CCE Award Submission

Atmospheric-Hydrothermal Modelling Platforms Open Up New Opportunities on Lake Huron

GOLDER

Project Summary

Bruce Power retained Golder to develop a methodology to distinguish their operational thermal effects on fish habitats in the vicinity of their site from background atmospheric heating influences. Golder constructed a hydro-thermodynamic modelling platform to assess the effects of thermal discharges on lake temperatures and current fields, information used by biologists to assess potential impacts on habitat. The innovative approach combined transient weather and lake models to resolve the complex hydrometeorological interactions influencing lake processes. The platform enables Bruce Power to maintain site operations, by providing the understanding necessary to satisfy regulators and educate interest groups about the thermal and hydrodynamic impacts associated with plant operations.

Bruce Power site

Innovation

Lake Huron is the second largest of the Great Lakes by surface area, third largest by volume and connects the upper Great Lakes (Lake Michigan and Lake Superior) to the Lower Great Lakes (Lake Erie and, subsequently, Lake Ontario). Although its shores are less densely populated than those of Lakes Erie and Ontario, its economic importance extends far beyond its catchment boundaries. The lake represents a major shipping conduit for mineral and commercial resources between the Atlantic and Upper Great Lakes, supports the commercial fishing industry and sustains a wide geography of popular recreation/tourism destinations. It also services Bruce Nuclear Generating Station, the world's largest nuclear facility (by reactor count) operated by Bruce Power, supplying power to southern Ontario and New York State.

Through regulatory and operational limits, the sustainability of Bruce Power's nuclear operations are closely tied to the lake's hydrodynamic, thermodynamic and biochemical states which are heavily influenced by a plethora of multivariate interactions resulting from meteorological, hydrological, anthropological and geo-glacial factors. The complexities of these interactions can make it challenging to evaluate environment-infrastructure interactions, at the level required for regulatory confidence without significant and costly conservatisms in approach, as demonstrated by multiple years of regulatory and public consultation for Bruce Power.

A comprehensive modelling platform of Lake Huron capable of assimilating the various components influencing these interactions is necessary to deliver the detailed understanding required to establish the regulatory and operational confidence for cost-effective design, planning and permitting needs. The main goal of this modelling exercise was to quantify operational effects on current and temperature and to elucidate impact on specific fish habitat areas in the vicinity of the site. Current fields were compared against swim speeds for specific species to assess potential for impingement and entrainment by the plant intakes. Temperature fields are of relevance as they are linked to fish spawning, development and survival. The effects on fish habitat were quantified by identifying the percentage of time (over selected sensitive developmental life stages) when temperatures exceed a specified threshold value.

Golder developed an innovative meteorological and hydrodynamic modelling platform which generates continuous multivariable weather-field data and can be configured to assimilate emission-based climate change projections to develop future weather-field predictions. In turn, the hydrothermal modelling component uses these weather-field outputs to drive the computational fluid dynamics engine to simulate hydrodynamic and thermodynamic processes throughout the lake.

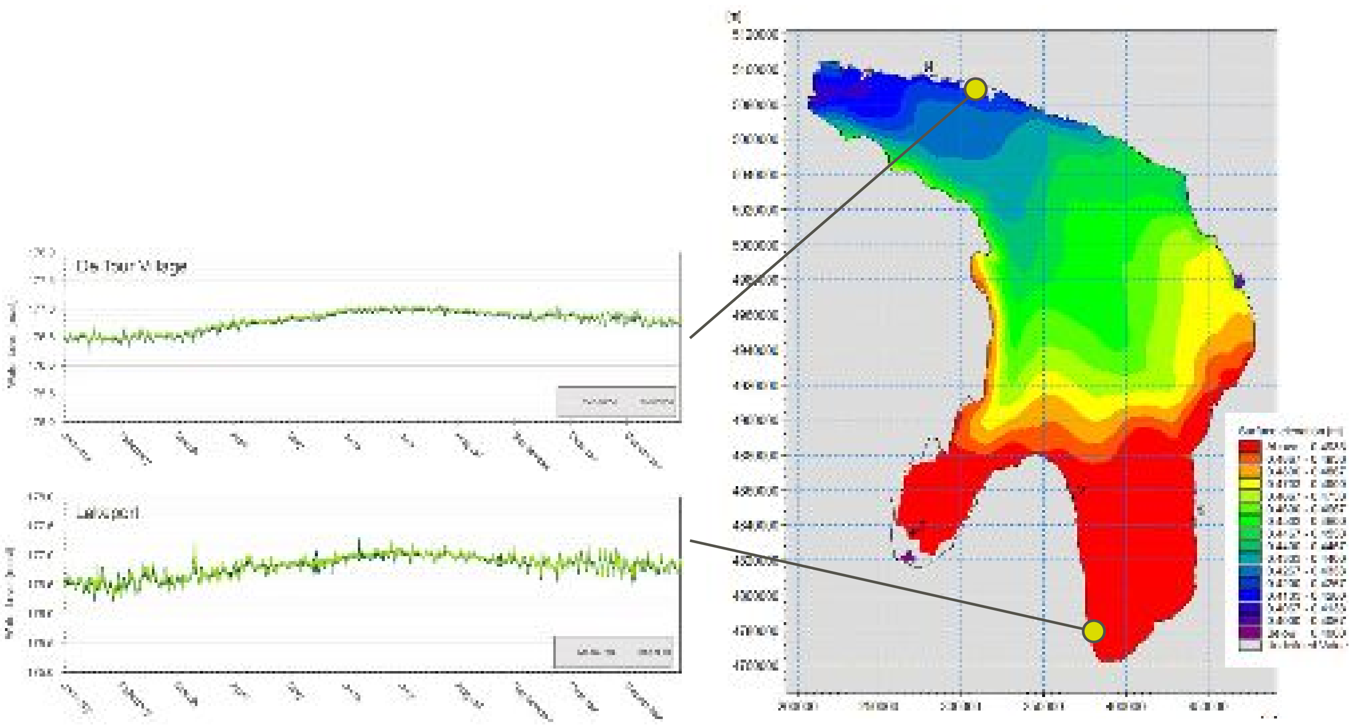
As such, the Golder team has developed a modelling system capable of generating both detailed and holistic results that fully consider the lake's hydrothermal responses to multivariate interactions and stimuli. It also provides new insights into the weather-dependent behaviour of seiching, up-and down-welling and thermal stratification. The new modelling platform now facilitates the opportunity for over-winter simulations (previously unfeasible due to the dearth of winter field data), water quality assessments, wave climate and ship wake modelling and can even serve as the computational basis for more advanced ecological modelling studies.

Computational domain and model boundaries

Golder's modelling platform, completed in 2018 for Bruce Power, provides several advantages over previous modelling exercises such as:

- local field-data is not required to drive simulations; instead, field-data simply serve to verify model accuracy;
- lake-wide and local water level and thermal phenomena such as seiching, upwelling, and downwelling are resolved;
- spatially-variable weather data, meaning that both regional and localised influences on hydrothermal behaviour can be properly integrated into model simulations;
- domain extending up to 5 vertical meters above the low water mark makes it possible to fully simulate short and long-term variations in lake levels and wave run-up;
- the meteorological model can be configured to assimilate emission-based climate change projections to assess the long-term sustainability of operations; and
- the model provides the basis for real-time emergency spill tracking and forecasting.

The new hydrothermal model capabilities are being pulled into thermal investigations to not only support Bruce Power's goal of determining thermal effects on fish habitat within their site vicinity but to address several other permitting and regulatory initiatives for Bruce Power, projects proposed to be started in 2019. By showcasing a successful methodology that combines atmospheric and hydrothermal models in this way, this approach also demonstrates its potential value to other applications throughout the Great Lakes.



Predicted water level during seiching event. Measured and modelled water levels during 2016 at a northern (De Tour Village) and southern (Lakeport) hydrometric stations

Complexity

The primary driver behind the project was the identified need for increased model functionality and reliability in order to fully simulate the hydrothermal process complexities of the lake. The Ontario Ministry of Environment suggested several technical improvements they would like to see to enhance the functionality of a previous regulatory-accepted hydrothermal model which had served Bruce Power well through almost a decade of permitting and approval studies. Meanwhile, the previous model also required extensive field data to facilitate its operation, data that weren't always obtainable given sometimes catastrophic loss of field monitors as a result of storms or ice sheer.

By constructing a lake-wide meteorological model (CALMM5) to drive a new lake-wide hydrothermal model (MIKE3FM), the need for field data was significantly reduced – the new model can effectively be operated without lake temperature or current data, relying only on meteorological model data and lake level data from the National Oceanic and Atmospheric Administration, United States Army Corps of Engineers and Environment Canada.

Integrating the two models (CALMM5 and MIKE3FM) successfully required a substantial effort in coding and parameterization, something not normally pursued at the intensity required for this modelling approach.

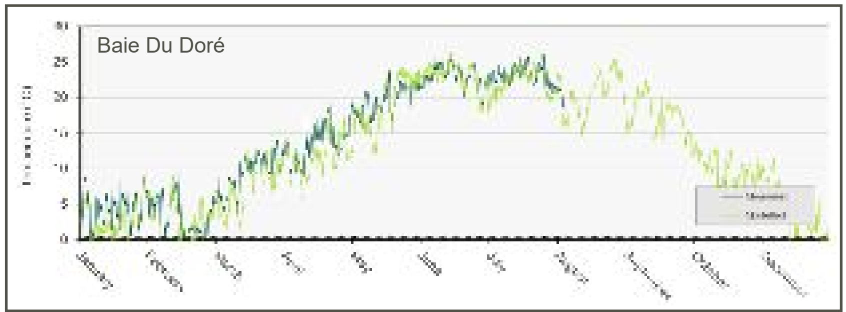
A further challenge that needed to be overcome was that isostatic rebound (in response to the last major deglaciation event approximately 14,000 years ago) continues to differentially distort the relative differences between the vertical position of water level gauges and their measurements across the lake, meaning that the team needed to develop a dynamic lake level correction tool that would normalize water level records according to their location and date of measurement.

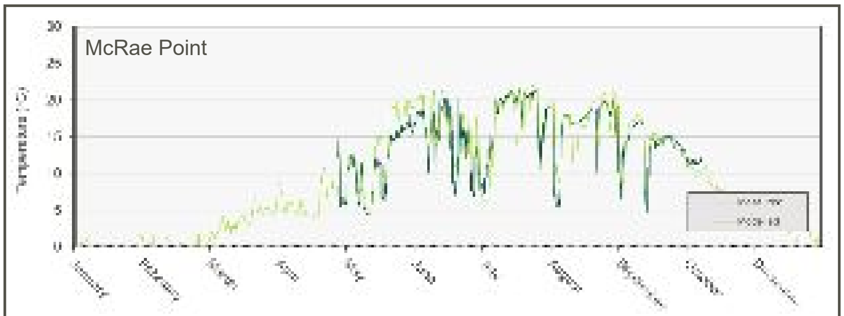
The most challenging aspect of this project, however, were the significant calibration efforts required to fully resolve the complex hydrodynamic and thermodynamic influences controlling event-based, day and seasonal temperature fluctuations at the substantial range of depths that these occur. Not only did the model need to account for the modifying influences of relative humidity, windiness and cloud cover in resolving atmosphere-lake heat exchanges, but the timing and location of upwelling and downwelling events, often attributed to lake seiching, required extensive and often painstaking calibration efforts. The prediction of temperature throughout the water column was a key element of the successful development of the model as lake bottom temperature is a key criterion to evaluate impact on fish habitat.

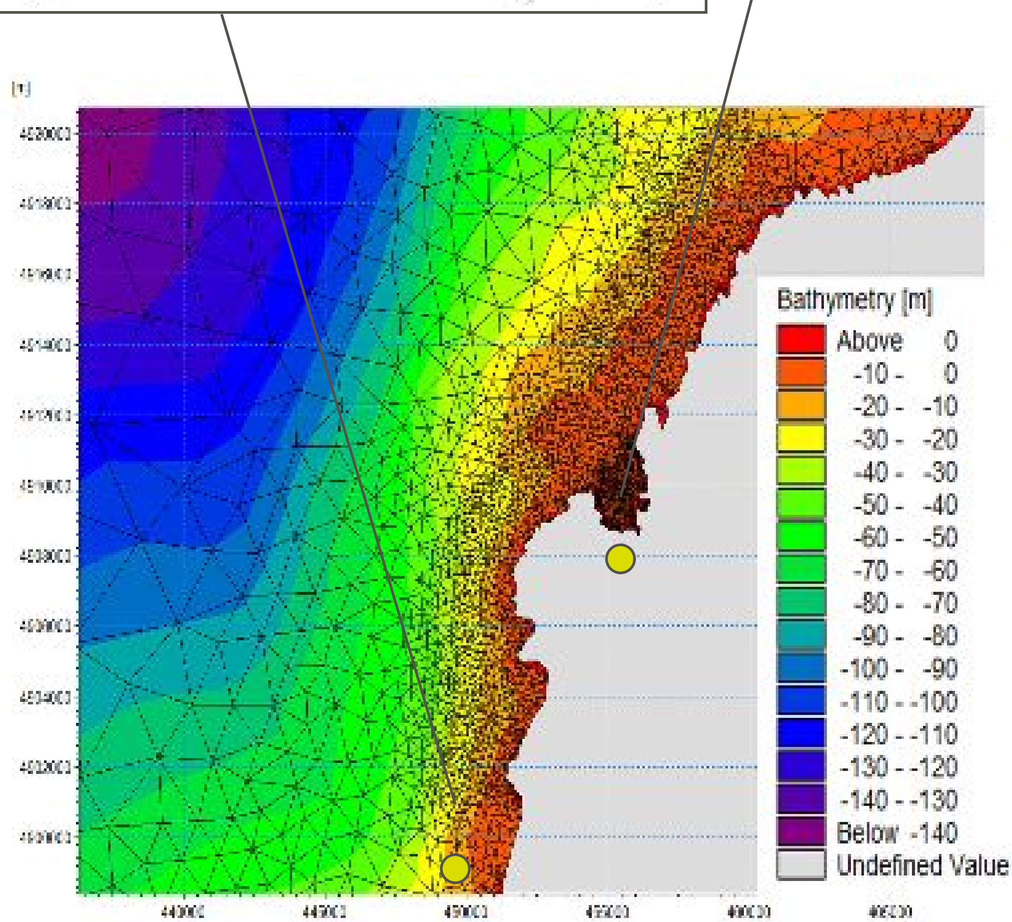
The successful implementation of this hydrothermal modelling platform ultimately followed a number of technical and process advancements that include:

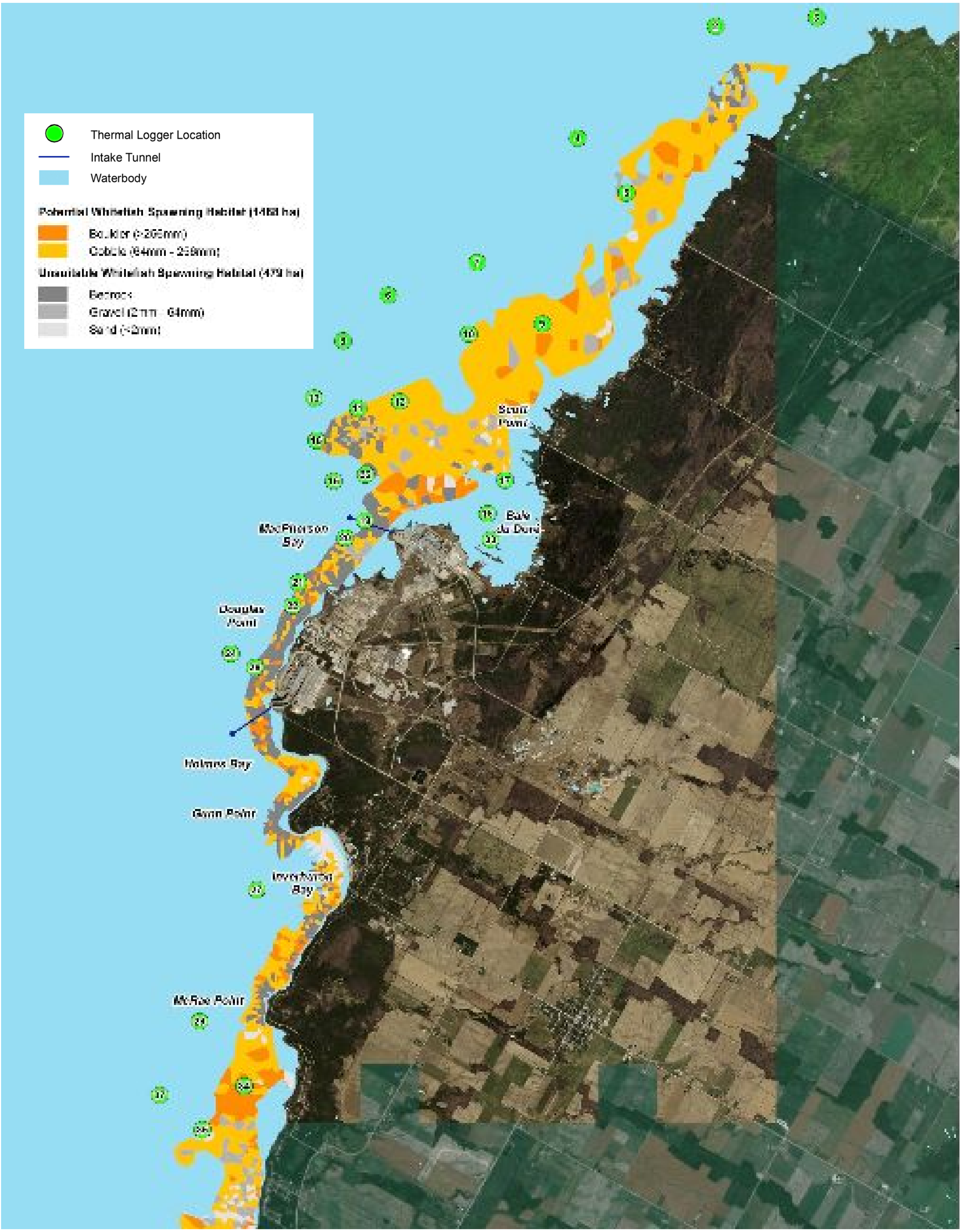
- development of a suite of automated data QA/QC and preprocessing tools to auto-transcribe large binary meteorological outputs for the hydrothermal model environment;
- detailed investigation into, and parameterisation of, the key atmospheric stimuli governing particular lake process events of interest and implementing these within the model framework;
- automated generation of appropriate long-wave radiation data to accurately reflect temperature gradient dependent heat losses to the atmosphere; and
- research into, and establishment of, a tool to facilitate spatially and temporally dynamic corrections to measured water level records to reflect the ongoing effects of isostatic rebound across the lake.

Measured and modelled temperatures during 2016 at one of the monitoring stations near the Bruce Power site









Evaluated White Fish spawning habitat near the Bruce Power site

Social and/or Economic Benefits

The socioeconomic benefits of the new Lake Huron hydrothermal model are being realized at multiple organizational levels. Apart from addressing ongoing regulatory approvals issues in a more comprehensive manner than previously possible, the ability to hindcast and forecast operational and atmospheric effects on the lake in former years (when insufficient data were available) and under future climate change conditions, allows model output to be used for a variety of purposes. These include:

- characterizing the overwinter conditionality of fish spawning habitat (not previously feasible with monitoring equipment);
- the change in thermodynamics associated with various climate change forecasts; and
- improving planning for and tracking of, emergency spills throughout the lake.

Together, the increased functionality and data-independence of the new hydrothermal model has and will variably foster, a better understanding of hydrothermal behavior in Lake Huron, leading to greater confidence, better informed decision-making and more optimized investment strategies for Bruce Power, regulators and affiliated interest groups such as the Council of the Great Lakes Region.

Given the success of the adopted approach, it is anticipated that similar meteorological-hydrothermal model coupling approaches can and will be successfully applied at other Great Lakes.

Environmental Benefits

Few organisations have a detailed understanding of the extent to which climate change effects are likely to manifest themselves operationally, socially and economically when considered at the local scale. By creating the computational platforms that allow global circulation model (GCM) output, in its varied outcomes, to be downscaled to drive regional meteorological models and, ultimately, be used to examine local hydrothermal outcomes, it is possible to begin evaluating the risk and implication of various climate change outcomes at lake and basin level. Establishing this range of changes at a meaningful spatial and temporal scale is fundamental to identifying a viable long-term balance between sustainable fish populations, their underlying ecosystems and habitats and local commercial or socio-economic interests or instead planning for appropriate mitigation measures should these be warranted.

Golder's current development of the emergency spills forecasting system is premised on the successful completion of the coupled meteorological-hydrothermal model platform which allows weather forecasts to be directly tagged to the hydrothermal responses that determine contaminant transport within the lake. The water quality forecasting system will provide Bruce Power with the means of examining hypothetical spill scenarios for planning purposes, tracking and mitigating accidental spills on the fly and forecasting the potential timing and magnitude of impacts of spills at sensitive receivers according to changing weather conditions and implementing contingency measures, if warranted.

Meeting Client’s Needs

Bruce Power’s goal was to increase their understanding of operational influences on fish habitats in the vicinity of their site, to satisfy regulatory requirements to thereby maintaining operations. This goal was achieved by developing a lake-wide model in MIKE3FM and a supporting meteorological model of the Central Great Lakes Region in CALMM5 which have together increased functionality and reliability, significantly reduced field data dependency and provided the ability to implement and interrogate year-round thermal effects studies. Golder found that elevated thermal impacts are very localized, and far field effects are relatively negligible.

In addition to meeting client expectations, this modelling platform has opened up opportunities for farther reaching investigations including climate change studies to assess the thermal and hydrodynamic implications of various representative concentration pathways (formerly socio-economic emission scenarios) with and without operations as well as meteorologically-driven water quality studies that may be integrated into an emergency spills forecasting system for Bruce Power.

Fundamentally, this project has been considered a success as it solves previous technical and logistical challenges while opening up a range of new opportunities for improving the predictability of other environmental concerns.

Appendix

Golder Project Team

Greg Rose (B.Sc. (Hons) M.Sc.)

Associate, Senior Water Resources Specialist
T: (905) 567-6100 x1197
E: Greg_Rose@golder.com

Marta Lopez-Egea (M.A.Sc.)

Water Resources Specialist
T: (613) 592 9600
E: Marta_Lopez-Egea@golder.com

Gerard Van Arkel (M.Eng., P.Eng.)

Associate, Senior Water Resources Engineer
T: (905) 475-5591 x6040
E: Gerard_VanArkel@golder.com

GOLDER

golder.com