Culvert design for fish passage in an uncertain future

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10/13/2021
Project Team

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Expertise: culvert design for fish passage

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Expertise: hydrologic modelling and climate change vulnerability analysis
Habitat connectivity:
• Access to spawning
• Access to refuge habitat
• Viability and persistence of populations (genetic diversity)
How do culverts impact fish passage?

Behavioral Barriers
• LOW LIGHT?
• Habitat?
• Other

Physical Barriers
• Flow depth
• Flow velocity
• Perched
• Pool depth
• Turbulence
Culvert Design for Fish and Aquatic Organism Passage

Goal: Improve culvert design to accommodate fish passage and improve stream connectivity through culverts at road-stream crossings.

Project Partners:
- Sara Mielke, Matt Hernick, Bill Herb, and many undergraduate researchers, SAFL
- Britney Mosey and Jay Hatch, Fish., Wild. and Con. Bio., CEHR and Bell Museum
- John Nieber, Chris Lenhart, Bioproducts and Biosystems Engineering
- TAP members – Petra DeWall, Nicole Danielson-Bartelt, Peter Leete, and many others
- Bob Gubernick, USFS

Projects:
1. Design considerations for recessed/embedded culverts
2. Novel boundary roughness retrofits
3. Evaluation of behavioral barriers in dark culverts
4. Development of design guidance
5. Resiliency of fish passage design culvert to extreme events

Funding:
Minnesota Aquatic Organism Passage Guide

Available for download (free)
don.state.mn.us/bridge/hydraulics/resources.html

Search ‘MnDOT AOP’

Funded by MnDOT and LRRB
Training sessions (also free! and virtual)
Register Online:
www.mnltap.umn.edu/training/topic/customized/culvert/
Embedded (recessed) culverts

Goal: Natural streambed roughness/slower velocities than culvert set at streambed grade.

Eliminates the need for specific hydraulic criteria of an individual fish species (or community of fish species)

*Culvert width* guidelines vary (multiplier of bankfull width)

Placing sediment and roughness structures in culvert.

Investigate the parameters of *culvert design* through a modeling study that integrates fish swimming ability for Minnesota fish species with current and future hydrologic scenarios.
Culvert design (including sizing) is critical for both safety and fish passage.

Example: Larger culverts designed for fish passage
- More expensive upfront
- More resilient (greater hydraulic capacity)
- Too wide -> insufficient flow depths/sedimentation
In addition to peak flows, we estimated flows relevant to fish passage.

**High fish passage flow, QHP**
- Determines the **velocity threshold** for fish passage
- 10% exceedance

**Low fish passage flow, QLP**
- Determines the **depth threshold** for fish passage
- 95% exceedance

Based on average **daily** flow exceedance.

Example from Beaver River
Hydrologic methods summary

- The fish passage flows depend on the seasonal balance of precipitation and evapotranspiration – analyzing individual storm events is not sufficient
- For present conditions, we used USGS Streamstats to quickly estimate the fish passage flows
- For future conditions, we used 20 year, continuous simulations of stream flow using HSPF (Hydrologic Simulation Program Fortran)
4 watersheds containing 5 surveyed culverts were selected for detailed hydrologic models.

<table>
<thead>
<tr>
<th>Study Catchment</th>
<th>Culvert</th>
<th>Area (km²)</th>
<th>Average Slope (%)</th>
<th>Dominant Land Covers</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Branch Beaver River</td>
<td>LSS21</td>
<td>76</td>
<td>2.3</td>
<td>Forest</td>
</tr>
<tr>
<td>East Branch Beaver River</td>
<td>LSS22</td>
<td>120</td>
<td>5.0</td>
<td>Forest</td>
</tr>
<tr>
<td>Snake River</td>
<td>Snake4</td>
<td>156</td>
<td>0.84</td>
<td>Forest, Ag</td>
</tr>
<tr>
<td>South Fork Root River</td>
<td>Root2</td>
<td>47</td>
<td>3.3</td>
<td>Ag</td>
</tr>
<tr>
<td>Cottonwood River</td>
<td>CW2</td>
<td>5.7</td>
<td>2.7</td>
<td>Ag</td>
</tr>
</tbody>
</table>
Future Climate Inputs

- Each global climate model (GCM) gives different projections for future changes in precipitation and air temperature.
- We used 4 GCMs to capture a range of future climate and stream flow response.
- We also used an EPA database of future storm events for overtopping analysis.
Projected % Change in Precipitation, from 1971-2000 to 2071-2100

**Hадley**

- **GFDL**

Legend:
- **13.5 - 17.3**
- **9.5 - 13.4**
- **5.6 - 9.4**
- **1.6 - 5.5**
- **-2.3 - 1.5**
- **-6.4 - -2.4**

Legend:
- **26.3 - 32.4**
- **23.2 - 26.2**
- **19.3 - 23.1**
- **15.4 - 19.2**
- **11.8 - 15.3**
- **7.4 - 11.7**
Projected Future Change in Fish Passage Flows

The model results indicate that low flows (-90% to +200% change) may be more impacted than high flows (-40% to +70% change)
Hydrologic Study Limitations

• Both the GCM model outputs and much of the observed stream flow data are at daily steps - we did not attempt make stream flow projections at sub-daily time steps
• This is a limitation for overtopping analysis, particularly smaller watersheds, but not so much for fish passage flows
• Projections of future precipitation at sub-daily time scales is a current topic of research

flooded culvert in District 6. Photo: Minnesota DOT
Designing for ecological connectivity

O'Shaughnessy et al. 2017, Fisheries
Designing for resiliency

- Bridge
- Embedded culvert/floodplain connectivity
- Embedded culvert
- Culvert designed to fish swimming abilities
- Hydraulic design for flood capacity

Gillespie et al. 2014
Results of modelling generally support current guidance

1. Both low-flow depth barriers and high-flow velocity barriers present concerns for fish passage in MN across culvert types
2. Bankfull width ratios > 2 are a concern for low-flow depth barriers
3. Low bankfull width ratios (<1) are a concern for high-flow velocity barriers.
Designing for ecological connectivity at low flows

Ensure passage at low flows:
- Offset multiple barrels
- Low flow channels

Note: limited design information available.
Culvert designs that can adapt are more resilient to future climate scenarios, especially considering the uncertainty.

Hydrologic predictions
- there remains lot of uncertainty
  - balance of rainfall/air temperature changes
  - low flows are particularly sensitive (ET changes, droughts)

More resilient culvert designs account for changes in both high and low flows
- width \( \approx \) channel bankfull width or slightly greater
- incorporates a low flow channel
- includes embedded sediment of similar roughness to the channel
More Information

Previous Projects:
• Sediment Transport through Recessed Culverts: Laboratory Experiments (2014) – Kozarek
• Culvert Length and Interior Lighting Impacts to Topeka Shiner (*Notropis Topeka*) Passage - Kozarek.
• Use of Mussel Spat Rope for Fish Passage in Culverts - Kozarek
• Risk, Response and Weather (MN Seagrant, with NRRI) - Herb
• Criteria for Land and Water Management to Sustain Healthy Aquatic Ecosystems in a Changing Climate (NOAA funded, with NRRI and Nature Conservancy) – Herb

Photo sources: MPR photo gallery, Carol Andrews (St. Louis County), J. Kozarek and research team

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