Technical Note

New Transboundary Hydrographic Data Set for Advancing Regional Hydrological Modeling and Water Resources Management

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Abstract: The authors document the development and testing of a new suite of hydrologic and hydraulic data for the customization of the new National Water Model (NWM) to the Great Lakes basin. The NWM was recently (August 2016) deployed operationally across the United States, including extensions across the international basins of the Columbia and Rio Grande Rivers. In its current configuration the NWM does not extend across the entire Great Lakes basin due to the challenges of reconciling data discontinuities along the United States–Canada border. The new hydrographic data set was developed by harmonizing data from existing sources across the Great Lakes basin, and by leveraging a strong binational partnership between US and Canadian federal agencies and research institutions. The completed hydrographic data set allows the NWM to be customized to the Great Lakes basin, and to be applied to water resources management problems including differentiating drivers behind long-term changes in Great Lakes water levels, forecasting water supplies for regional hydropower management, and understanding the physical processes along the Great Lakes coastline that govern the fate and transport of waterborne pollutants. **DOI: 10.1061/(ASCE)WR.1943-5452.0001073.**

Author keywords: Water resources management; Water supply; Water quality; International water use.

Introduction

Advancing the state of the art in basin-scale water supply and water quality modeling (Kauffeldt et al. 2016; Beck et al. 2017) requires comparable advancements in fundamental hydrologic, meteorological, and hydrographic data sets. However, developing these data sets can be challenging, particularly in areas where geographic features (including terrain and coastlines) and jurisdictional bounds limit the spatial extent of monitoring infrastructure deployed by federal and state agencies (Gronewold et al. 2018). Despite these intrinsic limitations, new hydrological models are continually being developed with the ultimate goal of supporting water resources management planning (Liang et al. 1994; Haghnegahdar et al. 2014; Gaborit et al. 2017). However, the authors find that few of these models are employed in real-world operational water management environments, and more importantly even fewer are consistently developed across all of North America's large freshwater basins.

In this paper the authors summarize a recent multiagency, international effort to address this problem across the Laurentian Great Lakes basin (Fig. 1). More specifically, the authors document the successful development and testing of a new fundamental hydrographic data set that extends seamlessly across the entire Great Lakes basin (including the land surfaces of both the United States and Canada) and provides a critical stepping stone for the regional customization of state-of-the-art hydrological models for water resources management applications.

This paper focuses specifically on supporting expansion of the new National Water Model (NWM), which was deployed in operational forecasting by the National Oceanic and Atmospheric Administration (NOAA) Office of Water Prediction (OWP) in August 2016 (Alcantara et al. 2017). Tributaries from the US portion of the Great Lakes basin are included in the NWM; however, those tributaries alone do not provide the full range of inflow and coastal boundary conditions needed to run Great Lakes water supply

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Note. This manuscript was submitted on March 22, 2018; approved on November 8, 2018; published online on March 22, 2019. Discussion period open until August 22, 2019; separate discussions must be submitted for individual papers. This technical note is part of the ***Journal of Water Resources Planning and Management***, © ASCE, ISSN 0733-9496.

Fig. 1. (Color) Geographic domain of the Laurentian Great Lakes basin including key geographic features.

and water quality models (Pietroniro et al. 2007; Gronewold et al. 2011). Unless these gaps are filled, water supply and water quality forecasting needs of regional stakeholders (including hydropower authorities, drinking water intake managers, and the commercial shipping industry, among others) will have little choice but to continue relying on legacy systems (Croley and Hartmann 1987; Garen 1992), and the Great Lakes water resources management community at large will be underserved.

Study Area

The Laurentian Great Lakes (hereafter referred to simply as the Great Lakes) constitute the largest lake system on Earth; its two largest lakes (Lake Superior and Lake Michigan-Huron) are the two largest lakes on Earth by surface area (Gronewold et al. 2013). Accurately representing physical processes across these massive freshwater surfaces in regional models is a challenge (Xiao et al. 2016), as is reconciliation of discrepancies in hydrometeorological data along the international border between the US and Canada (Gronewold et al. 2018). Encoding regulatory guidelines for controlling outflows from Lakes Superior and Ontario represents yet another challenge to developing hydrologic models for the Great Lakes basin (Lee et al. 1994).

Because of these challenges the state of the art in operational land surface modeling for water supply and water quality management across the Great Lakes basin has traditionally lagged behind advancements in other large river basins of North America and the world, as has the ability to use hydrologic models to answer important regional water resources management planning questions (Maurer et al. 2002; Hamlet et al. 2002; Wood and Lettenmaier 2006; Shiklomanov et al. 2006). Recently, water levels on Lake Ontario rose to record highs, leading to widespread flooding, property damage, and displacement of homes. The absence of an authoritative state-of-the-art operational hydrological model that encompasses the entire Great Lakes basin (including the Lake Ontario basin) has made it challenging for regional water supply and lake level management agencies to clearly differentiate the drivers behind the Lake Ontario flooding event and other historic water level extremes (Assel et al. 2004; Stow et al. 2011; Gronewold and Stow 2014; Gronewold et al. 2016).

In addition to improving simulations of hydrologic drivers behind Great Lakes water level changes, advancements in regional hydrologic modeling arising through new hydrographic data include more accurate forecasts for hydropower management, coastal infrastructure planning, and simulation of lake circulation patterns that govern the fate and transport of waterborne pollutants (Beletsky and Schwab 2001; Chapra 2003). These model simulations depend on linkages between oceanographic-scale circulation models and land surface hydrological models. Over the past decade, significant advancements have been made in the development, testing, and operationalization of oceanographic-scale models of the Great Lakes (Chu et al. 2011). Complementary advancements in Great Lakes land surface modeling enabled through the new hydrographic data described in this paper would promote capabilities of Great Lakes water quality models that might otherwise not be realized.

Leveraging a Strong Binational Water Management Partnership

Developing hydrologic and hydraulic data for Great Lakes basin-scale water supply modeling and forecasting has historically been conducted by US and Canadian federal agency representatives by aligning (through conventional quantitative and qualitative methods) their respective data sets along the international border. The tendency for many of these historical data sets to abut, but not cross the international border is a consequence of the conventional practice of constraining the spatial domain of federal hydrological products within jurisdictional and geopolitical boundaries (Gronewold et al. 2018). This outdated paradigm needs to evolve and needs to do so through the adoption of new practices in which water management products, regardless of their country of origin, are developed and shared seamlessly across Earth's large freshwater river and lake basins.

One ongoing initiative, implemented through the International Joint Commission (IJC)-sponsored Transboundary Hydrographic Data Harmonization Task Force, represents an ideal testing ground for this new paradigm. The Task Force is charged with the development of "a binational, coordinated approach to the harmonization and long-term stewardship of hydrographic data sets covering binational drainage areas along the [US–Canada] International Boundary" (Laitta 2010). The harmonization effort is based on extending existing federal data sets across watersheds that intersect the international boundary, and has progressed nearly to completion; of the 15 hydrologic basins intersecting the US–Canada border, data harmonization has been completed for 14. However, the Great Lakes basin has not been resolved through this effort to date, due in part to the complexities mentioned earlier related to the size of the lakes, the collective length of their coastlines, and other unique regional geologic and geomorphologic features.

Therefore, the effort summarized in this paper represents an alignment between the goal of expanding spatial coverage of the NWM across the entire Great Lakes basin, and the goals of the IJC Transboundary Data Harmonization Task Force. This multiobjective initiative evolved when representatives from regional, state, and federal agencies, as well as academia converged for a 2-day workshop in June 2016 at the NOAA Great Lakes Environmental Research Laboratory (GLERL) to discuss coordination of regional hydrological modeling priorities, along with other pressing binational water management topics. A notable outcome of that workshop was the clear recognition of an urgent need to develop a new hydrofabric that could support deployment of the NWM across the entire Great Lakes basin. In the following section, the authors describe the development, testing, and potential future application of this new hydrological modeling and water management resource.

New Hydrographic Data Set

The core hydrological modeling capabilities of the NWM are currently met using the WRF-Hydro package of the Weather Research and Forecasting (WRF) system (Powers et al. 2017). One advantage of WRF-Hydro is its ability to simulate tributary flows (and support water resources management planning decisions) at a fine spatial scale. To support this capability, WRF-Hydro in its current operational configuration within the NWM is built on the medium resolution (1:100,000 scale) National Hydrography Data Set Plus, Version 2, or NHDPlus V2 (McKay et al. 2012).

However, the NHDPlus V2 does not extend onto the Canadian land surface of the Great Lakes basin, nor does it include full representation of the Great Lakes water bodies. Therefore, to ensure continuity of key features of the NWM throughout the entire Great Lakes basin, the authors created a new suite of seamless binational hydrographic data (also referred to as a hydrofabric) specifically for the NWM by combining NHDPlus V2 data from the US portion of the Great Lakes basin with the Great Lakes hydrography data set, or GLHD (Wang et al. 2015; Forsyth et al. 2016), for the Canadian portion. Note that the GLHD was not developed to serve as a seamless hydrologic network. Instead, it was simply intended to represent consistent land catchment and watershed areas. Therefore, while combining NHDPlus V2 on the US land surface with the GLHD on the Canadian land surface leads to a suite of information suitable for building the NWM, it does not lead to consistent streamlines along the international border or along the coastlines of the Great Lakes. Overcoming this deficiency required three important steps (hereafter collectively referred to as harmonization).

First, the authors ensured accurate representation of the coastlines and surfaces of the Great Lakes and other large water bodies. To complete this step, the authors employed the complete representations of the Great Lakes encoded in the GLHD, along with representations of other large lakes from both NHDPlus V2 and the

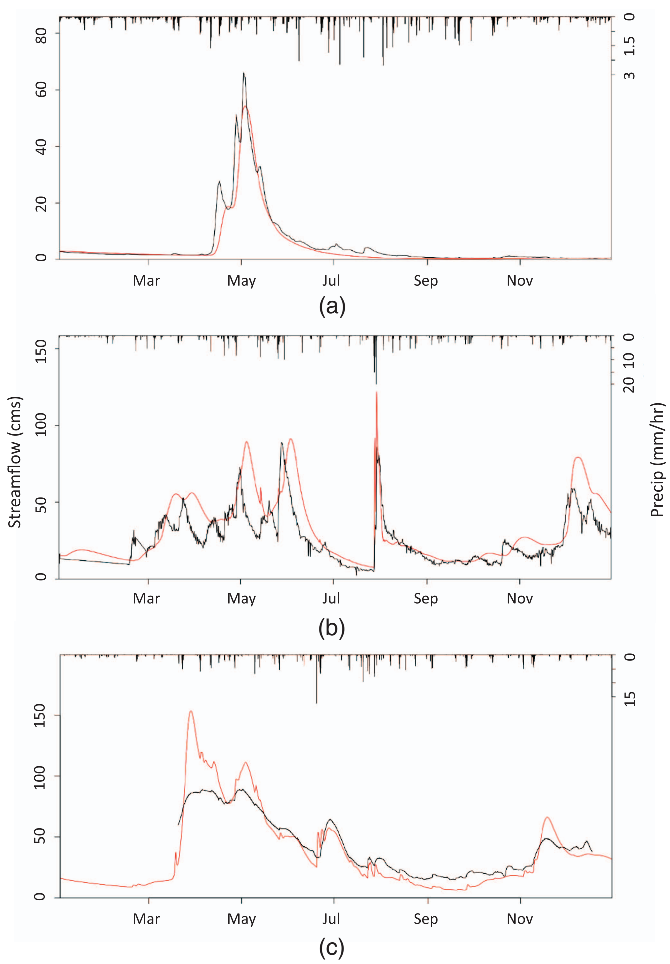

Fig. 2. (Color) Comparison between observed (black) and simulated (red) streamflow from the WRF-Hydro land surface model in its native parameterization as implemented using the authors' new hydrographic data set. Observed streamflow data is from (a) Water Survey of Canada (WSC) gauge 02AC001; (b) USGS gauge 04111000; and (c) USGS gauge 04073500. All panels cover a time period from January 1 to December 31, 2011. Precipitation rates are presented along the top of each panel and are derived from the North American Land Data Assimilation System (Cosgrove et al. 2004).

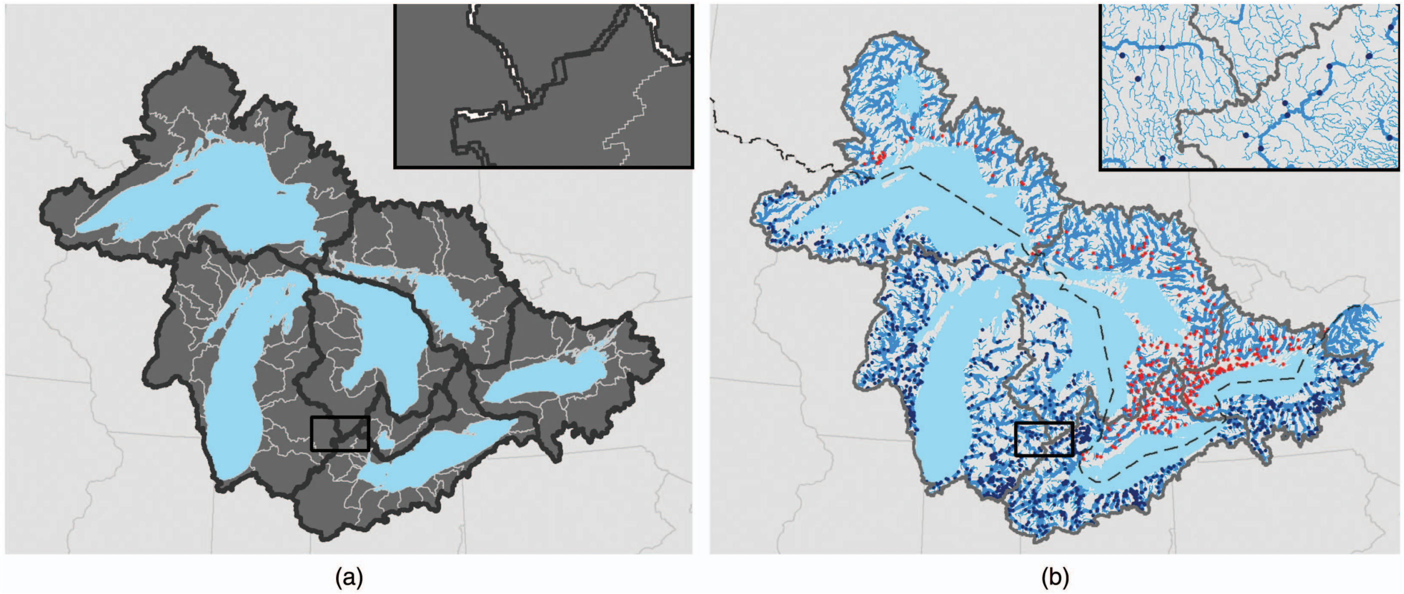

Fig. 3. (Color) (a) Land surface representation used by a legacy hydrological model for the Laurentian Great Lakes; and (b) new geospatial hydrofabric. The location of US and Canadian streamflow monitoring stations within the new hydrofabric are identified as blue and red dots, respectively. Insets present a detailed view of boxed region in the middle-bottom of each panel, and underscore the discontinuities and coarse spatial resolution of the conventional land surface scheme [seen in (a)] relative to the new hydrofabric [shown in (b)].

Ontario Hydro Network. While there are differences in how large lakes are represented in these two sources due to geological heterogeneities (among other features) across the international border, the authors do not expect them to have a detrimental or significant impact on model results.

The authors then made manual modifications to stream segments to ensure they were consistent along the international border, and that they flowed continuously into lake objects along the entire Great Lakes coastline. They also ensured that stream attributes (including maximum elevation, slope, length, and Strahler stream order) were calculated correctly, and that readily-available federal stream gauges from both the US and Canada were represented. For streams on the US land surface, the authors utilized attributes readily available within NHDPlus V2. For streams on the Canadian land surface, the authors calculated these attributes directly from topographic information because they are not included in the GLHD.

As a final step, the authors converted the spatial hydrologic flow network into static hydrofabric and parameter inputs for the WRF-Hydro model as a set of netCDF files. More information about the required static hydrofabric files can be found in the WRF-Hydro ArcGIS Preprocessor toolbox and in associated documentation (Sampson and Gochis 2018). The final comprehensive data set includes all of the foundational information needed for building WRF-Hydro (and other land surface models), including delineation of catchments and lakes, characterization of flow lines, and the location of stream gauges.

Hydrographic Data Set Testing and Verification

The authors conducted two tests to confirm that the new hydrographic data set is robust and suitable for supporting the NWM in water prediction and applications to real-world water resources management problems. First, the authors ensured that the entire hydrologic network was connected by confirming that all precipitation-induced runoff across the land surface domain eventually propagated to the domain outlet along the St. Lawrence River at Cornwall, Ontario.

Second, the authors fully linked the new hydrographic data set with WRF-Hydro in a research environment to provide a more robust representation of streamflow routing through the network. The authors assessed the timing and magnitude of streamflow simulations at multiple gauges across the domain using this preliminary model implementation, and found a reasonable comparison between simulated and observed streamflow (Fig. 2). These results indicate that the new hydrographic data set [Fig. 3(b)] has the potential to serve as a quantifiable improvement over previous conventional land surface representations of the Great Lakes basin [Fig. 3(a)] used in historical operational hydrological forecasting (Croley 1983; Croley and Hartmann 1987; Gronewold et al. 2011).

The authors envision next steps in the customization of this new system including focused calibration and verification of the WRF-Hydro land surface model to improve flow simulations across the basin, as well as transitioning of updated model parameters and configuration files into real-time operational water supply and water quality forecasting systems.

Conclusions

The new hydrographic data development effort documented in this paper facilitates a significant evolution in regional water supply and water quality modeling, not only because it supports customization of a new state-of-the-art modeling system, but also because that modeling system is embedded within a robust federal operational hydrological forecasting framework. Canadian and US federal agencies have a shared responsibility for effectively managing and protecting the Great Lakes, and meeting this responsibility has historically been achieved by combining data and modeling products developed exclusively for either the US or Canadian side of the international border. The authors' development of a transboundary geographic data set directly acknowledges this responsibility, and represents a new paradigm in which state-of-the-art models such as WRF-Hydro can be applied seamlessly across the entire Great

Lakes basin and developed in coordination with existing federal and provincial data sets.

Moving forward, the authors anticipate the new hydrographic data set will be used not only to enhance representation of the Great Lakes system in the NWM, but also to support continued model research and development efforts including the design and implementation of Great Lakes coastal hydrologic-hydrodynamic-atmospheric model coupling schemes (Notaro et al. 2015).

Finally, note that maintenance and continued development of Great Lakes regional hydrologic models (including the NWM) requires periodic updates to underlying binational hydrographic data. This effort aligns with the short- and long-term objectives of the IJC Transboundary Task Force, and is expected to propagate into additional customized hydrographic data sets suitable for a broad suite of hydrologic models.

Data Availability Statement

The new hydrographic data set is not yet publicly available. Updates on its availability can be obtained from the corresponding author by request.

Acknowledgments

Funding for this project was provided by the NOAA Joint Technology Transfer Initiative (Award No. NA16OAR4590240) and by NOAA-GLERL. Kaye LaFond, Nicole Rice, and Joe Smith provided graphical and data management support. Chuliang Xiao provided WRF-Hydro model simulation results. This is NOAA-GLERL contribution no. 1912.

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