A logo for a water forum

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# PROJECT OVERVIEW

The Kenai Peninsula Borough in southcentral Alaska is home to diverse aquatic ecosystems crucial for the survival of numerous fish species. The region faces a pressing challenge in optimally directing rehabilitation funds to help ensure functionality of fish passage crossings, which play a pivotal role in supporting these valuable fish populations' health and resilience.

To address this challenge, we drafted a systematic approach to prioritizing ecological and physical conditions of fish passage crossings in the Kenai Peninsula Borough region (KPB). We present the first known published effort to integrate fish passage survey data from multiple agencies in the region, and apply this integrated dataset towards prioritizing the restoration needs of anadromous waterway crossings in the KPB.

This project focused on providing the Soldotna-based nonprofit Kenai Watershed Forum[[1]](#footnote-1) with a reproducible system that would allow them to integrate and apply diverse regional datasets. This integrated dataset contains a prioritization system for fish passage infrastructure in the Kenai Peninsula Borough region.

Ultimately, these efforts are the initial stages of organizing the region's hydrological and infrastructure data to best leverage rehabilitation funds. Collaboration among stakeholders, including fisheries biologists, engineers, and local communities, is essential to successfully applying this prioritization effort.

## OBJECTIVES

1. Coordinated and met with Kenai Watershed Forum and regional entities and maintained communications with Kenai Watershed Forum for project duration.
2. Collected and used existing data sources on fish passage structures and fish habitat extent in the Kenai Peninsula Borough.
3. Integrated all available current data sources into a combined database using R programming language.
4. Developed a prioritization value for each known crossing with available assessment data based on how infrastructure improvement would benefit fish habitat.
5. Provided a report that covers the work methods completed and can be molded into future funding opportunities.

## DELIVERABLES

1. Project Report (this document)
2. R-code script
3. Combined dataset spreadsheet
4. ArcGIS Pro shapefile of the combined dataset

## PROJECT HISTORY

Kenai Watershed Forum conducted this project in collaboration with River Focus Water Resource Consultants[[2]](#footnote-2) within the Kenai Peninsula Borough region. The region’s geography contains a network of anadromous waterways; many which intersect with roads, utility corridors, and other infrastructure. Crossing structures (e.g. culverts, bridges) are frequently decades old and not designed for ideal fish passage conditions. A strategic approach is needed to provide the most impact and help secure funding. Decisions on maintaining and repairing infrastructure can have both short and long-term implications for public safety, aquatic organism passage, watershed physical and ecological functions, and regional economies.

Through the analysis detailed in this report Kenai Watershed Forum and regional entities can systematically address the bridges, culverts, and fords that fragment the region’s rivers and watersheds. The application of this prioritization effort can help the region identify and address the most critical infrastructure needs to improve the region's overall transportation strength, flood resilience, and connectivity for aquatic and terrestrial organisms.

By developing a prioritization for all documented stream crossings in the region, local entities can leverage funding opportunities and ensure the long-term sustainability of its critical assets.

## REGIONAL HYDROLOGY

The importance of the borough’s anadromous waterways extends beyond their hydrological characteristics, thus an understanding of basic regional hydrology, geology, and geomorphology is a valuable lens to have when assessing regional stream road crossings.

The hydrology of the region’s anadromous waterways is shaped primarily by the region's climate, topography, and land use patterns. The presence of active and retreating glaciers has had a significant impact on the landscape by carving out deep valleys and shaping the morphology of the waterways. The interplay between tectonic activity, glacial processes, and fluvial dynamics has resulted in a complex network of channels, meanders, and floodplains that support the diverse habitats anadromous fish species require.

The region’s expansive coastline, coupled with its mountainous terrain, supports this complex network of rivers, streams, and lakes, which are fed by a combination of snowmelt, glacial runoff, and precipitation. The hydrological processes within these watersheds are closely tied to local weather patterns. Seasonal variations in precipitation and temperature affect the flow regimes and water availability.

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Figure 1 – Project area addressed in this work. Fish passage sites lying within all HUC8 watersheds within the Kenai Peninsula Borough political boundary were included.

## FUNDING

From current data, it is estimated that there are at least 412 known transportation crossings on anadromous waterways in the project region. Recognizing the importance of this regional transportation network and its waterways, state, federal, and local government agencies have invested significant resources in addressing the challenges posed by transportation infrastructure on these waterways. The analyses in this report aim to help to secure future investments.

See Appendix B for a list of potential funding sources to continue project efforts and opportunities to pursue research, design, and construction funds to address barriers.

# REPRODUCIBLE ANALYSIS

Data analysis often requires integration of multiple datasets, each with its unique structure and characteristics. Effectively managing and combining these datasets can be complex and time-consuming, but scripted programming languages such as R, Python, or others are powerful tools to streamline this process. This report includes a draft script using R to integrate diverse fish passage and hydrology datasets into a unified source.

One of the primary challenges in dataset integration is ensuring data quality and consistency. The concept of "tidy data" is crucial in this regard, emphasizing the importance of a structured and harmonized data format. By following the principles of tidy data, with each variable in a column and each observation in a row, researchers can significantly simplify the process of data manipulation and analysis.

Appendix A contains the code that was utilized in this project.

## DATA SOURCES

The following datasets on stream crossings in the Kenai Peninsula Borough were utilized to create the combined dataset:

* Fish Barrier Hunter 2022 (U.S. Fish & Wildlife Service)
* Fish Barrier Hunter 2023 (U.S. Fish & Wildlife Service)
* 2024 Anadromous Waters Catalog inventory (Alaska Department of Fish and Game)
* AquaticBarriers.org

## CODE

### OBJECTIVES

* Utilize R-code
* Structure a tidy/efficient script
* Create a script that is easily managed and modified
  + Easy addition of new datasets
  + Easy to manipulate the *CombineData* output sheet

### SCRIPT STRUCTURE

This project utilized the R coding language, which uses relative paths. Relative paths, as opposed to absolute paths, specify the location of files or directories relative to the current working directory or a specific parent directory.

The structure of the script makes the code portable, as it can be easily shared and executed on different machines without requiring changes to the file path. The organizational aspects and outputs with relative paths make the code self-contained and independent of the specific setup of your local file system, promoting portability and organizational clarity. Project code has one main project directory folder containing subdirectories for each entity dataset. The *CombinedData* output sheet will be produced in this main folder. All project-related files are kept within this structure.

### CODE FLOW

Install the latest version of R studio (v4.4.1 or later) here <https://cran.rstudio.com/>. Additionally, the following packages will need to be installed within R studio using the following commands.

* Openxlsx – install.packages('openxlsx')
* Tidyverse – install.packages('tidyverse')

Once the packages are downloaded, run the script in ‘create\_master\_sheet.R’. The following steps provide a detailed outline of the code flow.

1. All available sub-datasets in the sub-directory folder are loaded. (Note: the 16% NHD datasets still require some work to be incorporated).

A close up of a computer code

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1. Column names of the sub-datasets, each separate .csv file, are read and loaded. The column names are linked and associated with new column names. This portion needs to be done manually. When a new data set is added, the columns names in the new dataset need to be identified that correspond to the column headers in the master dataset.

A close up of text

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1. The master dataset column labels are created. These will be the key identifiers that link the sub-datasets.

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1. The sub-datasets columns are relabeled with the new associated column names. Any extra columns in the sub-datasets are removed.

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1. Errors are corrected in sub-datasets merging.

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1. The re-labeled sub-datasets are combined into the master dataset and checked to ensure all columns are present.

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1. Data is manipulated to create a tidy output and make the data usable to determine priority rankings.

A screenshot of a computer code

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1. Create functions to identify priority points for physical and ecological criteria. Each category has an individual function to determine priority.

A computer screen shot of a code

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1. The priority point functions are applied to the master dataset to determine the physical and ecological priority for each crossing. The two are summed to create a total priority score.

A screenshot of a computer code

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Finally, the new master sheet is saved in the output folder directory as a Microsoft Excel Open XML Spreadsheet file (.xlsx). The naming structure is ‘CombinedData\_’+ the date the code is produced (MMDDYYYY).

### ASSUMPTIONS

The script described above makes several assumptions. First, it is assumed that the relative path is correctly specified and accurately points to the desired file or directory. This requires that the file structure and naming conventions remain consistent across the various data sets.

Another assumption is that the combined data sets are compatible regarding their structure, variables, and data types. Failure to ensure compatibility can lead to errors or unexpected results when merging or manipulating the data. Specifically, if the number/order of columns are changed in a sub-dataset or columns are added or removed, the code will need to be updated at step 2.

Finally, using relative paths assumes that the data sets will remain in the exact relative location on the file system (i.e. the main code exists in a folder with the sub-datasets stored in a separate folder labeled “Formatted Data”). Any file structure or folder hierarchy changes could break the relative path references and prevent successful data retrieval.

### TROUBLESHOOTING

Failure to set the working directory correctly can result in R being unable to locate the necessary files. In order to resolve this, set directory names exactly as listed in the beginning of the script. Also, ensure that the sub-datasets have consistent column naming as they had previously.

# COMBINEDDATA SHEET

## SPREADSHEET

The *CombinedData* spreadsheet is a .xlsx (Microsoft Excel Open XML Spreadsheet) file. This spreadsheet contains the following attributes as columns:

1. Latitude
2. Longitude
3. Priority Total
4. Priority Ecological
5. Priority Physical
6. KPB Crossing Code
7. ADF&G Crossing Code
8. Fish Species Composition
9. ADF&G rating
10. Stream Name
11. Road Name
12. Structure Type
13. Structure Dimensions
14. Structure Slope
15. Perch Height
16. Outlet Scour Pool
17. Constriction Ratio
18. NHD+ Upstream Fish Habitat miles
19. Reported Upstream Fish Habitat miles
20. Reported Upstream Lake Fish Habitat acres
21. Upstream OHWM feet
22. Upstream Bankfull Width feet
23. Road Material and Fill Height Over Top of Culvert
24. Tidal Site
25. Visible Deformation
26. Landownership
27. External Report Links
28. Additional Notes

## SHAPEFILE

This project utilized ArcGIS Pro to produce a shapefile of all the crossings, their data, and their prioritization scores in a shapefile. See Appendix C.

Shapefile projection: WGS 1982 Web Mercator (auxiliary sphere)

# PRIORITIZATION SCORING

Analyses in this project sort different watershed features into physical and ecological conditions to develop a prioritization, following efforts similar to those of the Cordova, Alaska based nonprofit Copper River Watershed Project[[3]](#footnote-3). Evaluation of physical conditions refers to the structural integrity and functionality of the crossing itself. Evaluation of ecological conditions refers to the stream/crossing health, floodplain connectivity, fish species present, and upstream habitat.

Ideally, culvert restoration projects should maximize ecological benefit and physical condition. However, trade-offs may be necessary depending on available resources and site-specific constraints. A culvert in relatively good physical condition but with a high ecological benefit potential (e.g., it blocks access to a large amount of high-quality habitat) might be prioritized for improvement. Conversely, a culvert in poor physical condition might be prioritized for replacement even if it doesn't represent a complete barrier to fish passage. This is because a failing culvert could pose risks to human safety and infrastructure and replacing it would provide long-term benefits for both fish and people.

The factors considered in this prioritization are outlined below.

## PHYSICAL CONDITIONS

To establish a system for prioritizing ecological conditions, River Focus considered the criteria listed below. A higher score indicates worse physical condition.

### PERCH (SCORING: 0-10)

This parameter focuses on perched crossing outlets. Crossings with significant drops at the outfall can act as a velocity barrier for fish trying to pass upstream.

Crossings with no perch receive 0 points, less than 0.25 feet perch receive 2 points, 0.25 to 0.75 feet perch receive 5 points, 0.75 to 1.0 feet perch receive 7.5 points, and 1.0 feet or more perch receive 10 points.

### CONSTRICTION (SCORING: 0-10)

This parameter evaluates the degree to which the culvert restricts flow. This scoring prioritizes culverts that significantly impede water flow and potentially fish passage.

Culverts with no constriction, a value of 1 or higher, or unknown constriction receive 0 points, lower-moderate constrictions receive 2.5 points, higher-moderate constrictions receive 5 points, and severe constrictions receive 7.5-10 points.

### CROSSING SLOPE (SCORING: 0-10)

This parameter considers the slope of the existing fish passage structure. Steep culvert slopes can create challenging flow conditions for fish. A crossing with gentler slopes receives higher scores. Steep gradients can create challenging flow conditions for fish, hence the lower scores for steeper culverts.

Crossings with no gradient receive 0 points, lower-moderate gradient receive 2 to 3 points, higher-moderate gradient receive 5 to 7 points, and severe gradient receive 10 points.

## ECOLOGICAL CONDITIONS

To establish a system for prioritizing ecological conditions, River Focus considered the criteria listed below. A higher score indicates better ecological conditions.

### FISH SPECIES COMPOSITION (SCORING: 0-10)

This parameter focuses on the presence and type of fish species upstream of the culvert. The highest scores are assigned to streams with documented presence of anadromous salmonids, reflecting their ecological and cultural significance. This scoring emphasizes restoring connectivity for migratory species and maintaining healthy fish populations. Diverse fish communities signify a healthier ecosystem and greater potential benefits from improved passage.

Streams lacking fish or with an unknown fish presence receive 0 points. Streams with resident fish species receive 5 points, acknowledging their importance to the ecosystem. Streams with one anadromous fish species receive 8 points, while streams with more than one anadromous fish species receive 10 points

### HABITAT QUANTITY UPSTREAM (SCORING: 0-20)

#### LINEAR MILES (SCORING: 0-10)

This parameter considers the length of lotic (flowing waters) upstream habitat accessible to fish if the culvert were improved. Larger values of suitable stream receive higher scores, offering greater potential for fish spawning, rearing, and foraging.

Crossings with less than 0.1 mile of upstream habitat receive 0 points, 0.1 to 0.25 mile of upstream habitat receive 2 points, 0.25 to 0.5 mile of upstream habitat receive 4 points, 0.5 to 1 mile of upstream habitat receive 6 points, 1 to 1.5 mile of upstream habitat receive 8 points, and over 1.5 miles of upstream habitat receive 10 points.

#### AREA IN ACRES (SCORING: 0-10)

Areas scoring highlights the value of restoring access to larger habitat areas. The ecological linkages between streams and associated floodplains, wetlands, and lakes/ponds are essential particularly for juvenile habitats.

Crossings with less than 1 acre of upstream habitat receive 0 points, 1 to 5 acres of upstream habitat receive 2.5 points, 5 to 10 acres of upstream habitat receive 5 points, 10 to 15 acres of upstream habitat receive 7.5 points, and over 15 acres of upstream habitat receive 10 points.

## PROBABLE UPSTREAM HABITAT

To estimate the quantity of probable anadromous stream habitat upstream of fish passage structures, we identified all stream segments downstream of probable natural barriers to upstream movement of adult anadromous fish. We created a layer of all stream segments within the Kenai Peninsula Borough downstream of the first encounter of 16% gradient over a 35 meter distance.

The data set provided with the stream segments is segmented and has breaks that separate the stream segments at arbitrary locations. Because of this, it is not possible to determine the upstream habitat length until a continuous stream polyline system is obtained. Efforts were made to try and fix the segmented lines using buffers and Voronoi skeletons to generalize a centerline and join the segments. However, the effort required was beyond the scope of this work.

### PROBABLE UPSTREAM HABITAT (SCORING: 0-10)

This parameter considers the linear extent of suitable habitat upstream of the crossing up to a 16% grade over 35 m distance. Greater lengths of suitable habitat receive higher scores, offering more potential habitat area.

Crossings with less than 0.25 mile of upstream habitat receive 0 points, 0.25 to 0.5 mile of upstream habitat receive 2.5 points, 0.5 to 0.75 mile receive 5 points, 0.75 to 1.0 mile of upstream habitat receive 7.5 points, and over 1 mile of upstream habitat receive 10 points.

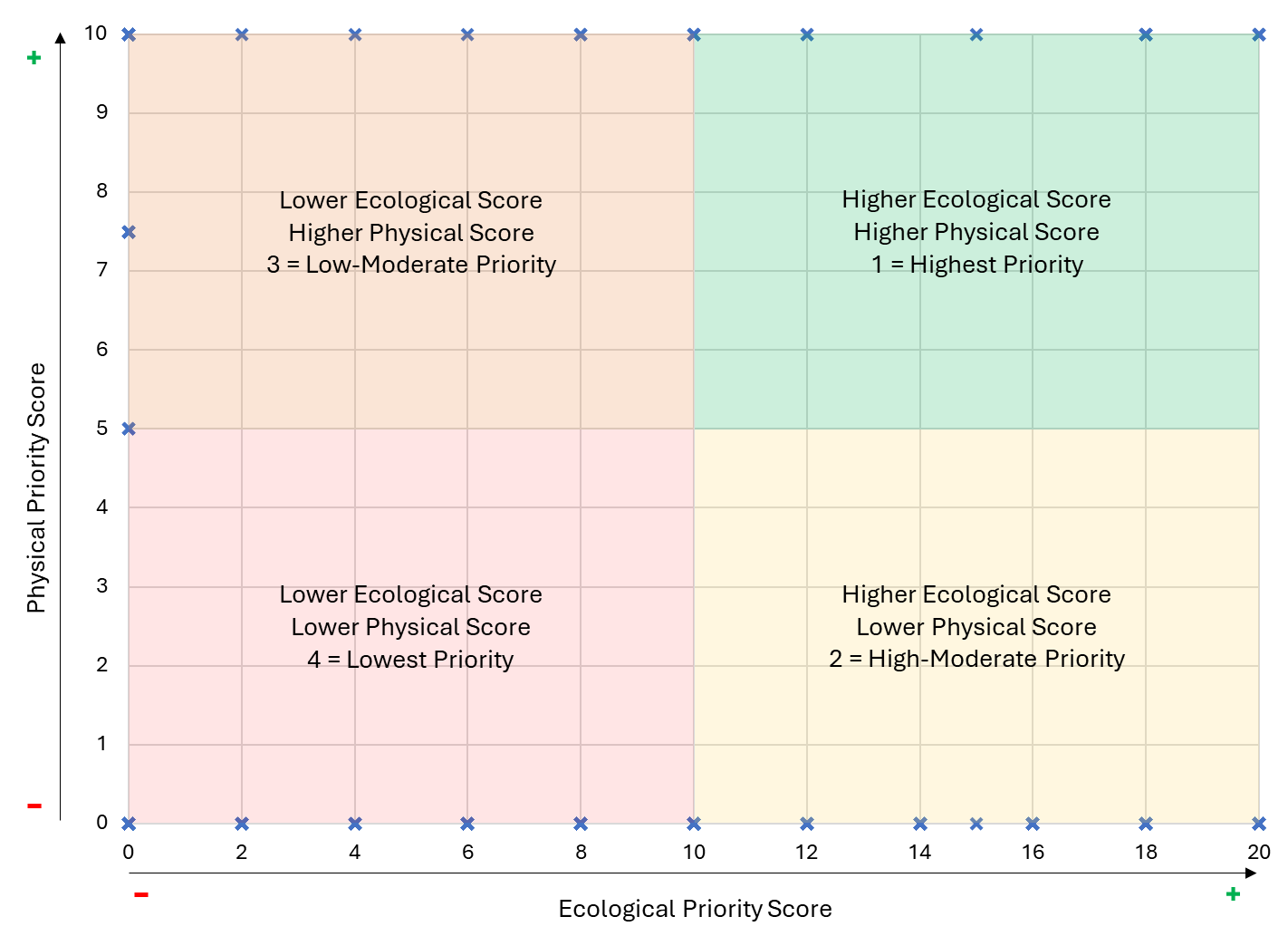
## SUMMARY OF SCORING MODEL

The scores from each parameter are summed to generate a total score for each culvert. This total score serves as a metric for prioritizing projects, with higher scores indicating a greater need for improvement based on both ecological and physical factors.

This scoring matrix considers each culvert's ecological benefits and physical constraints, providing a structured and transparent approach to prioritizing fish passage improvement projects.

The total score for each culvert is calculated by summing the scores from all seven parameters (three ecological, three culvert conditions, and one probable upstream habitat). This approach allows for a comprehensive assessment of both the ecological benefits and the physical limitations of each culvert, facilitating prioritization of projects based on their overall potential for improving fish passage and restoring habitat connectivity.

Once all crossing scores are completed, the prioritization score is calculated. The scores can be graphed to visually assess which projects may offer the best opportunity to improve both infrastructure and access to otherwise impeded habitat.



# FUTURE ENDEAVORS

## GROUND TRUTHING

Kenai Watershed Forum will establish a protocol and network of regional support to verify data associated with the stream crossings listed in its dataset with future funding. Ground-truthing will help confirm the accuracy of current data and gather information about additional features. During this process, new stream crossing locations not previously recorded are also likely to be discovered.

Kenai Watershed Forum and other qualified regional entities responsible for ground truthing will follow a standard survey protocol for recording new information, such as ADF&G and/or USFS protocols.

## FUTURE PRIORITIZING CRITERIA

### HABITAT QUALITY

With available future funding and community support, this effort could assess the quality of upstream habitat based on additional factors like water quality, streambed composition, riparian vegetation, and floodplain influences. Higher-quality habitats, which can support larger and more diverse fish populations, could receive higher scores.

### COST-EFFECTIVENESS

With available future funding and community support, this initiative has the potential to emphasize cost-effectiveness by thoroughly assessing the costs associated with different remediation strategies alongside their potential ecological benefits.

Forecasting the cost of restoration efforts at each crossing could be useful. A cost-estimating fillable form would allow discussions around cost-effectiveness to be held region-wide. In some cases, it may be more cost-effective to prioritize culverts with relatively simple fixes that can restore passage for many fish.

### SOCIAL EQUITY

With available future funding and community support, a multi-faceted approach that integrates considerations of social equity into watershed-wide infrastructure prioritization can occur.

The framework would begin by incorporating metrics that capture the differential impacts of infrastructure on disadvantaged populations. The analysis could involve assessing the crossing’s opening to the bank full width of the stream (which could disproportionately affect certain regional entities). By accounting for these disparities, decision-makers can ensure that infrastructure improvements provide tangible benefits to historically underserved communities.

Second, the prioritization process should actively seek to reconcile regional entities' diverse perspectives and objectives. This collaborative approach can help ensure the selected projects improve ecological outcomes and advance broader economic and social justice goals.

Finally, the framework should emphasize community engagement and capacity-building, empowering regional residents to participate in all stages of the decision-making process. This can involve public input mechanisms and targeted outreach and education efforts to build community knowledge and ownership over infrastructure projects.

By adopting this holistic, equity-focused approach to watershed infrastructure prioritization, KWF and regional entities can work towards a just and sustainable future in which benefits to environmental restoration and infrastructure improvements are equitably distributed.

# CONCLUSION

Kenai Watershed Forum has begun the first steps of producing a regional crossing prioritization model. Working with regional stakeholders, we will continue to build and refine the model.

By combining all available regional data into a prioritized database, Kenai Watershed Forum can create a systematic and cost-effective approach to maximizing ecological benefits. This prioritization model will play a crucial role in advocacy efforts to secure funds and partnerships. It provides a vital start for an effort to create a public-facing stream crossing prioritization tool for the region.

1. <https://www.kenaiwatershed.org/> [↑](#footnote-ref-1)
2. https://www.riverfocus.com/ [↑](#footnote-ref-2)
3. https://copperriver.org/programs/fish-habitat-restoration/restoration/culverts-are-the-culprits/culvert-mapper/ [↑](#footnote-ref-3)