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NATURAL FISH PASSAGE STRUCTURES IN URBAN STREAMS (PART 1: HYDROLOGIC AND RESOURCE ISSUES)

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Abstract: Fish passage is now an integral part of compensatory mitigation under the new Nationwide Permit regulations. Engineered structures and stream restoration designs are common solutions to fish passage; however, in urban systems such solutions may not be feasible. Natural structures such as riffle grade controls and flow constrictor/step pools can provide low-maintenance stable solutions to fish passage in urban systems. Steps to designing such structures include an evaluation of the target fish species characteristics, site-specific baseflow hydrology, and hydraulics of the structure. Analyzing baseflow is essential because urban flood flows exhibit relatively high velocities and short durations precluding upstream migration. Fish characteristics, hydrology, and hydraulics are all used to generate fish passage design criteria.

Introduction

Restoring fish passage has received significant attention by regulatory agencies and elected officials, and is a growing issue on many public works and land development projects. Fish passage is accomplished using either engineered structures (i.e., pool-weirs or fish ladders) or natural channel designs (partial or total stream restoration). Engineered structures are used to provide passage over or through an obstruction such as dams and culverts. Natural designs generally focus on restoring channel geomorphology by providing stable dominant-discharge geometry to properly transport sediments and pass flood flows (100-year events). However, in both natural and urban stream design the low-flow or aquatic habitat channel are forgotten. Engineered structures and natural channel design methods experience significant problems in urban stream systems due to debris and sediment loads, flashy storm flows, low baseflows, and the inability to properly locate the dominant-discharge stage.

Although fish ladders commonly pass sediment loads, they often clog with debris and thus require maintenance. Since daily maintenance is generally required during the migration season, a clogged ladder could prevent significant amounts of fish from reaching spawning areas. Pool-weir structures frequently accumulate sediment in urban streams rendering them ineffective for fish passage. Without the pool volume, fish would need to swim directly upstream negotiating velocities that would likely be overwhelming.

Natural design approaches are adequate in rural or wilderness watersheds because the natural baseflow can be relatively close to dominant discharges. In urban settings, baseflows decrease and flood flows become flashy, scouring channels to unnatural widths resulting in shallow homogeneous channel that are unable to struggle to support fish populations (Sovern 1997). Designing for dominant discharge in urban streams does not necessarily translate to fish passage because of the relatively large disparity between baseflow and dominant discharge. Consequently, the common use of stone cross vanes and other “natural” grade control structures in urban streams can create additional fish passage blockages in our wide urban streams (Figure 1). When these “natural” structures are added to the endless list of exposed utilities, dams, culverts and over-widened channels, fish passage is nearly impossible in these urban areas.

Fig. 1. Example of Natural Structure Becoming a Blockage

This paper is the first of a two-part document designed to present natural approaches for solving urban fish passage problems, by exploring the nested channel and grade control approaches, riffle grade control (RGC) structures, and specially designed flow constrictor/step pool (FC/SP) systems. This part focuses on regulatory issues and the methods to develop design criteria by examining the hydraulic conditions that promote fish passage and the use of baseflow data for estimating design flows. Examples used, herein, are based on designs within the Chesapeake Bay watershed; however, the concepts are applicable to any watershed.

Purpose and Need

Urban fish passage is necessary to reopen and/or create habitat for anadromous fish migration and, to a lesser extent, resident fish movement. Increasing the quantity and quality of spawning habitat would likely increase the size of fisheries for commercial/sport fishing, food, and attracting other wildlife.

Seven species of anadromous fish occur in the Chesapeake Bay watershed: American shad (*Alosa sapidissima*), hickory shad (*Alosa mediocris*), alewife (*Alosa pseudoharenqus*), blueback herring (*Alosa aestivalis*), white perch (*Morone americana*), yellow perch (*Perca flavescens*), and striped bass (*Morone saxatilis*). Anadromous fish are those that live in brackish or ocean water and migrate to freshwater to spawn. Between 1976 and 1985, commercial harvest of these fishes declined by 82 percent due to the pressures of over-fishing and habitat loss. Virginia and Maryland placed moratoria on these fish, which have allowed some fish to recover (i.e., striped bass); however, populations of alewife and blueback herring remain low (Chesapeake Bay Program 2000). Moratoria, in the absence of improved fish passage, will likely preclude some of these anadromous fish species from experiencing a rebound.

Similar to other environs, the quantity and quality of fish spawning habitat has diminished with increased urbanization. Effects of urbanization on streams are well documented and could include increased sediment load, decreased baseflow, higher flood flows, and channel instability. Urbanization may also result in anthropogenic stream blockages such as dams, utility lines, and weirs and culverts that further degrade the channel and habitat, precluding fish migration. Resident fish may be more adaptable to stream alterations caused by blockages; however, these blockages completely eliminate anadromous fish spawning habitat, contributing to fish species decline.

To address fish passage problems, the Anadromous Fish Conservation Act of 1965 was enacted requiring fish passage for large dams. Recently, fish passage has become an integral part of compensatory mitigation for construction projects under the Nationwide Permit (NWP) program. According to the Federal Register dated

March 9, 2000, the U.S. Army Corps of Engineers (USACE) views fish passage as stream enhancement. The Federal Register states, "Stream restoration and enhancement, including the restoration or preservation of riparian zones, can also provide compensatory mitigation for losses resulting from activities authorized by NWPs." NWP 27 authorizes such mitigation under the new NWP program. In addition, General Condition No. 4 of the new NWP program prohibits the disruption of indigenous or migratory aquatic species movement and requires that culverts be installed in a manner that maintains low flow conditions. In some regions of the United States, fish passage and stream restoration are commonplace because of the number of impacted streams located in urbanized watersheds. Recognizing the disproportional impacts to our fisheries and river systems, elected officials in Washington are considering a bill to help restore these resources in our urban environments. The Fishable Waters Act of 2001 (H.R. 325/5678) could provide significant funding over the next six years to improve the valuable resources.

Review of Existing Projects

Completed Structures

Numerous types of natural rock structures are available for stream restoration and habitat enhancement projects, some of which are described below. In California, the USACE --, Sacramento District constructed a Gradient Facility on the Sacramento River as a diversion device for an irrigation canal (Figure 2). As part of the design criteria, three feet of head was required on the RGC to provide fish passage and recreational boating (Hogan 2000).

The U.S. Bureau of Reclamation (BOR) constructed a Gradient Control Structure (GCS) downstream of Marble Bluff Dam in California, which was designed to provide sufficient head for the existing fish lock system to function properly. According to BOR, fish successfully migrated up the GCS and into the lock. BOR indicated that 500,000 fish migrated up the GCS in 1999, and that a second fish lock system is necessary to accommodate the quantity of fish migrating up the GCS (Valentine 2000).

Riffle designs in Canada are presented in a manual by Newbury Hydraulics, Ltd., in which a steep upstream glide surface meets the longer downstream riffle surface (Newbury 1993). Boulders are placed on the riffle surface to provide flow diversity and reduce velocities. Like the two preceding examples, design examples provided in Newbury's manual occur in relatively rural streams. However, each of these structures was designed to pass fish.

Fig. 2. GF in Sacramento River

Fig. 3. RGC in White Marsh Run

In Baltimore County, Maryland, six RGCs were constructed to stabilize White Marsh Run, a high bedload stream that has previously rendered traditional stabilization structures ineffective due to high sediment deposition (KCI 1995). Although these structures were not designed specifically for fish passage, spring flow depth and velocity measurements on these RGCs indicate that they would promote fish passage (MDNR 2000). The White Marsh Run RGCs are unique in that they are installed in series, whereas most constructed riffles were installed as point location structures (Figure 3).

More recently, the U.S. Environmental Protection Agency (USEPA) conducted a large study of stream restoration practices, including 290 grade control structures in the Baltimore/Washington D.C. area and northeastern Illinois to determine if restoration goals were being achieved (Center for Watershed Protection 2000). Grade control structures evaluated in this study were rock vortex weirs, rock cross vanes, step pools, and log drop/v-log drops. All structures were installed for stream restoration, except some of the step pool structures that were installed for habitat enhancement. According to the USEPA, step pool structures were resilient to flood flows and met the habitat enhancement/fish passage objectives. However, the study did not confirm through measurements or sampling that fish are actually passing through the structures. In general, the report stated that less than 60 percent of the inspected structures did not meet habitat enhancement goals.

Based on our review of these and other existing projects, one fact became apparent: restoration projects in urban streams will not likely pass fish if fish passage is an afterthought. However, stream restoration can be successful if it is the result of natural fish passage design. In the Baltimore County project, the fact that the RGCs provide hydraulic conditions conducive to fish passage was a coincidence.

Woodrow Wilson Bridge Project

Natural fish passage design became a substantial part of the compensatory mitigation for the $1,970,000,000 Woodrow Wilson Bridge Project occurring over the Potomac River through the southern tip of Washington D.C. To mitigate impacts of the new bridge construction and ancillary infrastructure construction, the Maryland State Highway Administration (SHA) was required to remove or traverse 21 blockages in 5 different streams, which in turn would re-open 17 miles of urban stream habitat to anadromous fish. These 21 blockages included dams, utility lines, gabion basket weirs, bridge culverts, and concrete fords.

To meet the fish passage goals, SHA first investigated engineered structures. A few factors weighed heavily against the use of engineered structures. Permitting agencies desired a more natural, self-sustaining approach *in-lieu* of engineered structures. Some of the blockages were in a historic park; therefore, visual impacts were a serious consideration. Furthermore, SHA's experience with engineered structures in urban streams indicated that a significant level of maintenance was required to keep them operational (ESA 2000). Significant organic debris loads typically block ladders, and high sediment loads filled concrete pool/weir structures.

SHA decided to use natural fish passage structures such as RGCs and FC/SPs to provide the required fish passage over blockages in Rock Creek, Northwest Branch (of the Anacostia River), Sligo Creek, Little Paint Branch, and Indian Creek. RGCs were designed for blockages in Northwest Branch, Little Paint Branch, and Indian Creek since the blockages where these streams flow (primarily through the Atlantic Coastal Plain Physiographic Province) exhibit high bed-loads, and the blockages are low profile (i.e., culverts, utility lines). FC/SPs were selected for Sligo Creek because the blockages were higher profile (sheet-pile dams) and the hydraulic gradients were too steep to provide the hydraulic environment for migration. For Rock Creek, FC/SPs were a necessity because the blockages are in Rock Creek Park, which is a national park and a historic district, and the fish passage structures could not visually impact the historic scene.

General Concepts

Natural fish passage structures such as FC/SPs and RGCs are used to restore passage over relatively low-profile blockages such as weirs, utility lines, culverts, and low-head dams. These rock structures are designed to produce a hydraulic regime that promotes fish passage, as well as providing additional habitat. Other uses include inducing backwater effects for water supply diversion and providing head for traditional fish structures. For higher head dams (hydraulic drops less than 8 feet) natural structures would not likely be used because construction costs would be excessive, in most cases. Therefore, engineered structures would be the primary means of providing fish passage through higher head dams.

Natural fish passage designs should be pursued sequentially by developing the hydraulic criteria, assessing the hydrology, and designing the structure. Essential components of the hydraulic criteria are documenting the species of concern and evaluating swimming and migrating behaviors. Hydrology evaluations should result in a complete understanding of present and past watershed conditions, future development plans, flood flow trends and frequencies, and base flow trends and frequencies.

Hydraulic Design Criteria

Hydraulic criteria must first address the species of concern and the manner in which they migrate. Migration behavior includes such characteristics as:

- Cruising and burst swimming speeds: Used to set the stream velocity limits through the natural structure. More than one species will likely be addressed by a fish passage structure; therefore, the velocities should be set to accommodate the weakest species.
- Duration of cruising or burst speeds: Measure of the distance a fish can swim before resting. This criterion is used to judge whether a structure is too long for a fish to successfully traverse. If this were the case, resting places such as pools or boulder clusters would be required.
- Leaping ability: Leaping ability could affect the slope of some structures or the size of steps.
- Size of fish. Fish size will help determine the slope of the structure and the minimum depth of flow required for fish passage.
- Months of migration: The period of migration is necessary to define the scope of the hydrologic study and design flow calculations.
- Water Movement: Considers turbulence and velocity. Velocity barriers occur in areas of abrupt change from slow or moderate flowing water to fast flow, and can greatly affect fish that do not leap. Excessive turbulence will also create a barrier because fish do not get useful information regarding current direction. Turbulence in step pool design is quantified by a parameter known as the Energy Dissipation Factor (EDF) (Washington Department of Fish and Wildlife 1999).

Figures 4 and 5 provide useful information regarding the swimming speeds and swimming durations for some anadromous fish. The U.S. Fish and Wildlife Service or state natural resource agencies can likely provide most or all of the above information. The Freshwater Institute, Manitoba, Canada, produced a fishway design document that contains useful information regarding swimming characteristics of anadromous fish (Katopodis 1992).

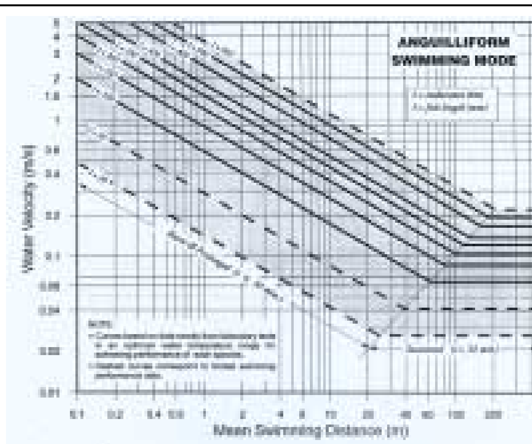

Fig. 4. Anquilliform Swimming Chart

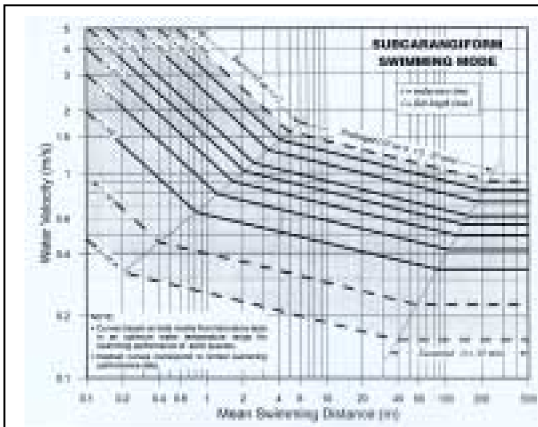

Fig. 5. Subcarangiform Swimming Chart

Hydrology

Project Area Watershed Characteristics

As with any hydrologic study, knowledge of the watershed is particularly important to understanding and modeling the characteristics of the study area. Primary watershed characteristics include: percentage of impervious surface, soil hydraulic parameters, topography, drainage density, future development, and watershed shape. Although not every parameter is used in actual design computations, this background information will guide the design in more subtle ways. For example, if the subject watershed will undergo future development, baseflows and flood frequency will likely be impacted. The designer must estimate the future baseflow impacts and design the natural rock structures to provide fish passage under reduced flow conditions. Future development would also increase flood flow frequency; therefore, rock must be sized appropriately to remain stationary under those conditions.

Urban Watersheds Storm Responses

Over the last two centuries, urbanization has caused significant changes to the landscape surrounding the urban centers and affecting natural hydrologic processes. Increasing percentages of impervious surfaces reduces rainfall infiltration and groundwater storage causing increased surface runoff and flashy stormflows. A common geomorphic response to such hydrologic changes is streambed erosion and/or channel widening. Reduced infiltration will also reduce baseflows, which compounded by an over widened channel, causes significant impacts to fish and macroinvertebrate habitats. Constantly changing environmental conditions and streambed instability are one of the primary limiting factors in urban systems affecting the sustainability of aquatic populations (Sovern 1997). If natural fish passage structures are to be successful, the proper flow depths and velocities must be attained at baseflow conditions.

Effects of Urbanization on Baseflow – Example

To highlight the impacts of urbanization on baseflow, the authors examined stream gage data from the Northwest Branch gage near Colesville, Maryland (USGS Gage No. 01650500), located in southeastern Montgomery County approximately 16 miles northeast of Washington, D.C. This particular gage was selected because it contained a lengthy data set covering watershed conditions from rural to developed (water years 1923 to 1982). Baseflow data were derived from the gage record using the fixed-interval method (USGS 1996).

After collecting the data, a hydrograph was constructed and a linear regression was performed to evaluate any obvious trends (Figure 6). A review of Figure 6 indicates that the regression line exhibits a slight downward trend indicating that baseflow decreased over the length of the record. Two sharp breaks were observed in the hydrograph; one in 1930 due to a significant drought and the second in 1955. The 1955 break corresponds to the beginning of a more permanent trend of lower baseflow due to development. Figure 7 presents development trends in the gaged watershed. According to land development data, significant development started in the 1950s and increased in the 1960s (Maryland Office of Planning 1998).

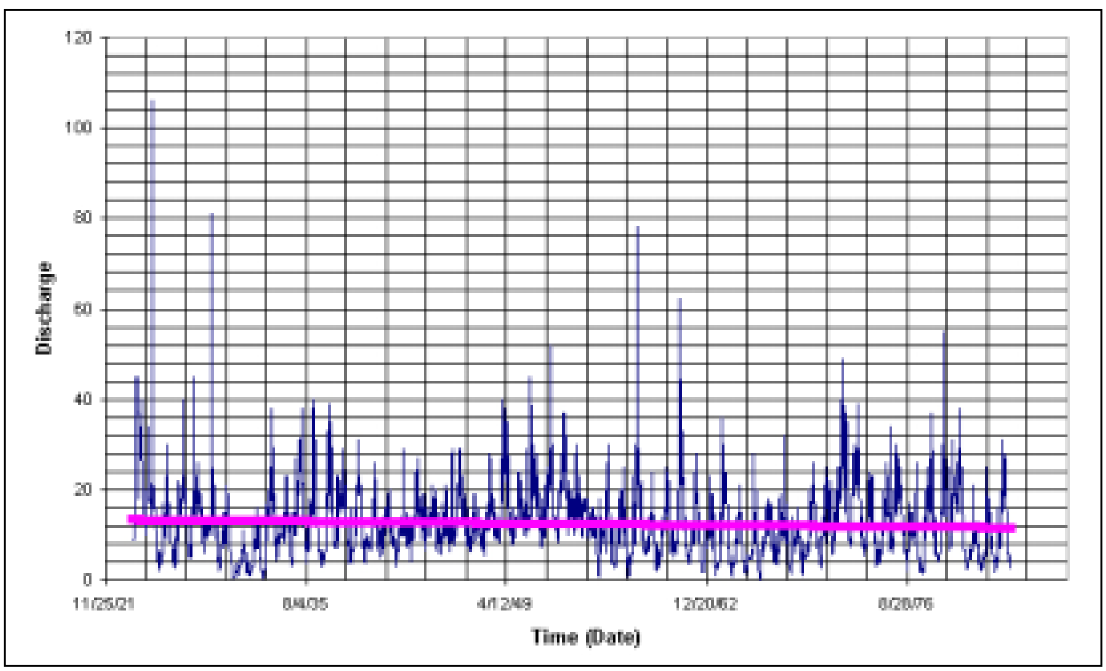

Fig. 6. Baseflow Hydrology, Northwest Branch near Colesville, MD

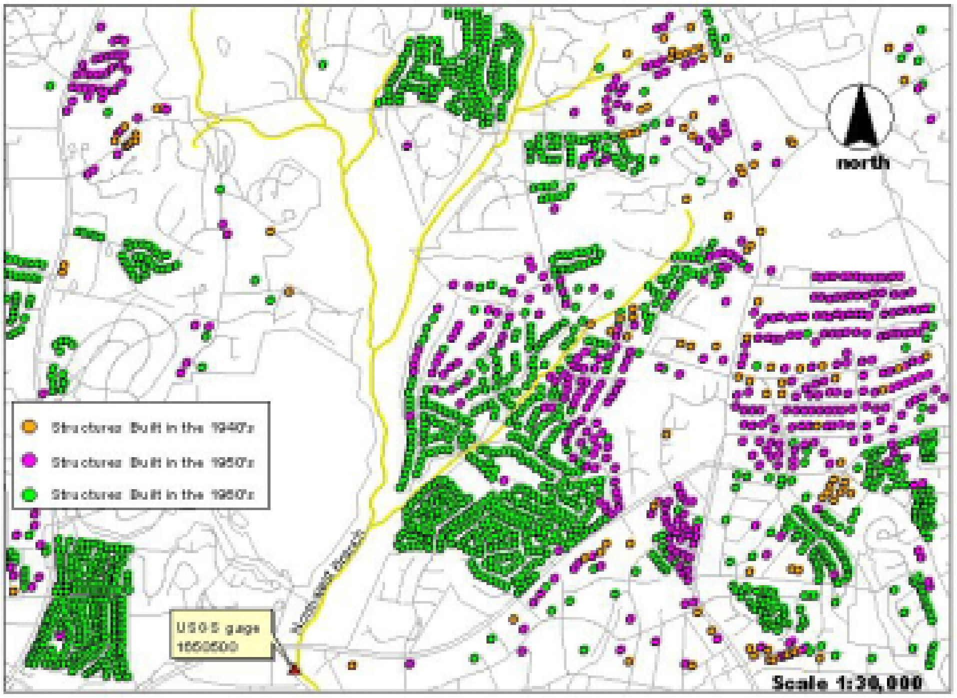

Fig. 7. Development Trends, Colesville, MD

Although the regression indicates a trend, the mechanism of the trend is not apparent; therefore, six 10-year histograms were constructed to review the flow frequencies through time (Table 1).

Table 1
Histogram results from baseflow separation of Northwest Branch Gage near Colesville, Maryland.

Histogram	0-0.14 m3/s	0.14-0.28 m3/s	0.28-0.43 m3/s	0.43-0.57 m3/s	0.57-0.71 m3/s	0.71 – 0.85 m3/s	0.85-1.00 m3/s	1.00-1.13 m3/s	1.1-1.3 m3/s	>1.3 m3/s
1923 – 1932	175	196	168	112	34	15	10	10	6	2
1933 – 1942	52	269	219	118	54	18	7	5	0	0
1943 – 1952	0	157	309	145	72	34	7	8	1	1
1953 – 1962	113	273	181	112	33	15	1	1	0	3
1963 – 1972	151	263	140	88	55	25	5	5	0	1
1973 – 1982	148	238	143	119	54	21	3	3	1	1

Table 1 shows that the frequency of low baseflows dramatically increases as development increased. Low baseflow is only one mechanism impairing fish passage.

Depth of flow is another critical mechanism for fish passage designs and may also be impacted by urbanization. As previously discussed, urbanization tends to cause increases in storm flows that over widen and incise stream channels over time. Over widening will spread flow over a greater surface area, reducing flow depths and ultimately precluding fish passage. While some urban channels have the ability to restore themselves through the creation of a new low flow/aquatic habitat channel with characteristics similar to the predevelopment channel. This process, however, is more the exception than the rule and without assistance will provide little to no aquatic habitat value especially for fish populations.

Baseflow Estimation for Natural Fish Passage

The previous discussion establishes the need for designing natural fish passage structures using baseflows. This section will discuss some available methods for calculating baseflows in gaged and ungaged streams.

Baseflow Estimation in Gaged Streams

In gaged streams, deriving baseflows first requires hydrograph separation from a gage record. Any hydrograph analysis requires that the designer select the applicable portion of the gage record and the applicable timeframe generally corresponding to a migration season. Since baseflows in urban watersheds likely experienced a reduction over time, statistical analyses are required to identify the applicable length of record that is most representative of current conditions. This may be accomplished by a double mass curve analysis, regression analysis, or t-tests. Limiting the analysis to a particular migration season (i.e., March 1 through June 30 of each year) ensures that the final design flows will be artificially biased toward the hydrology that fish use for upstream migration.

After isolating the gage records of concern, hydrograph separation is performed. At least seven different methods are available, including the following:

McCuen 1998
Constant-Discharge Baseflow Separation
Constant-Slope Baseflow Separation
Concave Baseflow Separation
Master-Depletion-Curve Method

Sloto 1996
Fixed-Interval Method
Sliding-Interval Method
Local-Minimum Method

For the Woodrow Wilson Bridge Project, hydrograph separation was performed using the fixed-interval method for the last 30 years of data (only the period between February and May for each year of data used, since this represents the fish migration period). Although some fish can migrate upstream in June, flows are so low in the project streams that large-scale migration is highly unlikely.

After compiling the baseflow data, average baseflows were calculated for each month for each year and the entire data set was regrouped by month. A frequency analysis was performed for each month using the Log-Pearson III distribution for specific exceedance probabilities. However, resulting flows were reported as annual non-exceedance probabilities, which were the 9-, 50-, and 90-percentile flows. These probabilities were selected based on recommendations from fisheries experts. Designers can select any probability deemed applicable; however, the usual non-exceedance probabilities would be 0.10, 0.50, and 0.90. Gages included in this analysis and the resulting flows are included in Table 2.

Table 2
Gages and Associated Baseflow Data

Gage	Watershed Area (mi^2)	9-Percentile Flow (cfs)	50-Percentile Flow (cfs)	90-Percentile Flow (cfs)
Northwest Branch at Hyattsville, MD	49.3	28.08	40.85	63.70
Rock Creek at Sherrill Drive	62.4	30.50	55.25	95.00

For Rock Creek and Northwest Branch, the drainage area ratio method was used to calculate flows at the sites that are distant from the Sherrill Drive and Northwest Branch gages. The drainage area ration method adjusts flows calculated from a gage based on the watershed area for different locations along the gaged stream (Maidment). Tables 3 and 4 present the discharges for the Rock Creek and Northwest Branch sites, respectively.

Table 3
Design flows in Rock Creek.

Site	Watershed Area (mi^2)*	9-Percentile Flow (cfs)	50-Percentile Flow (cfs)	90-Percentile Flow (cfs)
RC-1	74.4	36.37	65.88	113.27
RC-2	73.9	36.12	65.43	112.51
RC-3	69.0	33.73	61.09	105.05
RC-4	65.8	32.16	58.26	100.18
RC-5	65.8	32.16	58.26	100.18
RC-6	64.0	31.28	56.67	94.44
RC-7 (gage site)	62.4	30.50	55.25	95.00
RC-8	62.3	30.50	55.16	94.84

*Watershed areas obtained from GISHydro 2000 (University of Maryland, 2000)

Table 4
Design Flows in Northwest Branch

Site	Watershed Area (mi^2)	9-Percentile Flow (cfs)	50-Percentile Flow (cfs)	90-Percentile Flow (cfs)
NW-1	48.8	27.80	40.44	63.05
NW-2	49.2	28.08	40.85	63.70
NW-3	49.2	28.08	40.85	63.70
NW-4	48.8	27.80	40.44	63.05
NW-5	48.8	27.80	40.44	63.05
NW-6	46.7	26.60	38.70	60.34
NW-7	46.7	26.60	38.70	60.34
NW-8	34.9	19.88	28.92	45.09

*Watershed areas obtained from GISHydro 2000 (University of Maryland, 2000)

Baseflow Estimation in Ungaged Streams

Estimating flows at Little Paint Branch, Indian Creek and Sligo Creek posed a different problem. Although these streams are tributaries of gaged streams, they are far removed from the gage sites; therefore, the Drainage Area Ratio Method was abandoned. Instead, single return-period regression equations were calculated for each return period (non-exceedance probability) of concern using watershed area as a predictor variable. Gages used in this analysis included Northeast Branch, Northwest Branch, Watts Branch, East Branch of Herbert Run, and White Marsh Run. These particular gages were selected due to: 1) proximity to watersheds of interest, 2) watersheds traverse the Fall Line (separates the Piedmont and Atlantic Coastal Plain Physiographic Provinces) and 3) gage records were sufficiently large to use in the analysis. Selection of gages, based on these criteria resulted in only five data points. Although such a small data set weakens our modeled relationships, adding gages in watersheds that occur completely within either the Piedmont or Atlantic Coastal Plain would add another variable and source of error, which is not desirable in this analysis.

During the analysis, the authors discovered that the data did not conform to logarithmic plot, which is typical of stream data. The likely reasons is that the data set was small and the magnitude of the flows represented a small segment of the spectrum of flows that a stream experiences. Therefore, straight-line polynomial regression equations were used to model flows. Watershed area was used as the predictor variable. Although KCI investigated the use of watershed area, percent impervious surface, and a combined term, neither percent impervious surface nor the combined term sufficiently impacted the coefficient of determination, or "goodness-of-fit" (r^2) to warrant its use.

Equations were calculated by a linear regression analysis of flows vs. watershed area, and statistical software was utilized to obtain the b_o and b_1 coefficients. Below are the resulting equations:

- Q9 = 2.61 + 0.42 X1
- Q50 = 2.42 + 0.74 X1
- Q90 = 1.98 + 1.26 X1, where: X1 = watershed area

Table 5 presents the resulting discharges for Sligo Creek, Little Paint Branch, and Indian Creek.

Table 5
Sligo Creek and Little Paint Branch Design Flows

Site	Watershed Area (mi^2)	9-Percentile Flow (cfs)	50-Percentile Flow (cfs)	90-Percentile Flow (cfs)
SC-1 through SC-4	11	7.23	10.56	15.84
LPB-1	9.6	6.64	7.10	14.08
IC-1	26.9	13.91	20.35	34.78

Flows for all sites along Sligo Creek are considered the same because the difference in watershed area between S-1 and S-4 is 0.1 mi^2. Flows for Indian Creek were calculated using both the rational method and the above regression equations because the watershed does not traverse the Fall Line nor is the site near a gage used in the analysis. Results of both methods were relatively identical; however, the flows using the regression equations were reported.

Final Design Criteria

Results from the above investigations are incorporated into the design criteria for natural fish passage structures, which include the following:

- Design Flows
- Maximum velocity at the design flows
- Minimum depth of flow – usually to 12 inches at the 50-percentile baseflow
- Slope of the structure
- Construction materials – based on shear stresses for flows at top of bank, 2-, 10- and 100-year return periods.
- EDF – less than 4 lbs/ft^2s (essential for FC/SP approach)

Conclusions

New federal regulations are focusing on fish passage as part of compensatory mitigation. Fish passage structures such as fish ladders are suitable for dams and potentially culverts in urban streams; however, urban watershed conditions tend to create significant maintenance problems. Urban fish passage designs, accomplished with natural structures such as RGCs and FC/SPs, are more self-sustaining in urban watersheds and can provide habitat enhancement that is not otherwise possible with fish ladders and other engineered structures. Prior to selecting a method, designers must review the characteristics of the target fish species and perform the necessary hydrologic calculations to obtain the design flows. It is incumbent upon the designer to study the watershed and model the flows to correspond to migration patterns and future watershed conditions. The authors believe that designing for baseflow in urban streams provides a conservative platform for a fish passage design. Using the complete gage record for an urban stream may overestimate the design flows, resulting in an effective fish passage structure.

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