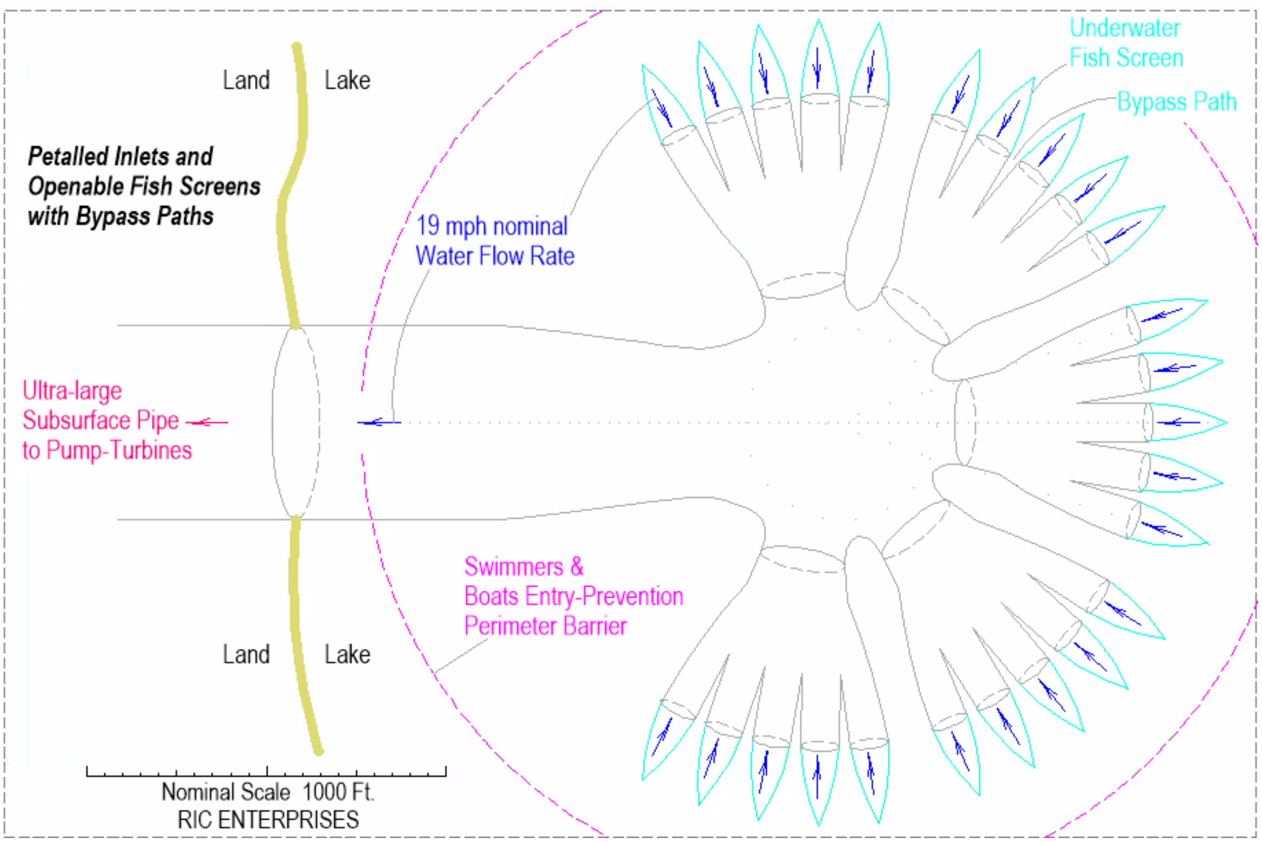
An inventive approach[1] [2] has been proposed by RIC Enterprises to managing flow over Niagara Falls to meet touristic value and erosion limiting objectives, while enabling this ultra-large scale pumped hydro system that incorporates pumping flow from Lake Ontario to Lake Erie during periods of high renewable production (e.g., solar power during daytime) and generating flow from Lake Erie to Lake Ontario during periods of high power demand (e.g., evenings after sunset). Water levels can be maintained well within historical levels on both lakes, with daily variation limited to no more than 1.75 ft on Lake Ontario and 1.3 ft on Lake Erie, as compared to historical variation bands[3] of 7-plus ft for Lake Ontario and 6-plus ft for Lake Erie . Flood risk and extreme variations on both lakes from storms, seiches and high precipitation seasons can also be significantly reduced by careful tailoring of upward and downward flow volume schedules using forecast-driven control algorithms. Environmental and ecological impacts will be inherently minimized due to the lack of any new land submergence that is typical of new pumped hydro storage projects. However, it is recognized that some ecological concern areas will still arise in association with the very large volumetric flows, sediment from tunneling & dredging during the construction phase, and increased daily up-and-down small water level variations associated with this ultra-large scale pumped hydro system. This paper will summarize the foreseen potential ecological concern areas and also propose some promising candidate mitigations.

During the operational phase of the proposed pumped hydro storage system, large amounts of water will flow both ways between Lake Ontario and Lake Erie, and the implementation of up to

360 billion cu.ft. of daily pumping can pose an ecological hazard to aquatic life and will require mitigation using one or more approaches to fish protection.

Historically, many hydroelectric facilities in the U.S. and elsewhere have built "fish screens" into their systems to help prevent local fish species from entering inlets or being harmed by the turbines. There is much variety in the structures and designs of fish screens, mainly attributed to customizations for the unique factors each system would have to take into consideration, such as specific fish species, water depth, water movement speed, volume of water passing through, overall system/turbine size, etc.[7]. After examining the various types of fish screens, we determined that an angled stainless-steel wedge-wire fish screen design with holes of around 10 mm would be a good starting point solution to meet the requirements of the proposed pumped storage system [8]. Using stainless-steel wedge-wire helps ensure the mesh is robust and less susceptible to rust or other degrading elements while constantly submerged in the lake. The small size of the gaps in the mesh helps ensure that nothing but the very smallest of fish species would have even a chance to penetrate past the screen into the pumps or turbines, and the angled setup helps enhance fish protection from harm by redirecting them around the inlets to the pumps and turbines and back into lake waters. These screens could be built into a large-scale screen architecture and structure as pictured in Figure 1 below, to best minimize damage to fish populations given such a large system.

Figure 1: Inlet / Outlet and Fish Screens Nominal Configuration Design



As pictured above, the fish screens could nominally be distributed across 25 different water intake entrances, organized into five petal-like structures. These multiple smaller entrances would be ideal for ensuring fish safety, being designed such that approaching fish could slide along the slanted mesh fish screen through a bypass path and into a central area where fish would be safe from the inlets and could then swim freely back into lake waters. If some fish wind up in the subsurface penstock pipe despite the fish screens in the inlet, they could still be expelled later using proposed opening-and-closing controls for the fish screen assemblies. Fish can readily exit a fish screen assembly in an open outlet configuration as the system converts between pumping and generating modes and inlets are converted to outlets and vice-versa. This setup ensures multiple layers of safety precautions for fish around and in the system while not posing a hindrance to the flow of water back and forth through the pumps and turbines. Further research or refinement will be necessary to lay out the detailed design and structure of these fish screens to realistically meet functionality requirements and optimization objectives, before construction.

The silt and sediment released into the lakes during the construction phase could pose a problem to lake water quality. Construction of the pumped storage system would require a decade-long period in which large-scale dredging and tunneling into lake and river beds and underground between Lake Erie and Lake Ontario would release large volumes of silt into both lakes, with the greatest quantity going into the downstream lake, Lake Ontario. During construction the total excavation volume could be on the order of 100 billion cu.ft., which could be transported as a gravity-driven mud slurry to land reclamation areas in Lake Ontario, with silt screens around the land reclamation areas to minimize silt and silt-induced ecological impacts in the majority of the water areas of the lake. Penstock pipeline routing will have to be carefully designed considering engineering and geotech considerations and to avoid existing infrastructure such as natural gas pipelines under the east side of Lake Erie.[4]

Poor water quality during the construction of the proposed pumped storage system due to the large volumes of silt loosened by tunneling and dredging has to be addressed as it could pose a general threat to many species in Lake Erie & Ontario. While it would be almost impossible to prevent any silt from being released into the lake at all, there are various methods that can be applied during the construction phase to significantly decrease the amount spreading to affect the lakes overall. The main method we researched was using silt curtains around the construction site to prevent release and spread of silt into the lake waters. Silt curtains are commonly used in marine construction projects similar to our proposed pumped storage system, to contain silt from construction and protect the surrounding environment. Throughout the duration of the construction phase, permeable geotextile silt curtains could be installed in the areas of each lake enclosing the construction sites. Permeable silt curtains allow water to pass through while acting as a filter as well as physical barrier for silt coming from construction [9].The skirts would reach from the lake bed to a few feet below the surface; suspended from buoys in a manner so that they would ideally be moveable and at a depth so as to not block the movement of ships into and out of the construction zone. As silt settles within the construction zone, dredging ships equipped to carry large loads of silt for land reclamation could move into the site periodically to dredge silt from the lake bed. This tunneling silt material collected could be used in local land reclamation projects building artificial land such as an artificial peninsula on Lake Ontario. With appropriate silt screens deployed during construction, any harm to aquatic life can be minimized.

Sediment currently on the lake floor of Lake Erie and Lake Ontario contains high amounts of phosphorus and nitrogen due to fertilizer runoff from local agriculture, and past dumping of dredged up sediment has shown the introduction of these elements into the lakes to greatly increase the chances of algae blooms detrimental to water quality as well as the burying of communities of marine organisms living near the lake floor [5]. However, nutrient-rich sediment from the lake floor would only make up a small portion of the silt being released into the lakes for the presently proposed pumped storage system, with the majority of the material coming from deeper underground. In view of this, the project tunneling and dredging operations are not expected to significantly exacerbate the existing algal bloom issue.

The up-and-down water level daily variations associated with the pumped storage system, while under a couple of feet in level, may still pose some potential ecological concerns for marine, land and avian life that inhabit shoreline areas. The intermittent flow of water between Lake Erie and Ontario through the pumped storage system will cause much more frequent fluctuations in water level along the lake shorelines on Lake Ontario and Lake Erie, similar to the daily fluctuations with tides on sea shores. Though the range of fluctuation would only be within two feet, the water line would be rising and receding daily, similar to a miniature tide, rather than current variability occurring over the course of seasonal or annual cycles driven by seasonal rainfall variations and El Nino / La Nina considerations over the Great Lakes region. While marine, land and avian life have adapted very successfully to over 10 feet of tidal range along many ocean shore areas, daily level variations do not have a corresponding precedence in the Great Lakes and hence merit methodical research to understand as to how this could affect lake organisms, particularly those living along the shoreline.

To further explore the possible impacts of all of the changes the pumped storage system could be introducing, we did some initial research into endangered or threatened species in and around Lake Erie and Ontario, that might potentially be vulnerable to such a large-scale infrastructure project. We came to some preliminary and tentative conclusions on whether aspects of the pumped storage system would be likely or not to affect specific sensitive species. Our findings are summarized in Figure 2 below.

Figure 2: Pumped Storage System Effect on Endangered/Threatened Lake Erie & Ontario Species [3]
* = Tentative; more research required.

Species:	Status:	Location:	Preliminary assessment of Pumped storage system likelihood to impact significantly:	Notes:
Piping Plover	Endangered	Erie, Ontario	Low/Medium	Hunts & nests along shoreline, however ~2 feet water level fluctuation is unlikely to significantly impact them
American Eel	Endangered	Erie, Ontario	Medium	Downstream spawning migration, many killed by existing hydroelectric turbines, will require effective fish screen mitigation
Black Redhorse	Threatened	Erie, Ontario	Low	Does not live primarily in the lakes, rather in streams and pools
Cutlip Minnow	Threatened	Ontario	Low/Medium	Requires clean, clear water, pollution and sediment can harm, will require effective silt screens during construction
Eastern Sand Darter	Endangered	Erie, Ontario	Low	Live in shallow water, bury themselves in sand
Lake Chubsucker	Endangered	Erie	Medium	Harmed by sediment and located in tributaries of the Niagara River, will require effective silt screens during construction
Lake Sturgeon	Endangered	Erie, Ontario	Low	Restoration efforts have been/are being taken in Lake Erie population, also issues with water quality. Fish screens effective for large fish like sturgeon.
Pugnose Minnow	Threatened	Ontario	Low	Found farther from the site of the system
Pugnose Shiner	Threatened	Erie, Ontario	Low	Mostly threatened by habitat destruction (wetlands)
Redside Dace	Endangered	Erie, Ontario	Medium/High	Sediment in their habitat can harm these fish, and they are found close to where the system is to be built. Effective silt screens during construction will be required.
Shortnose Cisco	Endangered	Ontario	Low	Endangered from overfishing and competition from invasive species
Silver Chub	Threatened	Erie	Low/medium	Sensitive to changes in water temperature and sediment
Spotted Gar	Endangered	Erie	Low	Habitat loss and pollution threaten the spotted gar
Warmouth	Endangered	Erie	Low	Threatened by urban development and habitat loss

Please note that all endangered or threatened species in/around Lakes Erie and Ontario have not been listed above. Preliminary conclusions about the pumped storage system's effects are subject to change upon further, more in-depth research.

There will be much interest in ensuring that the ecological impact of a large international project such as this one remains sufficiently small, by each nation (the U.S. and Canada) involved. A pumped storage system like the one we have proposed would require a long and thorough review process by multiple regulatory bodies in the field and across both nations in order to ensure its safety and compliance with all applicable regulations. As this project progresses, there are multiple notable authoritative bodies that will need to be engaged for advisory consultations and/or regulatory compliance. A few key authoritative bodies are listed in Figure 3 on the following page.

Being a large-scale project, it is unavoidable that this proposed pump storage system will have a certain degree of impact on the lake ecosystems, so in this report the potential areas of concern and possible solutions/mitigation strategies were examined in a first comprehensive preliminary investigation. Through our research, some of our key preliminary findings are:

(i) Relevant American and Canadian authoritative organizations can and should be engaged for consultation and regulatory approval of all aspects of the proposed pumped storage system.

(iii) The predicted small water level fluctuations are unlikely to pose a substantial threat to ecosystems due to the small range of water level fluctuation and prior history on the adaptability of shoreline species, with further research warranted.

(iv) The impact of the silt that will be loosened into the lakes during tunneling and dredging operations in the project construction phase can be mitigated by installing semi-permeable silt curtains [9] around the construction site, where settled silt can then be dredged by boats and used in monetizable land reclamation projects.

(v) To protect fish from getting injured by ingestion into inlets to pumps and turbines of the pump storage system, stainless-steel wedge-wire fish screens with small holes can be built into structures around the turbines, applying refined and scaled-up implementations of well-proven fish protection technology.

Figure 3: Notable American/Canadian Authoritative Bodies

Name	Location	Key Role(s)
U.S. Fish and Wildlife Service	U.S.	Service for the conservation and protection of wildlife in the U.S.
Great Lakes Commission (GLC)	U.S.	Advocacy group to protect the Great Lakes and Great Lakes water resources
Federal Energy Regulatory Commission (FERC)	U.S.	Approvals/regulations of hydropower and pumped storage systems
NOAA	U.S.	Monitoring water levels and quality in Great Lakes
Department of Energy (DOE)	U.S.	Energy project oversight, indigenous relations for energy projects
Environmental Protection Agency (EPA)	U.S.	Regulation and enforcement of environmental law; Great Lakes biology, fish and water quality monitoring
US Department of Transportation - Maritime Administration (MARAD)	U.S.	Managing U.S. maritime transportation system; including infrastructure, industry and labor.
US Department of Homeland Security (DSH)	U.S.	Preventing terrorist attacks within the United States, reducing vulnerability to terrorism, and minimizing damage from potential attacks and natural disasters.
US Army Corps of Engineers (USACE)	U.S.	Providing engineering services including planning, designing, building and operating water resources and other civil works projects.
Coast Guard	U.S. and Canada	Protecting public, environmental and economic interests in waterways and any maritime region.
Environment and Natural Resources	Canada	Sustainability, environmental and ecological protections
Fisheries and Oceans Canada	Canada	Project reviews and authorizations, fish and fish habitat protection, information about federal contaminated sites.
Environment and Climate Change Canada: Canadian Water Agency	Canada	Restoring, protecting, and managing water bodies of national significance, and improving freshwater quality.
Transport Canada - Marine Transportation	Canada	Laws concerning navigable waters, vessel regulations, marine safety & security, marine pollution & environmental response, boating safety, emergencies, accidents & investigations.
CSA group	Canada	Standard creation/approval of infrastructure, energy systems, etc.
Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC)	Canada	Indigenous relations and interests
Ontario Energy Board	Canada	Provincial regulatory authority on renewable energy

Conclusions and Recommendations

Large infrastructure projects over history such as the Suez Canal, Panama Canal, Grand Coulee Dam and St. Lawrence Seaway System have all involved finding win-win solutions satisfactory to many stakeholders. The present opportunity to build an ultra-large pumped storage system to enable America to cost-effectively achieve a 100 percent renewable electricity system by 2035 despite of the intermittencies of solar and wind power, will also require engagement and vetting by many key stakeholders including communities, governments, waterfront property owners, Indian & First Nations interests and all applicable regulatory authorities in the USA and Canada. Developing a roadmap to win-win solutions for all stakeholders should include strategic goals to provide ultra-large economics benefits, job-creation benefits and climate change mitigation benefits while meeting stringent modern standards for safety, security and ecological stewardship. This preliminary study of ecological aspects of the Niagara region pumped storage proposal has identified some potential concern areas being (i) fish protection needed for large water volumetric flows; (ii) potential concerns related to increased daily water level variations even while reducing extreme water level variations; and (iii) silt containment during the construction phase of the project. Our preliminary study and analysis indicate that none of these potential concern areas are deemed to be insurmountable, and that promising mitigation approaches using existing technologies and systems can be applied to address all three of these potential concern areas. Scale-up of existing fish screen technologies and solutions should enable satisfactory fish protection. Daily water level variations being limited to no more than 1.75 ft on Lake Ontario and 1.3 ft on Lake Erie are well below historical level variations for both Lake Ontario and Lake Erie. Based on seashore wildlife systems highly successful adaptation to much larger daily water level tidal variations of over 10 ft, our preliminary assessment is that ecological impacts on lakeshore creatures will be acceptable, possibly with a few targeted interventions for high-sensitivity or endangered species that rely on lakeshore habitats. Further research is warranted to identify what if any targeted interventions will be needed. Finally, silt containment to minimize ecological impacts during the construction phase involving extensive tunneling and dredging, should be possible using appropriate application of known silt containment technologies such as silt screen systems with proven efficacy. Further research and analyses are warranted and should enable development of low-risk, optimized solutions to all the above-identified potential concern areas.

Our conclusion at this preliminary state of research, is that we can maintain a guarded optimism that this Niagara area ultra-large pumped storage system requiring no new dam and no new reservoir, has very good potential to offer overall low ecological & environmental impacts for the terawatt-hours of needed daily energy storage[10] for 2035, that are acceptably low to meet current stringent standards while also being lower per terawatt-hour of storage than other benchmark large-scale energy storage options such as ultra-large battery banks.

Our key recommendation is that more research, development, analyses and trade studies are conducted building upon this first study, to further improve the fidelity of our understanding and the development of optimized solutions.

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