Medium Resolution Digital Elevation Model (MRDEM)

– CanElevation Series –
Technical Specifications

Edition 1.1

2025-03-19

Government of Canada
Natural Resources Canada

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RELEASES HISTORY

Date	Version	Description
2024-06-15	1.0	Initial release of the technical specifications
2025-03-19	1.1	Adjustment of the vertical datum transformation method resulting in an average vertical change of around 40 cm in the MRDEM-30-DTM and MRDEM-30-DSM compared with the previous version. Integration of DSM source data from the lidar-derived HRDEM mosaic in the creation of MRDEM-30-DSM. Update of the vertical accuracy values.

ACRONYMS

ANPD	Aggregate Nominal Pulse Density
CDEM	Canadian Digital Elevation Model
CFS	Canadian Forest Service
CGVD28	Canadian Geodetic Vertical Datum of 1928
CGVD2013	Canadian Geodetic Vertical Datum of 2013
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EGM2008	Earth Gravitational Model, 2008
EPSG	European Petroleum Survey Group
FABDEM	Forests and Buildings Removed Copernicus DEM
GEDI	Global Ecosystem Dynamics Investigation
GLAS	Geoscience Laser Altimeter System
GFCH	Global Forest Canopy Height
GLO-30	Copernicus DEM instance available as a 30m public product
HRDEM	High Resolution Digital Elevation Model
ICESat	Ice, Cloud and land Elevation Satellite
InSAT	Interferometric Synthetic Aperture Radar
LE90	Linear Error at the 90% Confidence Level
Lidar	Light Detection and Ranging
MRDEM-30-DSM	Medium Resolution Digital Surface Model
MRDEM-30-DTM	Medium Resolution Digital Terrain Model
MRDEM-30-DTMS	Medium Resolution Digital Terrain Model Source
NBAC	National Burned Area Composite
NAD83(CSRS)	North American Datum of 1983 (Canadian Spatial Reference System)
NHN	National Hydro Network
NRCan	Natural Resources Canada
RMSE	Root Mean Square Error
RTK	Real-Time Kinematic

TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984
WSF	World Settlement Footprint

TERMS AND DEFINITIONS

Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

The Canadian Geodetic Vertical Datum of 2013 (CGVD2013) is the reference standard for heights across Canada. This system has replaced the Canadian Geodetic Vertical Datum of 1928 (CGVD28). For more information on CGVD2013, visit the following resource: https://www.nrcan.gc.ca/maps-tools-and-publications/tools/geodetic-reference-systems/canadian-spatial-reference-system-csrs/9052

Digital Elevation Model (DEM)

A digital representation of relief composed of an array of elevation values referenced to a common vertical datum and corresponding to a regular grid of points on the earth's surface. These elevations can be either ground or reflective surface elevations.

Digital Surface Model (DSM)

A representation of the earth's surface including vegetation and man-made structures. The Digital Surface Model (DSM) provides the height of the vegetation, canopies and structures relative to the vertical datum.

Digital Terrain Model (DTM)

A representation of the bare ground surface without any objects such as vegetation and man-made structures. The Digital Terrain Model (DTM) provides the height of the ground relative to the vertical datum.

Lidar

Stands for Light Detection and Ranging. It is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.

North American Datum 1983 CSRS (NAD83(CSRS))

The North American Datum of 1983 CSRS (NAD83(CSRS)) is the official geometric reference system in Canada. NAD83(CSRS) is a dynamic 3D representation of NAD83(Original) adapted for Canada. NRCan maintains NAD83(CSRS) aligned to the North American plate using plate motion estimation. For more information on NAD83(CSRS), visit the following resource: https://www.nrcan.gc.ca/maps-tools-and-publications/tools/geodetic-reference-systems/canadian-spatial-reference-system-csrs/9052

EPSG:3979

Definition of the NAD83(CSRS) / Canada Atlas Lambert projection which is used by Natural Resources Canada for onshore and offshore mapping.

High Resolution Digital Elevation Model Mosaic (HRDEM Mosaic)

The High Resolution Digital Elevation Model Mosaic provides a unique and continuous representation of the high resolution elevation data available across the country. The High Resolution Digital Elevation Model (HRDEM) product used is derived from airborne lidar data (mainly in the south) and satellite images in the north. The mosaic is available for both the Digital Terrain Model (DTM) and the Digital Surface Model (DSM) from web mapping services. It is part of the CanElevation Series created to support the National Elevation Data Strategy implemented by NRCan. This strategy aims to increase Canada's coverage of high-resolution elevation data and increase the accessibility of the products.

TABLE OF CONTENTS

1. Overview

This document presents the data, methods, and results of the generation of a new, modern, medium resolution (30m x 30m) Digital Elevation Model (DEM), MRDEM. Within the dataset are three assets: digital surface model (MRDEM-30-DSM), digital terrain model (MRDEM-30-DTM), and a source asset, which indicates the underlying source of the elevation data used for both the DTM and DSM, referred to as MRDEM-30-SOURCE. This new product provides complete, nationwide, coverage for Canada, and the spatial extent extends into the USA, where needed, to provide coverage for cross-border watersheds in support of hydrological studies and applications.

The complete specifications of the product are available in another document. The present focus on the technical aspects involved in the product creation.

2. Reference Datasets Descriptions

To generate the MRDEM collection, several datasets were used. They are described below and summarized in Table 1.

2.1. Digital Elevation Models

2.1.1. Copernicus DEM

The Copernicus DEM is a digital surface model (DSM) and contains buildings, vegetation and infrastructure in its representation of the surface of the earth (AIRBUS, 2022). It is based on an edited version of the WorldDEM™. The data used to create WorldDEM™ is radar satellite data acquired during the TanDEM-X Mission, which is a funded public private partnership between the German State and Airbus Defence and Space. To produce this dataset, two satellites, TerraSAR-X and TanDEM-X operated as a single-pass SAR interferometer (InSAR) using the bi-static InSAR StripMap mode (AIRBUS, 2020). The data collection period is 2011 to 2015.

Copernicus DEM edits of the WorldDEM™ include flattening of waterbodies, introducing consistent flow of rivers, and editing of implausible terrain structures, among others (AIRBUS, 2022). Copernicus DEM comes in a few different resolutions. For this work, only the 30 meters resolution dataset (GLO-30) has been used as it provides continuous coverage across Canada. The GLO-30 dataset is available in geographic coordinates, EPSG:4326, and is referenced to EGM2008 vertical datum. The grid spacing for GLO-30 is 1.0” latitude with variable longitudinal spacing, 0.4” up to 50°N, 0.6” between 50° and 60°, 0.8” between 60-70°, 1.2” between 70-80°, and 2.0” between 80-85°.

License:

The GLO-30 dataset is available worldwide with a free license with the exception of two countries, Armenia and Azerbaijan, and available within the datasets COP-DEM_GLO-30-DTED-R and COP-DEM_GLO-30-DGED-R (Copernicus Digital Elevation Model, 2022).

Data:

The data were accessed via the OpenTopography portal, which provides GLO30 access through a Global API (OpenTopography, 2023).

Data Citation: European Space Agency, Sinergise (2021). *Copernicus Global Digital Elevation Model*. Distributed by OpenTopography. https://doi.org/10.5069/G9028PQB. Accessed: 2023-05-23

2.1.2. HRDEM Mosaic

The HRDEM Mosaic is a seamless representation of high-resolution digital elevation models derived from lidar or satellite imagery. This product was implemented by NRCan and is part of the CanElevation Series. The underlying data of the HRDEM mosaic has been acquired through multiple projects and different partners. In this work, both the digital terrain and surface models derived from lidar are used.

License:

The data is made available under the Open Government Licence - Canada

Data:

The data is available on open.canada.ca.

2.2. World Settlement Footprint

The World Settlement Footprint (WSF) layer is a 10m resolution, global, binary dataset, which outlines the extent of human settlements. It was derived from multitemporal Sentinel-1 and Sentinel-2 imagery.

License:

The WSF is made available under the Creative commons license.

Data:

The data is available at: https://download.geoservice.dlr.de/WSF2019

2.3. Forest Heights

Several datasets were explored which describe forest heights in Canada and around the globe. Two datasets were selected for use in this work.

2.3.1. Canadian Forest Heights

The Canadian Forest Heights (CFH), mean forest heights 2015 dataset published by Canadian Forest Service, is generated through the combination of lidar plot-derived information with Landsat pixel-based composites, using a nearest neighbor imputation and Random Forests based distance metric (Matasci et al., 2018).

License:

The data is made available under the Open Government Licence - Canada

Data:

The data is available on open.canada.ca.

2.3.2. Global Forest Canopy Height

The global forest canopy height (GFCH) map was developed by the Global Land Analysis and Discovery, University of Maryland. The GFCH dataset is a derived product, created through the combination of the Global Ecosystem Dynamics Investigation (GEDI) lidar forest structure measurements and Landsat imagery for 2019 (Potapov et al., 2021). This global dataset contains forest height data from 52°N to 52°S. The methodology of this prototype map was published in Remote Sensing of the Environment. The authors indicate several limitations of this dataset that are to be considered, including over-estimation on slopes in the certain mountain grasslands and conflation with building heights in urban areas.

License:

None specified.

Data:

The data is available at: https://glad.umd.edu/dataset/gedi

2.4. Other

A few auxiliary datasets were used to complement the modelling process.

2.4.1. National Burned Area Composite

The national burned area composite (NBAC) contains calculations of yearly burned forest areas on a national scale, since 1986 (Canada, 2023a). The fire composite is determined from evaluation of data from a variety of sources and techniques in Canada, presenting a best overall measure of burned area to build a composite picture.

License:

The data is made available under the Open Government Licence - Canada

Data:

The data is available at: https://cwfis.cfs.nrcan.gc.ca/datamart/metadata/nbac.

2.4.2. National Hydro Network

The National Hydro Network (NHN) provides a geometric description of Canada's inland surface waters. The dataset contains features such as lakes, reservoirs, watercourses (rivers and streams), canals, islands, drainage linear network, toponyms or geographical names, constructions and obstacles related to surface waters, etc. (Secretariat & Secretariat, 2023). It was created from data at the scale of 1:50,000 or better. Just the permanent waterbodies feature is accessed in the creation of the MRDTM.

License:

The data is made available under the Open Government Licence - Canada

Data:

The data is available on open.canada.ca.

Table 1 Summary of main datasets used

Dataset	Coverage	Year Collected	Spatial Resolution	Accuracy	Vertical unit and reference system (if applicable)
GLO-30	Global	2011-2015	Latitude: - 1.0" Longitude: - variable	Absolute vertical accuracy: - <4m (90% linear error) Relative vertical accuracy:	Meter EGM2008 vertical datum

				- < 2m for slopes below or equal 20%; - < 4m for slopes above 20%; - (90% linear point-to-point error within an area of 1° x 1°) Absolute horizontal accuracy: - <6m (90% circular error)	
HRDEM Mosaic	Variable* across Canada (includes 100 major cities)	2006-Ongoing. *As of May 2024, the median year of lidar projects in the HRDEM Mosaic is 2018.*	1m or 2m depending on the ANPD of the source data	Generally, < 1m. Specific metadata for each project area can be found in the file geodatabase[1]	Meter CGVD2013
World Settlement Footprint	Global	2019	10m resolution	Binary mask based on multitemporal Sentile-1 (S1) and Sentinel-2	-
CA Forest	Canada	2015	30m	Lidar (mean height of first returns) validation - RMSE = 2.66 - RMSE% = 38.6 - R^2 = 0.639 - Bias = -0.03	Meter
GFCH	52°N to 52°S globally*	2019	30m	GEDI validation: - RMSE = 6.6 m - MAE = 4.45 m - R^2 = 0.62 Airborne lidar: - RMSE = 9.07 m - MAE = 6.36 m - R^2 = 0.61	Meter
*may not provide complete coverage					

[1] File Geodatabase and accuracy metadata can be accessed: https://open.canada.ca/data/en/dataset/957782bf-847c-4644-a757-e383c0057995

3. Method

3.1. MRDEM-30-DSM

The MRDEM-30-DSM is partially based on the GLO-30 DSM. Where available, the lidar-derived surface data from the HRDEM mosaic is integrated. The modifications made to create the MRDEM-30-DSM include:

- reprojection to NAD83(CSRS) Canada Atlas Lambert (EPSG:3979).
- resampling to a 30 meters resolution grid.
- vertical datum transformation from EGM2008 to CGVD2013 (GLO-30 DSM only).

3.2. MRDEM-30-DTM

To create the MRDEM-30-DTM from the Copernicus GLO-30 DSM and HRDEM, several models were developed, each tasked with a specific objective (Figure 1).

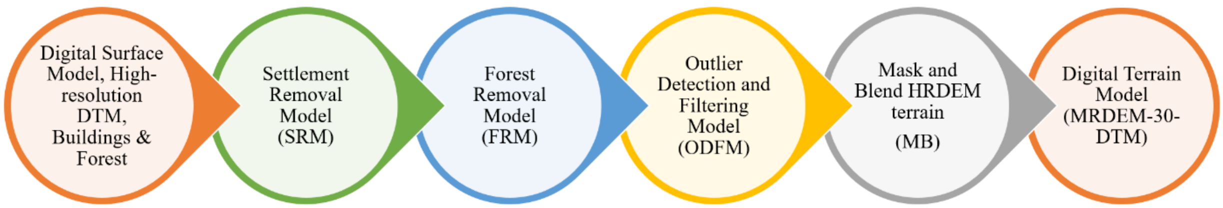

Figure 1 Generalized method to create digital terrain model from digital surface model.

3.2.1. Settlement Removal Model (SRM)

The Settlement Removal Model (SRM) explores the elevation values around settled area pixels, to identify outliers. From the binary WSF data, the corresponding elevation values from COP Glo30 DSM are processed in the Percent Elevation Range (PER) tool from Whitebox, using a 7x7 filter. The result is a raster providing a measure of the local topographic position within the specified neighborhood size. A threshold is set on the output of the PER to retain only higher values representing the building artefacts existing in the terrain data. These areas are then masked and nulled in the elevation data and a void filling algorithm is run to interpolate elevation values for these areas. Figure 2 shows the different steps involved.

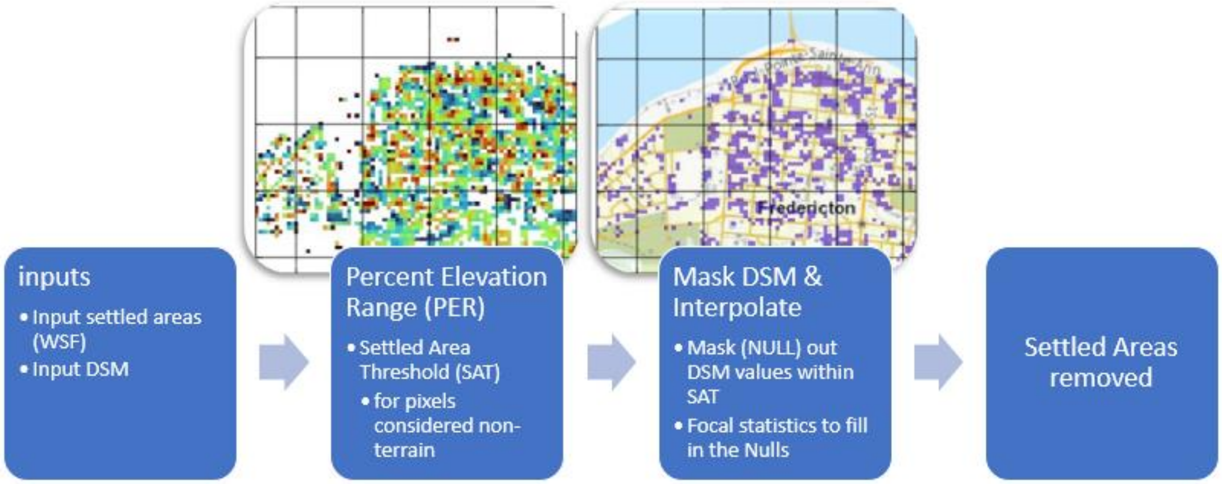

Figure 2. Steps involved with Settlement Removal Model (SRM)

3.2.2. Forest Removal Model (FRM)

The forest removal model (FRM) combines the CFH and the GFCH data, Figure 3, and builds from the result of SRM. Where there is overlap of CFH and GFCH, priority is given to CHF, Figure 4. A spatial query on the NBAC data is carried out to determine if any fires have occurred. The area is then compared to the forest heights data to determine if forest heights should be interpolated in this area or masked out. A permanent waterbodies mask is created and applied to forest heights to remove any potential erroneous forest heights from the waterways. Additionally, as described by Potapov et al., (2021) the GFCH dataset does not discriminate between natural and man-made features, thus, while the canopy heights are primarily trees, it is possible that some of the pixel values may represent urban structures. Therefore, the settlement footprint data is compared to the canopy height and the DSM elevation values to determine if the tree height pixel should be nulled. A mean filter is applied to the processed forest dataset before it is subtracted from the DSM.

Figure 3 Steps involved in the Forest Removal Model (FRM)

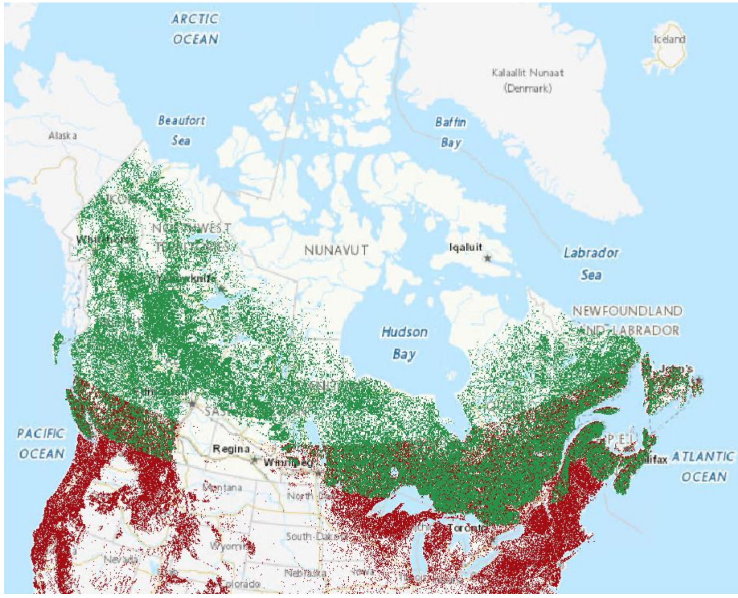

Figure 4 Coverage of CFS Mean Forest Height (2015) in green and global forest canopy height (GFCH) in red.

3.2.3. Outlier Detection and Filtering Model (ODFM)

The ODFM detects for outliers (e.g.: erroneous spikes/dips) from the settlement and forest removal process from the MRDEM-30-DSM data and a spatial filter is applied to remove any residual artifacts from the process to provide a more realistic terrain representation.

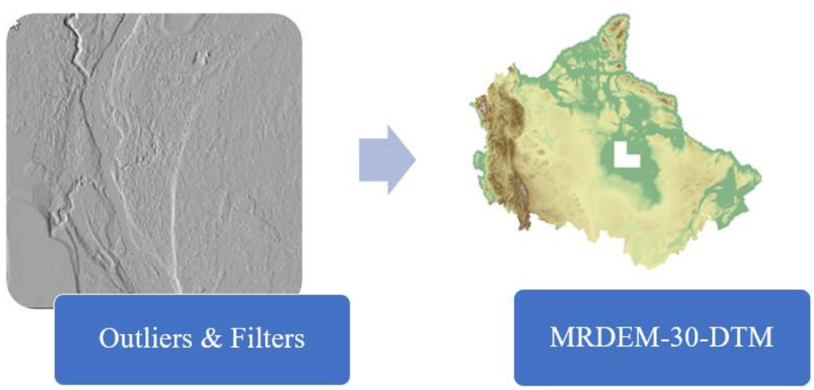

Figure 5 Outlier Detection and Filtration Model (ODFM)

3.2.4. Mask and Blend (MB)

Once the steps to convert the MRDEM-30-DSM to a DTM are completed, the HRDEM Mosaic terrain data is included into the raster. This data is first resampled to 30 meters resolution using the bilinear interpolation method. A positive and negative buffer around the boundary of the dataset is then generated. Finally, a filtering and blending process is applied to create a more seamless transition between the two terrain models.

3.3. MRDEM-30-SOURCE

Different sources are used to create the MRDEM-30-DTM and MRDEM-30-DSM datasets. To help users identify the source used at any given point, an additional dataset was created. The MRDEM-30-SOURCE asset is a raster which has three unique values. These represent the source and treatment of the underlying elevation data. The dataset largely contains values of 1 and 10. The blended area values represent the portions where the blending process was applied to minimize the vertical differences between the high resolution lidar derived data and the medium resolution, satellite derived terrain or surface.

Table 2 Index of values used in the MRDEM-30-SOURCE

Label	Source
1	Adjusted GLO-30 data
5	Blended area
10	HRDEM Mosaic

3.4. Sample Sites

To evaluate the results of the MRDEM-30-DTM modelling process, several sample sites were identified. These sample sites are primarily 15km x 15km square tiles which have an overlap with existing HRDEM coverage areas, Figure 6. Up to 30 sample sites per terrestrial ecozone were created. The smallest sample, 4 sites, is in the Hudson Plains (HP) terrestrial ecozone, which contains only a very small amount of HRDEM data. Additionally, samples were taken in the three non-forested ecozones. In total, from these sites 1,448,626 sample pairs were randomly generated and evaluated. For validation of the areas with HRDEM terrain as the base elevation, 54,487 RTK check points were used, covering both vegetated and non-vegetated areas.

3.5. Spatial Extent

The spatial extent of this product covers all of Canada and a small portion of the United States of America (USA), Figure 6. The southern and north-western boundaries were determined based on a combination of the National Hydrographic Network Work Units and drainage areas of the USGS Watershed Boundary Dataset, level 8 (HU08), flowing towards Canada. A 5 kilometers buffer was applied to this extent to compensate for errors that might have occurred during the delineation of these units.

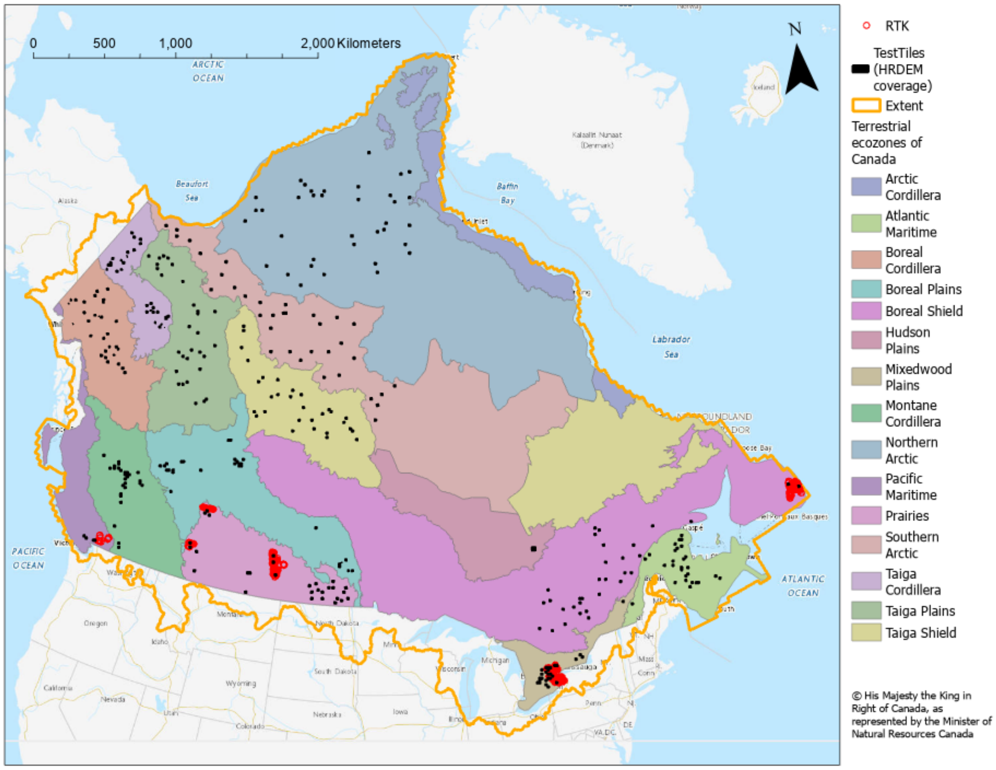

Figure 6 Location of sample sites for testing and validation, limited to HRDEM Coverage area, as of April 2024.

4. Results

As the MRDEM-30-DTM contains data from two inputs, the accuracy validation was completed in two ways.

4.1. Evaluation

For the MRDEM-30-DTM areas derived from the HRDEM Mosaic, the vertical accuracy was evaluated against RTK check points, Table 2. This accuracy assessment mostly provides information on the effect of the bilinear resampling from 1m to 30m. Pixels with MRDEM-30-DSM as the base data were compared to HRDEM data resulting from Step 3.2.3, Table 3.

The RTK check points used in the analysis are the same used to perform accuracy assessment of the HRDEM product. In this case points were selected across the country and include urban centres and rural areas. We see the largest RMSE and LE90 in the lower mainland of British Columbia (BC) and lowest in Saskatchewan (SK), which aligns with the representative topography in these regions (mountainous and high relief vs broad, flat plains of SK). The mean difference across all sample points is -0.36m with an RMSE of 1.02m, and LE90 of 1.65m, Table 3. Overall, the results are in the range of expected values resulting from the rounding and resampling differences from the 1m to 30m cell size and the filtering techniques which were applied at the borders of the HRDEM terrain coverage to smooth the transition with the MRDEM-30-DTM elevation data.

For areas where MRDEM-30-DSM is the source elevation data, the smallest amount of modification was completed in the three non-forested ecozones of the Prairies, South Arctic and North Arctic. The changes to this data in these areas are related to only to the removal of buildings and the various filters which were applied. The Prairies is the only region of these which used the HRDEM based on lidar for evaluation. The

South and North Arctic were both compared to the HRDEM, which in the north is actually a surface model (DSM). Only DSM datasets are generally generated due to the relatively low density of vegetation and infrastructure lying north of the productive forest line, Figure 7. The results of the MRDEM-30-DTM in the non-forested regions have an average mean difference of -0.03 m, RMSE of 1.59 m. These statistics align with the initial reported accuracy of the COP GLO-30 in the AIRBUS report. The results from Boreal Cordillera, Taiga Cordillera, Taiga Plains are not as good as the southern counterparts, with reported RMSE of 7.37 m, 1.48 m, and 1.12 m, respectively. This is likely due to the nature of the control data used for comparison being the DSM. The control DSM is not a bare earth terrain model, and due to the low density of vegetation, there is not significant processing to remove trees, infrastructure, and other vegetation.

Examples of the MRDEM-30-DTM results are shown in Figure 8, 9 and 10, and illustrate the changes between the elevation value from the MRDEM-30-DSM and the HRDEM.

Table 3 Results of MRDEM-30-DTM as compared to RTK check points in meters. (NVA = non-vegetated areas, and VVA = vegetated areas)

	Region	Statistics				# Samples
		MEAN	RMSE	LE90	StDEV	
NVA	AB (Calgary)	-0.68	1.17	1.86	0.90	162
NVA	AB (Edmonton)	-1.12	1.36	2.07	0.78	38
NVA	BC (lower mainland)	-0.64	1.98	3.22	1.88	8893
VVA	BC (lower mainland)	-1.86	2.66	4.25	1.93	9485
NVA	NL (St. Johns)	-0.03	1.70	2.74	1.70	33196
NVA	NL (St. Johns)	-0.03	1.61	2.61	1.61	269
NVA	ON (GTA)	-0.22	0.91	1.48	0.88	211
NVA	ON (Hamilton/ Niagara)	-0.15	0.89	1.46	0.88	1154
VVA	ON (Hamilton/ Niagara)	-0.12	0.91	1.49	0.90	802
NVA	SK (Last Mountain Lake)	-0.54	1.00	1.61	0.84	189
VVA	SK (Last Mountain Lake)	-0.01	0.68	1.11	0.69	88
Average Non-Vegetated Areas		-0.37	1.01	1.63	0.90	
Average Vegetated Areas		-0.11	1.44	2.34	1.42	
Average		-0.36	1.02	1.65	0.91	

Table 4 Results by forested (F) and non-forested (N) Ecozone for areas with MRDEM-30-DSM (with settled areas and forests removed) as the base elevation data, as compared to HRDEM data.

Forested / Non-Forested	Ecozone Region	Statistics			
		MEAN	RMSE	LE90	St.DEV
F	Atlantic Maritime	1.18	3.80	6.08	3.61
F	Boreal Cordillera	0.26	7.37	12.11	7.37
F	Boreal Plains	3.81	8.05	13.16	7.09
F	Boreal Shield	1.19	3.86	6.13	3.67
F	Hudson Plains	2.83	3.18	4.59	1.47
F	Montane Cordillera	0.48	5.09	8.26	5.07
F	Mixedwood Plains	-2.55	5.15	8.47	4.48
N	Northern Arctic	0.29	1.54	2.52	1.51
F	Pacific Maritime	0.12	5.24	8.50	5.24
F	Taiga Cordillera	-0.54	1.48	2.43	1.38
F	Taiga Plains	-0.36	1.12	1.81	1.06
N	Taiga Shield	1.70	3.83	6.22	3.43
N	Prairies	3.49	5.42	8.59	4.14
N	South Arctic	0.46	2.36	3.85	2.32
	Avg Forested	0.88	4.99	8.07	4.55
	Avg Non-Forested	-0.03	1.59	2.60	1.53
	Average ALL	-0.48	3.51	5.69	3.23

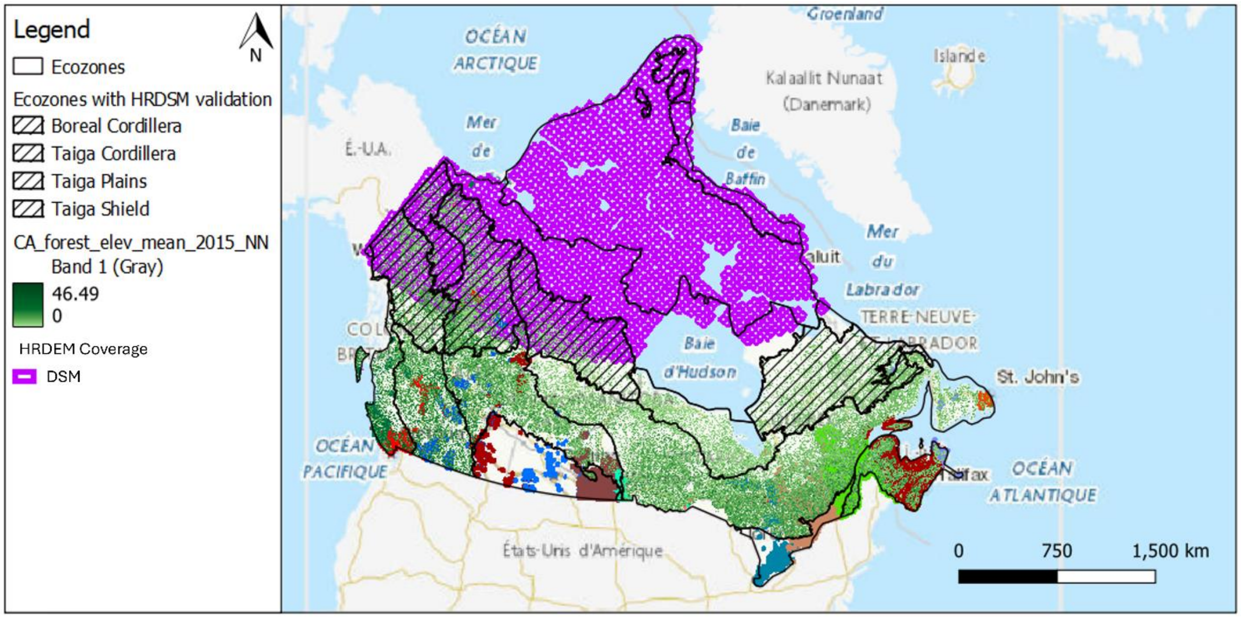

Figure 7 Extent of HRDSM Coverage, ecozones and forest height data.

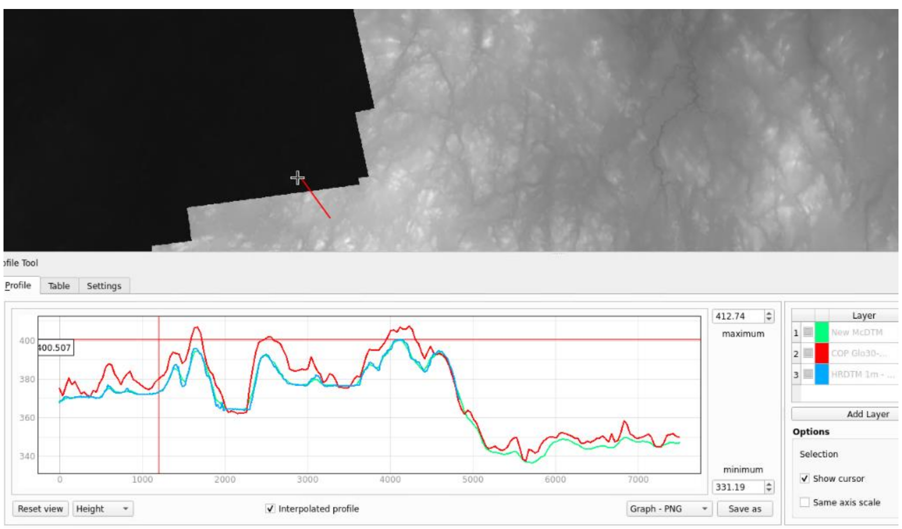

Figure 8 Example of removal of forested areas in southern Ontario, where there is only GEDI Global coverage and partial HRDEM coverage. Red line is the MRDEM-30-DSM, blue line is HRDEM DTM and Green is MRDEM-30-DTM. At the right of the profile is where the HRDEM coverage ends.

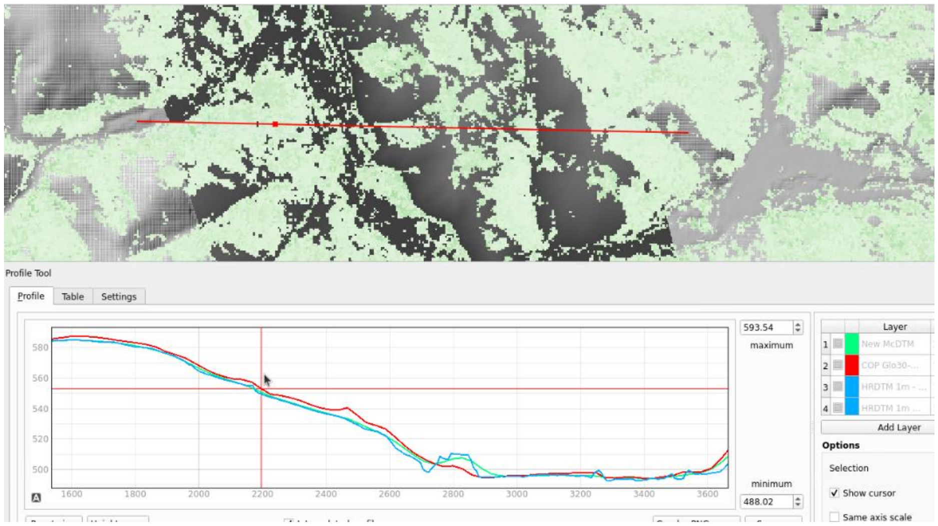

Figure 9 Northern Canada example, illustrating improvement of MRDEM-30-DTM (green line) to MRDEM-30-DSM (red line) and removal of forest and buildings from the HRDTM (blue line).

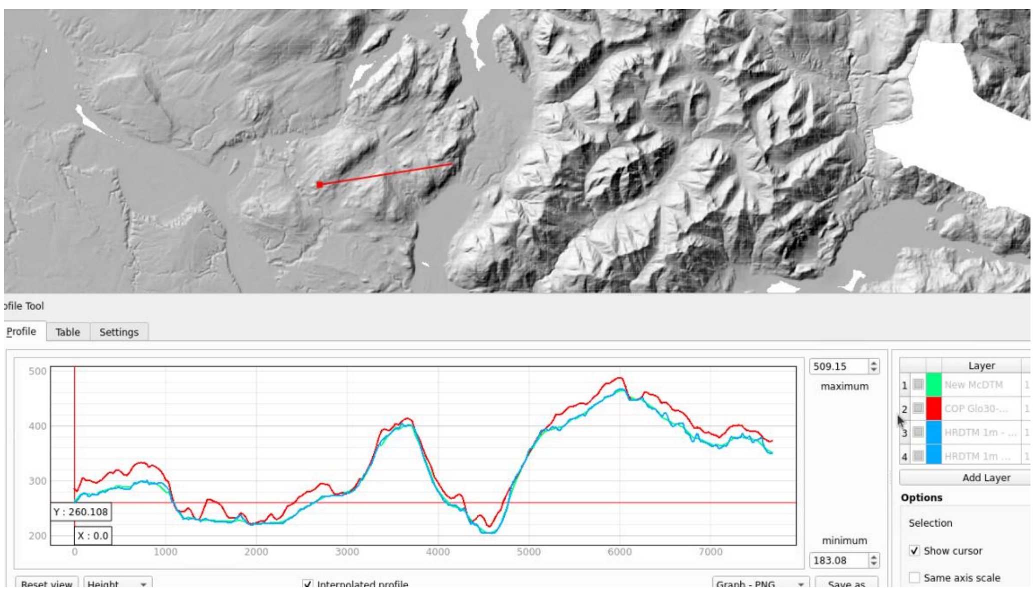

Figure 10 Western Canada example, alignment of MRDEM-30-DTM (green line) to HRDEM (blue line) in comparison with the MRDEM-30-DSM (red line).

4.2. Evaluation against other similar products

In addition to comparing the MRDEM-30-DTM against the HRDEM, similar resolution products: Canadian Digital Elevation Model (CDEM) from NRCan and Forests and Buildings Removed (FABDEM) from Fathom are also evaluated against the HRDEM.

The legacy product CDEM is the previous national elevation dataset for Canada which was archived in 2011. Per the Canadian Digital Elevation Model: Product Specifications – Edition 1.1, CDEM source is described as follows:

> "…stems from the existing Canadian Digital Elevation Data (CDED). The latter were extracted from the hypsographic and hydrographic elements of the National Topographic Data Base (NTDB) at the scale of 1:50 000, the Geospatial Database (GDB), various scaled positional data acquired by the provinces and territories, or remotely sensed imagery."

The second comparison product is FABDEM released by Fathom. This dataset also relies on Copernicus GLO-30 as its base elevation data. The method used by Fathom to create FABDEM is via machine learning techniques, specifically random forest regression models, (Hawker et al., 2022). Lidar DTMs from 12 countries were selected to use in the training data for the models. The GFCH was used by Fathom for forest height predictors, and ICESat-2 L3A Land and Vegetation Height (version 4) ATL-08 data in locations where GFCH did not provide coverage (Hawker et al., 2022). A range of filters were applied, including: sobel edge detector, unsharp, gaussian - of varying sizes, bilateral edge-preserving smoothing filters.

Table 5 CDEM and FABDEM results compared to MRDEM-30-DTM.

	CDEM				FABDEM			
	MEAN	RMSE	LE90	StDEV	MEAN	RMSE	LE90	StDEV
Atlantic Maritime	-1.53	6.70	10.89	6.52	-2.05	3.99	6.45	3.43
Boreal Cordillera	-4.23	16.29	26.43	15.73	0.59	6.96	11.44	6.93
Boreal Plains	2.70	8.04	13.21	7.58	2.20	6.54	10.73	6.16
Boreal Shield	-1.51	4.87	7.80	4.63	-1.65	3.84	6.19	3.47
Hudson Plains	-1.46	4.10	6.45	3.83	-0.24	1.15	1.86	1.12
Montane Cordillera	-2.60	5.37	8.65	4.70	-0.58	4.86	7.95	4.83
Mixedwood Plains	-0.80	2.33	3.78	2.19	-1.80	2.91	4.73	2.29
Northern Arctic	0.92	5.05	8.16	4.96	0.37	1.48	2.43	1.44
Pacific Maritime	-5.02	6.68	10.49	4.40	0.64	5.15	8.37	5.11
Taiga Cordillera	-0.02	2.55	4.11	2.55	-0.87	1.40	2.23	1.09
Taiga Plains	-0.72	3.73	5.90	3.65	-0.48	1.13	1.81	1.02
Taiga Shield	-2.94	8.13	13.04	7.58	0.93	2.68	4.37	2.51
Prairies	0.30	7.67	12.49	7.66	1.66	3.90	6.36	3.53
South Arctic	0.10	4.14	6.64	4.14	-0.21	2.15	3.50	2.14
Avg Forested	**-1.12**	**6.16**	**9.97**	**5.84**	**-0.67**	**4.19**	**6.82**	**3.80**
Avg Non-Forested	**0.14**	**3.94**	**6.33**	**3.90**	**-0.25**	**1.51**	**2.45**	**1.40**
Average ALL	**-0.57**	**5.19**	**8.39**	**5.00**	**-0.49**	**3.02**	**4.92**	**2.75**

In general, it is found that MRDEM-30-DTM performs better than CDEM in all regions (Table 3,

Table 4 and Table 5). Compared to FABDEM, the results vary, MRDEM-30-DTM performs marginally better in some regions (Boreal Cordillera, Taiga Cordillera, Taiga Plains and Boreal Plains) while a little bit poorer in others (Hudson Plains, Mixedwood Plains, Atlantic Maritime). The addition of the HRDTM data into the MRDEM-30-DTM provides a better bare earth terrain representation.

When evaluating derivatives of the DTM, e.g. slope, aspect, HAND model, the results look more realistic in the MRDEM-30-DTM than in FABDEM (not shown here). Preliminary analysis finds that some terrain features are smoothed out from the GLO-30 with the processing steps completed by Fathom. Therefore, while the statistics may slightly favour FABDEM, the use of MRDEM-30-DTM data, especially those involving hydrologic applications in Canada, provides an overall better baseline dataset.

4.3. Limitations

The results presented for the MRDEM-30-DTM are a best-fit based on the available data and are limited based on the availability and accuracy of the reference data.

As noted earlier, there is no single, comprehensive, dataset which combines all building footprints – at the time this work was conducted. Instead, a world settlement layer, which is available under the Creative Commons license was selected. This layer may not include all existing buildings. However, since the HRDEM Mosaic data covers most of the larger urban centres and was included in the MRDEM-30-DTM, we are confident that the impact is limited.

Future work may investigate forest types, coniferous and deciduous, as some of the observed elevation differences may relate back to the interferometric response from the sensor when the data was collected and may be capturing values other than the canopy peak in different forest types.

The final point to mention is with respect to the elevation data used for comparison. In the southern portion of Canada, the HRDEM LiDAR derived terrain model provided an excellent benchmark for validation. The issue is with respect to the northern validation, namely the HRDEM DSM. In the northern part of the country, with some exceptions, only DSM datasets are generally generated due to the relatively low density of vegetation, infrastructure and its location, north of the productive forest line. The HRDEM DSM have optical digital images as their source data, and it is generated at a 2 meters resolution Please see to the HRDEM specifications for more details.

References

AIRBUS. (2020). *Copernicus DEM Copernicus Digital Elevation Model Validation Report* (AO/1-9422/18/I-LG). https://spacedata.copernicus.eu/documents/20123/121239/GEO1988-CopernicusDEM-RP-001_ValidationReport_I3.0.pdf/c80c5e85-9aea-356d-c877-80d8b5e028bb?t=1668162072523

AIRBUS. (2022). *Copernicus DEM Copernicus Digital Elevation Model Product Handbook* (Product Handbook AO/1-9422/18/I-LG; p. 36). AIRBUS. https://spacedata.copernicus.eu/documents/20123/121239/GEO1988-CopernicusDEM-SPE-002_ProductHandbook_I4.0.pdf/92df0801-6714-20e4-75ae-0be634b9e301?t=1666775307957

Canada, N. R. (2023a). *Canadian Wildland Fire Information System | Metadata*. https://cwfis.cfs.nrcan.gc.ca/datamart/metadata/nbac

Canada, N. R. (2023b, February 24). *National Elevation Data Strategy*. Natural Resources Canada. https://natural-resources.canada.ca/maps-tools-and-publications/satellite-imagery-elevation-data-and-air-photos/national-elevation-data-strategy/24977

Copernicus Digital Elevation Model. (2022). Copernicus Contributing Missions Online. https://spacedata.copernicus.eu/collections/copernicus-digital-elevation-model

Ellesmere Island | The Canadian Encyclopedia. (n.d.). Retrieved May 24, 2023, from https://www.thecanadianencyclopedia.ca/en/article/ellesmere-island

Hawker, L., Uhe, P., Paulo, L., Sosa, J., Savage, J., Sampson, C., & Neal, J. (2022). A 30 m global map of elevation with forests and buildings removed. *Environmental Research Letters*, *17*(2), 024016. https://doi.org/10.1088/1748-9326/ac4d4f

Matasci, G., Hermosilla, T., Wulder, M. A., White, J. C., Coops, N. C., Hobart, G. W., Bolton, D. K., Tompalski, P., & Bater, C. W. (2018). Three decades of forest structural dynamics over Canada's forested ecosystems using Landsat time-series and lidar plots. *Remote Sensing of Environment*, *216*, 697–714. https://doi.org/10.1016/j.rse.2018.07.024

Microsoft. (2023). *Canadian Building Footprints* [dataset]. Microsoft. https://github.com/microsoft/CanadianBuildingFootprints (Original work published 2019)

OpenTopography. (2023). *OpenTopography—Copernicus GLO-30 Digital Elevation Model*. OpenTopography - Copernicus GLO-30 Digital Elevation Model. https://portal.opentopography.org/raster?opentopoID=OTSDEM.032021.4326.3

Potapov, P., Li, X., Hernandez-Serna, A., Tyukavina, A., Hansen, M. C., Kommareddy, A., Pickens, A., Turubanova, S., Tang, H., Silva, C. E., Armston, J., Dubayah, R., Blair, J. B., & Hofton, M. (2021). Mapping global forest canopy height through integration of GEDI and Landsat data. *Remote Sensing of Environment*, *253*, 112165. https://doi.org/10.1016/j.rse.2020.112165

Secretariat, T. B. of C., & Secretariat, T. B. of C. (2021, November 12). *High Resolution Digital Elevation Model (HRDEM)—CanElevation Series—Open Government Portal*. https://open.canada.ca/data/en/dataset/957782bf-847c-4644-a757-e383c0057995

Secretariat, T. B. of C., & Secretariat, T. B. of C. (2023). *National Hydro Network—NHN - GeoBase Series—Open Government Portal*. https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977

Statistics Canada. (2019, January 3). *The ODB - an experimental Open Database of Buildings Metadata document: Concepts, methodology and data quality* [Government of Canada]. The ODB - an Experimental Open Database of Buildings Metadata Document: Concepts, Methodology and Data Quality. https://www.statcan.gc.ca/en/lode/databases/odb/metadata