# SAFETY AND FISH PASSAGE FOR LOW-HEAD DAMS

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**Abstract:** There are eight low-head dams on the Red River of the North that impede fish passage and create unsafe conditions for humans using the river. Already constructed and proposed dam modifications benefit the basin's eighty-four species of fish and will prevent people from drowning at these dams. The St. Paul District, Corps of Engineers, has been acting with state and local agencies to place fill downstream of several of these dams to allow fish passage and eliminate the hydraulic roller. The rock fill is generally placed at a 5% grade with rows of large boulders (boulder vanes) that dissipate energy and provide low velocity resting areas for fish. The boulder vanes are also designed to provide deeper water depths towards the center of the channel and to protect the downstream riverbanks from erosion during flood events. Three-dimensional hydrodynamic modeling has been conducted for two of the dams to address concern over whether the rock fill will increase upstream flood stages. For these two dams, the modeling has show that the 5% rock fill section does not increase the 100-yr flood elevation.

## INTRODUCTION

Eight low-head dams exist on the Red River of the North within the United States. These dams were constructed in the twentieth century with the primary purpose of securing a supply of water during low flow conditions. The commonly used names for these dams, listed downstream to upstream and shown in the following figure, are:

1. Drayton Dam
2. Grand Forks Riverside Dam
3. Fargo North Dam
4. Fargo Midtown Dam
5. Fargo South Dam
6. Hickson Dam
7. Christine Dam
8. Wahpeton Kidder Dam

**Safety Concerns:** The dangerous flow conditions downstream of a low-head dam are not readily apparent to most people. Water plunging over the dam typically creates a deeper scoured region immediately downstream of the dam, which in turn supports the development of a hydraulic roller or undertow. Recreational users who approach the dam from the downstream side can be surprised by the deeper water and get caught up in the hydraulic roller. At moderate river flows, when the depth of flow allows for boat passage, traversing the dam looks like a fun whitewater ride, but the strength of the roller can easily trap boaters that fall overboard and can even trap the boat itself. A number of injuries and deaths have occurred at the low-head dams on the Red River of the North. The greatest number of fatalities has occurred at the Fargo Midtown Dam, where nineteen people have drowned since it was constructed in 1960.

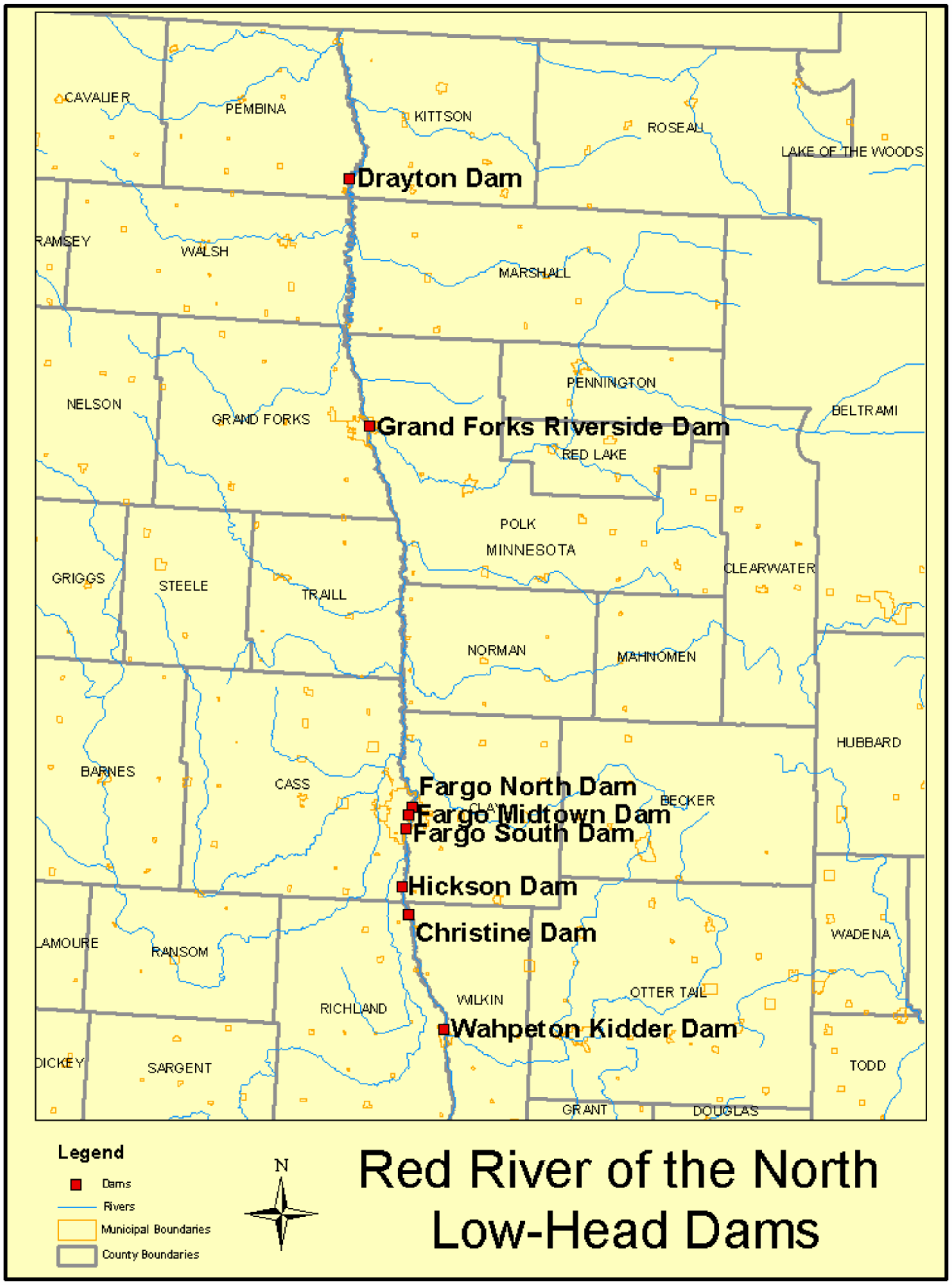


Figure 1 Location of Low-Head Dams on the Red River of the North

Figure 2 Grand Forks Riverside Dam Before Modifications

**Fish Passage Concerns:** According to data collected between 1892-1994, 77 native and seven introduced species of fish inhabit the Red River of the North and its tributaries in the United States (Peterka and Koel, 1996). By hindering the upstream and downstream movement of fish, these eight low-head dams limit access to important habitat and spawning areas. For example, data on fish migration indicate the Fargo South Dam is typically passable less than 10 percent of the time on the average from March through July, and even less during the fish spawning months of May through July. In some years, conditions favorable for upstream fish passage do not occur at the Fargo South Dam.

## DESIGN

**Low-Head Dam Modifications:** Since 1999 five of the eight dams have been modified to address the safety and fish passage concerns. At each of these dams the fundamental design consists of a 20H:1V sloping rock fill section downstream of the dam crest with upstream-pointing concave boulder vanes incorporated into the rock fill to help dissipate energy, direct flow towards the center of the channel, and provide hydrodynamic diversity. The top-of-boulder elevation increases as you move from the channel centerline to the banks. This further protects the banks and provides a chute of deeper flow in the center of the channel that promotes recreational use. A plan view of the Grand Forks Riverside Dam design is shown in the following figure.

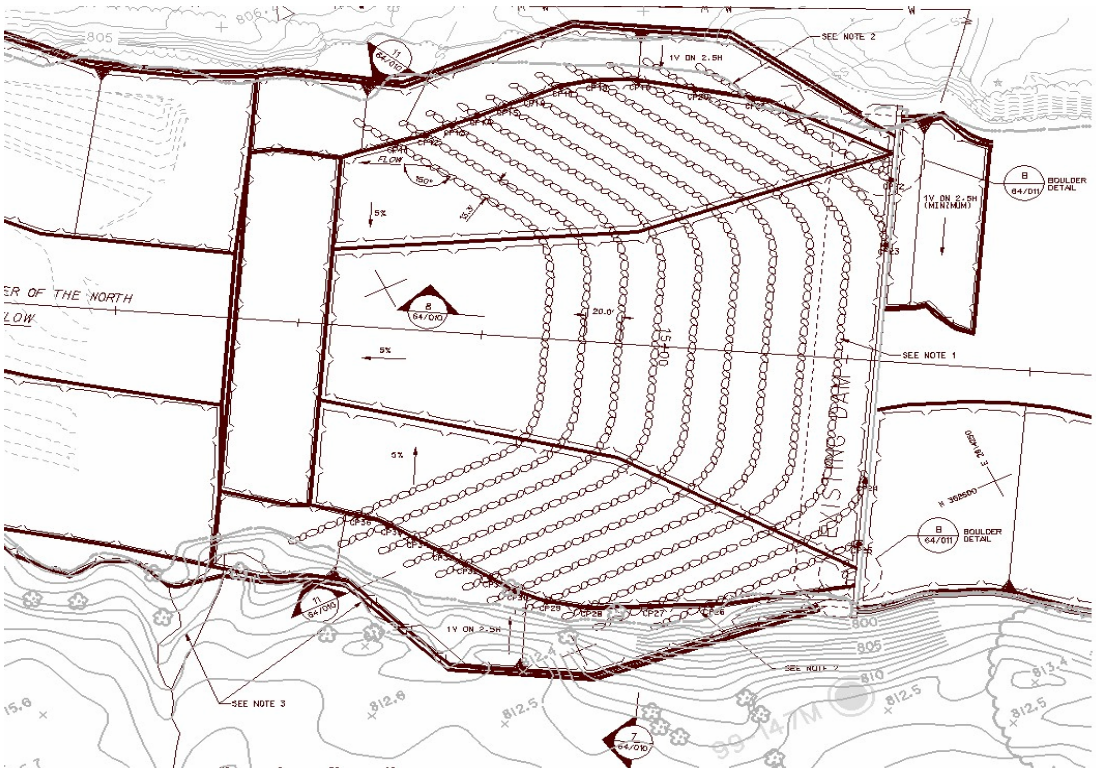


Figure 3 Grand Forks Riverside Dam Modification Plan

The rock fill section eliminates the vertical drop and hydraulic roller thereby improving the safety of the area. The 20H:1V slope and the boulder vanes provide velocity conditions and flow depths that allow many species of fish to navigate upstream and downstream across the dam. Table 1 summarizes the status of the effort to modify the eight low-head dams on the Red River of the North.

**Rock Fill Design:** For the Grand Forks and Fargo dams, an HEC-RAS model was developed to model existing and proposed conditions over a range of flow conditions. Because flow passes through critical depth during low to moderate flow conditions, HEC-RAS was run in its mixed flow mode. Using the maximum velocity obtained from the HEC-RAS model, the high turbulence curves of the Corps' Hydraulic Design Criteria, Sheet 712-1, were used to determine $D_{50}$ minimum and $W_{50}$ minimum for the rock fill. The steep slope riprap design equation of EM-1110-2-1601 was also used as a check of the sizes obtained from Sheet 712-1. The results of this analysis for the Grand Forks Riverside Dam rock fill design are provided in Table 2. The selected gradation is shown in Table 3. $W_{50}$ of the selected gradation is slightly lighter than $W_{50}$ minimum based on Sheet 712-1, but this is considered acceptable since the HEC-RAS model did not account for the roughness provided by the boulders placed throughout the area of rock fill.

**Floodplain Impacts:** Since the projects involve placing fill within the floodway, the North Dakota State Water Commission requires that these projects do not increase the 100-yr flood stage (a 0.01 ft. stage increase is considered unacceptable). Detailed modeling was not requested for the first three dam modifications, but it was required for the Fargo North Dam and the Fargo

South Dam. The initial HEC-RAS analysis for the Fargo North Dam indicated that the stage increase would be between 0.01 and 0.02 ft. Knowing that the HEC-RAS model might be underestimating the hydraulic losses in the hydraulic roller of pre-fill conditions, and therefore the 0.01 to 0.02 ft stage increase might be conservative, the St. Paul District recommended using a slightly higher expansion loss coefficient for pre-fill conditions. Not satisfied with this approach, the North Dakota Water Commission recommended physical or three-dimensional numerical modeling to more accurately compute the true stage increase. After exploring both options, all parties agreed to three-dimensional modeling performed by Corps' Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi.

Table 1 Status of Work on Red River of the North Low-Head Dams

| Name | Status | Volume of Rock (cubic yards) | Construction Cost |
|---|---|---|---|
| Fargo Midtown Dam | Completed – Feb 1999 | 4400 | $261,000 |
| Wahpeton Kidder Dam | Completed – Mar 2000 | 2700 | $120,000 |
| Grand Forks Riverside Dam | Completed – Nov 2001 | 150,000 | $4,800,000 |
| Fargo North Dam | Completed – Feb 2002 | 2600 | $119,000 |
| Fargo South Dam | Rock Placed – Project to be Completed in Spring 2004 | 14,400 (est.) | $810,000 (est.) |
| Hickson Dam | Preliminary Restoration Plan in Progress | N/A | N/A |
| Christine Dam | Preliminary Restoration Plan in Progress | N/A | N/A |
| Drayton Dam | Preliminary Restoration Plan in Progress | N/A | N/A |

With the Fargo North Dam rock fill section in place and the Manning's n value raised from 0.035 to 0.050 in the rock fill section, the three-dimensional model computed the upstream 100-yr flood water surface elevation to be 0.05 ft lower than that of pre-fill conditions. For the Fargo South Dam the elevation decrease due to the rock fill was calculated to be even greater at 0.12 ft. The 20H:1V slope roughly follows the upper boundary of the hydraulic roller so the filled area is mostly an area of ineffective flow under pre-fill conditions. With the hydraulic roller eliminated by the rock fill, the overall energy losses are less, even with the greater bottom roughness. The result is a slightly lower upstream water surface elevation. The pre-fill and post-fill velocity vectors from the three-dimensional model of the Fargo North Dam are presented as Figures 4 and 5, respectively.

**Performance of Dam Modifications:** A major flood in 2001 tested the stability of the already completed dam modifications in Fargo and Wahpeton, and the partially completed modifications in Grand Forks. The rock fill performed very well with only minor movement of rock. No repairs were required at the dams, and the configuration of the boulder vanes appears to reduce the amount of bank erosion downstream of the dams.

Table 2 Sizing Rock Fill for Grand Forks Riverside Dam (USACE, 2001)

| **Fish Passage Rockfill Bed Riprap Sizing based on Mixed Flow HEC-RAS Model Results** | | | | | **Fish Passage Rockfill Bed Riprap Sizing based on EM-1110-2-1601** | |
|---|---|---|---|---|---|---|
| (HEC-RAS Model assumes a 5% riprap slope downstream of the dam crest and does not include the fish passage vanes/boulders. This results is conservative velocities and; therefore, a conservative riprap design/gradation.) | | | | | $D_{30} = (1.95 * S^{0.555} * q^{2/3})/g^{1/3}$ for Steep Slope Riprap Design (2 to 20 percent) Eq. 3-5 on page 3-8 of EM-1110-2-1601 | |
| Discharge in cfs | Maximum Velocity in fps | D50 Minimum based on 712-1 High Turbulence | W50 Minimum based on 712-1 High Turbulence | Flow Conditions through Fish Passage Structure assuming 5% Slope (CONSERVATIVE ASSUMPTION THAT DOES NOT INCLUDE AFFECT OF BOULDERS ON FLOW) | q in cfs/ft | $D_{30}$ in feet |
| 1000 | 5.4 | 0.37 | 4 | Supercritical with hydraulic jump | 3.25 | 0.26 |
| 2000 | 6.9 | 0.61 | 20 | Supercritical with hydraulic jump | 6.49 | 0.4 |
| 3000 | 8.2 | 0.86 | 55 | Supercritical with hydraulic jump | 9.74 | 0.53 |
| 4000 | 9.1 | 1.06 | 103 | Supercritical with hydraulic jump | 12.99 | 0.64 |
| 5000 | 9.9 | 1.25 | 169 | Supercritical with hydraulic jump | 16.23 | 0.75 |
| 6000 | 10.6 | 1.44 | 258 | Supercritical with hydraulic jump | 19.48 | 0.84 |
| 7000 | 11.1 | 1.58 | 341 | Supercritical with hydraulic jump | 22.73 | 0.93 |
| 8000 | 7.7 | | | Subcritical throughout | | |
| 9000 | 5.9 | | | Subcritical throughout | | |
| 10000 | 5.1 | | | Subcritical throughout | | |

Table 3 Selected Rock Fill Gradation for Grand Forks Riverside Dam (USACE, 2001)

| **Selected R270 Riprap Gradation $D_{30}$(min) of Gradation = 1.22 feet** | | | | |
|---|---|---|---|---|
| Percent Lighter by Weight | Limits of Stone Weight in pounds | | Diameter based on Limits of Stone Weight and a spherical shape | |
| | Maximum | Minimum | Maximum | Minimum |
| 100 | 1350 | 550 | 2.5 | 1.9 |
| 50 | 570 | 270 | 1.9 | 1.5 |
| 15 | 260 | 85 | 1.4 | 1.0 |
| 5 | 220 | 50 | 1.4 | 0.8 |

Luther Aadland, a research scientist with the Minnesota Department of Natural Resources and a key player in the design and monitoring of these dams, reports that about two dozen species of fish are making their way to upstream spawning areas because of these dam modifications. At one site he has observed walleyes and suckers spawning in the newly constructed rock rapids. Luther feels that all of the approximately 90 species of fish will benefit from the dam modifications. He is especially optimistic about the impact these projects will have on the once abundant lake sturgeon, which have declined in numbers drastically since these dams were built (Minnesota Department of Natural Resources, 2003).

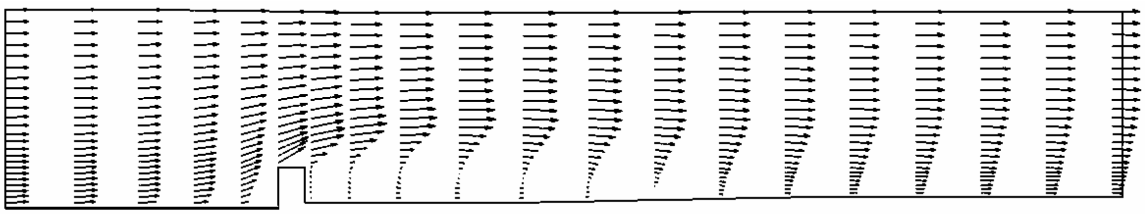

Figure 4 Velocity Vectors for Pre-Fill Conditions at Fargo North Dam (USACE, 2000)

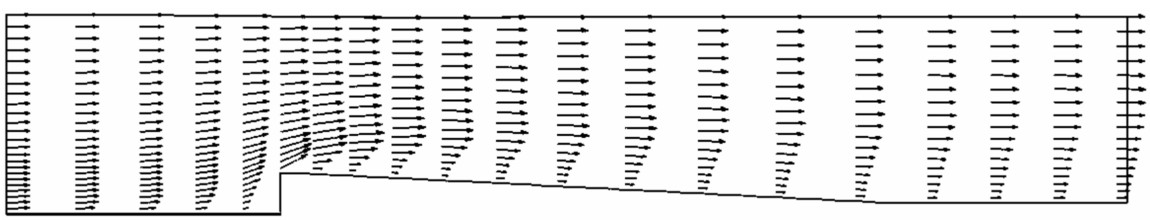

Figure 5 Velocity Vectors for Post-Fill Conditions at Fargo North Dam (USACE, 2000)

## REFERENCES


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