THIRD PARTY REVIEW OF PROPOSED INSTREAM FLOW STANDARDS FOR NORTHERN NEW CASTLE COUNTY, DELAWARE

Prepared for
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1. INTRODUCTION

The purpose of this report is to provide Delaware Department of Natural Resources and Environmental Control (DNREC) with a third party review of the instream flow standards recommended for northern New Castle County, Delaware. The proposed flow standards are presented in Phase I and Phase II: 7Q10 Assessment Reports (1995; 1997) prepared by DNREC. EA Engineering, Science, and Technology (EA) conducted the assessments, and developed conclusions and recommendations outlined in this draft report based on the contract scope of work which included:

Task 1 - Evaluation of Appropriate Instream Flow Standards (ISF)

- *Subtask 1A. Research and review relevant literature on ISF standards applicable to the study area to include 7Q10 and Wetted Perimeter. A meeting with the DEPARTMENT will be held to discuss the JTF Reports (Phases I and II) and a field inspection performed to conduct a separate literature search of ISF studies and protocols, water quality, and habitat criteria of relevant species.*

- *Subtask 1B. Compile background information on existing surface water supply intakes and assemble into tables to supplement the literature search conducted in Subtask 1A consisting of data determined in CONTRACTOR's best professional judgement as relevancy to the study area and the primary issue of passby flow standards.*

- *Subtask 1C. Produce a draft Report recommending appropriate standards for the designated stream reaches with supporting documentation and critical appraisal of the DEPARTMENT's ISF reports, Phases I and II.*

Task 2 - Presentation of Findings

- *Subtask 2A. Present to DEPARTMENT oral summary of findings following receipt of one set of written comments from DEPARTMENT of the draft report of Subtask 1C.*

- *Subtask 2B. Deliver final report to DEPARTMENT*

Based on the scope of work and on-going discussions with DNREC's Project Manager, EA's effort specifically focused on:

(1) determining if the proposed 7Q10 passby flow is adequate to protect indigenous instream aquatic habitat uses in Brandywine Creek and the Christina River Basin;

(2) evaluating the principles and techniques used by others to substantiate the 7Q10 recommendation; and

(3) comparing the selected principles and techniques to those typically used in the region to assess pass-by flows based on "best professional judgement, BPJ."

EA used a combination of information from scientific literature and technical staff best professional judgement to evaluate the passby flow requirements. Based on our experience in instream flow evaluations, differing viewpoints of water supply withdrawal rates typically exist among different water purveyors in a region and within groups associated with resource agencies responsible for management of the water resources. To make the review and recommendations as objective as possible, EA did not solicit input from any interest groups. Importantly, EA's scope of work did not include a task to consider alternative water supply options or other alternative strategies which might be required to meet the growing need for water in northern New Castle County.

This report focuses on the topics that are most critical to DNREC's conclusions and recommendations. Additional information gathered as part of the literature review, is summarized in tabular format and is not discussed in detail unless it is used to support major conclusions. The following section of this report discusses pertinent instream flow methodologies, fish habitat requirements, and water quality criteria. The third section provides a review of DNREC's Phase I and II reports. Conclusions and recommendations are discussed in the final section.

2. REVIEW OF EXISTING INSTREAM FLOW INFORMATION

Background Information: There are four major surface water withdrawals for public water supply in northern New Castle County, Delaware.

Location	Purveyor	7Q10 flow (MGD)	Maximum Withdrawal Capacity (MGD)	7Q10 + Max withdrawal (MGD)
Brandywine Creek at City Dam	Wilmington WTP	49.31	44	93.31
Christina River at Smalley's Pond	United Water Delaware	2.09	6	8.09
White Clay Creek at Newark	City of Newark	7.27	5	12.27
White Clay Creek at Stanton	United Water Delaware	17.20	30	47.20

Source: Phase I Report (1995)

Based on these withdrawal data, the natural flow would have to equal or exceed the 7Q10 flow plus the maximum water supply withdrawals to meet a 7Q10 minimum passby flow. Based on flow exceedence data at each water withdrawal location, the flow would be less than the 7Q10 plus maximum withdrawal between 10 and 20 percent of the time depending on the withdrawal location (DNREC 1995).

Review of Instream Flow Methodologies: Instream flow methodologies have been developed to estimate the minimum flow that could occur in a stream to protect the existing aquatic community downstream of water diversions or intakes. A list of methods that have been used to estimate the necessary minimum flow is presented in Table 2-1. The majority of these methods were identified in a comprehensive summary and review document of existing national instream flow methodologies funded by the Electric Power Research Institute (EPRI 1986). Since 1986, many of the instream flow methods have been slightly refined, altered, or modified, but no significantly different types of models have been developed. The most commonly or widely used methods, based on best professional judgement, are identified in Table 2-2 and have been characterized based on data needs, strengths, limitations, and other information relevant to each of the selected methods.

Different instream flow methodologies have been developed for regional use in various parts of the country. Based on information presented in Reiser et. al. (1986), a summary of the federal and state methods employed in the mid-Atlantic and New England areas was developed (Table 2-3). Instream Flow Incremental Methodology (IFIM) is the most commonly used method in the eastern part of the country, as well as throughout other regions, based on the 1986 survey of state and federal resource agencies. EA's observations indicate that the popularity of the IFIM method has increased since 1986, and in most parts of the country it is currently the preferred method of estimating minimum flows. IFIM is, however, one of the more data intensive methods and often requires substantial field data collection.

All of the existing instream flow methodologies have some limitations (Table 2-2). The 7Q10 flow statistic and the wetted perimeter method have been and are currently used by several states to estimate the required minimum flow (e.g., they have been used alone or in combination with other methods in Massachusetts, New Jersey, North Carolina, Pennsylvania, and Virginia).

- The 7Q10 flow statistic is related more to hydrology and water quality compliance assessments rather than to instream habitat; for example, the 7Q10 flow statistic is often used as the critical low flow for determining surface water discharge permit limits. Critical low flows for application of water quality standards are typically specified as *x*Q*y*, where *x* is the averaging period in days and *y* is the average frequency of occurrence in years. For example, the 7Q10 is the 7-day average low flow that occurs, on the long-term average, once every 10 years. These flows are derived from a statistical analysis of stream flow data, typically using a log-Pearson Type III estimation technique. For example, in Delaware, design flows for application of water quality standards are based on the following flow statistics:

Non-toxic substances	7Q10
Toxic substances	
Acute aquatic life criteria	1Q10
Chronic aquatic life criteria	7Q10
Human health criteria	
Carcinogens	Median flow
Non-carcinogens	30Q5

It is important to recognize that there is no demonstrated scientific basis to assume *a priori* that the 7Q10 flow also maintains suitable aquatic habitat. Rather, it is a statistically-based low flow that on average is expected to occur in a 10-year period and is affected by flow modifications such as dams, reservoirs and water intakes.

- The wetted perimeter method requires a low to moderate field data collection effort to estimate the minimum flow. The wetted perimeter is a conceptual model using discharge and hydraulic variables, and there is little evidence that the values used in the model have documented biological significance. Additionally, the wetted perimeter vs. stream flow curves are often smooth and the identification of inflection points (defined as critical flow values) is often subjective and influenced by the base flow used in the model.

Fish Habitat-Use Data: Habitat requirements of the fish species present in the stream of interest are important for determining and recommending a minimum flow that will maintain and protect the fish community. In an attempt to compile habitat data for use in the IFIM models, the U.S. Fish and Wildlife Service (USFWS) developed habitat suitability index (HSI) models for 40 fish species in the early 1980s (Table 2-4). Although no new USFWS HSI models have been developed, other groups continue to develop habitat suitability index models to meet the requirements of IFIM studies that are conducted across the country.

Tables 2-5 through 2-18 present the results of EA's literature search for habitat requirements of the fish that were identified as target species during the Phase I and II reports prepared for DNREC. Shaded text in the tables represents supplemental habitat information provided by EA scientists; non-shaded text represents information previously compiled by or for DNREC. For target species that DNREC had previously compiled habitat-use data, comparisons between values derived from supplemental literature and initial literature indicated that habitat use information was reasonably consistent.

Water Quality: Water quality can be altered by changes in the natural flow regime. The water quality parameters that are typically of interest in minimum flow studies are temperature and dissolved oxygen. For this project, salinity is also a parameter of concern because portions of the study area are tidally influenced and subject to saline intrusion.

Overall, there are no *obvious* water quality problems based on the data which are presented, and the summary conclusions in the Phase 2 report (Section 3B4) are reasonable given the data that were available. However there are minimal data for certain water quality parameters (particularly during low flow periods), and compliance with certain water quality criteria/ standards cannot be accurately determined because only one sample was collected per day (probably at the same time each day) and ambient criteria have important duration and frequency components.

For example, DNREC's freshwater dissolved oxygen (DO) standard is an average of ≥5.5 mg/L and a daily minimum value of ≥4.0 mg/L. Instream DO concentrations follow a fairly typical diurnal cycle where concentrations are lowest just before dawn and highest mid-afternoon when photosynthetic aquatic plants are producing the most oxygen[1]. As a result, a single DO sample cannot be properly be compared to daily average and daily minimum dissolved oxygen criteria. Similarly, pH varies throughout the day as a result of photosynthesis, and a single value taken at the same time each day may not be acceptable for determining compliance with daily average or minimum pH criteria.

Recognizing these limitations in the dataset, EA's evaluation of the water quality data presented in the Phase 2 report resulted in the following conclusions:

Smalleys Pond (Christiana Basin)
No water quality data are presented in the Phase 2 report for review.

Brandywine Creek at Wilmington
Less than 7Q10 flows occurred between 24 August and 14 September 1995. Only 4 DO measurements were made during this 3 week period, and two of these were 6.4 mg/L [DNREC's DO standard is 6.5 mg/L as an average, and 5.0 as a daily minimum]. Measured values of 6.4 mg/L may or may not indicate a problem depending upon the time of day these 4 daily samples were collected, and what actual daily average and minimum values were.

For pH, the reported values were very consistent (generally 7.1-7.3), *suggesting* the samples were collected at the same time each day.

White Clay Creek at Newark
Instream flows were at or below 7Q10 from 19 August-16 September. Only four DO measurements were made during this low flow period and these values ranged from 8-10 mg/L. Again, these cannot be compared to the instream criteria, although there does not appear to be a concern.

Instream temperature measurements ranged from 59-77 F. One value was listed as 86 F, but this value is inconsistent with the rest of the dataset, and is believed to be incorrect.

Reported pH values ranged from 7.5-8.1, but there were only 4 values during the four week low flow period (10 values over 3 months), and these all appear to be individual grab samples. As pH values can vary significantly over a 24-hour period, it is not possible to compare these daily results to the DNREC standard of 6.5-8.5 units. No chloride data were reported in the Phase 2 report.

White Clay Creek at Stanton
Instream flows were at or below 7Q10 for only a short period of time (~6-7 September 95). DO measurements were not reported for this low flow period, but single daily values of 6 mg/L were presented for 11 and 14 September. These single measurements are close to DNRECs 6.5 mg/L

1 A typical diurnal cycle for dissolved oxygen might range from 4 mg/L at 5AM up to 12 mg/L at 5PM (Thomann and Mueller 1987).

average and 5.0 minimum values, but clear conclusions cannot be made because sample times are not presented, and these single values do not reflect diurnal variability.

Instream chloride data show a sharp increase from 31 August through 6 September when flows are decreasing and saltwater intrusion is increasing. Values exceeding EPA's SMCL (human health-based) value of 250 mg/L occurred at instream flows as high as 18.4 mgd.

The flow:chloride regression presented on page 22 of the Phase 2 report concludes that the chloride levels will begin to exceed 250 mg/L when the flow in White Clay Creek drops below 18.1 cfs. However, there is a reasonable amount of variability in this fairly small dataset and it might be better to use an upper 95th percentile confidence limit value rather than the "mean" value for this analysis. This recommendation is further supported by the fact that an instream chloride value of 600 mg/L was reported at a flow of 18.4 mgd (1 September), and a value of 230 mg/L was reported at a post-rain flow of 69.2 mgd (8 September).

Finally, the Phase 2 document does not mention U.S. EPA's (1988) ambient water quality criteria for chloride which presents a 1-hour average (acute) criterion of 860 mg/L and a 4-day average (chronic) criterion of 230 mg/L for the protection of freshwater aquatic life. These numbers should be considered in the analysis of aquatic impacts in addition to the human health-based SMCL.

3. CRITICAL REVIEW OF PHASE I AND PHASE II REPORTS

EA critically reviewed DNREC's Phase I and II reports for weaknesses or limitations that in our professional judgement could be used to question the results and conclusions outlined in the reports. The limitations that EA identified in these reports are outlined as follows:

General Comments

- The 7Q10 flow value used in the analysis was based on data from the Churchman's Marsh EIS (Metcalf and Eddy, 1991). While EA is confident that the 7Q10 analysis developed for this project was done according to standard procedures, it would be helpful to future readers unfamiliar with standard protocols, to briefly summarize how the values were determined (e.g., the data set used, USGS gauge locations, period of record).

HEC-2 Model

- The rationale for selecting the length of stream to be considered as the study reach for each of the four water withdrawals is unclear. For example, it is unclear from existing documentation how the longitudinal limits of the "impacted" area that warranted evaluation were determined.

- The HEC-2 stations included in the FEMA model input data are heavily influenced by dams and bridges, the hydraulic controls of concern for *high* flow analyses. The hydraulic controls in the free flowing sections at low flow are typically different and may not have been properly represented in the FEMA data set. DNREC realized this potential problem and ten additional transects were surveyed in riffle (free flowing) sections within the study area. While, it may have been beneficial to have even more transects in these areas, it was not practical given budget and time constraints.

  The following table summarizes the number of transects that were placed at dams or bridges in each of the four study reaches. Based on these data, approximately 50% of the transects at Brandywine Creek and White Clay Creek at Newark were associated with dams or bridges and were not representative of free flowing conditions.

Site	Total Number of Stations	Stations at the Crest of Dams	Stations Upstream / Downstream of Hydraulic Controls	Free Flowing Stream Stations	
				Pool	Riffle
Brandywine Creek	17	3	6	4	4
Christina River at Smalley's Pond	14	1	1	12	0
White Clay Creek at Newark	22	3	8	5	6
White Clay Creek at Stanton	27	0	0	25	2

- The flow assessment presented in the Phase I report relies on extrapolating the "maximum" depth at each section longitudinally (along the length) along the river to estimate the proportion of study area greater than one foot in depth. The inclusion of crest of dams and cross-sections directly upstream and downstream of hydraulic controls is expected to slightly alter the results from what would be expected if only free flowing channel cross-sections were included in the analysis. The free flowing sections were the primary focus of the biological portion of the analysis.

- The pool/riffle designation used in the above table was based on the usage in Tables 6 to 9 of the Phase I Report. An examination of the depths and velocities in Tables 6 to 9, however, indicates inconsistencies in classification of transects as pools or riffles. Based on data presented in these tables, the maximum depth at cross-sections classified as riffles ranged from 0.07 ft to 2.79 ft with velocities ranging from 0.24 ft/sec to 4.42 ft/sec. Pools varied in maximum depth from 0.07 ft to 7.96 ft and average velocity ranged from 0 ft/sec to 3.0 ft/sec. Definitions of riffles and pools should have been developed and consistently used. DNREC realized this inconsistency and the riffle sections that were included in the wetted perimeter analysis conducted in the Phase 2 study reflect more consistent definitions of riffles.

- The "up to 0.4 ft error" indicated for the HEC-2 model, while relatively small, is significant relative to the 1 foot depth criterion used for habitat assessment. At many of the shallower transects, a change in depth of this magnitude could result in 200% variation in stream velocity. A more detailed discussion of model accuracy relative to low flow habitat assessment would be important.

Habitat Assessment

It is important to realize that the fishery evaluations used in the Phase 1 and 2 studies were not designed or intended to address the habitat use or preference of fish species in any of the drainages. The objectives of the study were to address the more fundamental issue of fish survival during extreme low flow events and the habitat information gathered was used to support the survival evaluation. However, because of the limited time and budget available, these data were determined to be the best available and subsequently were used in evaluating suitable habitat at different stream discharges. The limitations presented below are not a criticism of the methodology or conclusions drawn in that report relative to fish survival under low flow conditions. Rather they represent limitations relative to what ideally is considered in evaluating fisheries habitat assessments.

- The rationale for selecting 1 foot as the critical depth is not consistent with what ideally would be used in minimum flow studies. Depth criteria are usually coupled with minimum velocity criteria and typically include a full range of depths used by resident species.

- The habitat characterization of the sites based upon the longitudinal extrapolation of maximum depth does not adequately address the issue of what percent of the stream reach is greater than 1 foot in depth. The use of maximum depth results in an over estimation of the portion of stream that exceeds 1 foot in depth and thus an overestimation of the amount of suitable habitat as defined in these reports.

- While habitat analysis based on average velocity (as used in DNREC's assessment) is more appropriate than maximum velocity, it still provides insufficient information to make habitat-based flow decisions because it is an oversimplification of the available velocities.

- Riffles, runs, and pools are all important habitat types for various fish species and lifestages. Ideally all these habitat types are included in a habitat-based analysis. For example, the percentage of area greater than 2 or 3 feet in depth can be important for centrarchid species. The premise that if depth in riffles is maintained, depth in pools (artificial or natural) is also maintained is true in terms of fish survival, but, may not be true in terms of preferred habitat for species that utilize pools.

- A discussion of the relationship between depth and velocity at each of the measured transects would have been useful. It is the combination of depth, velocity, and substrate type that play the major role in determining habitat suitability for fish. Because substrate can be treated more or less as a constant in a study such as this, depth and velocity are the more important variables.

Target Species Selection

- There appears to have been a three step process leading to the final selection of longnose dace as the target species. The first target species list used in this process included an ecologically representative variety of indigenous and non-indigenous species. The second list of target species was based on fish actually collected from the study reach during drought conditions; however, the second list included only riffle species, or species that were collected in the riffles during low flow conditions. The final list included only the longnose dace. Longnose dace was selected to represent all the species that were collected in riffle habitat during drought conditions and hence can be used to represent this group of species, which is consistent with other studies.

  In typical warm and cool water streams such as those considered in this study, it is more common to include a variety of individual species or representative species that occur in a greater variety of habitat types in instream flow habitat evaluations. To fully consider the potential impacts of passby flow, a suite of species that better represent the availability of all habitat types would have been beneficial. To facilitate such selection in future studies (on similar streams) habitat requirements for a large suite of species are included in the supplemental tables to this report (Tables 2-5 through 2-18).

Wetted Perimeter Analysis

- A reasonable description of the methods and assumptions used in this analysis was not provided. For example, what was the base flow used to derive the curves?

- The wetted perimeter curves are generally smooth and the selection of breakpoints appears to be subjective (this is a major criticism of the wetted perimeter method in general, and not a reflection of improper analysis). There appears to be a limited basis for using these curves to support the 7Q10 recommendation, since there are no obvious inflection points to correlate to the 7Q10 flows.

4. CONCLUSIONS AND RECOMMENDATIONS

When managing water resources it is important to establish minimum flow requirements from both a water-use management and a biological perspective. Although the DNREC study has some limitations and could be improved by the recommendations listed below, it is sufficient to recommend flow standards particularly from a water quality and fish survival perspective, given the budget and time constraints in conducting more comprehensive studies.

Based on the data presented in DNREC's Phase 1 and 2 reports, the 7Q10 flow appears to be minimally sufficient for fish survival and to maintain water quality sufficient to support most aquatic life in each of the four study areas. However, having annual prolonged periods where the flow level is at or close to the existing 7Q10, may result in increased degradation of water quality and changes in instream and near channel biological communities over time. Although more comprehensive studies could be conducted, it is EA's professional opinion that a 7Q10 minimum flow is on the lower end of what would likely be deemed acceptable to all parties if a more complete instream flow analysis such as IFIM were conducted. This applies to all locations in the current study and is particularly true for the Piedmont locations considered in this evaluation.

From a habitat perspective the stream reaches where the 7Q10 appears to be most protective and potentially least protective are as follows based on EA's professional judgement.

Downstream Smalley's Pond: The 7Q10 should be adequate to maintain minimum water quality and fish habitat requirements. This conclusion is based on observed channel morphology of the Christina River in this vicinity and tidal influence. This does not imply that after a prolonged period of low flow that water quality (particularly dissolved oxygen and temperature), will consistently remain within standards. The stream channel appeared to be characterized by steep banks and relatively uniform depth. No obvious thalweg or other dominant channel characteristics that would affect habitat at low flow were observed.

White Clay Creek at Stanton: The 7Q10 flow should be adequate to maintain minimum water quality requirements, but some instream habitat characteristics may be degraded. This does not imply that water quality (particularly dissolved oxygen, salinity, and temperature), will consistently remain within standards after a prolonged period of low flow. White Clay Creek has a well defined thalweg and alternating sand bars as well as some "riffle" habitat. Reductions in flow would likely result in confinement of the channel to the thalweg and expose the sand bar habitat. In riffle areas, the depth appeared to be fairly uniform (except right in the thalweg) and a reduction in flow would potentially result in very shallow water depths during low tide.

White Clay Creek at Newark: The 7Q10 flow may or may not maintain water quality standards during prolonged periods of low flow. Based on existing data, the potential exists for both temperature and dissolved oxygen to exceed standards. From a fish habitat standpoint, the amount and diversity of habitat would likely be significantly reduced as a result of the 7Q10 flow, but still sufficient for fish survival. However, long term population changes could occur as a result of low flows over a period of years.

Brandywine Creek: The 7Q10 flow may or may not maintain water quality standards during prolonged periods of low flow (e.g., both temperature and dissolved oxygen may exceed standards). From a fish habitat standpoint, the amount and diversity of habitat would likely be significantly reduced as a result of the 7Q10 flow, but still sufficient for fish survival. From a fish habitat standpoint the amount and diversity of available habitat (depth and velocity) in the free flowing sections would likely be significantly reduced and potentially fragmented.

Recommendations to Improve the Evaluation

- Provide a more complete description of the methods and assumptions used for model development and data analyses. This information would facilitate an improved basis for understanding what was done and the rationale behind the decision-making process. Supplemental / supporting information could be presented as a summary report that is a compilation of the Phase I and II reports.

- Rather than trying to longitudinally extrapolate maximum depth data across pools and riffles, a better approach would be to use the habitat mapping data that were collected during the fish survey to determine and differentiate the proportion of the study area that would be classified as riffles or pools. These data could then be used to better describe existing cross-sections, and locate additional cross-sections, if required for any future evaluations in these areas.

- Use the HEC-2 model output to estimate depth and velocity characteristics of an average riffle, run, and pool for each stream segment. The best way to do this would be to develop depth and velocity frequency distributions for each transect by habitat type.

- The information generated from the preceding two items could be used to describe in detail the riffle and pool habitat, each of which represents a known percentage of the study area.

- As an alternative to using a single target species that represents riffle species during drought conditions, it is recommended that habitat-use guilds be developed to broadly define the habitat criteria of species that prefer riffles, runs, pools, etc. These data could be used to determine if the required habitat is available at the 7Q10 flow for the different species of the habitat-use guilds. This analyses could be repeated at several different flows to determine habitat sensitivity to changes in increased or decreased flow.

- Historical flow data could be statistically classified into distinct wet, average, and dry year categories. Flow exceedence evaluation, in terms of the percentage of time the stream flow would fall below the critical level, could be conducted for each classification.

This recommended approach is based on our best professional judgement, similar in concept to what would be conducted under the IFIM approach (and is similar to what is being conducted in trout waters in Pennsylvania) and would provide a better illustration of what the habitat characteristics would be under different flow regimes. Based on our review of existing data, it appears that no new data collection would be needed to complete such analyses. Although this approach is best suited to Piedmont streams, it would also provide useful data for the Coastal Plain streams under a variety of tidal conditions. If a more rigorous evaluation of passby flow is required to implement standards, or defend against potential litigation, an IFIM study should be conducted at representative Piedmont and Coastal Plain locations to more fully characterize habitat versus flow relationships and thus more comprehensively support future water resource management decision-making.

Table 2-1. Instream Flow Habitat Quality Methodologies

Annear and Conder 1983	Wetted Perimeter Method
Barber et al. 1980	Diagrammatic Mapping Method
Binns and Eiserman 1979	Wyoming Habitat Quality Index
Bovee 1982	USFWS Instream Flow Incremental Methodology
Collings 1974	Spawning and Rearing Discharge
Dunham and Collotzi 1975	USFS Region 4 Method
Geer 1980	Utah Water Records Methodology
Hoppe 1975	Minimum Stream Flows for Fish
Larsen 1980	USFWS New England Flow Recommendation Policy
Layher 1983	Habitat Suitability in Prairie Streams
Li et al. 1984	Discriminant Habitat Analysis
Milhous et al. 1984	USFWS IFG4 Hydraulic Simulation Model
Milhous et al. 1984	USFWS Water Surface Profile Model
Milhous et al. 1984	USFWS HABTAT Model
Nelson 1984	Montana DFWP Wetted Perimeter Method
Nickelson 1976	Habitat Needs for Salmon Rearing
Nickelson et al. 1979	Stream Flow Requirements for Salmonids
NGPRP 1974	Northern Great Plains Resource Program Method
Orsborn 1981	Spawning Habitat Using Watershed and Channel
Parsons et al. 1981	Fish Habitat Index Using Geomorphic Parameters
Rabern 1984	Habitat Based Georgia Standing Crop Models
Sams and Pearson 1963	One Flow Method
Swank and Philips 1976	USFWS Region 6 Single Transect Method
Swift 1976	Washington Basin Variables Method
Swift 1976	Washington Toe-Width Method
Swift 1979	Washington One-Variable Regression Method
Taylor 1982	Riparian Strip Width Model
Tennant 1975	Montana Method
Thompson 1974	Oregon Usable Width Method
Waters 1976	California Instream Flow Method
Weatherred et al. 1981	R2-CROSS-81 Sag Tape Method
Wesche 1980	WRRI Trout Cover Rating Method
White 1976	Idaho Instream Flow Method
White et al. 1976	Midwestern Trout Standing Crop

Source: EA 1986

Table 2-2. Characteristics and requirements for selected instream flow and habitat quality methodology.

Method and Objectives	Data Needs	Strengths	Limitations	No. of States using Method as of 1986	General Comments / Discussion
Wetted Perimeter Method (Annear and Conder 1983) Objective: To develop a reproducible method of identifying appropriate maintenance flow from plots of wetted perimeter versus discharge.	" Office / minimal field method" Mean annual flow data Requires relationship between wetted perimeter and discharge from either field observations or hydraulic simulation model	Low level of effort required after relationship between wetted perimeter and discharge is determined.	Little evidence that the values used have biological significance. Because the model uses the Least Significance Difference (LSD) statistical function, the less homogeneous the stream, the lower the acceptable base flow. Due to the typical shape of wetted perimeter vs. discharge curves, the lower the chosen base flow, the larger the acceptable flow reduction.	4 ID, MI, NC, VA	Primarily a conceptual method using discharge and hydraulic variables. Model has two fundamental assumptions: 1) Either mean annual flow or twice mean annual flow is an appropriate baseline from which to determine acceptable flow reduction; 2) Flow reductions that are statistically detectable at 90% probability are reproducible and of biological consequence. Authors provide little documentation to justify the method and allow for evaluation of the technique.
USFWS Instream Flow Incremental Methodology (Bovee 1982) Objectives: 1) To describe design, scoping, and site selection processes and the sequence of analyses used by USFWS Instream Flow Service Group to resolve instream flow and project impact issues. 2) To describe methods for data compilation, presentation, and interpretation. 3) To describe techniques for compiling hydrological data and for predicting potential stream channel changes created by changing flows or sediment yield. 4) To describe simulation techniques for physical microhabitat conditions at different flows. 5) To describe stream channel modifications that increase/improve available habitat.	"Field / office method" Channel characteristics Stream flow Water quality Temperature Hydraulic characteristics Structural characteristics Requires use of IFG4 or WSP hydraulic simulation model, and use of HABTAT model (Milhous et al. 1984).	Methodology assists with identifying the most important/critical habitat areas or stream reaches for study. Eliminates study of stream areas that are not in equilibrium or have unacceptable water quality or temperature values. Comprehensive analysis that includes wide variety of physical, chemical, and hydraulic variables. Identifies potential for fish habitat improvement by modifying channel structure.	Requires high level of effort to collect field data. Provides little guidance for determining if the stream channel is in equilibrium or if water quality is within an acceptable range.	31 AL, AK, AZ, AR, CA, CO, GA, HI, ID, IL, IN, KS, ME, MS, MO, NH, NM, NY, NC, OK, OR, SD, TN, TX, UT, VT, VA, WA, WV, WI, WY	Conceptual method that uses biologically transformed hydraulic, structural, physical and chemical data. Uses several existing models to resolve stream flow questions. Documentation includes discussion of choosing representative stream reaches and interpretation of IFG4/HABTAT and WSP/HABTAT results.

Table 2-2. Continued.

Method and Objectives	Data Needs	Strengths	Limitations	No. of States using Method as of 1986	General Comments / Discussion
USFWS New England Flow Recommendation Policy (Larsen 1980) Objective: To encourage/ promote natural stream flows and preserve indigenous aquatic organisms.	"Office method" 25 years of daily flow data (derived from records) or drainage area (mile^2) calculated from maps	Requires low level of effort.	Level of flow is arbitrarily set. Little evidence that the assigned flows are either essential or sufficient to perpetuate indigenous aquatic organisms.	5 MA, NH, NJ, VT, WV	Conceptual method using discharge variables. Uses median monthly flows or 4 cfsm (spring), 0.5 cfsm (summer), and 1 cfsm (fall) as criteria. Bases flow on drainage area. Assumes that median flows or the assigned flows are sufficient to support indigenous fish fauna.
USFWS IFG4 Hydraulic Simulation Model (Milhous et al. 1984) Objective: To predict depths and mean column velocities as a function of discharge at fixed transect locations across a stream, specifically for use in the HABTAT model	"Field / office method" Depth and velocity data from at least 20 points along each stream transect during at least three discharges / flows.	Provides detailed cross-sectional discharge information and information broken down by transect cell. Model provides several internal checks to measure the quality of the simulation.	Requires high level of field effort. Simulations are likely to be less accurate for more complex and steep beds, turbulent flow, and shallow water scenarios.	4 CA, IN, MO, WY	Conceptual method using hydraulic variables. Assumes that a power function relationship between stream stage and discharge and velocity and discharge is suitable, and assumes velocity correction techniques in the model are legitimate. As of 1986, validity of the model had not been tested.
Montana DFWP Wetted Perimeter Method (Nelson 1980) Objective: To derive instream flow recommendations using simplistic methodology	"Field / office method" Field measurements of 1 to 5 stream channel cross sections. Water stage at each cross section must be measured for at least three discharges.	Requires low to moderate level of effort.	Method only identifies flow that fills the permanent stream channel. Designation of a recommended flow from the plots is highly subjective.	1 MT	Empirical model using hydraulic variables. Wetted perimeter (WETP) = the distance (ft) measured along the bottom of the stream from one edge to the other. The selection of recommended flow from the WETP vs discharge plots is subjective. Model has the following assumptions: 1) a stage-discharge relationship is appropriately modeled by linear regression of log-transformed data; 2) Curve point(s) are reproducible; 3) Reprodcuible points are related to biological response.

Table 2-2. Continued.

Method and Objectives	Data Needs	Strengths	Limitations	No. of States using Method as of 1986	General Comments / Discussion
Montana Method (Tennant 1975) Objective: To determine flows protective of aquatic resources that will be used to establish minimum stream flow standards and operational flow regimes.	"Office method" Average Annual Flow (AAF)	Quick and easy method; requires very low to moderate effort and only average annual flow data. Commonly used for reconnaissance-level evaluations.	Flow recommendations based on this technique are entirely subjective. Because the method is based on average annual flow, it does not account for flow fluctuations or seasonal variability.	11 AL, AK, IN, MO, ND, OK, PA, UT, WA, WV, WY	Conceptual model using discharge variables. Assumes that the following criteria are appropriate: minimum flow = 0.1 AAF = instantaneous flow recommended for short-term survival of aquatic organisms good flow = 0.3 AAF = base flow recommended to sustain good aquatic habitat excellent flow = 0.6 AAF = base flow recommended to provide excellent habitat for aquatic organisms and recreation Technique can be used to justify a wide range of flows, as well as for setting operational stream flows. Consequently, recommendations based on this method are neither specific nor easy to defend. Documentation provides little advice on how to use and apply supplemental habitat information.
7Q10 Definition: the 7-day average low flow that occurs, on the long-term average, once every 10-years. Derived from statistical analysis of stream flow data, typically using a log-Pearson Type III estimation technique.	"Office method" At least 10 years of flow data	Quick and easy method; requires low to moderate amount of effort. Commonly applied when instream water quality problems exist; often used as the critical low flow for determining surface water discharge permits.	Related more to hydrology and water quality compliance assessments rather than to instream habitat. Value affected by flow modifications such as dams, reservoirs and water intakes.	5 GA, MA, NJ, PA, VA	No demonstrated scientific basis to assume *a priori* that 7Q10 flow maintains suitable aquatic habitat.

Table 2-3. Summary of instream flow methods used in the northeast and mid-Atlantic states.

State	Methods Used
Delaware	Evaluate water quality with respect to flow
District of Columbia	Information not available
Maine	HEP and IFIM and modifications thereof; professional judgement
Maryland	Information not available
Massachusetts	MA Balance, Aquatic Base Flow; 7Q10
New Hampshire	Aquatic Base Flow; IFIM; HEC-2; site specific data; historical flow data
New Jersey	MT Method; New England Method; 7Q10
New York	IFIM; professional judgment; flow duration curves
North Carolina	IFIM; wetted perimeter; September median flow
Ohio	Standard USCS methods
Pennsylvania	Q(7-10); 30% Annual Average Flow (Tennant); 0.25 cfsm
Rhode Island	N/A (not applicable)
Vermont	VT Fisheries Flow Needs Method; IFIM; New England Aquatic Baseflow (ABF)
Virginia	Wetted perimeter; 7Q10; IFIM
West Virginia	IFIM; Aquatic Baseflow (ABF); Tennant

Source: Reiser, Wesche and Estes 1986

Table 2-4. USFWS Habitat Suitability Index Models

Species (Common name)	Author
Alewife / blueback herring	Pardue 1983
Atlantic salmon	Trial et al. 1984
Bigmouth buffalo	Edwards 1983
Black crappie	Edwards et al. 1982
Black bullhead	Stuber 1982
Blacknose dace	Trial et al. 1983
Bluegill	Stuber et al. 1982
Brook trout	Raleigh 1982
Brown trout	Raleigh et al. 1984
Channel catfish	McMahon and Terrell 1982
Coho salmon	McMahon 1983
Common carp	Edwards and Twomey 1982
Common shiner	Trial et al. 1983
Creek chub	McMahon 1982
Fallfish	Trial et al. 1983
Green sunfish	Stuber et al. 1982
Gulf menhaden	Christmas 1982
Juvenile Atlantic croaker	Diza 1982
Juvenile spot	Stickney and Cueno 1982
Lake trout	Marcus et al. 1984
Largemouth bass	Stuber et al. 1982
Larval and juvenile red drum	Buckley 1984
Longnose sucker	Edwards et al. 1983
Longnose dace	Edwards et al. 1983
Northern pike	Inskip 1982
Paddlefish	Hubert et al. 1984
Rainbow trout	Raleigh et al. 1984
Redbreast sunfish	Aho and Terrell 1986
Redear sunfish	Twomey and Nelson 1984
Slough darter	Edwards et al. 1982
Smallmouth bass	Edwards et al. 1983
Smallmouth buffalo	Edwards and Twomey 1982
Southern kingfish	Sikora and Sikora 1982
Spotted bass	Layher and Maughan 1984
Spotted seatrout	Kostecki 1984
Striped bass	Bain and Bain 1982; McMahon et al. 1984
Walleye	McMahon et al. 1984
Warmouth	Hickman and Raleigh 1982
White crappie	Edwards et al. 1982
White sucker	Twomey et al. 1984
Yellow perch	Krieger et al. 1983

Sources: EA 1986 and Rosenthal 1985

Table 2-5. Literature review of life history and habitat criteria for Blacknose Dace (*Rhinichthys atratulus*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
MAN	Bartnik 1970b	—	—	0.66 - 1.48	—	Gravel	Reproduction
NE	Bragg and Stasiak 1978	—	—	—	—	Gravel	—
MI	Braxo et al. 1978	—	—	—	May - July	Gravel	—
ONT	Cunjak and Power 1986	—	2.3	0.44	—	—	Mean summer values
MAN	Gibbons and Gee 1972	—	—	0.49 - 1.48	—	—	Greatest densities of adults
PA	Johnson et al. 1992	—	0.16 - 0.49 —	— 0.43	—	—	77% of occurrence Mean velocity
IA	Noble 1965	—	—	—	May - July	—	—
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	April - June	Gravel	Natural history information
VAN	Schwartz 1958	—	<0.82	—	May - July	Gravel	Spawning depths
NY	Sheldon 1968	—	0-2+	—	—	—	Range of occurrence
Various	Trial et al. 1983	—	0 - 1.64 —	— 0.36 - 1.90	—	—	Category I spawning depths Average velocities in riffles
WI	Becker 1983	—	0.3 - 1.6	—	May - June	—	Prefer headwater streams with moderate to rapid water
VA	Jenkins and Burkhead 1994	—	—	—	April - July	—	—
—	Terrell and Nickum 1984	Spawning Adult Juvenile Fry	≤ 1.15 — — —	0.5 - 1.6 0.5 - 1.8 0.33 - 1.3 ≤ 0.5	May-July	—	SI= 0.8-1.0, stream depth in spawning riffles; velocity in riffles SI= 0.8-1.0, avg velocity in pools and slow channels SI= 0.8-1.0, velocity in riffles SI= 0.8-1.0, velocity along stream margins
DE	Wang and Kernehan 1979	Spawning	0.2 - 0.5	—	May - June	Gravel or sand/gravel mix	Spawning depth in shallow, fast riffles

Shaded information provided by EA.

Table 2-6. Literature review of life history and habitat criteria for Bluegill sunfish (*Lepomis macrochirus*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
WI	Becker 1983	—	—	—	Late May - early Aug	Sand or gravel	—
GA	EA 1993	Spawning Adult	0 - 3 0 - 3 and ≥ 3	0 - 1 0 - 1	—	Variable	Based on habitat use guilds for Oconee River
TX	EA 1995	—	>2	<1	—	—	Based on habitat use guilds for the San Antonio River watershed
—	Gilbert 1984	Adult Embryo Fry Juvenile	— — — —	≤ 0.49 ≤ 0.59 ≤ 0.15 ≤ 0.26	February-August	—	SI= 0.8-1.0, avg velocity during growing season SI= 0.8-1.0, avg velocity during spawning SI= 0.8-1.0, avg velocity during early summer SI= 0.8-1.0, avg velocity during growing season
—	Hardy 1978	—	6.9 - 9.8	Non-flowing water preferred	—	—	Maximum depth during summer stratified conditions. Typically reside in shallow near shore areas with larger individuals in deeper water.
VA	Jenkins and Burkhead 1994	—	—	—	May - Aug/Sept	Sand or gravel	—
MD/VA	Lippson and Moran 1974	—	—	—	May -August	—	—
MD/VA	Murdy et al. 1997	Spawning	3.3	—	April-September	Sand or fine gravel	Nest depth; multiple spawning
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	May or June	Sand or gravel	—
DE	Wang and Kernehan 1979	—	—	—	May - August (June peak)	Sand and gravel	—

Shaded information provided by EA.

Table 2-7. Literature review of life history and habitat criteria for Brown Trout (*Salmo trutta*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
WI	Becker 1983	—	—	—	October-December	Gravel	—
MT	Berg 1977[a]	Spawning	0.93 - 1.98	1.58 - 2.49	—	—	Redd sites; depth range; mean velocity
MI, WI	Daly 1968[b]	Stocked YOY	10 - 15	—	—	—	As juveniles grow, they tend to move towards shallower wtaer
—	Frost and Brown 1967[a]	Spawning	0.25	—	—	Gravel	Normal redd depth
—	Hooper 1973[a]	Spawning	—	1 - 2.5 (1.53 mean)	—	—	Redd site; velocity range
WI	O'Donnell and Churchill 1943[a]	Spawning	1.5	—	—	—	Reported water depth at redd
—	Raleigh, Zuckerman, and Nelson 1986	Spawning / Embryo Fry Juvenile Adult YOY	≥ 0.8 1 - 2.5 ~2 - 3.5 ~1.5 - 3.5 ~1.5 - 2.5	0.6 - 2 0.4 - 1 0.1 - 1.2 0.1 - 0.8 0.5 - 1.0	Fall	Gravel	SI =0.8-1.0, Category I curves SI =0.8-1.0, Category I curves SI =0.8-1.0, Category I curves SI =0.8-1.0, Category I curves SI =0.8-1.0, Category II curves
—	Reiser and Wesche 1977[a]	Adult / Spawning	0.52 0.21 - 0.6 —	— — 0.45 - 1.5	—	—	Deepest redd construction Reported water depth Water velocity range for spawning
SC,NC,VA MD,DE	Rodhe et al, 1994	—	—	—	Fall	Gravel	Embryos develop over winter and hatch in spring
—	Shirvell and Dugey 1983[a]	Spawning	1.04	1.29	—	—	Preferred spawning depth; mean preferred velocity
OR	Smith 1973[a]	Spawning	—	0.67 - 2.24 (1.46 mean)	—	—	Redd site; velocity range
—	Waters 1976[a]	Spawning	0.8 - 1.5 0.4 - 3	1.75 - 2.25 0.5 - 3	—	—	Optimal redd depth and velocity Suitable redd depth and velocity
—	Wesche 1980[a]	—	≥ 0.49	< 0.49	—	—	—

[a] cited in Raleigh, Zuckerman, and Nelson 1986 [b] cited in Becker 1983 Shaded information provided by EA.

Table 2-8. Literature review of life history and habitat criteria for Channel Catfish (*Ictalurus punctatus*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
IA	Bailey and Harrison 1948[a]	—	—	<0.49	—	—	—
WI	Becker 1983	—	—	—	May - July	Cavities and crevices	—
LA	Bryan et al. 1975[a]	Fry	<1.64	—	—	—	Concentrate in shallow areas of turbid rivers and bayous
—	Clemens and Sneed 1957[a]	—	—	—	late May - mid July	—	—
KS	Davis 1959; Cross and Collins 1975[a]	Fry	—	<0.49	—	—	Concentrate in slow-flowing areas
TX	EA 1995		>2	<1	—	—	Based on habitat use guilds for San Antonio River watershed
—	Gilbert 1984	—	—	≤ 0.66	—	—	SI = 0.8-1.0, average velocity in cover areas during average summer flows
NM	Jester 1971[a]	—	6.6 - 13.1	—	—	Rubble and boulder	Depth for spawning in impounded areas
—	Layher and Maughan 1984	Adult	≥ 4.2	≤ 0.8	—	—	SI = 0.8-1.0
MO	Marzolf 1957; Pflieger 1975[a]	—	—	—	late May-mid-July	Dark and secluded areas; cavities, burrows, under rocks	—
—	McMahon and Terrel 1982	—	≤1.64 —	— 0.43 - 0.52	—	—	Assumed to be optimum SI=0.8-1.0, average summer flow in cover areas
VA	Menzel 1945[b]	—	—	—	Late May - early July	—	James River
MD/VA	Murdy et al. 1997	—	—	—	Late spring	—	Adults prefer deep pools near cover; Juveniles prefer faster flowing shallower water
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	Spring-early summer	—	—

Table 2-8. Continued. (Channel Catfish)

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
DE	Wang and Kernehan 1979	—	—	—	May - July	Protected areas; underneath submerged objects	—

[a] cited in McMahon and Terrell 1982
[b] cited in Jenkins and Burkhead 1994
Shaded information provided by EA.

Table 2-9. Literature review of life history and habitat criteria for Common Shiner (*Notropis cornutus*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
NY	Miller 1964	—	0.04 - 0.14	—	—	Sand, gravel	Spawning depth occurrence
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	May - July	Gravel	—
Can.	Scott and Crossman 1973	—	—	—	May - July	—	—
NY	Sheldon 1968	—	0.49 - 1.97	—	—	—	Range of occurrence
NY	Smith 1985	—	—	—	May - July	Gravel, sand	—
Various	Trial et al. 1983	—	—	0.39 - 1.12	May - July	Sand, gravel	Category I data
WI	Becker 1983	—	0.3 - 1.6	—	May - July	Gravel	Average depth of occurrence; spawning takes place in running water
GA	EA 1993	Adult	0 - 3	0 - 1	—	Variable	Based on habitat use guilds for Oconee River
VA	Orth et al. 1984	—	—	—	May - July	—	James River basin
—	Raney 1940[a]	—	—	—	—	Gravel, sand	—
—	Terrell and Nickum 1984	—	—	0.33 - 0.82	—	—	SI = 0.8-1.0, avg. current velocity above substrate in riffles
—	Trial et al. 1983	—	—	~0.1 - 0.33	—	—	SI=0.8-1.0, average current velocity at 60% depth in pools (Category I data)
		—	—	~0.33 - 0.82			SI=0.8-1.0, average current velocity above substrate in riffle (Category I data)
		Juvenile	2.2 - 2.8	<0.1			SI=0.8-1.0, Category III curve

[a] cited in Trial et al. 1983
Shaded information provided by EA.

Table 2-10. Literature review of life history and habitat criteria for Largemouth Bass (*Micropterus salmoides*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
WI	Becker 1983	—	up to 5	—	April - early July	—	—
—	Carlander 1977	Adult	2.95 - 3.94	Non-flowing water preferred	—	—	Rest on bottom in shallows at night. Also collected at depths > 6.6 ft.
GA	EA 1993	Adult	≥3	0 - 1	—	Variable	Based on habitat use guilds for Oconee River
TX	EA 1995	—	> 2	< 1	—	—	Based on habitat use guilds for the San Antonio River watershed
VA	Jenkins and Burkhead 1994	Spawning	1 - 2	—	May - June	Variable	Nesting depth
—	Layher and Maughan 1984	Adult	—	0.16	—	—	SI = 0.8-1.0
MD/VA	Lippson and Moran 1974	—	—	—	May - June	—	—
MD/VA	Murdy et al. 1997	—	<3.3 < 20	—	—	Gravel preferred	Nest depth Optimal habitat includes presence of SAV
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	Spring	Sand	—
DE	Wang and Kernehan 1979	—	—	—	April - June	Sand, gravel, debris	—

Shaded information provided by EA.

Table 2-11. Literature review of life history and habitat criteria for Longnose Dace (*Rhinichthys cataractae*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
MN	Aadland et al. 1991	—	0.67	1.61	—	Gravel	Mean spawning criteria
MN	Aadland et al. 1991	—	0.1-1.44	1.41-3.94	—	Gravel	Category III curves
MAN.	Bartnik 1970	—	—	1.48	—	—	—
N. Great Plains	Bovee 1974	—	0.49-1.02	1.31-4.92	—	—	Range of occurrence
MI	Brazo et al. 1978	—	—	—	June-July	Gravel	Life history information
Various	Edwards et al. 1983	—	0.72-3.38	0.69-3.28	April-July	Gravel	Category I curves
Unknown	Edwards et al. 1983	—	—	1.48-5.97	—	Gravel	Preferred criteria
NC	Facey and Grossman 1992	—	—	1.45	—	—	Mean occurrence velocity
NY	Finger 1982	—	0.3-0.56	0.56-0.85	—	—	Range of occurrence
BC	Gee and Northcoat 1963	—	<0.98	—	—	—	—
MAN.	Gibbons and Gee 1972	—	—	1.48	—	—	—
PA	Johnson et al. 1992	—	0.16-0.49	1.01	—	—	76% of total occurrence Mean velocity
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	April-June	Gravel	—
UT	Sigler and Miller 1963	—	<3.3	—	—	—	—
—	Bartnik 1970 [a]	Spawning Adult Fry	— — —	1.5 - 2 > 1.48 > 1.48	—	Gravel and rock	Shelter from current must be present
WI	Becker 1983	—	1 - 2	—	April - June	—	Prefer riffles with torrential water
MD	Carlander 1959 [a]	—	—	—	Beginning in May	—	—
—	Edwards, Li, and Schreck 1983	—	0.66 - 3.3	~1 - 2.6	—	—	SI= 0.8-1.0, maximum depth of riffle and average current velocity during spring and summer (Category I data)

Table 2-11. Continued. (Longnose Dace)

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
VA	Jenkins and Burkhead 1994	—	—	—	April - May	—	—
—	McPhail and Lindsey 1970 [a]	—	—	up to 6	June-early July	—	Surface velocity
VA	Orth et al. 1984	—	—	—	May - June		James River Basin

[a] cited in Edwards Li, and Shreck 1983
Shaded information provided by EA.

Table 2-12. Literature review of life history and habitat criteria for Pumpkinseed Sunfish (*Lepomis gibbosus*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
WI	Becker 1983	Spawning	<5	—	May - August	—	Nesting depth
VA	Jenkins and Burkhead 1994	—	—	—	April - August	—	Associated with macrophytes and other cover; prefer calm waters
MD/VA	Murdy et al.	—	—	—	Spring - early summer	Sand or gravel	Build nests in shallow water
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	Spring - early summer	—	—
DE	Wang and Kernehan 1979	—	—	—	May - August (June peak)	Sand or gravel	—
WI	Wisconsin Conservation Commission 1958[a]	Spawning	1 - 2.5	—	—	—	Nesting depth

[a] cited in Becker 1983
Shaded information provided by EA.

Table 2-13. Literature review of life history and habitat criteria for Rainbow Trout (*Oncorhynchus mykiss*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
—	Greeley 1932; Orcutt et al. 1968[a]	—	—	—	—	Gravel	—
ID	Griffith 1972[a]	Adult Juvenile	— —	0.33 - 0.46 (0.72 max) 0.33 - 0.39 (0.72 max)	—	—	Focal point velocity for cutthroat trout. Values assumed to be similar for rainbow trout.
—	Griffith 1972; Horner and Bjornn 1976[a]	Fry	—	<1	—	—	<0.26 ft/sec preferred
TN	Hill and Hauser 1986	Spawning Fry Juvenile Adult	0.5 - 8.5 0.5 - 2.0 ≥ 1.5 ≥ 1.5	1.5 - 3 ≤ 0.5 ≤ 0.75 ≤ 2.5	—	—	Spawning in shallower riffles and runs; preferred habitat in deeper runs and pools; SI = 0.8 - 1.0 (all values)
—	Hooper 1973[a]	Spawning	0.49	—	—	—	Average depth of egg deposiition
WI	Niemuth 1970[b]	—	—	—	March - May (April peak)	—	—
—	Raleigh et al. 1984				Jan-July	—	Time of spawning dependent on location and strain of hatchery fish.
		Spawning	~0.5 - 8.5	~1.4 - 3			SI = 0.8-1.0
		Fry	~0.5 - 2	≤ 0.4			SI = 0.8-1.0, mean water column velocity
		Juvenile	~1.5 - 2	≤ 0.7			SI = 0.8-1.0, mean water column velocity
		Adult	~1 - 1.5	≤2			SI = 0.8-1.0, mean water column velocity
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	Spring-early summer	Gravel or sand	—
—	Wesche 1980[a]	Adult	≥ 0.49	≤ 0.49	—	—	—

[a] cited in Raleigh et al. 1984
[b] cited in Becker 1983
Shaded information provided by EA.

Table 2-14. Literature review of life history and habitat criteria for Redbreast Sunfish (*Lepomis auratus*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
—	Aho, Anderson, and Terrell 1986	Adult and Juveniles Fry and Embryo Spawning	0.66 — 0.66 - 4.9	≤ 1.15 ≤ 0.66 —	May -August	—	North to south cline in timing of reproduction; prefers quiet back waters — Preferred spawning depth
NC	Davis 1972 [a]	—	1.15 - 1.25 (<4.9)	0.11 - 1.85	—	Sand or gravel; near structural objects	Nesting site depths and water velocities
TX	EA 1995	—	>2	<1	—	—	Based on habitat use guilds for the San Antonio River watershed
GA	EA 1993	Spawning Adult	0 - 3 0 - 3 and ≥3	0 - 1 0 - 1	—	Variable	Based on habitat use guilds for Oconee River
VA	EA 1991	Spawning Adult	~1 - 3.5 ~2 - 4.5	≤ 0.2 ≤ 0.5	—	—	SI=0.8-1.0
VA	Jenkins and Burkhead 1994	—	<3.3	—	May - July	Silt- free or lightly silted sand and gravel near cover	Nesting depth
SD, NE, IA	Kallemyn and Nototny 1977 [a]	Fry	—	<0.33	—	—	Low flow required for fry to maintain position in water column for feeding
—	Leonard et al. 1984	—	—	—	May-July	—	—
MD/VA	Murdy et al. 1997	—	—	—	June -July	Gravel; among plants near shoreline	—
VA	Orth et al. 1984	Spawning	0.7 - 3.3	Little current	mid-May - July (nests observed in July)	Variable	Nesting depth observed in Maury River and Dunlap Creek (James River basin)
NY	Raney 1965 [b]	—	0.5 - 1.3	—	—	—	Nesting depth
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	April-June	Sand	Build nests near shelter areas

Table 2-14. Continued. (Redbreast Sunfish)

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
—	Scott and Crossman 1973	—	—	—	—	Sand, fine gravel near structure	Inhabit areas with slower current; deeper areas with rock and gravel
NC	Shannon 1967 [b]	—	—	—	Late spring - early summer	Sand or fine gravel	—

[a] cited by Aho, Anderson, and Terrell 1986
[b] cited by Wang and Kernehan 1979
Shaded information provided by EA.

Table 2-15. Literature review of life history and habitat criteria for Rock Bass (*Ambloplites rupestris*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
WI	Becker 1983	—	<1 to >3	—	May - June	Coarse sand or gravel	—
TN	Hill and Hauser 1986	Fry Juvenile Adult	~0.5 - 1.0 ~0.5 - 1.0 ~0.5 - 1.5	~≤ 0.1 ~≤ 0.1 ~≤ 0.1	—	—	SI = 0.8 - 1.0
VA	Jenkins and Burkhead 1994	—	—	—	April - July	Coarse sand or gravel	Inhabit pools and backwaters with available shelter
VA	Orth et al. 1984	—	0.7 - 3.3	Little current	May - June (nests observed June)	Variable	Observed nesting depths in Maury River, James River basin
MO	Pflieger[a] 1975a	Spawning	1 - 5	Slight current	April - June	Coarse sand/gravel near boulder or other submerged objects	Spawning depth
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	May - June	Sand or gravel	—
	Scott and Crossman 1973	—	—	—	—	Coarse sand/gravel with slight current	—

[a] cited in Hill and Hauser 1986
Shaded information provided by EA.

Table 2-16. Literature review of life history and habitat criteria for Satinfin Shiner (*Cyprinella analostanus*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	May - June	Crevices of rocks and logs	—
NY	Sheldon 1968	—	1.97	—	—	—	Range of occurrence
PA	Smith 1985	—	—	—	June - August	—	—
VA	Jenkins and Burkhead 1994	—	3.3 - 4.3	—	Late May - mid August	Crevice spawning	Preferred depth from winter to late April; occur in shallow water with moderate current early May to late August
DE	Wang and Kernehan 1979	—	—	—	May - July	Submerged objects	—

Shaded information provided by EA.

Table 2-17. Literature review of life history and habitat criteria for Smallmouth Bass (*Micropterus dolomieu*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
WI	Becker 1983	—	—	—	May - June	—	—
—	Coble 1975 [a]	Spawning	1 - 3	—	—	—	Nesting depth
—	EA 1991	YOY Adult	~ 0.5 - 1.5 ~ 1.8 - 4.5	~ ≤ 0.5 ~ 0.1 - 1	—	—	SI = 0.8-1.0 SI = 0.8-1.0
—	Edwards, Gebhart, and Maughan 1983	— Fry Spawning Juvenile Adult	3.3 - 26.2 ≥ 2.4 1.8-5.5 ≥ 1.8 ≥ 3.4	— ≤ 0.7 ≤ 1.4 ≤ 0.2 ≤ 0.3	—	—	SI=0.8-1.0, depth of pools during midsummer SI=0. 8-1.0, Category I curve SI=0. 8-1.0, Category I curve SI=0.8-1.0, Category III curve SI=0.8-1.0, Category III curve Adults and juvenile prefer low water velocities near a current.
NY	Forney 1972[a]	Fry	15-20	—	—	—	Maximum depths
TN	Hill and Hauser 1986	Spawning Fry Juveniles Adult	2 - 5.5 ≥ 2.5 ≥ 2 ≥ 3.5	~ ≤ 1.5 ~ ≤ 0.7 ~ ≤ 0.25 ~ ≤ 0.25	April - June	—	—
TN	Hubert and Lackey 1980[a]	Adult	> 33	0.36 - 1.05	—	—	Seasonal mean current velocity in Tennessee River reservoir
VA	Jenkins and Burkhead 1994	Spawning	1 - 2	Slow current	May	Firm bottom near cover	Nesting depth
—	Larimore and Duever 1968[a]	Fry	—	≤ 0.66	—	—	Fry cannot tolerate velocities greater than 0.66 ft/sec
WI	Latta 1963; Mraz 1964 [a]	—	—	—	—	Gravel or broken rock	—
MD/VA	Murdy et al. 1997	—	—	—	mid April-July	—	Nest and spawn on rocky lake shoals and river shallows

Table 2-17. Continued. (Smallmouth Bass)

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
VA	Orth et al. 1984	—	~1.4	~0.2	Late May - early June	Large cobble	Average nest depth and water velocity observed in Maury River, James River basin
—	Robbins and MacCrimmon 1974[a]	—	≤23	Slow current	—	Stone, rock, or gravel	Nesting depth
SC,NC,VA MD, DE	Rohde et al. 1994	Spawning	1 - 4	—	Late spring - early summer	Gravel	—
—	Scott and Crossman 1973[a]	—	—	—	—	Near boulders, rock, or cover	—
ME, WA, IA	Watson 1955; Henderson and Foster 1957; Harlan and Speaker 1969; Turner and MacCrimmon 1970; Smitherman and Ramsey 1972; Neves 1975; Pflieger 1975[a]	—	—	—	mid April - July	—	—

[a] cited by Edwards, Gebhart, and Maughan 1983
Shaded information provided by EA.

Table 2-18. Literature review of life history and habitat criteria for Tesselated Darter (*Etheostoma olmstedi*).

State or Provence	Source	Lifestage	Depth (ft)	Velocity (ft/sec)	Spawning Period	Spawning Substrate	Remarks
Unknown	Page 1983	—	—	—	April - June	Underside of stones	—
SC,NC,VA MD,DE	Rohde et al. 1994	—	—	—	Spring - early summer	Under rocks, sticks, logs, etc.	—
NY	Sheldon 1968	—	0.49 - 1.97	—	—	—	Range of occurrence
NY	Smith 1985	—	—	—	May - June	—	—
GA	EA 1993	Adult	0 - 3	0 - 1 and > 1	—	Variable	Based on habitat use guilds for Oconee River
VA	Jenkins and Burkhead 1994	—	—	—	—	—	Occupy pools and slow runs
MD/VA	Murdy et al. 1997	—	—	—	Late April - June	Underside and sides of rocks	—
MD	Tsai 1972 [a]	—	—	—	May - June	—	—
DE	Wang and Kernehan 1979	—	—	—	March - May	Undersides of elevated stones, submerged logs, or other submerged objects	Young and adults prefer shallow water with slow or fast currents.

[a] cited in Jenkins and Burkhead 1994
Shaded information by EA.

Table 2-19. Salinity tolerance and range of occurrence for selected Delaware fish species

Species	Source	Location	Lifestage	Salinity (ppt)	Remarks
Alewife	Dove and Nyman 1995	—	—	22.0	Egg tolerance level
	Dove and Nyman 1995	—	—	0.0-6.0	Spawning can occur
	Dove and Nyman 1995	—	—	<1.0	Most spawning occurs
	Dovel 1971	—	—	0.0-2.0	99% of spawning occurred (March-May) at 0.0 in
	Dovel 1971	—	—	0.0-8.0	Range of occurrence for larvae and juveniles
	Pardue 1983	—	—	<5.0	Optimal salinity
	Lippson and Lippson 1984	Chesapeake Bay	—	0-30	Range of occurrence
Banded Killifish	Weisberg 1986	—	—	0.0	Preferred
	Weisberg 1986	—	—	0.0-5.0	Range of occurrence
	Leim and Scott 1966[a]	—	—	—	Able to tolerate salinities up to close to seawater
	Lippson and Lippson 1984	Chesapeake Bay	—	0-18	Range of occurrence
	Murdy et al. 1997	Chesapeake Bay	—	≤ 5	Rarely found above 5 ppt
	White 1989	Chesapeake Bay	—	0-20	Range of occurrence
Bluegill	Kilby 1955	—	—	<3.6	Preferred salinity
	Kilby 1955	—	—	<5.6	Tolerance level
	Stuber et al. 1982a	—	—	4.0	HSI=0.4
	Christmas and Waller 1973[a]	Mississippi	—	16.1	Highest salinity of occurrence
	DeSylva et al 1962[a]	Delaware estuary	—	12	Highest salinity of occurrence
	Gilbert 1984	—	—	≤ 3	SI=0.8-1.0, maximum monthly average during
	Lippson and Lippson 1984	Chesapeake Bay	—	0-15	Range of occurrence
	Murdy et al. 1997	Chesapeake Bay	—	18	Upper tolerance
	Musick 1972[b]	Virigina	—	up to 18	Range of occurrence
	White 1989	Chesapeake Bay	—	up to 18	Range of occurrence

Table 2-19. Continued.

Species	Source	Location	Lifestage	Salinity (ppt)	Remarks
Brown Trout	Murdy et al. 1997	Chesapeake Bay	—	≤ 5	Sometimes found in waters up to 5 ppt
Channel Catfish	Allen and Avault 1969	—	—	12.0	salinity tolerance of age 6 mo. to 1 yr.
	Jones et al. 1978	—	—	<2.0	Spawning requirement (March-July)
	McMahon and Terrell 1982	—	—	8.0	HSI=0.4 Adults
	Mc Mahon and Terrell 1982	—	—	8.0	HSI=0.4 fry, juveniles
	Perry 1973	—	—	<1.7	Most abundant
	Perry and Avault 1968	—	—	2.0-11.0	Range of occurrence
	Allen and Avault 1970[a]	—	Fry / Juvenile	0-5	optimal
	Gilbert 1984	—	Adult	≤ 7	SI= 0.8-1.0, summer maximum
	McMahon and Terrell 1982	—	Adult	0-5	SI= 0.8-1.0, summer maximum
	Murdy et al. 1997	Chesapeake Bay	—	up to 18	Range of occurrence; often found in waters ≥ 5ppt
	Musick 1972[b]	Virginia	—	15.1	Highest salinity of occurrence
	Perry and Avault 1968[a]	—	Adult	≤8	no change in growth rate
	White 1989	Chesapeake Bay	—	up to 15	Range of occurrence
Eastern Silvery Minnow	Hardy 1998	—	—	8.3	Maximum salinity tolerance for adults
	de Sylva et al. 1962[a]	Delaware	—	8.3	Highest salinity of occurrence
	Musick 1972[b]	Virginia	—	up to 14	—
	Smith 1971	Delaware	—	5.9	Highest salinity of occurrence

Table 2-19. Continued.

Species	Source	Location	Lifestage	Salinity (ppt)	Remarks
Largemouth Bass	Bailey et al. 1954	—	—	24.0	Upper range of occurrence
	Meader and Kelso 1990	—	—	1.0-12.0	Range of occurrence
	Stuber et al. 1982b	—	—	4.5	HSI=0.4 fry
	Stuber et al. 1982b	—	—	10.0	HSI=0.4 juveniles, adults
	Tebo and McCoy 1964	—	—	>1.66	Growth rate declined
	Tebo and McCoy 1964	—	—	6.0	Growth rate =0
	Christmas and Waller 1973[a]	Mississippi	—	2 - 9.9	Tolerate moderately saline water
	Gilbert 1984	—	Adult / Juvenile	≤ 6	SI = 0.8-1.0, summer maximum
	Layher and Maughan 1984	—	Adult	≤ 2	SI = 0.8-1.0
	Lippson and Lippson 1984	Chesapeake Bay	—	0-8	Range of occurrence
	Musick 1972[b]	Virginia	—	12.9	Highest salinity of occurrence
	Murdy et al. 1997	Chesapeake Bay	—	13	Upper tolerance
Mummichogs	Fritz and Garside 1974	—	—	20.0	High preference of 20 ppt over 8ppt
	Hardy 1978	—	—	0-41	Salinity range
	Lippson and Lippson 1984	Chesapeake Bay	—	0-30	Range of occurrence
Pumpkinseed Sunfish	DeSylva 1962[a]	Delaware estuary	Juveniles	7.7	Highest salinity of occurrence; adapted to spawning
	Lippson and Lippson 1984	Chesapeake Bay	—	0-15	Range of occurrence
	Murdy et al. 1997	Chesapeake Bay	—	> 5	Frequently encountered in brackish water > 5 ppt
	White 1989	Chesapeake Bay	—	up to 18	Range of occurrence
Redbreast Sunfish	Schwartz 1981[b]	North Carolina	—	7	Maximum salinity
	Shannon 1967[a]	North Carolina	—	3	Highest salinityof occurrence
	Murdy et al. 1997	Chesapeake Bay	—	≤ 5	Occasionally encountered in brackish water > 5 ppt
	White 1989	Chesapeake Bay	—		Freshwater only

Table 2-19. Continued.

Species	Source	Location	Lifestage	Salinity (ppt)	Remarks
Satinfin Shiner	Lippson and Lippson 1984	Chesapeake Bay	—	0-5	Range of occurrence
	Mansueti and Hardy 1967[b]	Chesapeake Bay	—	2	Highest salinity of occurrence
Smallmouth Bass	Lippson and Lippson 1984	Chesapeake Bay	—	0-5	Range of occurrence
	Murdy et al. 1997	Chesapeake Bay	—	7	Maximum tolerance
	White 1989	Chesapeake Bay	—	up to 7	
Striped Killifish	Dahlberg 1972	—	—	7.0-34.0	Range of occurrence
	Lippson and Lippson 1984	Chesapeake Bay	—	0-18	Range of occurrence
	Murdy et al. 1997	Chesapeake Bay	—		Prefer higher salinities, rarely enter freshwater
	Wang and Kernehan 1979	Delaware estuary	Spawning	10 - 25	Spawning salinities
	White 1989	Chesapeake Bay	—	0-20	Range of occurrence
Sunfish spp.	Jones et al. 1978	—	—	<5.0	Spawning requirement (April-June)
	Jones et al. 1978	—	—	11.0	Tolerance level
Tesselated Darter	Lippson and Lippson 1984	Chesapeake Bay	—	~0-8	Range of occurrence
	Murdy et al. 1997	Chesapeake Bay	—	≤ 13	
	Smith 1971	Delaware estuary	—	8	Highest salinity of occurrence
	Wang and Kernahan 1979	Delaware estuary	—	4	Highest salinity of occurrence; most frequently

Table 2-19. Continued.

Species	Source	Location	Lifestage	Salinity (ppt)	Remarks
White Perch	Dove and Nyman 1995	—	—	0.0-20	Range of occurrence in DE River (juvenile to adult)
	Dove and Nyman 1995	—	—	10.0	Egg tolerance level
	Dove and Nyman 1995	—	—	<30.0	Range of occurrence in DE Bay (adults)
	Funderburk et al. 1991	—	—	<4.2	Spawning requirement (March-June)
	Funderburk et al. 1991	—	—	0.0-8.0	Larvae and juvenile occurrence
	Jones et al. 1978	—	—	0.0-2.0	Optimal salinity
	Stanley and Danie 1983	—	—	<1.5	Larval preference
	Stanley and Danie 1983	—	—	<3.0	Juvenile preference
	Stanley and Danie 1983	—	—	5.0-18	Adult occurrence (Chesapeake Bay)
	Jenkins and Burkhead 1994	Virginia	—	5-13	Salinity range with greatest occuurrence
	Lippson and Lippson 1984	Chesapeake Bay	—	0-30	Range of occurrence
	Murdy et al. 1997	Chesapeake Bay	—	0-34	Range of occurrence
	White 1989	Chesapeake Bay	—	up to 12	—
White Sucker	Hardy 1978	—	—	2.0	Maximum salinity tolerance for adults
	Hildebrand and Schroeder 1928	Chesapeake Bay	—	1.5	Uppermost salinity
	Murdy et al. 1997	Chesapeake Bay	—	≤5	

[a] cited in McMahon and Terrell 1982
[b] cited in Jenkins and Burkhead 1994
[c] cited in Wang and Kernehan 1979

Shaded information provided by EA.

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