Report P4B Culverts and Low Water Crossings

Prepared for Project 0-7095-01 Flood Assessment System for TxDOT (FAST)

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Introduction

Task 4 in the FAST project agreement describes the development of a Flood Transportation Geodatabase. This report covers subtask items 4.5 Bridge-Class Culverts and 4.6 Low Water Crossings. The methods and data associated with low water crossings (LWCs) are similar enough to bridge-class culverts (BCCs) that they are described together in this report.

This report includes sections on background, data sources, data development, rating curve methodology, and example implementation in FAST.

Background

FAST uses rating curves to convert forecast streamflow into forecasted water surface elevation, which can then be used to forecast road and bridge flooding. Modeling culverts gives us better rating curves at LWCs and BCCs than reach-averaged Height Above Nearest Drainage (HAND) synthetic rating curves used by default in FAST. To achieve this, we need data about culvert configurations at LWCs (typically collected in the field since data are not otherwise readily available), a model to compute the rating curves, and a go-between to feed survey data into the model. For the model, we use HY-8, a culvert hydraulic analysis program developed by the U.S. Federal Highway Administration. Since TxDOT has access to ArcGIS technology, we use ArcGIS Field Maps for data collection and Arc Hydro as a go-between. Arc Hydro can automate HY-8 execution for simple culvert configurations, greatly reducing the time required to compute rating curves for a significant number of culverts throughout the state. Note that the exact number of simple culvert configurations in use is not available since such data do not exist statewide, but in example surveys conducted for this project, 51 out of 58 culvert locations were compatible with automated processing.

When surveying culverts, one needs a database design for storing survey results. To design the database, one should have an idea of commonly used culvert configurations in Texas. To know where to go for the survey, one needs locations of possible LWCs or BCCs. An understanding of the survey application (ArcGIS Field Maps) is also required. Culvert configurations, culvert locations, and background on ArcGIS Field Maps are described in this Background section.

Culvert Configurations in Texas

Trent Ellis, a former TxDOT employee, provided information on culvert types to expect in Texas, as shown in Figure 1.

Shapes

- Circular (concrete, metal, or plastic)
- Arch (concrete, masonry, metal, or plastic)
- Elliptical (concrete, metal, or plastic)
- Box (concrete)

Figure 1. Culvert Shapes.

A few additional notes on shapes:

- Arch shape can be circular (Figure 2) or elliptical (Figure 3).
- Arch culverts may be 3-sided (i.e., bottomless), or they may be a standard pipe or elliptical pipe with channel material/riprap covering the bottom area.
- Some (very few) newer culverts are designed for animal passage by including ledges on either side of the opening (Figure 4).

Figure 2. Arch Culvert Example 1.

Figure 3. Arch Culvert Example 2.

Figure 4. Culvert with ledges for animal passage.

Multiple openings

- In most cases, multiple-opening culverts will have identical barrels arranged in a linear array.
- There are multiple opening culverts where different barrel sizes and shapes are included in the linear array.

Road surface

- concrete, asphalt, or dirt/gravel

Culvert materials

- Concrete
- Masonry
- Corrugated metal
- Smooth metal
- Corrugated plastic
- Smooth plastic

Safety end treatments

This is not included in our computational process but many culverts - especially at low water crossings, have safety end treatments as depicted in Figure 5:

Figure 5. Example safety end treatments.

Culvert Options in HY-8 version 8.0

HY-8 is a culvert hydraulics program developed by the Federal Highway Administration[1]. It is a Windows program used for the analysis and design of culverts. The program is supported by the Aquaveo firm associated with Brigham Young University in Provo, UT.[2] Normally, HY-8 is used one location at a time using a graphical user interface. As part of the FAST project, the project team collaborated with Aquaveo to create a "headless" version of HY-8 that could be executed as a subsystem of Arc Hydro[3], part of the ESRI ArcGIS geographic information System. This enables automated calculation of culvert rating curves for a large number of culverts for culverts with a limited range of shapes and physical properties. As part of the FAST project, several versions of a field work program to measure the required attributes were developed, each simpler than the one before, so that the required information can be developed with a minimum of time spent in the field at each culvert location.

HY-8 can model several culverts shapes and materials, but for automated model setup and execution with Arc Hydro, only a few options are allowed.

All HY-8 Options

Shapes:

- Circular Pipe
- Box
- Elliptical long axis horizontal
- Pipe-Arch
- Arch
- Low-Profile Arch
- High-Profile Arch
- Metal Box
- Concrete Open Bottom Arch
- South Dakota Concrete Box
- User Defined

Materials:

- Corrugated Steel
- Steel Structural Plate
- Corrugated Aluminum
- Aluminum Structural Plate
- Reinforced Concrete
- PVC
- Smooth HDPE
- Corrugated PE

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[1] https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/
[2] https://aquaveo.com/software/wms/models/hy-8
[3] https://www.esri.com/en-us/industries/water-resources/arc-hydro/downloads

Options Available via Arc Hydro

Arc Hydro can run HY-8 automatically for several culverts at once, but the options are limited. At a given crossing, all culverts must be uniform (same height, length, shape material, etc.), and options are limited to the following.

Shapes:

- Circular Pipe
- Box

Materials:

- Metal (lumps the various steel and aluminum options together)
- Reinforced Concrete

Still, Arc Hydro can be used to initialize a model for a given culvert even if the culvert configuration is not simple or does not adhere to the allowed options. The user would then need to open HY-8 and finish the model configuration manually before executing the model.

Bridge-Class Culvert Data Source

To locate bridge class culverts, one can use the Specifications for the National Bridge Inventory (SNBI) dataset, which defines data to be reported for highway bridges to the Federal Highway Administration. TxDOT provides Texas bridge locations with SNBI attributes as a dataset named "TxDOT Bridges SNBI" on their open data portal at

https://gis-txdot.opendata.arcgis.com/datasets/8eed197947bd4936aff4eab4eda9d55e_0/

Culverts can be identified as those have a culvert condition rating other than N (not a culvert) or 0 (out of service). This means that the query selects structures that have a culvert condition rating between 1 and 9, which means an active bridge class culvert, and not a span bridge.

```
"C04_CULV_COND_RTNG_CD NOT IN ('N', '0') And C04_CULV_COND_RTNG_CD IS
NOT NULL"
```

The resulting features can be added to a geographic information system (GIS) and shared with team members for culvert surveys.

Low Water Crossing Data Sources

There are a couple of online sources of low water crossing GIS files for Texas: one from the Texas Water Development Board (TWDB) and the other from the Texas Geographic Information Office (TxGIO). Neither is an exact subset of the other, so one might need both datasets to map all LWCs in Texas. Also note that points at LWCs common to both datasets are not spatially coincident, with an offset exceeding 15 meters in some cases. However, since the **TWDB dataset** is 11 years more current as of this writing, we recommend starting with that one. Once all LWCs from that dataset are field-surveyed to get culvert attributes, if there are still resources available, one could survey additional crossings from the TxGIO dataset. There is also a potentially useful dataset from the U.S. Geological Survey (USGS).

Note that the subsections below report information valid as of April, 2026, unless otherwise indicated.

TxGIO Low Water Crossings

This dataset[4] is available on the Texas Water Data Hub at https://txwaterdatahub.org/dataset/low-water-crossings. It was last updated in 2013 with no plans for future updates. Clicking the download link takes you to an ArcGIS Server endpoint, https://feature.tnris.org/arcgis/rest/services/Basemap/Low_Water_Crossing/MapServer/0. The Texas Low Water Crossing layer 8339 features with crossing types:

- BRIDGE CLASS
- PEDESTRIAN CROSSING
- UNVENTED FORD
- VENTED FORD

We could filter those to just VENTED FORD to help narrow the search for LWCs with culverts.

Note: An unvented ford is a low water crossing where the stream goes directly over the road, i.e., the road is wet if there is water flowing in the stream. For unvented fords, we recommend staying with the HAND rating curves used by FAST unless better local hydraulic models are available.

TWDB Flood Infrastructure Points

Flood infrastructure points can be found on the Texas State Flood Plan website, https://texasstatefloodplan.org/infrastructure. At the time of this writing, according to geoprocessing summaries in the metadata, this dataset was last updated 2024-06-18. It has 11395 LWCs. The data are in NAD 1983 (2011) Texas Centric Mapping System Lambert (Meters), EPSG 6580.

To download and filter the points for LWCs:

1. Browse to https://texasstatefloodplan.org/infrastructure.
2. Select **Explore the Data > Download GIS Data**.
3. Select **By Layer**.
4. Complete the CAPTCHA.
5. Select **Major Flood Infrastructure - Point**. The download will start.
6. Unzip the geodatabase and add the ExFldInfraPt feature class to a map.
7. Select rows where Infrastructure Type (INFRA_TYPE) equals 'LWC'. Note that there are two infrastructure type fields (INFRA_TYPE and TWDB_INFRA_TYPE), but for LWCs, their values are the same.
8. Use the **Copy Features** geoprocessing tool in ArcGIS Pro to copy the selected rows to your own LWC feature class.

USGS StreamStats Culvert Breach Lines

To support StreamStats functions on higher resolution elevation data in Texas, the USGS digitized breach lines for culverts so that water flow paths are properly represented. Culvert line geometry, including orientation, vertices, and length, prioritize elevation-based flow connectivity rather than actual culvert shape. Therefore, this dataset is useful to identify possible culvert locations, but not necessarily for deriving other culvert properties. An example dataset for the Austin area was provided to the project

[4] Texas Geographic Information Office (TxGIO). Low Water Crossings, https://txwaterdatahub.org/dataset/low-water-crossings. Accessed 2025-12-17

team by Jon Thomas <jvthomas@usgs.gov> on 2026-01-07. This dataset could be used to find survey locations after locations from the TWDB and TxDIO datasets are exhausted. The reader should contact Jon Thomas for data access if interested.

About ArcGIS Field Maps

Culvert surveys are submitted using ArcGIS Field Maps using a procedure developed in the FAST project. Field Maps requires a database for receiving survey results. Initial survey tests were performed using a database supporting simple culvert configurations for automation with Arc Hydro. However, this means surveys for other configurations, such as when a given low water crossing has culverts of different shapes, cannot but submitted. To adopt a more robust solution, the goal is to enable surveys for more complex configurations. Automating modeling of simple water crossings can still be accomplished with Arc Hydro, and other configurations can be modeled manually if there one has the desire, expertise, and resources available to do so.

This story map authored by Christine Thies and Tim Whiteaker provides culvert survey instructions online. https://storymaps.arcgis.com/stories/fa738abceca9410aa5ba962a64944dfc

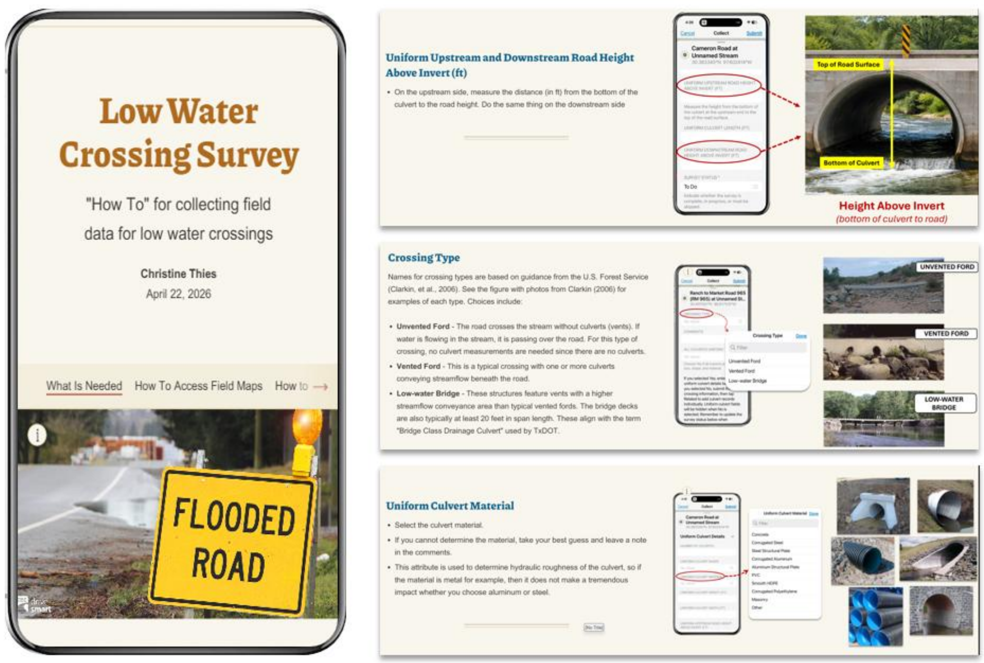


Figure 6. ArcGIS StoryMap for Culvert Survey procedure.

To allow for non-uniform culverts at a given LWC or BCC (i.e., a stream crossing), the field collection database needs two tables: a feature class of **stream crossing locations**, and a related table for **culverts** associated with the crossings. To streamline data entry for uniform culverts at a given crossing, attributes describing culverts such as height and width are part of the stream crossing feature class along with an attribute indicating whether culverts at the crossing are uniform and an attribute indicating number of culverts. For the case when culverts are not uniform, the user can add related culvert records and describe each culvert independently of the other culverts.

We can use [conditional visibility] in the Field Maps form to hide the uniform culvert fields in the LWC feature class when the user has toggled "non-uniform culverts". We can enter data for non-uniform culverts following this [Esri example on related records in Field Maps].

Unfortunately, we can't use conditional visibility to hide the related records portion of the form in the case of uniform culverts.

Culvert Surveys

This section describes the data model used for culvert surveys and steps to prepare data and a Field Maps app.

Culvert Survey Data Model

At a high level, the culvert survey data model includes a StreamCrossing dataset representing locations where roads are designed to accommodate streams passing under or over them, and a Culverts dataset representing an individual culvert's design at a given stream crossing. One StreamCrossing can have zero to many related Culverts. The relationship is zero-to-many to support unvented fords and low-water bridges which would not have culverts. The relationship also supports the case when all culverts are uniform at a given stream crossing and the culverts can be described using attributes on StreamCrossing rather than requiring a related Culverts table. The datasets are related via the GlobalID attribute on StreamCrossing and the Crossing_ID attribute on Culverts as shown in Figure . Other attributes on those datasets are hidden in the figure to keep the figure simple, but are described later in this section. The figure also shows that a StreamCrossing can have zero to many field survey photos associated with it. How the photos are related and stored is implementation-specific. In the case of an ArcGIS geodatabase, photos are stored as attachments on the StreamCrossing feature class.

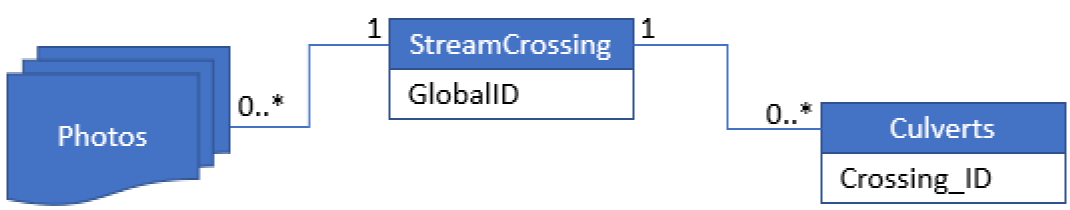


Figure 7. Culvert Survey Relationships.

StreamCrossing Attributes

Attributes for the StreamCrossing dataset are listed below, along with data type and description.

- GlobalID (GUID) - Globally unique identifier for each StreamCrossing, i.e., a GUID.
- SurveyStatus (Text) - Status of survey. Allowable values are:
    - To Do
    - In Progress
    - Complete
    - Skip - Surveys may be skipped if conditions are unsafe or culverts are inaccessible.
- SurveyorName (Text) - First and last name of person or people conducting the survey.
- SurveyDate (Date) - Date and time of survey.
- RoadName (Text) - Road name.

- StreamName (Text) - Stream name.
- RoadSurface (Text) - Road surface material. Allowable values are:
    - Asphalt
    - Concrete
    - Gravel
    - Dirt
- RoadWidth_ft (Double) - Road width in feet, measured from the outer edge of one shoulder to the outer edge of the opposite shoulder, including any median.
- CrossingType (Text) - Type of stream crossing. Allowable values are:
    - Unvented Ford - i.e., no culverts. Stream flows over the road.
    - Vented Ford - has culverts.
    - Low-water Bridge - Less common case of when the structure is a bridge with very low clearance above the stream.
- AllCulvertsUniform (Text) - Indicates whether all culverts at this crossing are uniform. If Yes, the uniform culvert attributes are expected to be populated; otherwise, the uniform culvert attributes are expected to be left blank and the related Culverts table is used. Allowable values are:
    - Yes
    - No
- NumCulverts (Short) - Number of culverts.
- UniformCulvertShape (Text) - Culvert shape. Allowable values are:
    - Box
    - Circular
    - Arch
    - Elliptical
    - Other
- UniformCulvertMaterial (Text) - Culvert material. Allowable values are:
    - Concrete
    - Corrugated Steel
    - Steel Structural Plate
    - Corrugated Aluminum
    - Aluminum Structural Plate
    - PVC
    - Smooth HDPE
    - Corrugated Polyethylene
    - Masonry
    - Other
- UniformCulvertHeight_ft (Double) - Culvert height in feet, measured from the interior of the culvert from bottom to top at the tallest point.
- UniformCulvertWidth_ft (Double) - Width of the culvert opening in feet, measured from the interior of the culvert at its widest point.
- UniformCulvertLength_ft (Double) - Length of the culvert opening in feet, measured from one opening to the other, e.g., from the upstream opening to the downstream opening.

- UniformUSRoadHtAbvInvert (Double) - Height from bottom of culvert to top of road on the upstream side, measured in feet.
- UniformDSRoadHtAbvInvert (Double) - Height from bottom of culvert to top of road on the downstream side, measured in feet.
- Comments (Text) - Comments, e.g., "Too much traffic to safely measure road width."
- Label (Text) - Human-friendly short name for the stream crossing, e.g., "Colorado River at I-35".

Culvert Attributes

- Culvert_ID (GUID) - Globally unique identifier for each culvert.
- Crossing_ID (GUID) - Identifier of related StreamCrossing.
- SequenceNum (short) - Sequence number of the culvert, starting at 1, from left to right while standing downstream of the crossing and facing the crossing.
- CulvertShape (Text) - Culvert shape. Allowable values are:
    a. Box
    b. Circular
    c. Arch
    d. Elliptical
    e. Other
- CulvertMaterial (Text) - Culvert material. Allowable values are:
    a. Concrete
    b. Corrugated Steel
    c. Steel Structural Plate
    d. Corrugated Aluminum
    e. Aluminum Structural Plate
    f. PVC
    g. Smooth HDPE
    h. Corrugated Polyethylene
    i. Masonry
    j. Other
- CulvertHeight_ft (Double) - Culvert height in feet, measured from the interior of the culvert from bottom to top at the tallest point.
- CulvertWidth_ft (Double) - Width of the culvert opening in feet, measured from the interior of the culvert at its widest point.
- CulvertLength_ft (Double) - Length of the culvert opening in feet, measured from one opening to the other, e.g., from the upstream opening to the downstream opening.
- USRoadHtAbvInvert (Double) - Height from bottom of culvert to top of road on the upstream side, measured in feet.
- DSRoadHtAbvInvert (Double) - Height from bottom of culvert to top of road on the downstream side, measured in feet.
- Culvert_Comments (Text) - Comments for the given culvert.

Data and App Preparation

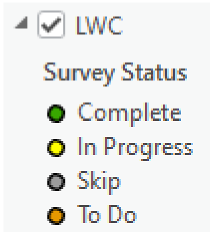
Prepare Data

These steps show how to initialize the stream crossing feature class and related culvert table in ArcGIS Pro version 3.5.0. It assumes you are using the TWDB low water crossing dataset, but any appropriate dataset can be used to create stream crossing point locations. Note that if you use different datasets, some of the steps below may differ if your dataset does not have the same attribute names as the datasets the author used.

1. Make a new ArcGIS Pro project called **CulvertSurvey**.
2. Add FAST road lines to the project. These are based on OpenStreetMap. You can download them from https://web.corral.tacc.utexas.edu/nfiedata/road3d/.
3. Add polyline streams used by the National Water Model to the project. You can download them from https://maps.water.noaa.gov/server/rest/services/reference/static_nwm_flowlines/FeatureServer/0. You'll use roads and streams to populate attributes on the StreamCrossing feature class later.
4. Use the **Create Domain** and **Add Coded Value To Domain** tools to create the following **text** domains in the geodatabase.
    a. YesNo
        i. Yes
        ii. No
    b. SurveyStatus
        i. To Do
        ii. In Progress
        iii. Complete
        iv. Skip
    c. CulvertShape
        i. Box
        ii. Circular
        iii. Arch
        iv. Elliptical
        v. Other
    d. CulvertMaterial
        i. Concrete
        ii. Corrugated Steel
        iii. Steel Structural Plate
        iv. Corrugated Aluminum
        v. Aluminum Structural Plate
        vi. PVC
        vii. Smooth HDPE
        viii. Corrugated Polyethylene
        ix. Masonry
        x. Other
    e. RoadSurface

        i. Asphalt
        ii. Concrete
        iii. Gravel
        iv. Dirt
    f. CrossingType
        i. Unvented Ford
        ii. Vented Ford
        iii. Low-water Bridge
5. Download LWCs from the TWDB dataset as described above.
6. Import stream crossings.
    a. Projection units should match measurement units since Arc Hydro reads the units from the spatial reference. If they currently don't match (e.g., we measure culvert height in feet, but the spatial reference linear unit is 'meter'), project the feature class to use the same linear unit as is desired for the culvert measurements.
    b. Filter the dataset for LWCs and import them into the project geodatabase as **StreamCrossing**.
    c. Run the **Enable Attachments** tool on StreamCrossing. This allows us to collect photos in the field for each crossing.
7. Prepare fields for the StreamCrossing feature class.
    a. Run the **Add Global IDs** tool to add a global ID field to stream crossings.
    b. Add these fields to StreamCrossing:
        i. SurveyStatus (Text, SurveyStatus domain)
        ii. SurveyorName (Text)
        iii. SurveyDate (Date) - Ideally we would use the "Date only" type so that time isn't included, but "Date only" is not compatible with syncing edits in Field Maps.
        iv. RoadName (Text)
        v. StreamName (Text)
        vi. RoadSurface (Text, RoadSurface domain))
        vii. RoadWidth_ft (Double)
        viii. CrossingType (Text, CrossingType domain)
        ix. AllCulvertsUniform (Text, YesNo domain)
        x. NumCulverts (Short)
        xi. UniformCulvertShape (Text, CulvertShape domain)
        xii. UniformCulvertMaterial (Text, CulvertMaterial domain)
        xiii. UniformCulvertHeight_ft (Double)
        xiv. UniformCulvertWidth_ft (Double)
        xv. UniformCulvertLength_ft (Double)
        xvi. UniformUSRoadHtAbvInvert (Double)
        xvii. UniformDSRoadHtAbvInvert (Double)
        xviii. Comments (Text)
    c. Calculate SurveyStatus as "To Do".

8. Assign a Unique Values Renderer based on possible values of SurveyStatus.



9. Populate **RoadName**.
    a. Use **Spatial Join** to join OpenStreetMap road lines to StreamCrossing, closest geodesic, with a 10 m search radius.
    b. OpenStreetMap roads include road name in two possible fields: name and ref. Use **Calculate Field** to compute RoadName with this function signature:
    `x(!name!, !ref!)`
    and this function:

```
def x(n, r):

    result = ''
    n = n.strip() if n else ''
    r = r.strip() if r else ''
    if n == '' and r == '':
        return result
    elif n:
        if r and r != n:
            result = n + ' (' + r + ')'
        else:
            result = n
    else:
        result = r
    return result
```

    c. Join the result back to StreamCrossing via OBJECTID and the target FID.
    d. Use **Calculate Field** to copy RoadName from the joined table to the StreamCrossing table.
    e. Remove the join.
10. Populate Stream Name.
    a. Use **Spatial Join** to join stream lines to StreamCrossing, closest geodesic, with a 50 m search radius.
    b. Use **Calculate Field** to compute StreamName from the joined stream name.
    c. Join the result back to StreamCrossing via OBJECTID and the target FID_ID.
    d. Use **Calculate Field** to copy StreamName from the joined table to the StreamCrossing table.
    e. Remove the join.
11. Use Calculate Field to compute a "Label" attribute.
    a. Set the function as:
    `x(!RoadName!,!StreamName!)`
    b. Set the code block as:

```
def x(r, s):
  label = ''
  if r:
    label = r + ' at '
    if s:
      label += s
    else:
      label += 'unnamed stream'
  elif s:
    label = 'Unnamed road at ' + s
  return label
```

12. Create the **Culverts** table with the following fields and relate it to StreamCrossing via Crossing_ID (points to GlobalID on StreamCrossing).
    a. Culvert_ID (GUID)
    b. Crossing_ID (GUID)
    c. SequenceNum (short)
    d. CulvertShape (Text, CulvertShape domain)
    e. CulvertMaterial (Text, CulvertMaterial domain)
    f. CulvertHeight_ft (Double)
    g. CulvertWidth_ft (Double)
    h. CulvertLength_ft (Double)
    i. USRoadHtAbvInvert (Double)
    j. DSRoadHtAbvInvert (Double)
    k. Culvert_Comments (Text)
13. Publish the data.
    a. Aside from the online basemap, make sure the map only has the StreamCrossing layer and Culverts table in it.
    b. In the Contents pane, right-click the map (probably named "Map") and click **Properties**.
    c. On the General tab, ensure the **Allow assignment of unique numeric IDs for sharing web layers** box is checked.
    d. Click **OK**.
    e. In the Contents pane, click **StreamCrossing** to select that layer.
    f. On the **Share** tab, in the **Share As** group, click **Web Layer**.
    g. For Name, type **StreamCrossing_for_Survey**.
    h. Verify that Layer Type is set to **Feature**.
    i. Near the top of the **Share As Web Layer** pane, click **Configuration**.
    j. Under Layer(s), next to Feature, click **Configure Web Layer Properties**.
    k. Under Operations, check **Enable editing and allow editors to** and **Enable sync**. Verify that Add and Delete, and Update are selected. Checking these boxes allows mobile workers to edit the features (including the table data) of your published feature class.
    l. Back on the General tab, set the Folder where the service will be published.
    m. Leave sharing level as **Owner**.
    n. Click **Publish**.
    o. Save the project and close ArcGIS Pro.

Create the Map for Field Maps

1. Sign in to Arcgis.com.

2. Select **Content**.
3. Open the **StreamCrossing_for_Survey** hosted feature layer in **Map Viewer**.
4. **Options > Rename**, and rename the layer as **Stream Crossings**.
5. Select **Tables**. Rename the culvert table as **Culverts**.
6. Configure the pop-up for Stream Crossings and Culverts to hide **OBJECTID**.
7. Save the map as **Stream Crossing Map for Survey**.
8. Click **Map properties > Item details**.
9. Allow the user to search for low water crossings by name. In **Settings > Web map > Application settings**, toggle on "By layer" and change the attribute to **Label**.
10. Click **Save**.

Create a Group for Editors

1. At the top of the map, click the **Home** menu and choose **Groups**.
2. Click **Create group**.
3. Name your group **LWC Surveyors**. For the summary, type **Content for low water crossing surveyors in Texas**. Add search tags that describe the group's content and geography, like the ones you used for the map.
4. For who can view this group, select **Only group members**.
5. Accept the default for the remaining questions.
6. Click **Save**.
7. Next, you'll share your web map with the members of the group.
8. On the blue ribbon for the group, click the **Content** tab.
9. Click **Add items to group**.
10. In the Add items to group window, check the boxes for the **Stream Crossing Map for Survey** web map and the **StreamCrossing_for_Survey** feature layer.
11. Click **Add items**.
12. On the ribbon, click **Overview**.
13. Verify the group details and recently added content.

Configure Field Map Forms

1. In the Overview pane, click the web map to open the item details page.
2. Click **Open in Field Maps Designer**.
3. Click **Forms**.
4. Customize the Stream Crossings form.
    a. Expand **Layers** and click **Stream Crossings**.
    b. To organize the form, drag a **Group** onto the form canvas.
    c. Name the group **Survey Information**.
    d. Click the x to close the group Properties window.
    e. From the Form builder, drag the **Surveyor Name** and **Survey Date** fields into the group.
    f. On the form, click **Surveyor Name**. Check the **Required** box.
    g. Make **Survey Date** required.
    h. Create another group named **Crossing Information**. Add these fields to it.
        i. Road Name
        ii. Stream Name
        iii. Label

   iv. Road Surface
   v. Road Width
   vi. Crossing Type
   vii. Comments
   viii. All Culverts Uniform

i. Uncheck **Include "No value" option** for these items:
   i. Road Surface
   ii. Crossing Type
   iii. All Culverts Uniform

j. Click the **Comments** field.

k. Change the Input type to **Text - Multiline**.

l. Set this description for **Road Width (ft)**:

```
Measure from the outer edge of one shoulder to the outer edge of the opposite
shoulder, including any median. Use decimal feet, e.g., for 25 feet and 6 inches,
enter 25.5. If conditions are too dangerous, skip this measurement.
```

m. Set this description for **All Culverts Uniform**:

```
Choose Yes if all culverts are the same size, shape, and material.
```

n. Add an **Info** element with this text:

```
If you selected Yes, enter the uniform culvert details below. If you selected No,
submit the crossing information, then tap Related to add culvert records individually.
Uniform culvert fields will be hidden when No is selected. Remember to update the
survey status below when finished.
```

o. Create a group named **Uniform Culvert Details**. Add **Number of Culverts** and all fields beginning with "Uniform" to the group.

p. Uncheck **Include "No value" option** for these items:
   i. Uniform Culvert Shape
   ii. Uniform Culvert Material

q. Set this description for **Uniform Upstream Road Height Above Invert (ft)**:

```
Measure the height from the bottom of the culvert at the upstream end to the top of
the road surface.
```

r. Set visibility of the uniform culvert details based on the value of AllCulvertsUniform.
   i. Click **Uniform Culvert Details**.
   ii. In the Logic section, next to "Visible", click the gear icon.
   iii. Click **New expression**.
   iv. Set the condition to be when **AllCulvertsUniform is Yes**.
   v. Change the expression title to **Uniform = Yes**.
   vi. Click **Done**.

s. Add Survey Status:
   i. From the Form builder, drag the **Survey Status** field onto the form.
   ii. Set this description for **Survey Status**:

```
Indicate whether the survey is complete, in progress, or must be skipped.
```

        iii. Uncheck **Include "No value" option**.
        iv. Check **Required**.
    t. Update the form title.
        i. Click the title of the form to edit it.
        ii. Change the form title to **{Label}**. This uses the value of the Label field as the form title.
    u. Click **Save to map** to save the form.

5. Customize the Culverts form.
    a. From the Forms pane, under **Tables**, click the **Culverts** table.
    b. Create a **Culvert Details** group.
    c. Starting with **Sequence Number** and below, drag the fields onto the group.
    d. Set this description for **Sequence Number**:

```
Sequence number of the culvert, starting at 1, from left to right while standing
downstream of the crossing and facing the crossing
```

    e. Set this description for **Culvert Height (ft)**:

```
Use decimal feet. For example, for 2 feet and 6 inches, enter 2.5.
```

    f. Set this description for **Upstream Road Height Above Invert (ft)**:

```
Measure the height from the bottom of the culvert at the upstream end to the top of
the road surface.
```

    g. Change the Input type for **Culvert Comments** to **Text - Multiline**.
    h. Uncheck **Include "No value" option** for these items:
        a. Culvert Shape
        b. Culvert Material
    i. Add an **Info** element with this text:

```
When finished, remember to update the survey status at the bottom of the stream
crossing form.
```

    j. Make **Sequence Number** and **Culvert Shape** required.
    k. Click **Save to map**.

Test in Field Maps

1. Install **Field Maps** on your mobile device. Launch the app and sign in.
2. Select **Stream Crossing Map for Survey**.
3. Tap a crossing and tap **Edit**.
4. Scroll to see the attributes. Enter some values. Try out numeric fields, the date field, a comments field, and a drop down field such as road surface.
5. Set **All Culverts Uniform** to Yes. Now you should see the uniform culvert fields which were previously hidden. Set it to No to see the uniform fields disappear.
6. Tap **Submit**. This saves the crossing details, and next you will enter culvert details as if this crossing did not have uniform culverts.

7. Scroll to the bottom to the **Related** section and tap **Culverts**. Then you can tap **Add** to add a culvert.

Unfortunately, the author does not know how to prevent adding related records when All Culverts Uniform is set to Yes.

Survey Guidance

This section provides guidance for surveyors in the field collecting data for low water crossings (LWCs) and bridge class culverts (BCCs).

What Is Needed

To safely perform measurements in the field, we recommend using at a minimum the following equipment. However, all procedures, training, and safety requirements established by your organization take precedence over these recommendations. These recommendations are provided for general informational purposes only.

Field conditions vary, and it is your responsibility to assess risks, follow your organization's safety guidelines, and use appropriate judgment in all situations. We are not responsible for any injuries, damages, or losses resulting from the use or misuse of this information.

Personal Protective Equipment (PPE)

- Sturdy footwear
- Weather-appropriate clothing
- Hard hat
- High visibility safety vest
- Traffic cones, traffic plan
- Waders

Measurement Equipment

To conduct accurate measurements, you will need a combination of three items: Survey Rod, Laser Line Generator, and a Laser Detector.

The line generator and the laser detector can be used (in conjunction with a survey rod) to determine the distance from the bottom of the culvert to the surface of the road. The user will attach the line detector to the survey rod, and use the line generator to identify the bottom of the culvert, which in turn will result in a measurement on the laser detector.

If you do not have a laser detector or a line generator, standard survey equipment could be used, for example a transit level and survey rod. The tape measure can be used as a backup or alternative measuring tool.

Measurement equipment:

- Survey rod in decimal feet
- Digital Laser Line Detector, e.g., DeWalt Laser Line Generator Model DW088CG
- Digital Laser Line Generator, e.g., DeWalt Digital Laser Detector Model DW0892G
- Tape Measure (in decimal feet)

- Transit Level for establishing level lines

Figure 8. Example equipment for survey field work.

To Report Survey Data You Will Need

- Mobile device (Apple or Android) with ArcGIS Field Maps (download from App store)
- ArcGIS login (you can create a free version here: www.arcgis.com)
- Membership in the **LWC Surveyors** ArcGIS Online group. This group will have write access to the stream crossing hosted feature layers.

How To Access Field Maps

- Make sure your mobile device has internet access and has location settings enabled
- Open Field Maps application
- Log in with your ArcGIS account
- Search for data collection map "Stream Crossing Map for Survey"
- Open map by clicking on the map below the search bar

If map has been updated, you will need to reload the map. You can do this my clicking the menu button (three dots) to the right of the map name and selecting 'Reload Map'.

How to Navigate Application

The application includes a map of low water crossing locations.

- Use your touch screen to move around the map by dragging or zoom by pinching.
- Use the Search button at the top right to search for a place name or the name of an LWC.
- In the menu (three dots), you can change the basemap or view the legend for the map layers.

Begin Survey

Once you have located a crossing to survey, tap the LWC point.

- Verify that the label names the crossing as expected and then tap **Edit**.
- As you scroll through the attributes for the crossing, you will see sections for the surveyor name and date, the crossing information, and finally the survey status.

The directions below guide the user on each section of the survey.

Details for Data Collection

Survey Information

- Enter your name.
- Enter survey date and time (it will default to current date and time). If the auto populated date and time are correct, tab to next section.

Crossing Information

The road name and stream name are provided, but you can edit these as needed.

Road Surface

- Select the road surface material from the available choices. This choice affects how water is modeled passing over the road.
- If the road is made of a material not included amongst the choices, select the material that is most similar to the actual road in terms of surface roughness and make a note about the actual surface in the COMMENTS section further down the form.

Road Width

- Measure from the outer edge of one shoulder to the outer edge of the opposite shoulder, including any median.
- Do not include the length of a sloped embankment between the culvert opening and the edge of the shoulder. The idea is to model the road as the top of a weir, so include the length of the "flat" part of the land surface above the culvert.

- If conditions are too dangerous, skip this measurement. You can estimate the width using the Measure tool in Field Maps (menu button > Measure) or back at the office with Geographic Information Systems (GIS) software.

Figure 9. Measure road width from outer edge of each shoulder.

Crossing Type

Names for crossing types are based on guidance from the U.S. Forest Service (Clarkin, et al., 2006). See the figure with photos from Clarkin (2006) for examples of each type. Choices include:

- **Unvented Ford** - The road crosses the stream without culverts (vents). If water is flowing in the stream, it is passing over the road. For this type of crossing, no culvert measurements are needed since there are no culverts.
- **Vented Ford** - This is a typical crossing with one or more culverts conveying streamflow beneath the road.
- **Low-water Bridge** - These structures feature vents with a higher streamflow conveyance area than typical vented fords. The bridge decks are also typically at least 20 feet in span length. These align with the term "Bridge Class Drainage Culvert" used by TxDOT.

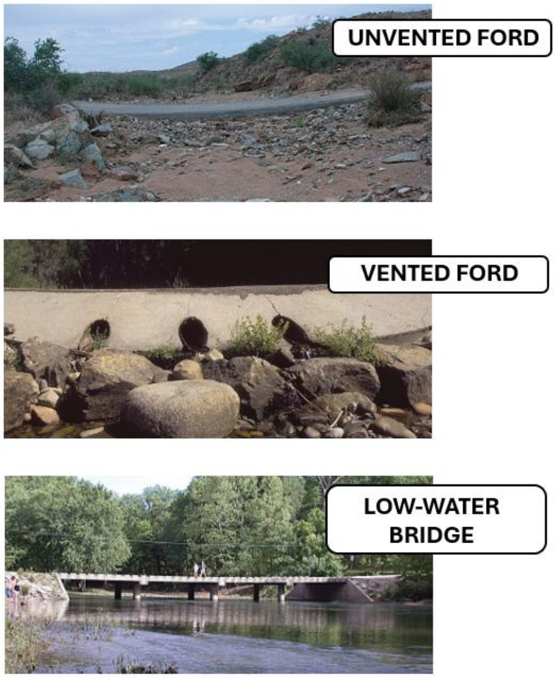


Figure 10. Example photos of crossing types, from Clarkin, et al., 2006.

Comments

Document unusual culvert conditions or situations which impeded the survey here.

All Culverts Uniform - YES

At a given crossing, all culverts may be identical which is commonly the case. In other cases, different culvert configurations are used, such as two larger culverts and two smaller culverts.

If all culverts are of the same material and dimensions

- If all culverts at a given crossing are of the same material and dimensions, then select "Yes" for **All Culverts Uniform**.
- A hidden section about culvert details will become visible where you can enter the number of culverts and the uniform culvert properties.
- In this case, there is no need to add related culvert records for the crossing as described in the next section for non-uniform culverts.

Number of Culverts

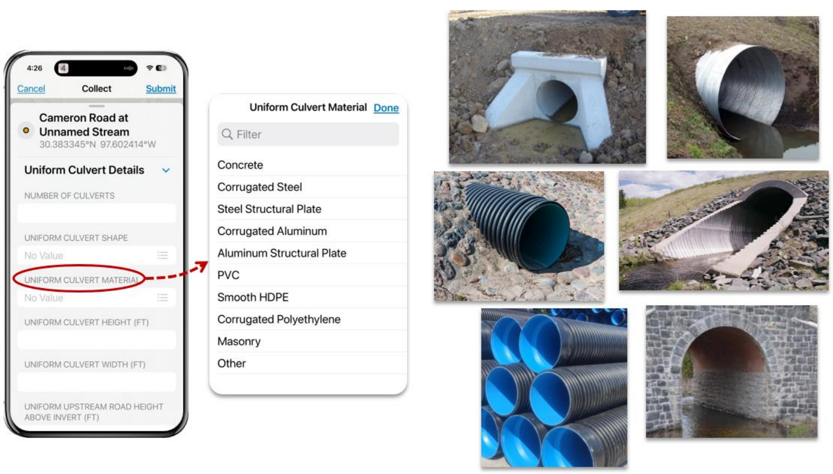
- This attribute for the crossing is visible when you select "Yes" to **All Culverts Uniform**.
- Enter the total number of culvert barrels.

Uniform Culvert Shape

- Select the shape of the culvert opening.
- Culverts are generally box shaped or circular, though some elliptical and arch-shaped culverts may also be in service. An arch is typically rounded at the top and may be round or flat at the bottom.
- The actual shapes may have subtle differences from a truly box or circular shape, but if the culvert strongly resembles one of the choices, select it and leave a comment if desired.

Uniform Culvert Material

- Select the culvert material.
- If you cannot determine the material, take your best guess and leave a note in the comments.
- This attribute is used to determine hydraulic roughness of the culvert, so if the material is metal for example, then it does not make a tremendous impact whether you choose aluminum or steel.



Uniform Culvert Height & Width

- Measurements should be in decimal feet
- Measure the culvert height and width (to the nearest 0.1 decimal ft)
- For circular culverts, enter the diameter for both attributes.

Figure 6. Guidance for measuring culvert width and height. For circular culverts, use the diameter for both the height and width.

Uniform Upstream and Downstream Road Height Above Invert (ft)

On the upstream side, measure the distance (in ft) from the bottom of the culvert to the road height. Do the same thing on the downstream side.

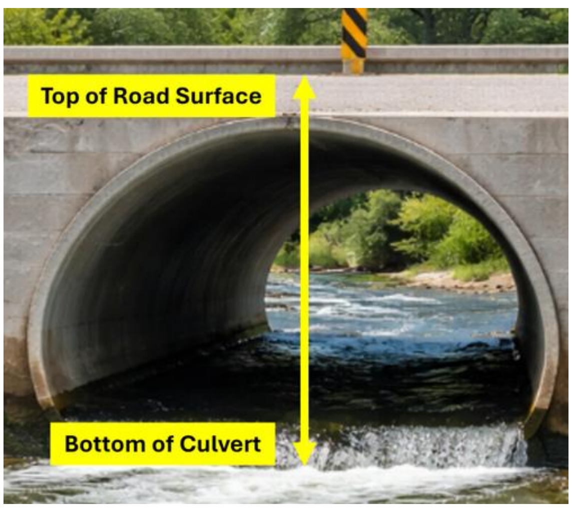


Figure 7. Guidance for measuring road height above culvert invert.

Uniform Culvert Length

To measure the length of the culvert, measure from the longest part of the culvert. Often, metal culverts extend past the road. If so, measure the extended metal from upstream to downstream.

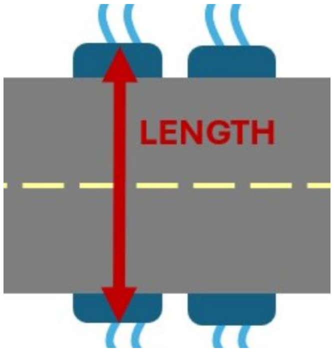


Figure 8. Guidance for measuring culvert length.

All Culverts Uniform - NO

If culverts are made of different materials or have different dimensions

- If culvert properties vary at a given crossing (shown in the photo), then select "No" for **All Culverts Uniform**.
- Update the **Survey Status** to "In Progress" and then select **Submit** in the top right. This should bring you back to a view of the crossing attributes.
- Above the attributes, select **Related > Add** to add information for the first culvert.
- The items to report here for each culvert are the same as in the previous form in the case when all culverts are uniform except for the addition of a **Sequence Number** attribute and a **Comments** attribute.

For **Sequence Number**:

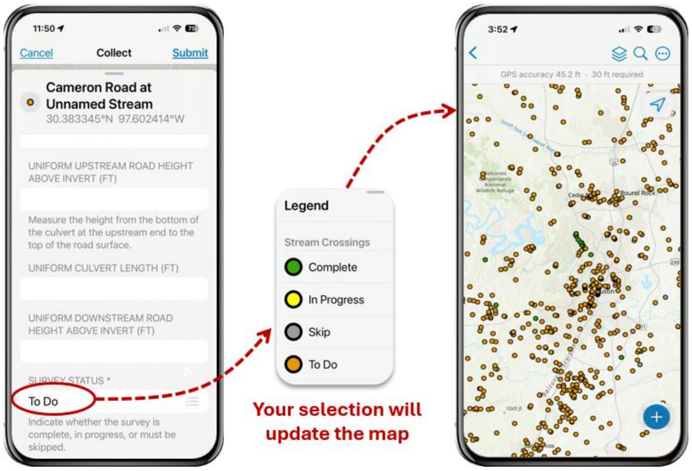
- From the downstream side, count the number culverts from left to right.
- Check YES when done.

For the **Culvert Comments**, enter any desired comments for this particular culvert.

- When you are finished, submit the culvert information and then add information for the next culvert.
- Once all culverts have been submitted, return to the attributes for the LWC to update the survey status and take field photos.

Survey Status

- Change the 'SURVEY STATUS' from 'To Do' to the appropriate status
- Selection will update crossing color on map



Photos

Photos can be helpful to ensure the user can visually see the area and take into account variables unique to the site.

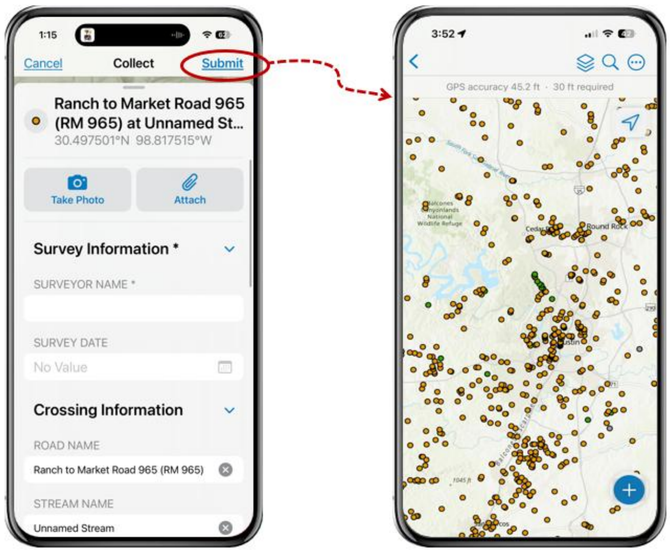
- After updating the survey status, scroll to the top of the survey and select the camera icon to begin taking photos.
- After accepting the photo, tap the photo thumbnail and then rename the photo, e.g., "Culvert Outlets".
- The critical photos are culvert inlets and culvert outlets.
- The road approaching the culvert is also important. If the road isn't captured in the photos of the inlets & outlets, take one of the road as it approaches the LWC.

Photos to be Collected:

- Upstream (from the upstream side looking downstream)
- Downstream (from the downstream side looking upstream)
- River left (from the upstream side, photo looking to the left)
- River right (from the upstream side, photo looking to the right)
- Staff gauge if present

Submit and Complete Survey

- Once done, click 'SUBMIT' to finish and complete survey.
- At this point the map will update and you can move to the next crossing.



References

Clarkin, Kim, Gordon Keller, Terry Warhol, and Suzan Hixson. 2006. Low-Water Crossings: Geomorphic, Biological, and Engineering Design Considerations. U.S. Department of Agriculture, Forest Service. Accessed February 25, 2026. https://www.fs.usda.gov/eng/pubs/pdf/LowWaterCrossings/

Updating Rating Curves

Each stream crossing occurs in a catchment for a stream segment, and each stream segment in FAST has a rating curve computed using HAND. These rating curves are unaware of the culvert and road geometry which act like a dam, restricting flow. As a result, we would expect a rating curve to overpredict the streamflow threshold for flooding the road, e.g., the rating curve may indicate the road is dry for a given streamflow but in reality the road is flooded because the culvert cannot convey as much streamflow as an open channel could.

By modeling stream crossings with HY-8, we can produce an update rating curve that properly takes into account road and culvert geometry. This section describes how to turn data from stream crossing field surveys into model inputs, run the model, and explore outputs.

This procedure was run with HY-8 Version 8.0.1.2, ArcGIS Pro 3.5.0, and Arc Hydro 3.5.82. This procedure assumes you are familiar with ArcGIS and Python.

Arc Hydro is an add-in to ArcGIS Pro that simplifies data processing and model integration aspects of implementation of GIS in water resources. Several tools have been developed in Arc Hydro to specifically support HY-8 integration and data preparation required for that integration. HY-8 is FHA application for culvert design that automates the design methods described in HDS No. 5, 'Hydraulic Design of Highway Culverts', FHWA-NHI-12-029 and in HEC No.14, FHWA-NHI-06-086. There are two specific HY-8 integration tools and four additional data processing tools that can be used in rating curve calculations and adjustments related to HY-8.

General data processing tools:

- **Create FTG Culvert Feature Class**. Create an empty point feature class with flood transportation geodatabase (FTG) culvert schema. This schema enforces correct data structures and enables other tools in the workflow to operate correctly.
- **Calculate FTG Culvert Properties**. Calculate several flood transportation geodatabase culvert attributes required for support of HY-8 culvert rating curve calculations.
- **Extract Lines on Distance and Z**. Create single line geometry per input point based on contiguous lines closest to the point. This constructs the weir portion of the culvert based on user provided maximum weir width and height.
- **Identify Culvert Overtopping Flow**. Calculate culvert overtopping flow based on its rating curve. This value indicates maximum discharge that culvert can pass through before being overtopped (flooded).

Specific HY-8 integration tools in Arc Hydro:

- **HY-8 Integration**. Calculate culvert rating curve using simplified hydraulic calculations in HY-8. Tool uses python library hy8runner developed by Aquaveo. hy8runner is designed as a python module that can be called from other python scripts to perform hydraulic analysis and generate results without invoking HY-8 interface and can be run in a loop. While efficient, it also limits what HY-8 modeling functionality is exposed and can be used for simplified culvert types.
- **Import HY-8 Rating Curve**. Import culvert rating curve from HY-8 .rst file into an existing culvert rating curve table. This tool allows import of HY-8 calculated rating curves. The input .rst file can be produced using full HY-8 hydraulic modeling capabilities through HY-8 user interface. This approach must be used when the culverts are complex and hy8runner simplifications are not adequate.

More details on Flood Transportation Geodatabase (FTG) design and use of HY-8 tools and workflows can be found in "Arc Hydro: Flood Transportation Geodatabase" document available on Arc Hydro documentation site: https://esrips.github.io/ah-docs/.

Data Acquisition

For data acquisition we create an ArcGIS Pro project to store the data and then add data to it as described below. This procedure assumes you are the same user who owns the StreamCrossing_for_Survey hosted feature layer.

Feature Dataset

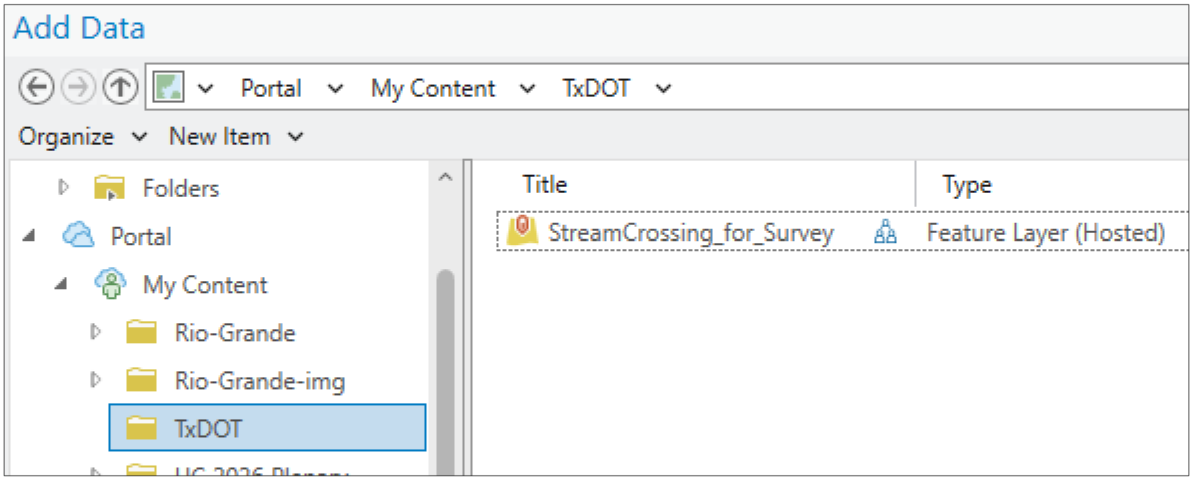
A feature dataset is like a container within an Esri file geodatabase where all feature classes within it use the same coordinate system. By placing feature classes within a feature dataset, we ensure consistency in coordinate system and therefore reduce the likelihood of errors in snapping, geospatial overlays, and so on.

For Arc Hydro and HY-8 integration, attributes, z-values on XYZ feature classes, and spatial references must be in consistent units, e.g., feet. For this walkthrough, the data that the author tested all fall within Texas StatePlane Central, so we'll use **NAD 1983 (2011) StatePlane Texas Central FIPS 4203 (US Feet) (WKID 6578)** as the coordinate system.

1. Create an ArcGIS Pro project.
2. Create a feature dataset named **Layers** in the project geodatabase and set its coordinate system to the target coordinate system.

Field Survey

1. To access the stream crossing field surveys in ArcGIS Pro, on the **Map** tab of the ribbon, click **Add Data**. Under **Portal > My Content**, select the **StreamCrossing_for_Survey** hosted feature layer and click **OK**.



2. Select the finished stream crossings with simple culvert configurations for circular or box culverts made of metal or concrete. These are the crossings that Arc Hydro can use when automating HY-8. We'll ignore other crossings at this time. You can add them later if you know how to run HY-8 manually.
    a. Click **Select By Attributes**.
    b. For the Input Rows, choose **StreamCrossing_for_Survey\StreamCrossing**.
    c. For the Expression, build a query like the one below.
    ```
    SurveyStatus = 'Complete' And AllCulvertsUniform = 'Yes'
    And UniformCulvertShape IN ('Box', 'Circular') And
    UniformCulvertMaterial IN ('Aluminum Structural Plate',
    'Concrete', 'Corrugated Aluminum', 'Corrugated Steel',
    'Masonry', 'Steel Structural Plate')
    ```
    d. If desired, further refine the selection to highlight just the desired crossings.
3. Use the **Copy Features** geoprocessing tool to copy the selected rows into your project geodatabase as **StreamCrossing**.
4. Remove **StreamCrossing_for_Survey** from the map.

Note: To include more crossings with uniform culverts, you could assume that other shapes approximate a box or circle. For example, for elliptical culverts, if the width:height ratio is greater than 1.75, you could treat it as a box.

Roads

Use Polyline XYZ roads for FAST. You can download them by district from https://web.corral.tacc.utexas.edu/nfiedata/road3d/. The file to get is **road_centerlines_xyz_3d.gpkg**.

1. Download roads for the district(s) of interest and add them to the map.
2. Select roads within **1000 feet** of **StreamCrossing** (Hint: **Map** tab of the ribbon > **Select By Location**).

3. Use the **Merge** geoprocessing tool to copy those rows into the project geodatabase in a feature class named **Road3D_m**.
4. Remove the district road layers from the map.

Streams

The streams are used to associate a stream crossing with its rating curve. Rating curves come from HAND, which has its own stream network independent of the one used by the National Water Model. You can download HAND streams as "Flowline dataset for the entire Texas (FileGDB format)" from https://web.corral.tacc.utexas.edu/nfiedata/pin2flood/texas/.

1. Download HAND streams.
2. Select streams within **1000 feet** of **StreamCrossing**.
3. Copy selected streams into the project geodatabase as **Stream**.
4. The HydroID attribute on Stream is Text, but an integer version is useful for relationships. Add a **HydroID_int** field of type **Long** to Stream, and calculate it to be **HydroID**.
5. Remove the original HAND streams layer.

Key stream attributes:

- HydroID - unique identifier (ID) for each stream in HAND
- feature_id - National Water Model (NWM) ID for the NWM stream that best matches the HAND stream. Note that generally HAND has a finer spatial resolution than NWM, which means multiple HAND stream segments could be part of the same NWM stream.

Rating Curves

FAST uses HAND rating curves that have been improved to remove artifacts from burning streams. These rating curves are delivered with FAST in Esri file geodatabase format in **HydroTable.gdb**.

1. From your FAST datasets, add **HydroTable.gdb\RatingCurve** to the map.
2. Add a Relate from **Stream** to **RatingCurve** (1 to many) based on **HydroID_int - HydroID**.
3. Select all **Streams**.
4. Open the **Stream** attribute table, click the hamburger menu on the right, and click **Related Data > RatingCurve**. This selects RatingCurve rows associated with the streams.
5. Use the **Copy Rows** geoprocessing tool to copy the rows into the project geodatabase as **RatingCurve**.
6. Remove the original RatingCurve table.
7. Clear selected features.

Data Preparation

For FAST data, spatial references are in feet, survey data are in feet, but HAND rating curves and road z-values are in meters. Much of data preparation is ensuring consistent units. Attributes must also conform to what Arc Hydro expects, e.g., "V" as the velocity field name rather than "vel_m_s".

Map

1. In the **Contents** pane, right-click the map name and click **Properties**.
2. On the **Coordinate Systems** tab, change the coordinate system to the target coordinate system.
3. Click **OK**.

Roads

1. Use the **Project** geoprocessing tool to project Road3D_m to the target coordinate system. When running the tool, be sure "Preserve Shape" is checked. Save the result in the **Layers feature dataset** as **Road3D_ft**. The Project tool does not update Z values, so you will do that with Python.
2. On the **Analysis** tab of the ribbon, click the **Python** dropdown and click **Python Window**.
3. Enter this function.

```
def scale_z(layer_name, multiplier):
    import arcpy
    aprx = arcpy.mp.ArcGISProject("CURRENT")
    m = aprx.activeMap
    lyr = m.listLayers(layer_name)[0]

    with arcpy.da.UpdateCursor(lyr, ["SHAPE@", "OBJECTID"]) as cursor:
        for row in cursor:
            geom = row[0]
            if geom is None:
                print(f"Warning: Null geometry for OBJECTID {row[1]}")
                continue
            new_parts = []
            for part in geom:
                new_part = [
                    arcpy.Point(p.X, p.Y, p.Z * multiplier)
                           if p and p.Z is not None else p
                    for p in part
                ]
                new_parts.append(arcpy.Array(new_part))
            new_geom = arcpy.Polyline(
                arcpy.Array(new_parts),
                geom.spatialReference,
                has_z=True
            )
            row[0] = new_geom
            cursor.updateRow(row)
    print('Done')
```

4. With Road3D_ft added to the map, enter this Python command:

```
scale_z("Road3D_ft", 3.28084)
```

5. You can check the final Z values by selecting a road in an area where you know approximate elevations. Then on the **Edit** tab of the ribbon, click **Edit Vertices**, and you'll see a panel showing the Z values for each vertex.
6. Remove **Road3D_m** from the map.

Streams

1. Use the **Project** geoprocessing tool to project **Stream** to the target coordinate system in the **Layers feature dataset** as **Stream_ft**.

2. Remove **Stream** from the map.

Field Survey

After projecting the field survey to match the target coordinate system, verify that the measurements from the culvert to the road surface were measured from the culvert invert, not the culvert top. One way to check is to see if the measurement is less than the culvert height, which is impossible if the measurement was taken from the culvert invert. If the measurement is less than the culvert height, assume the surveyor measured from the culvert top and add the culvert height to the measurement in the attribute table.

1. Use the **Project** geoprocessing tool to project **StreamCrossing** to the target coordinate system in the **Layers feature dataset** as **StreamCrossing_ft**.
2. Remove **StreamCrossing** from the map.
3. Select from **StreamCrossing_ft** where `UniformUSRoadHtAbvInvert_ft <= UniformCulvertHeight_ft`. If any rows are selected, compute **UniformUSRoadHtAbvInvert_ft** as `!UniformUSRoadHtAbvInvert_ft! + !UniformCulvertHeight_ft!`
4. Repeat the previous step for **UniformDSRoadHtAbvInvert_ft**.

APUNIQUEID

HydroID is a unique identifier for rows in a geodatabase. Arc Hydro manages HydroID population using a table named APUNIQUEID. The rating curve table already has HydroID values in it, so we need to initialize and update APUNIQUEID so that it doesn't reuse the existing HydroIDs. To do this, we'll ask it to populate HydroID on another feature class, which will trigger creation of the APUNIQUEID table.

1. Use the **Assign HydroID** geoprocessing tool to assign HydroID to **StreamCrossing_ft**.
2. Delete the **HydroID** field from **StreamCrossing_ft**. It was just a temporary field to spawn the APUNIQUEID table.
3. Open the **RatingCurve** table. Copy the largest **HydroID** value (Hint: Sort Descending). Close the table.
4. Add **APUNIQUEID** to the map. Open the table.
5. Paste the HydroID in the **LASTID** column.
6. On the **Edit** tab of the ribbon, click **Save**.
7. Remove **APUNIQUEID** from the map.

Rating Curves

To fix the HAND rating curves we must convert meters to feet and add several fields which Arc Hydro expects.

1. Copy the **RatingCurve** table to **RatingCurve_ft**.
2. Use the **Add Field** geoprocessing tool to add a **stage_ft** field of type **Double**.
3. Use the **Calculate Field** geoprocessing tool to compute **stage_ft** as `!stage_m!*3.28084`
4. Remove **RatingCurve** from the map.
5. Use the **Add Field** geoprocessing tool to add a **FeatureID** field of type **Long**.
6. Use the **Calculate Field** geoprocessing tool to compute **FeatureID** as `!HydroID!`

7. Similarly, add and calculate these fields, all of type **Double**.
    a. **H** : `!stage_ft!`
    b. **Q**: `!discharge_cfs!`
    c. **V**: `!vel_ft_s!`

Arc Hydro Workflow

Create FTG culvert feature class and populate basic attributes

This step involves initializing the Arc Hydro culvert point feature class (really, it represents stream crossings). There are several ways in which the survey data can be loaded into the Flood Transportation Geodatabase (FTG) culvert data structure needed to support HY-8 headless operations (hy8runner). Survey data can contain a much richer attribute list and value domains than are supported by hy8runner. The approach described here is one of many possible ones. It keeps the survey data unaltered (for potential other purposes) and calculates required hy8runner attributes.

The following table indicates FTG culvert attributes needed for hy8runner operations and their match in the stream crossing survey data. Values in parenthesis in the "FAST stream crossing layer fields and values" column indicate matching/mapping values in the "FTG culvert layer fields and values" column.

Table 1. Field Mapping from FAST to Arc Hydro Stream Crossings.

FTG culvert layer fields and values	FAST stream crossing layer fields and values	Comment
Crossing_ID	Crossing_ID	GUID type
RoadSurface: • 1 – paved • 0 – not paved	RoadSurface: • Asphalt (1) • Concrete (1) • Gravel (0) • Dirt (0)	
RoadWidth	RoadWidth_ft	Numerical value / units
CulvShape: • 1 – circular • 2 – box	UniformCulvertShape: • Box (2) • Circular (1) • Elliptical (2*)	Elliptical shape with width/height ratio < 1.75 is treated as box (2) type. Unlisted shapes are ignored.
CulvMaterial: • 1 – concrete • 2 – metal	UniformCulvertMaterial: • Concrete (1) • Corrugated Steel (2) • Steel Structural Plate (2) • Corrugated Aluminum (2) • Aluminum Structural Plate (2) • Masonry (1)	Unlisted materials are ignored.
CulvBarrel	NumCulverts	Numerical value
CulvLength	UniformCulvertLength_ft	Numerical value / units
CulveHeight	UniformCulvertHeight_ft	Numerical value / units
CulvWidth	UniformCulvertWidth_ft	Numerical value / units
CulvUSHeight	UniformUSRoadHtAbvInvert_ft	Numerical value / units
CulvDSHeight	UniformDSRoadHtAbvInvert_ft	Numerical value / units

Comment	Label	Text. The FAST label includes stream and road name, which is what Arc Hydro assumes for the comment.

1. Run the **Create FTG Culvert Feature Class** geoprocessing tool to create a new feature class (**CulvertWorkflow**) with the FTG culvert schema and place it in the **Layers** feature dataset (this enforces correct spatial reference of the new feature class).
2. Use the **Append** geoprocessing tool to append **StreamCrossing_ft** to **CulvertWorkflow**. In this step, we want to bring in only the GlobalID (as Crossing_ID) and geometry of the stream crossing features.
    a. For Field Matching Type, select "Use the field map to reconcile field differences".
    b. Remove any field mapping besides Crossing_ID (Hint: **Edit Field Properties > Remove**). You can see that field mappings are removed if a yellow triangle with an exclamation mark appears next to the field name in the Field Map.

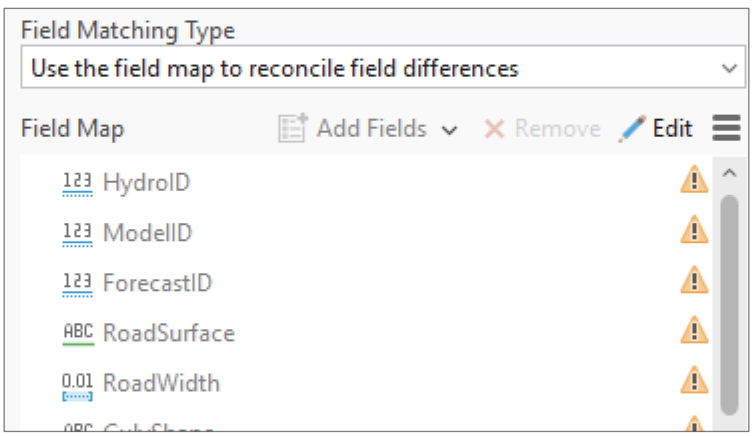


Figure 9. Example display showing no field mappings in the Append tool.

    c. For **Crossing_ID**, edit field properties and select **GlobalID** as the matching field.
    d. Click **Run**.
3. Use the **Join Field** geoprocessing tool to join all attributes from **StreamCrossing_ft** to **CulvertWorkflow** using **Crossing_ID** as the key field (maps to GlobalID on StreamCrossing_ft). Numbers are appended to field names automatically to prevent conflicts, e.g., RoadSurface from StreamCrossing_ft becomes RoadSurface_1 when joined to **CulvertWorkflow**.
4. Review the result. CulvertWorkflow should now have all FTG fields as well as desired survey fields.
5. Use the **Calculate Fields (multiple)** geoprocessing tool to calculate measurement and comment FTG fields on **CulvertWorkflow** using stream crossing attributes. These are a direct calculation from the survey data.
    a. Input Table - CulvertWorkflow
    b. Expression Type - Python
    c. CulvBarrel = !NumCulverts!
    d. CulvLength = !UniformCulvertLength_ft!

e. CulveHeight = !UniformCulvertHeight_ft!
f. CulvWidth = !UniformCulvertWidth_ft!
g. CulvUSHeight = !UniformUSRoadHtAbvInvert_ft!
h. CulvDSHeight = !UniformDSRoadHtAbvInvert_ft!
i. Comment = !Label!
j. RoadWidth = !RoadWidth_ft!

6. Use **Calculate Field** to calculate **RoadSurface** on **CulvertWorkflow** using a **Python** expression. This will use RoadSurface_1 from the survey as input, and map the numerous possibilities to the limited set that Arc Hydro can deal with.
   a. RoadSurface = roadsurfacemap(!RoadSurface_1!)
   b. Use the following for the Code Block.

```
def roadsurfacemap(RoadSurface_1):
    if RoadSurface_1 == "Asphalt":
        return "1"
    if RoadSurface_1 == "Concrete":
        return "1"
    if RoadSurface_1 == "Gravel":
        return "0"
    if RoadSurface_1 == "Dirt":
        return "0"
    return "-1"
```

   c. Check the resulting attribute table. If "-1" appears, then the road surface values could not be mapped and you will need to check the input data.

7. Use **Calculate Field** to calculate **CulvShape** on **CulvertWorkflow** using a **Python** expression.
   a. CulvShape = culvshapemap(!UniformCulvertShape!, !UniformCulvertHeight_ft!, !UniformCulvertWidth_ft!)
   b. Use the following for the Code Block. Note the part about elliptical culverts which you can modify or remove

```
def culvshapemap(UniformCulvertShape, h, w):
    if UniformCulvertShape == "Box":
        return "2"
    if UniformCulvertShape == "Circular":
        return "1"
    if UniformCulvertShape == "Elliptical":
        rat = w / h
        if (rat >= 1.75):
            return "2"
    return "-1"
```

8. Use **Calculate Field** to calculate **CulvMaterial** on **CulvertWorkflow** using a **Python** expression.
   a. CulvMaterial = culvmatmap(!UniformCulvertMaterial!)
   b. Use the following for the Code Block.

```
def culvmatmap(UniformCulvertMaterial):
    if UniformCulvertMaterial in ["Concrete", "Masonry"]:
        return "1"
    if UniformCulvertMaterial in ["Corrugated Steel", "Steel Structural Plate",
"Corrugated Aluminum", "Aluminum Structural Plate"]:
        return "2"
    return "-1"
```

Create weir component of the crossing

Create the weir component of the crossing by limiting the 3D road representation within specified horizontal (800 ft) and vertical (5 ft) distance. Note that this will populate Road3DID field in the input feature class with HydroID of the constructed weir segment for that crossing.

1. Open the **Extract Lines On Distance And Z** geoprocessing tool.
2. Set these inputs.
    a. Input Lines - Road3D_ft
    b. Input Points - CulvertWorkflow
    c. Buffer Distance - 800
    d. Delta Z Value - 5
    e. Link Back Field Name - Road3DID (the default)
    f. Output Lines - Layers\CulvertRoadSurface800_5 (i.e., save CulvertRoadSurface800_5 in your Layers feature dataset in your project geodatabase)
3. Click **Run**.

Finalize culvert attribution

Calculate additional culvert properties needed for HY-8 analyses. Note that in the previous step a link between the weir component of the culvert and the culvert point was already established, but we will include the layer here as well to calculate other properties related to the weir component.

1. Open the **Calculate FTG Culvert Properties** geoprocessing tool.
2. Set these inputs.
    a. Input FTG Culvert Layer - CulvertWorkflow
    b. Input 3D Road Segment Layer - CulvertRoadSurface800_5
    c. Input Stream Layer - Stream_ft
3. Click **Run**.
4. Delete rows in **CulvertWorkflow** which have null ModelID. These are stream crossings which Arc Hydro could not map to a stream for which we have a rating curve available.

Run HY-8 in silent mode

Run HY-8 in silent mode and calculate rating curves.

1. Open the **HY-8 Integration** geoprocessing tool.
2. Set these inputs.
    a. Input Culvert Layer - CulvertWorkflow
    b. Input 3D Road Segment - CulvertRoadSurface800_5
    c. Input Stream Rating Curve Table - RatingCurve_ft
    d. Output Culvert Rating Curve Table - CulvertWorkflow_rtc
3. Click **Run**.

To review the resulting culvert rating curves, open the resulting culvert rating curve table and inspect the results. Figure shows results for one stream crossing. The last row where Q_Roadway is zero is where water just starts to overtop the road, which for the example, the threshold stream discharge 75.2 cfs.

CulvertWorkflow_rtc CulvertWorkflow

Field: Selection: Highlighted:

	OBJECTID *	CrossingName	FeatureID	Elevation	H	Q	Q_Barrel	Q_Roadway
1	647	Crossing_25072461	25072461	611.44	0	20	20	0
2	648	Crossing_25072461	25072461	613.25	1.81	75.2	75.2	0
3	649	Crossing_25072461	25072461	613.42	1.98	80	78.98	1.02
4	650	Crossing_25072461	25072461	614.25	2.81	176	78.59	97.4
5	651	Crossing_25072461	25072461	614.71	3.27	310	55.81	254.15
6	652	Crossing_25072461	25072461	615.22	3.78	478	19.06	458.94

Figure 10. Example HY-8 rating curve output for one stream crossing.

Results

Here we compare the original HAND rating curves and the updated HY-8 rating curves for a few example locations. Since HY-8 uses HAND rating curves as the downstream boundary condition, the curves will look very similar, except for the part where the road and embankment act as a significant barrier for streamflow (see Figure). When the culvert conveyance is large enough to approximate the natural channel, then the rating curves will be almost identical (see Figure).

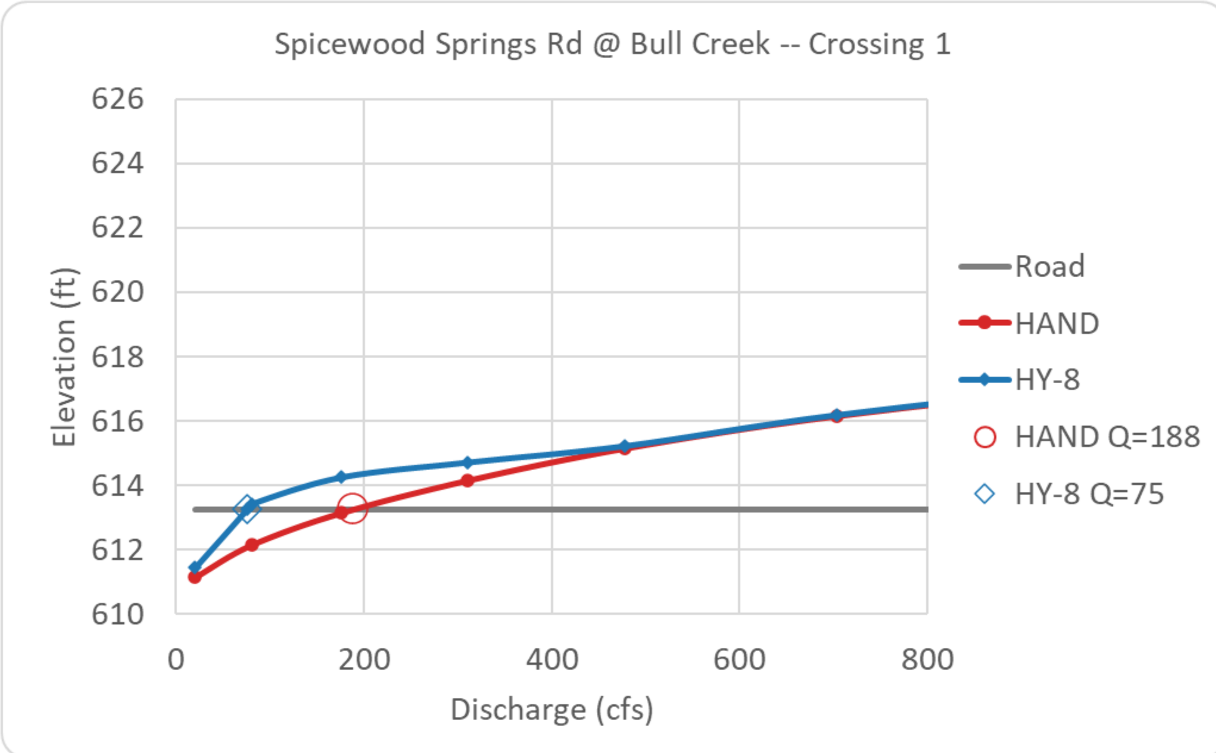


Figure 11. Rating curves from HAND and HY-8 for Spicewood Springs Rd at Bull Creek, crossing 1. The HY-8 threshold discharge for overtopping the road is 77 cfs, compared to 196 cfs for HAND. Without taking into account culvert size and the road embankment, it appears for this stream crossing that HAND may have been significantly overestimating the stream discharge required to flood the road.

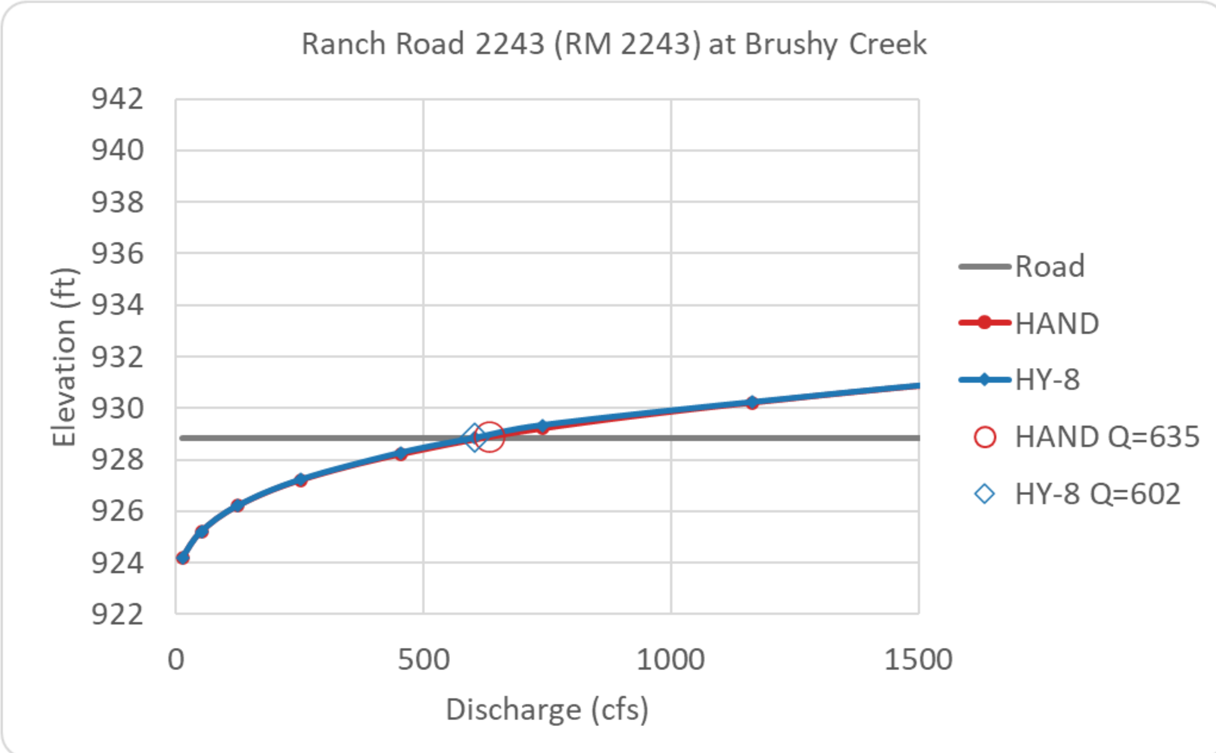


Figure 12. Rating curves from HAND and HY-8 for RM 2243 at Brushy Creek. The HY-8 threshold discharge for overtopping the road is about 5% lower than for HAND. Using a hydraulic model in this case did not significantly change the road flood threshold.

Shoal Creek at Anderson Lane

This is a bridge class culvert with five rectangular culverts. The bridge includes details such as gutters and railings that we are not modeling. There are also varying heights between each culvert invert and the bridge deck, and we are just using an average number (8.1 ft). The surveyor (David Maidment) determined that the culvert is flat (no slope).

Figure 18. Upstream view of Shoal Creek at Anderson Lane stream crossing.

Since this location is not a low water crossing, it was not in the TWDB LWC dataset referenced elsewhere in this report. Therefore, to obtain a point location, the author selected the bridge out of the SNBI bridge points dataset from TxDOT. Culvert and crossing attributes were then populated manually, just to provide the minimum data required for running HY-8 with Arc Hydro.

The procedure was:

1. In an ArcGIS Pro project, add the bridges and isolate the bridge of interest with this filter: `ID01_BRDG_NBR = '142270B00174006'`
2. Run **Create FTG Culvert Feature Class** with output name "Culvert".
3. Set the map coordinate system to match Culvert (USA Contiguous Albers Equal Area Conic USGS).
4. Run **Append** with the option "Use the field map to reconcile field differences" to load the bridge location into the culvert feature class.
5. Add a **Name** field (text) to **Culvert**.
6. Set these attribute values based on field survey by David Maidment:
    a. RoadSurface - 1
    b. RoadWidth - 72
    c. CulvShape - 2
    d. CulvMaterial - 1
    e. CulvBarrel - 5
    f. CulvLength - 72
    g. CulvHeight - 6
    h. CulvWidth - 10
    i. CulvUSHeight - 8.1
    j. CulvDSHeight - 8.1
    k. Name - Shoal Creek at Anderson Lane
7. Save edits.
8. Run **Extract Lines On Distance And Z** to create the weir component of the culvert.
    a. Input Lines - Road3D_ft
    b. Input Points - Culvert
    c. Buffer Distance - 800
    d. Delta Z Value - 5
    e. Link Back Field Name - Road3DID
    f. Output Lines - CulvertRoadSurface800_5
9. Run **Calculate FTG Culvert Properties**. Use **CulvertRoadSurface800_5** as the road layer.
10. Run **HY-8 Integration**.

In the results, the HY-8 rating curve basically matched the HAND rating curve. The difference in streamflow threshold to overtop the bridge is 1%. This implies that the culverts do not exhibit a significant reduction in flow capacity compared to the natural stream channel.

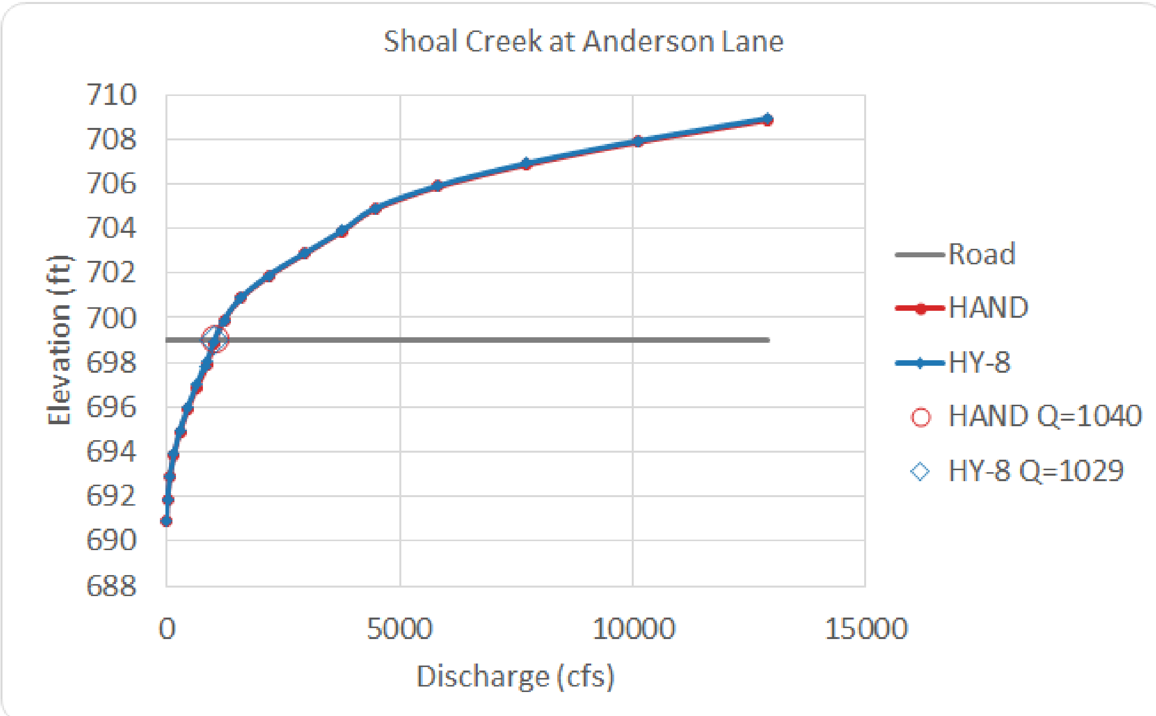


Figure 13. Comparing HAND and HY-8 adjusted rating curves for Shoal Creek at Anderson Lane.

The authors increased the distance from invert to top of road, simulating a higher embankment, to see how much height is needed to make a significant difference in the rating curves. Results are shown in Table 2. Assuming full lateral culvert coverage across the channel, it appears that for this particular location, adding an embankment approximately the same as the culvert height results in a significant (about 20% difference).

Table 2. Embankment Height Impact on Flood Thresholds (Qflood).

Additional road height, ft	Total "embankment" height	Qflood difference, cfs	Qflood diff, percent
0	2	11	1
2	4	85	5
5	7	947	25
10	12	8640	65

Caveats with the Rating Curve Workflow

This workflow uses HAND rating curves as a starting point and refines them based on culvert and road properties. If the HAND rating curve was already inaccurate, then the resulting rating curve from HY-8 will likely also not be accurate. To improve results, instead of relying on HAND, the workflow could use local elevation data to cut cross sections and derive rating curves independent from HAND. This functionality could be a future enhancement to the Arc Hydro tools which already have a tool for retrieving 1-meter elevation data from the USGS.

In the output rating curve table, for a given stream crossing, if there is only one row where Q_Roadway is zero, then the road flooded at the first discharge tested, which means the culverts are very undersized at the crossing. Since HY-8 did not report lower flows where culverts were not at capacity, we recommend acquiring additional data such as a 1-meter DEM for the area to compute proper boundary conditions rather than rely on HAND. This may improve results. One can manually run HY-8 to look at lower flows as well.

CrossingName	FeatureID	Elevation	H	Q	Q_Barrel	Q_Roadway
Crossing_25072558	25072558	522.21	0	20.67	20.67	0
Crossing_25072558	25072558	522.4	0.19	26	25.68	0.32
Crossing_25072558	25072558	523.6	1.39	106	59.1	46.88
Crossing_25072558	25072558	524.64	2.43	244	53.87	190.12

Figure 14. Only one row where Q_Roadway is zero indicates undersized culverts.

Display in FAST

Adding LWCs and BCCs to the FAST map is beyond the scope of this project. However, on the FAST development site, there is an example LWC layer for a few locations in Austin. The FAST site is maintained by KISTERS, so to display these features in FAST, one must prepare a GeoPackage of the data and send it to KISTERS.

Note: If LWCs and BCCs use rating curves from HY-8, then their flood status might not match that of their associated road line features since road flooding is based on HAND. We have not devised a method of updating rating curves for an entire catchment based on the rating curve at a given stream crossing.

Data Preparation

To prepare HY-8 outputs for use in FAST, Dr. Whiteaker wrote package_lwcs.py, a Python script that can be executed on a machine with access to the Arc Hydro and HY-8 outputs and which has ArcGIS Pro installed. This script takes hydraulic modeling results for stream crossings, calculates the streamflow levels that would cause roads to begin flooding (and optionally, reach several specified flood depths), attaches useful road information, converts everything to a common map coordinate system, and exports the final dataset for use in FAST. While the script was written when developing LWC workflows, it can be used without modification for BCC workflows as well.

Inputs to the script are hard-coded at the top as constants. The constants include:

- _IN_AH_CULVERTS - Path to the feature class from Arc Hydro representing stream crossing points. While Arc Hydro terminology calls them culverts, there could be several culverts at a given stream crossing, so this is really a stream crossing dataset, not purely a culvert dataset.
- _IN_ROADS - Path to the feature class from Arc Hydro representing the road segments associated with stream crossings.
- _RATINGS - Rating curve table with data generated by HY-8.
- _SCRATCH_GDB - Location of temporary geodatabase where intermediate outputs will be stored.

- _GPKG - Path to and name of the output GeoPackage where the result will be written. This geopackage will be sent to KISTERS for inclusion in FAST.
- _TARGET_CRS - EPSG code for the target coordinate system of the output.
- _STAGES - Road flood depths in feet at which to compute flood thresholds. 0 (road just overtopped) is automatically included.

At a high level, the processing steps are:

1. Copy the stream crossing dataset so you can work on it without altering the original.
2. Attach road information to each stream crossing.
    a. Match each stream crossing to its associated road.
    b. Bring over desired attributes such as road classification and OpenStreetMap ID.
3. Standardize the map coordinates.
    a. Check what coordinate system the stream crossing data is currently using.
    b. Convert it to a common format (e.g., WGS84 latitude/longitude) if needed so the data can be shared and mapped consistently.
4. Prepare the hydraulic model output.
    a. Load the HY-8 rating curve results (the table that relates stage and discharge).
    b. Remove records that are known to be unreliable or outside the valid model range.
    c. Clean up duplicate or problematic entries.
5. Determine flooding thresholds for each stream crossing.
    a. For every stream crossing:
        i. Find the flow rate where water first reaches the road surface (the road just starts to overtop).
        ii. Estimate the flow rates needed to produce additional depths of water on the road (from _STAGES in this script). This is done by interpolating between HY-8 model results when an exact value doesn't exist.
    b. Store those thresholds with each culvert.
        i. Add new fields such as:
            1. Flow when road first overtops
            2. Flow for 0.5 ft of water on the road
            3. Flow for 2 ft of water
            4. Flow for 5 ft of water
        ii. Write the computed values back to the stream crossing dataset.
6. Export the result.
    a. Save the enhanced stream crossing dataset with computed flood thresholds into a GeoPackage to be delivered to KISTERS for inclusion in FAST.

The GeoPackage produced by the script includes a dataset with stream crossing locations, where each crossing has attributes for flood thresholds and other attributes (such as road name) that were specified in the script.

Display Options

Unlike span bridges, which have several categories of flood warning severity, for LWCs and BCCs we recommend just showing whether the road is wet or dry. An example of this is shown in the FAST development site for the Austin District.

https://bridges.txdot.kisters.cloud/dev/fast/fast.html?district=14&mode=da

You can toggle off display of other flood layers to focus on the low water crossings. The crossings are shown with two symbols: red for overtopped, and green for clear (not overtopped). The symbol shape looks like an arch culvert with a horizontal road line on top.

The pop-up for the crossing includes worst-case status from the current forecast, crossing name, the maximum streamflow from the forecast, and the streamflow threshold at which flooding occurs for the crossing. These attributes are somewhat arbitrary for testing purposes. The pop-up could be reconfigured if adding this layer to the production environment.

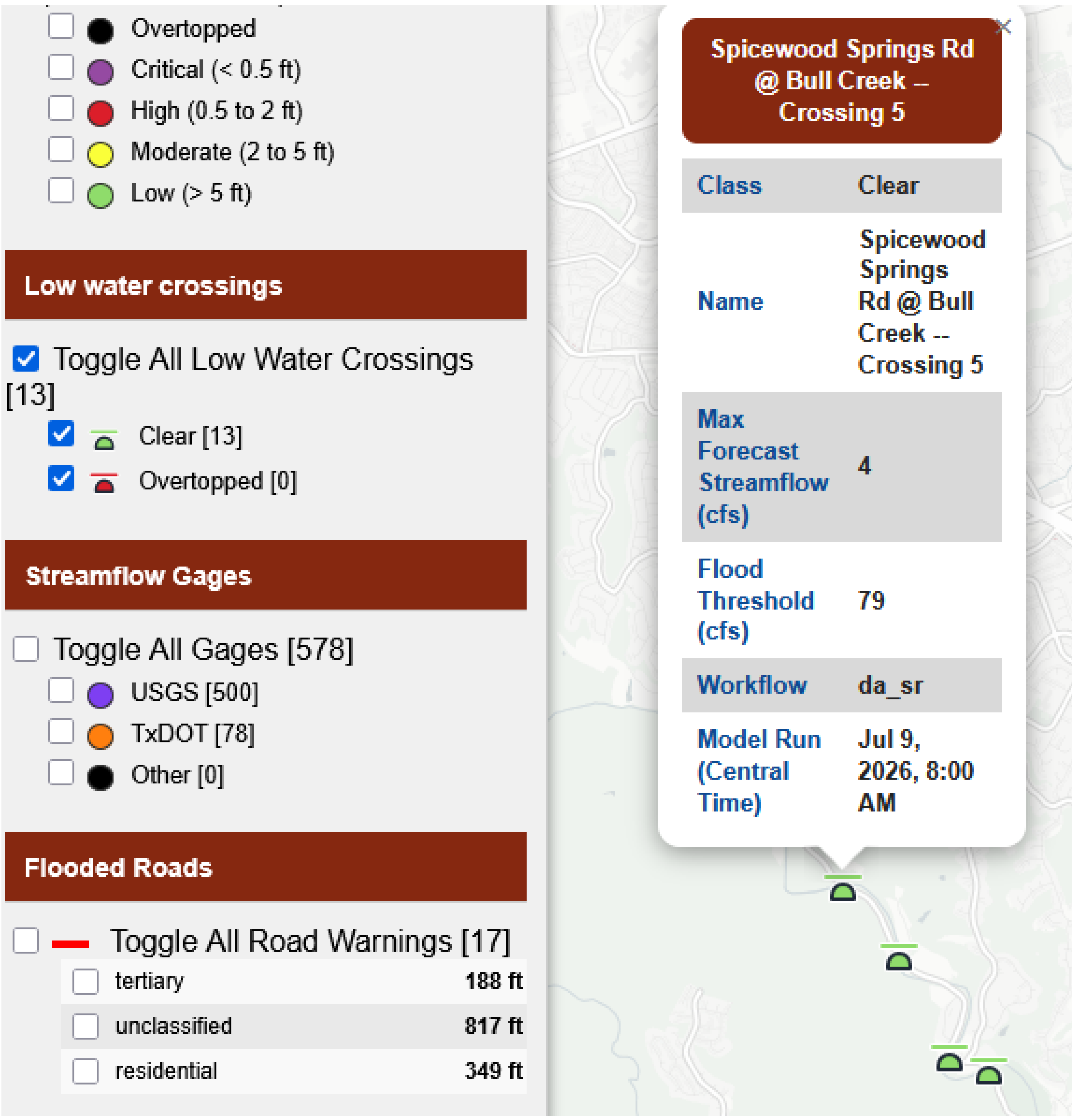


Figure 15. FAST Interface with Low Water Crossings

This concludes the report.

Appendix A: package_lwcs.py

```
"""Processes Arc Hydro HY-8 outputs and saves to a GeoPackage."""

import os

import numpy as np
import pandas as pd
from scipy.interpolate import interp1d
import arcpy

_IN_AH_CULVERTS = r"HY8Integration_Base.gdb\CulvertWorkflow_ft"
_IN_ROADS = r"HY8Integration_Base.gdb\CulvertRoadSurface_ft"
_RATINGS = r"HY8Integration_Base.gdb\CulvertWorkflow_rtc_ft"
_SCRATCH_GDB = 'scratch.gdb'
_GPKG = r"culverts.gpkg"
_TARGET_CRS = 4326  # WGS 84
_STAGES = [0.5, 2, 5]  # Stages in feet at which to compute thresholds. 0 (road just
overtopped) is automatically included.


def needs_transformation(crs1, crs2):
    if "NAD_1983" in crs1 and "NAD_1983" in crs2:
        return False
    if "WGS_1984" in crs1 and "WGS_1984" in crs2:
        return False
    if "NAD_1983" in crs1 and "WGS_1984" in crs2:
        return True
    if "WGS_1984" in crs1 and "NAD_1983" in crs2:
        return True
    if "1983" in crs1 and "1983" in crs2:
        return False
    if "1984" in crs1 and "1984" in crs2:
        return False
    if "1983" in crs1 and "1984" in crs2:
        return True
    if "1984" in crs1 and "1983" in crs2:
        return True

    raise ValueError(f'Could not determine if transformation is needed between {crs1}
and {crs2}')


def project_fc(fc, to_crs, out_fc):
    fc_name = os.path.basename(fc)
    print(f'Checking projection for {fc_name}')

    # Determine the appropriate transformation
    fc_crs = arcpy.Describe(fc).spatialReference.exportToString()
    if "1983_2011" in to_crs + fc_crs:
        transformation = "WGS_1984_(ITRF08)_To_NAD_1983_2011"
    else:
        transformation = "WGS_1984_(ITRF00)_To_NAD_1983"

    if fc_crs == to_crs:
        print(f'    {fc_name} is already in {to_crs}. Skipping projection, and just
copying features instead.')
        arcpy.management.CopyFeatures(fc, out_fc)
```

```
    else:
        print(f'    Projecting {fc_name} to {to_crs}')
        if needs_transformation(fc_crs, to_crs):
            arcpy.management.Project(
                in_dataset=fc,
                out_dataset=out_fc,
                out_coor_system=to_crs,
                transform_method=transformation,
                preserve_shape="PRESERVE_SHAPE"
            )
        else:
            arcpy.management.Project(
                in_dataset=fc,
                out_dataset=out_fc,
                out_coor_system=to_crs,
                preserve_shape="PRESERVE_SHAPE"
            )


def join_attrs_from_roads(in_roads, culv_with_name_fc):
    """Join roads to culverts via HydroID to Road3DID to get osm_id and fclass from
roads.

    This function modifies the input culvert feature class to add the attributes.

    Args:
        in_roads (str): Path to the road feature class created by Arc Hydro.
        culv_with_name_fc (str): Path to the culvert feature class with attributes
from LWC survey.
    """
    print('Joining road attributes to culverts')
    arcpy.management.JoinField(
        in_data=culv_with_name_fc,
        in_field="Road3DID",
        join_table=in_roads,
        join_field="HydroID",
        fields="osm_id;fclass"
    )


def add_threshold_fields(culvert_fc, stages_list):
    """Add fields to the culvert feature class for each stage in stages_list.

    This function modifies the input culvert feature class to add fields for each
stage in stages_list.

    Args:
        culvert_fc (str): Path to the culvert feature class.
        stages_list (list): List of stages (in feet) at which to compute thresholds.

    Returns:
        dict: A dictionary mapping each stage to its corresponding field name in the
culvert feature class
    """
    print('    Adding fields for specified stages')
    stage_field_dict = {}

    # Special case: Add threshold for when road just gets wet
```

```
    arcpy.management.AddField(culvert_fc, 'Q_overtopped', 'LONG', field_alias='Q (cfs)
to overtop road')

    # Add other stages
    for stage in stages_list:
        field_name = f'Q_{str(stage).replace(".", "_")}_ft'
        alias = f'Q (cfs) for {stage} ft of water on road'
        if field_name not in [f.name for f in arcpy.ListFields(culvert_fc)]:
            print(f'        Adding field {field_name}')
            arcpy.management.AddField(culvert_fc, field_name, 'LONG',
field_alias=alias)
        else:
            print(f'        Field {field_name} already exists. Skipping adding
field.')
        stage_field_dict[stage] = field_name
    return stage_field_dict


def interpolate_streamflow(rating_df_for_id, stage):
    interp_func = interp1d(
        rating_df_for_id['Elevation'],
        rating_df_for_id['Q'],
        kind='linear',
        fill_value='extrapolate',
        assume_sorted=True   # now safe because of the global sort
    )
    result = interp_func(stage)  # Likely a NumPy array

    # Convert to a scalar if it's a single-element array
    return result.item() if np.ndim(result) == 0 else result


def compute_thresholds(culvert_fc, ratings_table, stages_list):
    """Compute the streamflow thresholds for each culvert at the specified stages.

    This function modifies the input culvert feature class to add fields for each
stage in stages_list.

    HydroID in the culvert feature class matches FeatureID in the ratings table.
    In the culverts, TopofRoadElevation is the road elevation in feet.
    The ratings table has Q for discharge (cfs) and Elevation (ft).

    In the ratings table for a given FeatureID, the row with the highest Q where
Q_Roadway is still 0 is the threshold for overtopping (0 ft of water on road).

    Args:
        culvert_fc (str): Path to the culvert feature class.
        ratings_table (str): Path to the rating curves table (assume English units).
        stages_list (list): List of stages (in feet) at which to compute thresholds.
    """
    print('Computing streamflow thresholds for specified stages')
    stage_field_dict = add_threshold_fields(culvert_fc, stages_list)
    # Load the ratings table into a pandas DataFrame
    ratings_df = pd.DataFrame(arcpy.da.TableToNumPyArray(ratings_table, ['FeatureID',
'Q', 'Q_Roadway', 'Q_Barrel', 'Elevation', 'H']))
    # Remove rows where H > 83.1. 83' is the upper limit of HAND, which is the
downstream boundary condition for HY-8.
    # If H exceeds that, HY-8 can't figure out the flow correctly.
```

```
    ratings_df = ratings_df[ratings_df['H'] <= 83.1].copy()
    ratings_df = ratings_df.drop(columns=['H'])
    # If any rows have Q > 0 but Q_Barrel is 0, raise a warning
    problematic_rows = ratings_df[(ratings_df['Q'] > 0) & (ratings_df['Q_Barrel'] ==
0)]
    if not problematic_rows.empty:
        print("Warning: Some rows have Q > 0 but Q_Barrel = 0. These rows will be
removed.")
        problematic_ids = problematic_rows['HydroID'].unique()
        print(f"HydroIDs with this issue: {problematic_ids}")
        ratings_df = ratings_df[~((ratings_df['Q'] > 0) & (ratings_df['Q_Barrel'] ==
0))]

    # For each FeatureID, find the row with the highest Q where Q_Roadway is still 0,
and drop the other rows where Q_Roadway is 0
    zeroes_df = ratings_df[ratings_df['Q_Roadway'] == 0]
    # Group by FeatureID and keep only the row with the max Q
    print('    Filtering ratings table to remove duplicate zero Q_Roadway entries')
    zeroes_df = zeroes_df.sort_values(by=['FeatureID', 'Q'], ascending=[True, False])
    zeroes_df = zeroes_df.loc[~zeroes_df.duplicated('FeatureID', keep='first')].copy()
    # Combine the nonzero Q_Roadway rows with the filtered zero-Q_Roadway rows
    ratings_df = pd.concat(
        [ratings_df[ratings_df['Q_Roadway'] != 0], zeroes_df],
        ignore_index=True
    )
    # Sort globally by FeatureID and Elevation (safe for interp1d)
    ratings_df = ratings_df.sort_values(by=['FeatureID', 'Elevation'],
ascending=[True, True])

    # Get a dataframe of the unique culvert IDs and road elevations
    culvert_df = pd.DataFrame(arcpy.da.TableToNumPyArray(culvert_fc, ['HydroID',
'TopofRoadElevation']))

    # Warn if culverts missing from ratings
    culvert_ids = set(culvert_df['HydroID'])
    ratings_ids = set(ratings_df['FeatureID'])
    if len(culvert_ids - ratings_ids) > 0:
        print(f'    WARNING: Culvert IDs not in rating curve table, usually due to
missing culvert attributes: {culvert_ids - ratings_ids}.\n        Thresholds will not
be computed for these culverts.')
        culvert_df = culvert_df[culvert_df['HydroID'].isin(ratings_ids)]

    # Special case: Copy threshold value for when road just gets wet (0 ft of water on
road)
    # For each FeatureID, copy the Q value in the row where Q_Roadway is 0 to
Q_overtopped
    print('    Computing threshold for stage 0 ft (road just overtopped)')
    overtopped_df = ratings_df[ratings_df['Q_Roadway'] == 0][['FeatureID',
'Q']].copy()
    overtopped_df = overtopped_df.rename(columns={'FeatureID': 'HydroID', 'Q':
'Q_overtopped'})
    culvert_df = culvert_df.merge(overtopped_df, on='HydroID', how='left')
    culvert_df['Q_overtopped'] = culvert_df['Q_overtopped'].round().astype(int)
    with arcpy.da.UpdateCursor(culvert_fc, ['HydroID', 'Q_overtopped']) as cursor:
        for row in cursor:
            hydro_id = row[0]
            if hydro_id in culvert_df['HydroID'].values:
```

```
                threshold_value = culvert_df.loc[culvert_df['HydroID'] == hydro_id,
'Q_overtopped'].values[0]
                row[1] = threshold_value
                cursor.updateRow(row)

    # Compute thresholds
    for stage, field_name in stage_field_dict.items():
        print(f'    Computing threshold for stage {stage} ft')
        culvert_df['target_stage'] = culvert_df['TopofRoadElevation'] + stage
        print('        Interpolating streamflow values')
        culvert_df[field_name] = culvert_df.apply(lambda x:
interpolate_streamflow(ratings_df[ratings_df['FeatureID'] == x['HydroID']],
x['target_stage']), axis=1)
        # Round to the nearest whole number
        culvert_df[field_name] = culvert_df[field_name].round().astype(int)
        # Update the field in the feature class
        print(f'        Updating field {field_name} in feature class')
        with arcpy.da.UpdateCursor(culvert_fc, ['HydroID', field_name]) as cursor:
            for row in cursor:
                hydro_id = row[0]
                if hydro_id in culvert_df['HydroID'].values:
                    threshold_value = culvert_df.loc[culvert_df['HydroID'] ==
hydro_id, field_name].values[0]
                    row[1] = threshold_value
                    cursor.updateRow(row)


def save_to_geopackage(culverts_fc, output_gpkg):
    print('Exporting culvert feature class to GeoPackage')
    culverts_fc_abs_path = os.path.abspath(culverts_fc)
    gpk = os.path.abspath(output_gpkg)  # arcpy requires absolute path for this
function
    arcpy.management.CreateSQLiteDatabase(gpk, spatial_type="GEOPACKAGE")
    arcpy.conversion.FeatureClassToGeodatabase(culverts_fc_abs_path, gpk)


def main(in_ah_culverts, in_roads, ratings, stages, target_crs, output_gpkg,
scratch_gdb):
    culv_with_name = f'{scratch_gdb}/culvert_with_name'
    arcpy.management.CopyFeatures(in_ah_culverts, culv_with_name)

    # Get road attributes from roads
    join_attrs_from_roads(in_roads, culv_with_name)

    # Project the culvert feature class
    culvert_prj = f'{scratch_gdb}/culvert_prj'
    target_crs_obj = arcpy.SpatialReference(target_crs)
    target_crs_wkt = target_crs_obj.exportToString()
    project_fc(culv_with_name, target_crs_wkt, culvert_prj)

    # Compute thresholds
    compute_thresholds(culvert_prj, ratings, stages)

    # Write to geopackage
    save_to_geopackage(culvert_prj, output_gpkg)
    print('Processing complete.')
```

```
if __name__ == "__main__":
    arcpy.env.overwriteOutput = True
    main(_IN_AH_CULVERTS, _IN_ROADS, _RATINGS, _STAGES, _TARGET_CRS, _GPKG,
_SCRATCH_GDB)
```

Appendix B: Installing hy8runner and HY-8

To run HY-8 and its "headless" form, you need to have HY-8 and hy8runner installed on your local machine. You will also need Arc Hydro.

To request a download of the Arc Hydro tools, visit https://www.esri.com/en-us/industries/water-resources/arc-hydro/downloads.

For HY-8 installation, download the installation package from: https://www.fhwa.dot.gov/engineering/hydraulics/software/hy8/ and install it.

During installation, if you get a warning about "Visual C++ 2010 Redistributable x86 prerequisite was not correctly installed," you can install "Microsoft Visual C++ 2010 Service Pack 1 Redistributable Package MFC Security Update" separately from Microsoft and restart the computer. Then proceed with HY-8 installation.

For hy8runner installation, there are several steps involved. hy8runner should be installed in the "arcgispro-py3-ah" environment (cloned environment that holds additional packages needed for specific Arc Hydro functions). If needed, you can create a cloned environment through ArcGIS Pro > Project > Package Manager > Environment Manager capabilities.

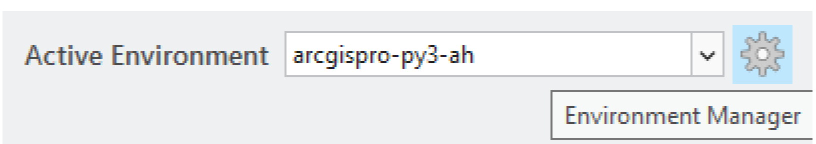


Figure 16. Gear icon to access the ArcGIS Pro Environment Manager for Python.

Download hy8runner from https://github.com/Aquaveo/hy8runner. Once "arcgispro-py3-ah" environment is established, open a Python command prompt (Start > Python Command Prompt) and execute the following sequence on the command prompt:

1. Activate "arcgispro-py3-ah" python environment by entering:
   `activate arcgispro-py3-ah-hy8`
2. Install the hy8runner from downloaded location:
   a. Move to the folder where you downloaded hy8runner, e.g.,
      cd c:\projects\hy8runner_git
   b. Install hy8runner:
      `python -m pip install .` (note "." at the end of the line – this indicates installation from the current folder)
3. To verify that the hy8runner was correctly installed:
   a. Go to ArcGIS Pro.
   b. Make sure that arcgispro-py3-ah is the active python environment.
   c. Start Python Window within Pro (Analysis > Python Window).

d. Enter the following. If installation was successful, you should see the path from which the module was imported:

   ```
   import hy8runner
   hy8runner
   ```

   (this returns something like <module 'hy8runner' from 'C:\\Program Files\\....)

4. Close the command window.