Water Quality Technical Note PD-06
August 1999

# Hydraulic Evaluation of Discharge Over Submerged Rock Wing Dams on the Upper Mississippi River

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**PURPOSE:** This technical note presents prototype data and equations for predicting discharge over the top of submerged wing dams. This analysis was part of a study, done through the Corps of Engineers' Land Management System, to determine the impacts of zebra mussels on water quality and ecological conditions in the Upper Mississippi River (UMR).

**BACKGROUND:** Wing dams (also called spur dikes) are rock structures constructed perpendicular to the flow direction in a river. They extend part way across the channel from the riverbank and constrict flow to a narrower deeper channel more suitable for navigation. Originally constructed in the 1800s as emerged structures, wing dams on the UMR were permanently submerged when the locks and dams were constructed in the mid-1930's. Submergence and deterioration have decreased the effectiveness of wing dams; however, they remain a prominent factor in the river landscape. The low velocity zones and scour holes associated with wing dams provide aquatic habitat diversity, shelter, food organisms, and spawning substrate for a variety of fish species and are an important component of river habitat (Pitlo 1998, Shields 1995). Since wing dams are likely colonization sites for zebra mussels, quantifying the hydraulic conditions near them is important.

**PROTOTYPE DATA:** Hydraulic and geometric data at wing dams (Table 1) were collected in 1994 (Barrientos and Associates, Inc. 1995), using an acoustic doppler channel profiler. Mississippi River total discharge was available from each lock and dam, and the main channel discharge at each wing dam was determined based on available hydraulic data. Figure 1 shows typical flow patterns found at submerged wing dams. Because of the submergence of the wing dams (average depth = 6.8 ft) and subsequent flow over the top of the wing dams, significant lateral eddies were not observed, as they often are at emerged wing dams. Similar observations were made by Maynord in 1999.[1] In Pitlo's 1998 study of wing dams, an average water depth of 5.6 ft was found.

**RELATIONSHIPS BASED ON PROTOTYPE DATA:** Most research on wing dams has focused on the hydraulics of emerged wing dams or morphometric changes associated with wing dams[1] (Shields 1995, Zaghloul 1983) and the habitat that results (Pitlo 1998). Several equations that relate discharge over wing dams to channel and structure geometry are presented in Burch et al. (1984). These equations were developed to predict the effects of constructing wing dams and require estimating depth and channel width before and after construction. The goal of this study was to develop relationships that predict wing dam discharge (i.e. discharge over the top of a submerged wing dam) as a function of easily measured geometric parameters. Prototype data from Table 1 were plotted in Figures 2 and 3. Figure 2 indicates that the ratio of wing dam discharge to main channel discharge is proportional to the ratio of wing dam area to main channel area. Figure 3 indicates that

1 Personal communication, 1999, Dr. Stephen Maynord, Research Hydraulic Engineer, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

**Table 1**
**Hydraulic and Geometric Data at Wing Dams**

| Pool | River Mile | Wing Dam | Measured Flow $Q_{wd}$ (cfs) | Main Channel Flow $Q_{mc}$ (cfs) | Total Flow $Q_t$ (cfs) | Avg. Depth $h$ (feet) | Wingdam Flow Area $A_{wd}$ (feet$^2$) | Main Ch. Flow Area $A_{mc}$ (feet$^2$) | Wingdam Length $L_{wd}$ (feet) | Main Channel Width $W_{mc}$ (feet) | Approx WSEL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 756.9L | 55 | 2184 | 33693 | 37900 | 5.4 | 1420 | 15380 | 264.78 | 1480 | 667.60 |
| 4 | 756.9R | 117 | 1778 | 33693 | 37900 | 6.4 | 1505 | 15380 | 232 | 1480 | 667.60 |
| 4 | 756.8L | 56 | 2154 | 33693 | 37900 | 4.8 | 1284 | 13237 | 267.16 | 1625 | 667.60 |
| 4 | 756.8R | 118 | 3108 | 33693 | 37900 | 5.5 | 2048 | 13237 | 371.03 | 1625 | 667.60 |
| 4 | 756.6L | 57 | 1479 | 33693 | 37900 | 4.9 | 540 | 14807 | 110.57 | 1825 | 667.57 |
| 4 | 756.6R | 119 | 1657 | 33693 | 37900 | 6.9 | 1254 | 14807 | 190.15 | 1825 | 667.57 |
| 5 | 749.1R | 42 | 767 | 33550 | 42300 | 4.7 | 687 | 15480 | 142.79 | 1275 | 669.75 |
| 5 | 749.0R | 43 | 1789 | 33550 | 42300 | 5.6 | 1204 | 15674 | 217.86 | 1360 | 669.50 |
| 5 | 748.8R | 44 | 2006 | 33550 | 42300 | 6.0 | 941 | 15106 | 155.89 | 1450 | 669.00 |
| 5 | 748.7L | 45 | 3383 | 33550 | 42300 | 5.6 | 1365 | 15293 | 242.05 | 1210 | 669.00 |
| 5 | 748.5R | 36 | 2080 | 33550 | 42300 | 5.7 | 1334 | 15447 | 236.66 | 1065 | 669.00 |
| 5 | 740.5R | 26 | 1055 | 50600 | 50600 | 7.3 | 781 | 22020 | 105.76 | 1800 | 660.00 |
| 5 | 740.4R | 25 | 3716 | 50600 | 50600 | 8.7 | 2261 | 21404 | 251.6 | 2000 | 660.00 |
| 5 | 740.2R | 4 | 6067 | 50600 | 50600 | 7.9 | 4001 | 22935 | 493.62 | 2400 | 660.00 |
| 5 | 740.1R | 29 | 4461 | 50600 | 50600 | 9.1 | 2294 | 23852 | 241.82 | 2400 | 660.00 |
| 5 | 740.0R | A | 15000 | 50600 | 50600 | 8.2 | 8986 | 31532 | 1074.13 | 2300 | 659.95 |
| 5 | 739.9R | 33 | 22451 | 50600 | 50600 | 9.9 | 15486 | 32918 | 1543.32 | 2300 | 659.95 |
| 5 | 739.8R | 34 | 28148 | 50600 | 50600 | 8.5 | 9738 | 32016 | 1131.13 | 2300 | 659.95 |
| 5 | 739.1L | B | 8004 | 50600 | 50600 | 8.7 | 4783 | 29636 | 542.9 | 2100 | 659.80 |
| 5 | 739.0L | 39 | 11579 | 51000 | 51000 | 10.1 | 7643 | 35995 | 745.64 | 2500 | 659.70 |
| 3 | 805.7R | 29 | 4772 | 22600 | 22600 | 6.1 | 1584 | 11178 | 263.52 | 1090 | 675.90 |
| 3 | 805.6R | 30 | 3870 | 21100 | 21100 | 4.8 | 1750 | 10967 | 388.55 | 1110 | 675.60 |
| 3 | 805.5R | 1 | 2335 | 21100 | 21100 | 5.7 | 2056 | 10683 | 362.93 | 1025 | 675.60 |
| 7 | 708.9L | 76 | 15340 | 51641 | 51900 | 6.6 | 5961 | 26335 | 897.23 | 2150 | 640.35 |
| 7 | 708.9R | 24 | 5996 | 51641 | 51900 | 7.0 | 2642 | 26335 | 375.51 | 2150 | 640.35 |
| 8 | 690.7L | 34 | 1550 | 41198 | 55900 | 4.6 | 1195 | 7559 | 258.15 | 1825 | 632.36 |
| 8 | 689.0L | 55 | 8894 | 30577 | 55900 | 7.8 | 4234 | 11858 | 542.04 | 1575 | 632.20 |
| 9 | 664.7R | C | 3020 | 29998 | 56600 | 6.2 | 1405 | 12444 | 226.75 | 1160 | 621.31 |
| 9 | 664.6R | D | 2914 | 27338 | 56600 | 7.4 | 1352 | 9081 | 180.31 | 960 | 621.28 |
| 9 | 664.4R | E | 1290 | 24678 | 56600 | 6.1 | 1057 | 8779 | 174.3 | 940 | 621.22 |
| 9 | 664.2L | F | 1705 | 24678 | 56600 | 6.8 | 964 | 9365 | 141.56 | 950 | 621.16 |
| 9 | 664.1L | G | 2936 | 24678 | 56600 | 6.3 | 1623 | 10679 | 257.16 | 925 | 621.13 |
| 9 | 663.9L | H | 4482 | 24281 | 56600 | 5.9 | 1457 | 10679 | 251.94 | 950 | 621.10 |
| 10 | 644.6R | I | 2552 | 34440 | 56000 | 9.1 | 1188 | 8609 | 129.84 | 1175 | 616.62 |
| 10 | 644.5R | J | 585 | 34440 | 56000 | 8.4 | 495 | 8609 | 59.12 | 1170 | 616.60 |
| 10 | 644.4L | 6 | 3657 | 34440 | 56000 | 7.1 | 1555 | 11750 | 221.82 | 1135 | 616.57 |
| 10 | 644.3L | 5 | 3290 | 34440 | 56000 | 8.0 | 1598 | 11856 | 200.69 | 1000 | 616.55 |

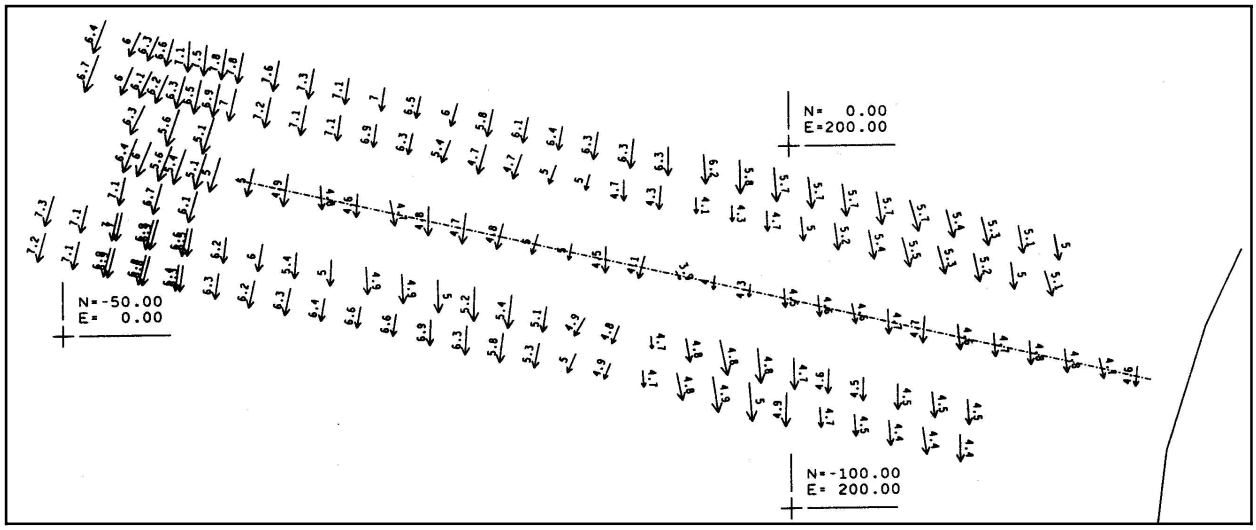


Figure 1. Typical flow direction (shown by arrow), velocity (shown by arrow length), and water depth (designated by numbers) at submerged wing dams (shown by dashed lines)

the ratio of wing dam discharge to main channel discharge is also strongly related to the ratio of wing dam length to main channel width.

The following two equations provide the best estimate of flow over submerged wing dams.

$$Q_{wd} / Q_{mc} = 0.98\ A_{wd} / A_{mc} - 0.019, \quad r^2 = 0.82$$

$$Q_{wd} / Q_{mc} = 0.69\ L_{wd} / W_{mc} - 0.030, \quad r^2 = 0.84$$

where

$Q_{wd}$ = discharge over wing dams, cfs

$Q_{mc}$ = discharge in main channel, cfs (includes wing dam discharge)

$A_{wd}$ = flow area over wing dams, $ft^2$

$A_{mc}$ = flow area in main channel, $ft^2$ (includes wing dam area)

$L_{wd}$ = length of wing dam, ft

$W_{mc}$ = main channel width, ft (includes wing dam length)

The first equation is probably more accurate for a full range of discharge conditions since it accounts for cross-sectional area. However, the second equation has more utility since wing dam length can be obtained from maps or aerial photographs. The constant 0.69, in the second equation, is directly related to the average ratio of wing dam depth to main channel depth found in the prototype data. If wing dam submergence is beyond the range of depths (5 to 8 ft) encountered in this study, the relationship based on length should be adjusted.

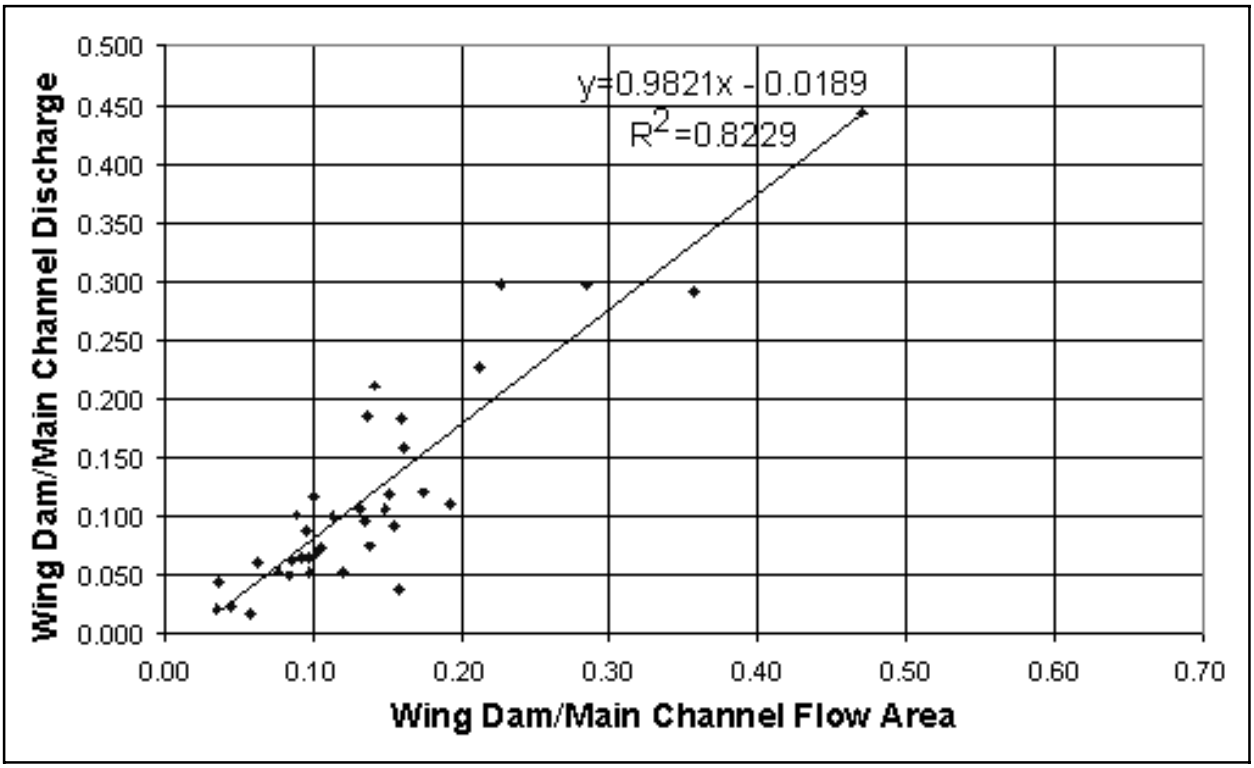


Figure 2. Wing dam discharge based on the ratio of wing dam flow area to main channel flow area

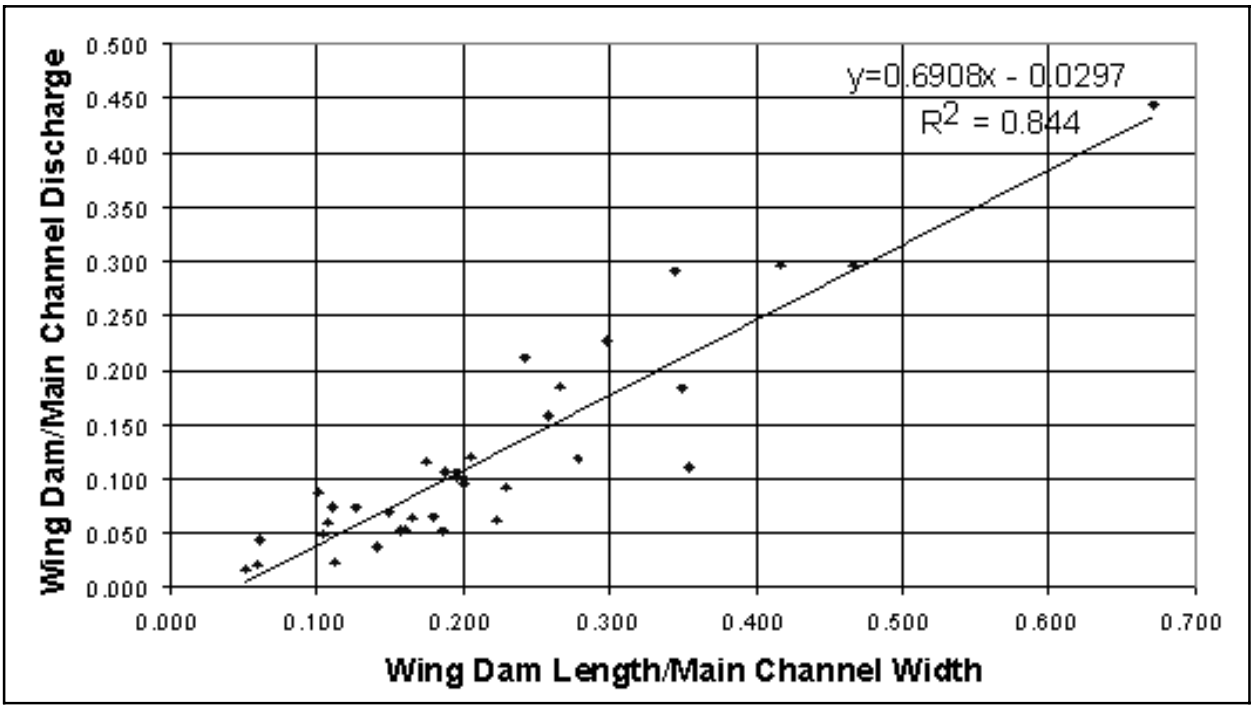


Figure 3. Wing dam discharge based on the ratio of wing dam length to main channel width

**CONCLUSIONS:** This analysis was initiated because of interest in the effects of zebra mussels on water quality in the Upper Mississippi River. Given that the rock substrate associated with wing dams is conducive to colonization by zebra mussels, quantifying the amount of water conveyed over wing dams was essential. The two equations developed above allow the calculation of wing dam discharge. These equations also can be used in other mass transport studies, which require knowledge of the flow distribution within a river channel or floodplain, or in various types of river management studies.

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> Hendrickson, J. S., and Schneider, M. J. (1999). "Hydraulic evaluation of discharge over submerged rock wing dams on the Upper Mississippi River," *Water Quality Technical Notes Collection* (WQTN PD-06), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/elpubs/wqtncont.html*

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