Chapter 1

Instream Flow Incremental Methodology (IFIM) for Modelling Fish Habitat

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The concept of instream flow criteria was first defined in the 1940's, and has since developed into a major component of water resources management (Doerksen, 1991). However, defining instream flow standards has been often criticized because of the costs associated with the determinations and maintenance of the chosen flow regime (Smith, 1990), and because of the ambiguity associated with instream flow criteria, because standards have not been clearly defined by regulatory agencies (Beecher, 1990). But even critics contend that there is a need to effectively manage water resources, including the need to establish instream flow criteria.

There are a variety of instream flow methods available to determine the impact of water flow on aquatic biota (Wesche and Rechar, 1980), but the use of the Instream Flow Incremental Methodology (IFIM) has become one of the

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predominant methods for establishing instream flow criteria. Some states use a hierarchical approach for selecting the methodology for determining instream flows, with IFIM selected for the most complex projects that: 1) are expected to have significant impacts on the aquatic biota, 2) impact a valuable fishery, 3) are peaking facilities, and 4) involve complex negotiations (Reed and Mead, 1990). In Michigan, the Michigan Department of Natural Resources (MDNR) requires that IFIM studies be conducted on projects that do not operate as run-of-river (flow into impoundment equals outflow from turbines). One major drawback to using IFIM is that this approach is the most costly and time consuming of the most frequently used instream flow methodologies (Reed and Mead, 1990).

The IFIM was developed in the late 1970's (Bovee and Milhous, 1978) and has continually been refined amid constructive criticism (Orth, 1987; Nestler et al., 1989). The methodology is based on habitat quality, as dictated by stream hydraulics, and the relationship between incremental changes in water flow as it affects available habitat (area that is suitable for a particular organism). Available habitat is based on the quality of microhabitat variables (water velocity, water depth, substrate and cover) and macrohabitat variables (water temperature, dissolved oxygen, and other water quality variables), depending on an individual organism's preference for these variables. The methodology can be used to determine available habitat for fish and wildlife, as well as determine suitability for recreational uses such as canoeing.

Annear and Conder (1984) contend that the ideal instream flow determination method should have the following attributes: 1) it should be based on biological data, 2) provide defensible results, and 3) provide for trade-offs in negotiation. The IFIM process incorporates all three attributes by using biological as well as physical data, while also providing the opportunity for intelligent interpretation of the data. Cavendish and Duncan (1986) also felt that the IFIM technique was the preferable approach because it is a good negotiating tool which allows for compromises based on alternate flow evaluations and the perceived trade offs between flow volume (= cost) and habitat suitability. Because of these attributes, IFIM appears to be the preferable approach for resolving complex/controversial instream flow issues.

A survey of U.S. Fish and Wildlife Service field users of IFIM conducted by Armour and Taylor (1991) revealed that the methodology incorporated assumptions that are technically too simplistic but yet the methods are too complex to apply. Technical simplicity of assumptions is an inherent characteristic of the methodology (and most models). However, literature and training are available to teach all aspects of IFIM to the uninitiated, so complexity of application should not be an insurmountable problem.

Armour and Taylor (1991) also reported a need for further research on the development of habitat suitability index (HSI - index that measures suitability of habitat based on preference for microhabitat variables) curves; the relationship

between weighted usable area (WUA - square feet of suitable habitat for 1000 feet of river) and fish responses; and the need for monitoring studies to determine the adequacy of the recommended flows. There have been studies conducted to fill some of the above research needs. Tyus (1992), Modde and Hardy (1992), and Lenard and Orth (1985) have dealt with fundamental concepts behind HSI curve development and their application, while numerous other studies have been conducted on habitat suitability of individual species and life stages. The relationship between available habitat and standing crop has been addressed by Conder and Annear (1987) and Moyle and Baltz (1985). However, it is likely that the lack of validation or monitoring studies to determine the adequacy of agency recommended flows will continue until follow-up studies are mandated by regulations (Armour and Taylor, 1991).

The Thunder Bay Power Company (TBPCo) owns and operates a series of hydroelectric facilities and water storage impoundments on the Thunder Bay River, located in northern Michigan. Because the water storage impoundments that we studied are not operated as run-of-river, MDNR requested that the TBPCo conduct an IFIM study as part of the Federal Energy Regulatory Commission (FERC) hydroelectric relicensing process. This study was conducted by the Great Lakes Environmental Center (GLEC) to determine the effect of various flow regimes on the WUA (available habitat) of four life stages (spawning adult, fry, juvenile, and adult) of smallmouth bass (*Micropterus dolomieu*), northern pike (*Esox lucius*), and white sucker (*Catostomus commersoni*) below the two water storage impoundments. Smallmouth bass and northern pike were selected because they are important game species and are representative of many other game species in the Thunder Bay River system while white sucker was selected because of their importance as a prey species. The objective of this study was to determine the effects of proposed minimum water release flows below these impoundments on the Thunder Bay River in northern Michigan.

1.1 Study Sites

The study sites are located on the Upper South Branch (below Fletcher Pond Dam) and Lower South Branch (below Hubbard Lake Dam) of the Thunder Bay River in northern Michigan (Figure 1.1). Fletcher Pond and Hubbard Lake are water storage impoundments which provide supplemental water to power producing hydroelectric facilities downstream. The downstream power producing facilities are operated as run-of-river. Because the downstream facilities are not peaking facilities, the water storage impoundment water levels are not manipulated on an hourly/daily basis, and are held close to full pool during spring, summer, and autumn. During the winter months, these impoundments are drawn down to winter pool level as a flood control measure, in anticipation of increased precipitation and runoff in the spring. Impoundment water level management is

Figure 1.1
Sampling locations on the Upper South Branch and Lower South Branch of the Thunder Bay River.

practiced according to legally binding agreements between the respective lake associations and TBPCo. The proposed minimum flows are 15 and 30 cfs (cubic feet per second) below Fletcher Pond Dam and 15cfs below Hubbard Lake Dam.

Fletcher Pond is a 9,000 acre flooded wetland, shallow in depth, heavily vegetated, and has relatively warm water temperatures. The dam is located at the northern most and deepest part of the lake, and has about 20 ft of head height at full pool. The tailwater (river segment downstream of the dam) is a low gradient system that is relatively shallow (1-4 ft) and wide (90 ft), with a bottom substrate consisting mainly of debris, vegetation, silt, and sand. Hubbard Lake is a 8,750 acre spring fed, cool water lake that was elevated about six feet by the construction of a dike and dam structure at the northern most tip of the lake. Because Hubbard Lake is an elevated lake, the dam is not at the deepest part of the impoundment, and has a head height of about 6 ft at full pool. The tailwater begins as a relatively large (1 acre) and deep (15 ft) pool, which flows into a low gradient system that is relatively shallow (1-4 ft) and wide (50 ft), with bottom substrate consisting mainly of silt, sand, gravel, and cobble.

1.2 Methods

Cross sectional transects were used to represent habitat typical of the Upper South Branch and Lower South Branch of the Thunder Bay River. One group of three transects were surveyed on the Upper South Branch. They were located approximately 700 feet downstream of the Fletcher Pond Dam (Figure 1.1). For the Lower South Branch, one group of three transects was located approximately five river miles downstream of Hubbard Lake Dam near Beaver Lake Road and the second group consisted of six transects and was located approximately two river miles downstream of Hubbard Lake Dam near Scott Road (Figure 1.1). These transects were selected because they were representative of the available habitat in each respective area.

Each transect was surveyed to determine stream width, distance between each transect and the water surface elevation. Water flow from the dams was manipulated to achieve a low, medium and high water flow regime. Water velocity, water depth and substrate type were recorded at one foot intervals (cells) across each transect during each flow regime. The measured low, medium and high flows at the Upper South Branch site below Fletcher Pond Dam were 22.5, 48.5 and 139.9 cfs, respectively. The measured low, medium and high flows on the Lower South Branch at the Beaver Lake Road site were 36.1, 63.0 and 148.1 cfs, and at the Scott Road site they were 34.4, 57.8, and 140.7 cfs, respectively.

The Physical Habitat Simulation System (PHABSIM) models, as described by Milhous et al. (1989), were used to calculate the available habitat for the four life stages of each fish species at the low, medium and high flows as well as at six simulated water flow regimes on the Upper South Branch (i.e. 15, 30, 40, 70,

100, and 200 cfs) and the Lower South Branch (i.e. 15, 30, 45, 70, 100, and 200 cfs). The PHABSIM models use a hydrologic component (HEC2 hydrologic simulation model - U.S. Army Corps of Engineers) and a biological component (HABTAV habitat simulation model - PHABSIM) to determine the available habitat for each life stage of each fish species for the selected flows (Figure 1.2). The PHABSIM models determine suitability of individual cells by determining the combined suitability of the microhabitat characteristics of each cell and the habitat needs of specific species and life stages of fish (based on the preference for the microhabitat variables) to determine the habitat quality of each cell. These cells are then extrapolated to determine the overall quality of the stream section.

Cover type is not an essential microhabitat variable in PHABSIM (Milhous et. al. 1989) and was not an important characteristic in this study; hence this variable was not included in the analysis. The assumption that microhabitat variables, not macrohabitat variables, limit available habitat must be met if the IFIM technique is to be used properly (Annear and Conder 1984). If it is determined that macrohabitat characteristics effect habitat suitability, then other modelling techniques must be incorporated into the IFIM process. In our study, it was determined that the macrohabitat variables were of sufficient quality for the species selected, and that the microhabitat variables were the most critical factors affecting habitat suitability.

The HEC2 hydrologic model, which determines water surface elevations using step backwater calculations, was used to determine water surface elevations for each transect at each water flow regime. The step backwater method uses energy loss between transects, as calculated by the Manning equation, to calculate the water surface elevation. These water surface elevations were input into the IFG4 model to determine water velocities and depths at each cell, for all transects and all flows. The output from the IFG4 model, together with the HSI curves for each life stage of each fish species (MDNR, 1990), were entered into the HABTAV habitat simulation model to determine available habitat versus water flow for each fish species and life stage, at each selected flow. The HABTAV model also has the option of using a migration component, which determines the suitability of individual cells by utilizing the individual cells suitability as well as the suitability of adjacent cells. The migration component is important when considering resting and feeding behaviour of various fishes.

The HSI curves used for habitat modelling were developed by the National Ecology Research Center, Riverine and Wetlands Ecosystems Branch (U.S. Fish and Wildlife Service), which were modified by MDNR for use in Michigan (MDNR, 1990). The HSI curves represent suitability of habitat for each species and life stage, with respect to water velocity, water depth, and substrate type. The substrate codes are those used by MDNR and are as follows: debris/vegetation (1), silt (2), sand (3), gravel (4), cobble (5), rubble (6), small boulders (7), large boulders (8), and bedrock (9); they are similar to the ones

Figure 1.2
Flow diagram of the major linkages for the Physical Habitat Simulation System (Milhous et al., 1989).

used by Bovee (1982). Because adult and juvenile smallmouth bass have a tendency to position themselves close to optimal habitat while feeding, these two life stages were modeled with a migration component. This migration component not only used the suitability of individual cells, but also used the suitability of adjacent cells (≤ 10 ft away) with suitable water velocity (≤ 2 ft/s) in determining available habitat. All of the other species were modeled using the suitability of individual cells.

1.3 Results

1.3.1 Upper South Branch

Total habitat (square feet of wetted channel for 1,000 feet of river) on the Upper South Branch of the Thunder Bay River increased from 82,000 ft² at 15 cfs to 97,500 ft² at 200 cfs (Figure 1.3). As water flow increased on the Upper South Branch, available habitat (square feet of suitable habitat for 1000 feet of river) increased for smallmouth bass spawning adult, juvenile and adult life stages; available habitat decreased for smallmouth bass fry (Figure 1.3). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat (percentage of total habitat) for smallmouth bass ranged from 500 ft² (one percent) for adults to 9,000 ft² (11 percent) for fry; at the proposed minimum flow of 30 cfs, available habitat and percent total habitat ranged from 1,000 ft² (one percent) for adults to 5,000 ft² (six percent) for fry (Table 1.1).

As water flow increased on the Upper South Branch, available habitat decreased for northern pike spawning adult, fry and juvenile life stages; available habitat increased for northern pike adults (Figure 1.3). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat ranged from 1,000 ft² (one percent) for adults to 53,500 ft² (65 percent) for juveniles; at the proposed minimum flow of 30 cfs, available habitat and percent total habitat for smallmouth bass ranged from 1,000 ft² (one percent) for adults to 35,500 ft² (47 percent) for juveniles (Table 1.1).

As water flow increased on the Upper South Branch, available habitat increased for white sucker juvenile and adult life stages; available habitat increased for white sucker spawning adults until a maximum was reached at 70 cfs, and then decreased; and available habitat decreased for white sucker fry until a minimum was reached at 70 cfs, and then increased (Figure 1.3). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat for white sucker ranged from 3,500 ft² (four percent) for spawning adults to 24,000 ft² (29 percent) for fry; at the proposed minimum flow of 30 cfs, available habitat and percent total habitat ranged from 7,000 ft² (eight percent) for spawning adults to 21,500 ft² (26 percent) for fry (Table 1.1).

Figure 1.3
Available habitat (left axis) and total habitat (right axis) versus flow (cfs) for
smallmouth bass, northern pike and white sucker on the Upper South Branch of
the Thunder Bay River.

Table 1.1

Total square feet of available habitat per 1000 feet of river, and percent total habitat (in parentheses) for smallmouth bass, northern pike and white sucker on the Upper South Branch the Thunder Bay River at the proposed minimum flows of 15 cfs and 30 cfs.

UPPER SOUTH BRANCH						
	Smallmouth Bass		Northern Pike		White Sucker	
Life Stage	15 cfs	30 cfs	15 cfs	30 cfs	15 cfs	30 cfs
Spawning	2,500 (3)	2,500 (3)	31,000 (38)	22,500 (27)	3,500 (4)	7,000 (8)
Fry	9,000 (11)	5,000 (6)	23,000 (28)	9,000 (11)	24,000 (29)	21,500 (26)
Juvenile	1,500 (2)	4,000 (5)	53,500 (65)	35,500 (47)	9,000 (11)	11,500 (14)
Adult	500 (1)	1,000 (1)	1,000 (1)	1,000 (1)	10,500 (13)	13,000 (15)

1.3.2 Lower South Branch

Beaver Lake Road

Total available habitat on the Lower South Branch of the Thunder Bay River below Beaver Lake Road increased from 57,500 ft² at 15 cfs to 81,500 ft² at 200 cfs (Figure 1.4). As water flow increased on the Lower South Branch at Beaver Lake Road, available habitat increased for smallmouth bass spawning adult, juvenile and adult life stages; available habitat decreased for smallmouth bass fry (Figure 1.4). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat for smallmouth bass ranged from 1,000 ft² (two percent) for adults to 5,000 ft² (nine percent) for fry (Table 1.2).

As water flow increased on the Lower South Branch at Beaver Lake Road, available habitat decreased for northern pike spawning adults, fry and juvenile life stages; available habitat increased for northern pike adults (Figure 1.4). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat for northern pike ranged from 0 ft² (zero percent) for adults to 19,500 ft² (34 percent) for juveniles (Table 1.2).

As water flow increased on the Lower South Branch at Beaver Lake Road, available habitat increased for white sucker adults; available habitat decreased for white sucker juveniles; for white sucker spawning adults, available habitat increased until a maximum was reached at 70 cfs, and then decreased; and for white sucker fry, available habitat decreased until a minimum was reached at 70 cfs, and then increased (Figure 1.4). At the proposed minimum flow of 15

LOWER SOUTH BRANCH, BEAVER LAKE ROAD SMALLMOUTH BASS

NORTHERN PIKE

WHITE SUCKER

Figure 1.4

Available habitat (left axis) and total habitat (right axis) versus flow (cfs) for smallmouth bass, northern pike and white sucker on the Lower South Branch of the Thunder Bay River at Beaver Lake Road.

Table 1.2

Total square feet of available habitat per 1000 feet of river, and percent total habitat (in parentheses) for smallmouth bass, northern pike and white sucker on the Lower South Branch the Thunder Bay River at the proposed minimum flow of 15 cfs.

LOWER SOUTH BRANCH			
Beaver Lake Road			
Life Stage	Smallmouth Bass	Northern Pike	White Sucker
Spawning	1,500 (3)	6,500 (11)	13,500 (23)
Fry	5,000 (9)	2,500 (4)	4,000 (7)
Juvenile	2,500 (4)	19,500 (34)	6,500 (11)
Adult	1,000 (2)	0 (0)	6,500 (11)
Scott Road			
Life Stage	Smallmouth Bass	Northern Pike	White Sucker
Spawning	2,000 (4)	<500 (<1)	15,500 (34)
Fry	2,000 (4)	500 (1)	500 (1)
Juvenile	3,000 (7)	3,000 (7)	500 (1)
Adult	1,000 (2)	0 (0)	2,000 (4)

cfs, available habitat and percent total habitat for white sucker ranged from 4,000 ft² (seven percent) for fry to 13,500 ft² (23 percent) for spawning adults (Table 1.2).

Scott Road

Total available habitat on the Lower South Branch of the Thunder Bay River below Scott Road increased from 45,500 ft² at 15 cfs to 88,500 ft² at 200 cfs (Figure 1.5). As water flow increased on the Lower South Branch at Scott Road, available habitat increased for smallmouth bass spawning adult, juvenile and adult life stages; available habitat decreased for smallmouth bass fry (Figure 1.5). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat for smallmouth bass ranged from 1,000 ft² (two percent) for adults to 3,000 ft² (seven percent) for juveniles (Table 1.2).

Figure 1.5
Available habitat (left axis) and total habitat (right axis) versus flow (cfs) for smallmouth bass, northern pike and white sucker on the Lower South Branch of the Thunder Bay River at Scott Road.

As water flow increased on the Lower South Branch at Scott Road, available habitat increased for northern pike spawning adult and adult life stages; for northern pike fry and juveniles, available habitat increased until a maximum was reached at 57.8 cfs, and then decreased (Figure 1.5). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat for northern pike ranged from 0 ft² (zero percent) for adults to 3,000 ft² (seven percent) for juveniles (Table 1.2).

As water flow increased on the Lower South Branch at Scott Road, available habitat increased for white sucker fry, juvenile and adult life stages; for white sucker spawning adults, available habitat increased until a maximum was reached at 70 cfs, and then decreased (Figure 1.5). At the proposed minimum flow of 15 cfs, available habitat and percent total habitat for white sucker ranged from 500 ft² (one percent) for fry and juveniles to 15,500 ft² (34 percent) for spawning adults (Table 1.2).

1.4 Discussion

1.4.1 Fish Habitat Preference Versus Available Habitat

Each life stage of each fish species has a preference for each of the microhabitat variables. The combination of these microhabitat variables determines the suitability of an area. For smallmouth bass, the preferred habitat for all four life stages is similar, except for fry which tend to prefer slower water velocity (MDNR, 1990). Spawning adults, juveniles and adults prefer water velocities ranging from 0.25 to 1.5 ft/s, water depths ranging from 1 to 6 ft, and substrate ranging from sand to small boulders; fry prefer similar water depths and substrate types as the other three life stages, but prefer velocities ranging from 0 to 0.25 ft/s. Therefore, higher flows benefit spawning adults, juveniles and adults and lower flows benefit fry.

For northern pike, the preferred habitat for all four life stages is similar, except for adults which prefer deeper water (MDNR, 1990). Spawning adults, juveniles, and adults prefer water velocities ranging from 0 to 0.4 ft/s, but fry prefer velocities ranging from 0 to 0.1 ft/s. Spawning adults, fry and juveniles prefer water depths ranging from 1 to 4 feet, while adults prefer water depths ranging from 3 to 6 feet. Fry, juveniles and adults prefer substrate ranging from debris/vegetation to gravel, while spawning adults prefer debris/vegetation and silt. Therefore, higher flows benefit adults and lower flows benefit spawning adults, fry, and juveniles.

For white sucker, spawning adults prefer fast (1-3 ft/s)/shallow (1-2 ft) water, fry and juveniles prefer slow (0-1 ft/s)/shallow (0-1 ft) water, and adults prefer fast (0-2 ft/s)/deep (2-10 ft) water; all life stages prefer a wide range of substrate types (MDNR, 1990). Medium flows benefit spawning adults, lower flows benefit fry and juveniles, and higher flows benefit adults.

1.4.2 Available Habitat Versus Flow, Upper South Branch

The Upper South Branch transects were shallow with a moderate flow, and a substrate composed mainly of debris/vegetation, silt, sand and cobble. For smallmouth bass spawning adults, juveniles and adults on the Upper South Branch, substrate quality was good and the quality of water velocity and water depth increased as flow increased. Consequently, available habitat for these life stages of smallmouth bass increased as flow increased. Increases in available habitat were not as substantial for spawning adults and adults because they prefer deeper water which was not available on the Upper South Branch even at higher flows. Because smallmouth bass fry prefer slower velocities and shallower water, increases in flow on the Upper South branch caused a decrease in available habitat for fry.

For northern pike spawning adults, fry and juveniles on the Upper South Branch, substrate quality was good but the quality of water velocity and water depth decreased as flow increased. Consequently, available habitat for these life stages decreased as flow increased. Decreases in available habitat were not as substantial for fry and spawning adults because even at low flow, velocities were too fast for fry and the substrate quality for spawning adults was marginal. Available habitat for northern pike adults increased slightly at the highest flows because only the highest flows produced the preferred combination of deep water and low flows; and this habitat was only found at the channel margins on the Lower South Branch.

For white sucker spawning adults on the Upper South Branch, substrate quality was poor, and the best combination of water velocity and water depth was achieved at medium flows. Consequently, only moderate increases in habitat were achieved at medium flows. For fry, substrate quality was good and the quality of water velocity and water depth was good at lower flows; consequently, available habitat decreased as flow increased. Available habitat increased slightly as flow increased for juveniles because substrate quality was good and the quality of water velocity and water depth increased slightly as flow increased. Available habitat for adults increased substantially as flow increased because deeper/faster water became more abundant at higher flows.

1.4.3 Available Habitat Versus Flow, Lower South Branch

Beaver Lake Road

The Lower South Branch transects at Beaver Lake Road were shallow with a moderate flow, and a substrate composed mainly of debris/vegetation and sand. For smallmouth bass spawning adults, juveniles and adults on the Lower South Branch at Beaver Lake Road, substrate quality was marginal and the quality of water velocity and water depth increased as flow increased.

Consequently, available habitat for these life stages increased as flow increased. Increases in available habitat were not as substantial for spawning adults and adults because they prefer deeper water which was not available at Beaver Lake Road even at higher flows. Because smallmouth bass fry prefer slow water velocity and shallow water depth, increases in flow at Beaver Lake Road caused a decrease in available habitat for fry.

For northern pike spawning adults, fry and juveniles on the Lower South Branch at the Beaver Lake Road, substrate quality was good and the quality of water velocity and water depth decreased as flow increased. Consequently, available habitat for these life stages decreased as flow increased. Decreases in available habitat were not as substantial for fry and spawning adults because even the lower flows produced velocities that were too fast for fry, and the substrate quality for spawning adults was marginal. Available habitat for northern pike adults increased slightly at the highest flows because only the highest flows produced the preferred combination of deeper water and lower flows; this habitat was only found at the channel margins at the Beaver Lake Road location.

For white sucker spawning adults on the Lower South Branch at Beaver Lake Road, substrate quality was good and the best combination of water velocity and water depth was achieved at medium flows. Consequently, increases in habitat were achieved at medium flows. For fry and juveniles, the quality of substrate and water depth were good, but water velocity was too fast even at lower flows. Thus, available habitat was unaffected by changes in flow. Available habitat for adults increased substantially as flow increased because deeper/faster water was available.

Scott Road

The Lower South Branch transects at Scott Road were shallow with a moderate flow, and a substrate composed mainly of debris/vegetation gravel and cobble. For smallmouth bass spawning adults, juveniles and adults on the Lower South Branch at Scott Road, substrate quality was good and the quality of water velocity and water depth increased as flow increased. Consequently, available habitat for these life stages increased as flow increased. Increases in available habitat were not as substantial for spawning adults and adults because they prefer deeper waters which were not available at the Scott Road location even at higher flows. Because smallmouth bass fry prefer slow water velocity and shallow water depth, increases in flow at Scott Road caused a decrease in available habitat for fry.

For northern pike spawning adults on the Lower South Branch at Scott Road, the quality of water velocity and water depth was good but substrate quality was poor in the main channel. However, available habitat increased as flow increased and flooded grassy banks, a higher quality substrate for spawning northern pike. For fry, the quality of water depth and substrate was good but

water velocities were too fast even at lower flows so available habitat fluctuated only slightly as flow changed. For juveniles, substrate quality was good but water depth was too shallow at the lowest flows and water velocity was too fast at the highest flows. Thus the maximum amount of habitat was only available at medium flows. Available habitat for northern pike adults increased slightly at the highest flows because only the highest flows produced the preferred combination of deeper water and lower flows; this habitat was only found at the channel margins.

For white sucker spawning adults on the Lower South Branch at Scott Road, substrate quality was good, and the best combination of water velocity and depth was achieved at medium flows. Consequently, medium flows produced the greatest amount of habitat. For fry and juveniles, the quality of substrate and water depth were good, but water velocity was too fast even at lower flows, so available habitat did not change as flow changed. Available habitat for adults increased substantially as flow increased because deeper/faster water was available.

1.4.4 Optimal Flows

The amount of available habitat for all life stages must be considered equally important when managing for a healthy fish population. If too much habitat for one or more life stages is sacrificed in order to maximize the amount of habitat for other life stages, then the health of the whole population would be compromised. On the Upper South Branch, optimization of habitat was achieved at medium flows for smallmouth bass, low flows for northern pike and medium flows for white sucker. On the Lower South Branch, optimization of habitat was achieved at medium flows for smallmouth bass, low/medium flows for northern pike and medium flows for white sucker. From these results it is evident that one flow can not provide optimal habitat for all species. Optimal flows at both locations appear to be species and life stage specific. But it is important to remember that the selected minimum flow is just that, a minimum flow. Minimum flow volumes should be selected to protect the fishery during periods of low flow. Actual flow will vary because there will usually be water available in excess of the minimum flow standard because of natural hydrologic conditions. Fortunately, reproductive and behavioral strategies for most fish are timed to coincide with seasonal fluctuations of low and high flows.

Maintaining a minimum flow greater than 30 cfs year-round would be difficult during the dryer seasons because this amount of water would not always be available under natural hydrologic conditions. But flows greater than 30 cfs would accommodate more habitat for some of the life stages and this higher flow would be available during certain seasons because of natural hydrologic conditions. A minimum flow of 15 cfs on both the Upper South Branch and the Lower South Branch would protect available habitat for most all species and life

stages of fish during the dryer seasons, which is the intent of establishing a minimum flow standard.

1.5 Management Implications

The relatively simplistic concept of defining a minimum water flow regime is confounded by many variables which complicate its real world application. These variables include: 1) the difficulty of managing different species and life stages using a single flow, 2) the need to manage available habitat equally for all life stages of each species, 3) the limitations of the impoundments to produce the needed flow under natural hydrologic conditions, 4) misconceptions that maintaining a single minimum flow is adequate to preserve healthy aquatic biota, and 5) the limitations of the impoundment to produce the needed flows without exceeding the water level criteria set forth by legally binding water level agreements. These factors can act separately or together, complicating the implementation of a meaningful minimum water flow regime.

In this study, simulations were conducted to calculate available habitat for four life stages of three species of fish, at nine different flows. These simulations produced 108 individual results (three species x four life stages x nine flows) which in turn were used to produce 12 habitat versus flow curves (three species x four life stages) for each location. Some of these curves had similar relationships (e.g. spawning adult and adult smallmouth bass) and some of these simulations produced quite different relationships (e.g. juvenile smallmouth bass and juvenile northern pike). To simultaneously manage to maximize habitat suitability for all of these species and life stages is unrealistic. Inevitably, there have to be management compromises if all species and life stages are to benefit in some way from a minimum water flow regime, or the habitat should be managed for a single species.

Available habitat for each of the four life stages for each species needs to be managed equally for a healthy population. It would be counter productive to manage for higher amounts of available habitat for later life stages of a species if the amount of available habitat for the earlier life stages (recruitment) is compromised. And it is unlikely that later or early life stages of all species would benefit at one flow regime. Conversely, if the amount of available habitat for recruitment is maximized at the cost of the later life stages, there would not be enough habitat to support the fish population as it aged. Obviously there must be some balance between available habitat for all life stages to maintain a healthy population of commingled species.

The impoundments in this study, like all impoundments, have hydrologic regimes that control the amount of water available for release at any one time, especially during dry seasons, when inflow may be less than the required outflow (minimum water flow release) which could conceivably cause a water deficit in the tailrace area. Maintaining a tailrace minimum flow would eventually drain

the impoundment under these circumstances. Conversely, if a low flow is desired, but inflow is high, the impoundment could eventually overtop the dam if release flow was regulated to maximize habitat at lower flows. These are extreme examples; however, they illustrate that the ability to maintain a single minimum water flow is often not feasible.

A minimum flow standard should be viewed as a standard that is not exceeded (i.e. flows are not allowed to be less than the standard). Stalnaker (1990) stresses that a minimum flow standard should be viewed as an objective and not a goal to be achieved. Water resource managers, especially in the western United States, have had a tendency to use the minimum flow standard as a management goal, managing the system down to this level. This management practice does not take into account the intended purpose of establishing a minimum flow (which is to prevent the stream from drying up), and may endanger the quality of lower gradient streams in the east (Stalnaker, 1990). He found that in the water limited western United States, where water is viewed as a premium resource, the minimum flow standard tended to become an average rather than a minimum for which it was intended. There are times when the natural hydrologic cycle puts water into the system in excess of the minimum standard, and if possible, this excess water should be passed down the river because it serves useful purposes (e.g. flushing sediments). Fish have also adapted to the natural fluctuations in water flow (e.g. high spring flow) and if it is possible to maintain these natural fluctuations, the fish population would benefit. These considerations are as applicable in the west as they are in the midwest.

The study impoundments, like many others, support important fisheries that may be impacted if impoundment water levels are fluctuated in order to maintain a downstream minimum water flow. The fisheries in the study impoundments are considered to be more valuable than the downstream river fisheries, and consequently there would be a conflict of interest if a mandated minimum water flow regime adversely effected the impoundment fisheries. These impoundments also have homes and cottages along the shoreline. These owners, with some justification, do not like their dwellings flooded by high water levels, or conversely, do not want to have their boats and docks left high and dry by low water levels.

It is evident that many variables and considerations must be taken into account when deciding on an instream flow standard that is not only sufficient in protecting aquatic biota downstream, but must also be achievable and realistic. In our study, it would not be realistic to maximize adult smallmouth bass habitat because the necessary flow of 200 cfs would eventually drain the impoundments. This type of flow would also be detrimental to northern pike. Conversely, flows less than the proposed minimum water flow of 15 cfs would be detrimental to all but a few select life stages.

Even though the two water storage impoundments in this study are not

operated as run-of-river, they are not fluctuated on a daily basis and consequently do not have the adverse effects associated with peaking facilities. Peaking facilities create hourly/daily changes in flow and, consequently, frequent changes in available habitat. Aquatic organisms are not adapted to these frequent habitat changes, and consequently abundance, diversity, and productivity in these systems decline (Cughman, 1985).

The suggested minimum flows of 15 and 30 cfs below Fletcher Pond Dam and 15 cfs below Hubbard Lake Dam provide for protection of habitat for most of the life stages that were simulated in this study. The exception is northern pike adults on the Lower South Branch below Hubbard Lake Dam which do not have any suitable habitat at 15 cfs. But even increases in flow on the Lower South Branch would not help adult northern pike because depth is the limiting factor, and higher flows are not enough to achieve the necessary depth. As a result of this study, a 15 cfs minimum water flow to protect aquatic life below both dams would be the most logical because it is achievable, realistic and protects habitat for most of the species and life stages simulated in this study.

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