Testbed-12 GeoPackage US Topo Engineering Report
Testbed-12 GeoPackage US Topo ER (16-037)

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Abstract

This OGC Engineering Report documents the outcome of the US Topo experiment. The focus of the US Topo experiment was to generate GeoPackages by combining USGS Topo Map Vector Data Products [1: http://viewer.nationalmap.gov/basic/?basemap=b1&category=vectorcmb&q=&zoom=4&bbox=-129.46289063,10.22843727,-64.42382813,58.07787627&preview=&avail=Topo%20Map%20Vector%20Data&refpoly=]; and the Topo TNM Style Template [2: https://viewer.nationalmap.gov/tools/topotemplate/]. The output GeoPackages will contain both features and instructions for styling these features as well as orthoimagery, shaded relief raster tilesets, national wetlands raster tilesets and elevation data derived from USGS provide 1/9 arc second elevation imagery. The process used to generate the GeoPackage is explained. Problems and obstacles encountered decoding the source product and styles and converting these artifacts to a GeoPackage are explained with recommendations for improvements. Additionally, the experience applying the generated GeoPackage in two use cases proposed for this testbed will be evaluated. The introduction of symbolization for vector features will be articulated as a proposed extension for GeoPackage. Any issues related to encoding the TNM style template using the extension are documented.

Business Value

GeoPackage is an open standard with an established extension mechanism. Using an extension to express a method of styling features will test the extension mechanism and advance the work of the GeoPackage SWG regarding the inclusion of at least one form of styling information in a GeoPackage.

Technology Value

This ER will provide a useful perspective for the GeoPackage SWG membership as they develop methodologies for encoding styling information and feature collections. This ER may also be relevant to efforts of working groups that advance the definition of symbology and approaches to styling that were also encountered in Testbed-12.

How does this ER relate to the work of the Working Group

This ER is relevant to the GeoPackage SWG because it addresses the need for symbolizing features in a GeoPackage. Methods for storing styles and evaluating styles are presented in this ER that will inform the pursuit of style encoding standards for GeoPackage.
Keywords
ogcdocs, testbed-12, topographic, GeoPackage, styles, styling, vectors, symbology, portrayal

Proposed OGC Working Group for Review and Approval
GeoPackage SWG
Chapter 1. Introduction

1.1. Scope

This OGC Engineering Report describes the processes and constructs used and challenges encountered while encoding USGS topographic feature data, shaded relief and orthoimagery tiled data in GeoPackage format. This Engineering Report will also detail the encoding schema for the data and styles used. Additionally, this Engineering Report will describe prototype GeoPackage extensions for storing styles and hierarchical feature classes. This OGC® document is applicable to the work of the GeoPackage SWG as a means of advancing the development of a method of encoding styles for vector features to meet Use Case 5 from OGC 15-122r1. Additionally, this document is applicable to readers interested in encoding datasets and styles like the ones addressed in the document.

1.2. Document contributor contact points

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

Table 1. Contacts

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert Cass</td>
<td>Compusult Ltd.</td>
</tr>
</tbody>
</table>

1.3. Future Work

It is expected that this document may result in changes in other documents. Additionally, this document provides recommendations for improved approaches to encoding the required data sources in a GeoPackage that bring the produced geopackage closer in alignment to the pdf maps that the USGS currently produces.

1.4. Foreword

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Chapter 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.

- SpatialLite, 2016, https://www.gaia-gis.it/fossil/libspatialite/home
Chapter 3. Terms and definitions

For the purposes of this report, the following terms and definitions apply.

3.1. GeoPackager

Computer software that uses input data sources to create a GeoPackage containing an encoding of those input sources.

3.2. Raster Tile

Rectangular piece of a larger tile mosaic or matrix intended to be viewed between certain map scales that is encoded in a raster format.

3.3. Symbology

Electronic encoding of all the information required to correctly visually portray a geographic feature.

3.4. Style

Electronic encoding of all the symbologies used to visually portray geographic features that also maps these symbologies to features.

3.5. Filter

Boolean clause used to evaluate the data attributes of a feature to determine what symbology will be used to portray this feature.

3.6. OGC Web Processing Service (WPS)

The term OGC Web Processing Service (WPS) describes a service instance of an OGC WPS server. A WPS is a container for one or many processes. The capabilities of a WPS contain the list of services which are hosted by the WPS. Each process is further described by the Process Description.
3.7. **Stylesheet**

A set of encoded instructions that determine how to render geographic features on a computer screen. The stylesheet is used to organize features into layers and to define rules that use the attributes of these features to determine how to physically represent these features using drawing instructions such as color, line width, fill patterns etc. A well known example of this sort of stylesheet is OGC Styled Layer Descriptor.
Chapter 4. Conventions

None.

4.1. Abbreviated terms

- API Application Program Interface
- TNM The National Map
- USGS United States Geological Survey
- WMS OGC Web Map Service
- WMTS OGC Web Map Tile Service
- WPS OGC Web Processing Service
- SE Symbology Encoding
- SLD OGC Styled Layer Descriptor
- CR Change Request
- GDAL Geospatial Data Abstraction Library [4: http://www.gdal.org/]
- SVG Scalable Vector Graphics [6: https://www.w3.org/Graphics/SVG/]

4.2. UML notation

Most diagrams that appear in this standard are presented using the Unified Modeling Language (UML) static structure diagram, as described in Subclause 5.2 of [OGC 06-121r9].
Chapter 5. Overview

5.1. Requirements

The requirements for this testbed-12 activity were:

- Document all problems and obstacles with using the USGS Topo Combined Vector Product to create the GeoPackage.
- Test a workflow and document all problems and obstacles with encoding the GeoPackage with standard USGS US Topo Map symbology as defined in the Topo TNM Style Template.
- Document the process used to convert the USGS Topo Combined Vector Product data to GeoPackage format (so that USGS can reproduce the GeoPackage format) must be recorded in the ER.
- Document the process used to encode GeoPackage data with US Topo Map symbology as defined in the Topo TNM Style Template (so that USGS can reproduce the encoded symbolized GeoPackage format) must be documented.
- Document the process for end users using the Use Cases described. Include any obstacles or limitations to the end users.

5.2. Use Cases

In a briefing presented to the GeoPackage Standards working group on Nov. 10th, 2015 by Randy Gladish of Image Matters LLC [7: https://portal.opengeospatial.org/files/?artifact_id=65723], use cases for styling and symbolization were articulated. Two of these use cases; UC4 and UC5 are addressed in the USGS Topo experiment.

- Geometry styling (UC4) - Geometry styles will be applied based on the application of styling directives such as those found in the OGC Style Layer Descriptor (SLD) standard. The output of the interpretation will be a set of symbols/drawing instructions cross-linked to the features they are meant to symbolize. The interpretation rules from the styling will not be carried over.
- Feature Type Styling (UC5) - similar to Geometry Styling, this approach relies on the interpretation of a set of styling directives that process feature attributes to determine the symbolization for a feature. The relevant rules for the style will either be stored in the GeoPackage to be interpreted at render time, or be pre-rendered into geometry styling. The benefit of maintaining these rules in the GeoPackage is that the symbolization of a feature can be re-interpreted if its attributes change. The USGS Topo experiment is designed to generate discussion regarding the implementation of UC5. The implementation created for the testbed will also expose an alternate method of styling within the OGC and it may be useful to provide the findings to spur more work developing and extending current styling methodologies or developing new ones.

5.3. Approaches

The processing of any GDBs will be done by a conversion engine. One publicly exposed interface is
a web accessible GUI that users can use to define GDB and OGC Web Map Tiling Service (WMTS) datasources. When a user prompts for the creation of a GeoPackage, the conversion engine will combine these datasources in combination with parameters such as Area of Interest (AOI), scale zoom levels and stylesheet to generate the required GeoPackage.

An additional interface will be a WPS providing clients the ability to programmatically follow the same flow.

### 5.3.1. Feature input source translation

Translation is performed using GDAL ogr2ogr which is a tool that translates various vector feature formats into other vector feature formats. The end result is a Spatialite database that can be worked with directly to query and encode into a GeoPackage. Feature classes in the FileGDB are directly translated to feature tables in the GeoPackage. Features are stored in a geographic projection.

### 5.3.2. Raster input source translation

Raster data is harvested directly using a WMTS/WMS client to populate a raster tile pyramid with tiles from online USGS tile and WMS sources. These include a shaded relief server and an imagery server. Tiles are provided in Web Mercator projection (EPSG:3857) [8: https://en.wikipedia.org/wiki/Web_Mercator]. This may prove to be less effective than providing the data in the correct UTM projection that the cell data should be viewed in.

Additional elevation data will be encoded in the GeoPackage produced using 1/9 arc second elevation data products directly available for download.

### 5.3.3. Styling approach

The approach to styling uses a stylesheet that includes:

- Filter rules for selecting features for symbology application.
- Appropriate matching of styles and scale denominators
- The definition of layers, and layer drawing order

### 5.3.4. Style and symbology encoding

- Style encoding according to UC4 is performed by mapping a set of symbologies directly to a feature type. Multiple symbologies can be applied to a single feature depending on scale and the creation of compound styles.
- The symbology encoding instructions such as line width or color are encoded in JSON in a single column in the table.

### 5.3.5. Raster tile encoding

- For the purposes of the experiment, raster tiles are encoded in a standard GeoPackage tile pyramid based on the Web Mercator tile matrix set.
5.3.6. Integration Use Case experiences

- A State Geologist intends to produce a 24,000-scale map using base map data and symbology in a US Topo Map design and layout. The Geologist will use ArcGIS to create the map and will add her own geologic data layers to the base data. The base data will be downloaded in the OGC GeoPackage and the US Topo Map specified symbology will be encoded with the GeoPackage.

- A County Emergency Manager would like to obtain symbolized base map data in a US Topo Map design to support an evacuation exercise. The Emergency Manager does not have any sophisticated GIS software. He has an iPad that he takes into the field with him and would like to be able to use a map-like display and query the attributes of the data. In addition, he would like to be able to display a hillshade and local imagery along with the map display.

5.3.7. Integration obstacles

- UTM projection v. Spherical Mercator. The data in the USGS FileGDBs is intended to be viewed in the correct UTM projection for the cell area. However, source data for hill Shading and orthoimagery is provided by WMTS services whose tiles are in Web Mercator.

- New methods for styling, storing generalized geometries and display hierarchies for views of a layer are all prototypical and are not defined in the current GeoPackage standard. To conform to the TNM template, these extensions to the GeoPackage standard are required, but will only be supported by client software capable of rendering this display.

- The requirement to create and maintain a proprietary stylesheet to support the proper creation of the GeoPackage can be a stumbling block as it requires extra training. The automatic generation of such a file is difficult as the proper tools are not available to generate this file. The ESRI MXD file is not readable. Therefore the stylesheet must be created manually.

5.3.8. Encoding Obstacles

- Determining symbology for display at different scales required a best guess. This is due to the fact that different scale ranges requiring different symbologies for the same feature is not part of the TNM template.

- Font sets are collections of encoded glyphs that are used by computer programs to display letters or icons. Styling approaches using Esri tools often use Unicode symbols from Esri supplied fontsets to create icons on the map. These symbols needed to be converted to images because the style system used in the experiment did not support this approach.

- SVG symbols should be used; instead, png symbols were created using screen shots of current symbology in ArcGIS

- There was no existing way to represent layer "hierarchies" as expressed in the TNM template.

- Some sophisticated filter expressions that exist in Esri tools are not supported directly e.g. "T" & Mid([PLSSID]. 5, 3)

- Font translation is tricky depending on the supported platforms.

- Contour lines have a polygon "z" shape. There is no way of preserving this in the stored geometries based on the GeoPackage design.

- Esri layer groupings in the MXD file allow for multiple "views" of the same feature class to
appear as "layers" in a client. In ArcMap, symbology can be assigned at this level. This was not supported in GeoPackage. Solutions to get around this are the creation of sub feature classes at the GeoPackage level; essentially a materialized view of the data or the merging of multiple styles under a single layer. Ultimately, in order to maintain the 1:1 mapping of feature classes to GeoPackage features, separate feature layers were created for each "view".

5.3.9. Process Obstacles

There were no significant process obstacles.

5.3.10. Interoperability Experiment Outcomes

While generated GeoPackage and the WPS service instances used for creating them were available early in the experiment, no client or service providers volunteered to participate in interoperability work despite invitations during telecons. Generated GeoPackages were visualized successfully in Compusult clients and new approaches for styling that were developed during the testbed were adopted by Compusult. Our best guess is that the nature of the symbology representation presented a challenge to GeoPackage clients that could not be met during the testbed. In the future, we recommend that the thread architects advocate for interoperability partnerships early in the testbed, so that there is at least one partnership per component.

5.4. Proposed style encoding extension

There are 2 aspects to the proposed style extension that are documented. One is the style encoding, the other is the relation of styles to the database. A style encoding consists of the symbology to be used at a particular scale, and in the case of dynamic styling, the filter expression used to evaluate a feature's symbology based on its attributes. The encoding will be documented in Symbology Encoding.

5.5. Proposed hierarchical layer/raster extension

The Testbed-12 thread participants decided that the layer hierarchy not be expressed in the production of GeoPackages for this experiment.
Chapter 6. Status Quo & New Requirements Statement

6.1. Status Quo

• Currently, there is no method for encoding the styles used for feature portrayal in a GeoPackage.
• Currently, the USGS has topographic data and its portrayal specification is encoded in a particular format, arcmap/geodatabase.
• Currently, the USGS provides topo data as well as contextual imagery and shaded relief in a combined PDF product.

6.2. Requirements Statement

• USGS requires that their topographic data be encoded in a GeoPackage. Additionally, the style for that data must be encoded in the GeoPackage according to the cartographic design used for US Topo maps
• USGS requires that supporting orthoimagery and shaded relief be encoded as raster tiles in the GeoPackage
• To support the USGS requirements, a GeoPackage extension must be created to support styling the stored vector features.
• Some OGC members have requested that elevation data be packaged in the GeoPackage as well.
Chapter 7. Solutions

7.1. Targeted Solutions

In order to achieve the immediate goals of the for Testbed 12, the following solutions were adopted:

1. Encoding of topographic data and supported data in GeoPackage using the GeoPackage Converter WPS

2. Encoding of styles from the USGS topographic style template to be used to render topographic data on a client using a style specification system that employs attribute based symbology assignment.

3. Encoding of shaded relief and orthoimagery provided by WMS/WMTS using the Compusult GeoPackage Converter WPS.

4. Use of a mobile client to demonstrate offline rendering of vector features and supporting raster data according to use cases

5. Generation of a new GeoPackage extension to support vector feature styles for rendering derived from symbology encoding that supports re-styling after feature changes.

6. Elevation data for supporting the 7.5' x 7.5' quad to be encoded in a tile pyramid in the GeoPackage using a GeoPackage Elevation Extension that was prototyped during an interoperability experiment [9: https://github.com/opengeospatial/geopackage-elevation].

7. All data to be placed in Web Mercator to support available tile sets for shaded relief.

7.1.1. Converter WPS

In order to make the conversion of stock USGS data to a GeoPackage encoded product, a WPS was designed and delivered to perform two basic tasks:

1. Register data sources which provide the base data that will be encoded in the GeoPackage. The following data sources were used:
   a. A Geodatabase provided by USGS as an example dataset for the Testbed 12 area of interest is: https://prd-tmn.s3.amazonaws.com/StagedProducts/Vector/GDB/VECTOR_27656_Mare_Island_7_5_Min.zip
   b. Shaded Relief WMTS tiles are located at: http://basemap.nationalmap.gov/arcgis/rest/services/USGSShadedReliefOnly/MapServer/WMTS/1.0.0/WMTSCapabilities.xml
   c. Wetlands tiles derived from: http://107.20.228.18/arcgis/services/Wetlands/MapServer/WMSServer?request=GetCapabilities&service=WMS
   e. Intersecting elevation products provided by the USGS such as: https://prd-
2. Combine registered data sources over an area defined by the bounds of the named GDB.

The WPS operations are described in Converter WPS Description

A simple client was created to use the WPS and demonstrate the call/response flow. It is located at http://ogc-tb12fo.compusult.net/wes/WPSClient.jsp.

The screenshot below shows the client with some requests and responses inline as the client executes the creation of a GeoPackage.
7.1.2. Resulting GeoPackage

The result of the conversion process yields a GeoPackage with the following table of contents:

Table 2. Table GeoPackage Contents
<table>
<thead>
<tr>
<th>table_name</th>
<th>data_type</th>
<th>identifier</th>
<th>description</th>
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</thead>
<tbody>
<tr>
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<td>2d-gridded-coverage</td>
<td>ned19_n38x25_w122x25_ca_sanfrancisco_topobathy_2010.tiff</td>
<td></td>
</tr>
<tr>
<td>GPKG8caeccd6_5595_48a4_b09e_6666a799817f</td>
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<td></td>
<td>USGSShadedReliefOnly</td>
</tr>
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<td>Perennial NHDArea</td>
</tr>
<tr>
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<td>features</td>
<td>Intermittent NHDWaterbody</td>
<td>Intermittent NHDWaterbody</td>
</tr>
<tr>
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<td>features</td>
<td>Intermittent NHDArea</td>
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</tr>
<tr>
<td>Wetlands</td>
<td>features</td>
<td>NWI Wetlands w/ US Topo Symbology</td>
<td>NWI Wetlands w/ US Topo Symbology</td>
</tr>
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<td>features</td>
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<td>features</td>
<td>NHD Points</td>
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<td>features</td>
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<td>features</td>
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<td>NHDLine</td>
</tr>
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<td>GU_PLSSTownship</td>
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<td>Township/Range</td>
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<td>features</td>
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19
<table>
<thead>
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<td>features</td>
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<tr>
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<td>features</td>
<td>State or Territory</td>
<td>State or Territory</td>
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<td>County or Equivalent</td>
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<td>Structures</td>
<td>Structures</td>
</tr>
<tr>
<td>Trans_AirportPoint</td>
<td>features</td>
<td>AirportPoint Labels Only</td>
<td>AirportPoint Labels Only</td>
</tr>
<tr>
<td>reQziqrDcOst_hMDi_Dxpp_1XIPFPgUMlnr</td>
<td>features</td>
<td>TNM Derived Names</td>
<td>TNM Derived Names</td>
</tr>
<tr>
<td>CellGrid_7_5Minute</td>
<td>features</td>
<td>7.5_min Cells</td>
<td>7.5_min Cells</td>
</tr>
</tbody>
</table>

### 7.1.3. Style Encoding

Style encoding was accomplished through the use of a stylesheet that defined the appropriate symbology for feature layers based on filter criteria and scale. If there is no filter criteria pertaining to a style, the style was generalized for the whole feature type. In the process of styling the features, ancillary tables for the encoded feature types were created to relate individual features to:

1. A determined symbology based on scale
2. If required, a rule that determined the symbology based on scale and a rule attribute

In the process of constructing the symbology for a feature type, we determined that there are
limitations in that the layer hierarchy defined in the Topographic Map Template could not be followed as there was no way of directly encoding the groups implied in the template. There were two ways the feature data could be encoded as closely as possible to the Feature Classes that appear in the GeoDataBase.

Styles covering all required symbologies and feature types defined by definition queries were merged into a set of styles applied to the single feature class. A good example of this is the group of sub layers derived from the GU_Reserve feature class. On their own in the template MXD, there were the following "sub features" each with an implied style based on a criteria.

In this case, the method employed did not segregate the data into separate feature tables in the GeoPackage. Instead, all features remained in the same base table and were simply styled according to the requirements dictated in the original MXD based template.

The other approach was to generate individual feature tables derived from the query definitions in the TNM template. This was the approach chosen as the user would have similar control over each layer as they would when viewing the data in ArcMap.

7.2. Alternatives considered

Regarding encoding of style information in the GeoPackage itself, the OGC SLD/SE standard was considered. However, this did not meet the requirements this Testbed activity. We were not aware of any other efforts and decided therefore to use the JSON based in-house approach developed by Compusult. This approach is described in UML For Symbology Encodings.

7.3. Recommendations

Having reviewed the GeoPackage output and comparing it to the available PDF maps that are provided by the USGS, and based on the experiences of this testbed, the following recommendations for encoding USGS Topo Data and supporting raster data as a GeoPackage are:

1. Encode all required data in proper UTM projection for the quad in question. For the testbed, the data was encoded in EPSG:3857, which is not ideal for the purpose. There are two main reasons this approach was adopted:
   a. There is no formal tile matrix set proposed for individual UTM zones.
   b. Supporting data sources were only available in EPSG:3857.

2. Ensure that supporting data sources are available in the desired projections as much as possible to ensure data quality. If the USGS provides the sources, they have control of the provenance and quality of the data.

3. Rigorous Quality Assurance needs to be done to ensure that the imagery and elevation products are accurately re-projected to the targeted projection

4. Data for non-critical datasets should be provided by WMS in order to provide UTM projected information. Primary examples would be wetlands and shaded relief data.

5. USGS provides metadata documents for the elevation and GDB products. A format for these metadata documents should be provided so that the metadata can be put in the correct place in
the GeoPackage. Metadata for basemap data produced by web services should be provided for this purpose as well.

6. WMTSes for source data will require larger scales to provide functionality parallel to pdf products. If this is not possible, WMS services should be made available for harvesting the data at these scales.

7. It would be beneficial for the USGS to provide a WCS interface that can be used to extract elevation data clipped to the bounds and correct coordinate system for the desired 7.5'x7.5' area. Currently a producer needs to clip and convert the elevation data provided in the zip file from the USGS. Providing this service will allow the USGS to control the quality of the elevation data provided in the required coordinate system.

8. In order to ease the development of styles based on all possible feature types and permutations, it would be a good idea to have a set of test data available that conformed to all possible style cases to verify that all the style encodings rendered correctly. Without this reference dataset, to prove all style rules, a producer would need to find sample data from across all available datasets.

9. It was noticed that the layer bounds for the Shaded Relief layer in the WMTS did not correspond to the bounds of its tile matrix. This should be fixed.

**7.4. Styling Examples**

The following screenshots show examples of styled topographic feature data displayed in the Compusult GOMobile Client.
Figure 2. Styled data for Benicia

This image shows the following USGS feature types superimposed on imagery harvested from the imagery server mentioned above:

- Schools
- Fire Stations
- Place Names
- Contours with labels
- Post Offices
- Rail Line
- Forested Areas

This image also shows raster imagery from:

- Shaded Relief
- Imagery
• Wetlands
• and 1/9th arc second Elevation Data

This data was derived from the USGS GDB product available at https://prd-tnm.s3.amazonaws.com/StagedProducts/Vector/GDB/VECTOR_3330_Benicia_7_5_Min.zip and generated using the WPS Converter. The GeoPackage is located at https://portal.opengeospatial.org/files/?artifact_id=71497.

![Figure 3. Styled data for Mare Island](image)

This image shows the following USGS feature types superimposed on imagery harvested from the imagery server mentioned above as well as wetlands raster data and shaded relief.
Appendix A: Data Mappings from GDB to SQLite

This appendix explains and illustrates the mapping of some GDB tables and fields to SQLite tables and fields.

It also details the process used to name and organize layers and contents in the GeoPackage for the various sources of data.

A.1. Naming and Organizing Layers Created from the GeoDatabase Source

The following USGS topographical layers are defined in the contents listed in TopoTNMStyleTemplate_v10_0. Each layer was reproduced in parallel in the resulting GeoPackage as a result of the conversion.

Table 3. Mapping from TNM layers to GeoPackage Tables

<table>
<thead>
<tr>
<th>Name from TNM Template</th>
<th>Generated GeoPackage Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5_min Cells</td>
<td>CellGrid_7_5Minute</td>
</tr>
<tr>
<td>Airport Runway</td>
<td>Trans_AirportRunway</td>
</tr>
<tr>
<td>AirportPoint Labels Only</td>
<td>Trans_AirportPoint</td>
</tr>
<tr>
<td>Bureau of Land Management</td>
<td>BureauofLandManagement</td>
</tr>
<tr>
<td>Census Roads</td>
<td>Trans_RoadSegment</td>
</tr>
<tr>
<td>Contours</td>
<td>Elev_Contour</td>
</tr>
<tr>
<td>County or Equivalent</td>
<td>GU_CountyOrEquivalent</td>
</tr>
<tr>
<td>Department of Defense</td>
<td>DepartmentofDefense</td>
</tr>
<tr>
<td>Fish and Wildlife Service</td>
<td>FishandWildlifeService</td>
</tr>
<tr>
<td>Forest Service</td>
<td>ForestService</td>
</tr>
<tr>
<td>Gaging Station</td>
<td>GagingStation</td>
</tr>
<tr>
<td>GU.GU_PLSSSpecialSurvey</td>
<td>GU_PLSSSpecialSurvey</td>
</tr>
<tr>
<td>Intermittent NHDArea</td>
<td>IntermittentNHDArea</td>
</tr>
<tr>
<td>Intermittent NHDWaterbody</td>
<td>IntermittentNHDWaterbody</td>
</tr>
<tr>
<td>National Cemetery</td>
<td>GU_Reserve</td>
</tr>
<tr>
<td>National Park Service</td>
<td>NationalParkService</td>
</tr>
<tr>
<td>Native American Lands</td>
<td>GU_NativeAmericanArea</td>
</tr>
<tr>
<td>NHD Points</td>
<td>NHDPoint</td>
</tr>
<tr>
<td>Name from TNM Template</td>
<td>Generated GeoPackage Table</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>NHDFlowline</td>
<td>NHDFlowline</td>
</tr>
<tr>
<td>NHDLine</td>
<td>NHDLine</td>
</tr>
<tr>
<td>NWI Wetlands w/ US Topo Symbology</td>
<td>Wetlands</td>
</tr>
<tr>
<td>Perennial NHDArea</td>
<td>NHDArea</td>
</tr>
<tr>
<td>Perennial NHDWaterbody</td>
<td>NHDWaterbody</td>
</tr>
<tr>
<td>Railroad</td>
<td>Trans_RailFeature</td>
</tr>
<tr>
<td>Section</td>
<td>GU_PLSSFirstDivision</td>
</tr>
<tr>
<td>State or Territory</td>
<td>GU_StateOrTerritory</td>
</tr>
<tr>
<td>Structures</td>
<td>Struct_Point</td>
</tr>
<tr>
<td>Structures from GNIS</td>
<td>TNMDerivedNames</td>
</tr>
<tr>
<td>TNM Derived Names</td>
<td>reQziqrD_cOst_hMDi_Dxpp_1XIPFPgUMlnr</td>
</tr>
<tr>
<td>Township/Range</td>
<td>GU_PLSSTownship</td>
</tr>
<tr>
<td>Trail</td>
<td>Trans_TrailSegment</td>
</tr>
<tr>
<td>USFS Roads</td>
<td>trans_roadsegment_ntdnofs</td>
</tr>
<tr>
<td>Woodland</td>
<td>LANDCOVER_WOODLAND</td>
</tr>
</tbody>
</table>

The layer organization of the TNM Topo data in the TNM Template MXD file has a hierarchy. Within this hierarchy, some layers are derived directly from feature classes, others are derived using layer definition queries against a feature class. For example, Boundaries is a group that contains the following sub-layers:

### Table 4. Boundaries Group Organization

<table>
<thead>
<tr>
<th>Presentation Layer</th>
<th>Source Feature Class</th>
<th>Definition Query</th>
</tr>
</thead>
<tbody>
<tr>
<td>State or Territory</td>
<td>GU_StateOrTerritory</td>
<td></td>
</tr>
<tr>
<td>County or Equivalent</td>
<td>GU_CountyOrEquivalent</td>
<td></td>
</tr>
<tr>
<td>National Cemetery</td>
<td>GU_Reserve</td>
<td>FType = 670</td>
</tr>
<tr>
<td>National Park Service</td>
<td>GU_Reserve</td>
<td>FType = 674</td>
</tr>
<tr>
<td>Forest Service</td>
<td>GU_Reserve</td>
<td>FTYPE = 671 OR FTYPE = 672</td>
</tr>
<tr>
<td>Fish and Wildlife Service</td>
<td>GU_Reserve</td>
<td>FTYPE = 676</td>
</tr>
<tr>
<td>Native American Lands</td>
<td>GU_NativeAmericanArea</td>
<td>NAME = 'Annette Island Reserve'</td>
</tr>
<tr>
<td>Bureau of Land Management</td>
<td>GU_Reserve</td>
<td>FTYPE = 675</td>
</tr>
</tbody>
</table>

As seen in Boundaries Group Organization, there are 8 presentation layers created using 4 different
feature classes.

When mapped to the GeoPackage, it was decided to create feature tables for each presentation layer as it was defined in the table of contents. However, layer groups such as Boundaries were not represented in the GeoPackage.

For example "Fish and Wildlife Service" was mapped to a feature table in the GeoPackage called "FishandWildlifeService". In the GeoPackage table of contents, the entry appears in Fish and Wildlife gpkg_contents:

Table 5. Fish and Wildlife gpkg_contents

<table>
<thead>
<tr>
<th>Column</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>table_name</td>
<td>FishandWildlifeService</td>
</tr>
<tr>
<td>data_type</td>
<td>features</td>
</tr>
<tr>
<td>identifier</td>
<td>Fish and Wildlife Service</td>
</tr>
<tr>
<td>description</td>
<td>Fish and Wildlife Service</td>
</tr>
<tr>
<td>last_change</td>
<td>2016-10-27T18:27:45.583Z</td>
</tr>
<tr>
<td>min_x</td>
<td>-20037508.342789</td>
</tr>
<tr>
<td>min_y</td>
<td>-20037508.3427892</td>
</tr>
<tr>
<td>max_x</td>
<td>20037508.3427892</td>
</tr>
<tr>
<td>max_y</td>
<td>20037508.3427892</td>
</tr>
<tr>
<td>srs_id</td>
<td>3857</td>
</tr>
</tbody>
</table>

The generated feature table is below. In addition, the data types for each column are provided.

Table 6. FishAndWildlifeService table

<table>
<thead>
<tr>
<th>column name</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source_Originator</td>
<td>TEXT</td>
</tr>
<tr>
<td>Distribution_Policy</td>
<td>TEXT</td>
</tr>
<tr>
<td>featureid</td>
<td>TEXT</td>
</tr>
<tr>
<td>Source_FeatureID</td>
<td>TEXT</td>
</tr>
<tr>
<td>Source_DatasetID</td>
<td>TEXT</td>
</tr>
<tr>
<td>GNIS_ID</td>
<td>TEXT</td>
</tr>
<tr>
<td>Shape_Length</td>
<td>REAL</td>
</tr>
<tr>
<td>OwnerOrManagingAgency</td>
<td>INTEGER</td>
</tr>
<tr>
<td>FCode</td>
<td>INTEGER</td>
</tr>
<tr>
<td>Shape_Area</td>
<td>REAL</td>
</tr>
<tr>
<td>Field</td>
<td>Type</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------</td>
</tr>
<tr>
<td>FType</td>
<td>INTEGER</td>
</tr>
<tr>
<td>Source_DataDesc</td>
<td>TEXT</td>
</tr>
<tr>
<td>AreaSqKM</td>
<td>REAL</td>
</tr>
<tr>
<td>id</td>
<td>INTEGER</td>
</tr>
<tr>
<td>Name</td>
<td>TEXT</td>
</tr>
<tr>
<td>CSLT_SOURCE_TABLE</td>
<td>TEXT</td>
</tr>
<tr>
<td>Data_Security</td>
<td>INTEGER</td>
</tr>
<tr>
<td>LoadDate</td>
<td>TEXT</td>
</tr>
<tr>
<td>AdminType</td>
<td>INTEGER</td>
</tr>
<tr>
<td>Permanent_Identifier</td>
<td>TEXT</td>
</tr>
<tr>
<td>OBJECTID</td>
<td>INTEGER</td>
</tr>
<tr>
<td>the_geom</td>
<td>MULTIPOLYGON</td>
</tr>
</tbody>
</table>

Some new columns have been added beyond the columns in the original feature class:

- **id** - this is a primary key used for feature identification in the GeoPackage context
- **CSLT_SOURCE_TABLE** - this is the originating table/feature class from the GDB
- **the_geom** - this is the GeoPackage compatible representation of the original geometry from the GeoDatabase.

The entry in the processing stylesheet to generate this table is below:

**Fish and Wildlife Definition**

```xml
<Fish and Wildlife Service sr="+init=EPSG:4326" identifiable="1">
    <Sources>
        <Source>
            <Table>GU_Reserve</Table>
            <SQL>SELECT *, ST_AsText(ST_GeomFromWKB(WKT_GEOMETRY)) geom FROM GU_Reserve
WHERE FTYPE = 676</SQL>
        </Source>
    </Sources>
</Fish and Wildlife Service>
```

**Fish and Wildlife Definition** illustrates that the feature type was populated using a query constructed from the basic query definition included in the TNM template.

A similar approach was followed for Hydrography Areas, two layers are derived from the NHDWaterbody feature class and two layers are derived from NHDArea feature class.
Appendix B: Symbology Encoding

This appendix covers the encoding of symbologies specific to the USGS Topographic case.

For any feature stored in a GeoPackage feature table, there may be 0 to many symbology encodings. It is up to a client application to determine how to render a feature with no symbology.

In the system used to render the USGS topographical data case, it is intended for clients to use the symbology linked to the current scale of the map. For any scale, a feature may have a an assigned symbology. The linking of features to styles is discussed in UML Models For Symbology Encoding.

For the purposes of the testbed, symbology was encoded using a JSON encoding. This annex discusses the JSON encoding and provides the encodings used for the USGS Topo data.

The JSON encoding is a straightforward encoding of symbology attributes in a KVP format such as strokeColor and strokeWeight, and their interpretation is determined by the geometry type of the feature being rendered. For example, a stroke attribute of a feature is interpreted as a border attribute for a polygon and a line attribute for a line feature.

The method of storing the symbology was chosen to be a single column in the styles table to support multiple encoding formats such as SE xml.

Supporting multiple encoding types has interoperability issues, and ultimately, as the GeoPackage community pursues symbology encoding and storage, it is hoped that the encodings supported are narrowed to those required and agreed upon as a group much the same as the image formats agreed upon in the tiling specification were narrowed to jpeg and png. It must be acknowledged that the requirements of various communities will force the need for more than one symbology encoding.

During production of a GeoPackage, filter rules based on feature type and attributes would be used to determine an appropriate style. In addition to filter rules, styles are grouped by scale range to determine which style would be applied by a rendering client at any particular scale. The symbology defined for the style is encoded in JSON and stored in the associated feature "_styles" table. The scale ranges are stored in the associated style_rules table. These styles are recorded as "fixed" styles used for rendering the feature.

In addition, to support changing feature attributes and corresponding styles, a separate set of tables to support these "dynamic" rules are constructed. These are linked to the main feature table using a mapping defined in the gpkgext_extended_contents using a mapping from the feature table name a style package name. The names of the tables associated with this style package start with the style package name followed by the suffixes "._dynamic_styles", "._dynamic_styles_expressions", "._dynamic_style_images". When a feature's attributes change, the client can look up the dynamic style expressions for that feature type and use each expression to determine if there is a match between the expression and the feature attributes. If there is a match, the style encoded in _dynamic_styles would be used to change the symbology encoded for the feature in the "fixed" style table so that the feature is rendered using the new symbology the next time the map is drawn.

JSON encoding was chosen for a number of reasons:
• JSON is more straightforward to parse than XML as would be the case with SE. When performance is a premium in mobile applications, this is an important consideration.

• A KVP approach is more flexible than a structured document in that new vendor specific extensions or versionable updates can be added, be backwards compatible and not be hampered by requiring schema adherence. A good example of this approach is the use of style attributes in HTML CSS. There are browser variants, deprecated attributes and experimental attributes in addition to core attributes defined in a specification.

Styling approaches also use images to represent features or fills. In order to maintain this approach and support portability and offline use, images used in styles are stored in a table for lookup. The reference to this image is accomplished in the symbology encoding by simply using the table id of the image in the style attribute:

```
imageencoding
{"imageOpacity":1,"image":9}
```

In the example `imageencoding` the image reference is simply a number. The number refers to the id of the image in the corresponding _style_images table (see Hydrography Areas Style Images as an example).

**B.1. History**

The JSON symbology encoding has its roots in the mapnik symbology stylesheet. Most attributes in the JSON encoding used in the testbed have mapnik equivalents and have the same function as those used in mapnik. There are also direct parallels with OGC Symbology Encoding as well as SVG names are commonly used.

Originally, the storage of the styles was done in a sparse table in which each possible attribute was stored in a column. It was determined that this would not work for two main reasons. It was not easily extensible, and did not support multiple encodings.

**B.2. Examples**

Here is an example of a JSON encoding for a Hydrography Line Feature:

```
{
    "strokeCap":"butt",
    "strokeJoin":"round",
    "strokeColor":"#bee8ff",
    "strokeOpacity":1,
    "strokeWeight":1
}
```

Here is an example of a JSON encoding for a Hydrography area label:
Here is an example of a JSON encoding for a Hydrography area polygon:

```json
{
  "fillColor": "#bee8ff", "fillOpacity": 1
}
```

Here is an example of a JSON encoding for a StructuresFromGNIS Point Feature using a png image as an example:

```json
{
  "imageOpacity": 1, "image": 1
}
```

Looking up the image in the corresponding table, we can see that the value of 1 in the “image” style attribute corresponds to the Cemetery image:

<table>
<thead>
<tr>
<th>id</th>
<th>path</th>
<th>data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>/opt/Compusult/GPKGUpload/GiJLqrWQ_tTIS_Cjgg_ntMM_YC3bZutwCfum/images/Cemetery.png</td>
<td>BLOB</td>
</tr>
<tr>
<td>2</td>
<td>/opt/Compusult/GPKGUpload/GiJLqrWQ_tTIS_Cjgg_ntMM_YC3bZutwCfum/images/PostOffice.png</td>
<td>BLOB</td>
</tr>
</tbody>
</table>

**B.2.1. Contour Styling**
Figure 4. Contour Style data over Ackerson

This image shows dense contours in Yosemite. The contours appear on top of the green woodland area, drainage lines are also visible. One can see the index contours (100m intervals) appear as thicker lines. The ticks used in various depression encodings are represented in the "linePattern" attribute. The values for this attribute will point to ids in the corresponding dynamic styles images table.

B.2.2. Examples of symbology generated for Layers found in VECTOR_3330_Benicia_7_5_Min.gdb

The following examples list the query definitions and symbology applied for each query definition for feature classes found in the Benicia GDB. This is not an exhaustive list of examples for all possible types of features, but it should give a good representative example of the symbology developed for the experiment.

B.2.3. BureauofLandManagement

$TYPE = 675$

{"fillColor":"#cdaa66","fillOpacity":1}

B.2.4. CellGrid_7_5Minute

null

{"strokeCap":"butt","strokeJoin":"round",
"strokeColor":"
"strokeOpacity":1,"strokeWeight":2.5}
B.2.5. Elev_Contour

- **FCode = 10101**
  ```json
  {
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#b38659",
    "strokeOpacity": 1,
    "strokeWeight": 1
  }
  ```

- **FCode = 10102**
  ```json
  {
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#a67442",
    "strokeOpacity": 1,
    "strokeWeight": 2
  }
  ```

- **FCode = 10103**
  ```json
  {
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#cfa48e",
    "strokeOpacity": 1,
    "strokeWeight": 1
  }
  ```

- **FCode = 10104**
  ```json
  {
    "strokeCap": "butt",
    "strokeJoin": "round",
    "linePattern": 1,
    "strokeColor": "#b38659",
    "strokeOpacity": 1,
    "strokeWeight": 1
  }
  ```

- **FCode = 10105**
  ```json
  {
    "strokeCap": "butt",
    "strokeJoin": "round",
    "linePattern": 2,
    "strokeColor": "#a67442",
    "strokeOpacity": 1,
    "strokeWeight": 2
  }
  ```

- **FCode = 10106**
  ```json
  {
    "strokeCap": "butt",
    "strokeJoin": "round",
    "linePattern": 3,
    "strokeColor": "#cfa48e",
    "strokeOpacity": 1,
    "strokeWeight": 1
  }
  ```

B.2.6. FishandWildlifeService

- **FTYPE = 676**
  ```json
  {
    "fillColor": "#9ed7b4",
    "fillOpacity": 1
  }
  ```

B.2.7. GagingStation

- **(Permanent_Identifier is not null and length(trim(Permanent_Identifier) > 0) and Permanent_Identifier <> 'NULL') and Permanent_Identifier <> 'UNK'**
B.2.8. GU_NativeAmericanArea

NAME = 'Annette Island Reserve'

B.2.9. IntermittentNHDArea

FCode = 43100

(FCode = 34300 or (FCode = 34306 or FCode = 34305))

FCode = 53700

FCode = 36400

FCode = 46003

FCode = 48400

(FCode = 40300 or (FCode = 40309 or (FCode = 40308 or FCode = 40307)))
B.2.10. IntermittentNHDWaterbody

\( FCode = 37800 \)

{"fillPattern":1,"fillOpacity":1}

\( FCode = 43605 \)

{"fillPattern":2,"fillOpacity":1}

\((FCode = 39001 \text{ or } (FCode = 39005 \text{ or } (FCode = 39006 \text{ or } FCode = 43614)))\)

{"fillPattern":3,"fillOpacity":1}

\( FCode = 36100 \)

{"fillPattern":4,"fillOpacity":1}

\( FCode = 43611 \)

{"fillPattern":5,"fillOpacity":1}

B.2.11. LANDCOVER_WOODLAND

null

{"fillColor":"#99e633","fillOpacity":1}

B.2.12. NHDArea

\((FCode = 46000 \text{ or } FCode = 46006)\)

{"fillColor":"#bee8ff","fillOpacity":1}

\((FCode = 33602 \text{ or } (FCode = 33600 \text{ or } FCode = 33601))\)

{"fillColor":"#bee8ff","fillOpacity":1}

\((FCode = 31200 \text{ or } (FCode = 36200 \text{ or } FCode = 44500))\)
B.2.13. NHDFlowline

(FCode = 42808 or (FCode = 42806 or (FCode = 42816 or (FCode = 42805 or (FCode = 42804 or (FCode = 42815 or (FCode = 42814 or (FCode = 42802 or (FCode = 42813 or (FCode = 42801 or (FCode = 42812 or (FCode = 42800 or (FCode = 42810 or FCode = 42809))))))))))))))

(FCode = 46000 or FCode = 46006)

(FCode = 33601 or FCode = 33600)

(FCode = 56600)

(FCode = 42000)

(FCode = 42803 or (FCode = 42807 or FCode = 42811))

(FCode = 46003)
B.2.14. NHDLIne

\[(FCode = 34306 \text{ or } (FCode = 36900 \text{ or } (FCode = 39800 \text{ or } FCode = 48300)))\]

\{
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#343434",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}

\[(FCode = 34300 \text{ or } FCode = 34305)\]

\{
    "dashPattern": [15.0, 5.0],
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#9f551f",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}

\[FCode = 36200\]

\{
    "dashPattern": [15.0, 5.0],
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#bee8ff",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}

\[FCode = 56800\]

\{
    "dashPattern": [15.0, 5.0],
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#9f551f",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}

\[FCode = 41100\]

\{
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#343434",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}

\[(FCode = 43100 \text{ or } FCode = 48700)\]

\{
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#bee8ff",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}

\[FCode = 43400\]

\{
    "dashPattern": [15.0, 5.0],
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#343434",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}

\[FCode = 45000\]

\{
    "dashPattern": [15.0, 5.0],
    "strokeCap": "butt",
    "strokeJoin": "round",
    "strokeColor": "#bee8ff",
    "strokeOpacity": 1,
    "strokeWeight": 1
\}
B.2.15. NHDPoint

(FCode = 44100 or (FCode = 44101 or FCode = 44102))

{"imageOpacity":1,"image":1}

(FCode = 34300 or (FCode = 34305 or FCode = 34306))

{"imageOpacity":1,"image":2}

FCode = 36900

{"imageOpacity":1,"image":3}

FCode = 39800

{"imageOpacity":1,"image":4}

FCode = 43100

{"imageOpacity":1,"image":5}

(FCode = 43600 or (FCode = 43601 or (FCode = 43618 or (FCode = 43619 or (FCode = 43609 or (FCode = 43603 or (FCode = 43606 or (FCode = 43625 or (FCode = 43626 or (FCode = 43607 or (FCode = 43623 or (FCode = 43610 or (FCode = 43611 or (FCode = 43612 or (FCode = 43605 or (FCode = 43604 or (FCode = 43624 or (FCode = 43617 or (FCode = 43614 or (FCode = 43615 or (FCode = 43613 or FCode = 43621)))))))))))))))))))

{"imageOpacity":1,"image":6}

FCode = 43608
FCode = 45800

FCode = 48700

FCode = 48800

B.2.16. NHDWaterbody

FCode = 49300

(FCode = 43619 or (FCode = 43603 or (FCode = 43626 or (FCode = 43607 or (FCode = 43608 or (FCode = 43609 or (FCode = 43610 or (FCode = 43612 or (FCode = 43623 or (FCode = 43624 or FCode = 43613))))))))

B.2.17. Struct_Point

FCode = 83006

(FCode = 73002 or (FCode = 73003 or (FCode = 73004 or (FCode = 73005 or FCode = 73006))))
B.2.18. TNMDerivedNames

GAZ_FEATURECLASS = 'Cemetery'

GAZ_FEATURECLASS = 'Post Office'

B.2.19. Trans_RailFeature

FCODE = 20200

B.2.20. Trans_RoadSegment

TNMFRC = 1
B.2.21. trans_roadsegment_ntdnofs

TNMFRC = 1

TNMFRC = 2

TNMFRC = 3

TNMFRC = 4

TNMFRC = 5

TNMFRC = 6

TNMFRC = 7
TNMFRC = 8

B.2.22. Trans_TrailSegment

FCode = 20600

W.23. Wetlands

WETLAND_TYPE = 'Freshwater Emergent Wetland'

WETLAND_TYPE = 'Freshwater Forested/Shrub Wetland'
Appendix C: UML Models for Symbology Extension

This appendix provides a UML model of the extension tables used to encode styling in GeoPackage for this experiment. The intent of this appendix is to illustrate these tables and their usage via an example for the USGS HydrographyAreas feature class.

Static Style Table Example is a DB profile UML diagram illustrating the tables involved in the symbolization of a specific feature table HydrographyAreas. These tables are required to use the static styling approach where a specific symbology is mapped to a specific feature using a style_links table. Following Static Style Table Example are detailed descriptions of the following extended tables:

HydrographyAreas_style_images
   A table containing binary encoded images referenced in symbologies

HydrographyAreas_style_rules
   A table defining style rule metadata such as applicable scale ranges and rule types

HydrographyAreas_styles
   A table that contains encoded styles defining the style, its encoding method and the priority/order of the style

HydrographyAreas_style_links
   A table mapping style rules to individual features
Figure 5. Static Style Table Example

Table 8. HydrographyAreas_style_rules

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>INTEGER</td>
<td>The primary key of the rule limited to values in the range [0, 922372036854775807]</td>
<td>PK</td>
</tr>
<tr>
<td>Column Name</td>
<td>Data Type</td>
<td>Description</td>
<td>Key</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>ordinal_pos</td>
<td>INTEGER</td>
<td>indicates the order of application for the rule if there are more than one style rules applicable for a feature. Falls into the range [0, 9223372036854775807].</td>
<td></td>
</tr>
<tr>
<td>min_scale_denom</td>
<td>REAL</td>
<td>A real value used for evaluating when the rule should be applied to a feature. When the scale denominator of the visible map is &gt; min_scale_denom, the rule is active.</td>
<td></td>
</tr>
<tr>
<td>max_scale_denom</td>
<td>REAL</td>
<td>A real value used for evaluating when the rule should be applied to a feature. When the scale denominator of the visible map is &lt; max_scale_denom, the rule is active.</td>
<td></td>
</tr>
<tr>
<td>is_else</td>
<td>INTEGER</td>
<td>a positive number that indicates true (1) or false (0). A true value indicates that the rule should short circuit any further evaluation of rules for a feature. A false indicates that further rules can be evaluated and applied.</td>
<td></td>
</tr>
</tbody>
</table>

Table 9. HydrographyAreas_style_images

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>INTEGER</td>
<td>The primary key of the image limited to values in the range [0, 9223372036854775807]</td>
<td>PK</td>
</tr>
<tr>
<td>path</td>
<td>TEXT</td>
<td>The original path of the symbol such as &quot;/usr/share/images/tower.png&quot;</td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>BLOB</td>
<td>binary data</td>
<td></td>
</tr>
</tbody>
</table>
Table 10. HydrographyAreas_styles

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>INTEGER</td>
<td>The primary key of the style limited to values in the range [0, 9223372036854775807]</td>
<td>PK</td>
</tr>
<tr>
<td>ordinal_pos</td>
<td>INTEGER</td>
<td>indicates the order of application for the style if there are more than one style rules applicable for a feature. Falls into the range [0, 9223372036854775807].</td>
<td></td>
</tr>
<tr>
<td>rule_id</td>
<td>INTEGER</td>
<td>A positive number that is a foreign key to the corresponding rules table</td>
<td>FK</td>
</tr>
<tr>
<td>style</td>
<td>TEXT</td>
<td>The encoded style or symbology instructions detailing how the feature should appear</td>
<td></td>
</tr>
<tr>
<td>style_encoding</td>
<td>TEXT</td>
<td>a mime type that indicates how the style is encoded e.g. &quot;application/vnd.ogc.se_xml&quot;</td>
<td></td>
</tr>
<tr>
<td>priority</td>
<td>REAL</td>
<td>A priority used to weight the symbolization of the feature used to remove cluttering</td>
<td></td>
</tr>
</tbody>
</table>

Table 11. HydrographyAreas_style_links

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>feature_id</td>
<td>INTEGER</td>
<td>A foreign key to a feature in the related feature table</td>
<td>FK</td>
</tr>
<tr>
<td>rule_id</td>
<td>INTEGER</td>
<td>A foreign key to a rule related rule table</td>
<td>FK</td>
</tr>
</tbody>
</table>

In addition to supporting direct representational styling an additional extension is used in GeoPackage to support dynamic styling of features. Dynamic styling is applicable when the attributes of a feature that determine its appearance have changed. For example, a user changes a road attribute such as lanes from "2" to "4". Styling rules exist that require road features with a lane value of "4" to be rendered with a median. Unless this rule is dynamically interpreted, the road will...
not be updated visually unless there is a mechanism to find an applicable set of style rules for the changed feature and determine which one applies to the new condition. If such a mechanism exists, the applicable rule will be used to determine the new symbology. In the road case, the expression `lanes=4` would be encountered, the corresponding symbology would be set for the feature and clients would now render the feature with a median.

To support this dynamic mechanism, a further extension to the style extension is encoded to encompass the necessary links between symbology and rule expressions.

**Dynamic Style Table Example** is a DB profile UML diagram illustrating the tables used to support the dynamic symbolization of a specific feature table HydrographyAreas. The core idea is that a set of expressions are evaluated for any feature in the feature table if the match expression is satisfied, any style from the dynamic styles table that is linked to that expression is applied to the feature. Application of these styles could occur at run time, or they can be computed and stored in the data model for static styles. Following **Dynamic Style Table Example** are detailed descriptions of the following extended tables. These extended tables are linked via a mapping in `gpkg_extended_contents` that maps the feature table to the corresponding style tables below:

**HydrographyAreas_dynamic_style_images**
A table containing binary encoded images referenced in symbologies used in dynamic styles.

**HydrographyAreas_dynamic_styles**
A table defining style rule metadata such as applicable scale ranges encoded styles defining the symbology, its encoding method and the painting priority of the style.

**HydrographyAreas_dynamic_style_expressions**
A table that contains match expressions in SQL syntax and order of evaluation for all match expressions.
Figure 6. Dynamic Style Table Example

Table 12. HydrographyAreas_dynamic_style_images

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>INTEGER</td>
<td>The primary key of the image limited to values in the range [0, 922372036854775807]</td>
<td>PK</td>
</tr>
<tr>
<td>Column Name</td>
<td>Data Type</td>
<td>Description</td>
<td>Key</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>path</td>
<td>TEXT</td>
<td>The original path of the symbol such as &quot;/usr/share/images/tower.png&quot;</td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>BLOB</td>
<td>binary data</td>
<td></td>
</tr>
<tr>
<td>mime_type</td>
<td>TEXT</td>
<td>mime type of the stored image such as &quot;image/png&quot;</td>
<td></td>
</tr>
</tbody>
</table>

**Table 13. HydrographyAreas_dynamic_styles**

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>INTEGER</td>
<td>The primary key of the rule limited to values in the range [0, 9223372036854775807]</td>
<td>PK</td>
</tr>
<tr>
<td>expression_id</td>
<td>INTEGER</td>
<td>A foreign key to the dynamic_style_expressions table for the feature table</td>
<td>FK</td>
</tr>
<tr>
<td>min_scale_denom</td>
<td>REAL</td>
<td>A real value used for evaluating when the style should be applied to a feature. When the scale denominator of the visible map is &gt; min_scale_denom, the style is active</td>
<td></td>
</tr>
<tr>
<td>max_scale_denom</td>
<td>REAL</td>
<td>A real value used for evaluating when the style should be applied to a feature. When the scale denominator of the visible map is &lt; max_scale_denom, the style is active</td>
<td></td>
</tr>
<tr>
<td>style</td>
<td>TEXT</td>
<td>the text encoding of the symbology information for example an OGC symbology encoding document</td>
<td></td>
</tr>
<tr>
<td>style_encoding</td>
<td>TEXT</td>
<td>the mime type of the style encoding such as &quot;application/vnd.ogc.se_xml&quot;</td>
<td></td>
</tr>
<tr>
<td>Column Name</td>
<td>Data Type</td>
<td>Description</td>
<td>Key</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------</td>
<td>-------------</td>
<td>-----</td>
</tr>
<tr>
<td>priority</td>
<td>REAL</td>
<td>indicates the order of application for the styles if there are more than one styles applicable for a feature.</td>
<td></td>
</tr>
</tbody>
</table>

Table 14. HydrographyAreas_dynamic_style_expressions

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>id</td>
<td>INTEGER</td>
<td>A foreign key to a feature in the related feature table</td>
<td>PK</td>
</tr>
<tr>
<td>match_expr</td>
<td>TEXT</td>
<td>A SQL expression that can be applied to attributes of the feature, the intention being that it can be used directly in queries against the feature table</td>
<td></td>
</tr>
<tr>
<td>precedence</td>
<td>INTEGER</td>
<td>This value determines the order of evaluation for all match expressions associated with a feature</td>
<td></td>
</tr>
</tbody>
</table>
Appendix D: Converter WPS Description

This appendix describes the operations available to clients of the GeoPackage generator WPS. This WPS takes a different approach than other WPSes that take a context document with offerings as input. JSON documents describe the nature of each datasource. Also JSON documents describe how to create a GeoPackage from multiple data sources. This WPS can also take multiple datasource arguments to generate a single GeoPackage.

The WPS is located at the following URL: http://ogc-tb12fo.compusult.net/wes/GeopackageWPS

D.1. Potential CR

WPS does not support arbitrary numbers of outputs of the same type. This introduces extra processing to the client because we want to call "Make these n data sources", the results are not matched to the requested data sources, so a custom client must be created to process a custom response that would parse the results. The nature of the results is not automatically discoverable from the capabilities, however the nature of the inputs is discoverable.

This issue was filed as an official CR and is visible at: http://ogc.standardstracker.org/show_request.cgi?id=403

D.2. High Level Map of Input/Output
Figure 7. Diagram of inputs

In this diagram, we can see the inputs from external sources for a single GeoPackage consist of:

1. Tiles created from the USGS Imagery WMS
2. Tiles created from the NWI Wetlands WMS
3. Tiles directly from the USGS Shaded Relief WMTS
4. 1/9th arc second IMG Elevation products from the USGS downloaded directly from the Amazon cloud store
5. USGS Topo GDB products downloaded directly from the Amazon cloud store
6. The stylesheet that indicates how to use the feature classes from the GDB to create feature layers and symbolize them

D.3. GetCapabilities

```xml
<wps:GetCapabilities
  xmlns:wps="http://www.opengis.net/wps/2.0"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.opengis.net/wps/2.0 ../wps.xsd"
  service="WPS">
</wps:GetCapabilities>
```
D.4. Datasource operations

D.4.1. CreateDatasource (GDB)

```xml
<wps:Execute
 xmlns:wps="http://www.opengis.net/wps/2.0"
 xmlns:ows="http://www.opengis.net/ows/2.0"
 xmlns:xlink="http://www.w3.org/1999/xlink"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="http://www.opengis.net/wps/2.0 ../wps.xsd"
 service="WPS" version="2.0.0" response="document" mode="async">
 <ows:Identifier>CreateDatasource</ows:Identifier>
 <wps:Input id="DATASOURCE">
   <wps:Input id="DATA">
   </wps:Input>
   <wps:Input id="STYLE">
   </wps:Input>
   <wps:Input id="TYPE">
     <wps:Data>GEODATABASE</wps:Data>
   </wps:Input>
   <wps:Input id="NAME">
     <wps:Data>Jamaica New</wps:Data>
   </wps:Input>
   <wps:Input id="DESCRIPTION">
     <wps:Data>Created</wps:Data>
   </wps:Input>
   <wps:Input id="SRS">
     <wps:Data>EPSG:4326</wps:Data>
   </wps:Input>
 </wps:Input>
 <wps:Output id="DATASOURCE_IDS">
 </wps:Output>
</wps:Execute>
```

D.4.2. CreateDatasource (WMTS)
D.4.3. UpdateDatasource
D.4.4. DeleteDatasource
D.5. GeoPackage operations

D.5.1. CreateGeoPackage

D.5.2. Transcript

The following transcript shows the process of creating datasources and the ultimate GeoPackage.
<ows:Identifier>CreateDatasource</ows:Identifier>
<wps:Input id="DATASOURCE">
    <wps:Input id="DATA">
    </wps:Input>
    <wps:Input id="STYLE">
    </wps:Input>
    <wps:Input id="TYPE">
        <wps:Data>GEODATABASE</wps:Data>
    </wps:Input>
    <wps:Input id="NAME">
        <wps:Data>Benicia, California 20160809</wps:Data>
    </wps:Input>
    <wps:Input id="DESCRIPTION">
        <wps:Data>Created</wps:Data>
    </wps:Input>
    <wps:Input id="SRS">
        <wps:Data>EPSG:3857</wps:Data>
    </wps:Input>
</wps:Input>
<wps:Output id="DATASOURCE_IDS"></wps:Output>
</wps:Execute>

<StatusInfo xmlns="http://www.opengis.net/wps/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
    <JobID>afa2f142-54c1-490d-bdf5-2781b0938754</JobID>
    <Status>Accepted</Status>
    <ExpirationDate xsi:nil="true"/>
    <EstimatedCompletion xsi:nil="true"/>
    <NextPoll>2016-10-27T15:37:43.000-02:30</NextPoll>
    <PercentCompleted>0</PercentCompleted>
</StatusInfo>
<wps:GetStatus xmlns:wps="http://www.opengis.net/wps/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:schemaLocation="http://www.opengis.net/wps/2.0 ../wps.xsd" service="WPS" version="2.0.0">
    <wps:JobID>afa2f142-54c1-490d-bdf5-2781b0938754</wps:JobID>
</wps:GetStatus>
<StatusInfo xmlns="http://www.opengis.net/wps/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
</StatusInfo>
<JobID>afa2f142-54c1-490d-bdf5-2781b0938754</JobID>

<Status>Running</Status>
<ExpirationDate xsi:nil="true"/>
<EstimatedCompletion xsi:nil="true"/>
<NextPoll>2016-10-27T15:37:43.000-02:30</NextPoll>
<PercentCompleted>0</PercentCompleted>

</StatusInfo>

<wps:GetStatus xmlns:wps="http://www.opengis.net/wps/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/wps/2.0 ../wps.xsd" service="WPS"
version="2.0.0">
<wps:JobID>afa2f142-54c1-490d-bdf5-2781b0938754</wps:JobID>
</wps:GetStatus>

<StatusInfo xmlns="http://www.opengis.net/wps/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
<JobID>afa2f142-54c1-490d-bdf5-2781b0938754</JobID>
>Status>Succeeded</Status>
<ExpirationDate xsi:nil="true"/>
<EstimatedCompletion>2016-10-27T15:37:06.000-02:30</EstimatedCompletion>
<NextPoll>2016-10-27T15:37:43.000-02:30</NextPoll>
<PercentCompleted>100</PercentCompleted>

</StatusInfo>

<wps:GetResult xmlns:wps="http://www.opengis.net/wps/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/wps/2.0 ../wps.xsd" service="WPS"
version="2.0.0">
<wps:JobID>afa2f142-54c1-490d-bdf5-2781b0938754</wps:JobID>
</wps:GetResult>

<Result xmlns="http://www.opengis.net/wps/2.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">60</Result>
<JobID>afa2f142-54c1-490d-bdf5-2781b0938754</JobID>
<ExpirationDate xsi:nil="true"/>
<Output>
  <Data mimeType="text/plain">238</Data>
</Output>
</Result>
<wps:Execute
  xmlns:wps="http://www.opengis.net/wps/2.0"
  xmlns:ows="http://www.opengis.net/ows/2.0"
  xmlns:xlink="http://www.w3.org/1999/xlink"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.opengis.net/wps/2.0 ../wps.xsd" service="WPS"
  version="2.0.0" response="document" mode="async">
  <ows:Identifier>CreateDatasource</ows:Identifier>
  <wps:Input id="DATASOURCE">
    <wps:Reference xlink:href="http://basemap.nationalmap.gov/arcgis/rest/services/USGSShadedReliefOnly/MapServer/WMTS/1.0.0/WMTSCapabilities.xml"></wps:Reference>
  </wps:Input>
  <wps:Input id="STYLE">
    <wps:Data>GoogleMapsCompatible</wps:Data>
  </wps:Input>
  <wps:Input id="TYPE">
    <wps:Data>WMTS</wps:Data>
  </wps:Input>
  <wps:Input id="MIN_SCALE">
    <wps:Data>10</wps:Data>
  </wps:Input>
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  </wps:Input>
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  </wps:Input>
  <wps:Input id="NAME">
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    <wps:Data>Created WMTS</wps:Data>
  </wps:Input>
  <wps:Input id="SRS">
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  </wps:Input>
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 xmlns:xlink="http://www.w3.org/1999/xlink"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="http://www.opengis.net/wps/2.0 ..../wps.xsd" service="WPS"
 version="2.0.0" response="document" mode="async">
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  <wps:Input id="DATA">
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  </wps:Input>
 </wps:Input>
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 </wps:Input>
 <wps:Input id="TYPE">
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</wps:Input>
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             xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
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             version="2.0.0" response="document" mode="async">
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  </Output>
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## Appendix E: Revision History

**Table 15. Revision History**

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<th>Editor</th>
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<th>Descriptions</th>
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<td>all</td>
<td>initial version</td>
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<tr>
<td>Jun 30, 2016</td>
<td>.2</td>
<td>R. Cass</td>
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<td>initial draft</td>
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<td>July 25, 2016</td>
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