ABMI Geospatial Centre Research Team (Edmonton): Evaluation of WorldDEM DEM

Prepared for:
German Aerospace Center (DLR)

Prepared by:
Jerome Cranston
Geospatial Centre, Alberta Biodiversity Monitoring Institute

Dr. Jahan Kariyeva
Geospatial Centre, Alberta Biodiversity Monitoring Institute

Dr. Ridha Touzi
Canadian Centre for Mapping and Earth Observation

Dr. M.C. Roy
Parks Canada, Mingan Archipelago National Park Reserve

About this Document

Title

ABMI Geospatial Centre Research Team (Edmonton): Evaluation of WorldDEM DEM

Authors

Jerome Cranston, Dr. Jahan Kariyeva. Dr. M.C. Roy, Dr. Ridha Touzi

Purpose

This document is the final report for proposal *DEM_HYDR1060: Catchment Delineation and Water Storage Capacity in the Prairie Pothole Region of Alberta*, which was submitted to the German Aerospace Center (DLR) on Nov. 30 2016.

Citation

Cranston, J., Kariyeva, J., Roy, M.C., Touzi, R. 2018. "ABMI Geospatial Centre Research Team (Edmonton): Evaluation of WorldDEM DEM." Version 2018-04-18. Edmonton, Alberta, Canada.

Contact Information

Jerome Cranston
Alberta Biodiversity Monitoring Institute
CW 405 Biological Sciences Centre
University of Alberta Edmonton, Alberta, Canada, T6G 2E9
Email: cranston@ualberta.ca
Phone: 1-780-817-4738

Contents

Executive Summary

This document is the final report for proposal ***DEM_HYDR1060: Catchment Delineation and Water Storage Capacity in the Prairie Pothole Region of Alberta,*** which was submitted to the German Aerospace Center (DLR) on Nov. 30 2016. The proposal had three objectives:

1: to compare and calibrate WorldDEM 10m DEM with LiDAR-derived 15m DEM and SRTM 30m DEM
2: to test the utility of the WorldDEM 10m DEM for delineating catchment basins for selected wetland sampling sites
3: to test the utility of the WorldDEM 10m DEM for estimating the water storage capacity of depressional wetlands in Alberta's prairie pothole region

This project compared a Digital Elevation Model (DEM) produced by the DLR's TanDEM-X mission (WorldDEM) with two other DEMs: a Digital Terrain Model (DTM) generated from airborne Light Detection and Ranging (LiDAR) scanning, and a Digital Surface Model (DSM) generated by Interferometric Synthetic Aperture Radar (InSAR) from NASA's Shuttle Radar Topography Mission (SRTM). The efficacy of each model in generating geomorphometric variables such as watersheds (catchment basins) and mapping depressional wetlands was tested.

Using a point-based sampling method, the Root Mean Square Error (RMSE) of the WorldDEM with respect to the LIDAR DTM was 1.1m, which compares favourably to SRTM, which had an RMSE of 2.9m. The WorldDEM was not suitable, however, for generating catchment basins, as surface features such as trees obscured terrain features that determine the direction of water flow. The volume of sinks for a sample area in the prairie pothole region as calculated by WorldDEM was within 17.5% of the volume calculated from the LiDAR DTM, which compared favourably to the SRTM DSM (33.6%) and a DSM generated from the Advanced Land Observing Satellite (ALOS) (28.3%).

1.0 Data Acquisition and Processing

The WorldDEM DSM was generated from interferometric X-band SAR carried by a pair of satellites, the TerraSAR-X (launched in 2007) and TanDEM-X (launched in 2010), flying in close formation (Faller and Weber, 2006). DEM generation is through bistatic InSAR, which is the simultaneous reception of SAR signals by two receivers, thus avoiding temporal decorrelation (Moreira *et al,* 2004). The WorldDEM had the lowest RMSE (2.9m) of six DEMs compared at latitudes above 60^{o} (Chu and Lindenschmidt, 2017).

A sample of WorldDEM DSM provided by DLR was downloaded via ftp on April 4 2017. The download package consisted of 12 tiles spanning 1^{o} x 1^{o} (87,500 km^{2} total) and each tile included:

DEM	Digital Surface Model: resolution 0.4" (arc-seconds) of latitude, 0.6" longitude (9.28m – 11.92m)
HEM	height error map data
AMP	SAR amplitude mosaic (mean value)
AM2	SAR amplitude mosaic (minimum value)
WAM	water indication mask (binary)
COV	coverage map
COM	consistency mask
LSM	layover & shadow mask
IPM	interpolation mask (IDEM only)

Each of the 12 DEMs was re-projected from geographic coordinates to a projected coordinate system (NAD83 UTM Zone 12), at 9.73m pixel size using ESRI ArcGIS 10.4 (Environmental Systems Research Institute, 2016). Tiles were then mosaicked to a single seamless raster in GeoTIFF format.

The product specifications indicate that TanDEM-X is unreliable in water-covered areas (Figure 1). Accordingly, pixels within waterbodies were assigned NoData values. Of the 87,500 km^{2} covered by the WorldDEM sample, 5266 km^{2} (6.24%) is surface water. Waterbodies were identified using the union of two polygon datasets. One consisted of features from Government of Alberta Base features, which were manually digitized from optical imagery and include feature types such as rivers, permanent and ephemeral lakes, reservoirs, wetlands, and islands within rivers and lakes (Alberta Environment and Sustainable Resource Development, 2004); and polygons derived from a SAR water mask developed by the ABMI (DeLancey, 2018). The water mask provided with the DEM was not used as it did not include waterbodies < less than 2ha, and it also misclassified some cultivated croplands as water.

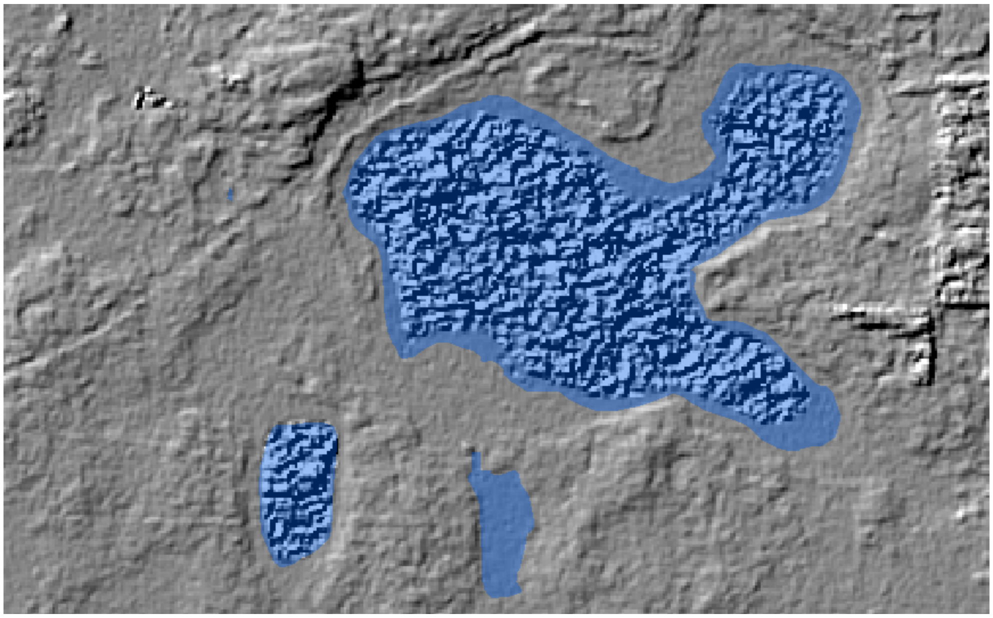


Fig.1: Hillshaded DEM showing incoherence of WorldDEM within waterbodies

The WorldDEM DEM was analysed in conjunction with the following datasets:

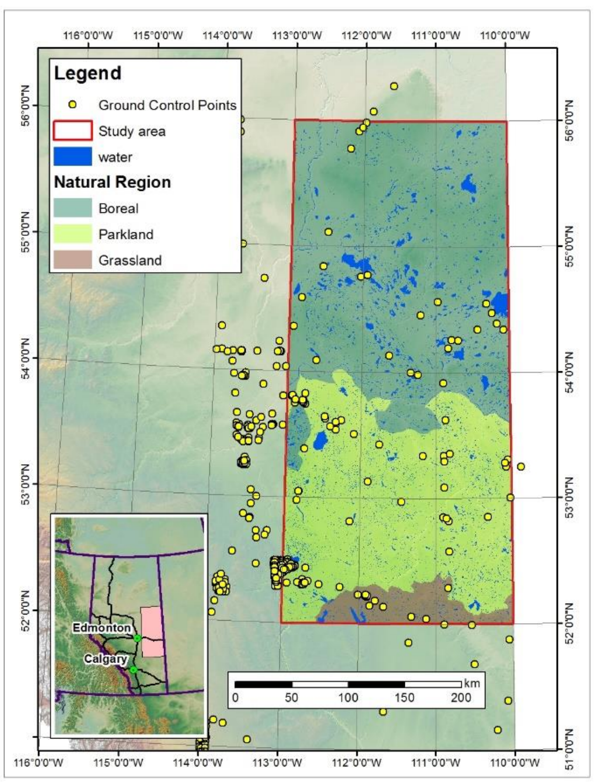
- SRTM DEM (obtained from NASA at 1 arc-second, ~30m horizontal resolution) (Farr *et al*, 2007).
- ALOS DEM (15m) downloaded from the Japan Aerospace Exploration Agency (JAXA) website (http://www.eorc.jaxa.jp/ALOS/en/aw3d/index_e.htm), generated circa 2010 using the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM) sensor on board the Advanced Land Observing Satellite (ALOS), which was launched in 2006 and operated until 2011.
- LiDAR-derived 15m DEM (obtained for 94% of the study area). LiDAR data in the Green Area (21,291 km^2; violet, Figure 2b) was acquired between 2006 and 2011. Data was collected with a scan angle of less than 25 degrees from nadir, a pulse density with a range of 1-4 returns per m^2, and a vertical accuracy of no more than 30 cm RMSE (Alberta Environment and Sustainable Resource Development, 2013). Data was received as 1m rasters and resampled using cubic convolution to 15m. LiDAR for the White Area (64,008 km^2; light green, Figure 2b) was received as Bare Earth 15m rasters. No LiDAR was available for the Cold Lake Air Weapons Range, federally administered land in the northeast of the study area used for military testing (blue, Fig. 2b).
- Alberta Survey Control Markers (Ground Control Points, n=1172) obtained from Alberta Sustainable Resource Development and based on the Canadian Spatial Referencing System (CSRS) derivation of the North American Datum 1983 (NAD83). These coordinates are based on the NAD83v4.0.0.AB.1 provincial readjustment of the Alberta Survey Control Network.
- In-situ water chemistry data (collected 2007 – 2016) from 170 ABMI sample sites dispersed at ~20 km spacing throughout the study area.

2.0 Study Area

The study area spans 4 degrees of latitude (~390 km north to south) between 52^{o} and 56^{o} North, and 3 degrees of longitude (~200 km east to west) between 110^{o} and 113^{o} West (Figure 1a). The sample covers one-eighth of the province of Alberta, Canada (87,500 km^{2}).

The study area elevation ranges from 410m to 950m above mean sea level. Topography is flat to rolling and hummocky, with numerous lakes, typical of post-glacial geomorphology (Norris, 2017). The northern half of the study area is the Boreal Natural Region (Natural Regions Committee, 2006), and is largely forested. Wetlands are predominantly peatlands (bogs and fens). The southern half is Parkland transitioning to Grassland in the extreme south. The majority of wetlands are isolated, ephemeral waterbodies, including prairie potholes.

In the northern third of the study area, the primary land use is forest management and this area is referred to as the Green Area (Fig. 2b) (Alberta Environment and Parks, 2011). In the southern two-thirds, the primary land use is agriculture and grazing and this area is referred to as the White Area.



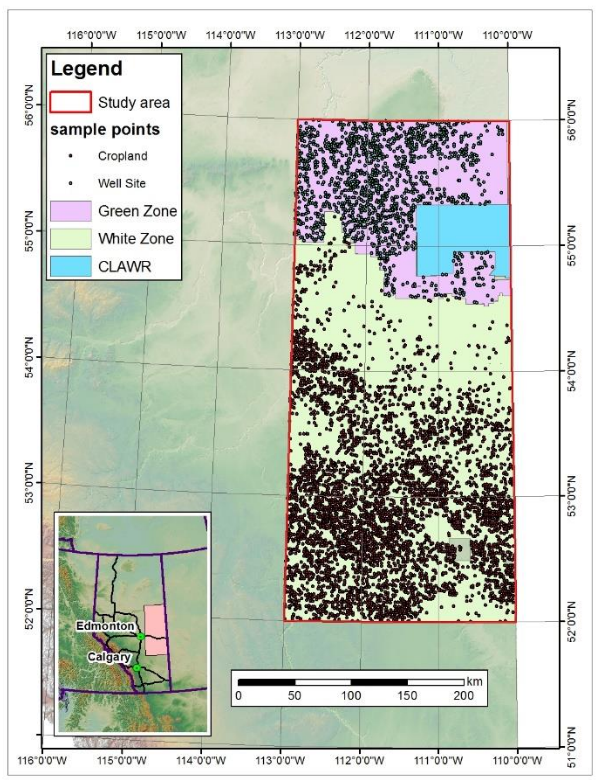


Fig. 2a (left): Natural Regions, Ground Control Points Fig. 2b (right): LiDAR sources, sample points

3.0 Objective 1: to compare and calibrate WorldDEM 10m DEM with LiDAR-derived 15m DEM and SRTM 30m DSM

The WorldDEM DSM was compared to a LiDAR-derived 15m DEM. This raster dataset is a DTM generated from a proprietary airborne Light Detection and Ranging (LiDAR) dataset covering 84% of Alberta, compiled and augmented with the Government of Alberta 25m DTM for the remaining 16% for which LiDAR is not available (Alberta Environment and Parks, 2009) (Figure 2b).

The putative accuracy of the LiDAR dataset was 0.3m RMSE. This value was tested by extracting LIDAR elevations at Alberta Survey Control Markers (ASCM) within the WorldDEM extent (n=132) and calculating the difference between LiDAR elevations and surveyed elevations. The RMSE was 0.65.

In comparing the WorldDEM DEM with a LiDAR-based DEM, it must be acknowledged that the former is a Digital Surface Model (DSM), where elevations represent the tops of features on the surface such as trees and buildings, whereas the latter is a Digital Terrain Model (DTM), where elevations represent the ground itself. Accordingly, analysis of elevations for WorldDEM was limited to ground pixels, known or assumed to be devoid of surface features.

A point-based method was used to compare the WorldDEM DSM with the LiDAR DTM, similar to the methods employed by Alganci *et al* (2018). Points were required to be dispersed (minimum distance between points 1 km), and known or assumed to be in non-vegetated clearings. Within the Green Area, which is mostly forested, we used the centroids of well pads. These are typically square, 1ha (100m x 100m), graded flat areas cleared for oil or gas extraction. Polygons were taken from the 2014 Human Footprint Inventory (HFI) (ABMI, 2017). To ensure only non-vegetated well pads were included, centroids for each feature were buffered by 10m and the mean LiDAR canopy height was extracted for each buffer; canopy height at the point itself (pixel) was also extracted. Canopy height was calculated pixel-by-pixel as the difference between Full Feature (first return) and Bare Earth (last return) surfaces. Only points with a mean height at the point of < 1.0m (n=13) AND mean height of 10m buffer < 0.2m (n=1452; total: n=1439) were included. In the White Area where no Full Feature LiDAR was available we used the centroids of cropland polygons from HFI2014, with minimum size of 1ha (n=5067).

Note that cropland polygons correspond, with minor variations, to legal parcels of land known as "sections" (262 ha) that are a square 1 mile x 1 mile (1620m x 1620m). These are legally further divided into quadrants called "quarter-sections" and the section polygons are often bisected north-south and east-west by shelterbelts of trees that coincide with quarter-section boundaries. The centroids within cropland polygons were therefore translated 100m east and 100m north to remove them from possible shelterbelts, and points that no longer fell within croplands following this translation were removed. Sample points were also overlaid with the COM (consistency mask) and only those points with a COM value = 8 (consistent heights) were retained. The total point sample size was 5991 (Figure 2b).

The WorldDEM elevations are ellipsoid heights whereas LiDAR heights are orthometric (geoid) heights. A correction was applied by subtracting the geoid undulation. To do this we used a subset of the Alberta

Survey Control markers (ASCMs). Points east of the 114^{th} meridian (n=541) were used to interpolate a raster surface representing geoid undulation ([GHz]), at a 100m resolution, using the Natural Neighbour algorithm for raster interpolation. Values for this raster ranged from 18.7m to 25.6m, with a mean of 21.7m.

Elevations at the point locations were extracted using ArcGIS Spatial Analyst for the LiDAR DTM (LDRz), the WorldDEM DSM (TDXz), and the geoid height grid (GHz). The signed error [TDX_ERR] was calculated as

$$[LDRz] + [GHz] - [TDXz]$$

and the magnitude of the error [TDX_ERRABS] was calculated as

$$ABS([LDRz] + [GHz] - [TDXz])$$

Statistics were generated for both samples. The signed error ([TDX_ERR]) ranged from a minimum of –16.3 to a maximum of +5.6, with a mean value of +0.70 and standard deviation of +0.84. Positive values of [TDX_ERR] indicate WorldDEM elevations below LiDAR ground elevation; these occurred on roadside embankments, suggesting that small positional differences in pixel centers translated into significant vertical differences. Negative values of [TDX_ERR] indicate WorldDEM elevations higher than ground elevations, generally indicating that WorldDEM elevations represented the height of surface features such as trees, rather than bare ground.

The magnitude (unsigned) of the error ([ERROR_ABS]) ranged from a minimum of 0 to a maximum of +16.3, with a mean of +0.88. Of the 5991 sample points, 3823 (64%) had an absolute error of < 1.0m (Figure 3). The RMSE was 1.096.

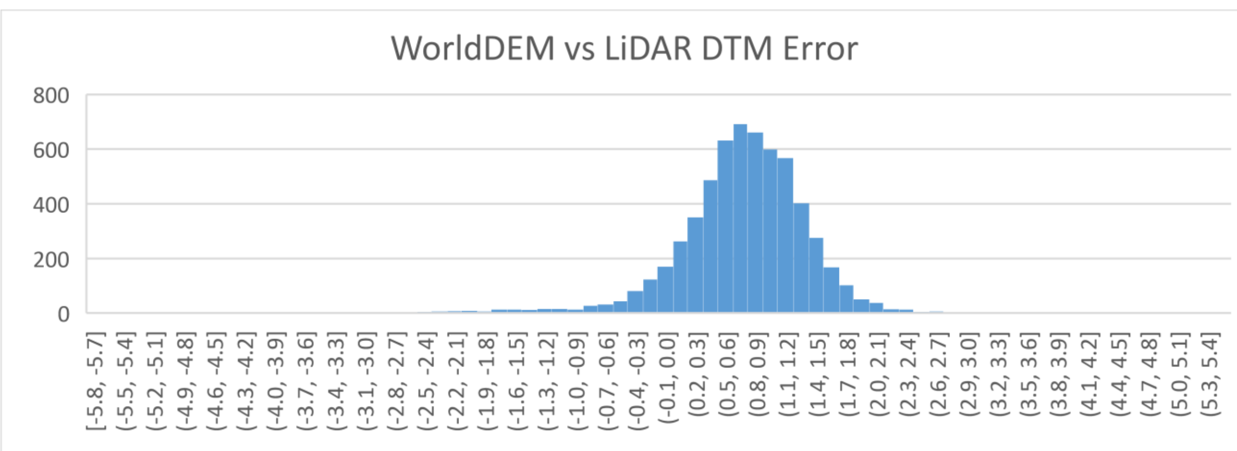


Fig. 3: Histogram of difference between WorldDEM and adjusted LiDAR-based elevations

The sample points were also overlaid with the 30m SRTM DSM and the elevations at each point were extracted and compared to LiDAR elevations. Both elevations were geoid, or orthometric height (above mean sea level) therefore no correction for undulation was applied. The RMSE was 2.875m.

Differences in elevation between LiDAR and WorldDEM outside of bare, non-vegetated land are not errors but represent the height of surface features such as trees and buildings. The WorldDEM DEM can in fact be normalized to ground elevations by subtracting a LiDAR-derived DTM, which provides a reasonably accurate canopy height surface, in areas where a Bare Earth surface is available but the associated Full Feature surface is not (Figure 4). Future work will attempt to calibrate WorldDEM pixels in the Green Area with 1m full feature LiDAR pixels aggregated to matching pixels, as a coarse estimate of biomass and stand height.

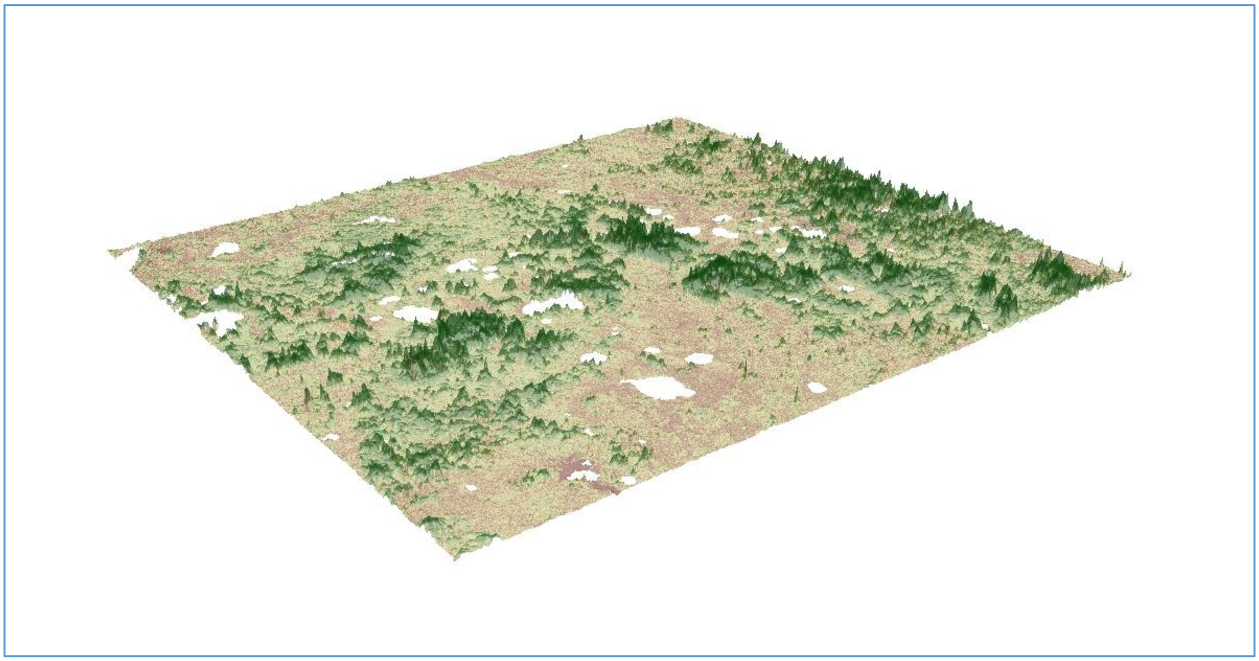


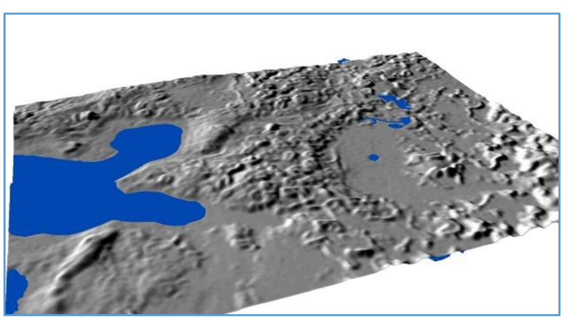
Fig. 4: 3d perspective view of WorldDEM DSM elevations normalized to surface heights

4.0 Objective 2: to test the utility of the WorldDEM 10m DEM for delineating catchment basins for selected wetland sampling sites

The second objective of the project was to delineate catchment basins for ABMI's field-sampled wetland sites using both the WorldDEM and LiDAR DEMs, and to compare the two datasets in terms of the strength of a modelled relationship between field-sampled water quality parameters and landscape conditions in the upstream contributing areas. The linkages between upstream conditions and water quality in prairie wetlands cannot be reliably determined since the contributing area for upstream conditions has not been defined. The ABMI has previously used a 250m buffer around the wetlands being sampled to represent proximate conditions; however this includes areas downstream of the waterbody (lower elevation than the pour point, or outlet), as well as excluding potentially very large areas upstream.

We used System for Automated Geoscientific Analyses (SAGA) (Olaya, 2004) and ESRI ArcGIS 10.4 (ESRI, 2016) to delineate catchment basins for the ABMI's field-sampled wetlands within the study area (n=134) from the LiDAR 15m DTM. Landscape metrics within the contributing area for each wetland, including terrain, human footprint, and vegetation characteristics, were analysed for correlations with *in situ* measurements of water physiochemistry (temperature, pH, dissolved oxygen, conductivity, salinity, nitrogen, phosphorus, and total dissolved organic carbon (DOC)).

We determined, however, that any terrain analysis, including the generation of catchment basins, must be performed on a DTM, not a DSM. The initial step to generating a catchment basin for a chosen pour point is to artificially fill any closed depressions in the DEM, to ensure that each pixel has at least one of its eight neighbouring pixels at equal or lower elevation so that the direction of water flow at any pixel can be defined. With the WorldDEM, surface features such as forests and shrubs created artificial sinks that interfered with actual flow direction as inferred from the LiDAR DTM, confirming that DEMs generated through InSAR do not represent a true terrain surface (Kellndorfer, 2004). For example, small depressional wetlands, which are ubiquitous throughout the prairie pothole region, are often colonized by copses of deciduous trees such as trembling aspen (*Populus tremuloides*). This manifests on the WorldDEM DEM as a raised feature, which will shed rather than accumulate water (Figure 5). This disconnect between WorldDEM elevation values and actual hydrological behaviour indicates that WorldDEM should not be used to represent terrain in hydrological modeling.



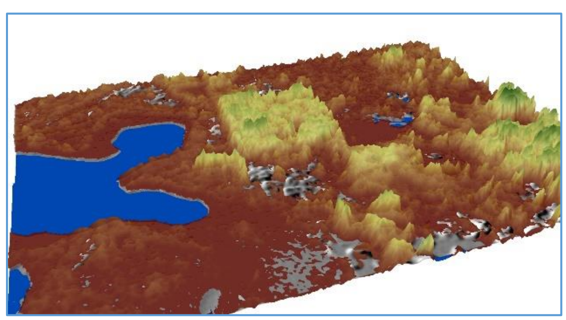


Fig. 5: LiDAR DTM ground features (left), WorldDEM DSM surface features (right). Scene extent is 4km x 3 km; vertical scale greatly exaggerated

5.0 Objective 3: to calculate water storage capacity of depressional wetlands in the Prairie pothole region

In Alberta's prairie region, which experiences intense summer precipitation events and chronic water stresses, temporary water accumulation in ephemeral wetlands acts as a hydrological buffer between rainfall and runoff and is of increasing importance to the productivity of Alberta's agriculture areas in the face of observed and expected climate change impacts. A reliable estimate of the benefit provided by these natural reservoirs will inform Alberta's emerging market for Ecosystem Services, which recognizes and evaluates a wetland's hydrological functions such as flood control, water purification, and habitat for aquatic species. This evaluation would improve the implementation of Alberta's Wetland Policy, which aims to measure functional equivalency among wetlands and provide a mechanism for calculating offsets.

Potholes are post-glacial terrain features characterized by small (<1ha), hydrologically isolated depressions formed when the leading edge of the Wisconsin ice sheet was incised and fractured into large ice blocks by channeling of meltwater streams on the surface of the glacier. These streams left deposits of till in ground moraines which isolated the depressions left behind after the ice blocks had melted (Kantrud *et al.,* 1989). Also known as kettle lakes, these ephemeral wetlands typically fill with water during spring thaw and lose water due to percolation and evaporation rather than runoff (Brinson 1993; Leibowitz & Vining, 2003).

We estimated the unused water storage capacity of depressional wetlands by artificially "filling" the depressions in the LiDAR DTM (Planchon & Darboux, 2001) and subtracting the unfilled from the filled DTM, on the assumption that the differences in elevation between the two surfaces represented real depressions and not artefacts (Lindsay & Creed, 2005). The volume of the resulting surface for a given area is the sum of pixel values multiplied by the pixel area. We used a sample of 100 legal land units in the pothole region called "sections", 1620m x 1620m square (262 ha, green squares in Fig. 6) to estimate the unfilled volume of depressional wetlands from the 15m LiDAR DTM, and calculated the RMSE of the difference between LiDAR-derived volumes for each section and volumes derived from the SRTM, ALOS, and WorldDEM DSMs.

The mean volume of filled sinks per section was 1,788,417 m^3 according to the 15m LiDAR DTM, corresponding to a mean depth of 68cm. The RMSE divided by the mean volume was 28.3% for ALOS DSM, 33.6% for SRTM DSM, and 17.5% for WorldDEM, indicating that WorldDEM may be more reliable for pothole capacity estimation in areas where LiDAR DTMs are not available.

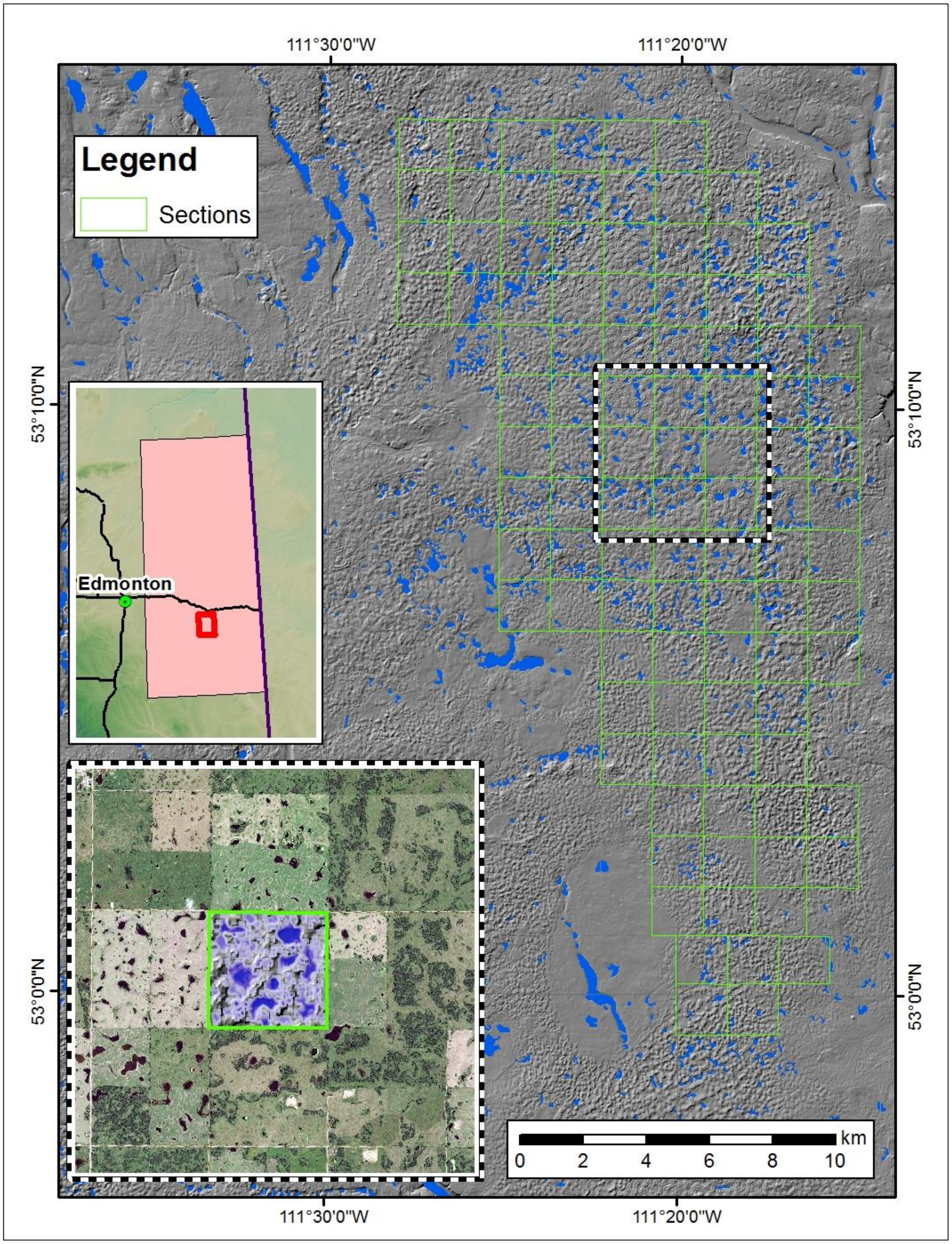


Fig. 6: Sample sections in pothole region (green squares). Inset: close-up of section. The pothole region is characterized by numerous small waterbodies not connected by streams.

6.0 References

Alberta Biodiversity Monitoring Institute Geospatial Centre. 2017. “Human Footprint Inventory 2014 – Public Version, Version 3.” Edmonton, Alberta, Canada.

Alberta Environment and Parks, Government of Alberta. 2011. “Green/White Area.” Edmonton, Alberta, Canada. https://maps.alberta.ca/genesis/rest/services/ASRD_Administrative_Area/Latest/MapServer/1

Alberta Environment and Sustainable Resource Development, Government of Alberta. 2004. Base Water Polygon. Edmonton, Alberta, Canada.

Alberta Environment and Parks, Government of Alberta. 2009. “Base Features Derived Watershed Delineation and Hydrocoding Specifications.” Edmonton, Alberta, Canada.

Alberta Environment and Sustainable Resource Development, Government of Alberta. 2013. “General specifications for acquisition of LiDAR data.” Edmonton, Alberta, Canada.

Alganci, U.; Besol, B.; Sertel, E. 2018. Accuracy Assessment of Different Digital Surface Models. *ISPRS Int*. J. Geo-Inf., 7, 114.

Brinson, M. 1993. A Hydrogeomorphic Classification for Wetlands. U.S. Army Corps of Engineers, Technical Report WRP-DE-4.

Chu, T. and Lindenschmidt, K.E. 2017. “Comparison and Validation of Digital Elevation Models Derived from InSAR for a Flat Inland Delta in the High Latitudes of Northern Canada.” *Canadian Journal of Remote Sensing*, Vol. 43 (No.2): pp. 109–123.

DeLancey, E.R., Kariyeva, J., Cranston, J., and Brisco, B. 2018. “Monitoring hydro temporal variability in Alberta, Canada with multi-temporal Sentinel-1 SAR data.” *Canadian Journal of Remote Sensing*, Vol. 44(No.1): pp. 1-10.

Environmental Systems Research Institute. 2016. “ArcGIS release 10.4.” Redlands, California.

Faller, N., Weber, M. 2007. “TerraSAR-X and TanDEM-X: Revolution in spaceborne radar." *Geoscience and Remote Sensing Symposium*, 2007.

Farr, T. G., P. A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, M. Kobrick, M. Paller, E. Rodriguez, L. Roth, D. Seal, S. Shaffer, J. Shimada, J. Umland, M. Werner, M. Oskin, D. Burbank, and Alsdorf D. 2007. “The Shuttle Radar Topography Mission.” *Report on the Jet Propulsion Laboratory (JPL), California Institute of Technology, California, US.* http://www2.jpl.nasa.gov/srtm/SRTM_paper.pdf

Kantrud, H.A., Krapu, G.L., Swanson, G.A. 1989. Prairie Basin Wetlands of the Dakotas: a Community Profile - U.S, Fish Wildlife Service. Biol. Rep. 85(7.28). 116 pp. https://www.nwrc.usgs.gov/techrpt/85-7-28.pdf

Kellndorfer, J. et al. 2004. Vegetation height estimation from shuttle radar topography mission and national elevation datasets. *Remote Sens. Environ*. 93, pp. 339-358.

Leibowitz, S., Vining, K. 2003. Temporal Connectivity in a Prairie Pothole Complex. *Wetlands*, Vol 23, No. 1, pp. 13-25.

Lindsay, J., Creed, I. 2005. Distinguishing actual and artefact depressions in digital elevation data. *Computers & Geosciences*, 32:1192–1204

Moreira, A. et al, 2004. “TanDEM-X: A TerraSAR-X Add-On Satellite for Single-Pass SAR Interferometry” http://www.dlr.de/hr/en/Portaldata/32/Resources/dokumente/tdmx/TanDEM-X-IGARSS-2004.pdf

Natural Regions Committee. 2006. Natural Regions and Subregions of Alberta. Government of Alberta, Edmonton, AB.

Norris, S., Margold, M., & Froese, D. 2017. Glacial landforms of northwest Saskatchewan. *Journal of Maps*, 13:2, pp. 600-607.

Olaya, V. 2004. “A gentle introduction to SAGA GIS” Edition 1.1. Madrid, Spain.

Planchon, O., F. Darboux, F. 2001. A fast, simple and versatile algorithm to fill the depressions of digital elevation models. *Catena,* 46 pp. 159–176