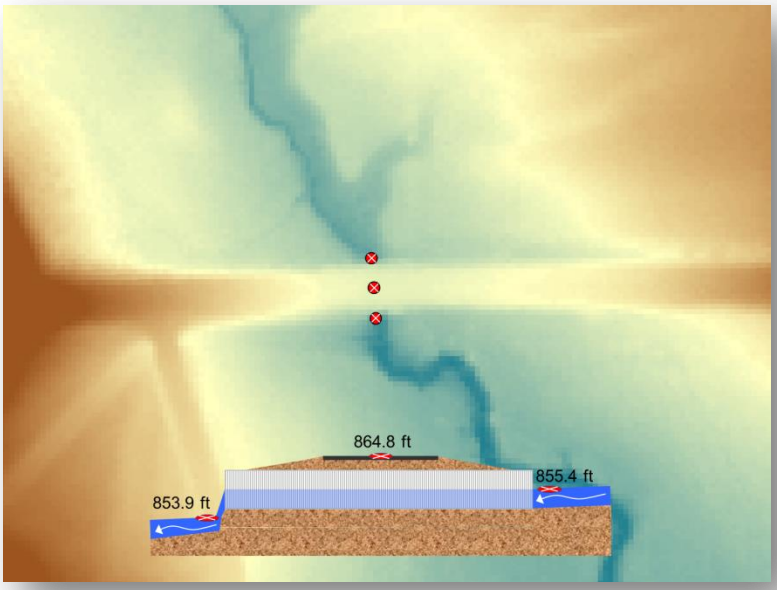
A Screening Method for Identifying Fish Passage Barriers at Road Crossings Using LiDAR-Derived Elevation Data



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Abstract

Reconstruction of road-stream crossings (RSX) provides opportunities to engineer and install structures that can better accommodate the passage of fish and other aquatic organisms. With limited resources, it is important to prioritize replacements that will be the most beneficial and cost effective. Traditional RSX assessments require investment in staff time and resources to travel to each site to take measurements in the field. Recent improvements in the accuracy and accessibility of LiDAR-based elevation data in Wisconsin has made it possible to assess and collect key RSX measurements remotely using GIS software, saving time and resources.

Beginning in April 2014, the Wisconsin Department of Natural Resources began a statewide assessment of public road crossings with an objective of classifying each crossing and assessing key measurements pertaining to the passage of aquatic organisms. A geodatabase of approximately 70,000 crossings was created by intersecting 2012 TIGER Roads data with Wisconsin DNR 24,000 scale hydrography flowlines. LiDAR-based Digital Elevation Models (DEM) and digital orthophotographs were used to interpret stream channel hydrography and classify each crossing into several categories related to the type of crossing and its significance as a potential fish passage barrier. Crossings classified as culverts with upstream channels significant for fish passage were digitized on screen and measurements of elevation drop, gradient, and road fill were calculated from the elevation and digitized culvert data.

Approximately 20,000 RSX were assessed in 16 counties, mostly in southwestern Wisconsin. Half of the assessed crossings were identified as culvert crossings with significant fish habitat upstream. Based on estimated elevation drop across the crossing, approximately 40% of those culverts are potential barriers to fish passage. The most significant crossings for stream connectivity and the most cost-effective replacement projects may be identified with GIS-based prioritization tools. All data generated by this project will be stored in the SWIMS database, and will be accessible to Department staff through the Surface Water Data Viewer. In addition to prioritization of replacement projects, these data have many potential uses, including fish habitat assessment, stream flow and channel geometry classification, and regulatory classification of road crossings.

Methods

I. Datasets

The data used to assess RSX included a combination of statewide geospatial datasets (2012 TIGER roads, minor civil divisions (MCD), counties, and WDNR 1:24,000 scale stream flowlines) as well as county-wide LiDAR-based digital elevation models (DEM) and digital ortho photography (DOP).

LiDAR-based DEMs are available to DNR staff for 53 of 72 counties in Wisconsin. These DEMs represent the "bare-earth" ground surface, and are created from the points left after returns from vegetation and structures are filtered out of the dataset. The majority of these DEMs have a 5 ft horizontal resolution, which based on comparison with high resolution aerial photographs, is sufficient to distinguish even the smallest stream channels from the surrounding terrain. The locations of bridges in the WI DOT bridge database were used to lower elevations of bridge decks to the elevation of the immediately adjacent stream surface, which allows the DEM to be used for hydrologic modeling. Road berms were not modified at culvert locations.

Thirteen county-wide LiDAR-based DEMs were downloaded from wisconsinview.org and are also available to the public. Three county-wide DEMs were acquired with assistance of the WDNR Bureau of Technology Services and were originally created by the WDNR Floodplains program with permission from the counties to distribute internally among WDNR staff.

DOPs are available to WDNR staff for every county in the State. The DOPs used in this project are Wisconsin Regional Orthophotography Consortium (WROC) 2010 imagery at 12-18 inch resolution.

Wisconsin Statewide 2012 TIGER roads, MCDs, and Counties are all publicly available data that was downloaded and maintained in the project folder on a GIS workstation.

Finally, a geodatabase of road crossing locations was created by intersecting the WDNR 1:24,000-scale stream flowlines with the 2012 TIGER roads. This database has been stored and maintained in the project folder on a GIS workstation and has been regularly backed up to an external storage device.

II. Workflow

This section is an overview of the workflow; a detailed, step-by-step protocol is provided in Appendix B.

An ESRI ArcMap Project was created containing the RSX database, WDNR 24k scale flowlines, and 2012 TIGER roads overlaid on the county DEM and the county DOP. Additional datasets were added to the project as needed to help with DEM and DOP

interpretation. These layers included WDNR Dams, MCDs, Counties, USGS Hydrologic Unit Codes (HUCs), and additional DOPs.

The RSX assessment was performed one county at a time because of variation in the date and quality of county DEMs, and consisted of two phases. First, all of the RSX points in a county were classified as one of seven different classifications and all crossings classified as a culvert had an accompanying culvert line digitized on screen based on the DEM. The second part of the assessment included a series of geoprocessing functions in ESRI Arc Map 10.1 to extract the elevation data from the DEM to the RSX database and estimate culvert measurements.

1. Crossing Classification

To perform the crossing classification, each RSX feature was viewed at a scale of 1:500 on screen with the DEM as the underlying base map. The site was then assessed and classified using the following seven classifications and guidelines (examples images of classifications are in Appendix A):

a. No crossing: The road and stream do not actually cross.
b. No channel: There is no evidence of a stream channel upstream of the crossing. Grassed waterways in farm fields that do not lead to a natural channel upstream are not considered channels.
c. Ford: The road crosses the stream without a structure.
d. Bridge: The DEM is already "cut" at the crossing to linearly connect the upstream and downstream channel elevations.
e. DEM Problem: There is evidence of a road-stream crossing but the culvert endpoints cannot be accurately identified on the DEM.
f. Previously Evaluated: The culvert has already been assessed in the field.
g. Culvert Digitized: None of the above apply.

If a crossing was determined to be a culvert, a culvert line feature was digitized on screen. Using the DEM color scheme as a guide, the culvert endpoints were placed at the lowest elevation cells upstream and downstream within at most 10 cells of the road berm. The first node was placed at the upstream end and the second node was placed on the downstream end. This allows for the line feature to have flow direction and is important for later analysis.

While classifying RSX features, new features were added to the geodatabase where WDNR hydro flowlines were found to cross roads or other man-made crossings that are visible on the DEM but not included in the 2012 TIGER Roads database. A new RSX point feature was digitized on the hydro flowline as close to the crossing as possible and classified as Culvert Digitized. A culvert line was then digitized following the standard protocol and the feature attribute fields were populated during the countywide database update process (see Appendix B).

2. Culvert Measurements

Geoprocessing functions in ESRI Arc Map were used to extract four measurements (upstream culvert elevation, downstream culvert elevation, maximum road elevation, and culvert length) from the DEM and the culvert feature class. These measurements were then used to estimate the elevation drop and slope of the culvert and the depth of road fill material above the culvert. Elevations were calculated by creating vertices along the culvert line feature at one meter intervals, converting the vertices to points, and then extracting elevations from the DEM. The road elevation was estimated from the point with the maximum elevation. Culvert length was taken directly from the geometry of the digitized culvert line. Queries in MS Access were used to calculate the following attributes:

a. Length = length of the digitized culvert (in ft, SHAPE_Length × 3.28084)
b. Drop = Elevation Upstream – Elevation Downstream
c. Slope = Culvert Drop ÷ Culvert Length
d. Fill = Maximum road height elevation – ((Elevation Upstream + Elevation Downstream)/2)

Results

I. Crossing Classification

A total of 19,420 crossings in 16 counties (Figure 1) were assessed using the methods outlined in this report. Of this total, 9,570 (49%) are culverts with stream channels upstream of the crossing that provide potential habitat for aquatic organisms ("Culvert Digitized"). Crossings designated as culverts also have a digitized culvert line associated with them and these lines represent the actual crossing location on the ground as opposed to the intersection of road and stream GIS data. Crossings of this classification are of the most interest for future use in stream network connectivity analyses.

Crossings with "No Upstream Channel" make up 27% of the overall inventory. At most of these locations, a culvert was visible on the DOP, but there was no stream channel identifiable on the DEM. It is unlikely that significant habitat for aquatic organisms exists upstream of these crossings.

"Bridges" and "Fords" make up 15% of the overall inventory. These crossings do not alter stream hydraulics to the same degree as culverts and therefore do not pose significant man-made barriers to fish passage.

The "No Crossing" classification has no impact on fish passage and instead represents errors in the spatial geometry of the roads and/or stream flowline. No Crossing features should not be

used for analysis but are still included in the data to represent that the intersection is a false positive.

Approximately 1% of crossings were classified as “DEM Problem”. This classification is most common on county boundaries where one end of the culvert falls within the county DEM and the other is outside the DEM. If vegetation is particularly thick in a certain area it can also cause imperfections in the underlying DEM interpolation making it difficult to place the culvert endpoints with any accuracy. DEM problems were most significant in Lincoln County due to calibration errors with the LiDAR dataset. Some areas of the countywide DEM exhibited problems with seams on the flight path or did not accurately differentiate between bare earth and vegetation. These issues were limited to smaller areas however and the vast majority of the county was still inventoried.

Table 1: Crossing Classification Results by County

County	Culvert Digitized	Bridge	No Channel Upstream	No Crossing	DEM Problem	Ford	Total Crossings
Brown	191	57	215	34	15	-	512
Crawford	589	164	203	97	-	22	1,075
Dane	1,495	292	640	258	19	-	2,704
Grant*	1,074	326	502	131	1	-	2,034
Green	827	143	321	73	1	-	1,365
Iowa	694	171	529	74	10	7	1,485
Kenosha	98	20	43	54	-	-	215
Kewaunee	292	70	154	9	12	-	537
Lafayette	701	166	499	93	19	6	1,484
Lincoln	329	96	245	27	64	2	763
Milwaukee	331	151	141	132	-	-	755
Monroe	805	422	567	191	2	4	1,991
Racine	77	12	21	11	1	-	122
Richland	801	287	392	155	-	-	1,635
Rock	440	137	318	44	1		940
Vernon	826	384	426	163	1	3	1,803
Total	9,570	2,898	5,216	1,546	146	44	19,420

* This dataset has known data quality issues; see discussion topic, Grant County RSX Inventory later in this report.

Figure 1: Inventory Progress Map

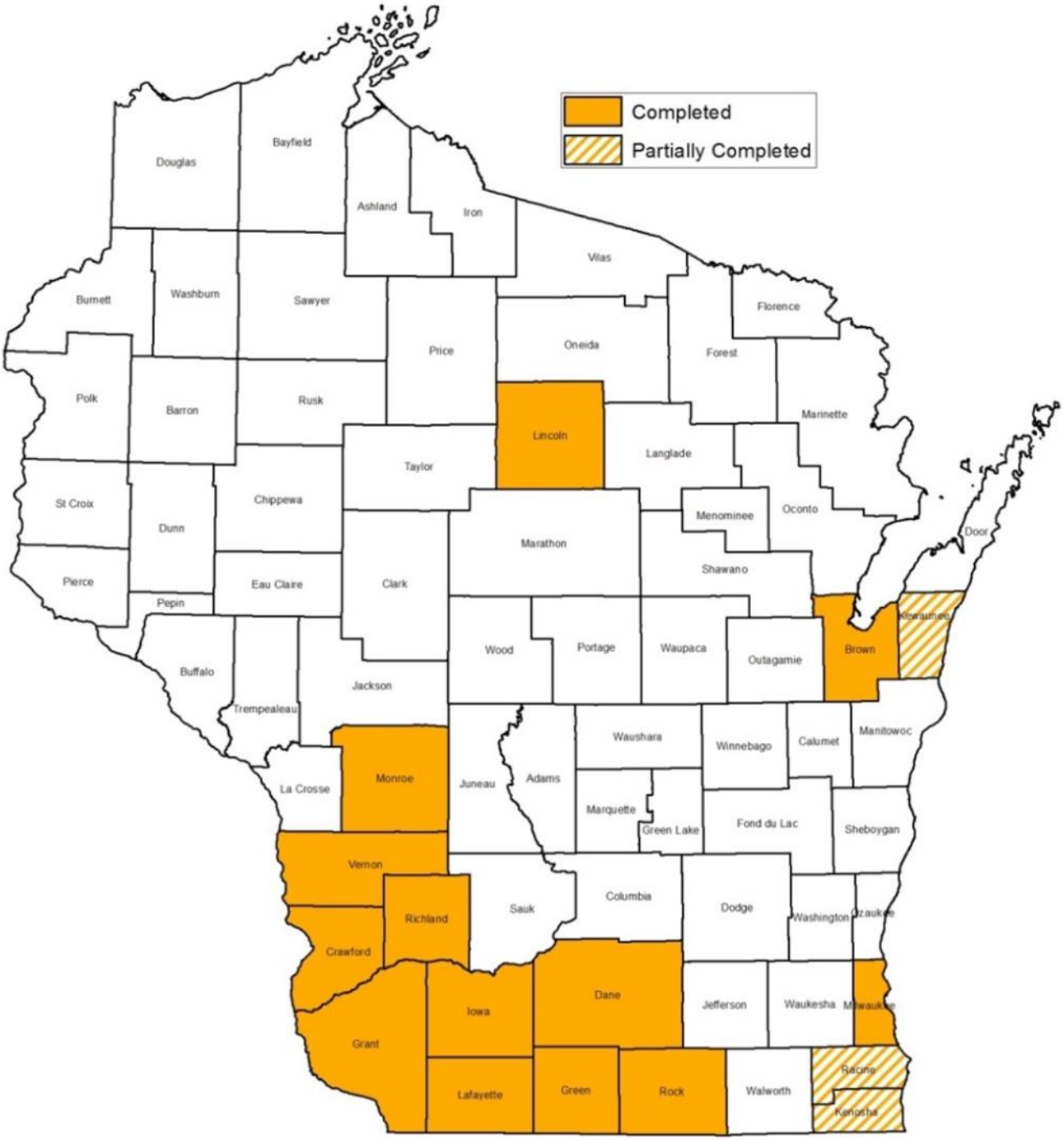
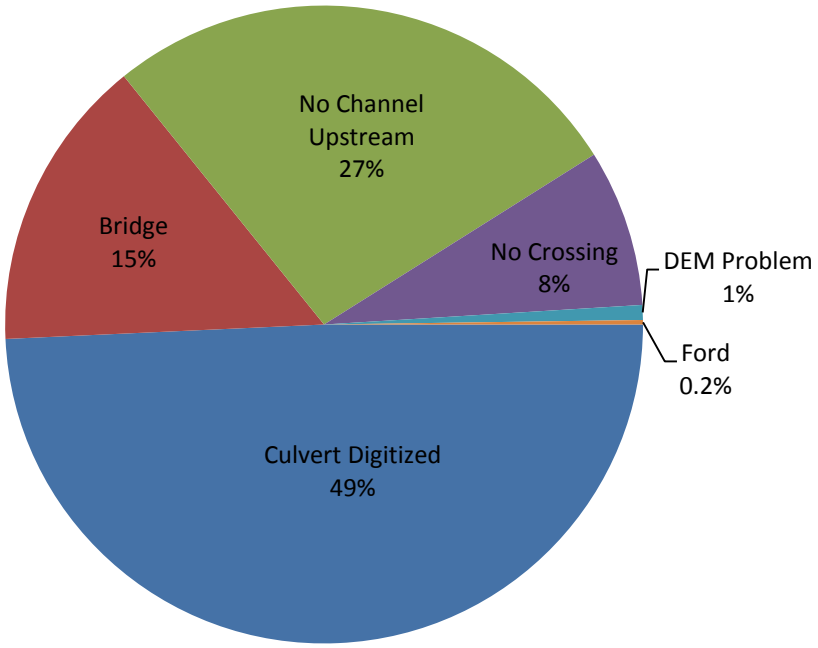


Figure 2: Proportion of road-stream crossings in each assessment class across 16 counties in Wisconsin



II. Crossing Measurements

The major product of this project is the set of culvert measurements that influence aquatic organism passage. By extracting the elevation from the DEM at each culvert's upstream and downstream end, the culvert elevation drop can be estimated. Elevation drop divided by the length of the culvert, which is estimated from the digitized length of the culvert, yields an estimated slope. Both of these measurements are important factors in determining fish and other aquatic organism passability at a given stream crossing. A large drop in elevation suggests an organism will find it difficult or even impossible to pass the crossing and swim further upstream, and similarly, the higher the slope of a culvert the greater the barrier to organisms that are not strong swimmers. The distribution of estimated elevation drops among assessed culverts is summarized in Figure 3. The relationship between LiDAR-derived drop and field assessments of passability is discussed in the accuracy assessment section.

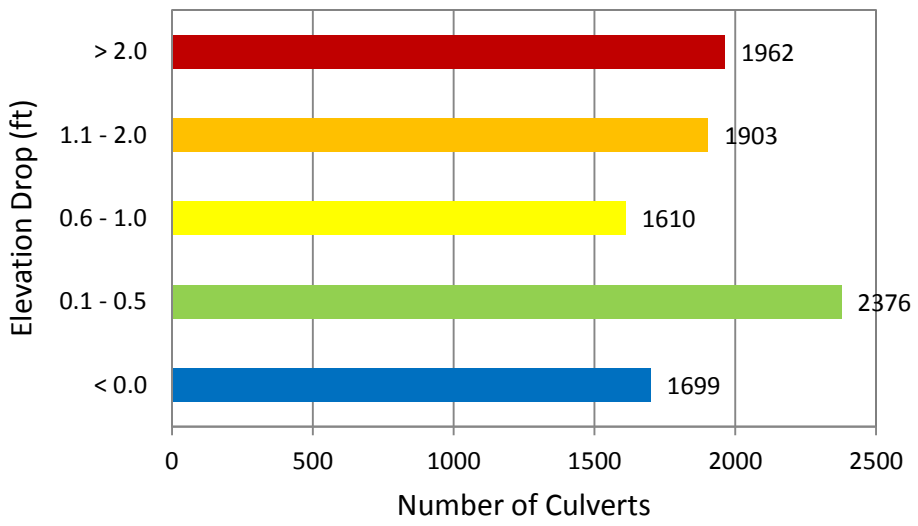


Figure 3: Number of culverts in elevation drop bins. Based on the accuracy assessment, drops > 1 ft are most likely to be fish passage barriers.

III. Accuracy Assessment

Field surveys were conducted at 70 crossings in Green (Sept 26-27, 2013), Rock (June 24, 2014), and Richland (Aug 14, 2014) Counties to assess whether the LiDAR-based methods accurately identify crossings that are barriers to aquatic organism passage. Streams were at summer baseflow conditions during all surveys. The relative elevations of water surface elevations at points immediately upstream and downstream of each culvert were surveyed with a 24x-power auto level and stadia rod. The presence/absence of an outlet drop on the structure was also noted as an indicator of passability by aquatic organisms. The accuracy of the LiDAR-derived elevation drop estimates was assessed by plotting them against corresponding field measures and calculating RMSE and R2.

The correspondence between LiDAR and field-measured elevation drops is generally very good (RMSE=0.52 ft, R^2=0.85), although there appears to be a small positive bias in the LiDAR-derived drop estimates (Figure 4). A LiDAR-derived elevation drop of 1.0 ft appears to be a good threshold for distinguishing crossings with and without outlet drops. For the 70 surveyed crossings, 28 of 30 (93%) of crossings with outlet drops and 34 of 40 (85%) of crossings without outlet drops would be correctly identified with this threshold. Out of the 19,420 crossings assessed, 3,865 (20%) have estimated drops >1.0 ft. While all of these crossings are likely to be barriers to fish passage, some would not be priorities for replacement because they block small amounts of habitat.

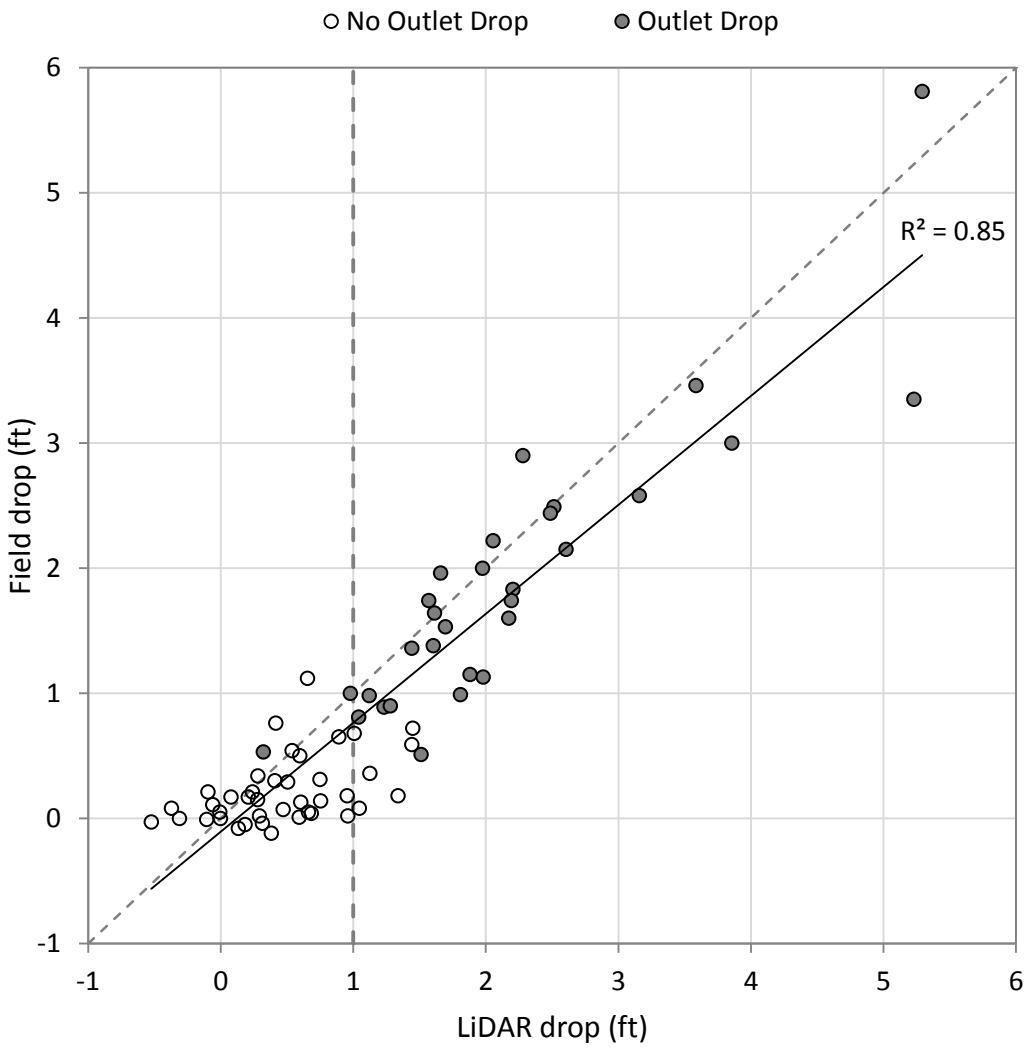


Figure 4. Plot of LiDAR-derived vs. field-measured elevation drop estimates at 70 road crossings in Green, Rock, and Richland counties, Wisconsin

Discussion

I. Usability Issues of LiDAR DEMs

We encountered usability and data integrity issues with some LiDAR derived Digital Elevation Models (DEMs). For example, the Lincoln County LiDAR DEM is the appropriate resolution to identify stream channels, but the DEM was a poor representation of the bare-earth terrain in some areas. On the other hand, Sheboygan County's LiDAR DEM had no underlying problems with the data but the DEM was not high enough in resolution to properly identify stream channels from the terrain. Fond Du Lac County also had similar issues with interpreting the stream channels from the DEM. It may be possible to improve the usability of these DEMs by reprocessing the DEM at a higher resolution, but this would depend on the density of the raw LiDAR point data. DEMs funded by FEMA and produced by Ayers and Associates have consistently provided the appropriate resolution and accuracy required to identify stream channels from the terrain. These high resolution DEMs are primarily available in southwest and southeast Wisconsin.

II. Alternative Elevation Estimation Method

Because digital elevation models are derived by interpolating an elevation for a given cell from a LiDAR point cloud or LAS dataset, there is room for error when extracting elevation for a single point within each cell. In an effort to mitigate the potential for inaccurate estimations, we investigated the possibility of extracting elevations directly from the raw LAS dataset.

This was done by digitizing culvert ends using the LiDAR-derived DEM as described above; however, instead of extracting the elevation from the DEM, a 10 ft buffer was created for each culvert end point and the lowest elevation LAS point within that buffer was taken. This process was performed for a subset of crossings in Richland County where both methods were used to extract the elevation data. Fieldwork was then done to test the accuracy of both the standard DEM elevation extraction method and the LAS point cloud extraction method against field-surveyed relative elevations. The results were mixed but about two thirds of the sites surveyed showed a slight increase in the estimated accuracy using the LAS method.

Though it was possible to improve the accuracy of elevation estimations, this method was determined unsuitable for the project. First, LAS point clouds are not always evenly distributed across the terrain and gaps can appear due to heavy vegetation that interrupts the instrument measurements, minor inconsistencies in the data collection flight path, or through post-processing. This method is also unsuitable because of the time and effort needed to process raw LiDAR point data clouds. Requirements for digital storage space can exceed 40 gigabytes per county, and the processing power to manage hundreds of thousands of data points is beyond the capabilities of a standard GIS workstation.

III. Grant County RSX Inventory

The RSX assessment for Grant County was performed by students from the University of Wisconsin Platteville. Data quality issues have been identified with the resulting dataset so the data will be kept separate from the published dataset until the issues can be resolved. A significant number of digitized culverts exhibit errors in the placement of digitized culvert endpoints. When the endpoints are placed incorrectly, the extracted elevation values are also incorrect and the resulting culvert measurement estimates can be off by several feet vertically. Some issues were also identified with crossing classification but are less common and do not impact the usability of the data to the same degree as errors in the estimated measurements. To resolve these issues, it is recommended that the digitized culvert lines be entirely redone following the project protocol and classifications be corrected as needed.

IV. Data Availability

The RSX inventory will be made available to WDNR staff in three ways:

1. Tabular data will be uploaded to the Surface Water Integrated Monitoring System (SWIMS) categorized as Resource of Interest: Stream Crossing. These data will be accessible by all WDNR staff for view and tabular download through the SWIMS user interface: http://prodoasint.dnr.wi.gov/swims/login.jsp
2. The geodatabase of crossing point features and culvert lines will be uploaded to the WDNR SDE database under the SWIMS Schema account. WDNR staff with access to the SDE database will have access to both point and line geospatial data. Furthermore WDNR staff will be able to use the crossing data for stream connectivity analyses, analysis of potential fish passage barriers, prioritization of culvert replacement, and other applications.
3. The geospatial data will be published as a map service to WDNR internet map servers and will be accessible to staff as a standalone add in to Arc Map and any of the numerous Geocortex webmap applications produced and maintained by WDNR programs. By offering a published map service, WDNR staff and the public will have access to a cartographically complete map service that does not require access to GIS software or the SWIMS system.

V. Additional County Inventories

A map of LiDAR DEM availability is available on the WDNR Geospatial Coordination Sharepoint site. If additional funding becomes available, counties should be selected for further inventory based on a combination of resource or regulatory priorities and data availability, currency, and quality. Adding counties that are contiguous with completed counties would allow for connectivity analyses of larger watersheds (details below).

VI. Connectivity Analysis and Prioritization

The significance of any particular RSX for aquatic organisms depends not only on the structure characteristics, but also on the spatial context of the structure in the stream network and relative to other structures and natural barriers. For example, an impassable culvert that is near the source of a stream has less influence on the connectivity of stream habitat than one that is farther downstream. Tools are available for prioritizing culvert replacement (and barrier removal in general) based on connectivity effect per cost.[1] If there is sufficient interest from water resources and road managers in improving infrastructure and aquatic connectivity in a particular watershed, we are available to assist with project prioritization.

VII. Other Uses of Project Data

The locations of fish passage barriers may be useful for fisheries assessments. First, interpretation of age class structure or natural reproduction of stream fishes may be aided by knowing whether a sampled population has access to spawning habitat. Second, the potential efficacy of habitat restoration projects could be influenced by the connectivity of the restored reach to potential recolonizing populations or to habitat that is critical to the life cycles of target species. And third, intentional segregation of competitive species, such as brook and brown trout, could be accomplished by existing barriers, though the negative effects of these barriers on channel stability and other species should be considered.

Streams that are classified as “no channel” may be considered for change in designated use because they are unlikely to serve as aquatic habitat. More work is needed to determine whether these streams should be classified as intermittent or ephemeral, or whether this classification could be used as a preliminary navigability determination.

A preliminary classification of RSX for designating regulatory jurisdiction and replacement project complexity was completed for Iowa and Lincoln Counties as part of this project (Table 2). If there is interest from the Local Roads program, this classification could be created for all of the counties where the LiDAR analysis was completed.

[1] Diebel, M. W., M. Fedora, S. Cogswell, and J. R. O’Hanley. 2014. Effects of road crossings on habitat connectivity for stream-resident fish. River Research and Applications. DOI: 10.1002/rra.2822

Table 2. Classes and criteria for draft road crossing classification

Symbol	Description	Selection Criteria
Blue Dot	DOT/DNR COA	Lidar Check = Bridge or (Road type = State or US or Other or Interstate and Lidar Check = culvert or no channel)
Green Triangle	CO HWY/DNR COA (County Rd Complex)	Road Type = County and Priority Water = False and Lidar Drop ≥ 1’ and Lidar Check = Culvert
Green Square	CO HWY/DNR COA (County Rd Priority)	Road Type = County and Priority Water = True and Lidar Check = Culvert
Green Circle	CO HWY/DNR COA (County Rd Simple)	Road Type = County and Priority Water = False and Lidar Drop ≤ 1’ and Lidar Check = Culvert or No Channel
Orange Diamond	CO HWY/DNR COA (Town Rd Priority)	Road Type = Municipal and Priority Water = True and Lidar Check = Culvert
Orange Square	CO HWY/DNR COA (Town Rd Complex)	Road Type = Municipal and Priority Water = False and Lidar Drop ≥ 1' and Lidar Check = Culvert
Grey Dot	Town Permit (Simple)	Road Type = Municipal and Priority Water = False and Lidar Drop ≤ 1’ and Lidar Check = Culvert or no channel
Open Circle	Private or Unknown	Lidar Check = DEM problem or Not checked or Road Type = Unknown

Appendix A. Crossing Classification Examples

Figure 5: Bridge & No Channel (DEM)

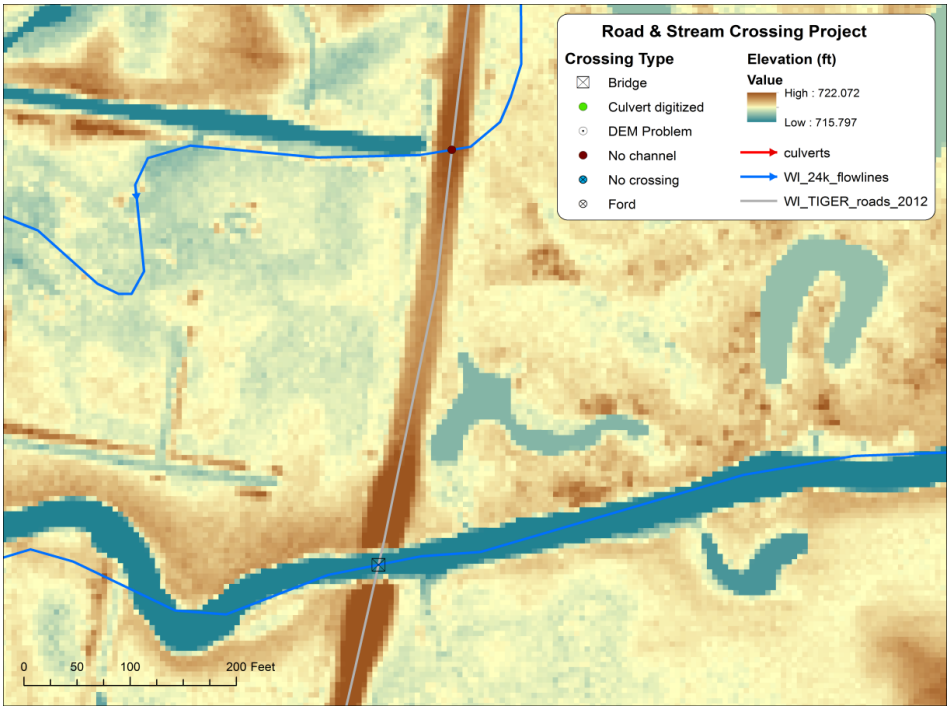


Figure 6: Bridge & No Channel (Ortho Photo)

Figure 7: Culvert Digitized & No Crossing (DEM)

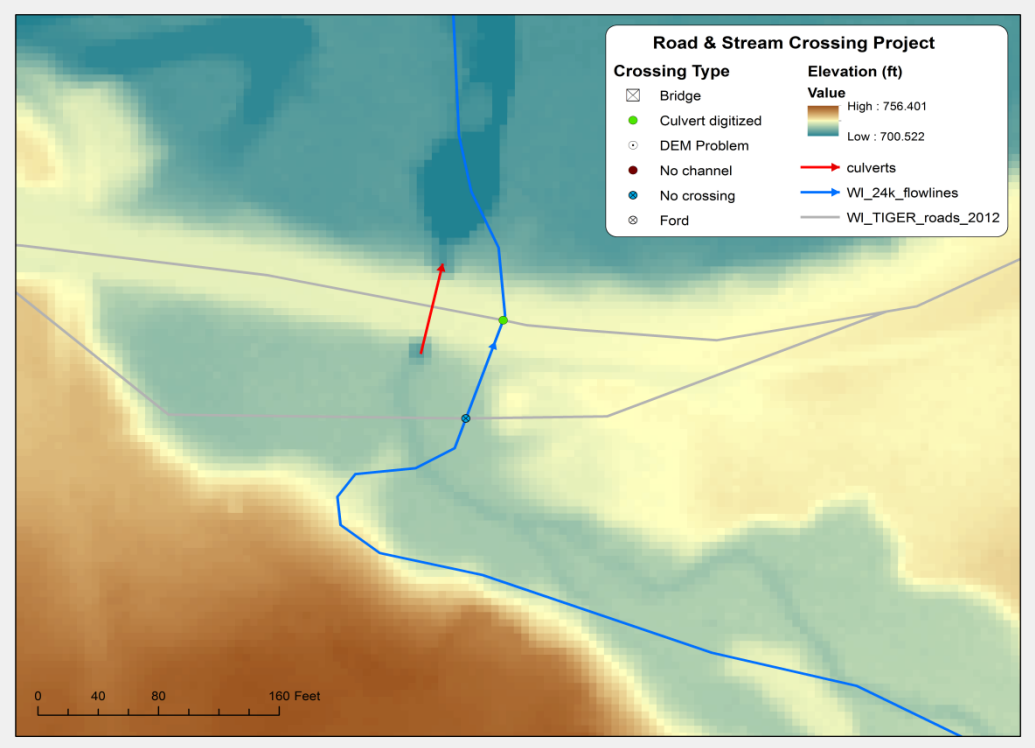


Figure 8: Culvert Digitized & No Crossing (Ortho Photo)

Figure 9: DEM Problem (DEM)

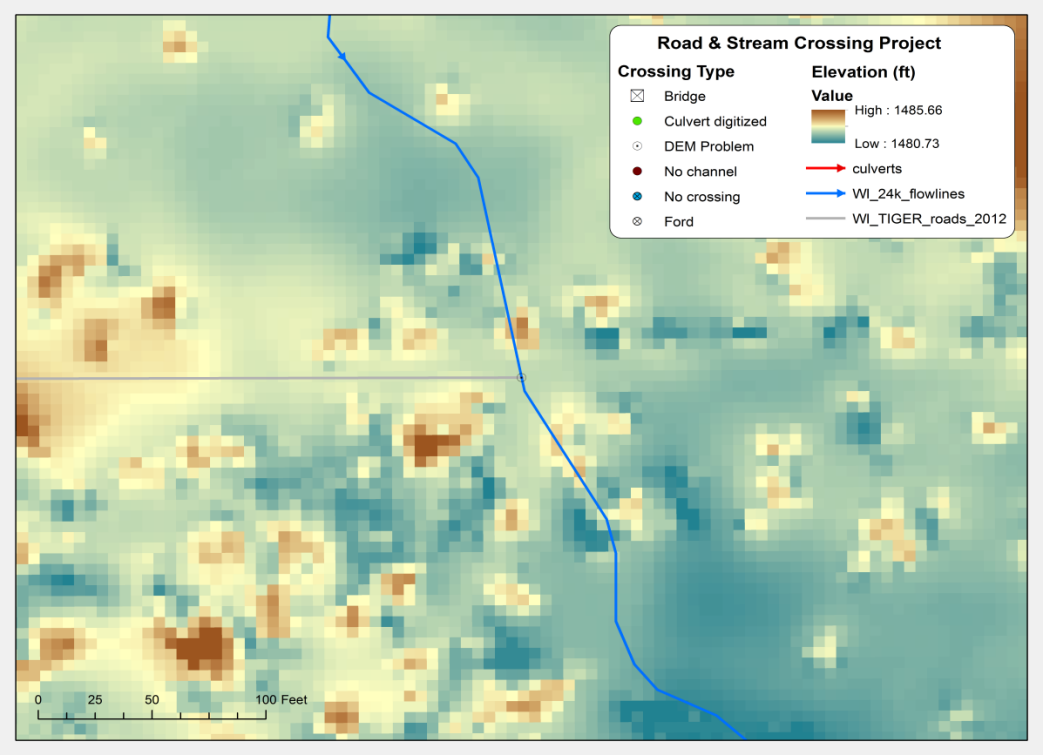


Figure 10: DEM Problem (Ortho Photo)

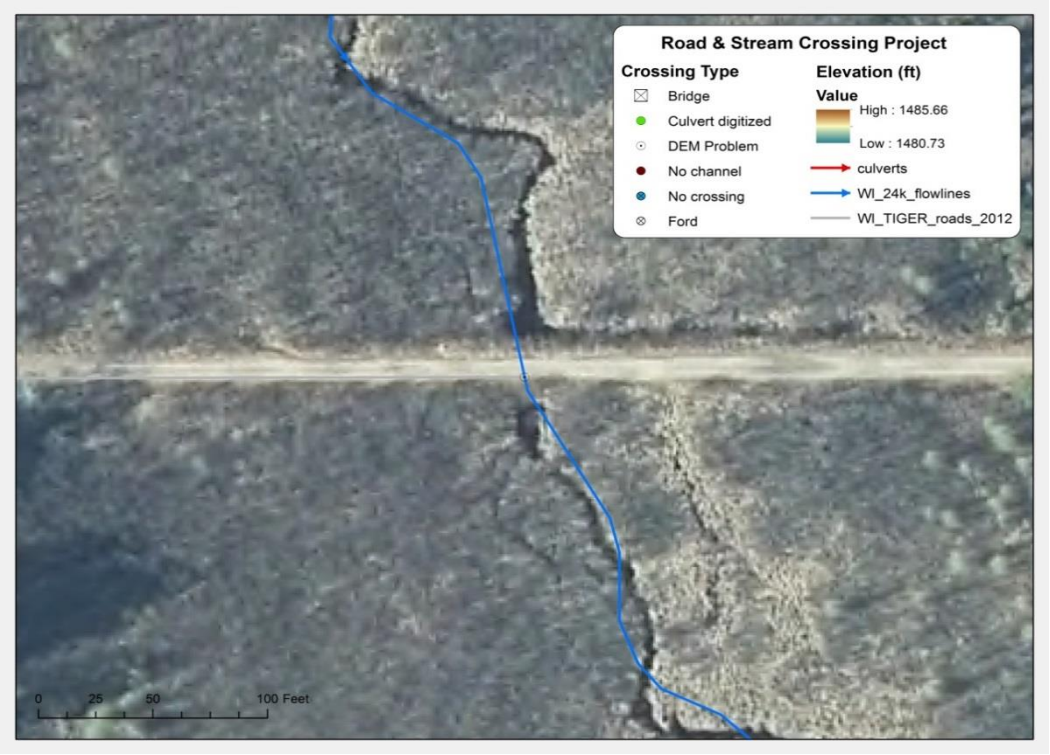


Figure 11: Ford (DEM)

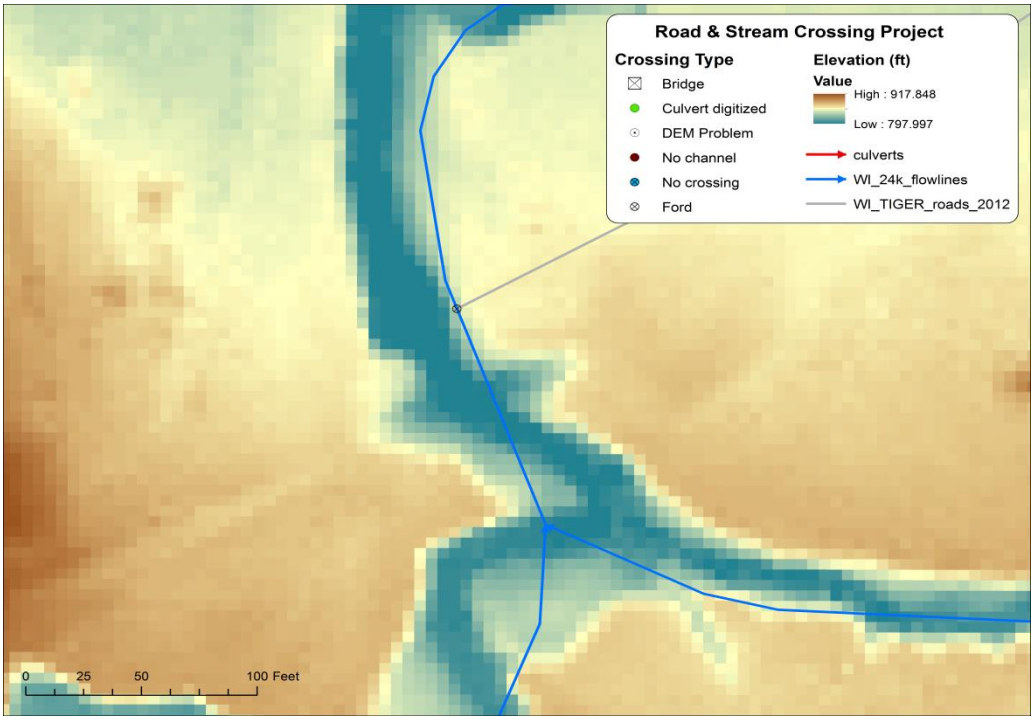


Figure 12: Ford (Ortho Photo)

Appendix B. Road Crossing Assessment Protocol

I. Classifying road crossings and digitizing culverts

1. Create an ArcMap project that contains the following datasets:
    a. LiDAR-based DEM (In the Symbology properties, choose the Stretched option using From Current Display Extent within the Statistics box, and choose a color gradient that spans multiple hues.)
    b. 2012 TIGER roads
    c. WDNR 1:24,000-scale hydrography flowlines
    d. RSX and culverts feature classes from the WI_RSX geodatabase.
    e. County digital ortho photo or imagery base map.
2. Start an editing session on the WI_RSX geodatabase.
3. Zoom to 1:500 scale on a RSX feature.
4. Using the DEM and, if necessary aerial photography, choose one of the following options for the LIDAR_CHECK attribute of the RSX:
    a. No crossing: The road and stream do not actually cross (Figures 1 and 2).
    b. No channel: There is no evidence of a stream channel upstream of the crossing. Grassed waterways in farm fields that do not lead to a natural channel upstream are not considered channels (Figure 3).
    c. Ford: The road-stream crossing is a ford.
    d. Bridge: The DEM is already "cut" at the crossing to linearly connect the upstream and downstream channel elevations (Figure 4).
    e. DEM Problem: There is evidence of a road-stream crossing but the culvert endpoints cannot be identified on the DEM.
    f. Culvert digitized: None of the above apply.
5. Digitize the culvert:
    a. Each culvert feature should only have two nodes. The nodes must be drawn in order, from upstream to downstream.
    b. Use the color scheme of the DEM to locate the lowest elevation DEM grid cell that is within four grid cells of the steep slope of the berm on the upstream side of the road (Figure 5). If it appears that the culvert has created a knickpoint in the stream channel within approximately 10 cells of the road berm, locate the lowest elevation cell upstream of the knickpoint (Figure 6). Digitize the upstream node on that cell.
    c. Next, locate the lowest elevation grid cell downstream of the road that is either:

i. immediately downstream of the break in slope from the road berm to the stream channel (Figure 5), or

ii. the first cell downstream of the break in slope from the road berm to the stream channel that is surrounded by higher elevation cells (Figure 7). Digitize the downstream node on that cell and finish the feature.

II. Road Crossing Database Update Protocol

1. Set Up

a. Open a new or existing ArcMap project and add the following data:

- RSX feature class (from RSX.mdb)
- culverts feature class (from RSX.mdb)
- flowlines_300m feature class (from RSX.mdb)
- WI_Tiger_roads_2012 (shapefile)
- WI_MCD (shapefile)
- counties (shapefile)
- W23324.WD_HYDRO_FLOWLINE_LN_24K feature class (from DNR SDE)
- The county DEM associated with the county you are updating

b. Open the RSX feature class properties and go to the definition query tab. Specify the definition query to only return RSX points that are culverts and within the county you are updating. This minimizes the amount of processing and hides the extraneous RSX points from view.

i. For example: [COUNTY] = 'Kewaunee' AND [LIDAR_CHECK] = 1

2. Attribute Table Updates (Only needed if you added new RSX points during the assessment)

a. As separate spatial joins, spatial join the RSX feature class to following data layers:

- WI_MCD naming it MCD_Join_Output
- Flowlines_300m feature class naming it Flowline_Join_Output
- W23324.WD_HYDRO_FLOWLINE_LN_24K feature class naming it 24k_Join_Output

Choose the second option for each spatial join ("is closest to it" for WI MCD and "Each point will be given all the attributes…" for the two flowlines):

b. Start an editing session on the RSX feature class

c. Table join the RSX feature class to MCD_Join_Output using ROI_ID.

    i. Select all of the RSX features whose MCD attribute is null

    ii. Double check the distance field to verify the spatial join is accurate

    iii. Field calculate MCD = NAMELSAD10

    iv. Remove Join

d. Table join the RSX feature class to Flowline_Join_Output using ROI_ID.

    i. Select all of the RSX features whose REACHID attribute is null

    ii. Double check the distance field to verify the spatial join is accurate

    iii. Field calculate REACHID = REACHID_1

    iv. Field calculate ELUP_REACH = Elev_Up

    v. Field calculate ELDN_REACH = Elev_Down

    vi. Field calculate GRAD_REACH = Gradient

    vii. Remove Join

e. Table join the RSX feature class to 24k_Join_Output using ROI_ID.

    i. Select all of the RSX features whose ROW_NAME attribute is null

    ii. Double check the distance field to verify the spatial join is accurate

    iii. Field calculate ROW_NAME = ROW_NAME_1

    iv. Remove Join

    v. Field calculate or fill out ROI_DESC attribute to say [Stream Name] at [Road Name] using “Unnamed Stream” and “Unnamed Road” as the names if none exists. See existing ROI_DESC for examples.

    vi. Stop editing session

3. Assign ROI_IDs to Culverts

a. With the definition query in place from step 1-b spatial join the culverts feature class to the RSX feature class using the second option, “Each line will be given all the attributes …” Name the output Join_Update.

b. Start an editing session

c. Table join the culverts feature class to Join_Update using the matching ObjectID field (Object_ID12).

d. Open the properties of the counties data layer and go to the definition query tab. Specify the definition query to only return the county you are updating. This is used to simplify the following spatial selection.

    i. For Example: "CTY_NAME" = 'Kewaunee'

e. Use a spatial selection to select the culverts that intersect with the county to be updated. Check the selection as some culverts overlap between counties. Remove extraneous culverts from the selection.

f. Select culverts with null ROI_IDs from the spatial selection.

g. Field calculate culverts ROI-ID = Join_Update ROI_ID_1.

h. Remove Join

i. Stop editing session

4. Create Culvert End Points for Elevation Extraction

   a. With the definition query in place from step 3-d, use a spatial selection to select the culverts that intersect with the county to be updated. Check the selection as some culverts overlap between counties. Remove extraneous culverts from the selection.

   b. Export the selection as a new feature class naming it Culvert_Update

   c. Use the Densify tool in Arc Tool Box on Culvert_Update and specify the distance interval to 1 meter.

   d. Use the Feature Vertices to Points tool in Arc Tool Box to create culvert endpoints, one for the upstream endpoint, one for the downstream endpoint, and one for all of the densified vertices. This can be done as a batch process.

      i. For Upstream endpoints Select Culvert_Update as the input feature, name the output Culvert_Update_Start. Choose Start for the point type.

      ii. For Downstream endpoints Select Culvert_Update as the input feature, name the output Culvert_Update_End. Choose End for point type.

      iii. For Densify vertices Select Culvert_Update as the input feature, name the output Culvert_Update_Densify. Choose All for the point type

   e. View the attributes to ensure the tool ran successfully.

5. Extract Elevations from LiDAR DEM

   a. Use the Extract Values to Points tool in the ArcGIS Spatial Analyst extension to extract the elevation of the culvert end points from the DEM for Culvert_Update_Start, Culvert_Update_End, and Culvert_Update Densify. Because the RSX.mdb is a personal file geodatabase, the outputs must be saved as a shapefile and not directly to the database. This can be done as a batch process.

      i. Specify the appropriate county DEM as the input raster and name the outputs Culvert_Update_Start_Extract, Culvert_Update_End_Extract, and Culvert_Update_Densify_Extract.

   b. View the attributes of the outputs and ensure each attribute has a rastervalu.

   c. Import the shapefile outputs into the RSX.mdb as feature classes

6. Close the Arc Map Project

7. Culvert Attribute Calculations
    a. Open RSX.mdb in Microsoft Access
    b. A number of queries have been set up to automate the culvert calculations using the naming conventions specified in earlier steps. Run each query in the order as numbered.
        - 1) Elev_Update_Query – updates the RSX table with elevation values from the Extraction feature classes.
        - 2) Road Height Query – selects the max road height elevation from the Culvert_Update_Densify_Extract feature class and creates a temporary table
        - 3) ElMax_LiDAR Update Query – updates RSX table with elevation values from temporary max road height table
        - 4) Update_Length_Drop_Fill_Slope – calculates culvert length, drop, fill and slope based on elevations and culvert shape length
        - 5) Final QAQC Query – Requires user input to specify the county being viewed. Otherwise returns all of the calculated values in a table for review.
8. Final QA/QC
    a. Sometimes one or more elevation and/or calculation fields are not updated. For elevation values this is almost always a result of a mismatched spatial join between the culvert and RSX point. If the number of missing elevations is small you can open an ArcMap editing session and manually assign the elevation values using an identify on the DEM. You will also need to edit the ROI_ID of the culvert to match the correct RSX point.
    b. If calculations are missing you can update them in Arc Map using the following field calculations:
        - LENGTH_LIDAR = length of the digitized culvert (in ft, SHAPE_Length × 3.28084)
        - DROP_LIDAR = ELUP_LIDAR - ELDN_LIDAR
        - SLOPE_LIDAR = DROP_LIDAR ÷ LENGTH_LIDAR
        - FILL_LIDAR = ELMAX_LIDAR – (([ELUP_LIDAR] + [ELDN_LIDAR])/2)
    c. Open the RSX feature class attributes table and sort on the various calculations fields. DROP_LIDAR is the best starting place.
        i. Pay special attention to outlying values and spot check them in your ArcMap project. Ensure the culvert end points are in in the correct location and that the values are correct.
    d. Once you are confident all of the calculated values are correct, delete all of the temporary outputs from the analysis.