Stream Resource and Water Management in the Delaware River Basin: Upper Delaware Instream Habitat Assessment Study Plan

Background

The Delaware River Basin occupies an area of 12,765 square miles, in portions of south central New York, northeast Pennsylvania, northeast Delaware, and western New Jersey (Fig. 1). The Delaware River begins as two (2) streams, the East and West Branches, in the Catskill Mountains. They flow in a southwesterly direction until they meet at Hancock, New York. The length of the river from Delaware Bay to the confluence at Hancock is about 200 miles.

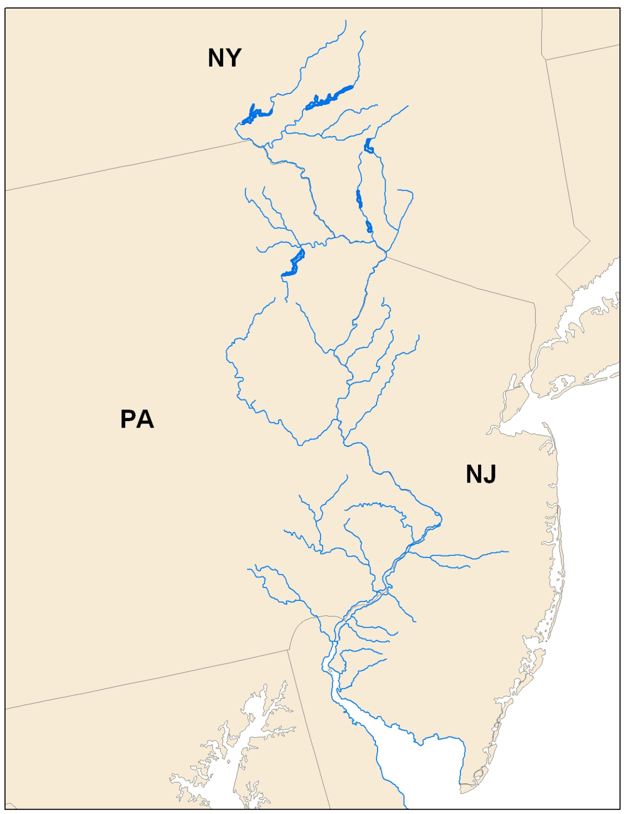

Figure 1. Tri-state map of the Delaware River Basin (Scale = 1:1,500,000).

New York City's Delaware system impounds Delaware tributaries in three reservoirs: Cannonsville Reservoir on the West Branch of the Delaware River, Pepacton Reservoir on the East Branch, and the Neversink Reservoir on the Neversink River (Fig 2). Approximately 650 million gallons a day (725,985 AF a year) is moved out of basin from these reservoirs through the Delaware Aqueduct. Typically, more than one fourth of the diverted water is from the Neversink system while Cannonsville supplies less than a quarter and Pepacton provides the remaining half. Water not diverted evaporates, spills from the reservoirs, or is released downstream through valves. On average, about 200 billion gallons a year is spilled or released, though inter-annual variation can be substantial.

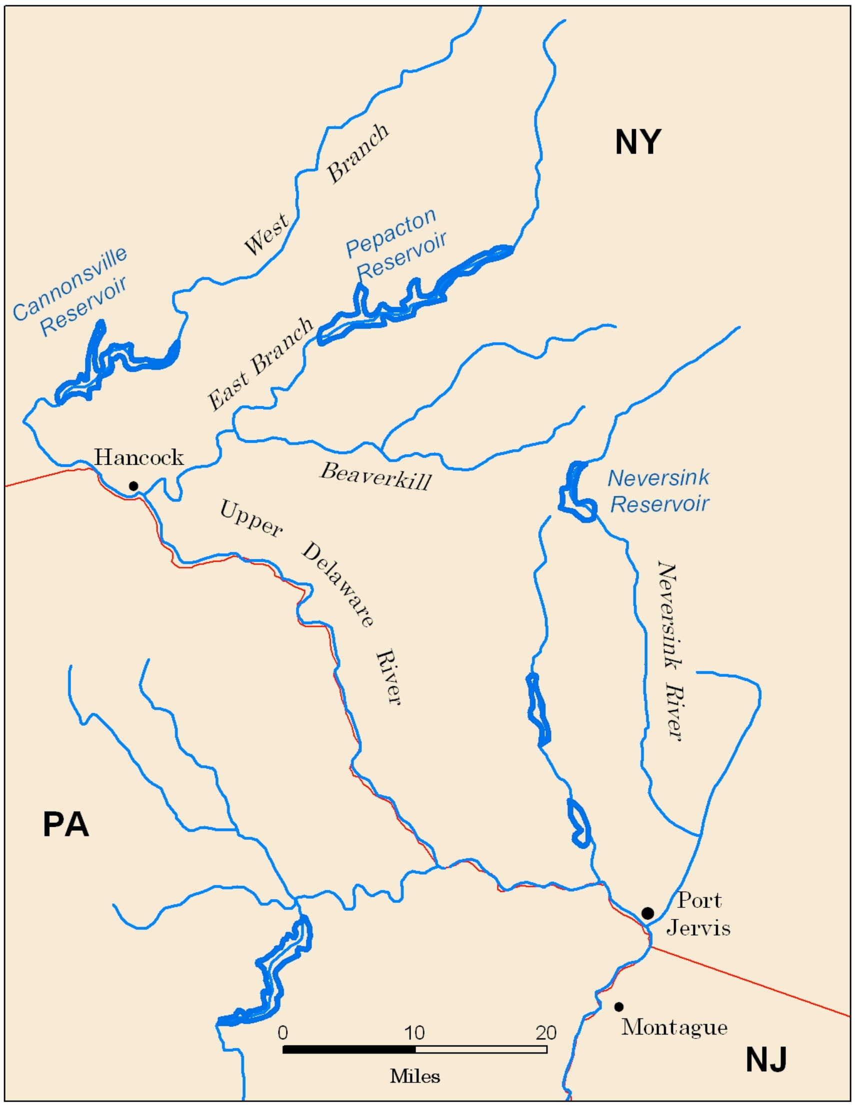

Figure 2. Upper Delaware River and reservoirs (1:500,000).

The river is currently managed under the terms of a 1954 Supreme Court Decree, the result of series of lawsuits brought by New Jersey and Pennsylvania to prevent New York City from diverting Delaware River water from the basin. The diversion and release rights and requirements created under this Decree cannot be changed without unanimous consent from the parties to the Decree (Delaware, New Jersey, New York, Pennsylvania, and New York City).

Under the 1954 Decree, New York City can divert up to 800 million gallons a day (2,456 AF) out of the three reservoirs as long as a Delaware River flow target of 1,750 cubic feet per second (cfs) is met at the Montague, NJ gage. (The Montague flow target was originally set in a 1931 Supreme Court decision using 0.5 cubic feet per second per square mile of watershed area above Montague as a rationale.) The Delaware River Master, a position within the U.S. Geological Survey established by the Decree, ensures that this target is met by requesting releases from New York City's reservoirs. New York City must comply with this request, but may use any of the three Upper Delaware reservoirs to do so. In addition, there is a lower basin target of 3000 cfs at Trenton, NJ meant to prevent the upstream movement of the salt front for the protection of public and private water supply. The Trenton target has recently been called into question by a 1999 USGS study which determined that even the drought of record in the mid-1960s did not significantly threaten the wells with saltwater intrusion.

The Delaware River Basin Compact, which became law in 1961, created the Delaware River Basin Commission (DRBC) to manage water resources of the basin and to help resolve regional resource conflicts without returning to court. The DRBC is made up of the governors' representatives from the states of Delaware, New Jersey, New York, and Pennsylvania. Using its authority, the DRBC has funded a "Flow Needs Study" designed to provide tools (featuring a flow simulation model called OASIS) to help resolve interstate flow management issues without imposing a single solution. This study, and the accompanying OASIS model, has provided much of the impetus behind the ongoing reexamination of the New York City's reservoir management policies and the flow targets set out in the Supreme Court Decree. In addition, the DRBC commissioned a study of flow management and natural resource management issues, completed in February, 2001 (Delaware River Basin Commission, 2001). Much of the following description of management issues affecting the basin has been compiled from this source.

New York State Department of Environmental Conservation (DEC) regulations, originally passed in 1977, require minimum releases from the three reservoirs for conservation purposes. These mandatory releases have been revised a number of times by unanimous consent of the Parties to the Decree. The current requirements, labeled "augmented experimental conservation releases," are listed in Table 1. These experimental releases were recently extended until April 30, 2002 at which time the "augmented conservation releases" will go into effect. Note that in periods of drought warning or drought, the "basic conservation releases" listed below are used as the minimum allowable releases from the reservoirs.

Table 1. Reservoir Release Rates [Found in D-77-20 CP (Revision No. 4)]

Reservoir and Operative Dates	Basic Conservation Releases (cfs)	Augmented Conservation Releases (cfs)	Augmented Experimental Conservation Releases (cfs)
Pepacton			
1/1 - 3/31	6	50	45
4/1 - 4/7	6	70	45
4/8 - 4/30	19	70	45
5/1 - 5/31	19	70	70
6/1 - 8/31	19	70	95
9/1 - 9/30	19	70	70
10/1 - 10/31	19	70	45
11/1 - 12/31	6	50	45
Neversink			
1/1 - 3/31	5	25	25
4/1 - 4/7	5	45	25
4/8 - 4/30	15	45	25
5/1 - 9/30	15	45	53
10/1 - 10/31	15	45	25
11/1 - 12/31	5	25	25
Cannonsville			
1/1 - 3/31	8	33	45
4/1 - 4/15	8	45	4/1- 5/31: 45
4/16 - 6/14	23	45	
6/15 - 8/15	23	325	6/1- 9/15:160
8/16 - 10/31	23	45	
11/1 - 11/30	23	33	
12/1 - 12/31	8	33	9/16 3/31: 45

Just as the mandatory conservation releases are reduced during a drought or drought warning, New York City's diversion allowance and the flow targets at Montague and Trenton change with the combined storage levels of the Cannonsville, Neversink, and Pepacton reservoirs. A set of operation curves, agreed to in 1982, defines the storage condition.

Although the conservation rules for the operation of the three reservoirs appear to be fairly comprehensive, several issues remain regarding the overall system operation and its effects on stream biota. First, the releases among the three reservoirs are not evenly divided among the West Branch, East Branch, and Neversink tributaries. The release from Cannonsville Reservoir on the West Branch equals 61% of its total storage. In contrast, the release from Neversink Reservoir is only about 19% of its total storage (Pepacton release is about 24%). The disparity in water allocation appears to be related to two circumstances related to the reservoirs. First, the water stored at Neversink and Pepacton is of higher quality than at Cannonsville. All things being equal (or at least consistent) it is logical to use the highest quality water possible for domestic purposes. There is no suggestion that the water at Cannonsville is unfit for domestic use; rather, it meets a lower standard for taste, odor, and color. Second, the diversion tunnels from all three reservoirs are fitted with turbines for the production of hydropower, for which NYC is compensated. The turbine capacity at Cannonsville is only about one-third the capacity at Neversink and 40% of the capacity at Pepacton. Thus, there is an added incentive to divert more water from the Neversink and East Branch reservoirs than from the West Branch.

A second issue related to water allocation and management pertains to the drought rule curve. Specifically, the rules for declaring a drought or drought warning have been invoked frequently in recent history. For example, from 1991 through 1998, a drought warning was declared for a portion of every year except 1996. The upshot of the current definition, nonetheless, has been the annual enforcement of the basic conservation release (Table 1), resulting in abnormally low flows for extended periods of time, frequently during fall and winter. New York City Drought Management Plan has three phases: drought watch, drought warning, and drought emergency. Drought watch is declared when there is less than a 50% probability that the reservoirs will fill by the next June 1 (the start of the water year). Drought warning is declared when the fill probability is less than 33%. Drought emergency is when there is a “reasonable probability” that without stringent consumption reduction, a protracted dry period would cause the draining of the reservoirs. This probability is estimated using a variety of system and environmental factors. The frequency at which drought warnings occur suggests that drought rule curves may require re-examination. In fact, the current rule curves triggering one of the definitions of impending drought may be overly conservative, or addressable by non-institutional means (such as increasing reservoir storage capacity). A revision of the curves might bring ecological benefits by reducing the frequency that the releases are lowered to the "basic conservation" level.

The converse of frequent use of the drought declarations is reservoir spillage, often the result of a large runoff event occurring when the reservoir is full or nearly full. Under natural conditions, peak flows would normally occur in April and May in response to snowmelt runoff. Under current operations, the April-May peaks are attenuated somewhat, although the reservoirs are too small to completely remove the peaks. Attenuation of peaks is greatest in the Neversink River and least in the West Branch due to differences in reservoir capacity and inflow. High flows occur less predictably throughout the year. The effects of reservoir operations on the hydrologic characteristics of three upper Delaware River tributaries are illustrated in Table 2, comparing various flow durations statistics before and after regulation.

Table 2. Pre-and post-impoundment flow duration statistics for selected locations in the upper Delaware River Basin.

	West Branch at Hale Eddy									
	Percent equaled or exceeded									
	10%		25%		50%		75%		90%	
Month	Pre-dam	Post-dam	Pre-dam	Post-dam	Pre-dam	Post-dam	Pre-dam	Post-dam	Pre-dam	Post-dam
Jan	2510	1200	1400	566	700	260	380	140	225	100
Feb	2350	1660	1200	720	600	360	380	181	230	120
Mar	4660	2880	2470	1690	1440	751	798	282	454	150
Apr	4620	3850	2920	2360	1820	1230	1200	493	840	228
May	2320	2210	1530	1340	900	637	551	244	351	131
Jun	1350	1330	799	776	420	449	223	254	146	121
Jul	1000	1270	478	868	242	509	119	369	76	193
Aug	720	1220	380	966	185	625	102	313	62	125
Sep	833	1210	367	903	190	504	106	168	62	74
Oct	1270	1300	575	910	262	423	130	160	76	70
Nov	2270	1180	1360	631	730	320	345	191	170	117
Dec	2410	1400	1300	625	700	316	442	180	280	140
	East Branch at Harvard									
Jan	2150	453	1200	208	633	124	340	82	230	58
Feb	2000	442	1160	230	540	130	270	88	215	64
Mar	3700	685	1950	405	1100	230	620	131	348	84
Apr	3120	1790	2150	874	1410	396	966	228	677	172
May	2250	1250	1460	569	882	199	507	132	311	101
Jun	1100	702	716	289	394	144	218	108	159	80
Jul	880	706	443	212	205	129	110	103	76	84
Aug	534	717	263	322	144	121	80	93	52	75
Sep	574	666	258	472	142	122	70	87	46	76
Oct	892	617	419	440	158	185	84	106	56	74
Nov	1690	654	1080	455	647	218	325	144	196	89
Dec	2000	440	1040	264	600	168	400	114	290	82
	Neversink River at Godeffroy									
Jan	1250	740	752	410	459	250	300	180	185	120
Feb	1240	840	790	494	442	300	282	200	175	130
Mar	2090	1290	1320	836	823	558	487	370	328	210
Apr	2310	1700	1520	1080	1020	606	699	382	467	271
May	1600	1070	1130	616	724	390	380	270	275	202
Jun	1040	719	680	405	415	235	238	159	161	123
Jul	691	380	360	257	230	167	145	120	102	90
Aug	430	355	240	245	148	145	98	106	72	76
Sep	508	360	240	245	148	143	81	98	61	77
Oct	678	517	342	310	147	184	107	114	77	81
Nov	1270	761	732	449	433	268	203	164	140	103
Dec	1380	860	740	521	459	320	274	206	174	136

GOALS AND OBJECTIVES

The USGS' involvement in the Upper Delaware is a the result of Congressional funding directed towards the study of instream habitat needs in the Upper Delaware. This project was proposed for federal funding by a coalition on non-profit groups (inluding The Nature Conservancy, Trout Unlimited, and the Delaware River Foundation) and supported by the Delaware River Basin Commission. The study plan was developed in conjunction with the Subcommittee on Ecological Flows for the Delaware Basin (SEF). *:* SEF was created by Resolution 2003-18 of the Delaware River Basin Commission (DRBC) with consent from the Parties to the 1954 Supreme Court Decree. SEF is a subcommittee of DRBC's Flow Management Technical Advisory Committee (FMTAC) made up of state, federal, non-profit, and academic representatives engaged in resource management and assessment in the Delaware Basin.

SEF's goal is to "to develop ecological flow requirements for the maintenance or restoration of healthy self-sustaining and managed aquatic ecosystems in the Delaware Basin." This work will include consideration of water quality impacts and flow variability (magnitude, timing, duration, frequency and rate-of change of flows). The goal of the present study is provide information relating instream habitat and streamflow to fill data gaps that currently exist in the OASIS model. Specifically, the objective of the study is the development of models capable of quantifying habitat and temperature characteristics over a range of discharges and seasons at selected locations in the three tributaries and mainstem Delaware.

STUDY SEGMENTS AND RESOURCE ISSUES

The natural resource issues associated with the upper Delaware vary by location within the system (Table 3, Fig. 3). Coldwater releases from the dams have resulted in the existence of tailwaters trout fisheries in the East and West Branches of the Delaware. Although the Neversink historically supported salmonid populations in the mainstem below the current reservoir, coldwater releases have extended the year-round downstream range for trout. The West Branch of the Delaware, from Cannonsville Reservoir to

Hancock, may be the most popular trout stream of the three tributaries. The primary resource issues in the tailwaters sections of the tributaries are related to production of brown trout (*Salmo trutta)* and rainbow trout (*Oncorhynchus mykiss*). The upper Delaware mainstem, from Hancock to the vicinity of Lordville (NY) is also very popular for sportfishing and is the primary habitat for the rainbow trout population. Issues related to trout production in these segments also include provision of adequate riffle habitat for macroinvertebrates, flow stability during the incubation period, and occasional high temperatures during the summer. Of particular concern is the reduction of flow during winter months, which may result in dewatering of redds and food-producing areas in the channel, as well as contributing to ice penetration into the substrate in shallow areas.

In the mainstem Delaware River and in the lower East Branch and Nevesink, recruitment and rearing of juvenile American shad (*Alosa sapidissima*) becomes a resource issue. In some segments, the target species include both trout and shad, whereas in others, shad is the only fish species of concern. Because American shad are anadromous, and because the juveniles rear in the Delaware system only from June until August or September, streamflow management in support of this species would be seasonal, rather than year-round.

Four sub-populations of the federally endangered dwarf wedgemussel (*Alasmidonta heterodon*) are known to exist in the upper Delaware basin. The dwarf wedgemussel population is in the Upper Delaware Scenic and Recreational River portion of the river, downstream of Hancock, NY where the East Branch and the West Branch of the Delaware meet and the mainstem begins. More specifically, the federally endangered mussels were found between the towns of Equinunk, PA (10 miles downstream of Hancock, (at river mile 323.3) and Calicoon, NY (to river mile 301.9). Any change in the release regime from Cannonsville Reservoir might benefit the mussel by eliminating fluctuations in release levels that may impact the mussel populations. The National Park Service is funding a study to characterize the size, reproductive status, and genetics of the dwarf wedgemussel population in the mainstem. One of the stated aims of this study is help better understand how a change in the flow release pattern from the reservoirs might affect this population and the populaiton in the lower Neversink. The Neversink River's population of dwarf wedgemussels is known to be one of the largest in the world. The section of the lower Neversink in which they inhabitat exhibits fairly natural seasonal variability in flow regime despite the reduction in overall water volume due to tributary input. Two other rare mussels exist in these reaches as well, and their preferences should be able to be easily modeled along with those of the dwarf wedgemussel. These are the brook floater (*Alasimodonta varicosa*) which is a state threatened species and the alewife floater (*Anodonta implicata*) which is on the NY Natural Heritage Program's watch list due to its decline in New York State. Temperature is a key ecological driver for all three of these mussel species, providing the rationale to improve the predictive capability in OASIS for temperature.

Other species of interest that can be modeled within this framework include native fish falling within the shallow-fast habitat guild. This guild, which includes the tesselated darter, cutlips minnow, blacknose dace, creek chubsucker, and a number of other prominent Delaware Basin species. In addition, the tesselated darter is likely the primary host species for the dwarf wedgemussel in the Upper Delaware, those this needs to be confirmed. Understanding habitat needs for this host fish, therefore, may be critical to the overall analysis. The primary host for the alewife floater is American shad, whose habitat needs will also be modeled in this study. The brook floater, on the other hand, likely has a set of generalist species (e.g. golden shiner, longnose dace) as its host fish.

Table 3. Proposed segment boundaries, site locations, and resourcess issues associated with upper Delaware basin. Abbreviations in parentheses refer to life stages of fish (S = spawning, A = adult, J = juvenile, F = fry).

River	Segment	Site	Resource issues
W. Branch	Cannonsville Dam to confluence	Hale Eddy to Ball's Eddy	Brown trout (SAJF) Rainbow trout (SAJF) Macroinvertebrate community Shallow/fast guild
E. Branch	Pepacton Dam to Beaver Kill	Ox Bow Campground to Beaver Del CG	Brown trout (SAJF) Rainbow trout (SAJF) Shallow/fast guild Macroinvert community
	Beaver Kill to confluence	Beaver Del CG to Saw Mill (Fish's Eddy)	Brown trout (SAJF) Rainbow trout (SAJF) American shad (SFJ) Shallow/fast guild Macroinvert community
Upper Mainstem	Hancock to to Long Eddy	Frisbie Island (RM 323.2) to RM 318 (2 miles above Long Eddy)	American shad (SFJ) Dwarf wedgemussel Brook floater, alewife floater Shallow/fast guild Macroinvert community
	Long Eddy to Damascus	RM 311.6 (just above Hankins) to RM 307. OR RM 307.2 to 301.9 (4 miles below Hankins to 1 mile below Calicoon bridge)	American shad (SFJ) Dwarf wedgemussel Brook floater, alewife floater Shallow/fast guild Macroinvert community
Neversink	Neversink Reservoir To Monticello	Thompsonville Bridge To Bridgeville	Brown trout (SAJF) Brook Floater Macroinvertebrates Shallow/fast guild
	Monticello to Port Jervis	Godeffroy ramp to above Port Jervis	Brown trout (SAJF) American shad (SFJ) Shallow/fast guild Dwarf wedgemussel Brook floater, alewife floater

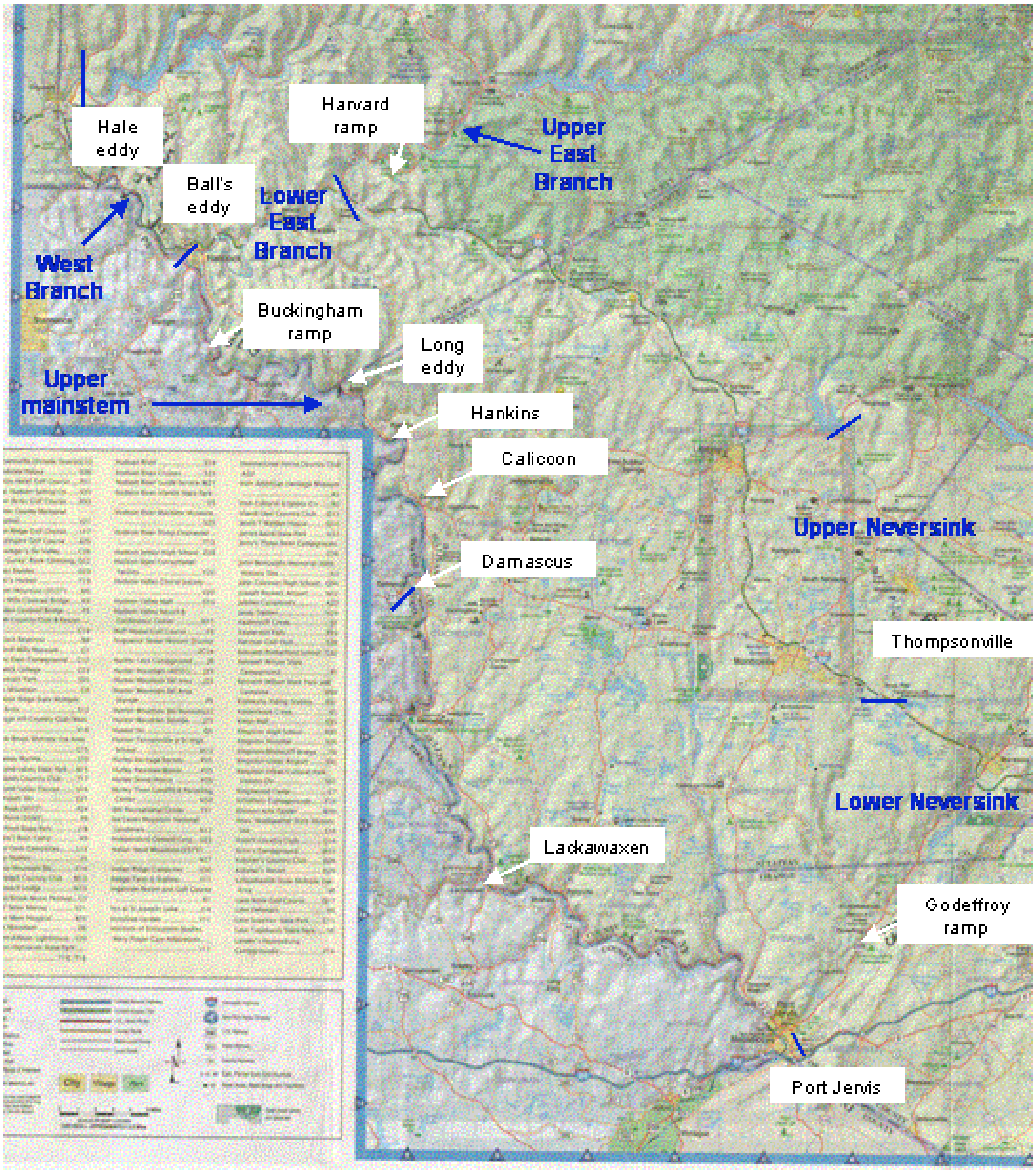

Figure 3. Map of the upper Delaware basin, showing proposed segment boundaries (blue), local landmarks, and points of access (white).

METHODS

With a few minor alterations, the development of habitat response models will follow the basic protocols used by Bowen et al. (2003b) in the upper Yellowstone River. We propose to develop composite habitat maps, containing layers for key habitats and classified mesohabitat types, for each of the study sites and for discharges encompassing a range of flows from approximately the current 10-year drought and flood events, respectively. This phase of the study will consist of eight parts: collection of bathymetric data, calibration of a 2-dimensional hydrodynamic simulation model, simulation of unmeasured discharges, development of habitat classification criteria, conversion of hydraulic output into classified habitat maps, development of a mesohabitat map layer, combination of the classified habitat maps with the mesohabitat map layer, and construction of flow versus habitat functions for various metrics extracted from the composite habitat maps.

Bathymetric data

Input to the two-dimensional hydrodynamic model consists of a topographic (x,y,z) description of the study reach, a roughness parameter for each x,y location, inflow discharge, and downstream (exiting cross section) water surface elevation. Underwater bathymetry will be measured using a boat-mounted survey grade GPS unit in conjunction with a narrow-beam scientific echosounder. Breaklines, such as the tops and toes of banks, cross-sections of floodplain side channels, and low-relief topography of floodplain surfaces, permanent islands, and other above-water features will be ground-surveyed using GPS or optical total stations. One or more temporary benchmarks will be installed at each study site. Presently, we intend to use local control data (uncorrected GPS) for co-ordinates and elevations, rather than tying all the benchmarks into the National Geodetic Survey system. The projections for all survey data will be consistent with USGS orthophoto quadrangles obtained from the EROS data center: Universal Transverse Mercator, zone 18, with datum = NAD83, and units = meters.

The preferred method for measuring bed elevations and coordinates with the boat-mounted equipment is to collect real-time kinematic (RTK) data from the GPS rover, using navigational software, and simultaneously collecting NMEA data with the echosounder computer. By this procedure, the GPS equipment provides precise x, y (horizontal) and z (elevation) data in real time, accounting for changes in water level due to standing waves, changes in discharge, and super elevation around sharp bends. Alternatives to this approach are available, using less sophisticated equipment, but are not as precise and require considerable post-processing of the data to account for unsteady flow during the measurement period. Regardless of the equipment, the basic sampling approach will be to trace breaklines, such as margins, bars, islands, and secondary channels with the echo sounder. Additional data will be collected longitudinally along approximate streamlines spaced 5 - 10 m apart between the channel feature traces. In addition, two or more diagonal courses will be traced from the top of the site to the bottom, with the purpose of filling in data between the longitudinal traces. Where the water is too shallow for echosounding (< 0.3 m deep) and in areas that were inaccessible by boat, ground survey data will be gathered using GPS or optical total station.

At the conclusion of the bathymetry measurements, boundary conditions of water surface profile and discharge must be measured at least once. Water surface elevations and positions will be measured at intervals of 100 – 200 m along the channel (with greater density at riffles) to generate a longitudinal profile of the water surface throughout each study site. Discharge will be measured at the bottom of the site using an Acoustic Doppler Current Profiler, or standard boat-mounted current meter. Discharge may also be obtained from a USGS gage if there is one in close proximity to the study site. These data are used as primary calibration data for the hydraulic simulation model. The calibrations can be improved significantly if more than one set of profile/discharge data are collected, but these are not absolutely necessary. However, it is necessary to obtain sufficient data to construct a rating curve of discharge vs. water surface elevation at the bottom of the site. This will require several repeated measurements of water surface elevation and discharge at or near the downstream extent of the study site. If a USGS stream gage exists near this location, the rating curve for the gage can be used in lieu of additional measurements.

Hydraulic Model Calibration

We will use the River-2D two-dimensional (depth-averaged) model developed at the University of Alberta (Ghanem et. al. 1995; 1996) to simulate depths and water velocities at unmeasured flows. Echosounder, GPS, and ground survey data will be processed to obtain point co-ordinates and elevations throughout the site (as well as substrate roughness and hardness data). An interpolation and filtering algorithm will be used to calculate bed elevations based on echosounder data and concurrently collected GPS positions and elevations. This algorithm also eliminates duplicate points, filtered based on minimum distance between points and flagged questionable GPS values.

These data will be entered into the bed-editor component of the hydraulic model, and smoothed to remove contour anomalies. A two-dimensional finite element computational mesh consisting of linear triangular elements will be generated for each site, created in an unstructured fashion with the primary criterion for refinement being topographic matching, assessed visually by overlaying contour maps in the mesh generation program. Typically, it is necessary to extend the computational domain of the model for approximately 100 m in the upstream and downstream directions to minimize the effect of inflow and outflow boundary conditions on flow characteristics at the upstream and downstream limits of the study sites. For calibration, we provide boundary conditions of inflow discharge and the measured water surface elevation at the outflow. Calibration is achieved by scaling the roughness values and mesh density for different parts of each study site. Our primary criterion for calibration will be matching of the predicted and measured water surface profiles for the site. In general, this criterion is satisfied if the predicted water surface elevations are within 2 cm/km of the measured values, although in very steep sections, it may not be possible to calibrate this closely without resorting to unreasonable parameterization (such as setting roughness height at 0.01 m at one node and 1 m at one adjacent to it).

Hydraulic Simulations

Once the model for a site is sufficiently calibrated, we propose to simulate 12 - 15 discharges ranging from the approximate 10-year drought flow to the 10-year flood. Boundary conditions (inflow discharge and outflow water surface elevation) will be input from stage-discharge relations that are either developed on-site or extrapolated from a nearby USGS stream gage. For each simulation, a file of node attributes will be created for input to habitat mapping and spatial analysis programs. These files contain information regarding location (coordinates), predicted depth, and predicted velocity at each node in the mesh.

Development of habitat classifications

Habitat classifications for this study will be derived from existing data and inferences thereof. For young of the year fish (salmonid fry and juvenile American shad), the key habitat feature will be defined as areas of shallow water with slow current velocity (SSCV). This habitat type has been demonstrated repeatedly as being critical to the survival and growth of young fish, virtually regardless of species (Welcomme 1979;

Sedell et al. 1984; Kwak 1988; Nehring and Anderson 1993; Bovee et al. 1994; Scheidegger and Bain 1995; Copp 1997; Bowen et al. 1998; Freeman et al. 2001; Zale and Rider 2003). For the purposes of this study, we will define shallow water to be between 10 and 50 cm deep, and slow water as having a velocity of less than 50 cm/s. In addition to the hydraulic characteristics of this key habitat feature, the physical location of SSCV habitat in side channels, backwaters, and channel margins may be important (Hjort et al. 1984; Ottaway and Clarke 1981; Ottaway and Forest 1983; Swales et al. 1986; Bowen et al. 2003a, 2003b).

Another of the key habitat group identified by the DRBC (2001) can be generalized as the shallow, fast current velocity (SFCV) guild (Table 3). This guild is composed of a wide variety of animals that make extensive, if not exclusive, use of riffle habitat areas, including: sub-adult forms of aquatic insects (nymphs and larvae) and members of the SFCV fish guild. Production of aquatic insects was identified as an important issue, because this group is the primary food supply for juvenile and adult trout. In clean-water systems having coarse substrates, it is generally accepted that the highest production rates of aquatic insects (particularly the EPT group, Ephemeroptera, Plecoptera, Trichoptera) are found in riffles or riffle-like areas (Usinger 1973). Riffles are also important habitat areas for the shallow, fast water guild of fishes, including the tesellated darter, which may be an important host for the glochidia of the dwarf wedgemussel. For the purposes of this study, we will define the SFCV habitat class as areas having depths between 5 cm and 75 cm, with velocities between 50 and 100 cm/s. In addition, suitable substrates for this key habitat type will be stipulated as large gravel to large cobble (5 cm to 25 cm median diameter).

A considerable body of information is available regarding the habitat preferences for juvenile and adult trout. Owing to a wide range of sampling designs methods, and streams of origin, however, the habitat suitability criteria may be inconsistent from one source to another. Rather than relying on local expert opinion regarding the appropriateness of one set of criteria or another, we propose to utilize a modified version of the procedures described by Thomas and Bovee (1993) to test one or more sets of existing criteria in the upper Delaware (primarily in the three tributaries).

For this test, we will use habitat maps generated for the study sites as a training device. Locations occupied by trout (juveniles or adults) will be identified with respect to species and life stage, and their positions determined by GPS survey. Occupied locations will then be incorporated with the habitat class map (based on the criteria being tested) for the discharge at which the observations were made. The basic data necessary to perform the Thomas and Bovee (1993) test include the number of occupied cells classified as suitable, the number of unoccupied cells classified as suitable, the number of occupied cells classified as unsuitable, and the number of unoccupied cells classified as unsuitable. If the criteria being tested fail to meet the statistical requirements for acceptance, we will either test another set, or refine the existing set until the criteria meet the test requirements. We will use a similar approach to verify spawning criteria for trout, utilizing observed locations of redds rather than observations of fish, to conduct the test.

Habitat suitability criteria for spawning and rearing juvenile American shad have been developed in the Delaware system (Ross et al. 1993, 1997), so transferability should not be an issue for this species. The authors of these studies found that shad utilized a wide range of depths and velocities, indicating plasticity in habitat use (Ross et al. 1993). However, they also found a significantly higher utilization of run and channel habitats, and speculated that the combination of physical attributes present in these habitat types may have explained such habitat preference. The authors noted that spawning shad tended to avoid deep and slow areas, and suggested that a combination of shallow, swift water might confer higher survival to newly spawned eggs. They proposed a range of velocities between 0 and 70 cm/s as limits defining suitable spawning habitat. Although they did not specify a corresponding depth range, data presented in their study indicated that most of the spawning activity occurred between 20 cm and 200 cm in depth.

In a companion study, Ross et al. (1997) examined habitat use and feeding ecology of juvenile American shad. The results of this study were similar to the spawning study, in that juvenile shad showed an affinity to particular mesohabitat types. They found that juvenile shad (average size 53 – 71 mm TL) fed extensively on larvae and pupae of midges (Chironomidae) and terrestrial invertebrates, which might explain the higher concentrations of fish in certain mesohabitats. Specifically, they noted higher concentrations of juvenile shad in riffle-pool habitats (the zone immediately downstream from riffles where the bed elevation decreases rapidly; i.e., the riffle tailout), riffles, and SAV (submerged aquatic vegetation) shallows. Based on data presented in the article, the highest concentrations of juvenile shad occurred within a depth range of approximately 40 cm to 150 cm, which is consistent with the depth ranges of the three most heavily utilized mesohabitat types. The velocity range observed in these habitats ranged from 0 cm/s to 76 cm/s. However, considerably higher numbers of juvenile shad were found in SAV shallows than in riffles or riffle-pools, so we propose to define the range of suitabile velocities to correspond to this habitat type, 0 cm/s to 48 cm/s.

No habitat suitability criteria have been specifically defined for the dwarf wedgemussel (DWM). However, generalized criteria for freshwater mussels as a group have been published by Layzer and Madison (1995), who proposed as habitat classification criteria, depth ≥ 6 cm and shear stress ≤ 50 dyne/cm^2. Over the next few years, Cornell University will be conducting a study of the species in the upper Delaware Basin to provide data for an Endangered Species act consultation related to a proposed DRBC-PPL drought management plan. A primary objective of the Cornell study is the determination of the physical characteristics of DWM habitat. We propose to use the results of this study to develop the habitat classifications for DWM. In the event that results from the Cornell study are not available in a timely manner, we will use the criteria from Layzer and Madison (1995).

Classified Habitat Maps

Following the final delineation of the habitat classes, we will construct a series of classified habitat maps in the GIS. Maps of the nodes (point coverages) of depth and velocity for each site and simulated discharge will be bounded at the predicted water surface profile and interpolated by Triangular Irregular Network (TIN). Each TIN will then be converted into a 1 x 1 m grid (raster) for depth and velocity, respectively. The grids will be reclassified according to depth and velocity categories meeting the criteria for each of the habitat classes. By re-classification, each cell in the depth grid falling within the specified range (e.g., 0.1 – 0.5 m) is assigned a numeric code value of 1. Likewise, each cell in the velocity grid meeting the classification criteria is assigned a numeric code value of 1. Individual depth and velocity classified grids are then be combined to form a composite classification grid. The habitat code for each cell is computed as:

$$CLASSCODE_{(Q)} = GRID\text{-}CODE_{(D,Q)} * 10 + GRID\text{-}CODE_{(V,Q)}$$

Where $CLASSCODE_{(Q)}$ is the composite classification code for a cell at a simulated discharge (Q), $GRID\text{-}CODE_{(D,Q)}$ is the depth classification for the cell at discharge (Q), and $GRID\text{-}CODE_{(V,Q)}$ is the velocity classification for the cell at discharge (Q). By this process, only those cells in which the codes for depth and velocity are both 1 (i.e., a composite class code of 11) are included as meeting all the criteria for SSCV habitat. Figure 4 illustrates an example of a composite habitat map developed for rainbow trout in the Yellowstone River, Montana.

Development of the Mesohabitat Layer

The purpose of the mesohabitat layer is to delineate the spatial distribution of SSCV habitat patches within a mosaic of major sub-units (mesohabitats) occurring in the main channel versus floodplain locations. We propose the following definitions of mesohabitats to be used in this study:

1. Main channel – delineated by the top-of-bank breaklines, buffered to account for the main channel margin (below) for the dominant (e.g., carries the greatest proportion of discharge) channel within the study site.
2. Main channel margin –parallel to the top-of-bank breakline, a polygon created by buffering a specified distance toward the interior of the main channel (typically 1 – 3 m).
3. SAV shallows – marginal areas with submerged aquatic vegetation, consistent with definitions provided by Ross et al. (1993).
4. Riffle-pool – areas delineated by rapid decrease in streambed elevation at the tail-out of the riffle, consistent with definitions provided by Ross et al. (1993).
5. Vegetated island – vegetated islands and bars within the main channel that may be inundated or partially inundated at high flows.
6. Floodplain - the area from the top-of-bank breakline to the toe of the low terrace, excluding side channels and distributaries incised in the floodplain.
7. Side channels – delineated by the top-of-bank breaklines for side channels and distributaries incised in the floodplain.

8. Tributary confluences – the area from the outlet of the tributary (estimated by connecting the main channel top-of-bank breakline on either side of the confluence) to the upstream extent of the backwater. Variable according to discharge.

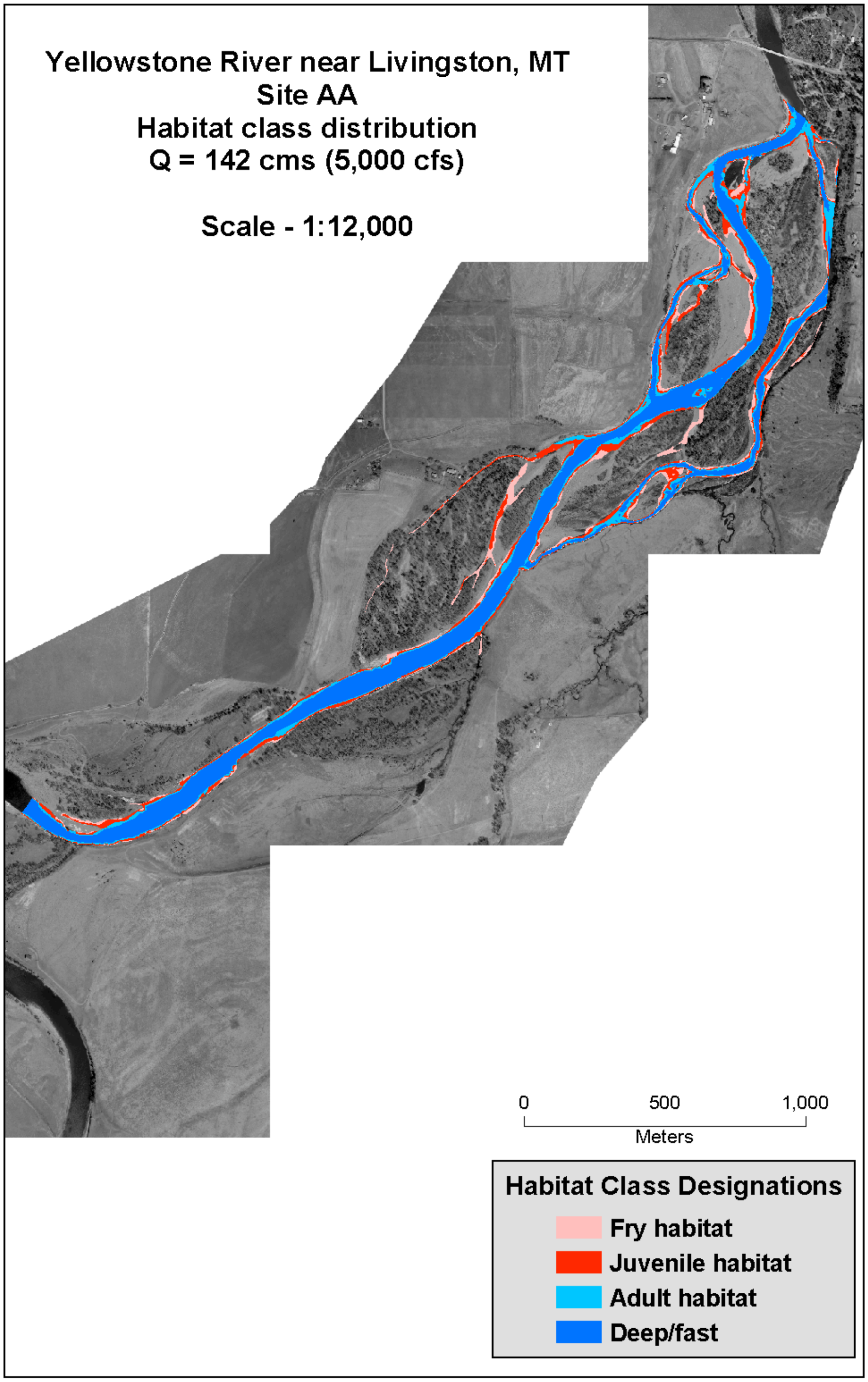

Figure 4. Example composite habitat suitability map with digital orthophoto.

Mesohabitat types will be hand-digitized from digital ortho-photos obtained from the USGS EROS data center. Photos will be registered to the habitat classification map coverages, using surveyed photo control points for each site, if necessary. Each polygon will be assigned a numeric code (MESO) corresponding to the numbers associated with the definitions listed previously. Polygons digitized for mesohabitat types will be converted to raster format with a cell size corresponding to the CLASSCODE grids.

Composite habitat maps

For each site and simulated discharge, a composite habitat map will be constructed by combining the from the habitat classification and the mesohabitat grids, respectively. A three-digit numeric code will be developed and applied to each of the overlain MESO and CLASSCODE grid cells, using the following convention:

$$MESOCLASS_{(Q)} = MESO * 100 + CLASSCODE_{(Q)}$$

where $MESOCLASS_{(Q)}$ is the composite code value for all cells at discharge (Q), having a unique combination of mesohabitat type (MESO) and habitat class ($CLASSCODE_{(Q)}$). A cell of SSCV habitat associated with a side channel would thus have a MESOCLASS code of 711. This convention makes it possible to determine the association between mesohabitat type (i.e., location) and habitat class throughout the study site, for each of the simulated discharges.

Discharge versus habitat functions

Data for MESOCLASS and AREA will be exported from each of the composite habitat maps, and arrayed according to simulated discharge in a look-up table. We anticipate that each site could be represented by multiple lookup tables, determined by the number of mesohabitat types present at the site times the number of habitat classes at issue. For example, if seven mesohabitat types are present at a site having four at-issue habitat classes, the total number of lookup tables would be 28.

Habitat persistence tables

Habitat persistence refers to the relative spatial stability of individual patches over a period of time when the discharge is unsteady. Rapid flow fluctuations can be detrimental to aquatic organisms having limited mobility, such as freshwater mussels and aquatic insects. During episodes of unsteady flow, patches of suitable habitat expand or contract, coalesce or become fragmented, appear where they did not occur at a different flow, or may disappear entirely. When the rate of change exceeds the ability of the organism to move to new locations of suitable habitat, the result is often local extirpations of the population. We will use the same basic procedures described in Bovee et al. (2004)to quantify patch persistence for SFCV and DWM habitat classes. An example of a habitat persistence map is illustrated in Figure 5.

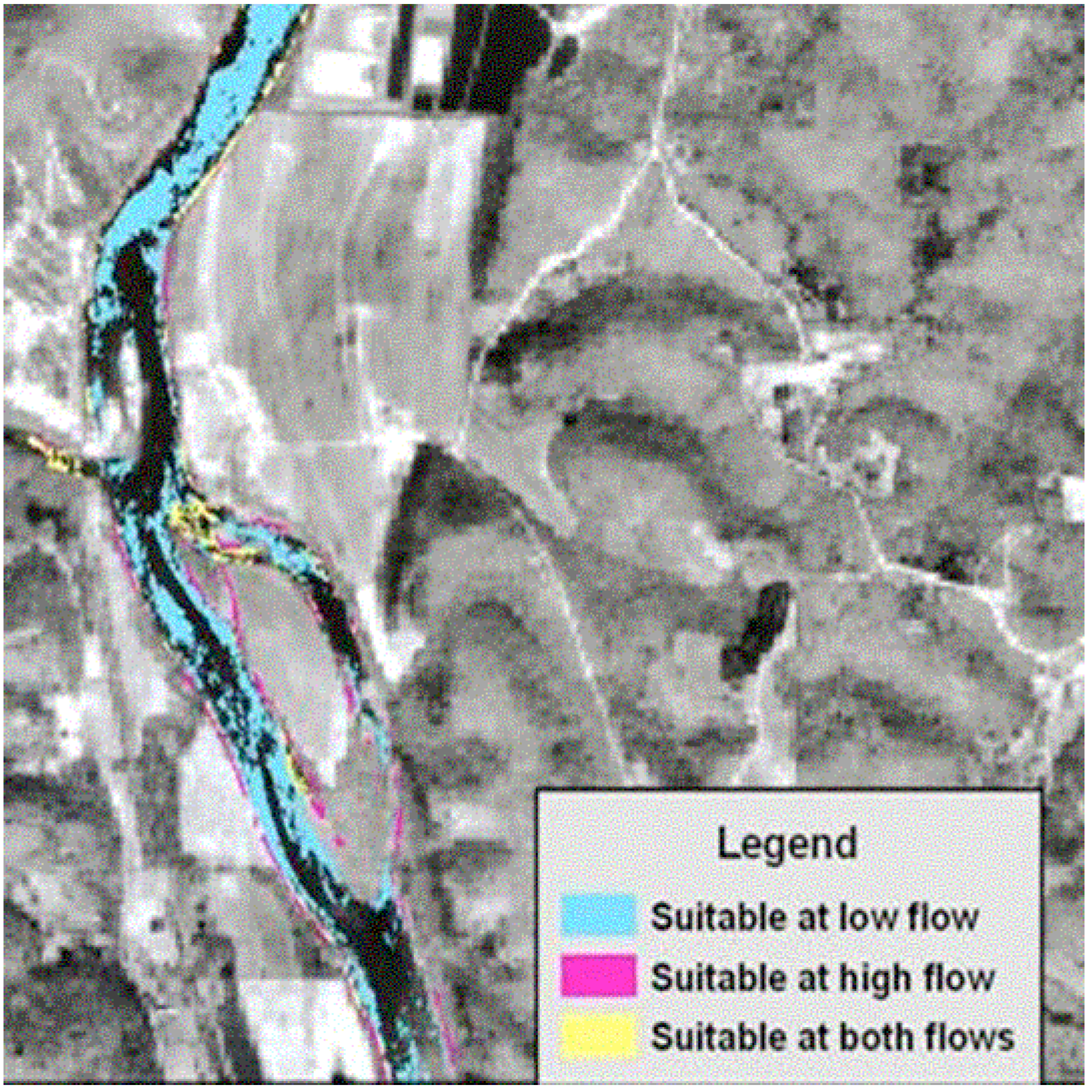

Figure 5. Example of a habitat persistence map for mussel habitat in the Osage River, Missouri.

This procedure involves overlay of the habitat class grids for a particular class (e.g., DWM habitat) at two different flows. Persistent, or spatially stable habitat for the discharge pair is determined as those patches that meet the class criteria at both flows. We will determine the area of persistent habitat patches for all combination of simulated discharges. These data will then be compiled into a persistence table (e.g., Table 4) that shows the total area of stable habitat patches of each class, for every combination of simulated discharge.

Table 4. Example habitat persistence table for mussel habitat patches. To find the area of persistent habitat for a pair of discharges, find Q1 in the Row Discharge field, and Q2 in the Column Discharge field. The associated habitat area (m^2) is located in the body of the table at the intersection of the row and column discharges. Note: Table is truncated at 849.9 m^3/s for brevity. Cells highlighted in yellow indicate habitat available under steady flow conditions.

Q1↓	←Q2 (m^3/s)→															
(m^3/s)	12.75	19.83	28.33	34.00	42.50	51.00	70.82	99.15	127.5	155.8	212.5	283.3	424.9	566.6	708.2	849.9
12.75	390530	384389	376858	372204	362855	352696	328117	301595	281317	259184	190102	104423	27802	14262	8623	5233
19.83		405822	394658	390600	381781	371682	346485	317966	295103	271396	200831	113150	33899	18870	12140	8419
28.33			417253	409318	400393	389811	364578	335472	310567	285662	214493	125935	43478	25668	16050	11268
34.00				422419	411244	400184	374248	344502	318003	292013	220000	130608	46793	28184	18041	13155
42.50					443805	430659	405170	373240	344938	316154	239930	148429	59887	38845	27193	21615
51.00						453972	425511	392606	363610	333316	253940	159117	65593	43196	30660	25097
70.82							463428	423404	394435	363065	278792	180083	80601	55421	41003	35661
99.15								466499	428004	394606	305069	200587	92737	63223	47009	41915
127.5									458300	418346	325858	215616	101585	70204	53158	48053
155.8										438985	337522	219271	103030	70473	53333	48367
212.5											366717	235181	111175	76579	58832	53578
283.3												254108	121016	84951	66155	59719
424.9													133799	96303	76560	67919
566.6														99831	77566	69235
708.2															80419	66214
849.9																78378

Temperature simulation

The current version of OASIS uses a series of nomographic solutions to predict average daily temperatures at various nodes in the system. According to users of the system, the current models within OASIS may be inadequate and unreliable for forecasting daily water temperatures. Because the existing model is highly empirical, temperatures are predicted on the basis of conditions that existed in the system when the data were collected (e.g., the release temperature and volume from the reservoirs, the measured air and water temperature for a particular day, the volume and temperature of ground and surface water accretions, as a few examples). A potential source of error may occur when the combination of input variables deviates significantly from the contextual database for the nomographs (a problem comparable to estimating the 100-year flood from ten years of flow records).

We propose to augment the database used in OASIS by using a physical process model to predict mean daily temperatures, given combinations of input variables that were not present when the data for the nomographs were collected. We intend to fill the database used in OASIS by simulating unmeasured input conditions in the SNTEMP model (Bartholow 1989, 1991). This model simulates steady-state stream temperatures throughout a dendritic stream network handling multiple time periods per year. SNTEMP is a mechanistic, one-dimensional heat transport model that predicts the daily mean and maximum water temperatures as a function of stream distance and environmental heat flux. Net heat flux is calculated as the sum of heat to or from long-wave atmospheric radiation, direct short-wave solar radiation, convection, conduction, evaporation, streamside vegetation (shading), streambed fluid friction, back radiation, and groundwater influx. Also incorporated in SNTEMP is a heat transport model, based on a dynamic temperature-steady flow equation.

We will use the same basic input data that was used to develop the OASIS nomographs to calibrate the SNTEMP model. Once calibrated, we will then supply different combinations of input variables to SNTEMP, producing as output, the predicted mean daily water temperatures throughout the basin (using a physical process model also allows the user to change the locations of nodes where temperature predictions are made).

One of the perceived deficiencies in OASIS is the way it handles daily flow accretions. It is beyond the scope of our proposal to attempt to correct this deficiency (if it exists). However, we can change the characteristics of the accretion within SNTEMP to determine the effect on stream temperature.

Ultimately, it may be possible to embed the calibrated version of SNTEMP directly into OASIS, eliminating the need for nomographic solution entirely. For the purposes of this project, however, the deliverable will be a calibrated SNTEMP model with instructions for gaming with alternative input variables, with examples of model runs showing the influence of different reservoir release options.

SCHEDULES AND DELIVERABLES

Activity (x) or product (P)	FY2004							FY2005												FY 2006		
	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Finalize study plan	x	P																				
Bathymetry data (tribs)			x	x	x																	
Bathymetry data (main stem)															x	x	x					
Fish observation data					x	x		x														
Calibrate hydraulic models								x	x	x	x						x	x	x			
Determine habitat classes (fish)											x	x	P									
Determine habitat classes (DWM)								x	x	x	x	x	x	x	x	x	x	x	P			
Develop habitat class maps								x	x	x	x	x	x	x	x	x	x	x	P			
Develop mesohabitat maps								x	x	x	x	x	x	x	x	x	x	x	P			
Composite MESOCLASS maps											x	x	x	x	x	x	x	x	P			
Habitat response functions																	x	x	P			
Habitat persistence tables														x	x	x	x	x	P			
Calibration of SNTEMP			x	x	x	x	x	x	x	x												
Temperature simulations										x	x	x	x	x	x	x	x	x	x			
Completion report																				x	x	P
Documentation and training																				x	x	P

BUDGET

Description	USGS Contributed Funds	
Salaries		
111 Permanent Federal Salaries	$	120,783
113 Temporary Federal Salaries		
Total Federal Salaries	$	120,783
210 Travel	$	20,000
231 Facilities	$	-
240 Printing/Report Preparation	$	2,000
250 Contracts		
252K Contractor Salaries (e.g., JCI)	$	33,000
252T Training		
260 Supplies	$	2,000
310 Equipment	$	37,000
410 Grants/Coop Agreements		
Other		
Total Operating Expenses	$	94,000
Net Funding Totals	$	214,783
Cost Center Indirect	$	32,217
Bureau Indirect Costs	$	-
Gross Funding Totals	**$**	**247,000**

REFERENCES

Bovee, K. D., T. J. Newcomb, and T.G. Coon. 1994. Relations between habitat variability and population dynamics of bass in the Huron River, Michigan. U.S. Department of the Interior, National Biological Survey Biological Report 21. 63 pp.

Bovee, K.D., T.J. Waddle, and R.B. Jacobson. 2004 (in press). Quantification of habitat patch persistence in rivers affected by hydropeaking. Proceedings Specialty Conference: GIS and Water Resources III. American Water Resources Association, Nashville, TN.

Bowen, Z. H., M. C. Freeman, and K. D. Bovee. 1998. Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes. Transactions of the American Fisheries Society 127:455-468.

Bowen, Z.H., K.D. Bovee, and T.J. Waddle. 2003a. Effects of flow regulation on shallow-water habitat dynamics and floodplain connectivity. Transactions of the American Fisheries Society 132:809-823.

Bowen, Z.H., K.D. Bovee, and T.J. Waddle. 2003b. Effects of channel modification on fish habitat in the upper Yellowstone River. U.S. Geological Survey Open File Report 03-476. 30 pp + appendices.

Copp, G. H. 1997. Importance of marinas and off-channel water bodies as refuges for young fishes in a regulated lowland river. Regulated Rivers: Research & Management 13:303-307.

Delaware River Basin Commission. (unpublished). Preliminary list of flow management issues. Delaware River basin flow management study, prepared by the Greeley-Polhemus Group, West Chester, PA, February, 2001.

Freeman, M. C., Z.H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11(1):179-190.

Ghanem, A., P. Steffler, F. Hicks, and C. Katopodis. 1995. Two-dimensional finite element modeling of flow in aquatic habitats. Water Resources Engineering Report No. 95-S1. University of Alberta.

Ghanem, A., P. Steffler, F. Hicks, and C. Katopodis. 1996. Two-dimensional simulation of physical habitat conditions in flowing streams. Regulated Rivers: Research and Management 12:185-200.

Hjort, R. C., P. L. Hulett, L. D. Labolle, and H. W. Li. 1984. Fish and invertebrates of revetments and other habitats in the Willamette River, Oregon. Technical Report E-84-9, U. S. Army Engineer Waterway Experiment Station, Vicksburg, Mississippi.

Kwak, T. J. 1988. Lateral movement and use of floodplain habitat by fishes of the Kankakee River, Illinois. American Midland Naturalist 120: 241-249.

Layzer, J.B. and L.M. Madison. 1995. Microhabitat use by freshwater mussels and recommendations for determining their instream flow needs. Regulated Rivers: Research & Management 10:329-345.

Nehring, R.B. and R.M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. Rivers 4(1):1-19.

Ottaway, E. M. and A. Clarke. 1981. A preliminary investigation in to the vulnerability of young trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*) to downstream displacement by high water velocities. Journal of Fish Biology 19:135-145.

Ottaway, E. M. and D. R. Forest. 1983. The influence of water velocity on downstream movement of alevins and fry of brown trout, *Salmo trutta*. Journal of Fish Biology 23:221-227.

Scheidegger, K. J. and M. B. Bain. 1995. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. Copeia 1995: 125-135.

Sedell, J. R. , J. E. Yuska, and R. W. Speaker. 1984. Habitats and salmonid distribution in pristine, sediment-rich valley systems: South Fork Hoh and Queets River, Olympic National Park. Pages 33-46 in W. R. Meehan, T. R. Merrel, and T. A.

Hanley, editors. Fish and wildlife relationships in old-growth forests. American Institute of Fishery Research Biologists.

Swales, S., R.B. Lauzier, and C.D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64:1506-1514.

Thomas, J.A. and K.D.Bovee. 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. Regulated Rivers: Research & Management 8:285-294.

Usinger, R.L. 1973. Aquatic insects of California. University of California Press, Berkeley. 508 pp.

Welcomme, R. L. 1979. Fisheries ecology of floodplain rivers. Longman Group Limited, New York.

Zale, A. V. and D. Rider. 2003. Comparative use of modified and natural habitats of the upper Yellowstone River by juvenile salmonids. Final project report to the U. S. Army Corps of Engineers, Omaha, NE. Montana Cooperative Fishery Research Unit, Bozeman, MT.