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GEOLOGICAL SURVEY OF CANADA
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Laurentian Great Lakes integrated hydrologic model data package

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2021

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2021

Permanent link: https://doi.org/10.4095/328298

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
Xu, S., Frey, S.K., Erler, A.R., Khader, O., Berg, S.J., Hwang, H.T., Callaghan, M.V., and Sudicky, E.A., 2021. Laurentian Great Lakes integrated hydrologic model data package; Geological Survey of Canada, Open File 8797, 1 .zip file, https://doi.org/10.4095/328298

Publications in this series have not been edited; they are released as submitted by the author.

Contents

Abstract

Modelling groundwater-surface water (GW-SW) interactions at scales of large river basins is a difficult challenge. Xu et al (2021) have completed such a modelling exercise for the 766,000 km^2 Laurentian Great Lakes basin using a HydroGeoSphere (HGS) fully-integrated surface water-groundwater model accounting for hydrologic seasonality under monthly normal climatology. Many datasets are developed on a national basis, and development of the underlying HGS model data required synthesis of both Canadian and United States data sets. Most of the datasets are in the public domain; however; considerable effort is required to standardize the respective data. The objective of this Open File data release is to make the underlying data layers and the finite element mesh available for use by anyone interested. The data release consists of 16 folders of data layers, and attribute information for aspects of the HGS modelling platform inputs. Not all layers may be necessary to run the model in alternative groundwater modelling software. Details on the model results are available in Xu et al (2021).

1 Data Package Overview

1.1 Data package overview

This document provides a general overview to the data sets used by Xu et al. (2021) for the construction of the Great Lakes Basin (GLB) fully-integrated groundwater – surface water model (Figure 1). The reader is referred to Xu et al. (2021) for additional details on model development and application.

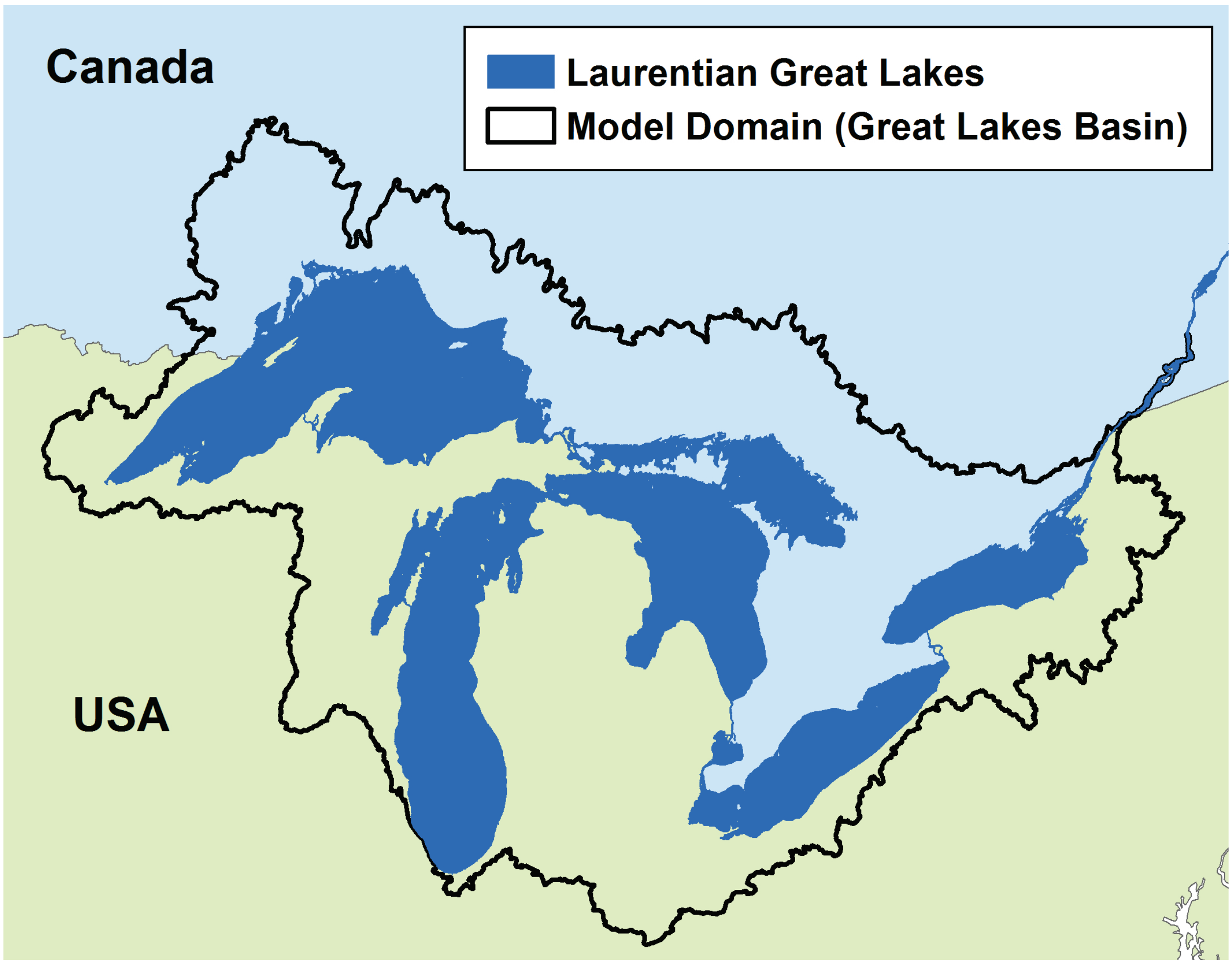

Figure 1. Great Lakes Water basin Model domain

The datasets included in this data package include:

1. Integrated bedrock topography for the entire Great Lakes Basin (GLB)
2. DEM used for the land surface, and Great Lakes bathymetry
3. Integrated landcover distribution
4. LAI – monthly aggregated data
5. Soil hydraulic properties
6. Soil texture triangle (USDA standard) for the soil polygons

7. Integrated soil texture distribution
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14. Groundwater monitoring well location
15. HydroGeoSphere (HGS) 3-D mesh
16. Monthly normal gridded liquid water flux and potential evapotranspiration (PET)

Note: The line numbers above correspond to the folder number in the digital data package. Each data folder contains a readme file that includes information on projection, resolution, and original data sources.

1.2 File Formats

The datasets are provided in a variety of formats including:

- **ASCII raster files (.asc)** are used for spatially distributed gridded data such as topography, geological contact surfaces, precipitation, and potential evapotranspiration (PET)
- **Time series files (.csv, xlsx)** are used for leaf area index (LAI), and over lake precipitation and PET
- **Data tables (.csv, .xlsx)** for material properties.
- **Shape files (.shp)** are used for spatial data such as polygons (i.e., soil texture classes) and vector data (i.e., stream networks) and include .dbf files that contain much of the header information and can be opened in most spreadsheet programs (e.g., MSExcel, Open Office).

The datum and projection for all spatial data is NAD83, UTM Zone 17 N.

2 Description of Datasets

2.1 Integrated bedrock topography for the entire Great Lakes Basin (GLB)

Two data sources were combined to generate bedrock topography for the GLB: the Ministry of Energy, Northern Development and Mines, Ontario Geological Survey, Ontario (Gao et al., 2006) for the southern Ontario portion, and from the United States Geological Survey for the U.S. portion of the model domain (Soller et al., 2012). Due to limited data for the northern Ontario portion (north of Lake Superior) of the model, a bedrock surface was created by vertically offseting the DEM by 3 m in order to reflect the thin or non-existant overburden in this region (GSC, 2014).

2.2 DEM used for the land surface, and Great Lakes bathymetry

Three separate topography data sources were combined to generate a homogenous data set for the GLB model. These data sources were: 1) the hydrologically conditioned Ontario DEM with a resolution of 30 m (https://geohub.lio.gov.on.ca/datasets/ontario-integrated-hydrology-data); 2) a Great Lakes bathymetry data set with a 3-arc second resolution (approximately 90 m) from the National Oceanic and Atmospheric Administration (https://www.ngdc.noaa.gov/mgg/greatlakes/); and, 3) for the USA the HydroSheds data set derived from the Shuttle Radar Elevation Model (https://www.hydrosheds.org/page/availability) and documented by Lehner et al. (2008).

Smaller lakes for which detailed bathymetry were lacking, were adjusted in the DEM to reflect average lake depth, per Table 1:

Table 1. Selected large non Great Lakes water bodies with bathymetry applied.

Lake Name	**Area km^2**	**Depth (m)**	**Data Source**
Lake Nipigon	4,848	55	https://wldb.ilec.or.jp/Lake/NAM-244
Lake Winnebago	557	4.7	https://dnr.wi.gov/lakes/lakepages/lakedetail.aspx?wbic=131100
Lake Nipissing	873	4.5	https://wldb.ilec.or.jp/Lake/NAM-236
Lake Simcoe	744	15	https://wldb.ilec.or.jp/Lake/NAM-42
Oneida Lake	206	6.7	https://www.dec.ny.gov/outdoor/41034.html

2.3 Integrated landcover distribution in the GLB area

The North American Land Change Monitoring System spatially distributed landcover data set (NALCMS, 2005) was used to capture the spatial variability in vegetation and land cover properties (e.g. leaf area index (LAI), evaporation depth, root depth), and surface water and overland flow properties (e.g. surface roughness/friction, rill storage height, obstruction storage height). NALCMS zones were mapped into HGS per Table 2.

Table 2. NALCMS Zones were assigned to the following land classes in HGS.

NALCMS Zone	**HGS Classification**
1, 5, 6	Forest
8, 10	Grassland
14	Wetland
15	Cropland
16	Barren land
17	Urban
18	Water

2.4 LAI data – monthly aggregated data.

The effect of plant growth on ET water demand was incorporated in the model by accounting for spatially and temporally varying LAI data which were downloaded from the MCD15A3H Version 6 Moderate Resolution Imaging Spectroradiometer (MODIS) Level 4 product. This data set is a 4-day composite dataset with a resolution of 500 m. The LAI data were obtained for the July 4, 2002 to

November 9, 2018 period and then processed to yield monthly average values for each landcover class.

2.5 Soil hydraulic properties

Soils data were collected from Soil Landscapes of Canada (SLC, 2010) for the Ontario portion of the GLB model and the State Soil Geographic (STATSGO) data base (USDA-NRCS, 1995) for the U.S. portion of the GLB model. The U.S. and Canadian soil maps were merged into a combined database comprised of 8961 polygons, including 367 polygons in Canada and 8594 polygons in the U.S. The U.S. polygons each contain a single type of soil, whereas the Ontario polygons are usually composed of multiple soil types in each polygon and each soil may contain several layers with different properties. Thus, the average soil composition (percentage of sand, silt and clay) and hydraulic/physical properties (e.g. horizontal and vertical hydraulic conductivity (K), bulk density and porosity) were estimated for each Canadian soil polygon. The data sets were simplified to 10 soil textural types, and texture-average hydraulic properties were assigned to each soil textural type (e.g. K_h, K_v, porosity, and bulk density).

2.6 Soil texture triangle (USDA standard) for the soil polygons within the GLB model

Soil textural types were derived from relative percentages of sand, silt and clay, using the USDA soil textural triangle. The raw data sources were for Canada: Canadian Data - Soil Landscapes of Canada (AAFC, 2010); and for the United. States: - State Soil Geographic (STATSGO) (USDC-NRCS, 1995). These data sets were simplified to 10 soil textural types based on relative percentages of sand, silt and clay, using the USDA soil textural triangle (Figure 2).

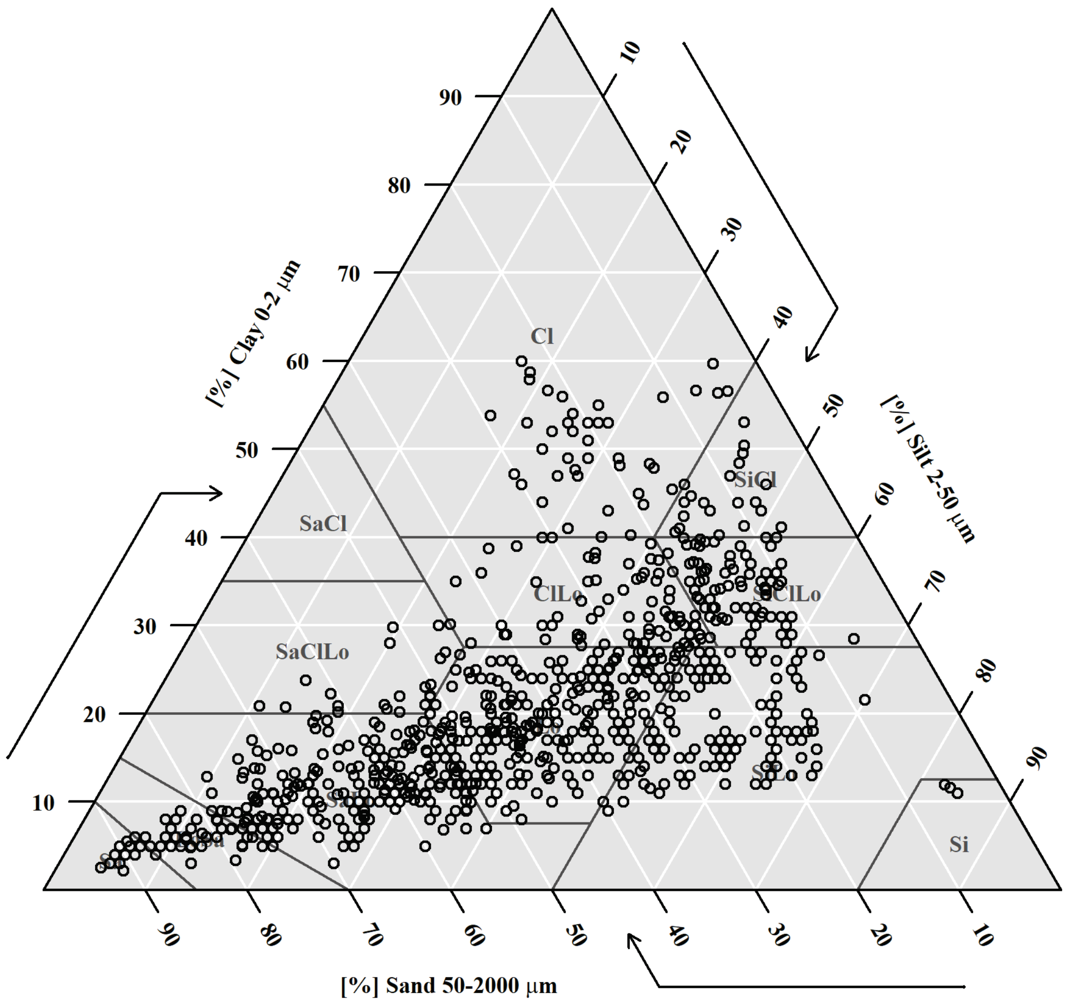

Figure 2. Distribution of GLB soil texture, on a per polygon basis, within the USDA soil textural triangle.

2.7 Integrated soil texture distribution

The Ontario soils data were collected from Soil Landscapes of Canada (SLC, 2010) with a map scale of 1:1 million. The soil data for the U.S. portion were obtained from the State Soil Geographic (STATSGO) data base with a map scale of 1:250,000 (USDA-NRCS, 1995). These data sets were simplified to 10 soil textural types based on relative percentages of sand, silt and clay, using the USDA soil textural triangle .

2.8 Soil hydraulic parameters

For each soil textural type, residual saturation and the moisture retention and saturation – permeability (α and n) parameters represented in the van Genuchten (1980) model, were estimated with the Rosetta pedotransfer model (Schaap et al., 2001), with final values presented in Table 3. Hydraulic conductivity in the vertical and horizontal directions (K_v and K_h) were calculated individually for each soil polygon using the following respective averaging approach: $K_v = \frac{\sum_{i=1}^{M} b_i}{\sum_{i=1}^{M} \frac{b_i}{K_i}}$, and $K_h = \frac{\sum_{i=1}^{M} K_i b_i}{\sum_{i=1}^{M} b_i}$ where b denotes layer thickness, K denotes the respective directional hydraulic conductivity, i is the layer index, and M is the total number of layers. Porosity for each polygon was determined using the same averaging approach as that used for K_h.

Table 3. Soil hydraulic parameters (in filename: van_Genuchten_parameters_K.xlsx).

Soil Zone*	Soil Texture	θ_r	θ_s	α	n	K_h	K_v
		(m^3/m^3)		(1/m)	-	(m/s)	(m/s)
1	clay	0.08	0.35	2.07	1.18	3.26E-06	8.06E-07
2	clay loam	0.06	0.32	1.62	1.25	6.47E-06	2.21E-06
3	loam	0.04	0.29	2.80	1.22	1.07E-05	3.86E-06
4	loamy sand	0.04	0.36	3.88	1.93	4.99E-05	2.20E-05
5	sand	0.05	0.29	3.59	2.37	5.94E-05	1.22E-05
6	sandy clay loam	0.06	0.40	1.97	1.39	1.83E-05	6.69E-06
7	sandy loam	0.04	0.32	4.48	1.30	2.34E-05	1.14E-05
8	silt loam	0.04	0.28	1.85	1.26	6.41E-06	2.28E-06
9	silty clay	0.08	0.36	1.44	1.26	2.38E-06	8.39E-07
10	silty clay loam	0.06	0.32	1.48	1.25	3.36E-06	1.13E-06

2.9 Integrated Quaternary geology mapping

Two surficial geology data sets were combined for the GLB model, 1) 1:5 million surficial geology from Natural Resources Canada (NRCan) for the Ontario portion of the model domain (GSC, 2014) and 2) 1:1 million scale mapping from the USGS for the U.S. portion (Soller et al., 2009).

2.10 Subsurface geological layers

Figure 3 provides a schematic of the layers used in the construction of the HGS model. In addition to the three soil layers the geological subsurface was assigned to 3 rasters were used, and intermediate layering was created using HydroGeoSphere 'offset layer' commands during model setup.

The three layers include:

- Topography
- The contact between shallow and deep Quaternary units
- Bedrock surface elevation

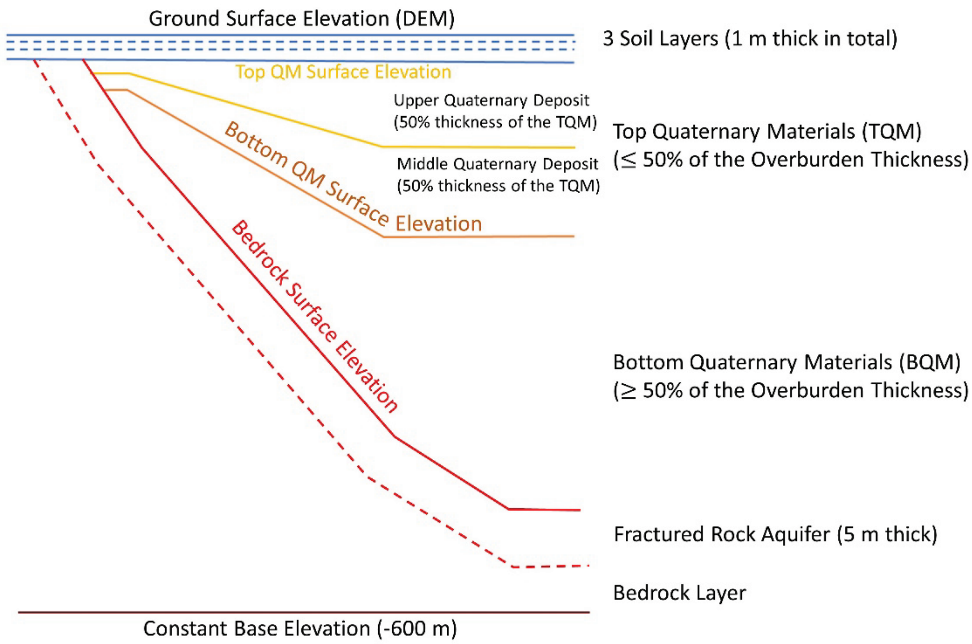

Figure 3. Hydrostratigraphic sequence of the GLB model

2.11 Description of Quaternary materials (QM) and horizontal hydraulic conductivity

A starting estimate of hydraulic conductivity for each type of quaternary material was determined from existing literature (Coon and Sheets, 2006; Earle, 2015; Fetter, 2001; Freeze and Cherry, 1979; Lappala, 1978; Olcott, 1992) and manually adjusted during model calibration, as described in Xu et al. (2021).

2.12 Drainage network

The river network used for the GLB model was derived from HydroSheds 15 arc-second resolution vector data (Lehner et al., 2008). The network was simplified such that only river segments with greater than 2500 contributing cells, or approximately a 250 km^2 catchment area, within the HydroSheds 15 arc-second DEM were included.

2.13 Selected surface water gauging stations

A total of 53 stream gauging stations (Table 4) were include in the GLB model for model validation, of which 25 are located in Canada (EC, 2016;), and 28 are located in the U.S. (USGS, https://waterdata.usgs.gov/nwis/sw).

Table 4. Gauging stations used in model validation.

Station No.	Station ID	Station Name	Latitude	Longitude	Drainage Area (km^2)
1	02BB003	PIC RIVER NEAR MARATHON	48.77	-86.30	4221.73
2	02BC004	WHITE RIVER BELOW WHITE LAKE	48.65	-85.74	4156.28
3	02BD007	MAGPIE RIVER NEAR WAWA	48.02	-84.81	1954.09
4	02CB003	AUBINADONG RIVER ABOVE SESABIC CREEK	46.97	-83.42	1451.66
5	02CC005	LITTLE WHITE RIVER NEAR BELLINGHAM	46.39	-83.28	1971.45
6	02CE002	AUX SABLES RIVER AT MASSEY	46.21	-82.07	1338.60
7	02CF010	ONAPING RIVER NEAR LEVACK	46.60	-81.38	1647.69
8	02DB005	WANAPITEI RIVER NEAR WANUP	46.35	-80.84	3154.02
9	02DC004	STURGEON RIVER NEAR GLEN AFTON	46.64	-80.26	3006.40
10	02EA011	MAGNETAWAN RIVER NEAR BRITT	45.77	-80.48	2839.38
11	02EB004	NORTH BRANCH MUSKOKA RIVER AT PORT SYDNEY	45.21	-79.28	1410.11
12	02EC003	SEVERN RIVER AT SWIFT RAPIDS	44.86	-79.54	5850.00
13	02EC014	SEVERN RIVER ABOVE WASDELL FALLS	44.78	-79.30	5310.00
14	02ED027	NOTTAWASAGA RIVER NEAR EDENVALE	44.48	-79.97	2686.37
15	02FC001	SAUGEEN RIVER NEAR PORT ELGIN	44.46	-81.33	3953.52
16	02FE015	MAITLAND RIVER AT BENMILLER	43.72	-81.63	2544.78
17	02GA003	GRAND RIVER AT GALT	43.35	-80.32	3515.27
18	02GB001	GRAND RIVER AT BRANTFORD	43.13	-80.27	5200.52
19	02GE002	THAMES RIVER AT BYRON	42.96	-81.33	3082.61
20	02GE003	THAMES RIVER AT THAMESVILLE	42.54	-81.97	4370.37
21	02HA003	NIAGARA RIVER AT QUEENSTON	43.16	-79.05	686000.00
22	02HK003	CROWE RIVER AT MARMORA	44.48	-77.68	1934.69
23	02HL001	MOIRA RIVER NEAR FOXBORO	44.25	-77.42	2594.93
24	02HM003	SALMON RIVER NEAR SHANNONVILLE	44.21	-77.21	906.73
25	04024000	ST. LOUIS RIVER AT SCANLON, MN	-92.42	46.70	8883.67
26	04040000	ONTONAGON RIVER NEAR ROCKLAND, MI	-89.21	46.72	3470.59
27	04059000	ESCANABA RIVER AT CORNELL, MI	-87.21	45.91	2253.29
28	04059500	FORD RIVER NEAR HYDE, MI	-87.20	45.75	1165.50
29	04066030	MENOMINEE RIVER AT WHITE RAPIDS DAM NEAR BANAT, MI	-87.80	45.48	8262.07
30	04067500	MENOMINEE RIVER NEAR MC ALLISTER, WI	-87.66	45.33	10178.66
31	04069500	PESHTIGO RIVER AT PESHTIGO, WI	-87.74	45.05	2797.19
32	04071765	OCONTO RIVER NEAR OCONTO, WI	-87.98	44.86	2501.93
33	04073500	FOX RIVER AT BERLIN, WI	-88.95	43.95	3470.59
34	04079000	WOLF RIVER AT NEW LONDON, WI	-88.74	44.39	5853.38
35	04101500	ST. JOSEPH RIVER AT NILES, MI	-86.26	41.83	9494.90
36	04108660	KALAMAZOO RIVER AT NEW RICHMOND, MI	-86.11	42.65	5050.48
37	04116000	GRAND RIVER AT IONIA, MI	-85.07	42.97	7355.57
38	04122001	MUSKEGON RIVER AT BRIDGE STREET AT NEWAYGO, MI	-85.81	43.42	6215.98
39	04122500	PERE MARQUETTE RIVER AT SCOTTVILLE, MI	-86.28	43.95	1763.78
40	04125550	MANISTEE RIVER NEAR WELLSTON, MI	-85.94	44.26	3758.08
41	04133501	THUNDER BAY RIVER AT HERRON ROAD NEAR BOLTON, MI	-83.64	45.12	1517.73
42	04137500	AU SABLE RIVER NEAR AU SABLE, MI	-83.43	44.44	4503.99
43	04156000	TITTABAWASSEE RIVER AT MIDLAND, MI	-84.24	43.60	6215.98
44	04157005	SAGINAW RIVER AT HOLLAND AVENUE AT SAGINAW, MI	-83.95	43.42	15695.34
45	04176500	RIVER RAISIN NEAR MONROE, MI	-83.53	41.96	2698.77
46	04193500	Maumee River at Waterville OH	-83.71	41.50	16394.64
47	04198000	Sandusky River near Fremont OH	-83.16	41.31	3240.08
48	04231600	GENESEE RIVER AT FORD STREET BRIDGE, ROCHESTER NY	-77.62	43.14	6407.64
49	04235600	SENECA RIVER (ERIE CANAL) NEAR PORT BYRON NY	-76.65	43.08	7290.82
50	04249000	OSWEGO RIVER AT LOCK 7, OSWEGO NY	-76.51	43.45	13208.95
51	04260500	BLACK RIVER AT WATERTOWN NY	-75.92	43.99	4827.74
52	04263000	OSWEGATCHIE RIVER NEAR HEUVELTON NY	-75.38	44.60	2553.73
A1	02HA019	WELLAND CANAL DIVERSION FROM LAKE ERIE	42.95	-79.22	N/A
A2	02MC002	ST. LAWRENCE RIVER AT CORNWALL	45.01	-74.80	774000.00

2.14 Groundwater monitoring well locations

A total of 416 groundwater monitoring wells were included in the GLB model, of which 352 are located in Canada and 64 are located in the U.S. The Canadian monitoring well data was obtained from the Ontario Provincial Groundwater Monitoring Network (https://www.ontario.ca/environment-and-energy/map-provincial-groundwater-monitoring-network) and the U.S monitoring well data was obtained from USGS National Ground-Water Monitoring Network (USGS, https://cida.usgs.gov/ngwmn). The data list is available as a dbf file in the respective file folders.

2.15 HydroGeoSphere (HGS) 3-D mesh

The 2-D triangular mesh for the HGS model was generated using AlgoMesh (Merrick, 2017) and included rivers and lake edges as mesh control features.. The spatial resolution of the mesh ranges from about 10 km in the offshore regions within the lakes to approximately 3 km over the land surface and 2 km along the surface water control features. Each mesh layer contains 54,409 mesh nodes and 107,194 triangular finite elements. The full 3-D model grid projects the 2-D mesh onto eight subsurface layers that can be generally described as three soil, three Quaternary material, one fractured bedrock, and one competent bedrock layer (Figure 1).

2.16 Monthly gridded liquid water flux and potential evapotranspiration (PET)

Monthly normal gridded (1/12 degree resolution) liquid water flux (liquid precipitation and snowmelt) and potential evapotranspiration (PET) for 1981 to 2010 was obtained from McKenney et al. (2011) and used as forcing data for the terrestrial portion of the GLB model. PET is calculated based on the diurnal temperature range (Hogg, 1997). Because snowmelt is not measured directly, it was estimated from changes in snow water equivalent (SWE), which in turn was estimated from snow depth using a snow density climatology (Sturm et al., 1995). Since snow depth data in the McKenney et al. (2011) dataset is only available for Canada, archival snow depth data from the Canadian Meteorological Center daily analysis was used for the U.S. part of the basin (Brown and Brasnett, 2010).

Climate forcing over the water surface of the Great Lakes requires separate consideration due to its different seasonal cycle from over land. For this reason, the over-lake precipitation was corrected for each of the Great Lakes in this monthly gridded liquid water flux data set, using the estimates from the NOAA Great Lakes Environmental Research Laboratory (Hunter et al, 2015; Hunter and Croley, 1993), based on the Large Lake Thermodynamic Model (LLTM; Croley and Assel, 1994).

3 Summary

This data release was motivated by the interest in supporting collaboration on transboundary USA–Canada groundwater–surface-water understanding and to facilitate intermodal comparison of results obtained by Xu et al. (2021).

4 Acknowledgements

An internal review at the Geological Survey of Canada by M. Bunn is much appreciated. Aquanty's efforts were partially supported by funding received from Ontario Centres of Excellence. Public access was enabled by Natural Resources Canada Groundwater Geoscience Program contract 3000722749 to Aquanty Inc. This data release is a contribution by Aquanty Inc. and the Geological Survey of Canada to a collaborative project of the U.S. Geological Survey (USGS) John Wesley Powell Center for Analysis and Synthesis, Improving representation of groundwater in foundational Great Lakes hydrologic and hydrodynamic models and data sets.

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