GLAHF Hydrology Data Package v 1.0

Read Me

Introduction

This document summarizes the Great Lakes Hydrography Dataset Version 1 (GLHDv1.0) (2014) and describes the purpose, processing background, and organization of the data package and the relationships between the datasets it contains.

We created the GLHDv1.0 as a part of the Great Lakes Aquatic Habitat Framework (GLAHF) project, a geospatial database and framework for the aquatic environment of the Great Lakes. The GLHDv1.0 contains consistent, basin-wide watershed layers and supporting datasets, including modified vector layers from hydrology datasets, and intermediate reference layers created during delineation of the watersheds. We specifically created the watershed layers to be incorporated into the GLAHF Great Lakes aquatic habitat classification and nearshore fish habitat assessment so that we could consistently link watershed data to the Great Lakes aquatic habitat across the basin. The purpose of this product was to: 1) delineate tributary watersheds for the Great Lakes basin that were consistent, integrated, and used the best available data, 2) develop repeatable, well-documented methodology, and 3) develop a product that incorporated input from experts across the U.S. and Canada. We conducted this work with the support of a technical advisory committee with members from the U.S. Environmental Protection Agency (EPA), Ontario Ministry of Natural Resources, International Joint Commission, Agriculture and Ag-Food Canada, Michigan State University, Michigan Department of Natural Resources, Nature Conservancy, U.S. Geological Survey, U.S. Fish and Wildlife Service, and the University of Michigan. This product represents substantive contributions from each team member and a rigorous, iterative review and decision making process.

Table 1: List of technical advisory committee team members and their affiliations

Name	Affiliation
Gust Annis	The Nature Conservancy
Chris Castiglione	United States Fish and Wildlife Service
Danielle Forsyth	Michigan Department of Natural Resources
John Gaiot	Ontario Ministry of Natural Resources
Tom Hollenhorst	United States Environmental Protection Agency
Dana Infante	Michigan State University
Craig Johnston	United States Geological Survey
Lacey Mason	University of Michigan
James McKenna	United States Geological Survey
Catherine Riseng	University of Michigan
Mike Robertson	Ontario Ministry of Natural Resources

Kent Todd	Ontario Ministry of Natural Resources
Lizhu Wang	International Joint Commission
Gary Whelan	Michigan Department of Natural Resources
Conrad Wyrzykowski	Agriculture and Ag-Food Canada

Methods

We used an ArcHydro process flow to delineate watersheds basin wide, which was based on a modified version of the stream interfluves delineation methods outlined in Hollenhorst et al. (2007) and ArcHydro processing steps outline in Merwade (2010). The process flow began with flow direction grids, which are grids derived from elevation and hydrology data that represent water moving through a landscape. (ESRI 2011) We used modified versions of the flow direction grids from the National Hydrography Dataset Plus Version 2 (NHD+v2) to delineate watersheds for the U.S. mainland, Drummond Island in Lake Huron, and Grand Island in Lake Superior, and modified versions of the flow direction grids from the Ontario Integrated Hydrology Data Version 1.0 (OIHDv1.0) to delineate watersheds for the Canadian mainland and all islands. Since the NHD+V2 only provided data for Drummond and Grand Islands, we created flow direction grids from the National Hydrography Dataset (NHD) and the National Elevation Dataset (NED) to derive watersheds for all other U.S. islands in the dataset. Using those flow direction grids as input, we used a multi-step ArcHydro process flow that started by creating flow accumulation grids, which are grids that estimate the amount of upstream flow on the landscape (ESRI 2011), for the OIHDv.10 and NHD data (flow accumulation grids are already packaged with the NHD+v2). We then used flow accumulation grids along with flow direction grids to create a synthetic drainage network based on the 3,000 cell threshold outlined in Hollenhorst et al. (2007) that required 3,000 cells (equivalent to 2.7km^2) of upstream area to drain to a cell before a stream could be delineated. Once the synthetic drainage network was delineated, we used ArcHydro to create associated reach catchments, sub watersheds, and basin-wide, consistent tributary catchment (watershed) boundaries. We also delineated the area between the watersheds and the shoreline, called interfluves (Gilliam 1997), in a secondary processing step by adding any area between the shoreline and the watershed boundaries in the flow direction grid back to the final layer as an interfluve.

Data Modifications

We made modifications to the data by altering input flow direction grids, output watersheds and interfluve layers, and hydrology layers associated with input flow direction grids. We made these alterations so that the layers better matched the intended purposes of the dataset and so that the product was easier to comprehend for end users. The next three sections outline the alterations we made the layers in the data package.

Input Flow Direction Grids

We used 17 flow direction grids as input to our ArcHydro process flow, running all of the ArcHydro steps for every input flow direction grid. Afterwards, we combined the synthetic intermediate layers and final watershed layers for the entire basin and then packaged them by individual Great Lakes Basins. The NHD+v2 and OIHDv1.0 packaged flow direction grids into four processing units each, and we packaged U.S. island flow direction grids into processing units corresponding to each of the five major Great Lakes and connecting channels. Additionally, we separated the Canadian islands from the mainland, creating four more processing units. We did not combine the flow direction grids and then run the ArcHydro process flow because 1) reprojecting or combining flow direction grids alters flow paths and changes watershed delineation, and 2) the dataset would have been too large and processing would have either been unreliable or too time consuming, and 3) we wanted to keep island watersheds separate from mainland watersheds.

Before we used the flow direction grids as input data into our delineation process, we modified the shoreline of these grids; that same modified shoreline therefore carried over into the intermediate layers and the watershed and interfluve layers since they were developed from the flow direction grids. Our technical advisory committee agreed to modify the grid shorelines in four main ways: 1) alter the OIHDv1.0 flow direction grids so that the data did not extend past the shoreline into the lakes (the unaltered grids created watershed boundaries that extended into the lakes), 2) clip the NHD+v2 flow direction grids so that the grid ended at the shoreline in the connecting channels (the unaltered grids extended across the entire connecting channel, creating large watersheds boundaries that only emptied into one of the five main Great Lakes), 3) enforce additional embayments into the shoreline of the grids using Environmental Protection Agency (EPA) data and team input, and 4) bound the extent of all of the flow direction grids to the Great Lakes Basin. Almost all of these changes enhanced the detail of the shoreline, which the technical advisory committee felt helped to clarify coastal habitat and aid in identifying the location of tributary load delivery. These enhancements were beneficial for habitat classification and assessment, since they allowed more areas in the lakes to be better classified and assessed. By enforcing the shoreline in the connecting channels, the final product could also be used for detailed nutrient and transport modeling throughout the Great Lakes.

Watershed and Interfluve Layers

After we ran the ArcHydro processing flow and interfluve processing steps, the technical advisory committee agreed to modify the output watershed and interfluve layers in six major ways:

- For mainland watersheds, we eliminated small coastal watersheds that were not associated with a reach on the NHD+v2 or OIHDv1.0 networks by merging the watershed with neighboring interfluves. This was done so that our watershed and interfluve layer only reflected streams that were represented on the OIHDv1.0 or the NHD+v2 networks.

- For all watersheds and interfluves, we used a size threshold of 7,200m^2 to eliminate very small interfluve or watersheds. Watersheds and interfluves smaller than threshold were merged with neighboring interfluves or watersheds because the technical advisory committee felt they were most likely created as an artifact of raster processing.
- We eliminated some small watersheds on the U.S. side of the connecting channels by merging them with surrounding interfluves. We enforced the connecting channels in the input grids using water features from the NHD 1:24,000 data package, which had much more detail than the NHD+v2 30m x 30m raster flow direction grid. This created several areas where the 1:100,000 network used to create the NHD+v2 flow direction grid did not line up with the NHD 1:24,000 features. In these areas, some small coastal watersheds were created that should have been part of the interfluves.
- There were some areas in watersheds derived from the NHD+v2 data which contained sinks, or watersheds that drained into the middle of a mass of land instead of draining into the Great Lakes or a connecting channel. We merged these with larger watersheds using guidance from topographic maps.
- We matched and edited layers in the boundary waters of Lake Superior between Minnesota and Ontario to remove gaps and overlap between the data derived from the OIHDv1 and the data derived from the NHD+v2.
- We attributed watershed pour points (the point where the entire area of the watershed emptied into the Great Lakes or connecting channel) with attributes from the most downstream segment from the NHD+v2, OIHDv1.0, and NHD (and names from the Geographic Extent (GEL) and the National Hydro Network (NHN) layers for Canadian data) within 200m of the watershed point. Watershed polygons were then attributed with information from associated watershed points
- We assigned unique identifiers to all watersheds and interfluves, by sequentially numbering them counterclockwise across the Great Lakes Basin, beginning with the mainland in the Lake Superior boundary waters between Minnesota and Ontario. Islands were then numbered in a similar fashion, beginning with the number 10,000 on Isle Royale, and moving counter clockwise across the basin.

NOTE: Representations of diversions such as the Welland Canal in the watershed and interfluve layers and the intermediate layers reflect decisions made by the OIHDv1.0 and NHD+ v2 teams. Diversions are represented exactly as they were handled in the OIHDv1.0 or the NHD+v2 input flow direction grids and do not reflect any additional decisions or alterations by the technical advisory committee.

Associated Hydrology Layers

Finally, our technical advisory committee decided that the GLHDv1.0 should include modified versions of the OIHDv1.0, NHD+v2, and NHD drainage networks and the NHD+v2 reach catchments that had been altered to better match the watershed and interfluve layers, and subsequently also better match the watershed and interfluve layer and synthetic layers derived from the flow direction grid. The NHD+v2, OIHDv1.0, and NHD are all data packages that contain a number of hydrology layers and supporting data layers. We incorporated only the drainage networks from the OIHDv1.0, NHD+v2, and the NHD, and the reach catchment layer from the NHD+v2, and modified these layers in the following ways: 1) clipped the NHD+v2, OIHDv1.0, NHD networks at the shoreline to match the shoreline of the watersheds and interfluve layers, 2) altered the NHD+v2 network to remove any "Uninitialized" streams, which were not incorporated into the NHD+v2 flow direction grids, 3) removed shoreline segments from the NHD+v2 and the NHD networks, and 4) removed pipelines from the NHD drainage network. Out of all the layers in each data package, we decided to only include the drainage lines from the OIHDv1.0 and the NHD and the reach catchments and drainage lines from the NHD+v2 because 1) they provided the best reference data for users, 2) packaged reach catchments were only available the NHD+v2 at the time of processing, 3) gridded data (such as flow direction grids) were very large files and we could not package them easily by Great Lake or the Great Lake Basin, so we did not include them in our data package.

Final Data Package Format

For the GLHDv1.0, we packaged the following data layers into ESRI file geodatabases by the entire Great Lakes Basin and by each Great Lake Basin: 1) final watersheds and interfluves and pour point layers (the point associated with each watershed where the entire area of the watershed emptied into the Great Lakes or a connecting channel), 2) modified official hydrology layers, and 3) all synthetic intermediate reference layers created with the ArcHydro process flow. We packaged connecting channels data with the associated downstream lake. Each geodatabase in the data package is comprised of five feature datasets (see Figure 1 below), including one feature dataset containing finalized watershed layers (GLHD_Final_Watershed_Layers), three reference feature datasets which contain modified base data from NHD 24k, NHD+v2, and OIHDv1, and one reference feature dataset containing intermediate synthetic layers created during ArcHydro watershed processing (Synthetic_Intermediate_Layers).

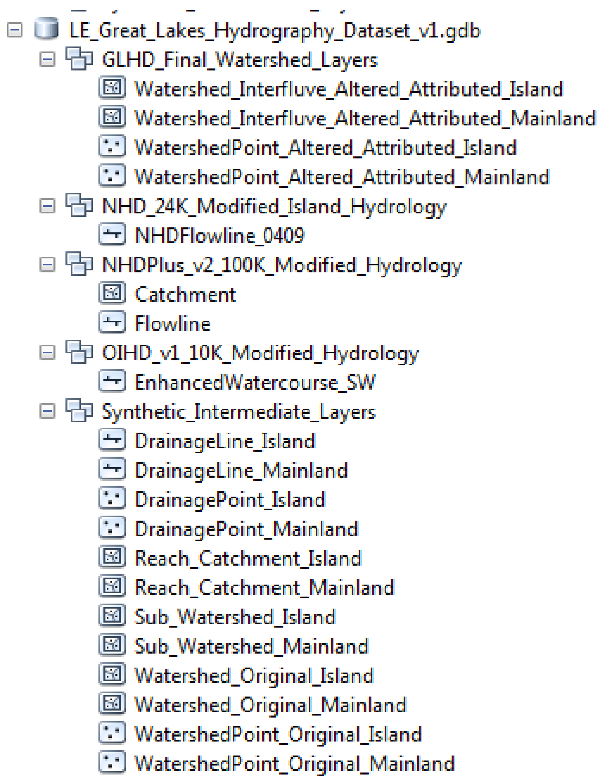

Figure 1: The GLHDv1.0 (2014) Geodatabase schematic for Lake Erie. All other lakes and the Great Lakes Basin will have the same format

GLAHF_Final_Watershed_Layers

This feature dataset contains the finalized watershed and interfluve and pour points (the terminal outlet point for each watershed in the Great Lakes or connecting channels) associated with each watershed.

a. **Watershed_Interfluve_Altered_Attributed—**this layer contains the final, post processed watershed and interfluve boundaries that were altered as described in the “Watershed and Interfluve Layers” section of the “Data Modifications” heading in this document. We made a copy of the Watershed_Layer that was created by the ArcHydro process flow (see Synthetic_Intermediate_Watershed_Layers), added interfluves, and edited some watershed and interfluve polygons following the rules outlined in the “Watersheds and Interfluve Layers” section of the “Data Modifications” heading.
b. **WatershedPoint_Altered_Attributed—**this layer contains the pour points that match the edited Watershed_Interfluve_Altered_Attributed layer. We made a copy of the WatershedPoint_Original layer delineated in the ArcHydro process flow (see

Synthetic_Intermediate_Watershed_Layers) and edited it to remove the pour points for watersheds that no longer existed in Watershed_Interfluve_Altered_Attributed.

NHD_24K_Modified_Island_Hydrology

The technical advisory committee decided to consistently delineate watershed data for islands across the entire basin. This was straightforward for the Canadian side of the basin since the OIHDv1.0 flow direction grids covered all Canadian islands. However, the NHD+v2 flow direction grids only covered the U.S. mainland and two islands—Drummond Island and Grand Island—so the technical advisory committee decided to create flow direction grids for watershed delineation for the remaining U.S. islands using the NHD 1:24,000 drainage lines and the NED 30m x 30m elevation grids. We implemented a threshold for watershed delineation so that only islands with drainage lines at the NHD 1:24,000 or the OIHDv1.0 1:10,000 scales were included in watershed data delineation in order to generate watershed data consistently across the basin. This feature dataset contains the modified NHD 1:24,000 drainage lines that we used to create the input flow direction grids and that we used to implement the threshold for the U.S side of the basin. The NHD 1:24,000 drainage lines were modified to remove shoreline and pipeline features. Since the NHD packages data into units, we have kept the layers in the same format. The NHD is packaged into 15 units for the U.S. side of the Great Lakes Basin, which are numbered from 0401-0415. (see Figure 2) The name of each layer in this feature dataset includes NHDFlowline + the four digit code. Therefore NHD_Flowline_0401 contains modified data from the NHD 0401 region. All of the feature attributes for each layer have been kept in their original format except for the addition of the GLHDID field, which contains the unique watershed identifier with the highest percent overlap with the NHD reach. To find further information on the original attributes and the NHD package, please consult the NHD User's Guide, which currently resides at http://nhd.usgs.gov/userguide.html.

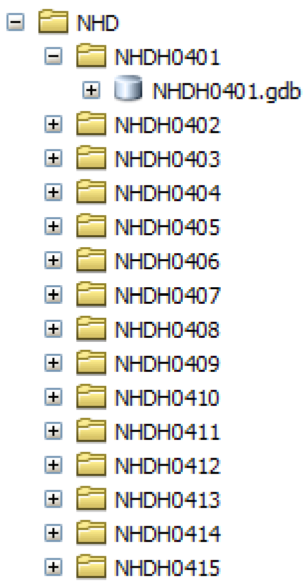

Figure 2: The NHD 1:24,000 file structure, with folders for each region, containing geodatabases with data layers covering each region. Note that NHD regions have some degree of overlap between many of the regions. (USGS, 2012a)

NHD_Plus_v2_100K_Modified_Hydrology

We delineated watershed and interfluve layers for the U.S. mainland, Drummond Island, and Grand Island using modified flow direction grids packaged with the NHD+v2. This feature dataset contains a modified version of the NHD+v2 reach catchments and drainage lines, which we altered to match the shoreline and hydrology of the flow direction grids (and the watershed and interfluve and the synthetic layers) in the following ways: 1) clipped drainage lines and reach catchments that were extending into the connecting channels at the shoreline, 2) enforced additional bays into the shorelines of the drainage line and reach catchment layers, and 3) removed any coastline and uninitialized features from the drainage lines (uninitialized features are those that appear on the drainage network but were not incorporated into the NHD+v2 flow direction grids). The NHD+v2 flow direction grids are packaged by processing unit, which are 4a, 4b, 4c, and 4d for the Great Lakes (see Figure 3), but the NHD+v2 packages the drainage line and reach catchment layer into one unit for the Great Lakes. Therefore, the modified drainage line and reach catchment layers are packaged into one layer each in this feature dataset to match the formatting of the NHD+v2. All of the feature attributes have been kept in their original format except for the addition of the GLHDID field, which contains the unique watershed identifier with the highest percent overlap with the NHD+v2 reach. To find further information on the original attributes and the NHD+v2 package, please consult the NHD+v2 User's Guide, which currently resides at ftp://ec2-54-227-241-43.compute-1.amazonaws.com/NHDplus/NHDPlusV21/Documentation/NHDPlusV2_User_Guide.pdf.

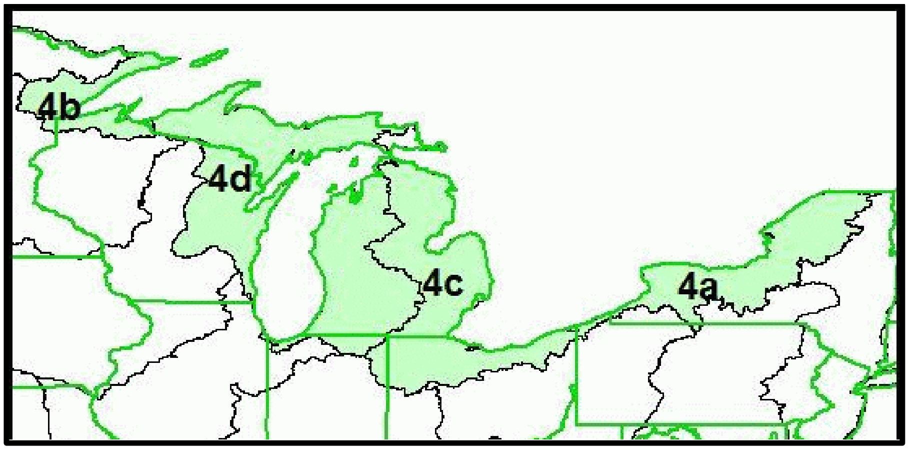

Figure 3: NHD Region 04 representing the Great Lakes. Region 04 is divided into units: a, b, c, and d. (McKay et al., 2010)

OIHD_v1_10K_Modified_Hydrology

We delineated watersheds from the modified OIHDv1.0 enhanced flow direction grids for the Canadian mainland and for all Canadian islands. We modified the associated OIHDv1.0 drainage to reflect the shoreline alterations made to the flow direction grids in the following ways: 1) clipped the drainage lines at the shoreline for the entire Canadian basin, which included clipping drainage lines that extended into the connecting channels at the shoreline, and 2) enforced additional bays into the shorelines of the drainage lines. This feature dataset contains the modified versions of the OIHDv1.0 drainage lines. All of the data in the OIHDv1.0 is packaged by region, with the North Central (NC), North East (NE), South East (SE), and South West (SW) covering the Great Lakes. (see Figure 4) We kept the drainage lines in this format, with modified drainage line layers retaining the original naming conventions. All of the feature attributes for each layer have been kept in their original format except for the addition of the GLHDID field, which contains the unique watershed identifier with the highest percent overlap with the OIHDv1.0 reach. Please consult the OIHDv1.0 User's Guide, which is available as part of the OIHDv1.0 package. Please contact Land Information Ontario at lio@ontario.ca to inquire about obtaining the dataset and user's guide. Associated metadata can be found at https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/iso19139.xml?id=13225 .

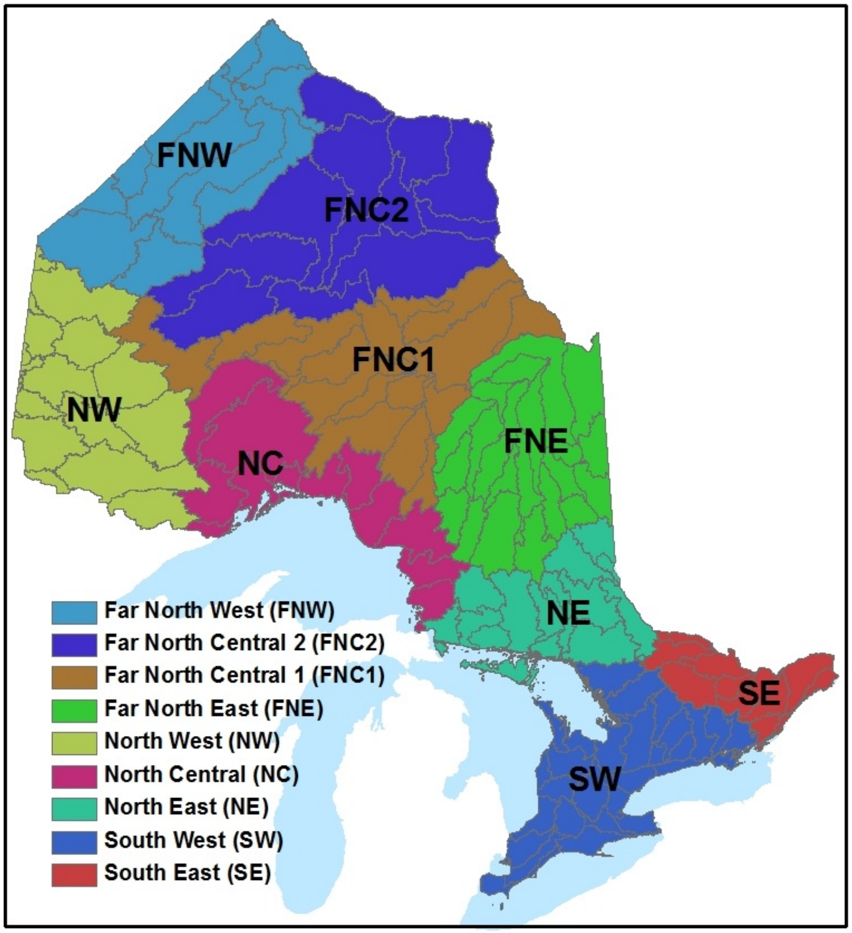

Figure 4: OIHDV1 regions for Ontario, with the NC, NE, SE, and SW covering the Great Lakes (Ontario Ministry of Natural Resources, 2012b)

Synthetic_Intermediate_Layers

We used the modified flow direction grids to delineate watersheds and interfluves across the basin. In order to create the final watershed and interfluve layers, we first created a number of intermediate layers using ArcHydro. These intermediate synthetic layers provide consistently derived data representing synthetic drainage lines, reach catchments, sub catchments, drainage points, unedited watershed pour points, and unedited watersheds and interfluves. These layers are provided for reference so that users can better determine how the finalized watershed and interfluve layers were created. We recommend whenever possible to use accepted hydrology standards such as the OIHDv1 or the NHD+v2 in lieu of these synthetically derived layers as follows. For applications requiring drainage lines, we recommend using the modified versions of the NHD+v2, OIHDv1.0, or NHD modified drainage liens included in this package. For applications involving reach catchments, we recommend utilizing the NHD+v2 reach catchments for the U.S. side of the basin. Some applications that require consistently derived layers may warrant utilizing synthetic layers in this package, however whenever possible those results should be linked back to the OIHDv1.0, NHD+v2, or NHD hydrology standards.

The following describes the synthetic layers that we delineated in the ArcHydro process flow and were used to create the finalized watershed and interfluve layer, in the order they were created:

a) **DrainageLine**—the synthetic drainage network that was created from the flow accumulation and flow direction grids, using a 3,000 cell (equivalent to 2.7 km^2) flow accumulation threshold. (Hollenhorst et al. 2007) If a cell on the flow accumulation grid had 3,000 cells emptying into it, then the pixel was labeled as a drainage line.
b) **Reach_Catchment**—every catchment in this layer corresponds to a single reach on the synthetic DrainageLine network. The reach catchments represent the area of land draining into each reach.
c) **Sub_Watershed**—the boundary for each group of catchments in the Reach_Catchment layer that aggregate into a larger drainage area, excluding the last catchment at the shoreline, which drains into one of the Great Lakes or a connecting channel.
d) **DraingePoint**—the drainage outlet point for every catchment in the Reach_Catchment layer, where the water drains from the upstream limit to the downstream limit of a reach.
e) **Watershed_Original**—each polygon in this layer represents the area of land draining from the headwaters to the terminal outlet point in the Great Lakes or the connecting channels. This dataset remains as it was originally delineated in ArcHydro, before post processing.
f) **WatershedPoint_Original**—contains points that correspond to the outlet point of all of the watersheds in Watershed_Original into the Great Lakes or the connecting channels. This dataset remains as it was originally delineated in ArcHydro, before post processing.

Acknowledgements

We would like to thank each member of the technical advisory committee for their valuable input in making this product and their participation in the iterative review process. The Great Lakes Aquatic Habitat Framework (GLAHF) project has been funded by the Great Lakes Fishery Trust and lead by the University of Michigan School of Natural Resources and Environment, with partners from Michigan Department of Natural Resources-Institute for Fisheries Research, NOAA Great Lakes Environmental Research Laboratory, International Joint Commission, Michigan State University, The Nature Conservancy, Ontario Ministry of Natural Resources, University of Minnesota-Duluth, U.S. Fish & Wildlife Service, U.S. Geological Survey and many collaborating partners in both the USA and Canada. More information about this project can be found at http://ifr.snre.umich.edu/projects/glahf/.

References

Environment Canada, Agriculture and Agri-Food Canada, United States Geological Survey, Natural Resources Canada, and the United States Environmental Protection Agency. 2013. Watershed Boundary Dataset for {U.S. and Canada in Great Lakes Basin} Last accessed: April 12, 2013.

Environmental Systems Research Institute. 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute. Computer Software.

Gilliam, J.W., Osmond, D.L., and Evans, R.O. 1997. Selected agricultural best management practices to control nitrogen in the Neuse River basin. North Carolina Agricultural Research Service technical bulletin 311, North Carolina State University, Raleigh, North Carolina.

Hollenhorst, T.P., T.N. Brown, L.B. Johnson, J.J.H. Ciborowski, and G.E. Host. 2007. Methods for Generating Multi-scale Watershed Delineations for Indicator Development in Great Lakes Coastal Ecosystems. *Journal of Great Lakes Research* 33 (Special Issue 3): 13-26.

Horizon Systems Corp. 2012. NHDPlus Home. < http://www.horizon-systems.com/nhdplus/>. Last accessed: February 10, 2012.

McKay, L., Bondelid, T., Dewald, T., Johnston, J., Moore, R., and Rea, A. 2010. NHD Plus User Guide. September 1, 2010. <ftp://ftp.horizon-systems.com/NHDPlus/documentation/NHDPLUS_UserGuide.pdf> Last accessed: February 17, 2012

Merwade, V., 2010. Watershed and Stream Network Delineation Tutorial. < http://web.ics.purdue.edu/~vmerwade/education/terrain_processing.pdf> Last accessed: February 17, 2012.

Natural Resources Canada. 2004. National Hydro Network. <http://geobase.ca/geobase/en/data/nhn/index.html;jsessionid=65626EC065720D7E88CD1BDFB017A8C0.geobase1>

Ontario Ministry of Natural Resources. 2010. Ontario Hydro Network. < https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/metadata.show?uuid=3ebaf6b2-6dd6-4ebb-a6bb-4fc778426709&currTab=simple> Last accessed: November 22, 2013.

Ontario Ministry of Natural Resources. 2011. Geographic Named Extent. <https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home> Last accessed: November 21, 2014.

Ontario Ministry of Natural Resources. 2012a. Ontario Integrated Hydrology Data. <https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home> Last accessed: October 25, 2012.

Ontario Ministry of Natural Resources. 2012b. Ontario Integrated Hydrology Data Technical Specifications Version 1.0. October 2012. Water Resources Information Program.

United States Geological Survey. 2009. National Hydrography Dataset. <http://nhd.usgs.gov/data.html> Last accessed: January 13, 2013.

United States Geological Survey. 2012. National Elevation Dataset. <http://nationalmap.gov/> Last accessed: March 1, 2013.