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OGC GeoPackage Elevation Extension Interoperability Experiment Engineering Report

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Contents

Page

Figures Page

Tables Page

Abstract

This OGC Engineering Report (ER) describes the setup, experiments, results and issues generated by the GeoPackage Elevation Extension Interoperability Experiment (GPKG-EE IE). The goal of the GPKG-EE IE was to implement and test a proposed elevation extension to the OGC GeoPackage Encoding Standard (12-128r1). The proposed elevation extension was successfully implemented by several IE participants and was demonstrated using both 2-Dimensional (2D) and 3-Dimensional (3D) software clients at the Washington, DC OGC Technical Committee (TC) meeting in [March 9, 2016]. This ER concludes with several recommendations for addressing remaining technical issues that must be resolved in order to complete a candidate GeoPackage Elevation Extension standard.

Business Value

Currently, there is not a standardized way to store elevation data in an OGC GeoPackage. Software clients that currently use a GeoPackage data store to display maps, imagery, and features could use elevation data within a GeoPackage to extend the client capabilities to include 2.5D/3D visualization and analytics such as line-of-sight (LOS). The GeoPackage elevation extension enables lightweight clients that run on handheld and tablet devices to perform visualizations and analytics directly on the device, thus provides access to these capabilities where a network connection and/or desktop GIS client is not available.

Keywords

ogcdoc, OGC document, GeoPackage, elevation, tiles, TIFF, PNG

OGC GeoPackage Elevation Extension Interoperability Experiment Engineering Report

1 Introduction

1.1 Scope

This OGC® document provides guidelines for the implementation of an OGC GeoPackage Elevation Extension to store gridded elevation data in a GeoPackage in order to support visualization and analysis operations. The elevation extension was successfully implemented by several Interoperability Experiment (IE) participants. Using elevation data stored in a GeoPackage, visualization and analysis capabilities were demonstrated. There are several remaining technical issues that must be resolved in order to fully define the GeoPackage Elevation Extension standard. This report describes the setup, experiments, and results of the IE, and concludes with recommendations for resolving the remaining technical issues with the GeoPackage Elevation Extension.

All questions regarding this document should be directed to the editor or the contributors:

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1.2 Future work

Improvements in this document are desirable to describe how the remaining technical issues with the GeoPackage Elevation Extension are ultimately resolved. In addition, the issues of elevation data interpolation and resampling methods that are not covered in this report should be addressed in a separate engineering report or best practices document.

1.3 Forward

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

2 References

The following documents are referenced in this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

[OGC 12-128r1] OGC GeoPackage Encoding Standard[1] (12-128r1) (http://www.opengeospatial.org/standards/geopackage)

[OGC 15-039] "Envisioning an Elevation Extension to the GeoPackage Encoding Standard"

[OGC 15-119] OGC GeoPackage Elevation Extension Interoperability Experiment (GPKG-EE IE) Activity Plan

[Adobe 1992] TIFF http://partners.adobe.com/public/developer/en/tiff/TIFF6.pdf

[Regenstrief Institute, Inc. and the UCUM Organization, 2014] The Unified Code for Units of Measure (UCUM) http://unitsofmeasure.org/ucum.html

[NGA.STND.0036_1.0.0_WGS84] "Department of Defense World Geodetic System 1984: Its Definition and Relationships with Local Geodetic Systems", 8 July 2014.

[ISO 19111:2007] "Geographic Information – Spatial Referencing by Coordinates", International Organization for Standardization 1 July 2007.

[ISO/IEC 15948:2004] Portable Network Graphics (PNG): Functional specification.

[OGC 16-011] Volume 8: CDB Spatial and Coordinate Reference Systems Guidance

[OGC 16-006] Volume 10: OGC CDB Implementation Guidance

[OGC 07-057r7] OpenGIS Web Map Tile Service Implementation Standard

[OGC 12-101] OGC Web Coverage Service 2.0 Interface Standard – GeoTIFF Coverage Encoding Extension

[Open Source Geospatial Foundation 2012] Tile Map Service Specification https://wiki.osgeo.org/wiki/Tile_Map_Service_Specification

3 Terms and definitions

For the purposes of this report, the definitions specified in Clause 4 of the OWS Common Implementation Standard [OGC 06-121r3] shall apply. In addition, the following terms and definitions apply.

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1 http://www.geopackage.org/ for more information.

3.1
Elevation
A height above a given level. The common methods of depicting elevation data include using a regular grid, a Triangulated Irregular Network (TIN), a point cloud, or contour lines. The GPKG elevation extension was designed for elevation data depicted using a regular grid (aka gridded)

3.2
GeoPackage
A platform-independent SQLite database file that contains GeoPackage data and metadata tables [OGC 12-128r1]

3.3
Extended GeoPackage
A GeoPackage that contains any additional data elements (tables or columns) or SQL constructs (data types, functions, indexes, constraints or triggers) that are not specified in [OGC 12-128r1].

3.4
Vertical Datum
Datum describing the relation of gravity-related heights or depths to the Earth. In most cases the vertical datum will be related to mean sea level. Ellipsoidal heights are treated as related to a three-dimensional ellipsoidal coordinate system referenced to a geodetic datum. Vertical datums include sounding datums (used for hydrographic purposes), in which case the heights may be negative heights or depths.[ISO 19111:2007]

3.5
Vertical Coordinate
One-dimensional **coordinate reference system** based on a **vertical datum [ISO 19111:2007]**

3.6
Height Above Ellipsoid (HAE)
Geodetic height *h* - distance of a point from the **ellipsoid** measured along the perpendicular from the **ellipsoid** to this point positive if upwards or outside of the **ellipsoid.** NOTE: Only used as part of a three-dimensional ellipsoidal coordinate system and never on its own. [ISO 19111-2007]

3.7
Geodetic Datum
Datum describing the relationship of a 2- or 3-dimensional **coordinate system** to the Earth [ISO 19111]

3.8
Geoid
Equipotential surface of the Earth's gravity field which is everywhere perpendicular to the direction of gravity and which best fits **mean sea level** either locally or globally [ISO 19111:2007]

3.9
Ellipsoid
Surface formed by the rotation of an ellipse about a main axis. In this International Standard, ellipsoids are always oblate, meaning that the axis of rotation is always the minor axis. [ISO 19111:2007]

3.10
World Geodetic System 1984 (WGS 84)
An Earth-centered, Earth-fixed (ECEF) worldwide geodetic datum and reference system based on a determination of the Earth's parameters and gravity field. NGA developed the system as the standard geographic reference system for use within the Department of Defense. NGA uses World Geodetic System 1984 in its production of maps and charts. In principle, NATO and the allied nations approved the use of the World Geodetic System 1984 for geospatial information purposes. It provides uniform datum and reference system information for use in joint and multinational operations. In addition, GPS - which is a navigation tool for air, land, sea and space operations within the Department of Defense - is designed to work in World Geodetic System 1984. [NGA.STND.0036_1.0.0_WGS84]

3.11
Coordinate System
Set of mathematical rules for specifying how coordinates are to be assigned to points [ISO 19111:2007]

3.12
Coordinate Reference System (CRS)
A Coordinate System that is related to an object by a datum. For geodetic and vertical datums, the object will be the Earth. [ISO 19111:2007]

3.13
Height
Distance of a point from a chosen reference surface measured upward along a line perpendicular to that surface. A height below the reference surface will have a negative value. [ISO 19111:2007]

3.14
Mean Sea Level (MSL)
Average level of the surface of the sea over all stages of tide and seasonal variations. Mean sea level in a local context normally means mean sea level for the region calculated from observations at one or more points over a given period of time. Mean sea level in a global context differs from a global geoid by not more than 2 meters. [ISO 19111:2007]

3.15
Gravity-Related Height
Height (H) dependent on the Earth's gravity field**.** NOTE: In particular, orthometric height or normal height, which are both approximations of the distance of a point above the mean sea level. [ISO 19111:2007]

4 Conventions

4.1 Abbreviated terms

2D	Two-Dimensional

2.5D	Two and One-Half Dimensional
3D	Three-Dimensional
AGC	US Army Geospatial Center
CDB	Common DataBase
CRS	Coordinate Reference System
DIL	Disconnected, Intermittent, or Limited
DTED	Digital Terrain and Elevation Data
ECEF	Earth Centered Earth Fixed
EE	Elevation Extension
EGM	Earth Gravitational Model
EPSG	European Petroleum Specialty Group
GDAL	Geospatial Data Abstraction Library
GIS	Geographic Information System
GPKG	GeoPackage
GPS	Global Positioning System
HAE	Height Above Ellipsoid
HLZ	Helicopter Landing Zone
IE	Interoperability Experiment
LOS	Line of sight
MSL	Mean Sea Level
NAN	Not a number
NATO	North Atlantic Treaty Organization
NGA	National Geospatial Intelligence Agency
NOAA	National Ocean and Aeronautical Administration
NSG	National System for Geospatial Intelligence
OGC	Open Geospatial Consortium
PNG	Portable Network Graphics
SRS	Spatial Reference System
TIFF	Tagged Image File Format
TMS	Tile Map Service
UK	United Kingdom
USGS	United States Geological Survey
WCS	Web Coverage Service
WKT	Well Known Text
WGS84	World Geodetic System 1984
WMTS	Web Map Tile Service

5 Objectives of this Interoperability Experiment

5.1 Technical Objectives

- Convert gridded elevation data from multiple source formats and store in an OGC GeoPackage;
- Load elevation data stored in a GeoPackage into a map viewer to display elevation data in 2D and 2.5/3D; and
- Accessing elevation data stored in a GeoPackage, perform analytics such as line of sight.

5.2 Interoperability Objectives

- Develop an interoperable method of storing elevation data in a GPKG that supports visualization and analysis use cases (Table 1) on a mobile device operating in a disconnected, intermittent, or limited (DIL) data network environment.
- Define a standardized approach to storing elevation data that is aligned with current or emerging OGC standards.

Table 1: Elevation Extension Use Cases

Use Case	**Example(s)**
2D Terrain Visualization	Hillshade, color relief, slope, contour lines
3D Terrain Visualization	Changing view angles and level of detail
Site Suitability Analysis	Viewsheds, line of sight, slope analysis for helicopter landing zones (HLZs)
Mobility Analysis	Calculating least cost paths to support terrain-based routing
Terrain Association	Adding photographs and/or imagery to mapped locations
Modeling and Simulation	Representation of 3D Geometries (e.g. buildings) and models needed to support augmented reality training

6 Summary of Key Findings

The technical objectives of the Elevation Extension Interoperability Experiment were achieved. Three IE participants were able to convert gridded elevation data from source data and store it in an OGC GeoPackage compliant data store. Two participants were able to display these GeoPackages in a map viewer and perform line of sight analysis. GeoPackage elevation extensions were shown to be interoperable, thus the first interoperability objective was met. Based on the implementation experience, this report recommends that the PNG and TIFF elevation data tiling options be split into two separate GeoPackage extensions in order to meet the second interoperability objective, alignment with existing or emerging OGC Standards.

7 Setup

Several source datasets were obtained and used to generate example Elevation Extension GeoPackages. These data sources are listed in Table 2 below.

Table 2: Elevation Extension Data Sources

Source	Location	Format	Spatial Resolution (m)	Area covered (km^2)	Size on disk (MB)
USGS	Alaska	TIFF	10	66	3
NOAA	Puget Sound	TIFF	24	28,000	25
USGS	Puget Sound	DTED2	30	75,000	26
Ordnance Survey	UK	ASC	50	243,000	159

The Alaska Elevation Data obtained from the United States Geological Survey (USGS) has the highest spatial resolution (10m) and also contains a mountain. Therefore, this dataset has a change of approximately 800 meters of height values. The Puget Sound Bathymetry Data obtained from the National Oceanic and Aeronautic Administration (NOAA) and contains depth values for a large portion of the Puget Sound area (Figure 1). However, the dataset also has sparse coverage for some areas. The Digital Terrain Elevation Data (DTED) has 30-meter spatial resolution and also covers the Puget Sound area. The elevation data obtained from the United Kingdom (UK) Ordnance Survey covers the entire UK at 50m spatial resolution and is the largest dataset at approximately 159MB in size.

Figure 1: NOAA Bathymetry Data

8 Experiments

Two experiments were performed to assess the suitability of the GPKG Elevation Extension in meeting the technical and use case objectives defined above. The first experiment tested the ability to implement the proposal elevation extension using the source datasets and the second experiment tested the suitability of these elevation data GeoPackages for visualization and analysis.

8.1 Experiment 1

For the first experiment the IE participants created GeoPackage elevation data instances using the three source datasets described above. These GeoPackages were tested for compliance with the OGC GeoPackage Standard [OGC 12-128r1] and with the requirements of the proposed elevation extension (please see Annex A for a description of the proposed GeoPackage Elevation Extension). The scope of this experiment was initially determined during the kick-off meeting and discussions continued throughout the IE. At the 18 January teleconference, the participants agreed to work with a limited number of data sets. The participants determined that the USGS Alaska data is interesting due to the large range of elevation values (i.e. lots of slope) but too small to test scalability. The UK Ordnance Survey data is better for testing scalability due to the larger size of the dataset. The NOAA Puget Sound bathymetry data is of value due to the sparseness of the data and the use of negative height values (i.e. below Mean Sea Level (MSL)). DTED2 is a global elevation dataset and is of special interest to the defense and intelligence communities.

8.2 Experiment 2

In the second experiment IE participants loaded the elevation data OGC GeoPackages into handheld and desktop software, visualized the data in 2D/2.5, and performed a line of sight analysis. At the 12 January teleconference, the participants reached a consensus to limit the scope of this experiment to color relief for visualization and line of sight for analysis. The advantage of this approach was that it simplifies the process of confirming that different software applications behaved similarly. A simple visual qualitative comparison of the color relief and line of sight outputs was sufficient to confirm that the elevation data GeoPackages were being used similarly by different software applications, rather than the more detailed quantitative comparison that would be required by more advanced elevation data based analytics such as terrain-based off-road routing.

9 Results

9.1 GeoPackage Creation

A total of fourteen elevation GeoPackages were created during the first experiment. Luciad and Brad Hards both created GeoPakages using the Alaska, Puget Sound, and UK source data while Compusult created GeoPackages using the three aforementioned data sources as well as the DTED2 data. These GeoPackages are listed below in Table 3. It is notable that the elevation extension GeoPackages that use PNG format tiles (uint16) are considerably smaller in size than the TIFF format tiles (float32). For example, the DTED2 source data is 26MB in size. The Compusult elevation extension GPKG that uses TIFF encoding (CSLT_n47_w123_1arc_v2_dt2_float32.gpkg) is 74.2MB in size, while the PNG elevation extension (CSLT_n47_w123_1arc_v2_dt2_uint16.gpkg) is 6.7MB.

Table 3: Elevation Extension GeoPackages

Creator	File name	Source data	Size on disk (MB)
Luciad	alaska_png_2016_02_04.gpkg	USGS	0.6
Luciad	puget_pseudomercator_20150210.gpkg	NOAA	10.8
Luciad	UK_elevation_20160228.gpkg	UK	125.1
Compusult	CSLT_All_Puget_16m_depths_float32.gpkg	NOAA	820.6
Compusult	CSLT_All_Puget_16m_depths_uint16.gpkg	NOAA	10.1
Compusult	CSLT_DSM_N6130W14900_3857_clip_float32.gpkg	USGS	6.2
Compusult	CSLT_DSM_N6130W14900_3857_clip_uint16.gpkg	USGS	0.5
Compusult	CSLT_n47_w123_1arc_v2_dt2_float32.gpkg	DTED	74.2
Compusult	CSLT_n47_w123_1arc_v2_dt2_uint16.gpkg	DTED	6.7

Compusult	CSLT_ukoselev_float32.gpkg	UK	2080
Compusult	CSLT_ukoselev_uint16.gpkg	UK	77.5
Brad Hards	alaska_bradh_2016-01-07_tiff.gpkg	USGS	6.4
Brad Hards	alaska_bradh_2016-01-07.gpkg	USGS	0.46
Brad Hards	osterrain50_2016-01-22.gpkg	UK	1790

9.2 OGC GeoPackage Compliance testing

Each of the elevation extension GeoPackages listed in Table 3 above was tested for compliance with the OGC GeoPackage 1.0 Specification using a Java-based GeoPackage verifier tool developed by Reinventing Geospatial, Inc. The Java code used to create this tool was recently integrated with OGC Team Engine, thus will form the basis of the OGC-approved method for verifying GeoPackage compliance.

The verify tool tests against the requirements in the Core, Tiles, and Schema sections of the OGC GeoPackage Encoding Standard (12-128r1). Most of the elevation extension GeoPackages passed the compliance tests with minor warnings. These warnings were a direct result of how the proposed elevation data extension was implemented, and indicated that more work is needed in specifying a) how the elevation data tiles table should be cross-referenced in other GeoPackage tables and b) how the CRS of the elevation data should be specified. Other minor issues uncovered by the testing tool included missing columns and values. The complete results of this testing can be found in Annex D.

9.3 Elevation Extension Compliance testing

For the final phase of Experiment 1 these GeoPackages were checked for compliance with the proposed GeoPackage elevation extension (Annex A). All GeoPackages complied with the requirements of the elevation extension as specified in Annex A, and no substantive irregularities were found in how the extension was implemented. There is some inconsistency in how the gpkg_contents identifier and description columns are being used, thus better guidance on appropriate usage should be developed for the next version(s) of the GeoPackage elevation extension.

9.4 Visualization and Analytics

In the second experiment, Compusult and Luciad successfully demonstrated the use of the prototype GeoPackages elevation extension for visualization and analytics. This demonstration was given at the OGC Technical Committee (TC) meeting in Washington, DC on March 9, 2016. Luciad used a desktop client to visualize the UK and Puget Sound Elevation Extension GeoPackages in both 2D and 2.5D, and also calculated a line of sight on each GPKG (Figure 2 and Figure 3). Compusult used a desktop client and a mobile Android client to produce a 2D shaded relief visualization using the Elevation Extension GPKGs (Figure 4), and also calculated LOS and produced an elevation profile (Figure 5). The Web Mercator Coordinate Reference System (CRS) was used for this demonstration since as this was the native CRS for the mobile clients used in the demonstration. The Luciad desktop software can re-project on the fly to support other CRSs.

Figure 2: Viewshed using the UK Ordnance Survey Elevation GeoPackage

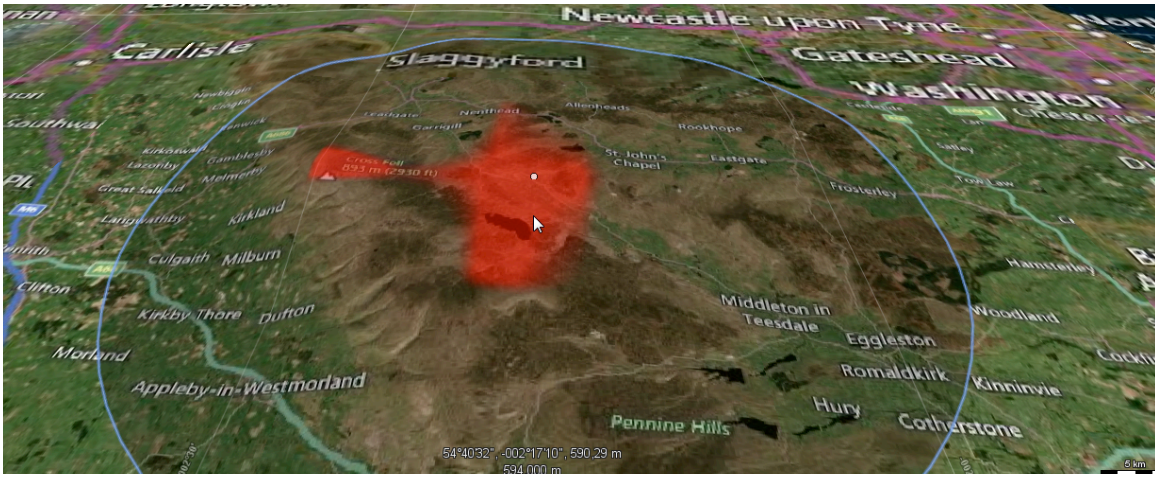


Figure 3: LOS using the NOAA Puget Sound Bathymetry GeoPackage

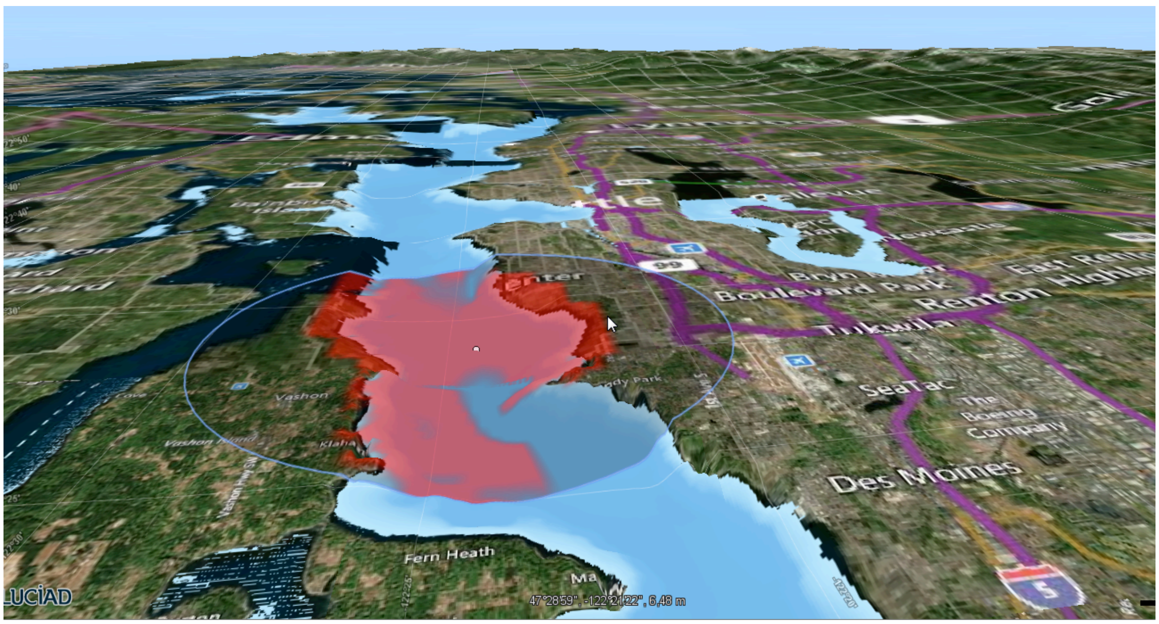


Figure 4: Shaded relief using a GeoPackage with NOAA and USGS data

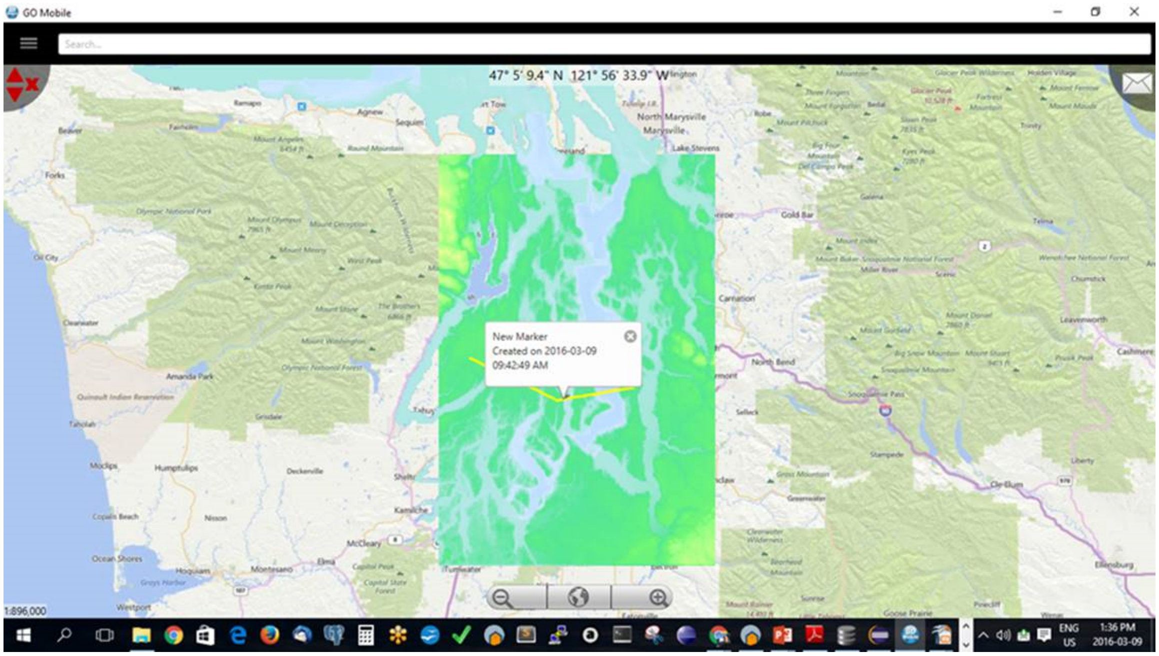
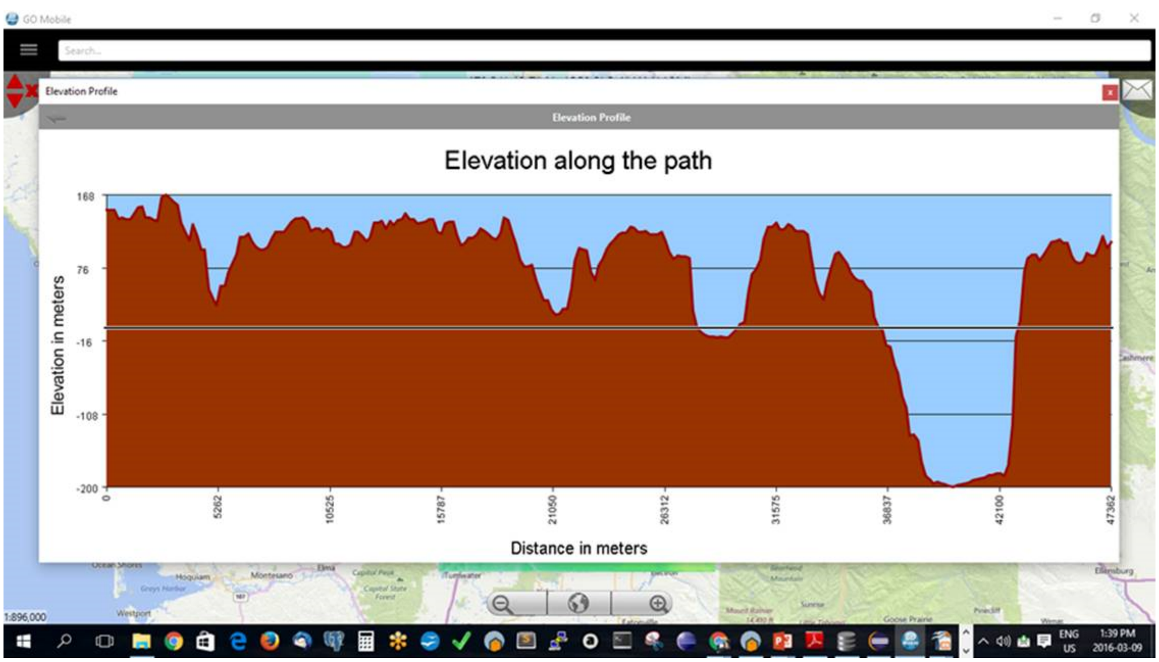


Figure 5: Elevation profile using a GeoPackage with NOAA and USGS data



10 Technical Issues

There are three significant technical issues that need to be resolved in order to maximize interoperability and simplify the implementation of the GeoPackage Elevation Extension. These technical issues were discussed in several forums:

- During the bi-weekly Interoperability Experiment teleconference meeting;
- On GitHub (https://github.com/opengeospatial/geopackage-elevation); and
- During the GeoPackage SWG session at the March 9, 2016 OGC TC meeting.

These technical issues are described below.

10.1 Data NULL vs. Data Missing

In the proposed GeoPackage elevation extension, the *gpkg_2D_gridded_ancillary* table contains a column named *data_null* and a column named *data_missing*. The intent of *data_missing* is to indicate the numeric value used for tiles where source data is missing. *data_null* is to be used where source data is available but does not have a height value for a tile. Some participants proposed that one of these columns be eliminated in favor of a single "no data" option. This would simplify the extension by eliminating the need for software clients to interpret two different values, and also allow data produces to use a single "no data" value when creating tiles from source data. However, having both of these columns does make data interpolation more clear. This could useful when working with sparse datasets.

The Data NULL vs. Data Missing issue raises the larger question of how the height values in source data should be sampled and encoded into tiles. The encoding issue is addressed in the following two sections of this report. However, the sampling issue remains an open question. One of the central questions is if the height values should be considered as area samples that can be applied to an entire pixel or as discrete point samples that fall within the center of each pixel. This question will impact the resampling methods that can be used to generate different zoom levels. More information on the resampling issue can be found in Annex B of this report.

10.2 Scale and Offset

The proposed GeoPackage elevation extension contains a *scale* column and an *offset* column in the *gpkg_2D_gridded_ancillary* table. These parameters are applied globally to each table containing elevation data tiles listed in the *gpkg_tile_matrix_set* table. The intent is allowing highly precise height measurements to be preserved within the 16-bit (~65000) value-range of a PNG color channel. One IE participant expressed two concerns about using the *scale* and *offset* parameters:

1) Even with the use of these values, the 16-bit precision of PNG is not enough to represent centimeter precision heights and;

2) Elevation extension implementers would need to know the minimum and maximum values of an elevation datasets before creating the GeoPackage elevation instance, which could be difficult in situations where metadata is lacking.

Therefore, there was a proposal that *scale* and *offset* columns be added to the *gpkg_2D_tile_ancillary* table, which would allow these values to be specified on a per tile basis. This would allow *scale* and *offset* values to be assigned to individual tiles based on their horizontal spatial resolution. Thus, high spatial resolution tiles could contain highly precise height values while low spatial resolution tiles would have less precise heights. This approach would also eliminate the need to calculate the minimum and maximum vales of an elevation dataset before creating tiles. Participants suggested that adding *scale* and *offset* columns to the *gpkg_2D_tile_ancillary* table makes the PNG format a more viable option for elevation data tiles by simplifying the tile production process and allowing for highly precise height values without adding significant client side overhead when reading in tiles.

A counter argument was made against adding a *scale* column and an *offset* column to the *gpkg_2D_gridded_ancillary* table. The central concern was that applying a linear transformation of height values on a per-tile basis would add significant complexity on the client side. Second order concerns focused on having to first decode all of the height values in order to determine the correct scaling for visualizations and the additional complexity of performing cross-tile analyses.

10.3 Coordinate Reference Systems

One of the early drafts of the GeoPackage Elevation Extension required that a 3-dimensional Coordinate Reference System (CRS) be used in the *gpkg_spatial_ref_sys* and *gpkg_tile_matrix_set* tables. The intent of the 3D CRS requirement was to explicitly specify the horizontal datum, projection, and coordinate system as well as the vertical datum and height type within a single EPSG code. Several participants expressed concern with this approach. The main concern is the lack of 3D CRS implementations in the software used to both create and read OGC GeoPackages and the limited variety of 3D CRSs currently specified in the EPSG CRS registry. Several alternatives to using a 3D CRS were proposed, including providing separate columns to specify a 2D CRS and a vertical CRS, or creating a custom Well Known Text (WKT) string to describe both the horizontal and vertical CRS components within a single field.

While creating a custom WKT to describe a 3D SRS offers a great amount of flexibility to GeoPackage elevation extension producers, this approach may ultimately hinder interoperability. Software clients that currently read WKT strings will need to be expanded to interpret a wide variety of non-standard, custom WKT strings, and software clients that do not currently read the WKT will need to add support. There was a general consensus among IE participants that specifying a 2D CRS plus a vertical CRS for each elevation data tile table is the preferred approach. The latter approach provides a flexible yet standardized way for GeoPackage elevation extension producers to georeference elevation data This approach also allows both simple, lightweight software clients and more complex GIS software read, display, and analyze elevation data GeoPackages.

11 Recommendations

11.1 Encode a single NO DATA value rather than Data NULL and Data Missing

The *data_null* and *data_missing* columns in the *gpkg_2D_gridded_ancillary* table should be eliminated and replaced with a single *no_data* column. This will simplify the extension by eliminating the need for software clients to interpret two different values, and also allow data produces to use a single "no data" value when creating tiles from source data. If data interpolation is needed, it should be performed during the tile creations process. Data interpolation is highly dependent on the underlying resampling process used to create tiles. This remains an open question that should be addressed but is outside the scope if this ER.

11.2 Use scale and offset values for each PNG tile

Scale and *offset* columns should be added to the *gpkg_2D_tile_ancillary* table allowing these values to be specified on a per tile basis. High spatial resolution tiles could contain highly precise height values while low spatial resolution tiles would have less precise heights, and the need to calculate the minimum and maximum vales of an elevation dataset before creating tiles would be eliminated. *Scale* and *offset* values are only needed for PNG tiles since the 32-bit float values encoded in the TIFF format tiles are already sufficient to support highly precise heights. The final recommendation below addresses this important different between the PNG and TIFF formats.

11.3 Specify a 2D CRS plus a vertical CRS reference for each tile table

This method of georeferencing elevation data will provide flexibility on both data production and client side data ingest, while ensuring that the height values being encoded into OGC GeoPackages are consistent with EPSG standards. One method of specifying the 2D CRS and vertical CRS of a tile set would be to add a column called *vert_srs_id* to the gpkg_tile_matrix_set table. The vertical CRS would be added as an mandatory additional row in the *gpkg_spatial_ref_sys* table.

11.4 Develop two separate elevation extensions for OGC GeoPackage

The GeoPackage elevation extension as currently written allows tiles to be generated in either the TIFF or the PNG format. The 16-bit integer storage constraints of the PNG format necessitate adding additional per-tile scale and offset values to support high precision height values, while the 32-bit float values encoded in the TIFF format are already sufficient to support highly precise heights. However, there are significant advantages in file size and built-in client support for the PNG format. Given the fundamental differences and trade-offs associated with the PNG and TIFF tile encodings, the IE participants recommend that each approach be developed into separate OGC GeoPackage elevation extension candidate standards.

The first extension should be designed for simple, lightweight clients that are used primarily for visualization and have limited data storage space and processing power. This extension should specify that PNG be used for tile encoding, and have the option for scale and offset columns in the gpkg_2d_gridded_tile_ancillary table. Different best practice documents should be developed that define the 2D and vertical CRS and tile indexing schemes to be used, and in general these best practices should match well-known industry standard tile sets such as Tile Map Service (TMS). This extension should maximize elevation data interoperability between existing commercial GeoPackage implementations, and will be suitable for the terrain visualizations specified in Table 1. These elevation data tiles should also be compatible with Web Map Tile Service (WMTS) [OGC 07-057r7]

The second extension should be designed for full-featured clients that require a high level of precision and accuracy and implement a diverse set of terrain-based analytics. This extension should specify that TIFF with LZW compression be used for tile encoding, thus eliminating the need for scale and offset columns. The rules for TIFF encoding and spatial referencing used in Common Data Base (CDB) Guidance [OGC 16-011] [OGC 16-006] should be considered. Finally, requirements to ensure that the elevation data tiles are also compatible with Web Coverage Service (WCS) [OGC 12-101] should be considered. Special consideration should also be given to CRS encodings to ensure the application-specific requirements for precision and accuracy of the height values are met. (See Annex C for further discussion). The elevation data in this second extension will be suitable for the 3D Terrain Visualizations, Analyses, Terrain Association, and Modeling and Simulation specified in Table 1.

Annex A: Tiled Gridded Elevation Data Extension

Extension Title

Tiled Gridded Elevation Data

Introduction

The GeoPackage Standards Working Group (SWG) has identified a need for the ability to store tiled gridded elevation data in a GeoPackage. This capability will be used to support use cases such as the following:

- Visualization
  - 2D (hillshade, color relief, slope)
  - 3D (supporting changing view angles and level of detail)
- Analysis
  - Viewshed and line-of-sight
  - Cross-country mobility (off-road routing)
  - Site suitability and planning (slope analysis such as helicopter landing zones)
  - 3D geometry representations of features (ground-based, airspace)
  - Terrain association (associating images to mapped locations)
  - Augmented reality training

This extension to the OGC GeoPackage Encoding Standard leverages the existing structure for raster tiles using PNG files as the container for the elevation values themselves. This capability was designed to be relatively easy to implement and to be suitable for a wide variety of computing environments including the mobile/handheld computing environment[1].

Extension Author

GeoPackage SWG, author_name `gpkg`.

Extension Name or Template

`gpkg_elevation_tiles`

Extension Type

New requirement dependent on Clause 2.2.

Applicability

This extension applies to tile pyramid user data tables that are used to hold tiled, gridded elevation data.

Scope

read-write

Requirements
Table Definitions
Coverage Ancillary

[requirement] A GeoPackage that contains tiled gridded elevation data SHALL contain a `gpkg_2d_gridded_coverage_ancillary` table or view as per Coverage Ancillary Table Definition. Subsequent extensions or custom implementations MAY add additional columns to this table. Clients SHALL ignore additional columns that are unrecognized.

Table 1. Coverage Ancillary Table Definition

Column Name	Column Type	Column Description	Null	Default	Key
`id`	INTEGER	Autoincrement primary key	no		PK
`tile_matrix_set_name`	TEXT	Foreign key to `table_name` in `gpkg_tile_matrix_set`	no		FK
`datatype`	TEXT	'integer'	no		
`scale`	REAL	Scale as a multiple relative to the unit of measure	yes	1	
`offset`	REAL	The offset to the 0 value	yes	0	
`precision`	REAL[2]	The smallest value that has meaning for this dataset	yes	1	
`data_null`	REAL[3]	The value that indicates NULL	yes		
`data_missing`	REAL[4]	The value that indicates data is missing	yes		

Tile Ancillary

[requirement] A GeoPackage that contains tiled gridded elevation data SHALL contain a `gpkg_2d_gridded_tile_ancillary` table or view as per Tile Ancillary Table Definition. Subsequent extensions or custom implementations MAY add additional columns to this table. Clients SHALL ignore additional columns that are unrecognized.

Table 2. Tile Ancillary Table Definition

Column Name	Column Type	Column Description	Null	Default	Key
`id`	INTEGER	Autoincrement primary key	no		PK
`tpudt_name`	TEXT	Name of tile pyramid user data	no		*unique*[5]

Column Name	Column Type	Column Description	Null	Default	Key
		table			
tpudt_id	INTEGER	Foreign key to id in tile pyramid user data table	no		*unique*[6]
scale	REAL	Scale as a multiple relative to the unit of measure	yes	1	
offset	REAL	The offset to the 0 value	yes	0	
min	REAL[7]	Minimum value of this tile	yes		
max	REAL[8]	Maximum value of this tile	yes		
mean	REAL	The arithmetic mean of values in this tile	yes		
std_dev	REAL	The standard deviation of values in this tile	yes		

[requirement] The `min`, `max`, and `mean` values SHALL be natural, i.e., not scaled or offset. Similarly, the `std_dev` SHALL be calculated based on the natural values.

Using the scale and offset values

[requirement] Integer elevation values MAY be scaled and offset in order to make more efficient use of 16-bit integer space available in PNG files. The scope the scale and offset apply to can be both the entire coverage and the individual tile.

Actual elevation values SHALL be calculated by

> first multiplying the stored value by the `gpkg_2d_gridded_tile_ancillary_table.scale` value and then adding the `gpkg_2d_gridded_tile_ancillary_table.offset`,
>
> followed by multiplying that value by the `gpkg_2d_gridded_coverage_ancillary.scale` value and then adding the `gpkg_2d_gridded_coverage_ancillary.offset`.

In pseudo-code, this conversion would look like:

```
elevationInUnitOfMeasure = (SomeElevationCoverage.tile_data-
>pngpixels[i] * gpkg_2d_gridded_tile_ancillary.scale +
gpkg_2d_gridded_tile_ancillary.offset) *
gpkg_2d_gridded_coverage_ancillary.scale +
gpkg_2d_gridded_coverage_ancillary.offset;
```

Table Values

`gpkg_spatial_ref_sys`

[requirement] GeoPackages complying with this extension SHALL have a row in the `gpkg_spatial_ref_sys` table as described in Spatial Ref Sys Table Record:

Table 3. Spatial Ref Sys Table Record

srs_name	srs_id	organization	organization_coordsys_id	definition	description
any	4979	EPSG or epsg	4979	any	any

[requirement] The geopackage_spatial_ref_sys table in a GeoPackage SHALL contain records to define all spatial reference systems used by tiled gridded elevation data in a GeoPackage. The spatial reference system SHALL be used to define the vertical datum, reference geoid, and units of measure for the tiled gridded elevation data.

gpkg_contents

[requirement] (extends GPKG-34) The gpkg_contents table SHALL contain a row with a data_type column value of 2d-gridded-coverage for each tile pyramid containing tiled gridded elevation data. The srs_id column value for that row SHOULD reference an SRS that has a vertical datum[9].

gpkg_extensions

[requirement] GeoPackages complying with this extension SHALL have rows in the gpkg_extensions table as described in Extensions Table Record:

Table 4. Extensions Table Record

table_name	column_name	extension_name	definition	scope
gpkg_2d_gridded_coverage_ancillary	null	gpkg_elevation_tiles	TBD [10]	read-write
gpkg_2d_gridded_tile_ancillary	null	gpkg_elevation_tiles	TBD [11]	read-write
name of actual tile pyramid user data table containing unsigned integer data	tile_data	gpkg_elevation_tiles	TBD [12]	read-write

gpkg_2d_gridded_coverage_ancillary

The following requirements refer to the gpkg_2d_gridded_coverage_ancillary table as per Coverage Ancillary Table Definition.

[requirement] Values of the tile_matrix_set_id column SHALL reference values in the gpkg_tile_matrix_set id column.

[requirement] Values of the datatype column SHALL be 'integer'.

gpkg_2d_gridded_tile_ancillary

The following requirements refer to the gpkg_2d_gridded_tile_ancillary table as per Tile Ancillary Table Definition.

[requirement] Values of the `tpudt_name` column SHALL reference existing tile pyramid user data tables.

[requirement] Values of the `tpudt_id` column SHALL reference values in `id` column of the table referenced in `tpudt_name`.

Tile Pyramid User Data Tables

[requirement] The `tile_data` BLOB in the tile pyramid user data table containing tiled, gridded elevation data SHALL be of MIME type `image/png` and the data SHALL be 16-bit unsigned integer (single channel - "greyscale").

Table Definition SQL

Table 5. Coverage Ancillary Table Definition SQL

```
CREATE TABLE 'gpkg_2d_gridded_coverage_ancillary' (
  id INTEGER PRIMARY KEY AUTOINCREMENT,
  tile_matrix_set_name TEXT NOT NULL,
  datatype TEXT NOT NULL DEFAULT 'integer',
  scale REAL DEFAULT 1.0,
  offset REAL DEFAULT 0.0,
  precision REAL DEFAULT 1.0,
  data_null REAL,
  data_missing REAL,
  CONSTRAINT fk_g2dgtct_name FOREIGN KEY('tile_matrix_set_name')
REFERENCES gpkg_tile_matrix_set ( table_name )
  CHECK (datatype in ('integer','float')));
```

Table 6. Tile Ancillary Table Definition SQL

```
CREATE TABLE gpkg_2d_gridded_tile_ancillary (
  id INTEGER PRIMARY KEY AUTOINCREMENT,
  tpudt_name TEXT NOT NULL,
  tpudt_id INTEGER NOT NULL,
  scale REAL DEFAULT 1.0,
  offset REAL DEFAULT 0.0,
  min REAL DEFAULT NULL,
  max REAL DEFAULT NULL,
  mean REAL DEFAULT NULL,
  std_dev REAL DEFAULT NULL,
  CONSTRAINT fk_g2dgtat_name FOREIGN KEY (tpudt_name) REFERENCES
gpkg_contents(table_name),
  UNIQUE (tpudt_name, tpudt_id));
```

References

Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of this document are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

[1] OGC 12-128r10 OGC® GeoPackage Encoding Standard (On-line)

[1a] OGC 12-128r10 OGC® GeoPackage Encoding Standard (PDF)

1 We acknowledge that this approach will not support certain applications that require a high degree of precision and/or accuracy (e.g., targeting).

2 This is a REAL to support extensions that use non-integer data.

3 This is a REAL to support extensions that use non-integer data.

4 This is a REAL to support extensions that use non-integer data.

5 These two values are designed to be jointly unique so that they refer to a single row in a single table.

6 These two values are designed to be jointly unique so that they refer to a single row in a single table.

7 This is a REAL to support extensions that use non-integer data.

8 This is a REAL to support extensions that use non-integer data.

9 Ideally the vertical datum for each pyramid of elevation will be specified. However, it is impractical to mandate this for a number of reasons, including the difficulty in testing whether a specific SRS has a valid vertical datum.

10 Pending OGC naming authority decision.

11 Pending OGC naming authority decision.

12 Pending OGC naming authority decision.

Annex B: Height Value Encoding and Sampling

The following content is from an issue raised by tseval on the GitHub GeoPackage Elevation extension website (https://github.com/opengeospatial/geopackage-elevation)

I cannot find anything in the specification on how the elevation samples should be georeferenced, if they should be considered as areas or grid points. I think the most common philosophy here is to consider everything as area pixels, and offset the 2D position by a half pixel to find the actual position of each sample. More background in these two links:

http://trac.osgeo.org/gdal/wiki/rfc33_gtiff_pixelispoint

http://www.remotesensing.org/geotiff/spec/geotiff2.5.html#2.5.2.2

If we only support area pixels this will have impact on the resampling methods we can use to generate the LOD (zoom) levels for each tile. This will also introduce a 2D offset that will vary by detail level, since the half pixel offset will vary in size from level to level.

In this case it would also be useful to include information on how the resampling is done. For elevation data it is significant if the zoom levels are made by averaging pixels or by selecting min/max values for example.

If we could support a point pixel grid with 2^n + 1 size, we could resample it by simply picking every second sample, and all the samples will be in their original positions. This is a commonly used resampling method for hierarchical 3D surface models, where you want the samples to move as little as possible from one detail level to the next.

I think the standard should include information on how to interpret the georeferencing of the samples, and what type of resampling has been used in the zoom levels.

Annex C: WGS 84 accuracy

The following content is from an issue raised by Dean Hintz on the GitHub GeoPackage Elevation extension website:

At the last EE.IE meeting there was broad agreement that 3D spatial reference should in general be expressed as a 2D spatial reference standard such as epsg, plus a separate vertical spatial reference (such as a separate vertical epsg). This agrees with the general consensus as discussed here under the #19 3D CRS github topic.

This led to some discussion about what it takes to be certain about a given location 2D using LL-WGS84. I expressed some concern that LL-WGS84 can vary significantly based on the time of the observation. WGS84 observations are dependent on the epoch or WGS84 realization that they are based on. Every GPS or survey instrument is tuned to a certain WGS84 epoch. This can result in variances of more than 0.7 metres, such as in the case of WGS84 (G730) epoch 1994 vs WGS84 (G1674) epoch 2005. This is due to both differences in the survey station network coordinates used and to tectonic plate movements over time. Transformations between epochs require a position-dependent velocity model, at least if accuracies of less than 1 meter are required.

On the other hand, I would agree that not all applications require this level of accuracy, so it may not be warranted to enforce the need to track epoch for all data. I believe it would suffice if we recommended the collection of survey date or epoch as an optional parameter or as a metadata entry. At the end of the day it does come down to the data custodian to maintain good metadata on any datasets they are responsible for, and the accuracy of any given dataset is hard for any standards group to ensure.

Still, I thought it important to raise this issue that a 2D CRS reference such as LL-WGS84 or epsg:4326 is not enough in and of itself to get sub metre accuracy, and that epoch or survey date would go a long way to raising the usefulness of any given dataset as it would allow for future corrections if and when higher accuracy is needed.

I don't disagree with the issue, and that for many purposes it would be better to use something other than WGS-84. I don't think we should embed epoch into the CRS, since most users are lucky to understand spatial reference on their GPS, let alone guess with epoch.

I do not think that this is specific to elevation extension, and probably should be raised as a geopackage spec issue, rather than an elevation-extension specific recommendation.

Annex D: GeoPackage Compliance Test Results

Participant A (Luciad)

Tiles Issues:

(Warning) Requirement 33: "The gpkg_contents table SHALL contain a row with a data_type column value of "tiles" for each tile pyramid user data table or view."

The Tile Pyramid User Data table that is not refrenced in gpkg_contents table is: uk_elevation_tiles. This table needs to be referenced in the gpkg_contents table.

(Warning) Requirement 42: "Values of the gpkg_tile_matrix table_name column SHALL reference values in the gpkg_contents table_name column for rows with a data_type of 'tiles'. "

There are Pyramid user data tables in gpkg_tile_matrix table_name field such that the table_name does not reference values in the gpkg_contents table_name column for rows with a data type of 'tiles'. Unreferenced table: uk_elevation_tiles

Participant B (Compusult)

Core Issues:

(Warning) Requirement 11: "The gpkg_spatial_ref_sys table in a GeoPackage SHALL contain a record for organization EPSG or epsg and organization_coordsys_id 4326 for WGS-84, a record with an srs_id of -1, an organization of "NONE", an organization_coordsys_id of -1, and definition "undefined" for undefined Cartesian coordinate reference systems, and a record with an srs_id of 0, an organization of "NONE", an organization_coordsys_id of 0, and definition "undefined" for undefined geographic coordinate reference systems. "

The gpkg_spatial_ref_sys table shall contain a record with an srs_id of -1, an organization of "NONE", an organization_coordsys_id of -1, and definition "undefined" for undefined Cartesian coordinate reference systems

Tiles Issues:

(Warning) Requirement 42: "Values of the gpkg_tile_matrix table_name column SHALL reference values in the gpkg_contents table_name column for rows with a data_type of 'tiles'. "

There are Pyramid user data tables in gpkg_tile_matrix table_name field such that the table_name does not reference values in the gpkg_contents table_name column for rows with a data type of 'tiles'. Unreferenced table: All_Puget_16m_depths

Participant C (Brad Hards)

Core Issues:

(Warning) Requirement 11: "The gpkg_spatial_ref_sys table in a GeoPackage SHALL contain a record for organization EPSG or epsg and organization_coordsys_id 4326 for WGS-84, a record with an srs_id of -1, an organization of "NONE", an organization_coordsys_id of -1, and definition "undefined" for undefined Cartesian coordinate reference systems, and a record with an srs_id of 0, an organization of "NONE", an organization_coordsys_id of 0, and definition "undefined" for undefined geographic coordinate reference systems. "

The gpkg_spatial_ref_sys table shall contain a record with an srs_id of -1, an organization of "NONE", an organization_coordsys_id of -1, and definition "undefined" for undefined Cartesian coordinate reference systems

Tiles Issues:

(Warning) Requirement 33: "The gpkg_contents table SHALL contain a row with a data_type column value of "tiles" for each tile pyramid user data table or view."

The Tile Pyramid User Data table that is not refrenced in gpkg_contents table is: DSM_N6130W14900. This table needs to be referenced in the gpkg_contents table.

(Warning) Requirement 34: "In a GeoPackage that contains a tile pyramid user data table that contains tile data, by default, zoom level pixel sizes for that table SHALL vary by a factor of 2 between zoom levels in tile matrix metadata table."

Note: This next message is an additional concern that is related to this requirement but not the requirement itself.

The pixel_x_size and pixel_y_size should satisfy these two equations:

pixel_x_size = (bounding box width / matrix_width) / tile_width AND

pixel_y_size = (bounding box height / matrix_height)/ tile_height.

Based on these two equations, the following pixel values are invalid for the table 'DSM_N6130W14900'.:

Invalid pixel_x_size: 41.934373, Invalid pixel_y_size: 41.949579 at zoom_level 1

Invalid pixel_x_size: 20.967187, Invalid pixel_y_size: 20.974790 at zoom_level 2

Invalid pixel_x_size: 10.483593, Invalid pixel_y_size: 10.487395 at zoom_level 3

(Warning) Requirement 42: "Values of the gpkg_tile_matrix table_name column SHALL reference values in the gpkg_contents table_name column for rows with a data_type of 'tiles'. "

There are Pyramid user data tables in gpkg_tile_matrix table_name field such that the table_name does not reference values in the gpkg_contents table_name column for rows with a data type of 'tiles'. Unreferenced table: DSM_N6130W14900

Schema Issues:

(Error) Requirement 60: "A GeoPackage MAY contain a table or updateable view named gpkg_data_column_constraints. If present it SHALL be defined per clause 2.3.3.1.1 Table Definition, Data Column Constraints Table or View Definition and gpkg_data_columns Table Definition SQL. "

Required column: gpkg_data_column_constraints.maxIsInclusive is missing

Annex E: Revision History

Date	Release	Editor	Primary clauses modified	Description