BEFORE THE FEDERAL ENERGY REGULATORY COMMISSION
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Cannonsville Hydroelectric Project

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Appendix E-8: USGS Report: A Decision Support Framework for Water Management in the Upper Delaware River

City of New York

NYC Environmental Protection

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A Decision Support Framework for Water Management in the Upper Delaware River

By Ken D. Bovee, Terry J. Waddle, John Bartholow, and Lucy Burris

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A Decision Support Framework for Water Management in the Upper Delaware River

By Ken D. Bovee, Terry J. Waddle, John Bartholow, and Lucy Burris [1]

Introduction

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 river begins as two streams in the Catskill Mountains, the East and West Branches. The two tributaries flow in a southwesterly direction until they meet at Hancock, N.Y. The length of the river from the mouth of Delaware Bay to the confluence at Hancock is 331 miles. Approximately 200 miles of the river between Hancock, N.Y., and Trenton, N.J., is nontidal.

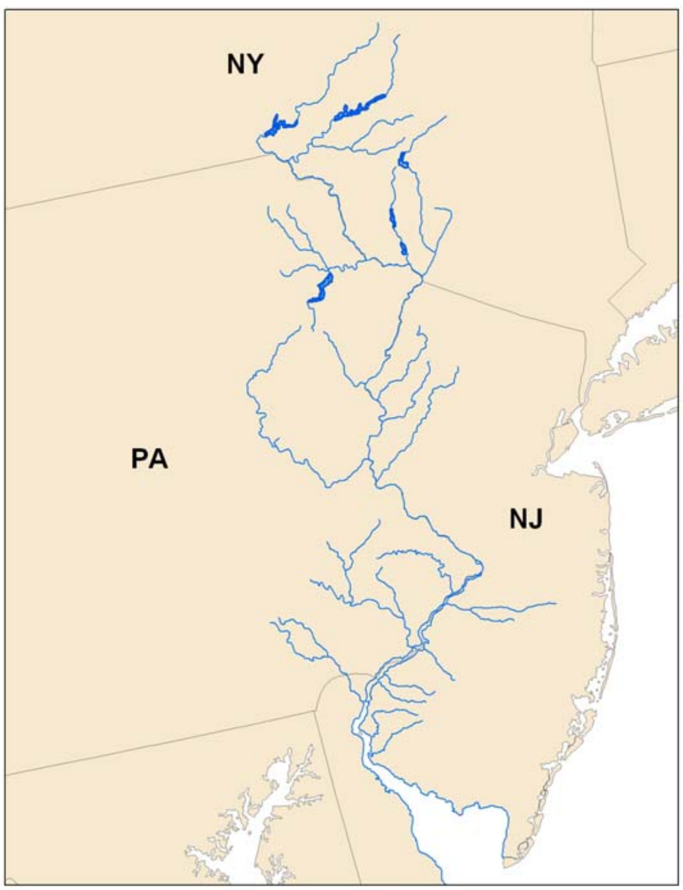

Figure 1. Tristate map of the Delaware River Basin (Scale = 1:1,500,000).

[1] U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Avenue, Building C, Fort Collins, Colo., 80526.

New York City's Delaware system impounds three tributaries at Cannonsville Reservoir on the West Branch, Pepacton Reservoir on the East Branch, and the Neversink Reservoir on the Neversink River (fig. 2). Approximately 895.5 million m^3 (725,985 acre feet) is diverted out of the Delaware River Basin from these reservoirs each year through the Delaware Aqueduct. Typically, more than one fourth of the diverted water is from Neversink Reservoir while Cannonsville Reservoir supplies less than a quarter and Pepacton Reservoir provides the remaining half.

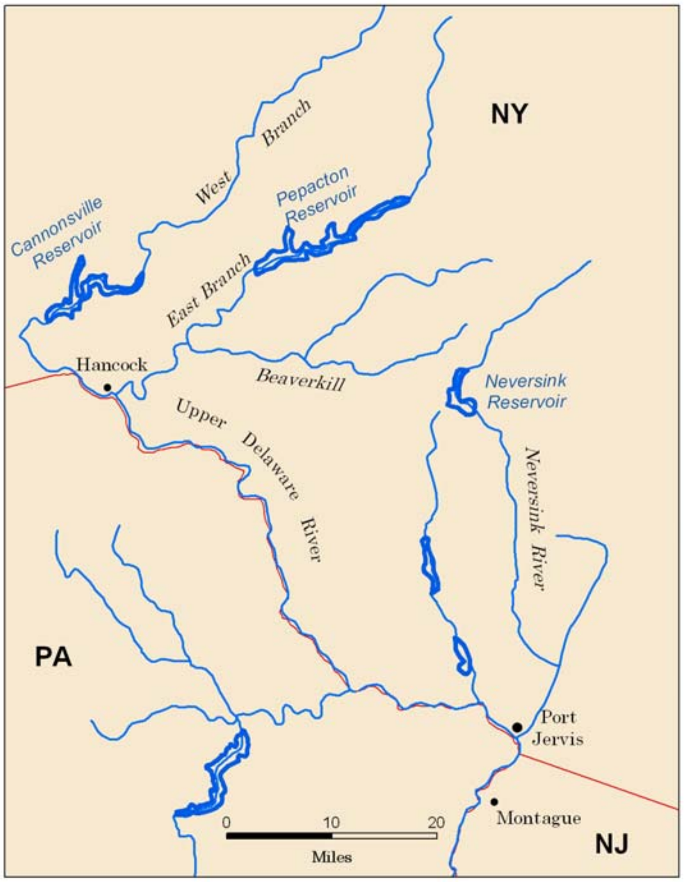

Figure 2. Upper Delaware River and reservoirs (Scale = 1:500,000).

The river is currently managed under the terms of a 1954 Supreme Court Decree (henceforth the Decree), the result of a series of lawsuits brought by New Jersey and Pennsylvania to regulate New York City's diversions from the Delaware River Basin. The diversion rights and release requirements created under the Decree cannot be changed without unanimous consent from the Decree parties (Delaware, New Jersey, New York, Pennsylvania, and New York City.) Numerous adjustments to the Decree's diversion and release formula have been made to modify the operations of the three New York City reservoirs in the Delaware River Basin. A coldwater fishery developed in response to the cold releases from the three New York City reservoirs. During the past 25 years, the Decree parties, at the request of the New York State Department of Environmental Conservation, have established schedules for minimum releases and have set aside a thermal bank for fishery protection. This program has been established, and on several occasions has been experimentally modified.

Several operational and management factors affect the flow regime in the upper Delaware River Basin. Among these are the use of the Montague flow target formula, minimum New York

City reservoir releases, New York City Department of Environmental Protection reservoir management decisions, the rule curves pertaining to the operation of the reservoirs, and reservoir capacity. Information in the following sections was extracted largely from "Preliminary list of flow management issues," prepared by the Greeley-Polhemus Group, West Chester, Pa. and provided courtesy of the Delaware River Basin Commission, January, 2004.

Montague Target Formula

During normal conditions as defined by the operating rule curves, New York City can divert up to 3.03 million m^3 (2,456 acre feet) per day, provided that a flow target of 49.6 m^3/s (1,750 ft^3/s) is met at the Montague, N.J., gage. The Delaware River Master, a position within the U.S. Geological Survey established by the Decree, directs New York City reservoir releases on a daily basis for the purpose of meeting the Montague flow target. New York City must comply with this direction but may use any of the three upper Delaware reservoirs to do so. In computing the directed release for the New York City reservoirs, the River Master must account for releases from the Lake Wallenpaupack and Rio hydropower facilities toward the Montague flow. These reservoirs are located downstream of the New York City reservoirs but upstream of Montague. Because the power releases and forecast precipitation are highly variable, the directed release requirements fluctuate, resulting in a highly variable flow regime in the upper Delaware River and tributaries.

Minimum Reservoir Releases

In 1977, the New York State Department of Environmental Conservation issued regulations that required minimum releases from the three reservoirs for conservation purposes. These mandatory releases have been revised a number of times by unanimous consent of the Decree parties. During periods of drought watch, drought warning, and drought, as defined by the operating rule curves, flow targets and minimum releases are reduced. The minimum releases may drop to the basic rates during drought conditions in the event that fishery protection banks are not available. In addition, thermal releases can be made when needed to protect coldwater fisheries below the reservoirs, provided that water is available in the thermal bank or can be traded from another allocation.

New York City Department of Environmental Protection Operating Decisions

Releases among the three reservoirs are not evenly divided. The water stored at Neversink Reservoir and Pepacton is of higher quality than that at Cannonsville. Consequently, more water is diverted from the East Branch and the Neversink than from the West Branch. Cannonsville releases to the West Branch equal approximately 61 percent of total storage. In contrast, the release from Neversink Reservoir is approximately 19 percent of its total storage, and the Pepacton release is approximately 24 percent of total storage.

Operating Rule Curves

The rule curves defining drought watch, drought warning, and drought conditions represent a seasonal water allocation of New York City reservoir storage among the Decree parties. They do not necessarily reflect observed hydrologic conditions elsewhere in the Delaware Basin. Drought or drought warning operations 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 result of the current definition has been the frequent enforcement of the basic conservation release, resulting in abnormally low flows for extended periods of time, frequently during fall and winter.

Reservoir Capacity

The converse of frequent use of the drought declaration is reservoir spillage, often the result of a large runoff event occurring when a reservoir is full or nearly full. Under natural conditions, peak flows would normally occur in April and May in response to snowmelt runoff and rainfall. Under current operations, reservoir volumes are maintained as full as possible to maximize deliverable water supplies. Consequently, there is little buffering capacity to reduce flood events during periods of high inflow and uncontrolled spills are common events. Attenuation of peaks is greatest in the Neversink River and least in the West Branch due to differences in reservoir capacity and inflow.

Goals and Objectives

Involvement of the U.S. Geological Survey in the Delaware River was the result of Congressional funding directed towards the study of instream habitat needs in the upper portion of the river basin. This project was proposed for Federal funding by a coalition of non-profit groups (including The Nature Conservancy, Trout Unlimited, and the Delaware River Foundation) and supported by the Delaware River Basin Commission (henceforth referred to as the Commission). The study plan was developed in collaboration with the Subcommittee on Ecological Flows for the Delaware Basin (henceforth, the Subcommittee). The Subcommittee serves the Commission's Flow Management Technical Advisory Committee, composed of State, Federal, non-profit, and academic representatives engaged in resource management and assessment in the Delaware Basin.

The goal of the present study was to provide information relating instream habitat characteristics and streamflow, integrated with the Commission's reservoir operations and streamflow routing model, OASIS. The specific objectives of the study were:

1. The quantification of habitat metrics over a range of discharges and seasons at selected locations in the three tributaries and main stem Delaware.
2. Development and calibration of a network-wide temperature simulation model for the upper Delaware River basin.
3. Development of a prototype Delaware River Decision Support System (DRDSS) to assist the Commission and other stakeholders to analyze and interpret water management and reservoir operations alternatives.

Study Segments, Resource Issues, and Site Selection

To facilitate compatibility of the habitat analysis with the hydrologic simulations derived from OASIS, the upper Delaware River and its tributaries were divided into eleven river segments (fig. 3, table 1) following the guidelines presented in Bovee and others (1998). Segment delineations were based on the following criteria, roughly in order of descending priority:

1. The flow regime was relatively homogeneous from the top of segment to the bottom (for example, boundaries were placed at confluences of major tributaries).
2. General temperature classification (for example, coldwater, transitional, or warmwater).
3. Resource issues, target species, and species of concern.

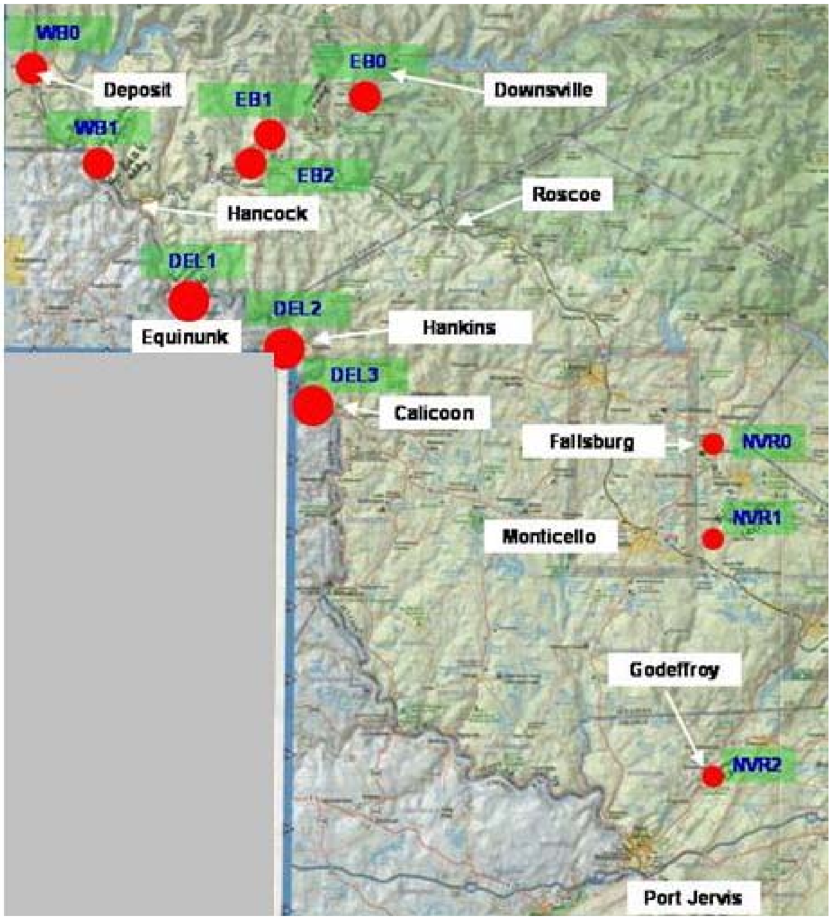

Figure 3. Segmentation and study site locations in the upper Delaware Basin.

Resource Issues

The natural resource issues associated with the upper Delaware varied by location within the system. Resource issues in the three tributaries were related primarily to production of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). The upper Delaware main stem, from Hancock to the vicinity of Lordville, N.Y., is also very popular for sport fishing, and trout production was considered in this reach as well. Issues related to trout production in these segments also included provisions for adequate riffle habitat for macroinvertebrates, flow stability during the spawning-incubation period, and occasional high temperatures during the summer.

In the main stem Delaware River, the lower East Branch (EB2), and lower Neversink (NVR2), factors affecting the recruitment and rearing of juvenile American shad (*Alosa sapidissima*) were added to the list of issues. 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 was considered seasonal, rather than year-round. Other species of interest included the bridle shiner (*Notropus bifrenatus*), blue spotted sunfish (*Enneacanthus gloriosus*), eastern mudminnow (*Umbra pygmaea*), American eel (*Anguilla rostrata*), margined madtom (*Noturus insignis*), fallfish (*Semotilus corporalis*), and cutlips minnow (*Exoglossum maxillingua*).

Table 1. Segment boundaries and resource issues associated with upper Delaware Basin.

River	Segment	Location	Resource issues
West Branch	WB0	Cannonsville to Oquaga Creek	Brown trout
	WB1	Oquaga Creek to Hancock	Rainbow trout
			Shallow-fast guild
			Shallow-slow guild
East Branch	EB0	Downsville to Shinhopple	Brown trout
	EB1	Shinhopple to Beaver Kill	Rainbow trout
			Shallow-fast guild
			Shallow-slow guild
	EB2	Beaver Kill to Hancock	Brown trout
			Rainbow trout
			American shad
			Shallow-fast guild
			Shallow-slow guild
Delaware	DEL1	Hancock to Lordville	Rainbow trout
main stem	DEL2	Lordville to Hankins	American shad
	DEL3	Hankins to Callicoon	Shallow-fast guild
			Shallow-slow guild
Neversink	NVR0	Neversink Reservoir to Fallsburg	Brown trout
	NVR1	Fallsburg to Bridgeville	Shallow-fast guild
			Shallow-slow guild
	NVR2	Bridgeville to Port Jervis	Brown trout
			American shad
			Shallow-fast guild
			Shallow-slow guild

Two species guilds were included in the list of issues for all sites and segments, following the basic concepts described by Bain and others (1988), Knight and others (1991), and Bowen (1996). The shallow-fast (SFCV) guild was intended to represent habitat for riffle-dwelling species of fish and aquatic macroinvertebrates. Of the species of concern not listed in table 1, the margined madtom can be considered a member of the SFCV guild (Lee and others, 1980). Juvenile fallfish and American eels may also use this habitat type extensively, but not exclusively (Scott and Crossman, 1973; Bain and others, 1982). The shallow-slow (SSCV) guild was designed to represent habitat necessary for young of the year for virtually all species, and for species found primarily in slack water areas. The bridle shiner, blue spotted sunfish, eastern mudminnow, and cutlips minnow all utilize subsets of this habitat guild, with the first three species highly associated with fine substrates and aquatic vegetation (Scott and Crossman, 1973; Lee and others, 1980). From our observations, fine substrates and aquatic vegetation were rare in most places, being most commonly found in backwater mesohabitat types. The cutlips minnow is also commonly associated with shallow, slow water, but in silt-free, unvegetated areas (Scott and Crossman, 1973). Although the habitats for these species were not studied specifically, their general habitat responses were assumed to correspond to the SSCV guild.

Four subpopulations of the Federally endangered dwarf wedgemussel (*Alasmidonta heterodon*) exist in the upper Delaware basin. Dwarf wedgemussel populations were discovered between the towns of Equinunk, Pa., and Callicoon, N.Y., depicted in table 1 as sites DEL1, DEL2, and DEL3. The lower Neversink River also reportedly supports a large population of dwarf wedgemussel, although this study investigated only the main stem Delaware mussel beds.

Site Selection

The rationale for the selection of study sites was that the habitat characteristics of the site should represent those of the segment. Habitat is related to hydraulics, channel structure, and edge effects. Hydraulics, channel structure, and edge effects are all related to planform. Therefore, we used planform as our initial criterion for site selection. Selections were based on how well the proportional distribution of channel types in the candidate site matched those of the total segment. Channel types were digitized from 1:40,000 scale digital ortho quarter quadrangles (DOQQ), and classified as:

1. divided channel on a bend (BDC),
2. single-thread channel on a bend (BSC),
3. delta/tributary confluence (DELTA),
4. multiple channel (MC),
5. straight, single-thread channel (SSC), and
6. straight, divided channel (SDC).

A divided channel (of either category) differed from a multiple channel according to the number of islands evident in the photographs or verified by site visitations. A divided channel was designated where there was a single island, usually in midriver, with approximately equal-sized channels on either side of the division. Multiple channel sectors were defined where two or more clearly defined islands were adjacent to one another. Unvegetated midchannel bars were not considered to be islands, even though multiple channels formed around them at low flows. In some cases the distinction between a divided channel and multiple channel was blurred by the presence of small secondary channels cutting across a single, dominant island. In these cases, a judgment was made regarding the dominant feature of the planform type. Although we strived for consistency, the subjectivity of these decisions may have influenced the site-segment comparisons somewhat.

The proportional distribution of each channel type was calculated by dividing the summed lengths for each type by the total length of the segment. The segment was then subsampled to find a shorter, contiguous reach that closely approximated the proportions of channel types in the segment (see appendix 1). This procedure was followed rigorously during the initial selection of study sites. After review by the Subcommittee, however, several members recommended the addition and modification of sites. Sites WB0, EB0, and NVR0 were added to the West Branch, East Branch, and Neversink, respectively, to better describe habitat conditions in the tailwaters areas of the three tributaries. The main stem sites (DEL1, DEL2, and DEL3) were concentrated in the Hancock-to-Callicoon reach, to correspond to areas of active dwarf wedgemussel research. Finally, the reach farthest downstream on the Neversink (NVR2) proved to be inaccessible, and was moved to a more accessible location. One consequence of the re-selection process was that the lower portion of the main stem of the Delaware from Callicoon to Port Jervis was not included in the study.

Methods

Three basic types of information were generated for this study. The first category included the development of various habitat patch metrics as a function of discharge. The second type was the simulation of daily temperatures at specified locations in the system under different input conditions of meteorology, reservoir releases, and network hydrology. The third category, used primarily for calculating summary statistics in the DRDSS, was the generation of time series of habitat metrics and temperature. Information related to other decision variables in the DRDSS, including reservoir storage, spills, downstream deliveries, and exports, were derived directly from the OASIS model. This section briefly describes the methods used to derive each of the three types of information and concludes with a description of the organization and functionality of the DRDSS.

Habitat Patch Metrics

Habitat patch metrics were derived from a combination of stream bathymetry, hydraulic model output, and spatially explicit patch morphometry utilizing ArcGIS (ESRI, Version 9.0). Development of this database involved seven steps: collection of bathymetric data, preparation of input to the hydraulic simulation model, determination of boundary conditions, model calibration, simulation of unmeasured discharges, classification of habitat for target organisms and guilds, and geographic information system operations to generate patch metrics as functions of discharge.

Bathymetric Data

Bathymetric data were collected remotely using boat-mounted echo sounders for deep-water areas and directly via ground surveys of shallow-water and exposed areas. At each study site, a semipermanent benchmark was established using the Wide Area Augmentation System (WAAS) differentially-corrected Global Positioning System. In effect, our benchmarks were considered as "local controls," but the submeter accuracy of the positions and elevations were well within acceptable mapping tolerances for our study. Secondary benchmarks were installed at additional locations within the sites by real-time kinematic Global Positioning System in the event that the primary benchmark was disturbed and to ensure continuity in radio transmissions from the base station. Precision estimates for survey data relative to the primary benchmarks were approximately 2 cm horizontally and vertically.

Hydroacoustic mapping was conducted using procedures described in Bowen and others (2003b). Bathymetric data were collected with Biosonics DT4000 and DE-X echosounders equipped with a single beam, 6° transducer mounted in an inboard acoustic well. The echosounders were calibrated by comparing depths recorded on the echogram with depths measured with a survey rod at stationary locations in a lake. In this setting, the accuracy of depth measurements was approximately 3 cm.

Five or more longitudinal bed profiles were measured in the main channel and all large side channels (20 m or wider), with two profiles tracing each bank, one profile down the centerline of the channel, and two other profiles at quarter-channel intervals between the centerline and the bank. In channels less than 20 m wide, at least three longitudinal traces were measured. In all channels, the longitudinal profile data were augmented by two or more bank-to-bank diagonals for the length of the site. All data were georeferenced in the field with a survey-grade Global Positioning System mounted adjacent to the acoustic well.

Direct survey measurements were made with real-time kinematic Global Positioning System (Trimble 5800 rover with model 5700 base station) and with an optical total station (Leica TC800) with 3-second horizontal and vertical angle precision. Direct survey measurements were taken along breaklines defining the toes and tops of banks, cross-sections of floodplain areas and islands, and in areas that were too shallow to measure with the echo sounder. All data were projected to the Universal Transverse Mercator coordinate system, zone 18 N, using the WGS1984 datum, and the CONUS99 geoid model.

Data Preparation

Raw bathymetry data are rarely, if ever, suitable for immediate use in the hydraulic simulation model. Echosounder depths must be converted into elevations, and these elevations merged with direct survey data. The resulting three-dimensional topography file (known as a bed file) must be edited to connect features such as bank edges or thalweg points and to smooth jagged contour lines that result from spurious triangulations among measured points. Finally, a computation mesh must be constructed as input to the simulation program.

Conversion of Echosounder Depths to Elevations

The elevation of the river bed at any point can be calculated as the elevation of the transducer face minus the depth. Echosounder data were recorded as binary files of depths and geographic locations in latitude and longitude. These data were converted to ASCII format using Biosonics Visual Bottom Typer software and projected from latitude-longitude geographic reference into the Universal Transverse Mercator coordinate system used with the direct survey data. The data were screened for duplicate points and obvious outliers and converted to a 0.5 m by 0.5 m grid in ArcGIS. Transducer data consisted of x, y coordinates and elevations measured at the transducer face using real-time kinematic Global Positioning System recorded at 10-m intervals along each of the boat traces.

Two different approaches were used to calculate the elevations of the transducer face. Where data were collected under steady flow conditions, a surface of transducer elevations was constructed by interpolation, using the TIN (Triangular Irregular Network) function in ArcGIS. The TIN surface was smoothed by removing obvious outliers and converted to a 0.5 m by 0.5 m grid, from which the depth grid was subtracted. The resulting grid of bed elevations was then converted back to point data that could be used compatibly with the direct ground survey data.

Where data were collected under unsteady flow conditions, the ping depth was subtracted from a transducer elevation interpolated between the two transducer positions bracketing the ping. The transducer pair to use was determined by looking up the time stamp of the ping in the time stamp list of the transducer points and interpolating a position on the basis of time differential The ping depth was subtracted from the interpolated transducer elevation to obtain a bed elevation.

Quality Control for Echosounder Data

Prior to constructing the bed files, we conducted an error analysis by comparing the bed elevations derived from echosounder data with those obtained by direct survey. We located comparable points that were within 1 m of each other and found the difference in surveyed elevations from those measured by the echosounder. The error distribution chart (fig. 4) indicated that 92 percent of the elevations derived from echo-sounding were within ±15 cm of the surveyed elevation, 78 percent were within ±10 cm, and that the errors were nearly normally distributed. Differences in elevations were related to the size of the bed materials, in that echosounders measure to the tops of the rocks, whereas the range poles used for direct surveys tend to slip into the low places between the rocks. The typical bed materials in our sites were commonly in the 20–30 cm range, so these differences were considered reasonable and acceptable. Because direct survey measurements are inherently more precise than echosounder data, however, precedence was given to surveyed data points when disparities in contoured elevations were apparent in the bed file.

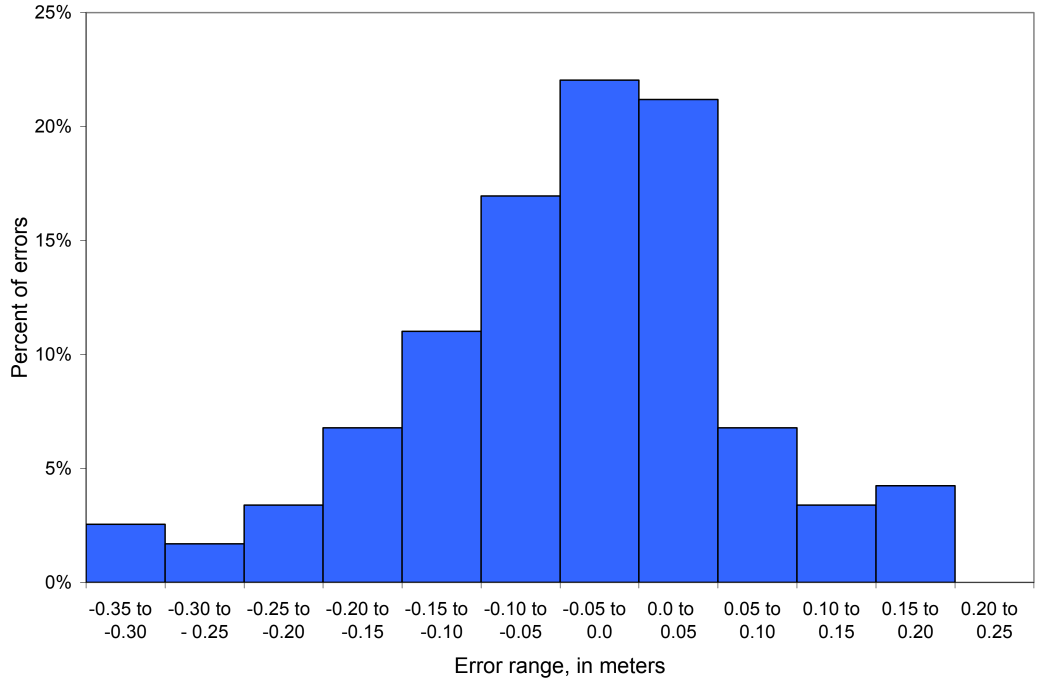

Figure 4. Error distribution of streambed elevations derived from echosounder data compared with those obtained by direct survey methods.

Bed Topography

The River2D model (Ghanem and others, 1995, 1996) was used to perform all the hydraulic simulations in this study. According to the authors of River2D (University of Alberta, 2006), "Accurate representation of the physical features of the river channel bed is probably the most crucial factor in successful river flow modeling. In addition to accurate and extensive field data, judgment and experience are necessary to connect the scattered data points into a digital surface representation." One of the components of the River2D suite of programs is a bed-topography editor, capable of rapid triangulation and contouring of point data. Generally, elevation transitions in rivers are relatively smooth (except for the toe-of-bank contour) and highly anisotropic (continuous features are aligned longitudinally in correspondence to the banks and thalweg, Turner and others, 1989). Triangulation of the raw elevation data invariably results in localized areas of sharp transitions, discontinuities of contours in continuous features, and other unrealistic geometry. By addition or deletion of points and by connecting points with breaklines, a contour is forced to override the River2D default computation. The locations and orientations of the "correct" contours were usually fairly obvious, based on DOQQ imagery we used as background, and from descriptive coding (for example, for edge-of-bank measurements) in the direct survey data. Where definitive information was unavailable, we relied on our collective experience and knowledge of each of the sites to modify contours.

Computational Mesh

The bed topography file is used in R2D_Mesh to develop a computational discretization as input to River2D. The mesh provides a template through which River2D solves for water depths and velocities. Generally speaking, larger mesh elements (less discretization) can be used in uniform or gradually-varying features, such as deep pools, and smaller elements where transitions are abrupt, such as along the edges of banks. Shallow water areas can be problematic in River2D because localized areas of super-critical flow may be computed, resulting in serious errors such as unrealistically high velocity predictions, recirculation (water running uphill), or both. In anticipation of such problems, we preemptively increased the mesh density at riffles, runs, delta areas, and over bars. As the simulation flows deviated from the calibration flow, new areas of shallow water appeared and old ones disappeared, so the mesh was revised accordingly for each run.

There is an inherent trade-off in mesh-building. The rate at which a run can be completed is a function of mesh density and mesh quality. Mesh quality refers to the degree to which the triangular mesh elements approach equilateral triangles. As mesh density and quality increase, problems with abrupt topographic changes and super-critical flow decrease (resulting in better accuracy of model predictions), but the time required for the model to converge to a stable solution can increase exponentially. Consequently, we used the fewest and highest quality mesh elements where appropriate (with at least 10 elements for each channel over 5 m wide), but increased mesh density where necessary to achieve high quality simulation runs in a reasonable amount of time.

Boundary Conditions

River2D requires the discharge at the inflow boundary and the water surface elevation at the outflow boundary as inputs for a simulation run. The boundary conditions for a study site were defined by a rating curve or table that related the stage at the outflow with the discharge at the inflow. Owing to the compact size of most of our segments, nearly all of the study sites were in close proximity to a USGS stream gage. Rating tables for appropriate gages were provided to us by the USGS New York Water Science Center located in Troy, N.Y. We translated the gage reading associated with a particular discharge with a reference water surface elevation measured at the site outflow for calibration purposes. At different simulation discharges, we determined the change in stage from the reference discharge and adjusted the outflow elevation by a like amount.

Model Calibration

Concurrent with the collection of bathymetric data, a direct-measurement survey of the water surface profile was conducted at each site. The discharge associated with the water surface profile was either determined from the USGS website for real-time discharge data, or measured in the field.

With the measured inflow discharge and the measured outflow water surface elevation as boundary conditions, River2D was run to produce a predicted water surface profile corresponding to the measured profile. Adjustments were made to the mesh where increased discretization was warranted, and the parameter for roughness height adjusted upward or downward to alter the resistance to flow provided by friction. For example, if the predicted water surface profile was uniformly lower than the measured profile, roughness height was increased. The increase in resistance caused the velocity to decrease and the depth to increase, thereby raising the elevation of the predicted water surface profile. This procedure was repeated until a reasonable match between the predicted and measured water surface profiles was obtained.

What constituted a reasonable match depended on the complexity of the profile, the elevation differential between the top of the site and the bottom, the behavior of the model during the calibration runs, and the potential error associated with individual water surface elevation measurements. In general, we attempted to match the measured water surface elevation to ±5 cm or less at all measurement points, with the goal of minimizing residuals throughout the profile. While it is possible to adjust the roughness at specific locations to match the predicted and measured water surface elevations exactly, past experiences in hydraulic modeling have demonstrated that doing so is inadvisable. Such tight calibration can introduce instabilities in the model that actually make subsequent simulations less accurate.

To avoid mathematical instabilities, we adopted the general guideline that regional adjustments to roughness height should not deviate from the site average by more that 50 percent without compelling empirical evidence to the contrary. In some cases, no amount of local roughness adjustment changed the predicted water surface elevation significantly. In several instances, the mismatch between measured and simulated elevations was associated with erroneous recording of water surface elevation (for example, miscoding a bed measurement as a water surface). Otherwise, the discrepancy was related to the conveyance area through the problem section as depicted in the bed file. When large differences (greater than 5 cm) between measured and simulated water surface elevations persisted, we first checked the quality of the measurement. If the calibration measurement was judged not to be the source of the error, we re-investigated the editing (especially breaklines) of the bed topography and modified it where changes were justified by the data. Final calibration results for all 11 sites can be found in appendix 2.

Simulation of Unmeasured Discharges

A range of simulated discharges was selected to bracket most of the discharges that would occur in the baseline or alternative hydrologic time series produced by OASIS. We constructed flow duration curves of the average daily discharges for the USGS gages associated with each of our study sites, and selected a range representing the 1 percent to 99 percent exceedance probabilities. We then applied a logarithmic sampling of this range to select 15 simulation discharges between and including these extremes. The effect of the logarithmic sampling process was to simulate discharges at closer intervals in the low end of the range, with fewer, more widely-spread discharges at the high end. For each of the simulation discharges, an outflow water surface elevation was derived using the procedure described previously under “Boundary Conditions.”

Habitat Classification

Ranges of suitable depths and velocities for each of the target species and habitat use guilds were defined (table 2) using the Delphi technique as described by Zuboy (1981). A small monitoring team devised a questionnaire that was sent out to a larger respondent group of experts. Each respondent was asked to provide his or her estimate of the maximum and minimum depths and velocities considered to be suitable for each of the target organisms and habitat use guilds. After the questionnaire was returned to the monitors, group opinion was summarized by providing the median and inter-quartile ranges of the initial responses. These estimates of group opinion were then returned to the respondents, who were asked to answer the questionnaire again in light of the new information. Anonymity of individual responses was maintained throughout this process to minimize the bandwagon effect associated with roundtable discussions. If a respondent’s second response was outside the inter-quartile range of the previous round, he or she was asked to provide a brief explanation in support of the response. These explanations were provided to the respondent group, along with the revised median and inter-quartile ranges of the responses, and the process was repeated until the group converged to a consensus of opinion or at least attained a stability in the distribution of responses.

Table 2. Suitable depth and velocity ranges for target organisms, as defined by the Delphi panel.

Target Organism	Depth Range (m)	Velocity Range (m/s)
Brown trout adult	0.3–100[1]	0.0–1.0
Brown trout juvenile	0.2–0.8	0.0–0.7
Brown trout spawning	0.2–0.6	0.3–0.81
Brown trout incubation	0.2–1.0	0.15–1.2
Rainbow trout adult	0.3–100[1]	0.0–1.2
Rainbow trout juvenile	0.2–1.0	0.0–0.8
American shad spawning	0.3–3.0	0.2–0.7
American shad juvenile	0.25–1.6	0.0–0.6
Shallow-fast guild	0.05–0.3	0.3–1.2
Shallow-slow guild[2]	0.05–0.3	0.0–0.3

[1] 100 m set to represent no effective upper limit.

[2] Includes fry for both trout and shad species.

Geographic Information System Operations

Several types of map layers and intermediate products were generated under the general heading of habitat maps. The hydraulic habitat layer consisted of a series of habitat classification polygons depicting the spatial distribution of suitable depths and velocities for each target organism at each simulated discharge. The hydraulic habitat layer was the source of metrics considered to be steady-state functions of discharge (for example, total area of adult brown trout habitat at a specific discharge). The mesohabitat layer was a spatial interpretation of larger scale habitat characteristics controlled mostly by planform and channel structure (for example, the spatial extent of riffles or pools at different discharges). Habitat persistence maps were constructed to quantify the spatial stability of habitat for brown trout spawning and incubation and for dwarf wedgemussels under conditions of unsteady flow.

The Hydraulic Habitat Layer

Output from a River2D simulation run for a particular discharge was exported as a text file containing the coordinates, depths, and velocities for each node in the computational mesh. This information was used to generate a map layer of the nodes and the attributes of depth and velocity. An interpolated surface (a Triangular Irregular Network, or TIN) was constructed for each hydraulic variable, using the nodal data as mass points. Each TIN was converted to a 0.5 m x 0.5 m grid, reclassified according to the habitat classification criteria (table 2), and the reclassified grids combined to create a single grid depicting suitable depth and velocity conditions for each target organism and guild. The composite grids were converted to polygon format and the area for each polygon was calculated. The attribute tables were exported to a spreadsheet for subsequent extraction of habitat metrics and development of the flow versus habitat lookup tables used in time series analysis.

The Mesohabitat Layer

The mesohabitat layer served two purposes in our analysis. First, this layer provided a context for the distribution of suitable hydraulic habitat within the channel. For example, several authors have suggested that habitat for young of the year fish (our shallow-slow guild) may be more valuable if located along shoreline margins than if located in the main channel where zooplankton production is lower and predation vulnerability is higher (Kwak, 1988; Freeman and others, 2001; Bowen and others, 2003a, b). The second application of the mesohabitat layer was to associate suitable spawning habitat with a specific mesohabitat type, defined as the pool tailout. Pool tailouts were identified as those portions of the channel having an adverse bed slope (the bed slope is opposite the direction of the water surface slope). This mesohabitat type occurs almost universally in the region between the deepest portion of a pool and the crest of the riffle downstream from the pool (fig. 5). Consensus among the Delphi participants, supported by visual observations of brown trout redds in the Neversink River, indicated that the pool tailout provided suitable substrates for salmonid spawning and created a favorable hyporheic environment that ensured interstitial flow through the redds during incubation.

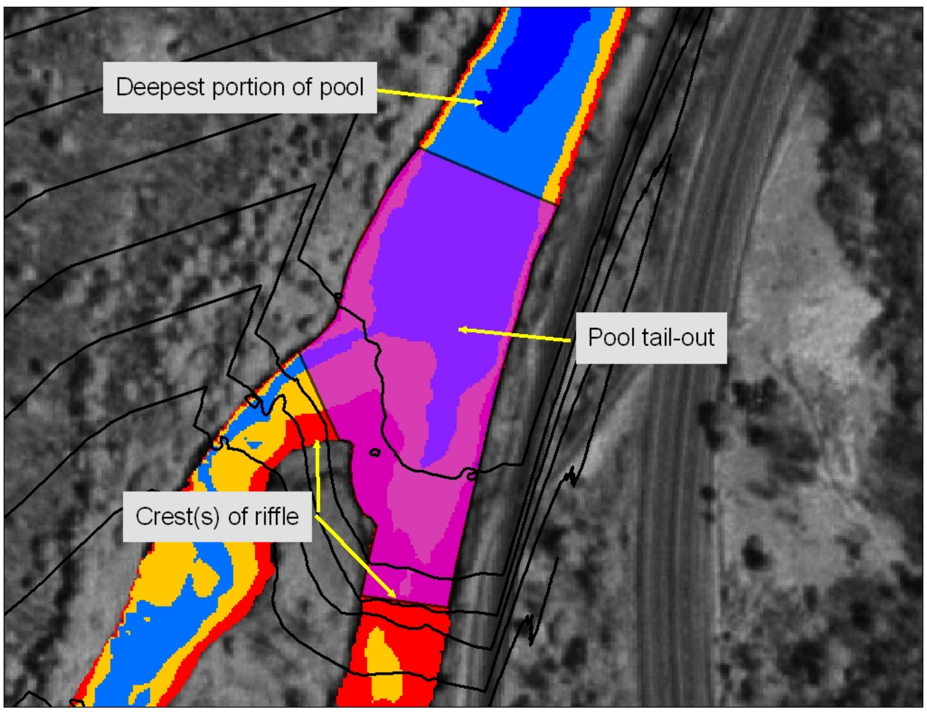

Figure 5. Digital representation of a pool tailout. Deepest portion of pool indicated by dark blue polygon and crest of riffle by compressed contours of water surface elevations.

Mesohabitat types were digitized using the water's edge contour from River2D for each of the simulated flows and 1:40,000 scale DOQQ images as templates. For the most part, we codified mesohabitat polygons using the definitions provided by Parasiewicz (2001). To ensure consistency in coding, we applied specific criteria to each of the mesohabitat types, rather than relying solely on the descriptions provided by Parasiewicz (2001). In addition, we added several mesohabitat types we considered to be potentially important, most notably the pool tailout, inundated terrestrial vegetation, and disconnected areas (table 3). The latter were included because they can either serve as refuges or as stranding areas, depending on their size and how long they persist.

Table 3. Hydromorphic units, descriptions, and codification criteria used to classify mesohabitat types.

Hydromorphic Unit	Description	Criteria
Riffle	Shallow stream reach with moderate current velocity, some surface turbulence, and high gradient. Convex streambed shape.	Water surface slope ≥ 0.002, depth <1 m.
Rapid	Higher gradient reach than a riffle with faster current velocity, coarser substrate, and more surface turbulence.	Water surface slope ≥ 0.002, depth >1 m.
Run	Deeper stream reach with moderate current velocity but no surface turbulence. Laminar flow.	0.0005< water surface slope < 0.002, depth <1 m
Fast run	Uniform fast-flowing stream channel.	0.0005< water surface slope < 0.002, Depth >1 m
Pool	Deep water impounded by a channel blockage or obstruction. Slow with concave streambed shape.	Slope <0.0005 regardless of depth.
Side arm	Channel around an island, smaller than half the width of the river.	Channel around an island, smaller than half the width of the river. Connected to river at inflow and outflow.
Backwater	Slack area along channel margins caused by eddies behind obstruction.	Standing water connected to the river only at its outflow.
Pool tailout[1]		Channel areas between deepest portions of pools and crests of riffles.
Inundated vegetation[1]		Areas containing perennial vegetation, inundated at high discharges.
Disconnected area[1]		Standing water with no surface connection to the river.

[1] Added definition. Not described by Parasiewicz (2001).

A special case of a mesohabitat treatment was our application of a shoreline buffer restriction to the calculation of habitat area for the shallow-slow habitat use guild. A 5-m shoreline buffer polygon was created around the water's edge arc at each simulated discharge. The hydraulic habitat polygons for the shallow-slow habitat use guild were intersected with the shoreline buffer polygon for each flow, resulting in polygons representing suitable hydraulic conditions within five meters of the shoreline. The attribute tables for the intersections were exported as lookup tables for subsequent use in the habitat time series analyses.

Habitat Persistence

Habitat persistence is a measure of the stability of individual habitat patches, applicable primarily to organisms with limited mobility (Bovee and others, 2004). Although habitat persistence can influence the well-being of many organisms, we confined our analysis to brown trout spawning and incubation and to patch stability for dwarf wedgemussels. The conceptual model for the spawning-incubation analysis was that trout would spawn in suitable hydraulic habitats within pool tailout areas and that hatching success would be related to the continued suitability of conditions over the redds throughout the incubation period. Incubation flows that were appreciably lower than the spawning flow could result in dewatering of redds, whereas high flows could result in their destruction by erosion. Similarly, unsteady flows can be detrimental to mussels by desiccation or stagnation at low flow and by excessive shear stress at high flow (Layzer and Madison, 1995). Whereas the effects of rates and magnitudes of change differ between spawning-incubation (measured over months) and mussels (measured over days), the process for measuring patch persistence was similar for both phenomena.

To quantify the persistence of spawning-incubation habitat we performed a multilayer intersection of the pool tailout polygons and suitable hydraulic habitat for spawning and incubation, respectively (fig. 6). Persistence of spawning patches is a time and flow dependent phenomenon. That is, for the same combination of flows, habitat persistence differs depending on whether the spawning flow was higher or lower than the incubation flow. Consequently, it was necessary to construct overlay maps for all 15 simulated spawning flows and all 15 simulated incubation flows (a 15x15 cell matrix). Areas of persistent spawning-incubation habitat were calculated in the attribute table for each composite map layer and exported to a persistence table (table 4) for subsequent use in the time series analysis.

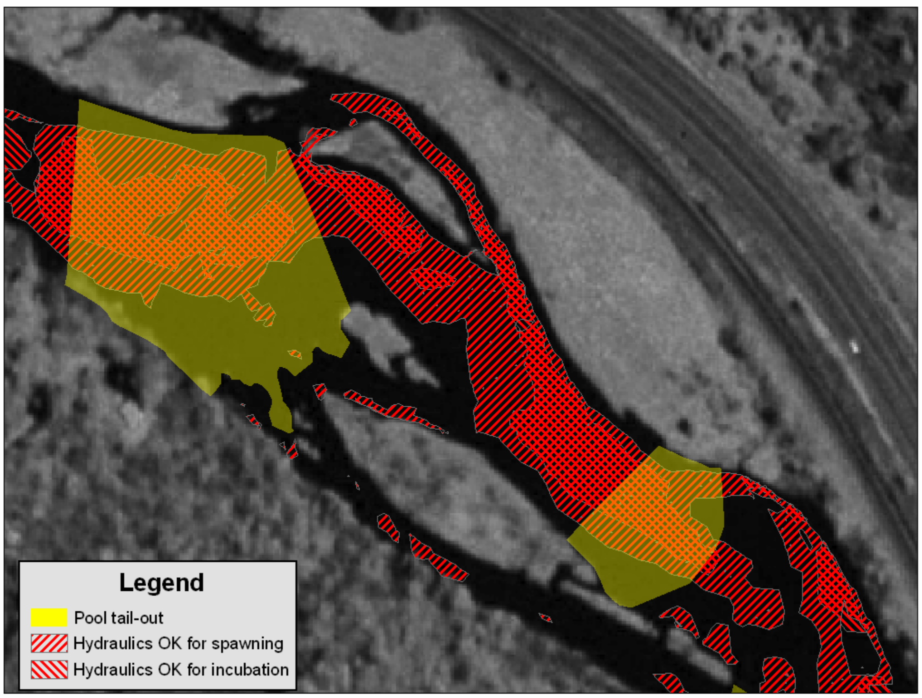

Figure 6. Illustration of a persistence map for a spawning discharge of 10 m^3/s (350 ft^3/s) and an incubation discharge of 2.5 m^3/s (88 ft^3/s).

For dwarf wedgemussels, we used surveyed mussel locations heuristically with hydraulic information generated from River2d to estimate suitable conditions for their survival. We obtained locations of individual mussels from a survey conducted in the summer of 2002 (personal communication, Dr. William Lellis, USGS Northern Appalachian Research Laboratory, Wellsboro, Pa., November 17, 2005). Overlays of low flow depths and velocities, high flow shear stresses, and mussel locations were developed to estimate the lower suitable limits of depth and velocity and the upper suitable limit for shear stress. In consultation with Dr. Lellis and his associates, and by recommendations provided by Layzer and Madison (1995), we developed the following interim habitat suitability criteria for the dwarf wedgemussel: minimum depth = 10 cm, minimum velocity = 2 cm/s, and maximum shear stress = 0.2 pound per square foot. We stress that these criteria are interim and are subject to change pending a more rigorous analysis by Dr. Lellis and others involved with dwarf wedgemussel research.

Table 4. Example of a persistence table for brown trout spawning and incubation[1].

	Spawning Discharge (ft^3/s)												
Incubation Discharge (ft^3/s)	64	88	125	177	247	353	494	706	953	1,341	1,906	2,683	3,777
64	58	59	59	59	59	59	59	59	59	59	45	23	23
88	233	482	483	483	483	483	483	483	483	483	405	107	80
125	493	862	1,153	1,152	1,153	1,152	1,153	1,153	1,153	1,152	933	280	192
177	1,077	1,606	2,095	2,530	2,530	2,530	2,532	2,531	2,531	2,530	2,242	844	420
247	1,505	2,661	3,403	3,979	4,603	4,600	4,602	4,602	4,601	4,598	4,300	2,063	695
353	1,422	2,647	3,952	4,838	5,705	6,645	6,643	6,645	6,642	6,632	6,338	3,851	1,381
494	1,266	2,421	3,767	5,381	6,888	8,172	9,044	9,043	9,041	9,028	8,742	6,143	3,329
706	849	1,844	2,978	4,550	6,127	7,791	8,939	9,644	9,640	9,625	9,506	7,002	4,438
953	411	932	1521	2,614	3,758	5,195	6,413	7,276	7,608	7,593	7,590	6,481	4,515
1,341	120	263	410	686	1,217	2,114	2,992	3,834	4,260	4,298	4,295	4,275	3,483
1,906	0	0	1	21	71	212	512	1,020	1,336	1,405	1,429	1,429	1,369
2,683	0	0	0	0	0	0	1	76	191	236	257	262	260
3,777	0	0	0	0	0	0	0	0	2	3	8	12	13

[1]To read table 4, find the row representing the spawning flow and the column representing the incubation flow. The normalized persistent habitat (expressed as m^2 of suitable habitat per kilometer of stream) is listed in the cell of intersection. For example, a spawning flow of 350 ft^3/s and an incubation flow of 177 ft^3/s yields a persistent habitat value of 2,530 m^2 per kilometer, shaded gray.

We used these criteria to develop polygons of suitable mussel habitat patches for each simulated flow using the same techniques for hydraulic habitat mapping described previously. We then conducted paired-flow polygon intersections for all combinations of simulated flows. This procedure was similar to the one used for spawning-incubation persistence, with the following exceptions:

1. A “mussel bed” mesohabitat polygon was digitized to encompass the general region of mussel locations from the 2002 survey, rather than using individual sightings. This polygon functioned in a manner similar to the pool tailout for spawning-incubation, but was more restrictive in that it applied only to known mussel beds.
2. Because mussels exhibit some mobility, the order of flows is less an issue for mussels than for spawning and incubation. Although the magnitude of change is important to both, the rate of change is more important for mussel survival. Consequently, we developed simple paired-flow (7x15 rather than 15x15) persistence tables for dwarf wedgemussels. In contrast, the analysis of short-term rates of change was considerably more sophisticated for mussels than for spawning-incubation (discussed in the section on habitat time series).

Temperature Analysis

Previous methods for predicting temperatures in the upper Delaware system have relied on a set of nomograms that had a tendency to overestimate the volume of water necessary to support thermal requirements at specific downstream locations. The goal of our analysis was to test alternative approaches to temperature predictions as potential replacements for the currently-employed nomograms. The test objectives included the determination of historical data sufficiency, calibration of the model, and validation to objective standards.

The upper Delaware study area was divided into two parts. The first portion included the West and East Branches from their respective reservoirs to their confluence at Hancock, and approximately 40 km (25 miles) downstream to Callicoon, N.Y. This portion included the Beaverkill upstream to the USGS gaging station at Cooks Falls, N.Y. The second portion included the Neversink River from the reservoir approximately 27 km (17 miles) to Bridgeville, N.Y.

Model Selection

The Stream Network Temperature model (SNTEMP; Theurer and others, 1984) was chosen for our initial investigations. This is a well-tested model, though most use has been in the western United States. The model has proven especially robust in predicting mean daily water temperatures. SNTEMP is normally capable of predicting mean daily water temperatures ±0.5°C (0.9°F), and almost always to within 1°C (1.8°F), depending on the quality of the input data (Bartholow, 1989). In addition, SNTEMP is far less demanding than many other models in terms of data requirements.

SNTEMP was an appropriate model to test for this application because of its public domain status and support. The model was readily available, as was its source code, allowing modification as necessary. In addition, a considerable body of material was available for technology transfer, including documentation (Theurer and others, 1984), self-paced learning material (Bartholow, 2000) and background on data collection techniques (Bartholow, 1989).

In spite of this model's advantages, there were also some potential disadvantages. One data input item, "percent possible sun" or cloud cover, is no longer regularly collected by National Climatic Data Center stations and often requires additional effort to estimate. Also, the model assumes steady state hydrologic conditions, which might signal problems when abrupt changes to reservoir releases or short term rainfall-driven runoff events occur. Though none of the existing reservoirs has a peaking power release, they can and do spill. The SNTEMP model is not a reservoir water temperature model, and requires reservoir release temperature estimates as a boundary condition. The model operates on a daily time step under steady-state conditions. Consequently, the maximum extent of the study area should typically be no more than one day's travel time from the furthest upstream point to the furthest downstream point. This constraint can be compromised, but with some degradation in predictive power.

Data Gathering and Synthesis

Data gathering generally followed guidelines presented in Bartholow (1989). There are three broad categories of data required by SNTEMP: meteorological data, hydrologic data, and stream geometry data. Measured water temperature data were also required to perform an objective model calibration and validation.

Representative meteorological data included air temperature, wind speed, relative humidity, percent possible sun (cloud cover), and solar radiation. In addition, the elevation of the meteorological station must be known. On occasion, it is advantageous to use data from more than one meteorological station to enable cross checking for data outliers, filling missing values, or creating composite sets that might better represent the whole watershed. Table 5 lists the major meteorological stations evaluated for this project. Hydrologic data included the best estimates of streamflow throughout the basin. There appeared to be 14 gages with a useful complement of data, including long-term water temperature data (table 6).

Table 5. Summary of available meteorology data.

Location	Source	Period of Record
Binghamton	NCDC[1]	May 1, 1994—Sept. 30, 2004
Monticello	NCDC[1]	May 1, 1994—Sept. 30, 2004
Stonykill	MesoWest	May 1, 2003—Sept. 30, 2004
Sherburne	MesoWest	May 1, 2003—Sept. 30, 2004

[1]National Climatological Data Center.

Table 6. U. S. Geological Survey discharge gages in the upper Delaware River study sites with four or more years of temperature data.

Gage Number	Name	Period of Record	Water Temperature Data?
1417000	East Branch Delaware River at Downsville, N.Y.	July 1, 1941—Sept. 30, 2003	No
1417500	East Branch Delaware River at Harvard, N.Y.	Oct. 1, 1934—Sept. 30, 2003	Yes
1420500	Beaverkill at Cooks Falls, N.Y.	July 25, 1913—Sept. 30, 2003	Yes
1420980	East Branch Delaware River above Read Creek at Fishs Eddy, N.Y.	Nov. 19, 1912—Sept. 30, 2003	Yes
1421000	East Branch Delaware River at Fishs Eddy, N.Y.	Nov. 19, 1912—Sept. 30, 2001	No
1425000	West Branch Delaware River at Stilesville, N.Y.	July 1, 1952—Sept. 30, 2003	Yes
1426000	Oquaga Creek at Deposit, N.Y.	Oct. 1, 1940—Sept. 30, 1973	No
1426500	West Branch Delaware River at Hale Eddy, N.Y.	Nov. 15, 1912—Sept. 30, 2003	Yes
1427405	Delaware River near Callicoon, N.Y.	Aug. 25, 1967—July 8, 1975	No
1427500	Callicoon Creek at Callicoon, N.Y.	Oct. 1, 1940—Sept. 30, 1982	No
1427510	Delaware River at Callicoon, N.Y.	June 27, 1975—Sept. 30, 2003	Yes
1436000	Neversink River at Neversink, N.Y.	Oct. 1, 1941—Sept. 30, 2003	No
1436500	Neversink River at Woodbourne, N.Y.	Oct. 21, 1937—Sept. 30, 1993	No
1436690	Neversink River at Bridgeville, N.Y.	Oct. 1, 1992—Sept. 30, 2003	Yes

Each of the rivers was partitioned into discrete segments according to aspect (direction of flow from the north-south axis). Channel geometry data for each segment included reach length, aspect, latitude, elevation, wetted width as a function of discharge, and Manning's roughness coefficient. Stream widths were generally characterized as power functions (for example, w=aQ^b) where the terms a and b were determined by regression of widths and discharges obtained from the River2D simulations.

The topographic elevation (the angle from the middle of the river to the average ridge line) was determined using the MapTech Terrain Navigator software and data base for New York. This software is composed of scanned 1:24,000 topographic maps that overlay a 10-m Digital Elevation Model (DEM). For each segment, a profile line perpendicular to the azimuth of the channel was constructed. The visual horizon was then estimated from the DEM and the distance from the river and the elevation change to the horizon calculated. The topographic altitude angle was calculated from these measurements. Riparian vegetative shading was estimated for the same river segments. Unlike topography, estimated vegetative characteristics of tree height, crown diameter, and leaf density were relatively uniform throughout the various river basins. Differences occurred principally in the relative continuity of trees along each bank and their offset from the river's edge. Field measurements, supplemented by the digital 1:24,000 topographic maps, aided the development of segment-by-segment riparian shading estimates.

Measured water temperature data were derived from existing USGS water quality gaging stations (see table 6) as well as New York Department of Environmental Conservation measurements. Reservoir release temperature data were taken from the most upstream site available on each of the three rivers. Groundwater accretion was estimated by prorated mass balance between gaging stations and temperatures were approximated by mean annual air temperature adjusted for elevation.

Quality Assurance/Quality Control

Large compilations of data must be scrutinized for data quality. Water temperature or other data may contain spurious values that must be culled from the database. Few strictly objective measures exist for examining every data value, but obvious outliers were eliminated from each data set. Missing data were generated for meteorological, hydrological data, and estimates of release temperatures using station-to-station regressions.

Potential errors in measured water temperatures were evaluated by comparison of data collected at the same location from two independent sources. We compared data collected by USGS and the Department of Environmental Conservation for the Harvard site for 1997—1999 and they agreed very well. Median absolute differences between the two were 0.3°C (0.5°F) for mean daily temperatures and 0.2°C (0.4°F) for the maximum daily temperatures (n=316). Some of the differences may be explained by the minimum resolution of the data. USGS data were reported to the nearest 0.5°C, whereas the Department of Environmental Conservation data were reported to the nearest 0.1°C.

Initial Model Simulations

SNTEMP models for both the Neversink River, and the Delaware network (East Branch-West Branch-Delaware main stem) were run with data available for the summers of 1997 through 1999, May 1 through September 30. We determined that the models performed best using meteorological data from Monticello, N.Y.

With current data limitations, but without calibration, the Neversink model performed passably. The correlation between predicted and measured values was relatively high (r=0.84), the mean error was 0.12°C, and the probable error 1.16°C . Initial model runs for the Delaware network showed that model performance was adversely affected by large amounts of missing data at some river locations. Although the correlation between measured and simulated temperatures was higher (r=0.89), so were the mean error (0.55°C) and the probable error (1.23°C). Maximum errors were -7.23°C in the Delaware network and -5.88°C on the Neversink River. These errors appear to be directly attributable to missing Monticello meteorological data and do not necessarily reflect on the model's overall predictive ability.

Model Calibration

Well-formulated temperature models with high quality input data require little or no calibration. Data are always limited to some degree, however. The ability of meteorological data to truly represent conditions at and along extensive stretches of a river is a universal problem. The goal of model calibration is to simultaneously minimize bias and error while maximizing correlation. Typical calibration criteria include: (1) near-zero bias, (2) 50 percent of the errors in mean daily temperatures less than 0.5°C, (3) absolute maximum errors under 4°C, and (4) overall model correlation greater than r=0.9. Criteria for maximum daily temperatures would be similar. The general philosophy in model calibration is to vary the least well-known input values within a representative range to maximize the model's goodness-of-fit.

Mean daily water temperatures were the initial focus of model calibration. Once mean daily temperature predictions were as accurate as possible, the focus shifted to maximum daily water temperatures. Calibration of maximum temperatures was accomplished via several empirical coefficients that account for heat gained over and above the daily average, depending on hydrologic and meteorological conditions.

An extensive analysis was made of the potential sources of model error by correlating many of the model inputs or calculated values with the model's residuals. Because of the preponderance of wide, shallow pools on these rivers, air temperature and relative humidity might tend to dominate the thermal response rate when discharge was low. However, only air temperature was marginally statistically significant in both models. Discharge was also a statistically significant contributor to model error on the Neversink River, a result that may have been attributable solely to outlying points that represented spills or rainstorms rather than more "normal" reservoir release conditions.

Development of Statistical Models

The accuracy of the SNTEMP models did not universally meet our initial calibration criteria. For this reason, we developed purely statistical models for several important locations throughout the two networks as a possible alternative to SNTEMP. Although somewhat less flexible in predicting temperatures at unmeasured locations, statistical models might correct for systematic biases in the SNTEMP models that we were unable to eliminate otherwise.

According to Theurer and others (1984), there are several forms of regression models that appear to provide a high degree of correlation in predicting stream temperatures, at least for "natural" conditions. They range from simple harmonic models:

$$T_w = T_{avg} + \Delta T_0 \cdot \cos[(2\pi/365)(D\mathrm{i} - P)] \qquad (1)$$

Where T_w = estimated water temperature (mean or maximum),
T_{avg} = average water temperature over all observations,
T_0 = half the initial temperature range over all observations,
D_i = Julian day number for day i, and
P = Phase delay in timing of the maximum seasonal temperature.

to polynomial models:

$$T_w = a_o + a_1T_a + a_2W + a_3R + a_4S + a_5H + a_6Q + a_7T_a^2 + a_8W^2 + a_9R^2 + a_{10}S^2 + a_{11}H^2 + a_{12}Q^2 \qquad (2)$$

where T_w = estimated water temperature (mean or maximum),
T_a = air temperature (maximum or mean),
W = wind speed,
R = relative humidity,
S = percent possible sun (cloud cover),

H = maximum possible solar radiation for the latitude and time of year, and
Q = discharge

to models that incorporate, at least to some degree, the physics of heat flux and heat transport. After a considerable amount of trial and error, we settled on a general regression model of the form:

$$T_w = k + a_1T_a + a_2T_a^2 + a_3H + a_4W + a_5S + a_6Q_1 + a_7(Q_2\text{-}Q_1) + a_9YT_w \qquad (3)$$

where T_w = the estimated water temperature,
T_a = air temperature,
H = relative humidity,
W = wind speed,
Q_1 = the discharge at the temperature node,
$(Q_2\text{-}Q_1)$ = the upstream to downstream accretion volume, and
YT_w = "yesterday's temperature estimate."

Though initially derived using standard minimization of residuals, final regressions were adjusted by weighting each daily squared residual by its dependent water temperature. This step was done because our experiments had shown that regressions of this type often tended to underestimate high water temperatures. The weighting served to improve the fit of the regressions at high temperatures.

Model Selection for the DRDSS

As a matter of operational efficiency, we selected the multivariate statistical model (equation 3) for use in the DRDSS. Use of SNTEMP as a data source for the DRDSS would have required generating the system hydrology in OASIS as input to SNTEMP, and then running the temperature model for each scenario to be tested. The advantage of the statistical model was that the meteorological data and model parameters could be incorporated directly into the DRDSS, along with hydrologic information from OASIS, to produce daily predicted temperatures of the same general accuracy as those produced by SNTEMP. Whereas SNTEMP can be used in the absence of calibration water temperatures, however, these data are necessary to calibrate the statistical model. Sufficient water temperature data for this purpose were not available for the Neversink River, so temperature simulations for that river were not included in the prototype version of the DRDSS.

A second disconnect in the scenarios generated for the DRDSS was that the meteorological records available for use in equation 3 extended only from 1994–2004 whereas the period of record for the hydrologic time series was from 1977–2003. We considered several options for matching the periods of record, including the generation of a stochastic meteorological series to use as input to equation 3, irrespective of the period of record. We also considered simple repetition of the meteorological data series as necessary to fill in all the dates in the hydrologic series. After weighing the advantages and disadvantages of the various models, we determined that using actual meteorological data from an actual period of record was preferable to the stochastic model. Consequently, the DRDSS contains three options for meteorological data. The first is the simple repetition model, which is basically a copy and paste of the existing record over previous decades. The second option is to use "normal" meteorological conditions for each day, calculated as the average air temperature, humidity, cloud cover, and wind speed from the 10-year period of record. The third option is a "worst case" meteorological scenario, developed as a combination of daily maximum air temperature, humidity, and wind speed, and minimum cloud cover. Although none of the options is completely realistic, in combination they can provide a range of “expectable” water temperatures for different water management scenarios and meteorological conditions.

Time Series Generation and Summarization

The structure of the DRDSS requires baseline and alternative management scenarios (or two competing alternatives), typically derived by changing the operating rules for one or more of the reservoirs in the OASIS model. Management scenarios translate into changes in flow regime, reservoir storage, temperature, habitat suitability, and other decision variables. DRDSS scores are based on the amount of change each decision variable exhibits between the alternative and the baseline over a specified time period.

Habitat Time Series and Metrics

The habitat time series is the fundamental building block for quantifying the effect of an alternative on the habitat for a target organism (Bovee and others, 1998). Construction of a habitat time series (fig. 7) is relatively straight-forward, requiring two essential components: a time series of discharges (either baseline or alternative) and a relationship between discharge and habitat area. Units of habitat can be expressed as the actual area of habitat within the study site (m^2), normalized habitat area expressed as an area per unit length of stream (m^2/km), or as total habitat (in hectares) for the entire segment, calculated by multiplying the normalized habitat area by the length of the segment. The third option was preferred by the Subcommittee and the Commission, so habitat areas in the DRDSS were expressed accordingly.

For every discharge in the flow series, there is a corresponding habitat value from the discharge-habitat function. Assembling a time series of habitat is merely a matter of translating the discharges for each time step (hours, days, weeks) into their associated habitat values and recording the translated values back to the time step.

Hydroperiods and Habitat Persistence

The year was divided into three hydroperiods, representing distinct hydrologic and biological conditions: October 1–April 15 (spawning/incubation period for brown trout), April 16–June 30 (emergence of young of the year fish), and July 1–September 30 (summer growing season). The October–April hydroperiod was further subdivided to quantify habitat persistence for brown trout spawning and incubation. October and November were considered the spawning months, and incubation was designated for the period from December 1 through April 15. Habitat time series as shown in figure 7 were constructed for pertinent target organisms for each hydroperiod, with the exception of habitat persistence for brown trout spawning-incubation and for dwarf wedgemussels.

We selected a spawning discharge to be used as input to the persistence table by calculating a trimmed mean discharge based on the central 60 percent of the flows for the months of October and November for each year to represent a “typical” discharge that would have occurred during spawning. Because habitat persistence is a function of the difference between the spawning flow and the incubation flow, we found the maximum and minimum discharges occurring between December 1 and April 15 to determine the persistent habitat areas for both combinations of spawning and incubation flow-pairs. The smaller of the two areas was then retained as the spawning-incubation value for a given year. The habitat time series for spawning-incubation was thus constructed as an annual series of these least-area values.

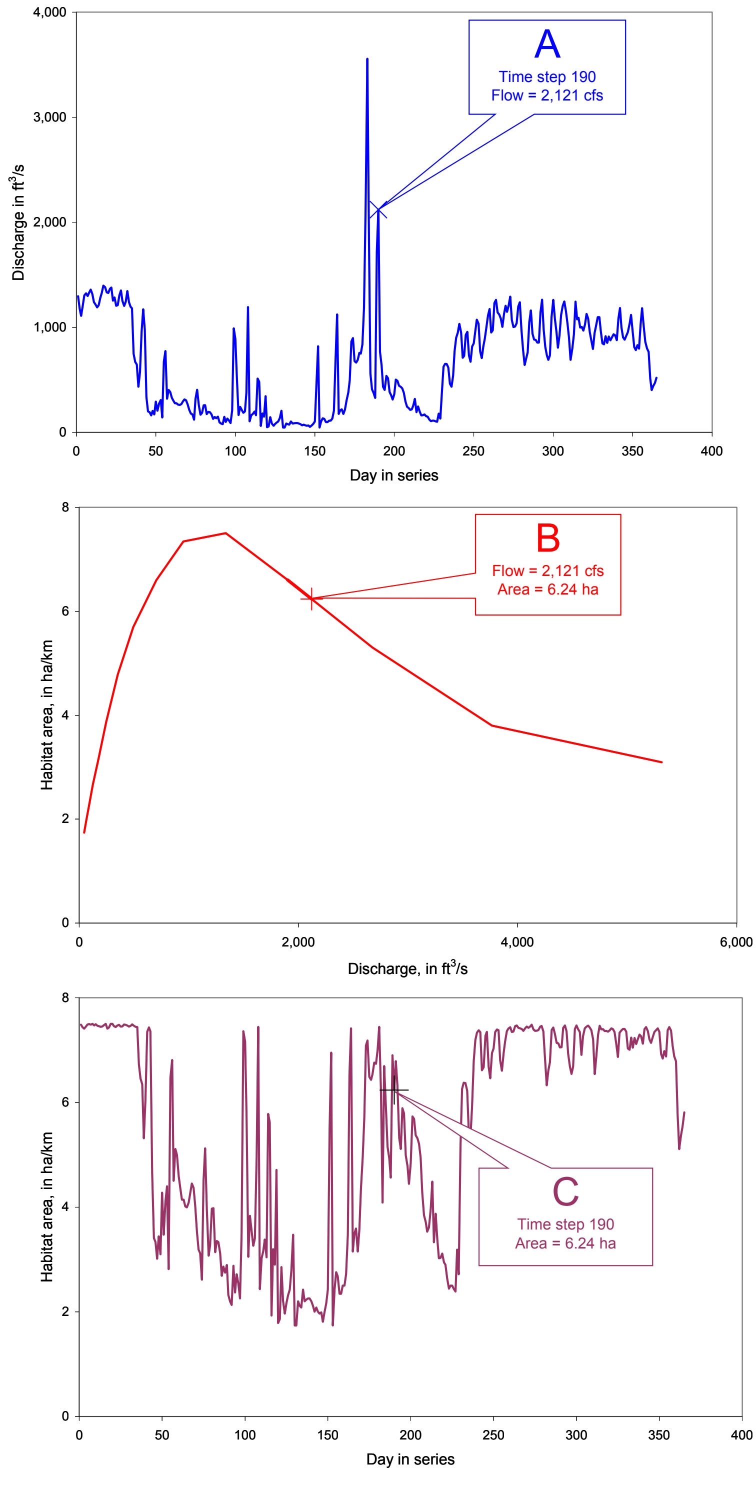

Figure 7. Elements used in the construction of a habitat time series: *A*, flow time series, *B*, flow versus habitat function, and *C*, the resulting habitat time series.

Habitat persistence for the dwarf wedgemussel differed from spawning-incubation in two significant ways. First, dwarf wedgemussels reside in the system year-round, rather than being confined to a single hydroperiod. Second, spawning-incubation persistence is primarily affected by the maximum differential between the spawning flow and the limiting incubation flow, regardless of the time interval between the two events. Dwarf wedgemussels are much more sensitive to rapid changes in flow, as they have the capacity to move to suitable habitat if the change is slow enough. To mimic this phenomenon, we conducted a search of the daily flows for each hydroperiod to find the largest flow differential over any consecutive five-day period. The maximum and minimum flows associated with this flow differential were then selected as the two flows to input to the persistence table for each hydroperiod, for each year.

Habitat Duration Statistics

Comparisons of baseline versus habitat time series plots or data may be qualitatively informative, but not very useful for quantification of potentially limiting events. There is a general consensus that the most likely habitat limitations for a life stage or species occur during periods when habitat is restricted (Bovee and others, 1998). These habitat bottlenecks are defined by episodes when the habitat value falls below the median of the habitat time series. More restrictive definitions of limiting events can be applied, and in the case of the DRDSS, we used the average of the lowest 25 percent of the habitat values in the time series as the criterion for comparison.

The determination of the cut-off point for any quartile or probability in a habitat time series is based on the concept of the habitat duration curve. Such curves were constructed for baseline and alternative conditions by the following method:

1. Habitat time series for each target organism and hydroperiod were sorted from highest to lowest and assigned a rank.
2. The probability that any particular habitat value would be equaled or exceeded was calculated as:

$$P = r/(n+1) \tag{4}$$

Where P = the probability that a value in the series will be equaled or exceeded,
r is the rank of the sorted data, and
n is the number of values in the series.

For comparative purposes in the DRDSS, the average of the lowest 25 percent of the values in the series was calculated and retained as the habitat metric for the series representing baseline and alternative scenarios, respectively. This metric was chosen for two specific reasons. First, biological populations tend to be limited during periods when resources (including space) are most restricted (Nehring and Anderson, 1993; Bovee and others, 1994). These values represent a compilation of the potentially limiting habitat events associated with either series. Second, the metric is a special case of a trimmed mean that removes the possibility that an increased occurrence of large values could offset an increased occurrence of small values. In essence, this combination could be worse from a biological perspective, but the average for the two series could be the same, indicating no impact.

Habitat Duration Series

This variation of the habitat duration concept is used to illustrate daily variability in a time series. In essence, the habitat duration series is a box-and-whisker plot for every day in the year.

The habitat duration series plot (fig. 8) was constructed by sorting the data hierarchically by month and day in ascending order, and magnitude of habitat in descending order. Probabilities of exceedance were calculated for each day using equation 4, and the lowest 25 percent of the values for baseline and alternative were plotted. Baseline habitat values in figure 8 are depicted as a light blue band. The solid lines on figure 8 represent the boundaries for the lowest-quartile habitat values for the alternative.

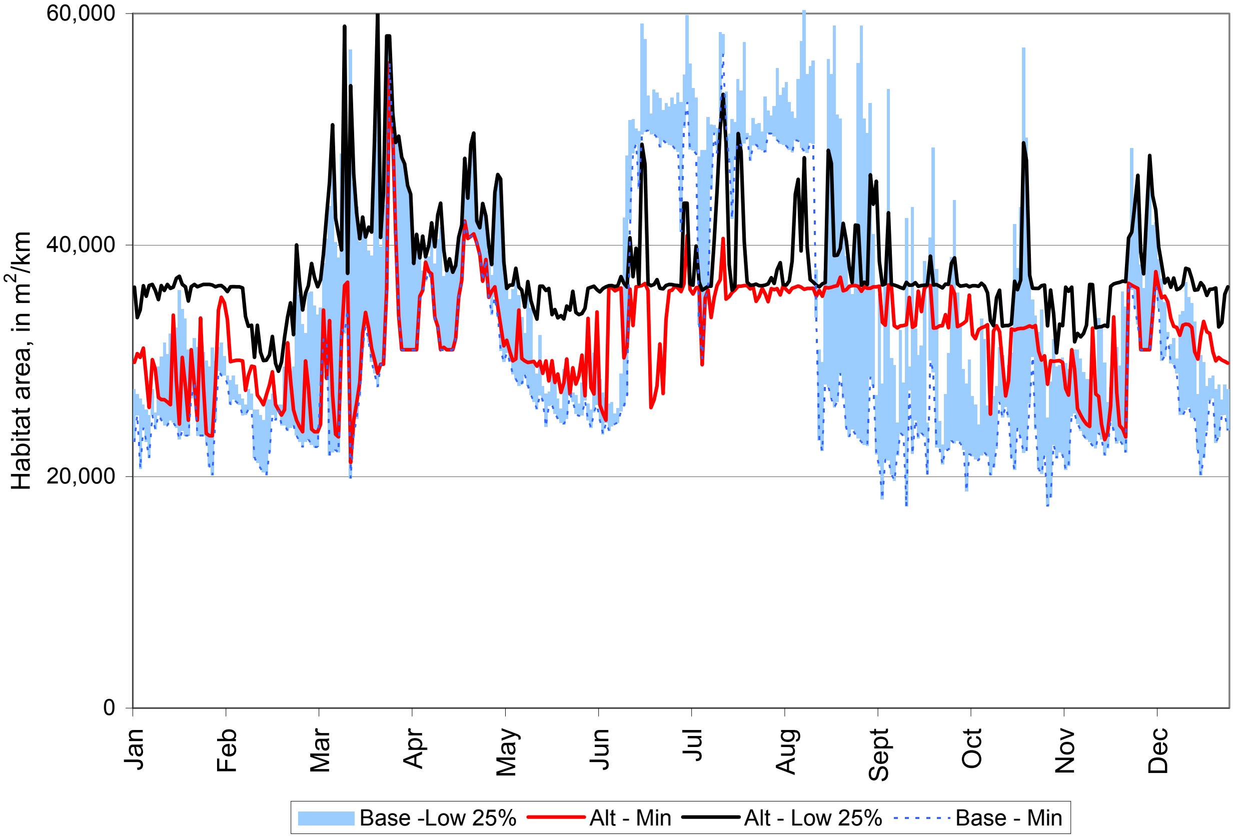

Figure 8. Comparison of habitat duration series for baseline and alternative scenarios.

The purpose of presenting information in this format is to allow decisionmakers to check for potentially adverse habitat conditions that might be masked by aggregation and summarization. The scoring metric derived from the habitat duration curve is an average from several month's data. It is possible to increase the metric during part of the hydroperiod and reduce it during another part, resulting in no change to the average. An example of this phenomenon can be seen in figure 8 during the months of July and August. For much of July, the light blue band for the baseline appears above the red and black quartile boundaries for the alternative. During August, the pattern is reversed. Compared to the baseline, the magnitude of the lowest 25 percent of the habitat events was reduced during July but elevated during August under the alternative scenario. Although the average of this metric over both months might show little or no difference between the baseline and alternative, the duration series plot indicates that this conclusion would not be entirely correct from a biological perspective.

Structure and Functions of the DRDSS

A prototype DRDSS (Version 1.0) was developed for presentation to the Commission and Subcommittee in October 2005. Version 1.0 was intended to have operational functionality (input data would provide real results) but not operational efficiency. Its primary purpose was to demonstrate the organization of the DRDSS and its use as a decisionmaking tool. During the developmental stages of the DRDSS, an Excel® spreadsheet was used as the computational platform. The advantages of this format were that changes could be made rapidly and transparently. The disadvantages were that the spreadsheets were very large (>160 MB), cumbersome to modify, and not portable to routinely available computers (required 2 GB of RAM and 3.0 MHz processor or better). However, given the volatility of earlier versions of the DRDSS, we believed that the advantages outweighed the disadvantages. Owing to the size of the files and slow turn-around on runs, however, Version 1.0 provided information only for a limited number of sites (7), and a small, fixed number of flows (10 years).

As a result of the October meeting and subsequent discussions with the Commission and Subcommittee, a number of revisions were suggested for a more operational Version 2.0. This version involved improvements in operational efficiency, expansion of capability to all study sites, and a more extensive set of decision variables and scoring mechanisms. Minor modifications have been made to version 2.0 as a result of extensive beta-testing performed by members of the Commission and Subcommittee, as well as debugging and quality assurance testing within the USGS Fort Collins Science Center. The current version (2.11) operates identically to version 2.0, but owing to the modifications, results from comparable runs using the two versions will deviate slightly from one another.

Structure and Organization

One of the most noticeable changes from Version 1.0 to Version 2.11 is that all the calculations in Version 1.0 were done in a single, very large spreadsheet. Version 2.11 is organized differently, having a master spreadsheet (DSS_AGG.xls) and four subsidiary spreadsheets (henceforth referred to as SUBS) for each of the river segments (DSS_WB, DSS_EB, DSS_DEL, and DSS_NVR). Reformatted output from OASIS, selected meteorological data, and user-supplied parameters are entered directly to the master spreadsheet, but the calculations for each of the decision variables occurs in the SUBS (fig. 9). Results from all the computations in the SUBS are then returned to the master spreadsheet, both as a whole system summary, and as segment-specific raw scores. Thus, the user can review the overall system response to an alternative, and also examine the details about each segment.

Functionality

The DRDSS requires as input two continuous (no days or flows missing) streams of daily flows for each of the identified study sites. One data set is for a baseline case and the other for an alternative. These data are derived from the OASIS model. Scoring comparisons are made for changes in habitat characteristics for pertinent target species and guilds, water temperature characteristics, spill and reservoir storage, and water deliveries and exports.

Habitat Time Series Metrics

Two types of habitat area calculations are used in the DRDSS. The first type is defined as “instantaneous habitat,” derived from the hydroperiod habitat time series and habitat duration statistics. This is the habitat area for a target species that occurs at a specific discharge, with no consideration of antecedent or subsequent discharges in the series. The second type is based on a time series of persistent habitat, where antecedent or subsequent discharges are directly accounted for in the calculation of the habitat metric. Habitat persistence analyses were performed for trout spawning-incubation and dwarf wedgemussel habitat only.

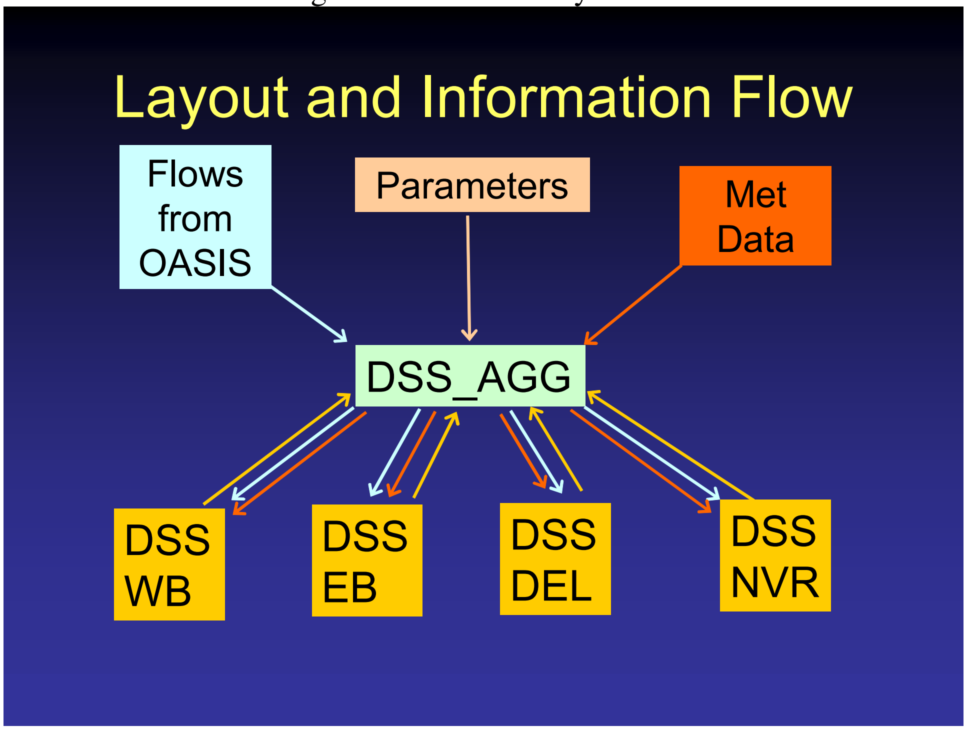

Figure 9. Layout and information flow in DRDSS Version 2.11. Blue arrows indicate the pathways for hydrologic data, orange arrows indicate temperature-related information, and gold arrows are for habitat metrics returned from each site to the master spreadsheet. The tan arrow represents user-supplied options that select different computational algorithms and scoring criteria. DSS_AGG; master spreadsheet. DSS_WB, DSS_EB, DSS_DEL, DSS_NVR; subsidiary spreadsheets for the West Branch, East Branch, Delaware main stem, and Neversink River, respectively.

Temperature

Water temperature was calculated using equation 3 with meteorological data from the Monticello weather station and streamflow data from OASIS as inputs. Temperatures were calculated only from May 1 to September 30. Three sets of meteorological data, as described in the section “Model Selection for the DRDSS” can be found in a separate database, met_data.xls. The first set of meteorological input data consists of a replication of the Monticello data to corresponding days for the period of record 1954–2003 (for example, May 1, 1954, has the same meteorological data as May 1, 1993; May 1, 1955, is the same as May 1, 1994; and so forth). The two sets of pseudometrological data (normal and worst-case) for the 50 year period 1953–2003 contained in the met_data.xls file are repetitive (for example, each May 1 has the same data).

Temperature is accounted for in two separate places in the DRDSS scoring summary. First, the number of days when temperatures exceed the specified thresholds are counted for the baseline and alternative conditions, with scores reported as percent change (in day counts), change in the number of days, and change in degree-days. Threshold temperatures can be adjusted by the DRDSS operator for each river segment on the page labeled “Parameters.” The second reference to temperature is defined as "Temperature-conditioned habitat." If temperature in a given segment exceeds the temperature threshold on a particular day, the habitat value for that day is set to zero. The zero-habitat days are then included in a time series analysis following the same protocols explained above for steady-flow habitat.

Spills

Spills are calculated as the difference between the discharge measured immediately downstream from a dam and the outlet capacity of the dam. If the discharge in the tailwater exceeds the outlet capacity, then a spill has occurred by definition. The severity of the spill is calculated as the proportion of the total flow in the tailwater that is attributable to the spill. There are three default levels of spill intensity. If the spill accounts for 10 percent or less of the tailwater discharge, it is considered minor. If it accounts for 50 percent or more of the discharge, it is considered major. Spills between 10 and 50 percent of the total discharge are considered moderate. Thresholds for each class of spill intensity can be adjusted by the user on the "Parameters" page. Spills are counted by hydroperiod for each category, and scores are reported as percent changes and as day-counts.

Storage Volume

Reservoir storage volume and triggers representing drought watch, drought warning, and drought are obtained directly from the OASIS model. Scores are derived by computing the number of days that reservoir storage fell into one of the three drought categories under the baseline and the alternative. Scores are reported as a percent change in the number of days within each drought category, and also as the difference in days counted in each category.

Montague Deliveries

Delivery of Decree flows at Montague is calculated in the OASIS model for both the baseline and alternative operations. Scoring of Montague deliveries is based on the number of days under each scenario when the specified delivery is not met. Delivery targets are variable, depending on system water supply, and the rules determining the targets are coded into OASIS. Three scoring criteria are used on the summary page of the DRDSS. A minor violation is scored if the delivery is less than 10 percent below the target, and a major violation is recorded if the delivery is more than 50 percent below the target. Moderate violations are recorded for deliveries between 10 and 50 percent below target. Scores are recorded as percent change in frequency of violations within each category and also as the actual change in frequency.

Out of System Deliveries

Similar to the scoring for Montague, deliveries to New York City and to the diversion at the Delaware-Raritan (D& R) Canal near Trenton, N.J., are calculated in OASIS, as are the delivery targets. In both cases, scoring is reported as both percentage and frequency. The defaults for minor, moderate, and major shortages are the same as for the Montague targets, and the classification criteria are likewise user-adjustable.

DRDSS Output and Displays

Decision support systems can be developed in a bewildering array of styles, functions, and purposes. The philosophy guiding our development of the DRDSS was that it should concisely display the consequences of a management alternative to a wide array of competing resource values, yet should be sufficiently transparent to allow diagnosis of causes and effects. The following sections describe some of the tabular and graphical outputs that are produced by the DRDSS, and how they can be accessed. For full user documentation, the reader is referred to appendix 5.

The Summary Scoring Page

The summary scoring page is the second page in the DSS_AGG.xls master spreadsheet, but is generally the initial focal point when reviewing the outcome of a scenario run. Figure 10 shows the layout and some of the features associated with the scoring summary.

Delaware DSS	**Run Date:**	**11/06/06**	**Start date**		**End date**
Provisional Version 2.11	**Baseline:**	**Rev1**	**10/1/1990**	**to**	**9/29/2000**
Summary	**Alternative:**	**Rev 7**	**10/1/1990**	**to**	**9/29/2000**

October - April 15

Resource	West Branch Pct Chg	West Branch Δ Hab	West Branch Pct Chg	West Branch ΔTCondHab	East Branch Pct Chg	East Branch Δ Hab	East Branch Pct Chg	East Branch ΔTCondHab
Trout Adult, ha	21%	13.50			8%	12.31		
Trout Spawning/Incu, ha	91%	2.39			3%	0.10		
SSCV, ha	8%	1.11			-9%	**-2.54**		
SFCV, ha	52%	2.44			41%	1.04		
Shad Juvenile, ha								
Shad Spawning, ha								
Dwarf Wedge Mussel, ha								
Spills, minor, count	-6%	-1.00			14%	**1.00**		
Spills, moderate, count	13%	**2.00**			15%	**2.00**		
Spills, major, count	-13%	-2.00			-14%	-4.00		

Resource	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon Δ Hab	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon ΔTCondHab	Neversink Pct Chg	Neversink Δ Hab	Neversink Pct Chg	Neversink ΔTCondHab
Trout Adult, ha	2%	7.80			16%	13.42		
Trout Spawning/Incu, ha	1%	0.06			155%	4.79		
SSCV, ha	0%	0.04			18%	3.83		
SFCV, ha	1%	0.02			27%	3.79		
Shad Juvenile, ha								
Shad Spawning, ha								
Dwarf Wedge Mussel, ha	3%	0.08						
Spills, minor, count					0%	**Base, Alt =0**		
Spills, moderate, count					-17%	-1.00		
Spills, major, count					0%	0.00		

April 16 - June

Resource	West Branch Pct Chg	West Branch Δ Hab	West Branch Pct Chg	West Branch ΔTCondHab	East Branch Pct Chg	East Branch Δ Hab	East Branch Pct Chg	East Branch ΔTCondHab
Trout Adult, ha	16%	11.47	16%	11.41	4%	6.77	4%	6.84
Trout Spawning/Incu, ha								
SSCV, ha	2%	0.24	2%	0.24	-4%	**-0.84**	-3%	**-0.77**
SFCV, ha	11%	0.40	11%	0.40	8%	0.24	8%	0.24
Shad Juvenile, ha								
Shad Spawning, ha					16%	5.50	16%	5.50
Dwarf Wedge Mussel, ha								
Spills, minor, count	0%	0.00			14%	**1.00**		
Spills, moderate, count	0%	0.00			-21%	-8.00		
Spills, major, count	0%	0.00			-5%	-2.00		

Resource	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon Δ Hab	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon ΔTCondHab	Neversink Pct Chg	Neversink Δ Hab	Neversink Pct Chg	Neversink ΔTCondHab
Trout Adult, ha	1%	3.25	1%	2.50	13%	11.57		
Trout Spawning/Incu, ha								
SSCV, ha	0%	0.02	0%	**0.00**	24%	4.43		
SFCV, ha	0%	0.02	0%	0.01	16%	2.34		
Shad Juvenile, ha								
Shad Spawning, ha	5%	6.50	4%	6.10	55%	7.86		
Dwarf Wedge Mussel, ha	0%	**-0.02**						
Spills, minor, count					0%	0.00		
Spills, moderate, count					-50%	-1.00		
Spills, major, count					-10%	-2.00		

July - September

Resource	West Branch Pct Chg	West Branch Δ Hab	West Branch Pct Chg	West Branch ΔTCondHab	East Branch Pct Chg	East Branch Δ Hab	East Branch Pct Chg	East Branch ΔTCondHab
Trout Adult, ha	-2%	**-1.45**	-2%	**-1.45**	16%	23.40	16%	22.86
Trout Spawning/Incu, ha								
SSCV, ha	22%	3.06	22%	3.06	-10%	**-3.29**	-10%	**-3.27**
SFCV, ha	85%	5.19	85%	5.19	-4%	**-0.72**	-4%	**-0.71**
Shad Juvenile, ha					9%	7.48	9%	7.48
Shad Spawning, ha								
Dwarf Wedge Mussel, ha								
Spills, minor, count	0%	**Base, Alt =0**			0%	**Base, Alt =0**		
Spills, moderate, count	0%	0.00			0%	0.00		
Spills, major, count	0%	**Base, Alt =0**			0%	0.00		

Resource	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon Δ Hab	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon ΔTCondHab	Neversink Pct Chg	Neversink Δ Hab	Neversink Pct Chg	Neversink ΔTCondHab
Trout Adult, ha	-1%	**-2.52**	-2%	**-7.48**	37%	30.01		
Trout Spawning/Incu, ha								
SSCV, ha	2%	0.80	1%	0.44	43%	10.85		
SFCV, ha	11%	1.50	10%	1.38	42%	7.08		
Shad Juvenile, ha	1%	2.11	-1%	**-1.59**	17%	7.00		
Shad Spawning, ha								
Dwarf Wedge Mussel, ha	-5%	**-0.34**						
Spills, minor, count					-50%	-1.00		
Spills, moderate, count					100%	**1.00**		
Spills, major, count					0%	0.00		

Full Period Scores

	West Branch Pct Chg	West Branch Δ Days	West Branch Pct Chg	West Branch ΔDegDays	East Branch Pct Chg	East Branch Δ Days	East Branch Pct Chg	East Branch ΔDegDays
Δ Days > Threshold C	0%	0.00	-2%	-0.14	0%	0.00	-1%	-0.13

	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon Δ Days	Main Hancock-Callicoon Pct Chg	Main Hancock-Callicoon ΔDegDays	Neversink Pct Chg	Neversink Δ Days	Neversink Pct Chg	Neversink ΔDegDays
Δ Days > Threshold C	150%	**6.00**	399%	**4.97**				

Global Scores

Montague Flow	Pct Chg	Δ Days	**Out of System Deliveries**	Pct Chg	Δ Days
Montague, minor shortage	-27%	-113.00	NYC, minor shortage	0%	0.00
Montague, moderate shortage	-22%	-19.00	NYC, moderate shortage	0%	**Base, Alt =0**
Montague, major shortage	0%	**Base, Alt =0**	NYC, major shortage	0%	**Base, Alt =0**
Montague, cfs-days	-24%	-12464.00	New York City, bg	0%	Base, Alt =0
System Drought	Pct Chg	Δ Days		Pct Chg	Δ Days
Days at Level 1	-22%	-92.00	NJ, minor shortage	0%	0.00
Days at Level 2	39%	**89.00**	NJ, moderate shortage	0%	**Base, Alt =0**
Days at Level 3	0%	**Base, Alt =0**	NJ, major shortage	0%	**Base, Alt =0**
			New Jersey, bg	0%	Base, Alt =0
System Storage, bg	0%	-2358.70			

Run Settings

Maximum Water Temperature	West Branch	20	New York Diversion Magnitude	Mild	10
(degrees C)	East Branch	20	(% minimum delivery)	Major	50
	Main Stem	25			
	Neversink	20	New York Diversion Magnitude	Mild	10
			(% minimum delivery)	Major	50
Spill Magnitude	Mild, <	10			
(% outflow capacity)	Major, >	50	Meterological Series		Actual
Montague Shortage Magnitude	Mild, <	10			
(% minimum flow)	Major, >	50			

Figure 10. Layout of the scoring summary page in the DRDSS.

The header lines at the top of the page contain information regarding the dates of the run, the names of the baseline and the alternative used in the OASIS run, and the period of record used in the time series analyses. The top portion of the scoring summary reports the habitat time series outcomes of the scenario for each of the target organisms of concern. This section of the report is divided in rows by hydroperiod, arrayed in blocks from hydroperiod 1 to hydroperiod 3, and in columns by major river system. From left to right, information is provided for the West Branch, East Branch, Delaware mainstem, and Neversink River. Biological decision variables and resources of concern are listed in the first column and repeated for each hydroperiod.

The cells in the summary page are conditionally formatted such that the cell background turns green if the scenario results in an improvement for a decision variable and red if it results in a decrement. In this portion of the summary, a change in a decision variable of less than 10 percent (±) was considered to be undetectable, so the cells do not change color unless the habitat metric changes by an amount greater than 10 percent. Some of the cells have grey backgrounds, which indicate that the decision variable is not applicable for that cell. For example, American shad do not inhabit the West Branch, and temperature conditioning of habitat was not performed for hydroperiod 1, so these cells all have grey backgrounds.

Also included in the upper portion of the scoring sheet are three rows of scores for spills, divided among hydroperiods and river components. The conditional formatting of these cells is different from that used to score changes in habitat. First, spills are tracked by magnitude and defined as minor, moderate, or major. The percentages refer to the proportion of spills in each category occurring under the two alternatives being compared. By definition, spills were considered to be undesirable, so any scenario that increases their frequency by 10 percent or more results in a red background. Conversely, if the scenario results in a 10 percent or greater decrease in the frequency of spills, the scoring cell turns green. The cell retains a white background if the change in frequency is less than 10 percent in either direction.

Figure 11 shows an expanded view of the biological resources and spills scores for the West and East Branches for hydroperiods 1 and 2. The various target species and guilds are shown listed under "Resource" in the leftmost column. Four columns appear for each resource under the header for the river system. Columns labeled "PctChg" contain the percentage change in the metric, whether change in habitat area or spill frequency. Columns labeled " Δ Hab" refer to the change in habitat area in hectares for the entire river reach. This metric is based on the prorated sum of the calculated habitat areas for all the segments in the reach. Columns labeled " Δ TCondHab" refer to changes in temperature-conditioned habitat area.

The lower portion of the summary page (fig. 12) contains "full period" and "global" variables. These include items such as the number of days when temperature thresholds were exceeded; violations of the delivery targets for Montague, New York City, and the D & R diversion; and changes in the frequency of drought warning and drought events caused by changes in system reservoir storage. Violations of temperature thresholds are considered full period rather than global because they are recorded separately by river component, but for the entire summer (hydroperiods 2 and 3) instead of each hydroperiod. Otherwise, the conditional formatting for this variable is the same as for spills. If the frequency of violations increases by more than 10 percent the cell turns red and if it decreases by more than 10 percent it turns green.

Delaware DSS	**Run Date:**	**11/06/06**
Provisional Version 2.11	**Baseline:**	**Rev1**
Summary	**Alternative:**	**Rev 7**

October - April 15

Resource	**West Branch** Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	**East Branch** Pct Chg	Δ Hab	Pct Chg	ΔTCondHab
Trout Adult, ha	21%	13.50			8%	12.31		
Trout Spawning/Incu, ha	91%	2.39			3%	0.10		
SSCV, ha	8%	1.11			-9%	**-2.54**		
SFCV, ha	52%	2.44			41%	1.04		
Shad Juvenile, ha								
Shad Spawning, ha								
Dwarf Wedge Mussel, ha								
Spills, minor, count	-6%	-1.00			14%	**1.00**		
Spills, moderate, count	13%	**2.00**			15%	**2.00**		
Spills, major, count	-13%	-2.00			-14%	-4.00		

April 16 - June

Resource	West Branch Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	East Branch Pct Chg	Δ Hab	Pct Chg	ΔTCondHab
Trout Adult, ha	16%	11.47	16%	11.41	4%	6.77	4%	6.84
Trout Spawning/Incu, ha								
SSCV, ha	2%	0.24	2%	0.24	-4%	**-0.84**	-3%	**-0.77**
SFCV, ha	11%	0.40	11%	0.40	8%	0.24	8%	0.24
Shad Juvenile, ha								
Shad Spawning, ha					16%	5.50	16%	5.50
Dwarf Wedge Mussel, ha								
Spills, minor, count	0%	0.00			14%	**1.00**		
Spills, moderate, count	0%	0.00			-21%	-8.00		
Spills, major, count	0%	0.00			-5%	-2.00		

Figure 11. Expanded view of the scoring summary page, showing details of the scores and metrics for biological resources and spills in the DRDSS.

Full Period Scores

	West Branch Pct Chg	Δ Days	Pct Chg	ΔDegDays	East Branch Pct Chg	Δ Days	Pct Chg
Δ Days > Threshold C	0%	0.00	-2%	-0.14	0%	0.00	-1%

Global Scores

Montague Flow	Pct Chg	Δ Days	**Out of System Deliveries**	Pct Chg	Δ Days
Montague, minor shortage	-27%	-113.00	NYC, minor shortage	0%	0.00
Montague, moderate shortage	-22%	-19.00	NYC, moderate shortage	0%	**Base, Alt =0**
Montague, major shortage	0%	**Base, Alt =0**	NYC, major shortage	0%	**Base, Alt =0**
Montague, cfs-days	-24%	-12464.00	New York City, bg	0%	Base, Alt =0
System Drought	Pct Chg	Δ Days		Pct Chg	Δ Days
Days at Level 1	-22%	-92.00	NJ, minor shortage	0%	0.00
Days at Level 2	39%	**89.00**	NJ, moderate shortage	0%	**Base, Alt =0**
Days at Level 3	0%	**Base, Alt =0**	NJ, major shortage	0%	**Base, Alt =0**
			New Jersey, bg	0%	Base, Alt =0
System Storage, bg	0%	-2358.70			

Figure 12. Expanded view of the scoring summary page, showing details of the scores and metrics for the full period and global resources in the DRDSS.

Delivery targets and deliveries for Montague, New York City, and the D&R canal are reported daily from OASIS and are input directly into the DRDSS (on the "Flows" page). The DRDSS records the number of days under baseline and alternative when the delivery was less than the target. These shortages are then classified according to severity (minor, moderate, or major) using criteria similar to those applied to spills. The defaults are ≤10 percent, 10 to 50 percent not inclusive, and ≥50 percent for each classification, respectively, but can be changed by the user to impose more- or less-restrictive definitions of severity.

The system drought component tracks daily reservoir storage and records the number of times that total volume drops below the rule curves for drought watch (Level 1), drought warning (Level 2) or drought (Level 3). Like data for deliveries, this information is generated by OASIS and is imported directly into the DRDSS. Scoring for this component is nearly identical to that used for delivery targets, except that the criteria for the defaults (≤10 percent, 10–50 percent not inclusive, ≥50 percent) cannot be changed.

The column headers in figure 12 are fairly self-explanatory and follow labeling nomenclature similar to that described for the river-specific metrics. A primary difference is the column labeled "Δ DegDays," which refers to the difference in degree-days between the two alternatives. Degree days are calculated as the sum of temperatures greater than the threshold for all the days in the time series. Dividing "Δ DegDays" by the term "Δ Days" provides the average magnitude of the temperature change (unless Δ Days = 0).

The Raw Scores Page

The raw scores page (fig. 13) is the third page in the DSS_AGG.xls master workbook. The layout and format of this page is similar to the summary page, but information is provided at the segment level, rather than at the whole-river scale. Aside from being segment-specific, the raw scores page displays total segment habitat areas for the baseline and scenario, with and without temperature conditioning.

Delaware DSS — **RunDate:** 11/06/06
Provisional Version 2.11 — **Baseline:** Rev1 — 10/01/90
Resource Scores — **Alternative:** Rev 7 — 10/01/90

By Study Site
Hydro Period

October - April 15

Resource	WB0 No Termperature adjustment Base	Scenario	% Change	WB0 Termperature adjustment Base	Scenario	% Change	WB1 No Termperature adjustment Base	Scenario	% Change	WB1 Termperature adjustment Base	Scenario	% Change
Trout Adult, sq m	2967	5357	81%	2967	5357	81%	27001	32373	20%	27001	32373	20%
Trout Spawning/Incu, sq m	0	27	26655%				1117	2134	91%			
SSCV, sq m	5358	6000	12%	5358	6000	12%	5083	5450	7%	5083	5450	7%
SFCV, sq m	384	2458	539%	384	2458	539%	1950	2646	36%	1950	2646	36%
Shad Juvenile, sq m												
Shad Spawning, sq m												
Dwarf Wedge Mussel, sq m												
Δ Days > Threshold												

April 16 - June

Resource	WB0 Base	Scenario	% Change	WB0 Base	Scenario	% Change	WB1 Base	Scenario	% Change	WB1 Base	Scenario	% Change
Trout Adult, sq m	5848	6850	17%	5413	6277	16%	28979	33712	16%	28979	33712	16%
Trout Spawning/Incu, sq m												
SSCV, sq m	4259	4516	6%	4004	4254	6%	4527	4589	1%	4527	4589	1%
SFCV, sq m	2304	2759	20%	2138	2587	21%	1196	1293	8%	1196	1293	8%
Shad Juvenile, sq m												
Shad Spawning, sq m												
Dwarf Wedge Mussel, sq m												
Δ Days > Threshold	12	12	0%				0	0	0%			

July - September

Resource	WB0 Base	Scenario	% Change	WB0 Base	Scenario	% Change	WB1 Base	Scenario	% Change	WB1 Base	Scenario	% Change
Trout Adult, sq m	15563	13183	-15%	15563	13183	-15%	36282	36057	-1%	36282	36057	-1%
Trout Spawning/Incu, sq m												
SSCV, sq m	4565	5457	20%	4565	5457	20%	5304	6465	22%	5304	6465	22%
SFCV, sq m	3800	4521	19%	3800	4521	19%	1974	4070	106%	1974	4070	106%
Shad Juvenile, sq m												
Shad Spawning, sq m												
Dwarf Wedge Mussel, sq m												
Δ Days > Threshold	0	0	0%				0	0	0%			

Figure 13. Expanded view of the "Raw scores" page showing details of the segment-specific scores and metrics for habitat and temperature decision variables.

Flow and Storage Time Series Graphics

Time series plots of segment discharges and reservoir storage (fig. 14) can be found on the "FlowPlots" page of the DSS_AGG.xls master spreadsheet. These plots show the hydrologic outcomes of an OASIS run chronologically, comparing the baseline (dark blue) with the alternative (pink). The plots can be scrolled horizontally to examine selected portions of the record. These charts are useful in determining what really happened in OASIS as opposed to what the alternative was intended to do. When such disparities occur, they provide insights into the mechanics of implementing an alternative and may help link the means with the desired ends. Flow and storage time series are also valuable during interpretation and diagnosis of habitat time series results.

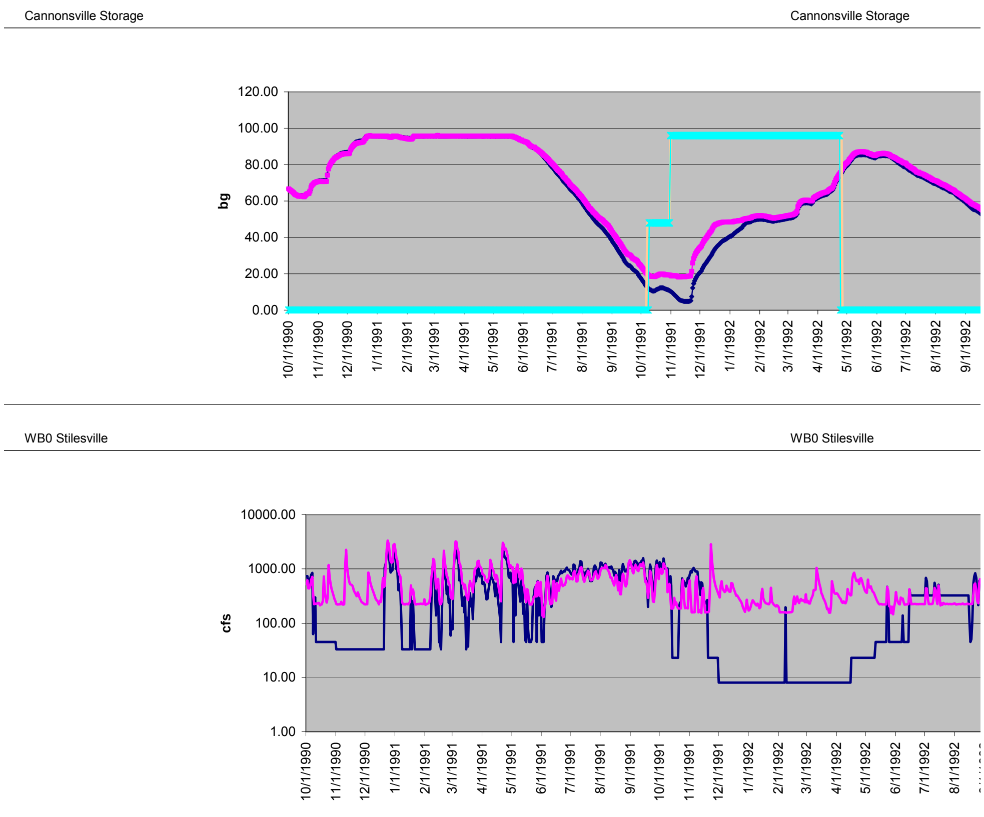

Figure 14. Time series of daily storage volumes and segment discharges from the "FlowPlots" page of the DSS_AGG.xls master spreadsheet.

Flow, Temperature, and Storage Duration Curves

Duration curves are commonly used to consolidate large masses of time series data, such as illustrated in figure 14, into a concise graphical form. Rather than depicting time series events chronologically, they are displayed as a cumulative probability function (fig. 15). Construction of a duration curve follows the same procedure described for "habitat duration statistics" except that daily flows, temperatures, or storage volumes are plotted instead of habitat areas. These curves are not restricted to the lowest quartile, but show the entire probability distribution. However, the Y-axis scaling can be changed to magnify portions of the curve that might be of greater interest, such as the low flow portion of a hydrograph.

The duration curves and the mechanisms for drawing them are located on the segment-specific SUBS workbooks. The variables and sites for which the duration plot are generated are selected on the page entitled “<site_name>DurCurve” as illustrated in figure 16. Drop-down menus of variables and sites are made available by clicking on the green activator buttons, and individual variables and sites selected by highlighting them. When the purple button is activated, the chart (fig. 15, for example) on the “DurCurveChart” page is automatically updated. An important distinction between this application and the chronological time series plots is that individual duration curve plots are not saved but change each time they are updated. Therefore, it is necessary to print each graph or save it to a separate file as it is generated if the information is to be saved for later reference.

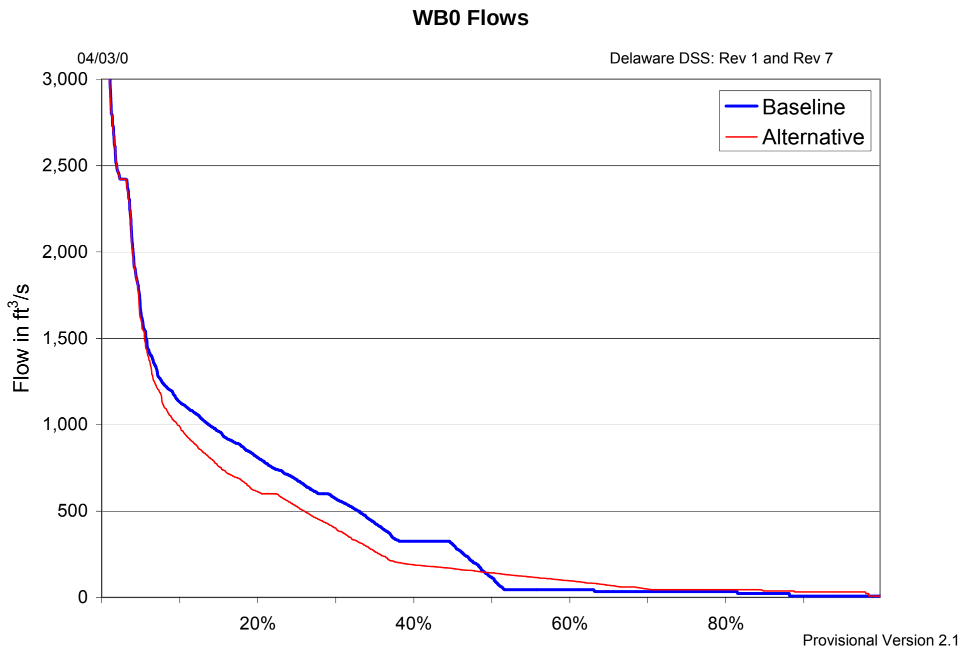

Figure 15. Example flow duration curves for site WB0. The Y-axis was truncated at 3,000 cubic feet per second in order to amplify the differences in the lower flow range.

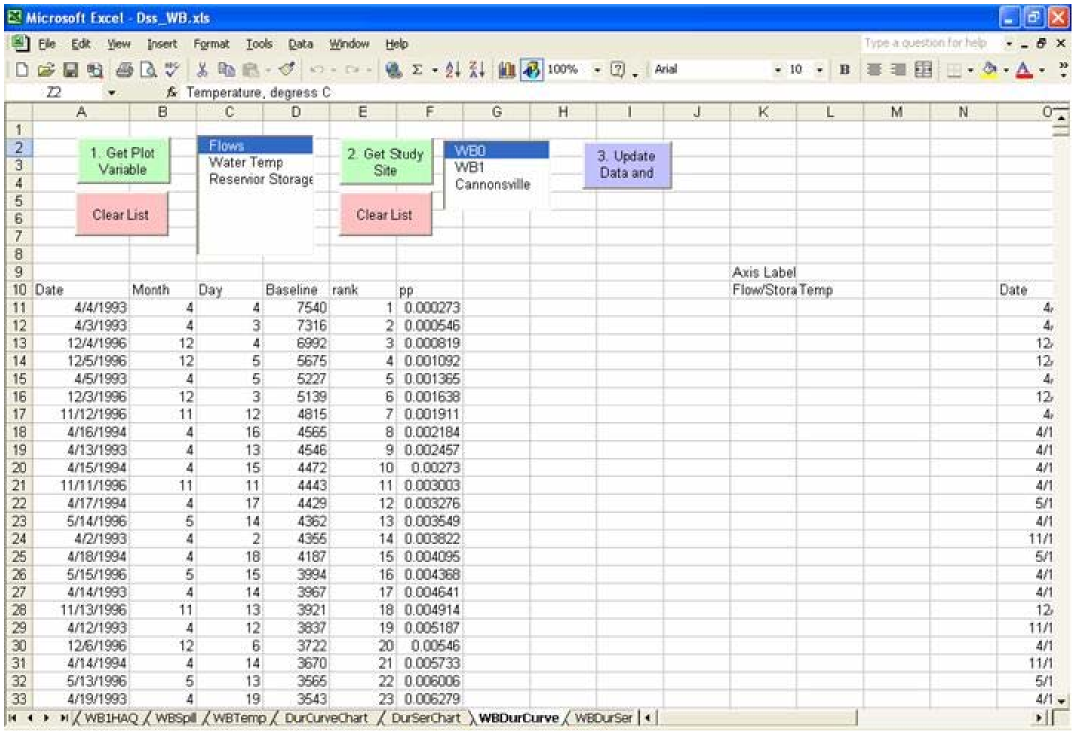

Figure 16. The "DurCurve" page of one of the subsidiary workbooks of the DRDSS, showing locations and functions of control buttons used to update a duration chart.

Habitat Duration Series Graphics

Habitat duration series charts are also site-specific and generated for only one habitat or flow variable at a time. Like the duration curves, these charts and their drivers are located in each of the SUBS workbooks under the pages entitled "DurSerChart" and "<site name>DurSer," respectively. The target resource (either habitat for one of the target organisms or the flow) and the segment can be selected from dropdown menus in the "DurSer" pages (fig. 17). The period of record is predefined by the period extracted from OASIS, but the number of leap days in the record must be specified on this page. Leap days are eliminated, but the program must be able to find them in the record. Selection of the variable and site follows the same general procedure described for the duration charts, but the user can specify whether the habitat duration series are temperature-conditioned (button 4). Button 5 (Update Duration) activates a macro that re-sorts the data. Once the duration series has been updated, button 6 (Update Chart) activates a macro that re-draws the graph on the "DurSerChart" page (see fig. 8, for example). Like the duration curves, these graphs are not saved automatically. Users are advised to copy and export graphs before each update.

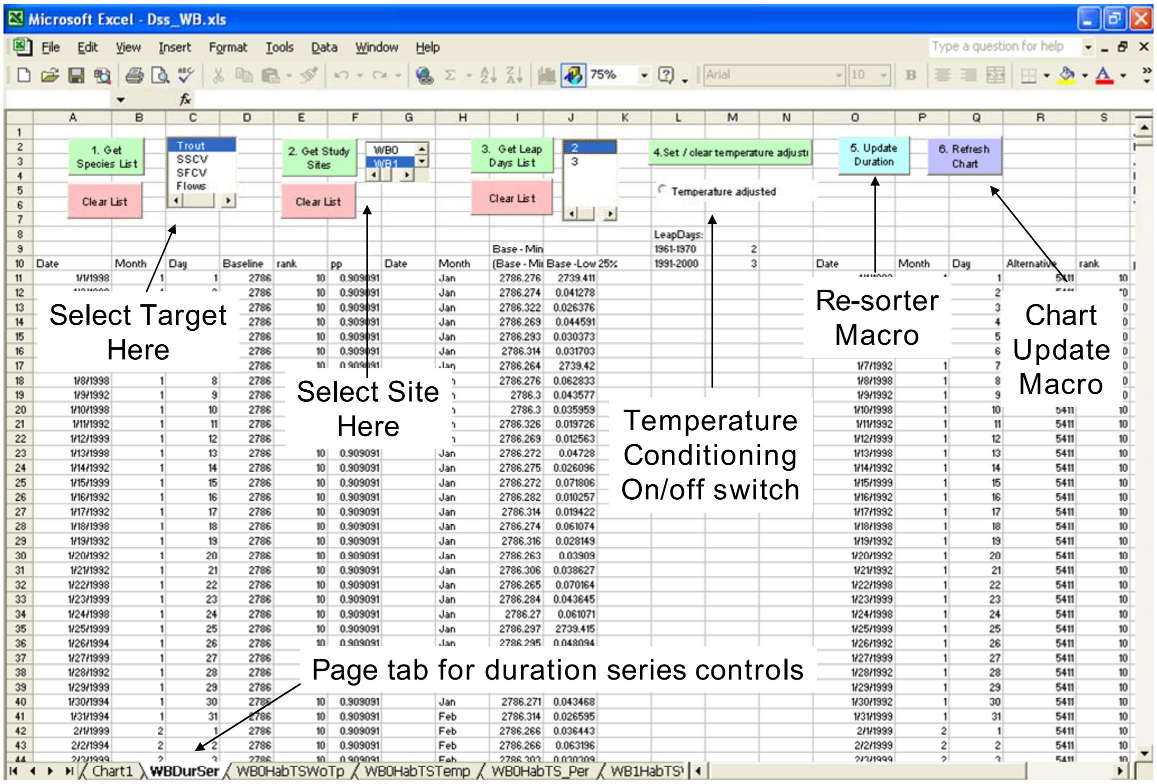

Figure 17. The "DurSer" page of one of the subsidiary workbooks of the DRDSS, showing locations and functions of control buttons used to update a duration series chart.

Results

Habitat Versus Discharge Functions

There are several ways to express the habitat versus discharge functions extracted from the map data. The discharges used to derive the habitat time series represent the average daily flows that would have occurred in a specific segment under baseline and alternative operating scenarios. This expression is necessary for generation of the habitat time series, but some form of normalized discharge may be more useful for comparing the habitat versus flow functions among the various sites. Similarly, habitat can be expressed as a total area for the segment or normalized for comparison. Discharge was expressed as segment-specific mean daily discharge and as "unit discharge," calculated as cubic meters per second per square mile of drainage. Habitat areas are expressed as both normalized area (ha/km) and as total area for the segment (ha). Conversion constants for each of the study segments are summarized in table 7, and habitat versus flow statistics are presented in appendix 3.

Table 7. Conversion constants and normalizing terms by segment.

Segment	Length (km)	Drainage area (mi^2)
WB0	3.9	456
WB1	23.2	595
EB0	12.2	372
EB1	15.1	458
EB2	25.6	784
DEL1	14.9	1,590
DEL2	17.1	1,668
DEL3	11.7	1,820
NVR0	12.9	113
NVR1	26	171
NVR2	23.7	307

Shallow-slow habitat types were maximized at the lowest range of flows, with peak areas occurring around 0.1 to 0.3 cubic feet per second per square mile (fig. 18). Shallow-fast habitat types were also maximized at relatively low flows (fig. 19), but not as low as shallow-slow habitat types. At discharges less than 0.3 cubic feet per second per square mile, water velocities tend to be too low to be suitable for this guild, but at discharges greater than 0.6 cubic feet per second per square mile, depths become too large to be considered "shallow."

Habitat areas for juvenile trout (fig. 20) and juvenile American shad (fig. 21) behaved similarly with respect to discharge, both showing an increase in area at discharges up to about 0.6 cubic feet per second per square mile and then declining at discharges greater than 0.9 cubic feet per second per square mile. Habitat areas for adult trout (fig. 22) and American shad spawning (fig. 23) also show similar patterns, but are shifted slightly to the right on the discharge axis, reflecting a preference for deeper and faster water than juveniles as indicated in Table 2. Habitat areas for these two target organisms were maximized in the range of about 1–3 cubic feet per second per square mile. In all cases, depths are too shallow for discharges below the peaks of the curves and velocities are too high at discharges above the peaks.

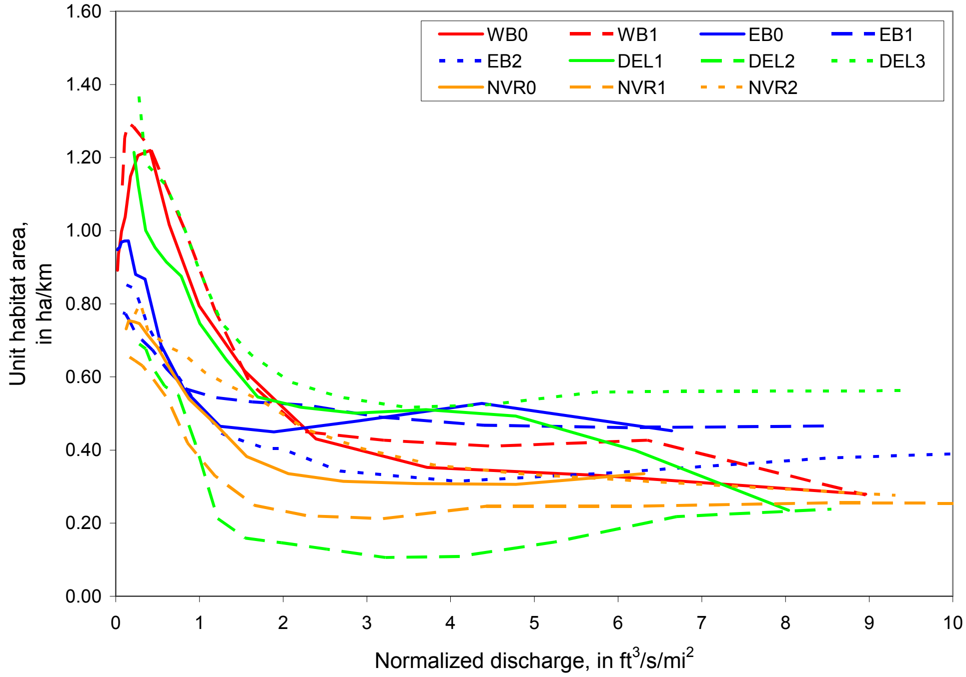

Figure 18. Normalized discharge versus unit habitat areas for the shallow-slow current velocity guild at 11 sites in the upper Delaware River.

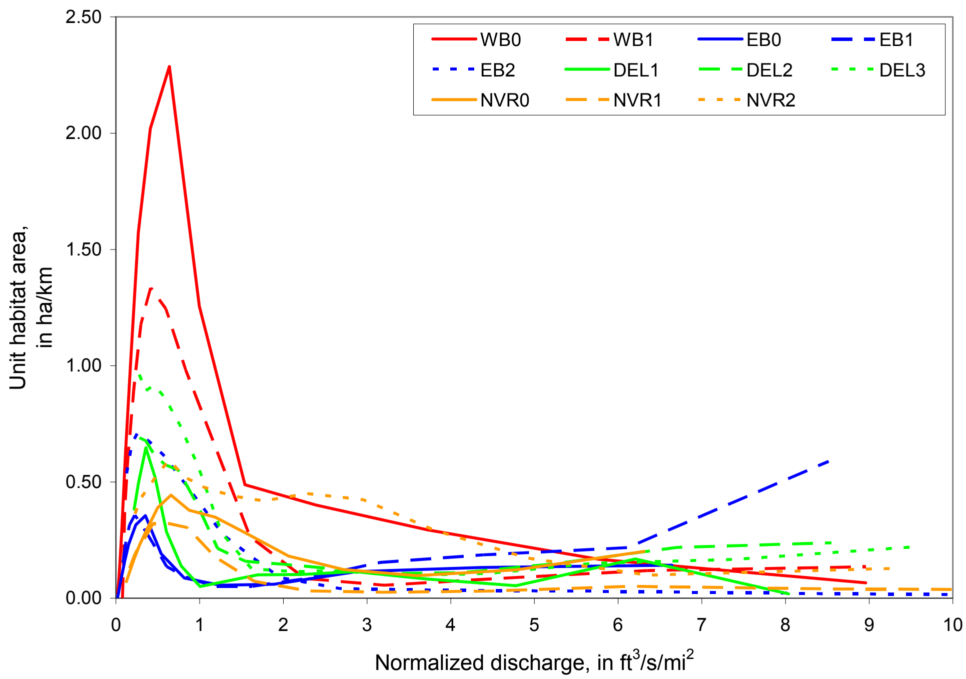

Figure 19. Normalized discharge versus unit habitat areas for the shallow-fast current velocity guild at 11 sites in the upper Delaware River.

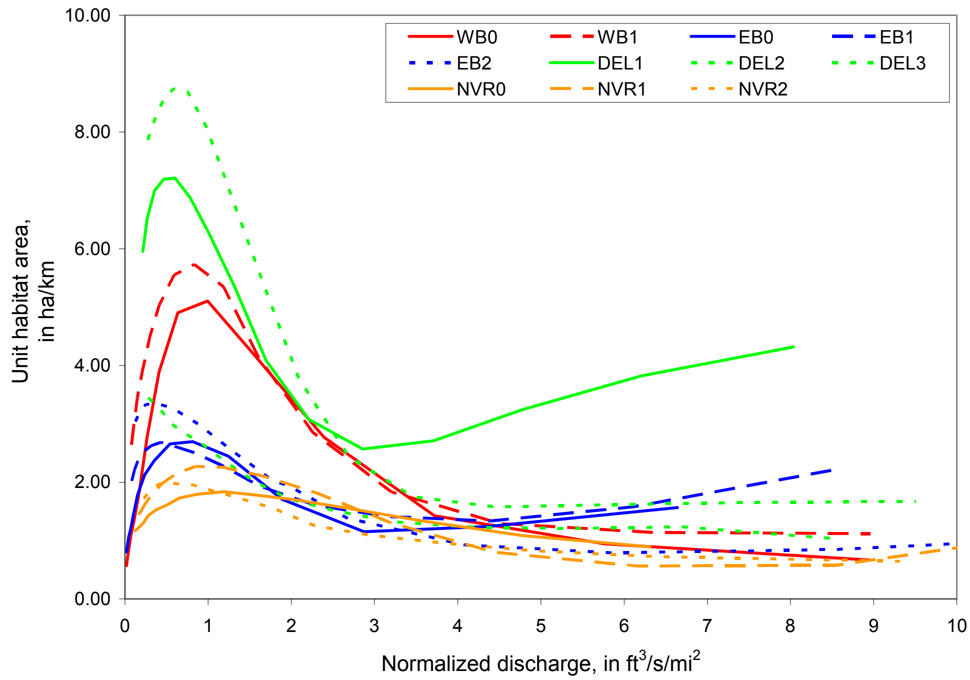

Figure 20. Normalized discharge versus unit habitat areas for juvenile trout (*Salmo trutta*) at 11 sites in the upper Delaware River.

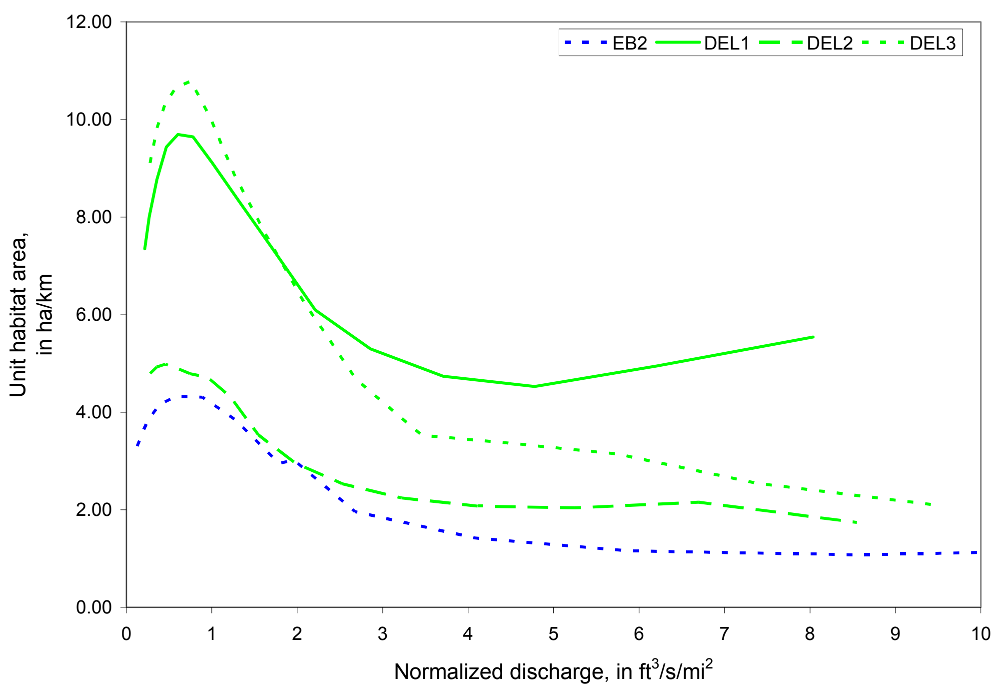

Figure 21. Normalized discharge versus unit habitat areas for juvenile American shad (*Alosa sapidissima*) at four sites in the upper Delaware River.

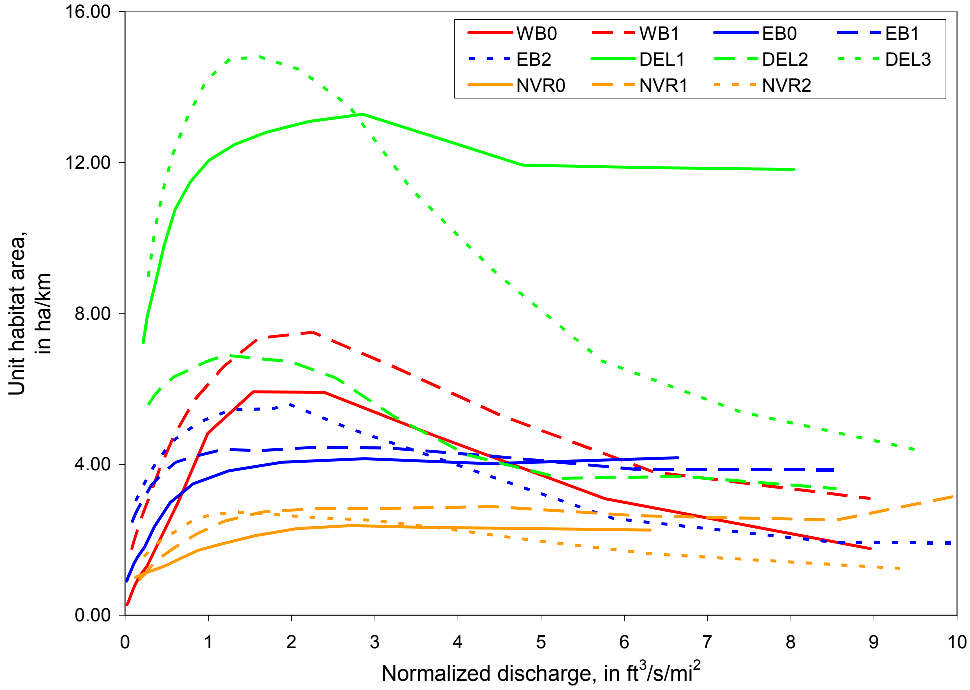

Figure 22. Normalized discharge versus unit habitat areas for adult trout (*Salmo trutta*) at 11 sites in the upper Delaware River.

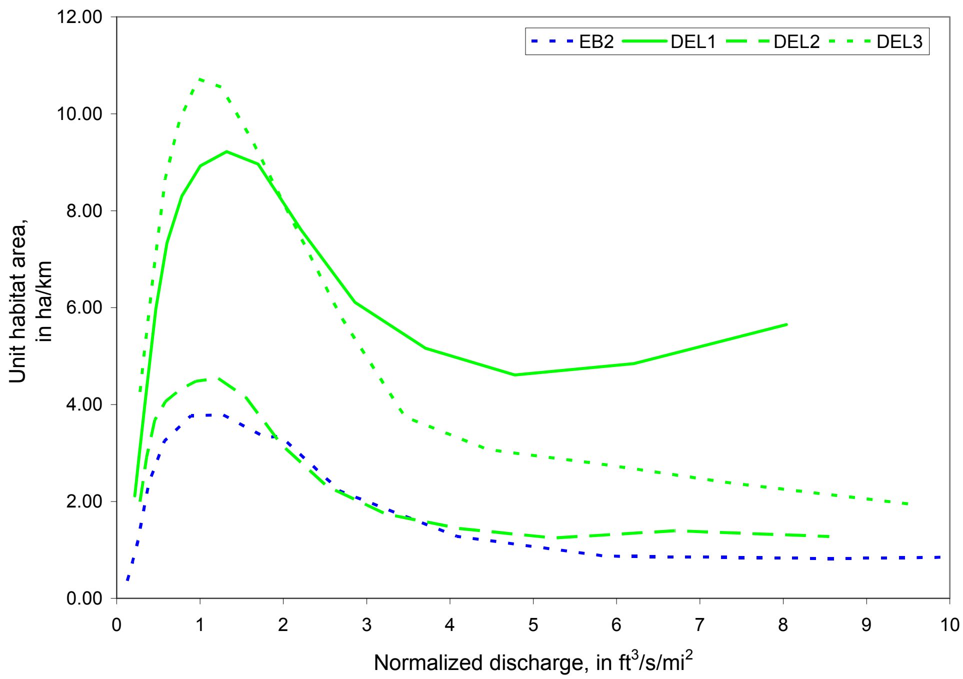

Figure 23. Normalized discharge versus unit habitat areas for spawning American shad (*Alosa sapidissima*) at four sites in the upper Delaware River.

Mesohabitat Versus Discharge

Patterns of mesohabitat distributions similar to those of the discharge versus habitat area functions were evident among the sites. Figures 24–29 and figures 31–32 illustrate the normalized areas of mesohabitat types, roughly in descending order of abundance. Pools were the most prominent mesohabitat types at low flows, but were replaced by fast runs at the higher flows (figs. 24 and 25). The shift from pool to fast run was indicative of the lesser influence of riffles as hydraulic controls (features in the stream that create backwater effects in an upstream direction) at higher discharges, resulting in an overall increase in hydraulic gradients. At low flows, runs were second in abundance to pools at most sites (fig. 26) and were also replaced by fast runs at the higher discharges. It is noteworthy that the two West Branch sites and the site farthest upstream on the Neversink (NVR0) did not develop very much fast run mesohabitat (except at WB1 at the highest flow), retaining about the same amount of pool and run mesohabitats across the entire range of discharges. We believe that this phenomenon may be related to the formation of very large deltas at tributaries in these sites. These deltas provided strong and stable hydraulic control over a wide range of flows, so the backwater effects needed to create pools were retained, rather than being "drowned out" at higher discharges.

Riffles (fig. 27) were comparatively less extensive than the other major mesohabitat types and generally mimicked the pattern of the shallow-fast habitat guild with respect to streamflow. The exceptions occurred at WB0 and in the Neversink (both for riffles and SFCV) where the amount of riffle habitat either remained constant or increased with increased discharge.

As might be expected, the area of inundated vegetation (fig. 28) was zero or near zero at all sites at low discharges and increased steadily as discharges increased. With the exception of DEL1, the area of inundated vegetation was minimal at discharges less than about 3 cubic feet per second per square mile.

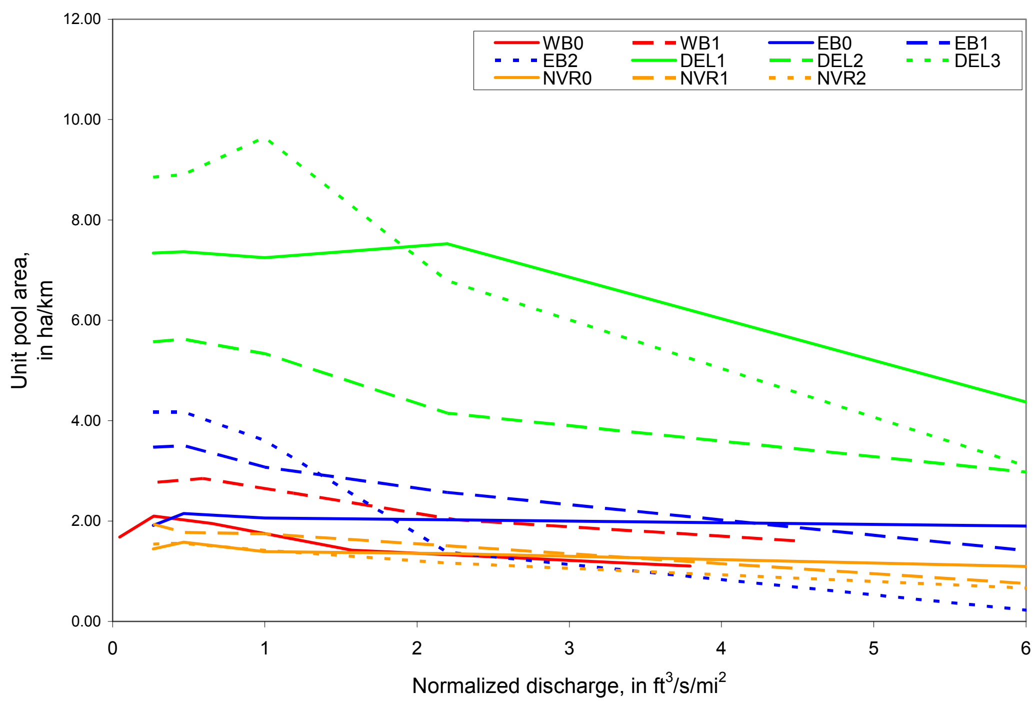

Figure 24. Normalized discharge versus unit areas of pool mesohabitat types.

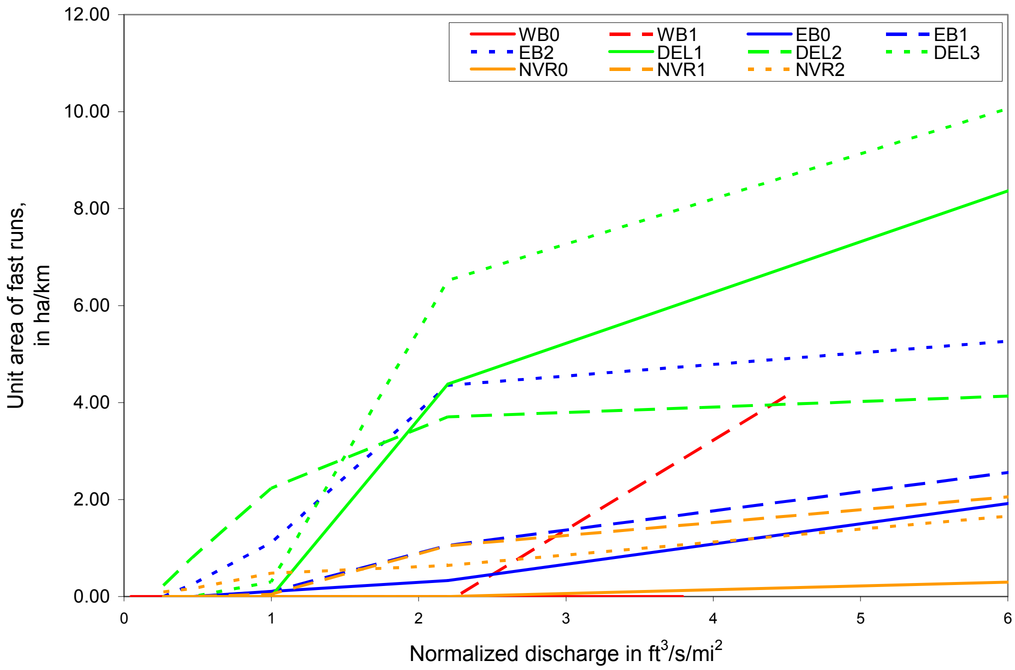

Figure 25. Normalized discharge versus unit areas of fast run mesohabitat types.

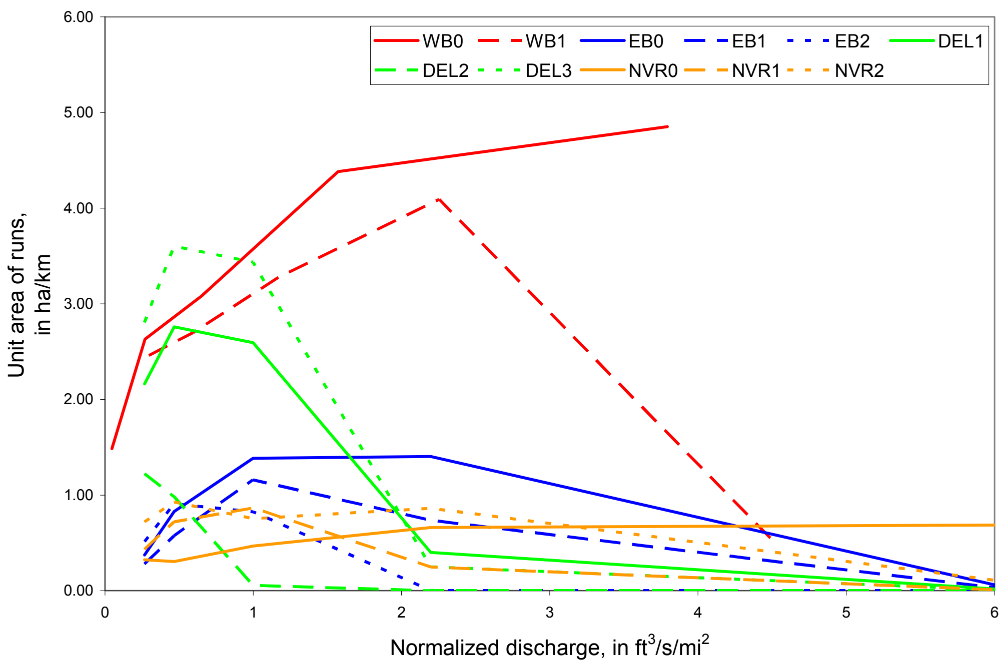

Figure 26. Normalized discharge versus unit areas of run mesohabitat types.

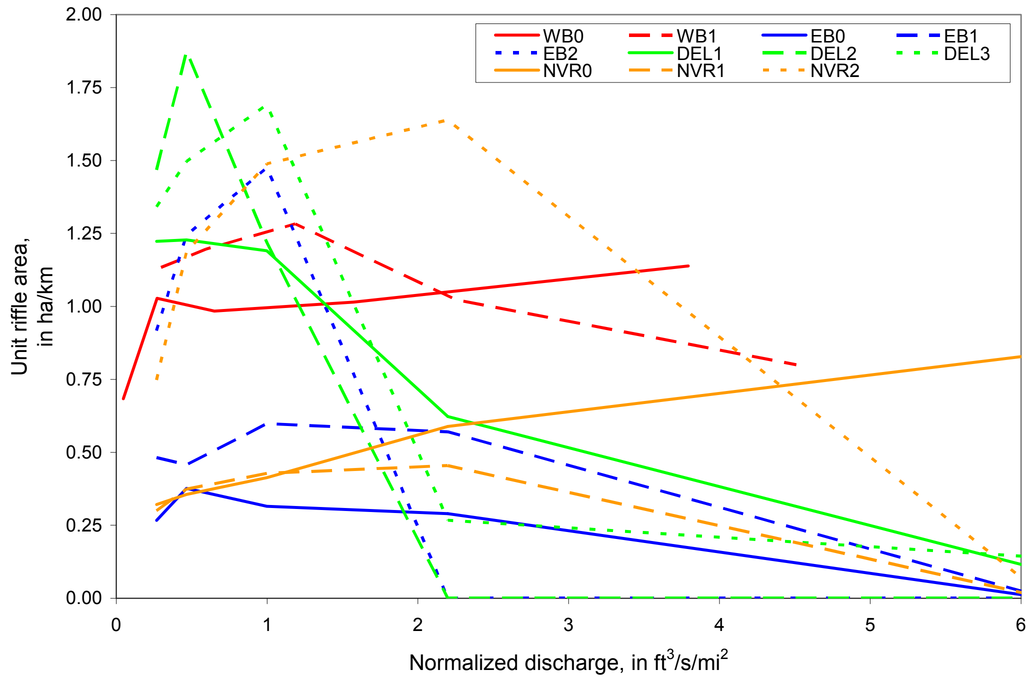

Figure 27. Normalized discharge versus unit areas of riffle mesohabitat types.

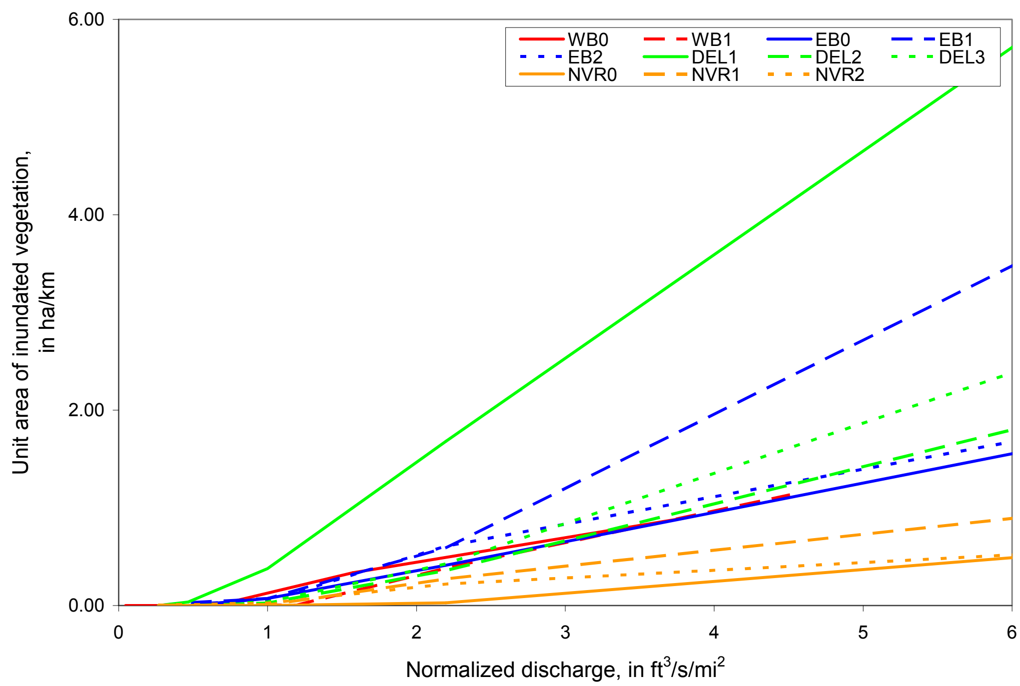

Figure 28. Normalized discharge versus unit areas of inundated vegetation.

The most dynamic mesohabitat types were side arms (fig. 29), backwaters (fig. 30), and disconnected areas (fig. 32). The variability in the areas of these three mesohabitat types occurred, at least in part, because they would change from one type to another depending on the discharge. An area might be disconnected at a very low flow, become connected as a backwater at an intermediate flow, and connected from top and bottom (thereby becoming a side arm) at higher flows. Generally speaking, side arms tended to be most consistent in stream reaches containing large, highly dissected, and relatively high-elevation islands (for example, DEL3,WB1, EB0, EB1, and the Neversink sites), and most variable where the side channels were around midchannel, low-elevation bars (for example, DEL1, WB0, EB2). A complicating factor was that not all sections of divided channel were classified as side arms. According to our definitions, bisected channels were not classified as side arms, even though they may have exhibited some of the same properties.

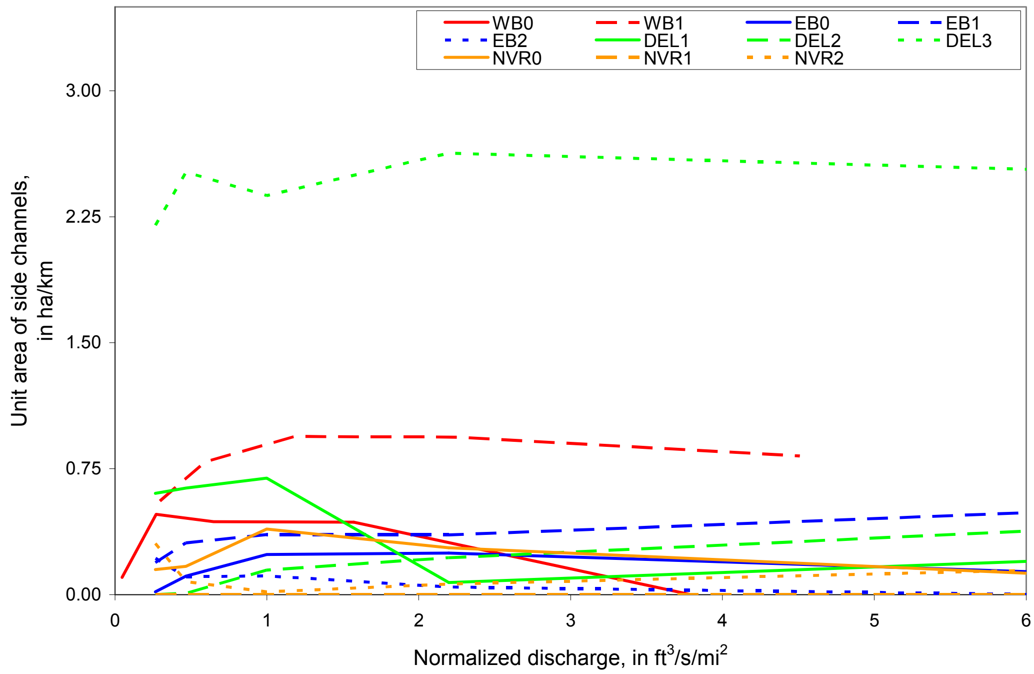

Figure 29. Normalized discharge versus unit areas of side arm mesohabitat types.

As discharge decreases, inflow to a side arm may cease and the extant channel will be come a backwater or a disconnected channel (fig. 30). Although neither mesohabitat type accounted for a large proportion of the surface area of any of the sites, some were impressive nonetheless. At the lowest classified discharges, very large backwaters formed at EB0, WB1, WB0, DEL1, and NVR0 (fig. 31). In each instance, the channel was divided by a very long island, with inflow to one of the divisions cut off at low flows. A similar process occurred at intermediate flows at DEL1 and DEL3, both in perched side arms that were disconnected from the main channel at low flows and connected at the inflow and outflow at high discharges.

Disconnected mesohabitats (fig. 32) occurred wherever there was a depression of sufficient depth that water could be stored by groundwater connection, but with no surface connection. Disconnected areas did not account for a significant proportion of mesohabitat area, although relatively large disconnects occurred at WB0 and at DEL2. In both of these locations, the outflows of long side arm channels were elevated sufficiently to isolate the channels at low discharges. At DEL2, the isolated channel persisted at lower flows, but the surface area was smaller owing to lower ground water levels.

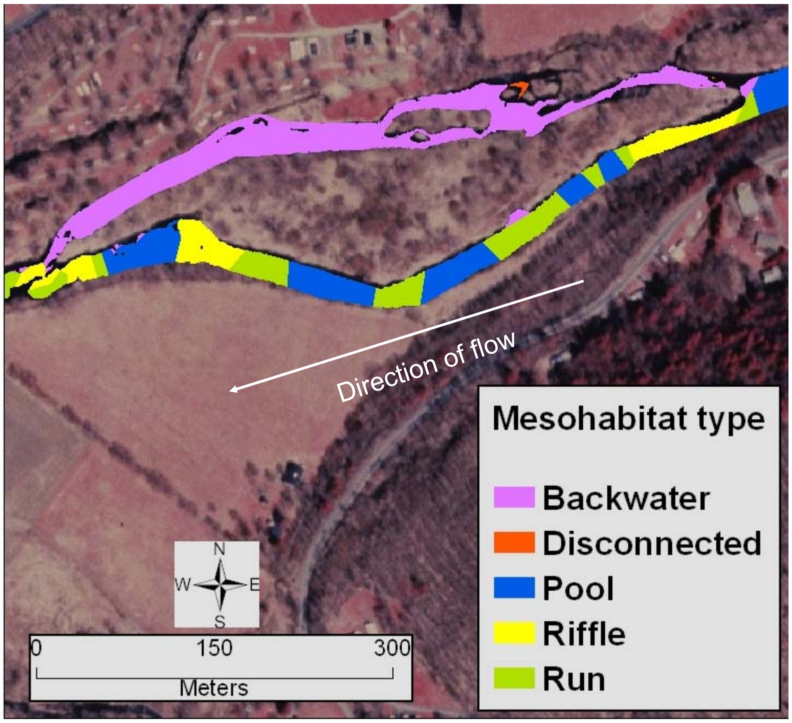

Figure 30. Backwaters and disconnected channels at 25 ft^3/s (0.7 m^3/s) in site EB0. Note the hydraulic connections or lack thereof at the outflow and the inflow in the north channel. At slightly higher discharges, the inflow is connected and the entire area is classified as a side arm.

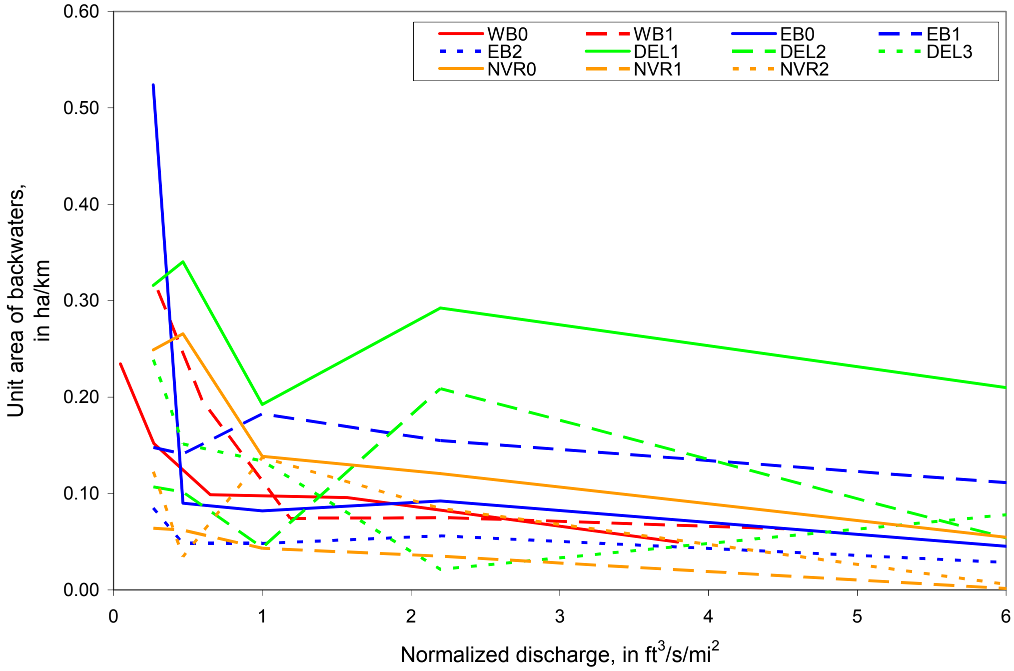

Figure 31. Normalized discharge versus unit areas of backwaters mesohabitat types.

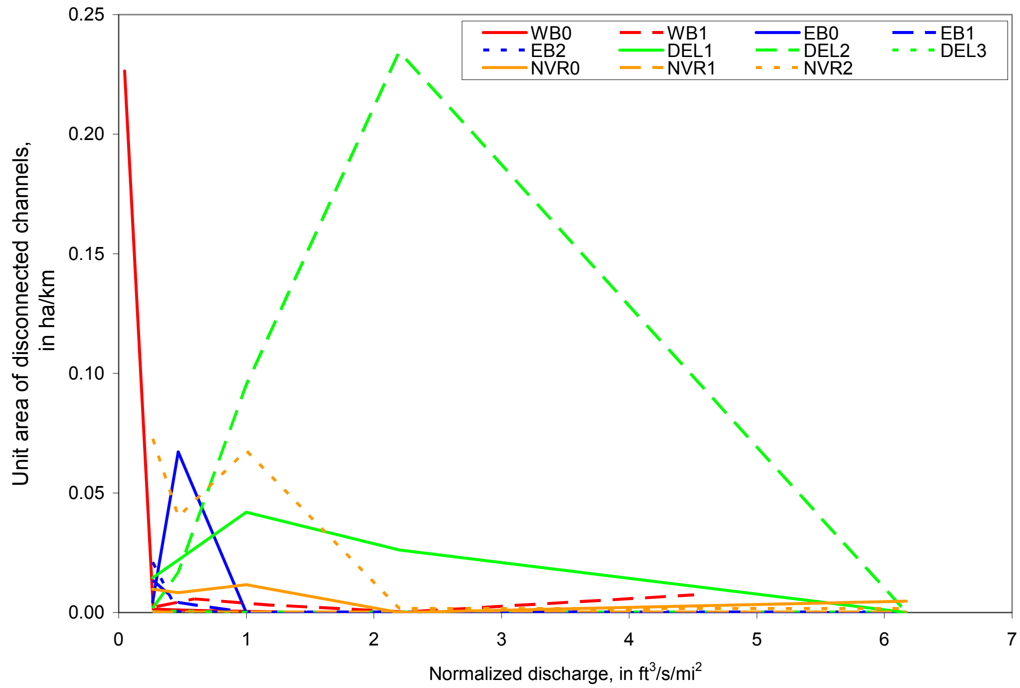

Figure 32. Normalized discharge versus unit areas of disconnected mesohabitat types.

Habitat Persistence

Habitat persistence was determined as the intersection of habitat patches for spawning and incubation and for dwarf wedgemussels for every combination of simulated discharges at each site. The exported and compiled persistence tables for both target organisms can be found in appendix 4.

Trout Spawning and Incubation

At most of the sites, maximum areas of persistent habitat appeared to be more influenced by the overlap of suitable incubation conditions than by the suitable spawning areas (figs. 33–43). This phenomenon was manifested by the maximum areas of the three-dimensional surfaces being elongated along the axes for spawning flows and narrowed along the incubation flow axis. The exception to this rule was at EB0 (fig. 36), which exhibited the opposite tendency. Here the maximum areas were associated with a fairly narrow range of spawning flows, but a relatively wide band of incubation flows.

At all sites, the axes of the maximum persistent area bands were essentially orthogonal, indicating a relatively independent relation between spawning and incubation flows in the optimal range. If the spawning and incubation flows were within their optimal ranges, it did not matter whether the incubation flows were higher or lower than the spawning flows. In contrast, all sites illustrated dependence among the smaller areas of persistent habitat, where the influences of the flow differential between spawning flows and the incubation flows were more evident. At higher spawning flows, more persistent habitat occurred if the incubation flows were also high. Likewise, persistent habitat associated with low spawning flows was more abundant if the incubation flows were also low.

We found distinct groupings of optimal flow ranges for spawning and incubation among the sites. In the West Branch, maximum persistent habitat occurred with spawning flows between approximately 0.8 and 3.8 $ft^3/s/mi^2$ and incubation flows between 0.8 and 1.6 $ft^3/s/mi^2$ (figs. 33 and 34). Regardless of discharge, however, WB1 contained a much larger area of spawning and incubation habitat than WB0, attributable primarily to the more extensive pool tail-outs that occurred at WB1. Overall, spawning and incubation habitat persistence at WB0 appeared to be somewhat more sensitive to incubation flows than at WB1, as indicated by the width of the polygons along the x (incubation) axis.

In the upper East Branch, maximum values of persistent spawning and incubation habitat occurred at much lower discharges than in the West Branch. At EB0, spawning flows between 0.4 and 1.0 $ft^3/s/mi^2$ and incubation flows in the range of 0.2 to 4 $ft^3/s/mi^2$ produced the maximum area of persistent habitat (fig. 35). At EB1, persistent habitat was maximized with spawning flows between 0.8 and 2.7 $ft^3/s/mi^2$ and incubation flows between 0.5 and 0.8 $ft^3/s/mi^2$ (fig.36). Maximum habitat persistence at EB2 (fig. 37) was similar to the West Branch sites with respect to spawning flows (maximized between 0.8 and 2.7 $ft^3/s/mi^2$), but more like the other East Branch sites with respect to incubation flows (maximized between 0.8 and 0.9 $ft^3/s/mi^2$).

The habitat versus discharge response surfaces for the main-stem Delaware sites were similar to those of the West Branch and lower East Branch. DEL1 (fig. 38) exhibited the widest range of optimal spawning flows of any of the sites (0.3 to 6.2 $ft^3/s/mi^2$), but was constrained by a relatively narrow range of optimal incubation flows (0.5 to 0.9 $ft^3/s/mi^2$). Unlike most of the other sites, persistent habitat areas were not skewed at the upper and lower ranges of spawning and incubation discharges. Maximum areas of persistent habitat at DEL2 and DEL 3 (figs. 39 and 40) occurred over flow ranges more typical of the West Branch and exhibited the high-low flow skew observed at other sites. At DEL2, the largest areas of persistent habitat occurred with spawning flows in the range of 0.7 to 2.5 $ft^3/s/mi^2$ and incubation flows of 0.7 to 1.0 $ft^3/s/mi^2$.

Smaller areas of persistent habitat were highly skewed at DEL2, indicating that spawning and incubation at this site were relatively sensitive to flow differential. DEL3 provided the largest maximum area of persistent spawning and incubation habitat of all the sites (fig. 40). Maximum persistent habitat for this site occurred with a range of spawning flows from 0.8 to 3.5 $ft^3/s/mi^2$ and incubation flows from 0.7 to 1.0 $ft^3/s/mi^2$.

The maximum areas of persistent spawning and incubation habitat in the Neversink River occurred at higher ranges of normalized discharges than in any of the other rivers studied. Maximum persistent habitat at site NVR0 occurred with a range of spawning flows from 1.2 to 3.6 $ft^3/s/mi^2$ and incubation flows from 1.5 to 1.7 $ft^3/s/mi^2$ (fig. 41). Peak areas of persistent habitat at NVR1 occurred with spawning flows between 0.7 and 5 $ft^3/s/mi^2$ and incubation flows ranging from 1.4 to 1.8 $ft^3/s/mi^2$ (fig. 42). Both sites showed relatively little skew in persistent habitat areas at the high and low extremes of discharge, indicating somewhat lower sensitivity to flow differential than other sites. Persistent habitat at site NVR2 was maximized with spawning flows between about 1 and 3 $ft^3/s/mi^2$ and incubation flows of 1 to 1.5 $ft^3/s/mi^2$ (fig. 43). The differences in the response surfaces for the Neversink compared with those of the other sites may be an artifact of stream order and size. All the Neversink sites had considerably smaller drainage areas (our discharge normalizing term) than the other sites, and the overall slopes were greater by 50 to 300 percent (except at NVR1, which was comparable to EB0). Consequently, the Neversink may have resembled more of a headwater stream than the others we studied.

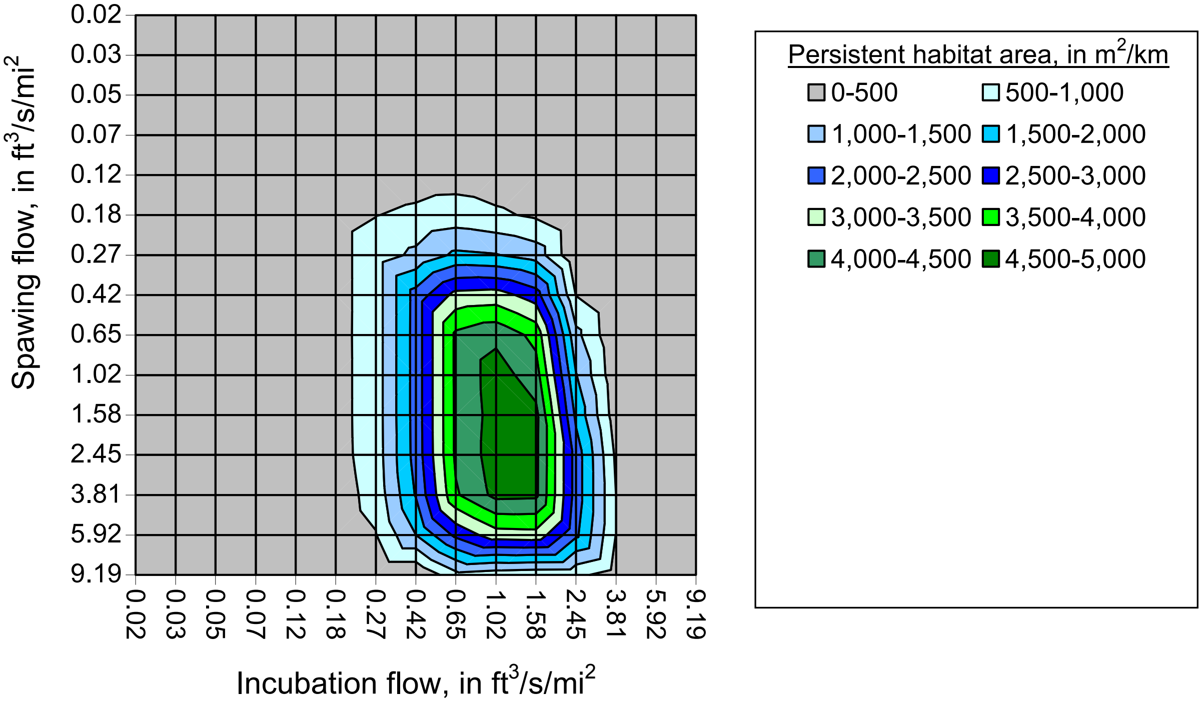

Figure 33. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site WB0.

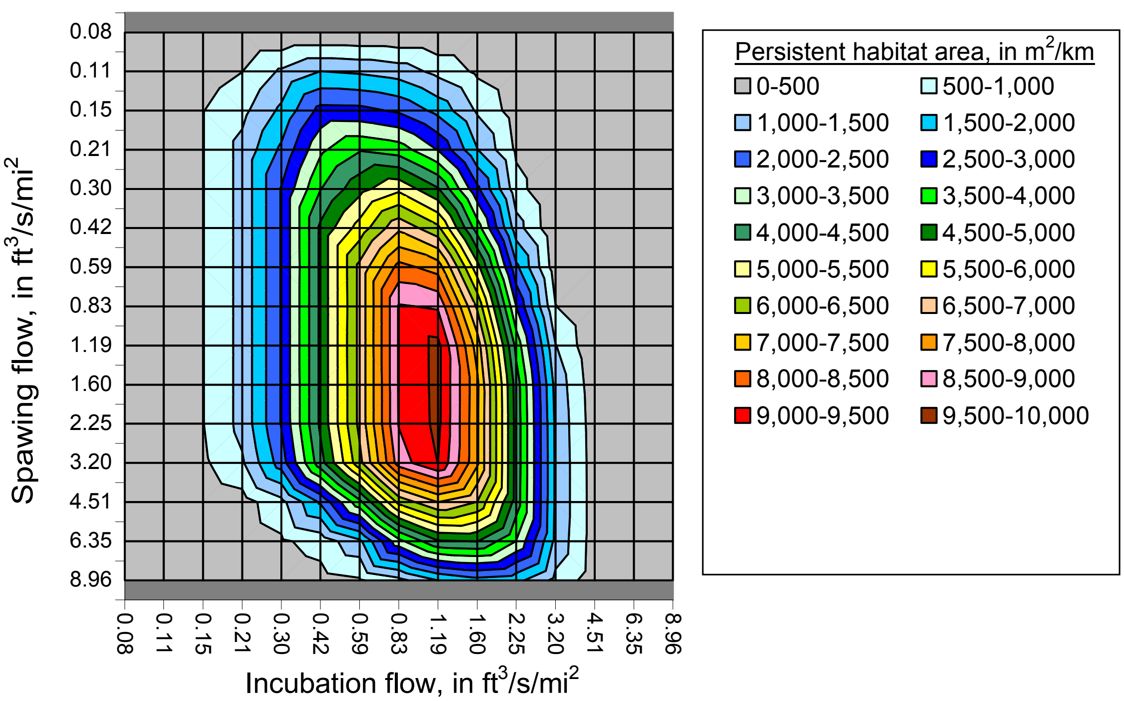

Figure 34. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site WB1.

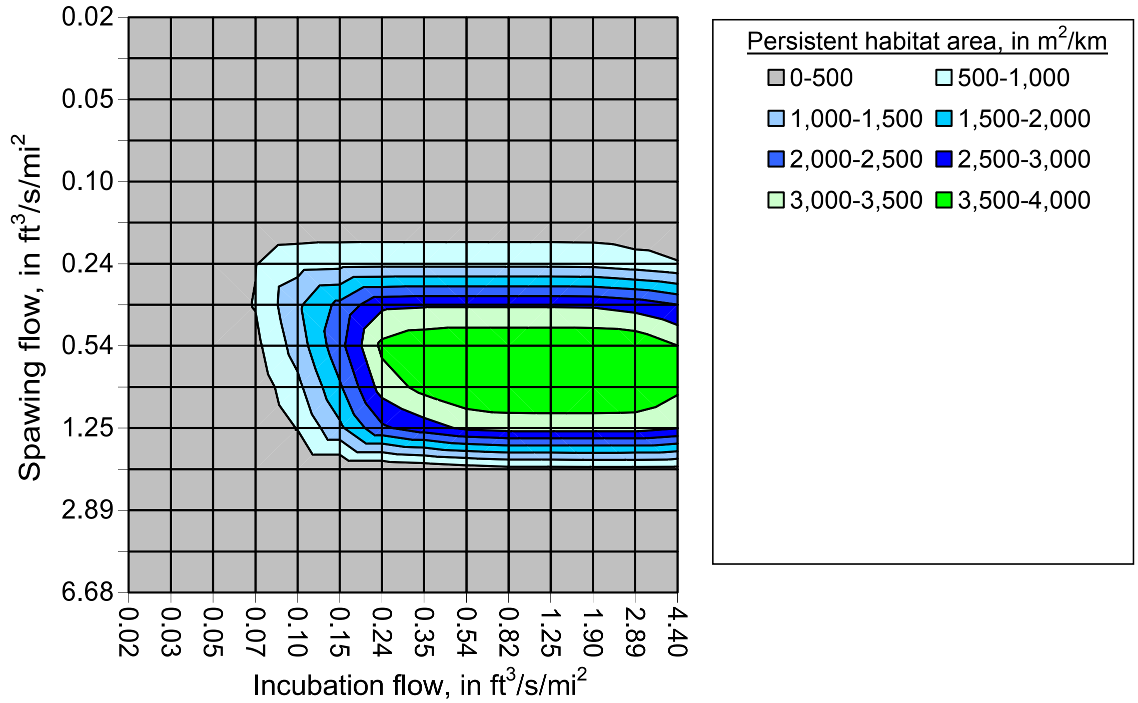

Figure 35. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site EB0.

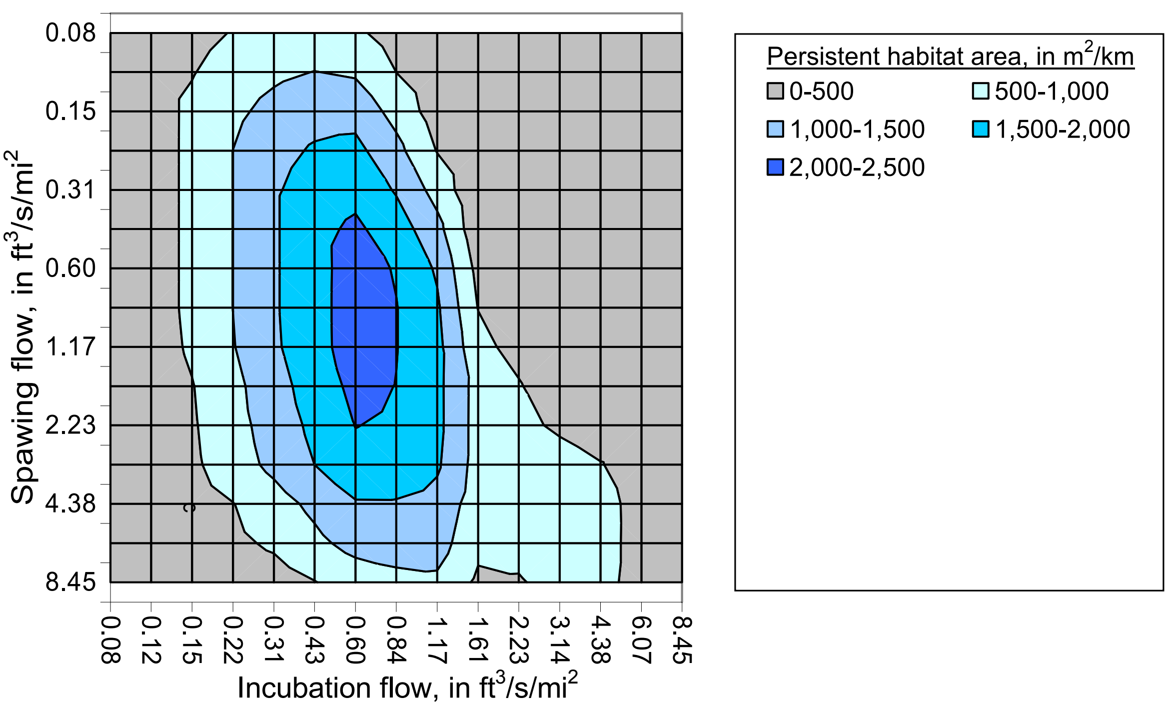

Figure 36. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site EB1.

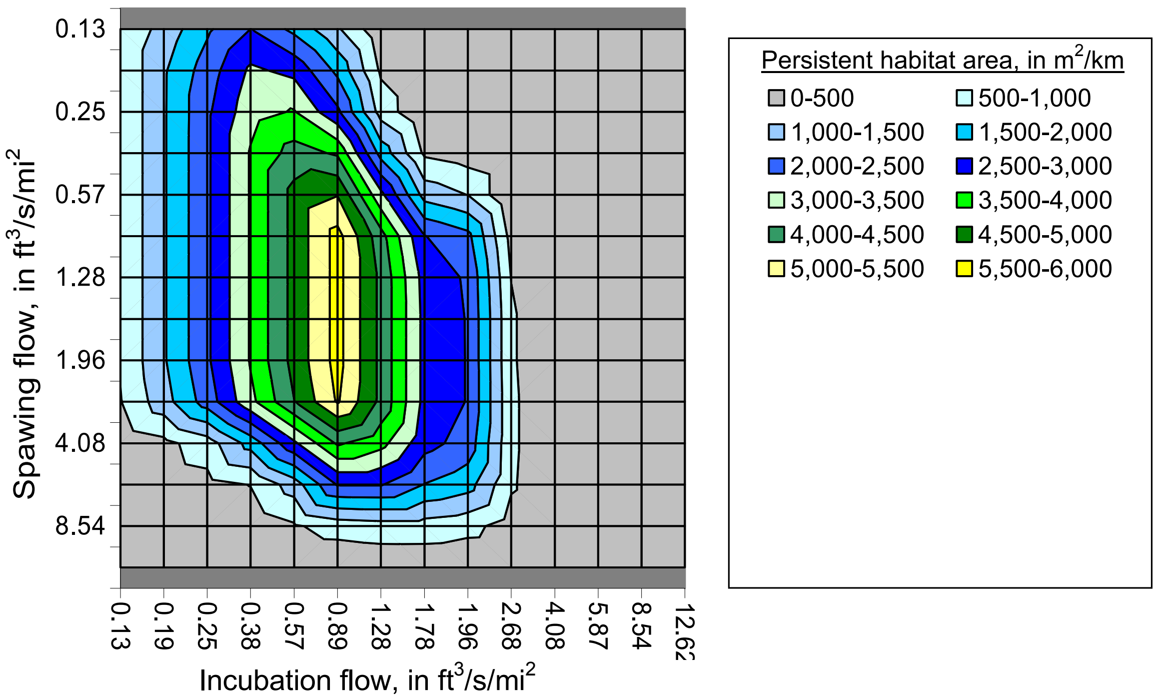

Figure 37. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site EB2.

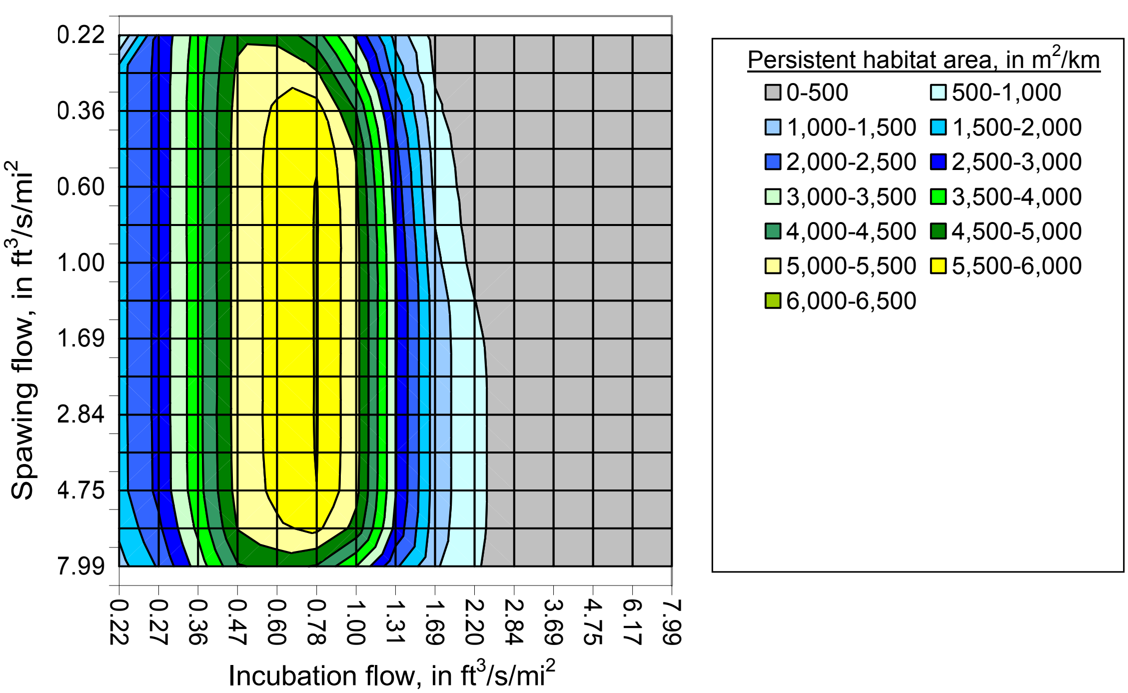

Figure 38. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site DEL1.

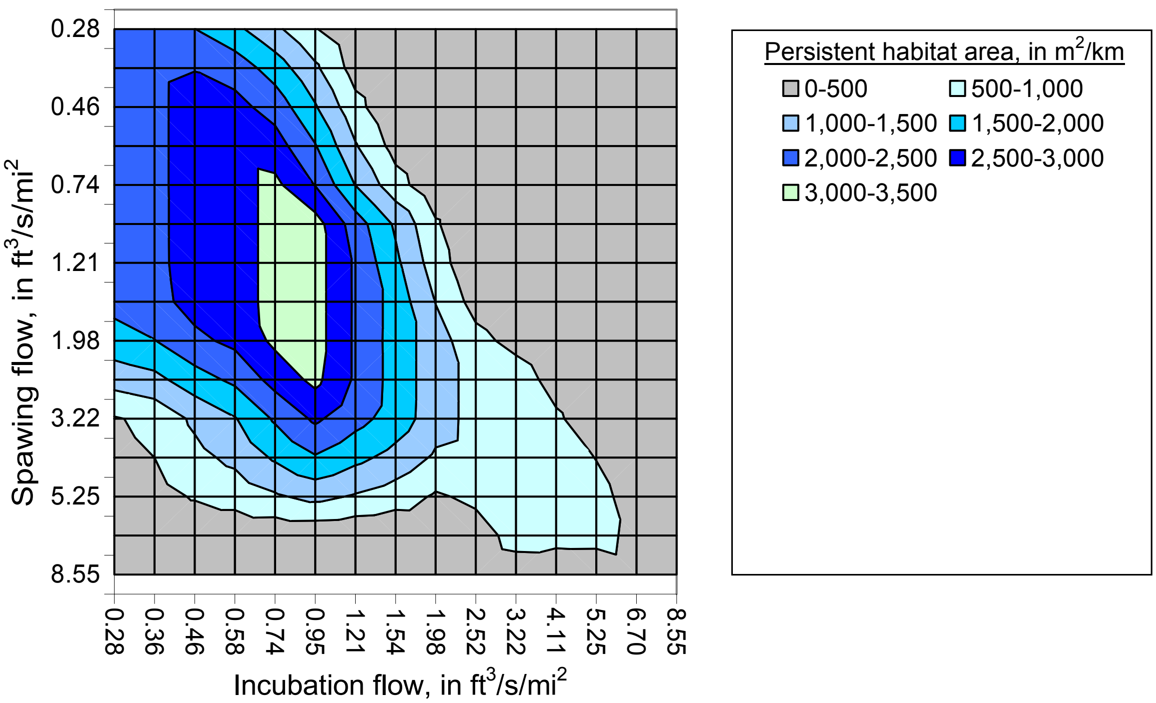

Figure 39. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site DEL2.

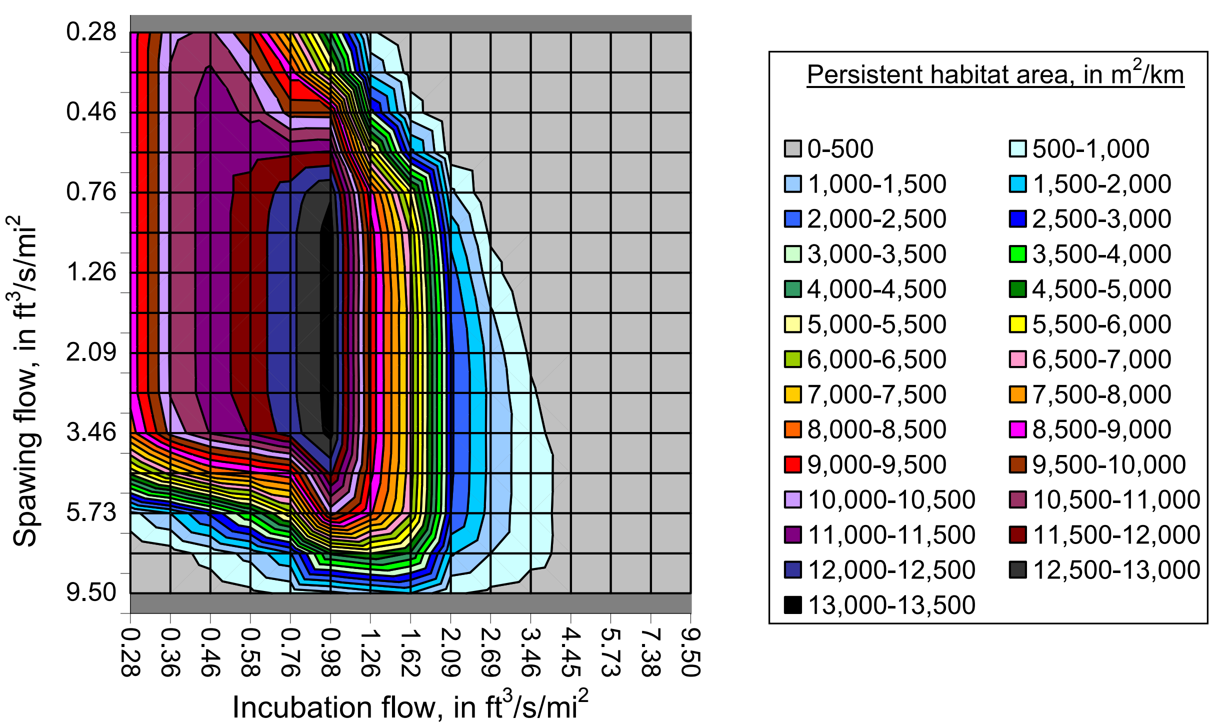

Figure 40. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site DEL3.

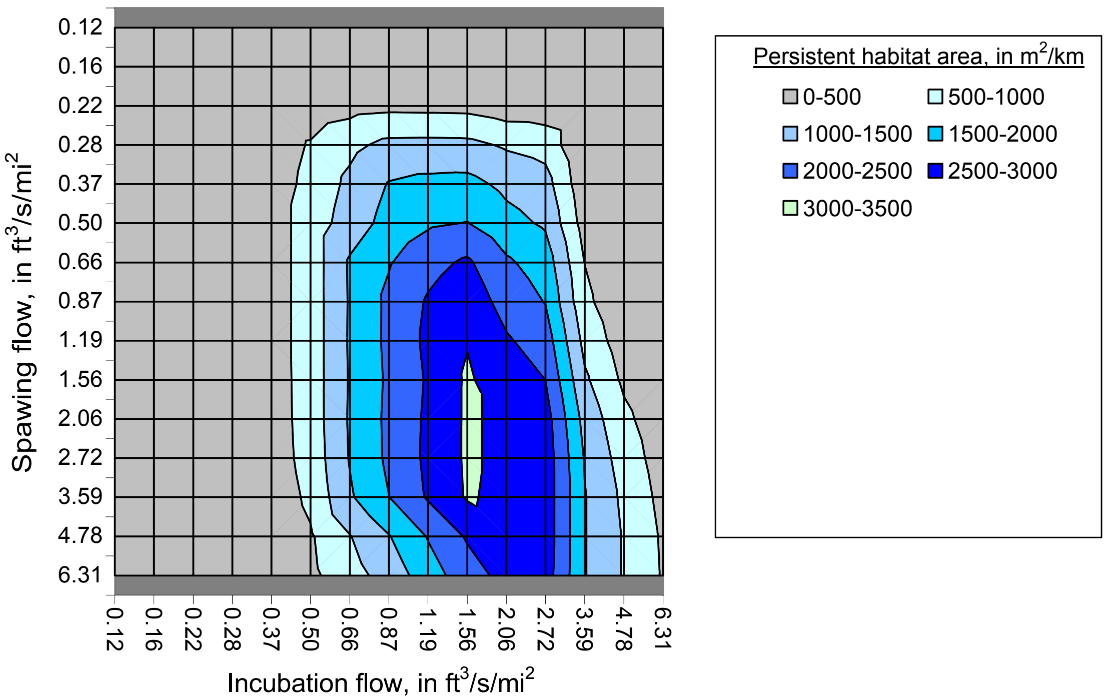

Figure 41. Normalized discharge versus unit area of persistent (*Salmo trutta*) trout spawning-incubation habitat at site NVR0.

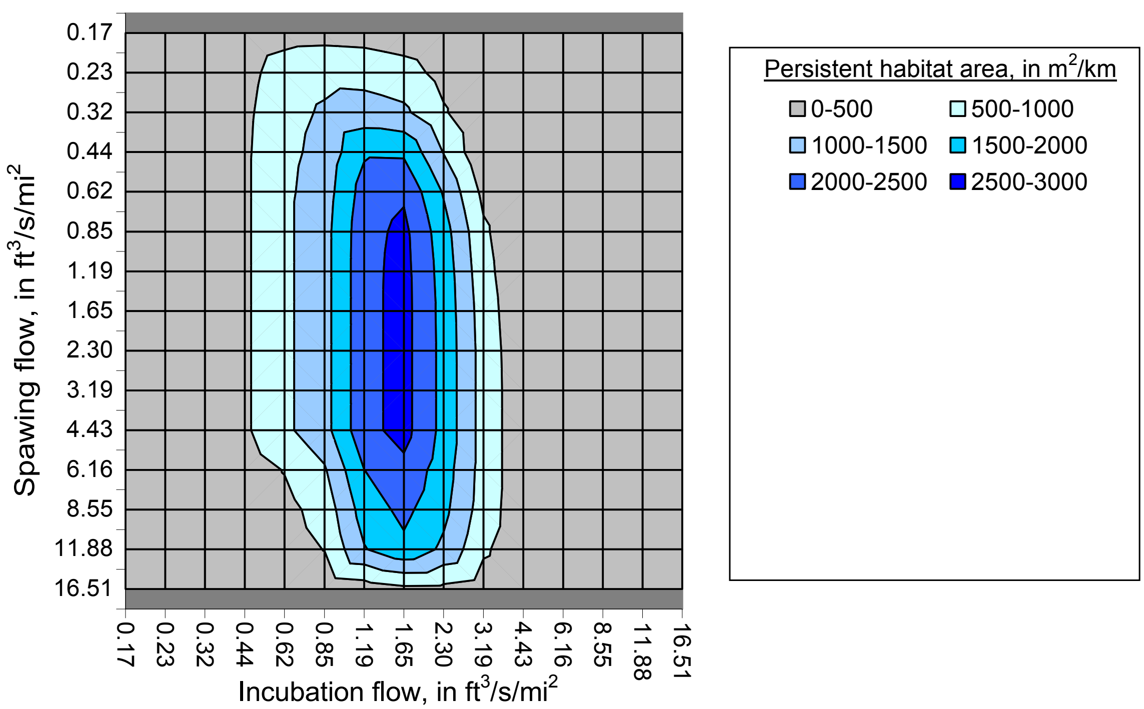

Figure 42. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site NVR1.

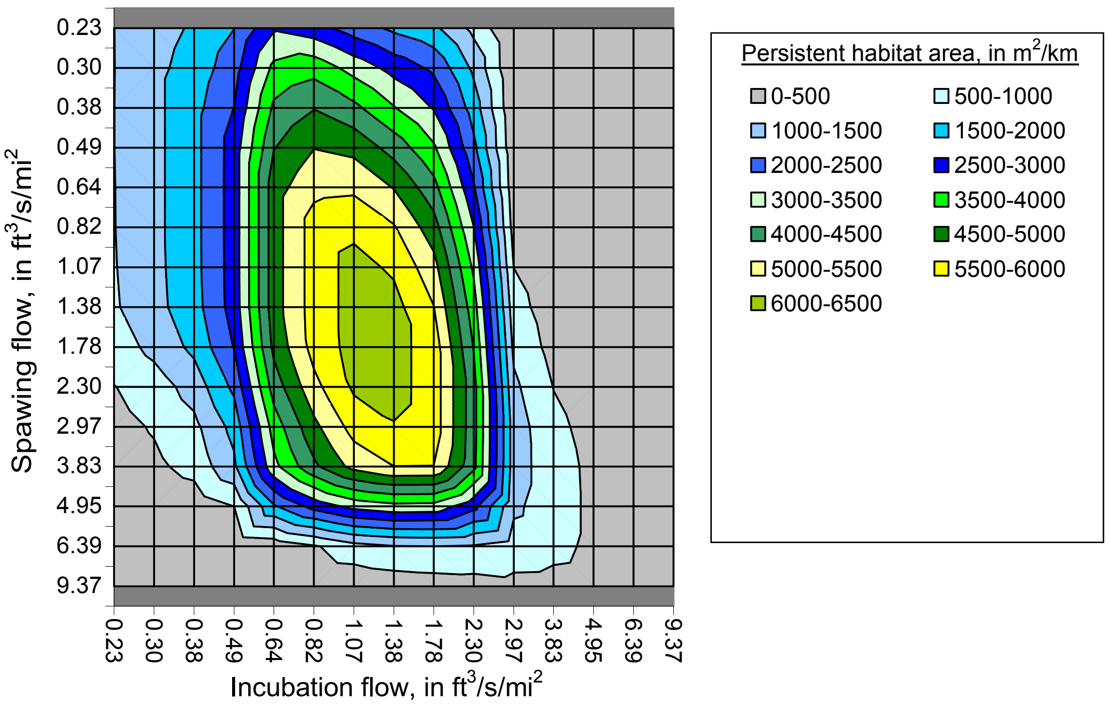

Figure 43. Normalized discharge versus unit area of persistent trout (*Salmo trutta*) spawning-incubation habitat at site NVR2.

Dwarf Wedgemussel

The analysis of persistence in dwarf wedgemussel habitat differed from that of trout spawning and incubation in one significant aspect. Two different sets of habitat suitability criteria were used to define the polygons intersected in the spawning-incubation maps, whereas the same criteria were evaluated at combinations of paired discharges for dwarf wedgemussels. In the spawning-incubation case, the habitat polygons were independent spatially, but order-dependent. For dwarf wedgemussels, the opposite was true. Consequently, the three-dimensional habitat response surfaces (figs. 44, 45, and 46) for the dwarf wedgemussel were highly skewed along a diagonal between pairs of discharges. This bias occurred because the largest area of persistent habitat for any pair of discharges occurs when they are the same. As the two discharge pairs deviate from one another, the area of persistent habitat always decreases. In this sense, habitat persistence for the dwarf wedgemussel (as we described it) was more sensitive to flow differential than it was for spawning and incubation. The second obvious characteristic of the habitat response surfaces for dwarf wedgemussels is that they were highly symmetrical (kaleidoscopic), compared to the more amorphous surfaces for spawning and incubation. This phenomenon was an artifact of comparing pairs of discharge for the same target organism in an order-independent fashion. That is, a flow combination of 100 ft^3/s and 1,000 ft^3/s produced the same amount of persistent mussel habitat as a combination of 1,000 ft^3/s and 100 ft^3/s. This was decidedly not the case for spawning and incubation.

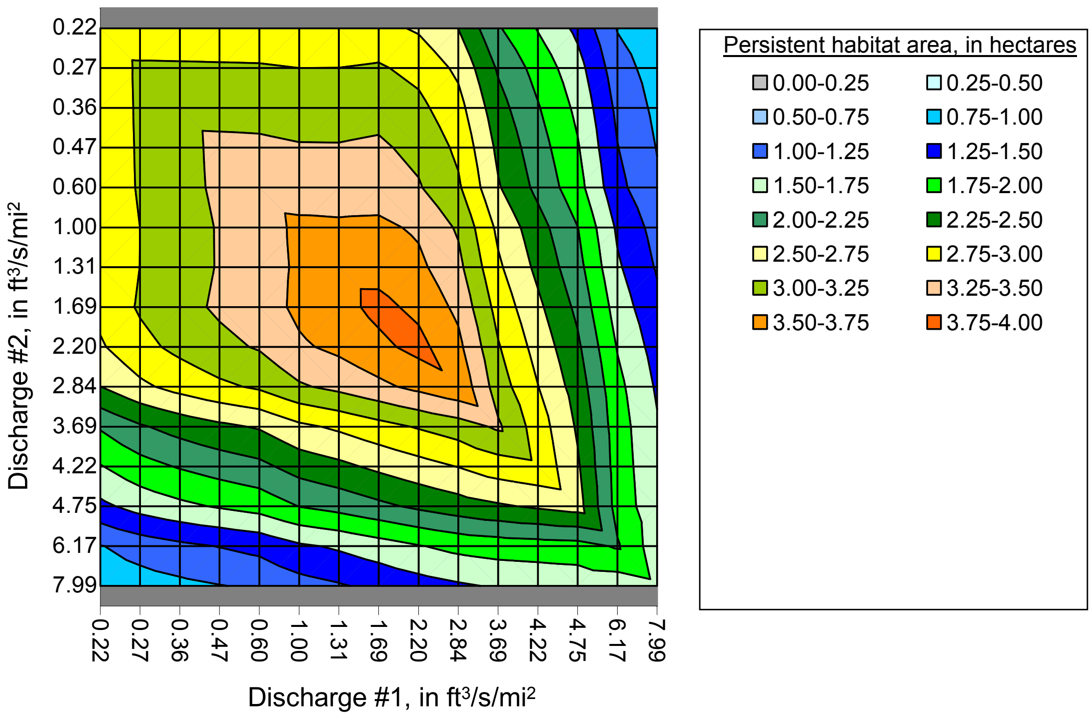

Figure 44. Normalized discharge versus area of persistent dwarf wedgemussel (*Alasmidonta heterodon*) habitat at site DEL1.

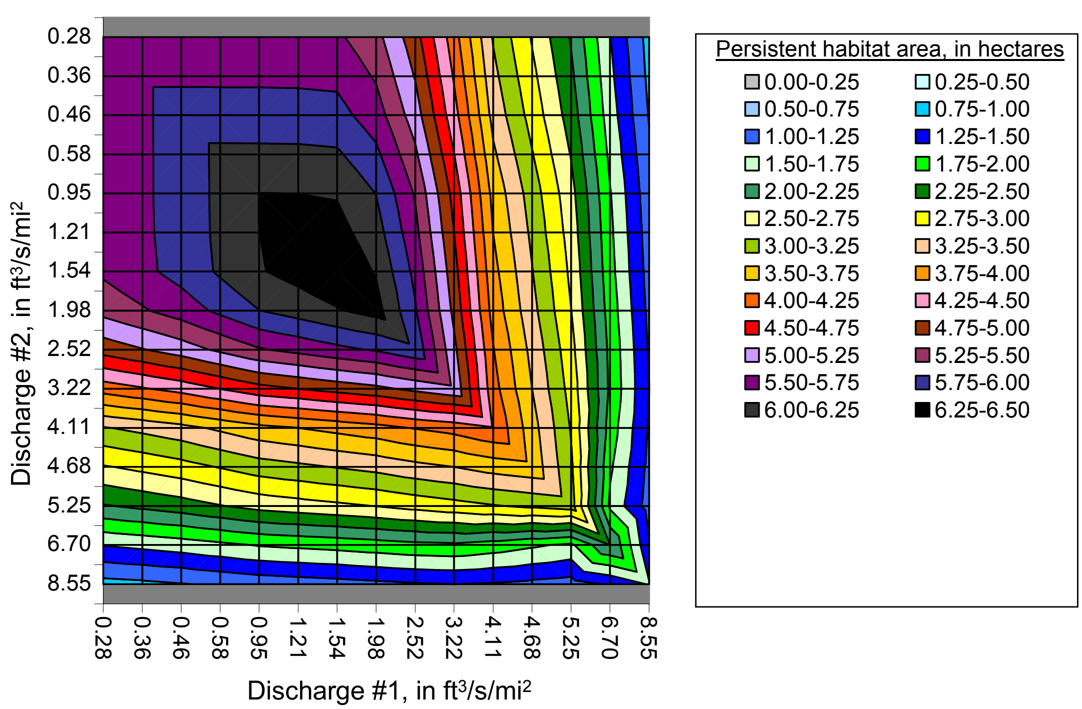

Figure 45. Normalized discharge versus area of persistent dwarf wedgemussel (*Alasmidonta heterodon*) habitat at site DEL2.

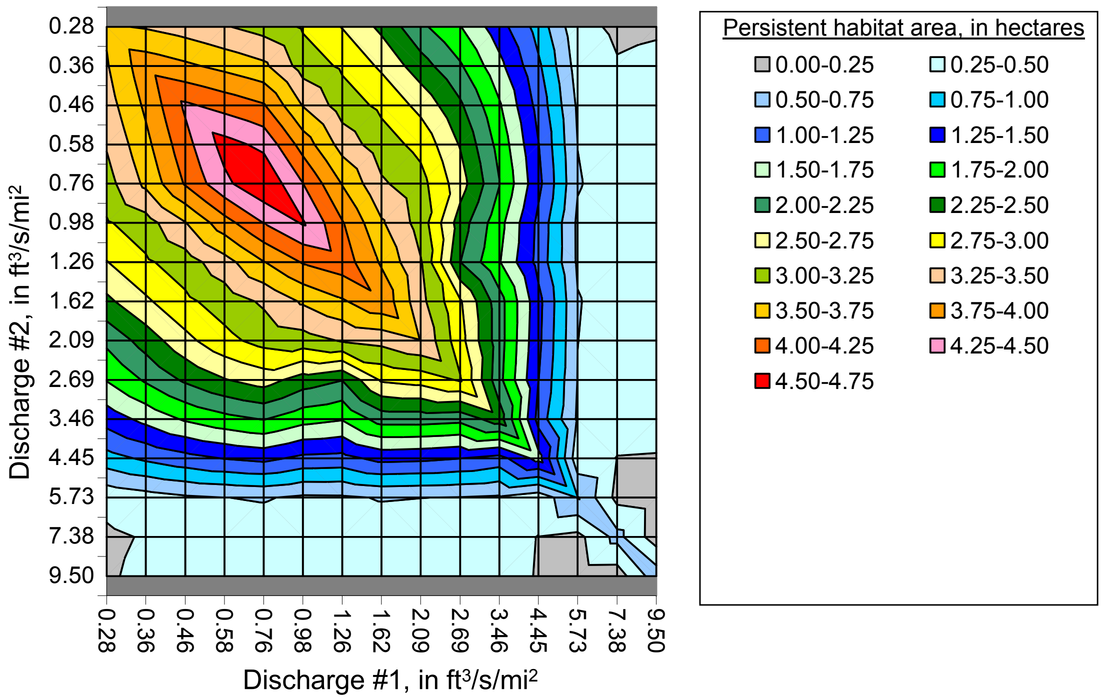

Figure 46. Normalized discharge versus area of persistent dwarf wedgemussel (*Alasmidonta heterodon*) habitat at site DEL3.

The habitat response surfaces were also highly influenced by the characteristics of the mussel beds observed by Dr. Lellis and his colleagues during the 2002 survey. We did not normalize habitat areas for dwarf wedgemussels, so each response surface and persistence table reflects a site-specific total area. Because the mussel beds at DEL2 were much larger than those at the other two main-stem sites, the maximum area of the response surface for that site (fig. 45) was also considerably larger. The response to discharge for DEL1 and DEL 2 were quite similar, with the maximum area occurring at discharges in the range of about 0.9 to 2.5 $ft^3/s/mi^2$ (figs. 44 and 45). In contrast to the upper two main-stem sites, persistent habitat at DEL3 was optimized at discharges between 0.5 and 1 $ft^3/s/mi^2$ (fig. 46).

A review of the characteristics of the mussel beds at DEL1 and DEL2 revealed a high degree of hydraulic and spatial similarity. Mussels were primarily found near the south shoreline in low velocity (but not stagnant) shallow pools, typically less than 1 m deep (figs. 47 and 48). The observed locations of the mussels at DEL3 may have affected the lower range of optimal flows for its habitat response surface. Whereas mussels at the upper sites were observed in shallow, slow pools, a number of mussels at the DEL3 site were found along the margins of a fairly steep riffle (fig. 49). The distribution of mussels at DEL3 influenced our delineation of the mussel bed in the original mapping exercise. The optimal flow range for this site may be lower because a large portion of the mussel bed was included in the riffle. Consequently, shear stresses likely became limiting at higher flows, thereby reducing the utility of the area as habitat for mussels. It is probably not too surprising that after a flood event in 2005, mussels were found in about the same locations at the two upper sites, but were not found at DEL3 (William Lellis, USGS, oral commun., April 2006).

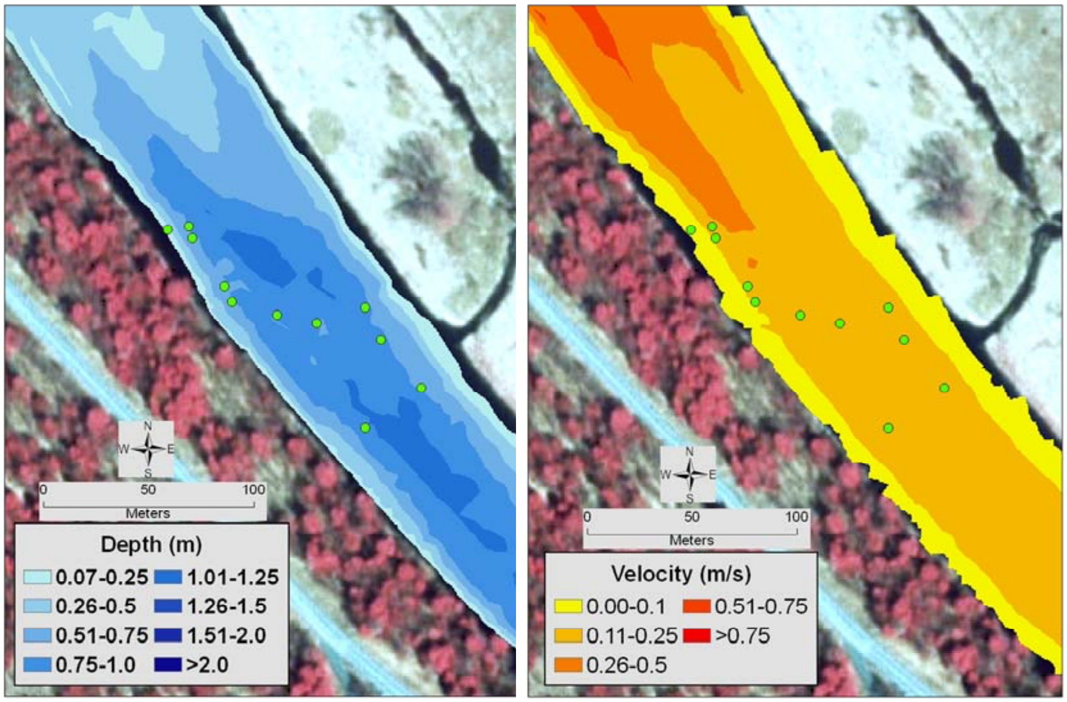

Figure 47. Depth and velocity distributions at DEL1 for the approximate discharge at which dwarf wedgemussel (*Alasmidonta heterodon*) observations (green dots) were made during 2002.

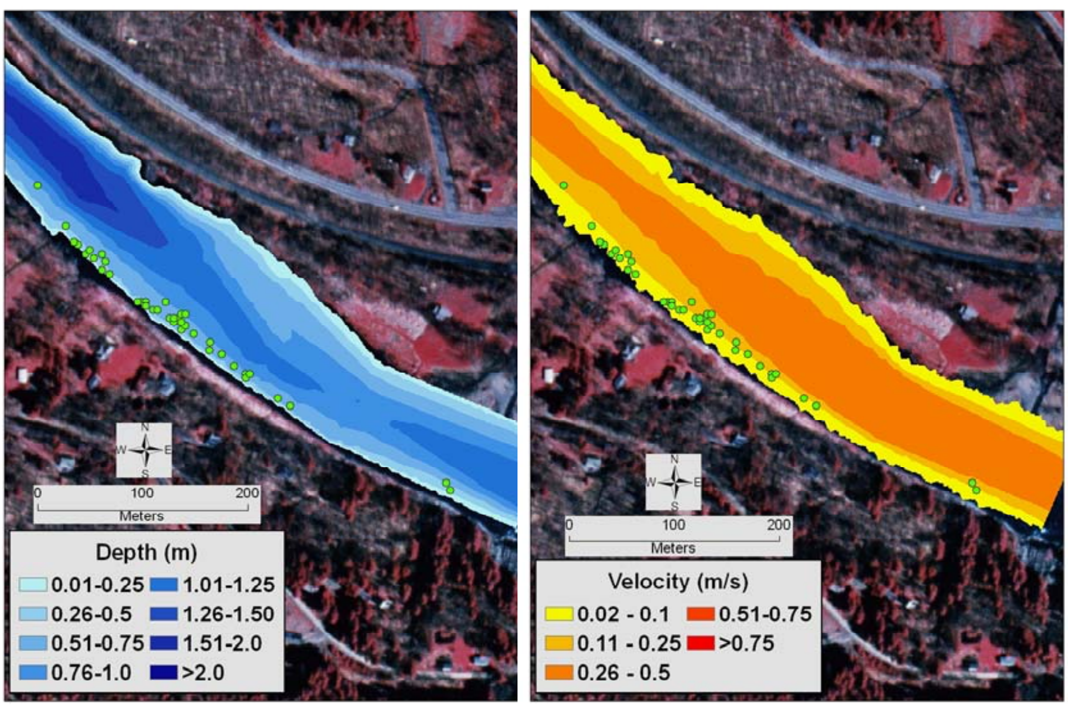

Figure 48. Depth and velocity distributions at DEL2 for the approximate discharge at which dwarf wedgemussel (*Alasmidonta heterodon*) observations (green dots) were made during 2002.

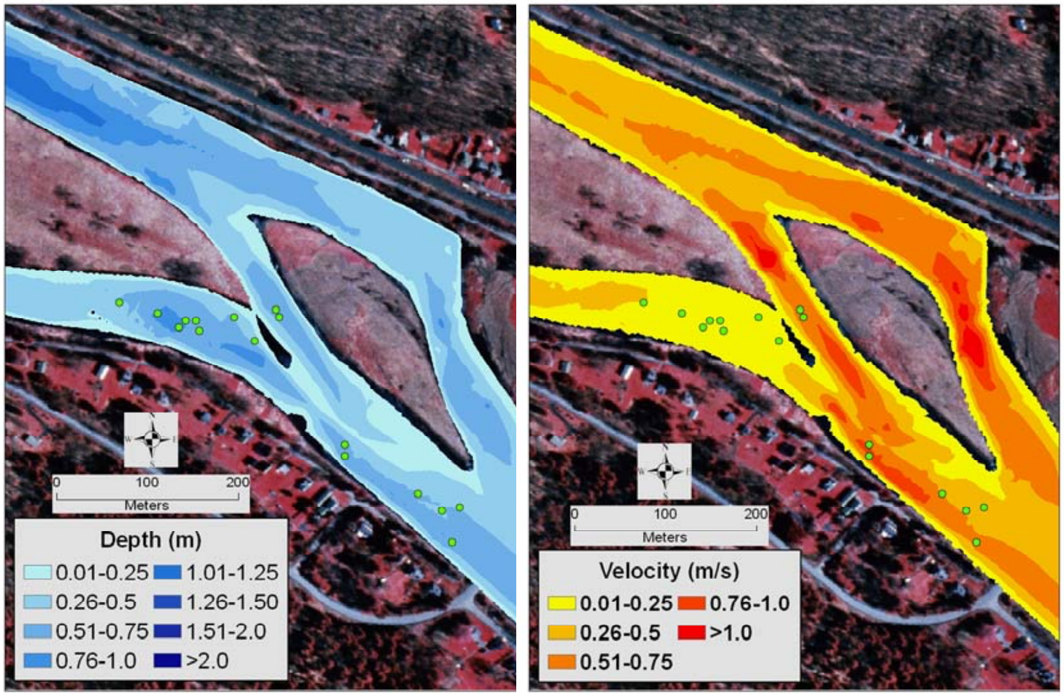

Figure 49. Depth and velocity distributions at DEL3 for the approximate discharge at which dwarf wedgemussel (*Alasmidonta heterodon*) observations (green dots) were made during 2002.

DRDSS Demonstration Run

To illustrate the operation and interpretation of Version 2.11 of the DRDSS, we performed an analysis of two alternative operating plans developed through the Commission and sanctioned by the Decree parties, known as Revision 1 and Revision 7. For this demonstration, we used the OASIS output for Revision 1 to serve as the baseline condition.

The intent of Revision 7 was to increase the lowest discharges that had occurred under Revision 1 to provide more habitat area during the (presumed) most limiting flow events in each hydroperiod. This objective was achieved in OASIS by withholding releases from the reservoirs during periods of relatively higher inflows, and releasing additional water when needed to meet downstream flow targets. Figure 50 shows flow duration curves for the two West Branch sites during hydroperiod 1 to illustrate the general changes in streamflow that resulted from the imposition of the Revision 7 rules for the water years 1990–2000. The basic pattern of change was to reduce flows in the intermediate range and increase the magnitudes of the lowest flows, as indicated by the differences between the solid and dashed lines on figure 50. Similar changes occurred in the other rivers and hydroperiods, with some subtle differences. Figure 51 shows the changes in storage volume at the three reservoirs that resulted from Revision 7. Essentially, storage was kept the same or somewhat higher under Revision 7, which may have provided the buffer needed for higher releases during low flow periods.

For this demonstration run, we used the “normal” meteorological data set and left all the adjustable scoring thresholds at their default values, except for the temperature threshold for the main stem Delaware, which was set to 25ºC. Summary results for the run are shown in figure 52.

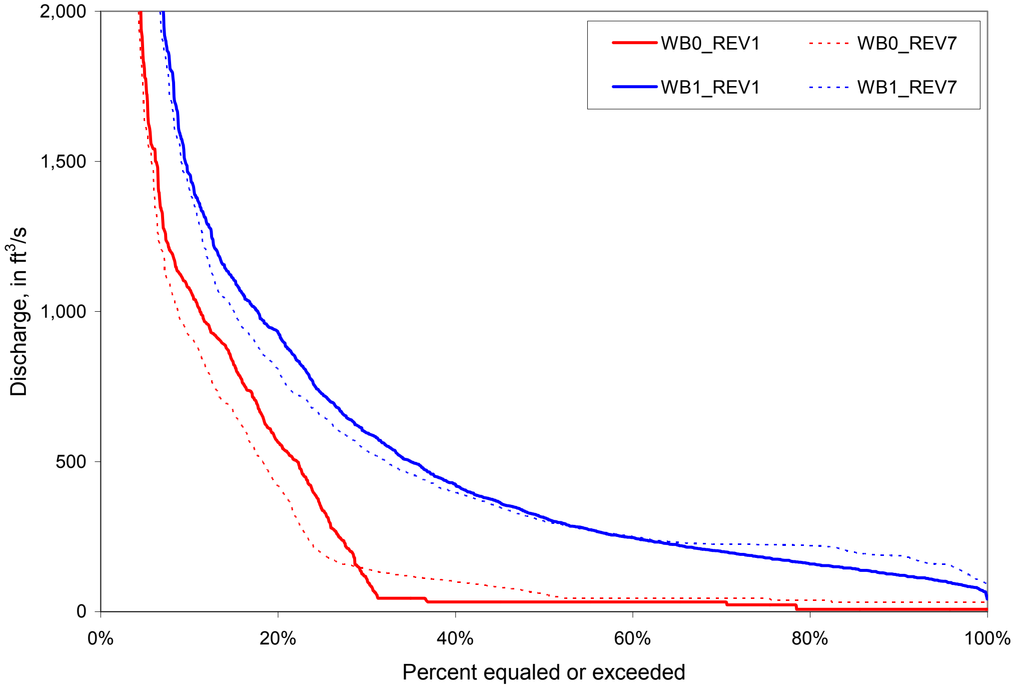

Figure 50. Flow duration curves for sites WB0 and WB1 on the West Branch, for hydroperiod 1 (October–April) from water years 1990–2000, under the operating rules for Revision 1 and Revision 7.

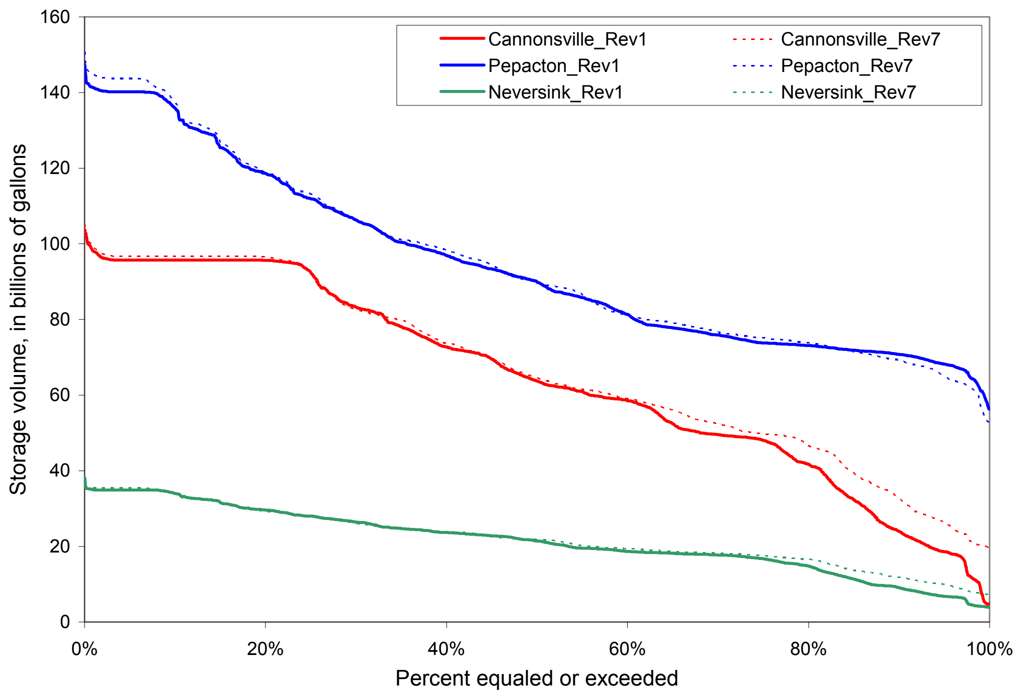

Figure 51. Storage duration curves for the three New York City reservoirs, for hydroperiod 1 (October–April) from water years 1990–2000, under the operating rules for Revision 1 and Revision 7.

Delaware DSS	**Run Date:**	**11/06/06**	**Start date**		**End**
Provisional Version 2.11	**Baseline:**	**Rev1**	**10/1/1990**	**to**	**9/29/**
Summary	**Alternative:**	**Rev 7**	**10/1/1990**	**to**	**9/29/**

October - April 15

Resource	**West Branch** Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	**East Branch** Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	**Main Hancock-Callicoon** Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	**Neversink** Pct Chg
Trout Adult, ha	21%	13.50			8%	12.31			2%	7.80			
Trout Spawning/Incu, ha	91%	2.39			3%	0.10			1%	0.06			
SSCV, ha	8%	1.11			-9%	**-2.54**			0%	0.04			
SFCV, ha	52%	2.44			41%	1.04			1%	0.02			
Shad Juvenile, ha													
Shad Spawning, ha													
Dwarf Wedge Mussel, ha									3%	0.08			
Spills, minor, count	-6%	-1.00			14%	**1.00**							
Spills, moderate, count	13%	**2.00**			15%	**2.00**							
Spills, major, count	-13%	-2.00			-14%	-4.00							

April 16 - June

Resource	West Branch Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	East Branch Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Main Hancock-Callicoon Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Neversink Pct Chg
Trout Adult, ha	16%	11.47	16%	11.41	4%	6.77	4%	6.84	1%	3.25	1%	2.50	
Trout Spawning/Incu, ha													
SSCV, ha	2%	0.24	2%	0.24	-4%	**-0.84**	-3%	**-0.77**	0%	0.02	0%	**0.00**	
SFCV, ha	11%	0.40	11%	0.40	8%	0.24	8%	0.24	0%	0.02	0%	0.01	
Shad Juvenile, ha													
Shad Spawning, ha					16%	5.50	16%	5.50	5%	6.50	4%	6.10	
Dwarf Wedge Mussel, ha									0%	**-0.02**			
Spills, minor, count	0%	0.00			14%	**1.00**							
Spills, moderate, count	0%	0.00			-21%	-8.00							
Spills, major, count	0%	0.00			-5%	-2.00							

July - September

Resource	West Branch Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	East Branch Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Main Hancock-Callicoon Pct Chg	Δ Hab	Pct Chg	ΔTCondHab	Neversink Pct Chg
Trout Adult, ha	-2%	**-1.45**	-2%	**-1.45**	16%	23.40	16%	22.86	-1%	**-2.52**	-2%	**-7.48**	
Trout Spawning/Incu, ha													
SSCV, ha	22%	3.06	22%	3.06	-10%	**-3.29**	-10%	**-3.27**	2%	0.80	1%	0.44	
SFCV, ha	85%	5.19	85%	5.19	-4%	**-0.72**	-4%	**-0.71**	11%	1.50	10%	1.38	
Shad Juvenile, ha					9%	7.48	9%	7.48	1%	2.11	-1%	**-1.59**	
Shad Spawning, ha													
Dwarf Wedge Mussel, ha									-5%	**-0.34**			
Spills, minor, count	0%	**Base, Alt =0**			0%	**Base, Alt =0**							
Spills, moderate, count	0%	0.00			0%	0.00							
Spills, major, count	0%	**Base, Alt =0**			0%	0.00							

Full Period Scores

	West Branch Pct Chg	Δ Days	Pct Chg	ΔDegDays	East Branch Pct Chg	Δ Days	Pct Chg	ΔDegDays	Main Hancock-Callicoon Pct Chg	Δ Days	Pct Chg	ΔDegDays	Neversink Pct Chg
Δ Days > Threshold C	0%	0.00	-2%	-0.14	0%	0.00	-1%	-0.13	150%	**6.00**	399%	**4.97**	

Global Scores

Montague Flow	Pct Chg	Δ Days	**Out of System Deliveries**	Pct Chg	Δ Days
Montague, minor shortage	-27%	-113.00	NYC, minor shortage	0%	0.00
Montague, moderate shortage	-22%	-19.00	NYC, moderate shortage	0%	**Base, Alt =0**
Montague, major shortage	0%	**Base, Alt =0**	NYC, major shortage	0%	**Base, Alt =0**
Montague, cfs-days	-24%	-12464.00	New York City, bg	0%	Base, Alt =0
System Drought	Pct Chg	Δ Days		Pct Chg	Δ Days
Days at Level 1	-22%	-92.00	NJ, minor shortage	0%	0.00
Days at Level 2	39%	**89.00**	NJ, moderate shortage	0%	**Base, Alt =0**
Days at Level 3	0%	**Base, Alt =0**	NJ, major shortage	0%	**Base, Alt =0**
			New Jersey, bg	0%	Base, Alt =0
System Storage, bg	0%	-2358.70			

Run Settings

Maximum Water Temperature (degrees C)	West Branch	20	New York Diversion Magnitude (% minimum delivery)
	East Branch	20	
	Main Stem	25	
	Neversink	20	New York Diversion Magnitude (% minimum delivery)
Spill Magnitude (% outflow capacity)	Mild, <	10	
	Major, >	50	Meterological Series
Montague Shortage Magnitude (% minimum flow)	Mild, <	10	
	Major, >	50	

Figure 52. Summary scores page for DRDSS demonstration run comparing Revision 1 and Revision 7 alternatives.

Based on the information summarized in figure 52, one could conclude that for most of the decision variables considered, Revision 7 resulted in improved or unchanged conditions compared to Revision 1, at least for the decade of the 1990's. The incidence of minor-to-moderate spill events from Cannonsville Reservoir increased during hydroperiod 1, from Pepacton Reservoir during hydroperiods 1 and 2, and from Neversink Reservoir during hydroperiod 3. Water deliveries to Montague, New York City, and the D&R diversion appeared to have improved or remained the same under Revision 7 operations. The only biologically-oriented warning flag occurred in the main stem Delaware, where the temperature threshold of 25ºC was exceeded on six more days under Revision 7 than under Revision 1.

Discussion

One of the most important characteristics of the DRDSS is its feedback mechanism. The primary driver of the DRDSS is the OASIS model, the output of which serves as input to a network of linked habitat and temperature models. This characteristic results in a cascading effect among the decision variables. For example, a simple change to the rule curves for one reservoir in an OASIS run can propagate throughout the hydrologic network, influencing the operations of other reservoirs, the magnitude and timing of stream discharges, the habitat dynamics of the receiving streams, and summer water temperatures. Feedback can be highly informative because it can reveal unanticipated consequences from a proposed action. Feedback can also be frustrating for the same reason, sometimes tempting decisionmakers to assume that something was wrong with the models, rather than examining their own paradigms and assumptions. From a pragmatic viewpoint, decisionmaking based on model output should consist of at least two separate processes: interpretation and evaluation. Interpretation refers to understanding the cause and effect relations between an input scenario and the results displayed in the decision support system. Evaluation refers to judging the relative degrees of success or failure to meet the multiple objectives of a scenario. Interpretation is necessary to determine why a certain outcome was produced. Evaluation is necessary to determine whether one alternative is substantially "better" than another. Both processes should include an understanding and acknowledgement of limitations of the models (including OASIS), as well as any preconceived notions of what the model results should have been.

Interpretation of Results

In the DRDSS, instream habitat is defined by the interactions among discharge, gradient, channel structure, and the physical requirements of the aquatic organisms. With a few exceptions, a typical response function between discharge and habitat area appears as a skewed bell-shaped curve, or in the case of persistent habitat, as a dome-shaped surface. The common characteristic of these functions is that habitat area tends to increase as discharge increases in the low-to-moderate flow range, but then decreases as discharge continues to increase. Where channel structure and gradient are similar, the peak of the habitat-discharge curve would be expected to occur at or near the same relative (normalized) discharge, although the magnitude of habitat area will vary as a function of channel width and concomitant surface area, as illustrated in figures 18–23.

In contrast, shallow-slow habitat types in streams dominated by single-thread channels (see appendix 1) generally exhibit a monotonic decline as discharge increases. Shallow-fast habitat types respond to flow in a similar fashion, but to a lesser degree (for example, figs. 18 and 19). This response is caused by increased depth and velocity as discharge increases, resulting in less area of shallow water (affecting habitat for both guilds) and slow water (affecting habitat for the shallow-slow guild). However, another characteristic of these habitat types is a leveling-off or increase in habitat area at very high flows, where new areas of shallow water are created as islands and floodplain areas are inundated. A comparison of figures 18 and 19 with figures 20–23 illustrates the fundamental conflict between shallow water habitats and the deeper habitats utilized by adult or juvenile fish. Flows that result in increased habitat for one group tend to reduce habitat for the other group.

Another common "within-resource" conflict occurs between shallow-slow habitat area and stream water temperature. Increasing flows to achieve lower temperatures will often result in a reduction in shallow-slow habitat areas. Conversely, attempts to mitigate habitat reductions associated with high flows may have the unintended consequence of elevated water temperatures, especially at downstream locations during late spring and summer.

A scenario designed to increase the magnitude of low flows is usually presumed to result in an overall increase in habitat area. When the results displayed in the DRDSS show no change or a negative change, one or two causal factors are often to blame. One common mechanism is reservoir depletion resulting from excessive releases to augment instream flows for habitat improvement. In this case, habitat area may be substantially increased during part of a hydroperiod, but decreased later in the season as reservoir storage is exhausted. The most immediate confirmation that this phenomenon has happened is a review of the flow and storage time series plots on the "FlowPlots" page of the DSS_AGG.xls master workbook. Symptoms of the mechanism are also expressed on the summary scoring page by an increase in the frequency of drought watches and warnings associated with the scenario. Review of the habitat duration series in the subsidiary notebooks can also be used to determine the day-to-day response of habitat to a scenario. It is worthwhile to review these graphics routinely, because they may show a counterbalancing increase and decrease in habitat area throughout the hydroperiod despite little or no change to the average for the period. Then, the decisionmakers must evaluate the outcome to determine whether the change was positive, negative, or neutral.

The second common mechanism for a counterintuitive result (reduced habitat area associated with increased base flows) is that the scenario may have resulted in an increased frequency of high flow events. An increase in the frequency of spills displayed on the summary scoring page is symptomatic of this feedback mechanism. To help identify potential feedback surprises, is advisable to generate flow duration and storage duration curves (for example, figs. 50 and 51) as routine input to the decision process. This simple step will provide early indications whether the scenario performed hydrologically as it was intended, or whether the scenario created unforeseen consequences.

Evaluation of Results

Public decisions are rarely made unilaterally. Those that are tend to be either inconsequential or short-lived. Nor are decisions made with complete and perfect information. Decisionmaking can be complicated by agency policies, values, assumptions, and paradigms that transcend the relatively simple processes of data interpretation and quantification. Not all the members of the Decree parties, the Commission, and the Subcommittee likely share a universal set of values, goals, and objectives related to the upper Delaware. One of the reasons for inclusion of global variables such as water deliveries to New York City, Montague, and the D&R Canal was to display the consequences of a management action to both water users and habitat resources. Developing shared ownership in the values and objectives of all parties is a worthwhile goal, and the DRDSS may facilitate progress toward that goal.

A frequent complaint of groups involved in multiple-use resource management is that there is insufficient (or irrelevant) information on which to base a decision. Through our interactions with the major stakeholders on the upper Delaware, we have attempted to provide accurate, realistic, and relevant information by way of the DRDSS. In contrast to the complaint of insufficient information, the DRDSS may produce too much information, in too many places, for easy comprehension. The structure of the system was designed to provide a broad overview for the "big picture" decisionmaker, with increasingly detailed information available for diagnostics and interpretation. The advantage of the summary scores page is that it provides a compact synopsis of the results of a scenario run. The disadvantage is that the synopsis can mask undesirable results (or causes) that can only be detected by examination of the duration series plots and duration curves. Therefore, the summary scoring page alone can be misleading.

Evaluation of alternatives also involves trade-offs, both between and among resources. It would be nearly impossible to derive an alternative that caused every cell on the summary page to turn green. Many of the values embodied by the scoring variables of the DRDSS work at cross purposes, which is a true reflection of the environment in which many water management decisions are made. In this sense, the DRDSS provides a modicum of realism with regard to the decision environment. Several techniques can be used to ameliorate some of these inevitable conflicts: establishing context, using adaptable management objectives, and developing contingencies.

Establishing Context

Loosely translated, establishing context means that a red cell on the summary scoring page is not necessarily a bad thing, and in fact, may be a positive outcome depending on one's perspective. For example, the summary scoring sheet for the Revision 1 and Revision 7 comparison (fig. 52) indicated an increase in temperature threshold violations in the main stem Delaware sites under Revision 7. In order to evaluate the biological ramifications of this temperature increase, the context of the change both in terms of magnitude and time scale should be examined. The average magnitude of the temperature change can be determined by dividing the degree-day sum in column M of the scoring summary by the days in column K (in this case, 4.97 ºC-days /6 days = 0.83ºC). Although the average threshold violation will not distinguish between six days at 0.83ºC above the threshold or one day at 4.0ºC and five at 0.2ºC above the threshold, it provides an indication of the relative severity of the problem. Examination of the temperature duration curve for the period (fig. 53) shows that the incidence of temperature threshold violations increased from about 0.1 percent of the time under Revision 1 to 0.5 percent of the time under Revision 7. Although the change represents a fivefold increase in the frequency of threshold violations, the data indicated that violations in either case occurred less than 0.5 percent of the time. That fact, combined with knowledge of the probable magnitude of the temperature change for this example, may suggest that the temperature flag on the scoring summary is not serious and could be ignored. Figure 53 also reveals that temperature generally increased across all time periods under Revision 7, but consistently remained below the threshold. This result suggests that temperature conditions may not have deteriorated significantly for salmonids and may have improved for the native species of concern.

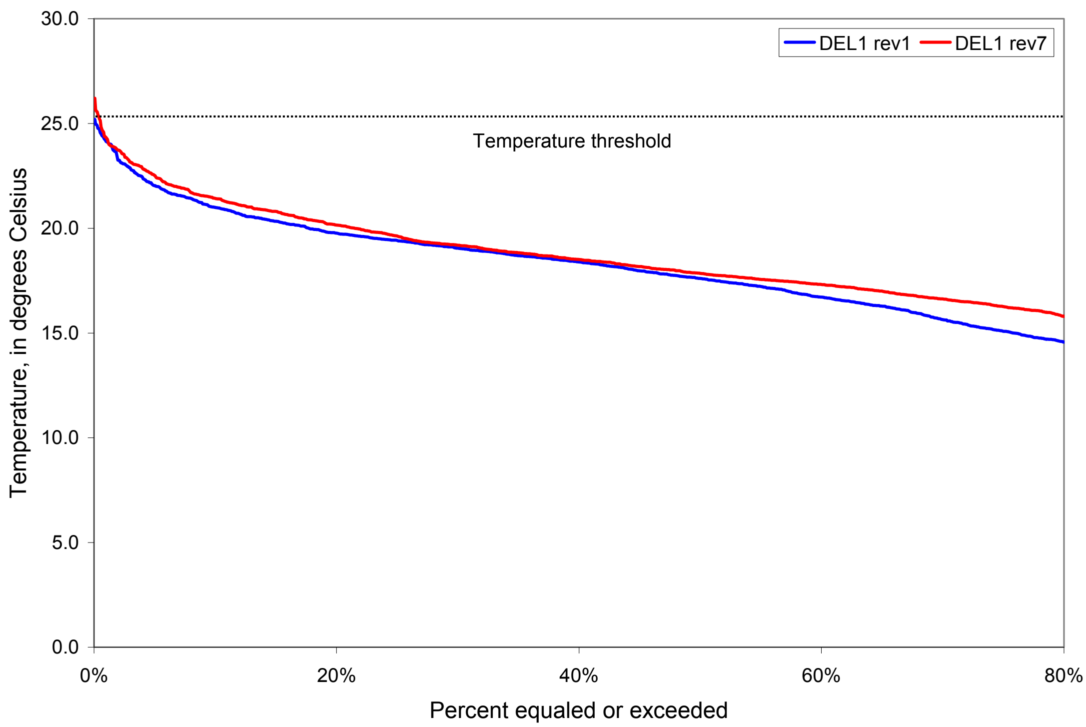

Figure 53. Temperature duration curves for the period May 1–September 30, 1990–2000, for Revision1 and Revision 7 alternatives at site DEL1.

Adaptable Management Objectives

Habitat management decisions must evaluate the differential responses of multiple habitat types to changes in flow. The issue is whether stream fish populations actually respond to habitat changes described by the model over spatial and temporal scales that are relevant to the decisionmakers. For example, a system managed consistently (and successfully) to increase habitat types related to reproduction and recruitment may eventually experience an increase of juvenile and adult fish density to the point that habitat for these life stages becomes a limiting factor. Furthermore, one might expect a shift in the size distribution of the population, with an abundance of relatively small members and a paucity of large fish. Conversely, managing to consistently favor adult habitat could result in population decline over time owing to insufficient recruitment. Adaptive management objectives are designed to manage habitat for different life stages or species periodically and opportunistically. Because shallow-slow habitat tends to be limited at high flows (fig. 18), it might be advantageous to manage flows to favor adult and juvenile habitat during wet years, and flows favoring spawning-incubation and young of the year habitat during dry years.

Contingency Planning

The physical feasibility of a management alternative in the DRDSS is a function of water supply, storage volume, and cumulative demand. When the demand exceeds the supply for a sufficient time period, the alternative is considered infeasible, at least for that time interval. In this context, it is highly unlikely that a single-alternative operating policy will be feasible everywhere at all times. A contingency plan acknowledges this fact and anticipates operational changes needed to ameliorate the mismatch between supply and demand. In practice, contingency plans are already imbedded within the OASIS model. For example, the delivery targets for New York City, Montague, and the D&R canal are scaled back when system inflow and reservoir storage fall to specified trigger levels. Likewise, reservoir releases for habitat maintenance may be reduced during drought periods, although in some cases reserves may be released to reduce impacts of low flows on temperature or habitat.

Because contingencies are intrinsic to OASIS, it is incumbent upon users of the DRDSS to recognize that developing an operating scenario will likely involve modification or redefinition of the rules of engagement for those contingencies. Several aspects of contingency planning should be observed when such modifications are made. First, how often and under what circumstances will normal operations fail due to insufficient water supply? Second, what trigger levels are imbedded in the operational rule curves to modify releases or exports? Third, how are allocations changed among downstream releases, deliveries, and exports during shortages?

The frequency of failure under normal operating conditions is somewhat a matter of context. If an operating scenario only fails once every 20 years, it may not be worth worrying about in a strategic planning mode. If it fails over 75 percent of the time (for example), perhaps another alternative should be considered. Although failure might be too strong a term, an increase in the frequency of days under the various levels of system drought displayed on the scoring summary page (fig. 52) should serve as a warning that normal operations cannot be sustained without causing eventual problems. Review of the storage duration curves (fig. 51, for example) will reveal which reservoirs are most affected and the respective probabilities of contingency-triggering events.

The circumstances leading to imposition of one of the drought rule contingencies result from cumulative demands exceeding inflow for a sufficient period of time to draw the reservoirs down to their respective trigger levels. Whether this is a concern during development and evaluation of an alternative is once again a matter of context. An alternative that increases the frequency of drought watch designations, but decreases the frequency of drought warnings (the opposite of the Revision1-Revision7 comparison in fig. 54) might be perfectly acceptable. One that increases the frequency of level 3 drought designations might be unacceptable regardless of changes to the lower categories.

Global Scores					
Montague Flow	Pct Chg	Δ Days	**Out of System Deliveries**	Pct Chg	Δ Days
Montague, minor shortage	-27%	-113.00	NYC, minor shortage	0%	0.00
Montague, moderate shortage	-22%	-19.00	NYC, moderate shortage	0%	**Base, Alt =0**
Montague, major shortage	0%	**Base, Alt =0**	NYC, major shortage	0%	**Base, Alt =0**
Montague, cfs-days	-24%	-12464.00	New York City, bg	0%	Base, Alt =0
System Drought	Pct Chg	Δ Days		Pct Chg	Δ Days
Days at Level 1	-22%	-92.00	NJ, minor shortage	0%	0.00
Days at Level 2	39%	**89.00**	NJ, moderate shortage	0%	**Base, Alt =0**
Days at Level 3	0%	**Base, Alt =0**	NJ, major shortage	0%	**Base, Alt =0**
			New Jersey, bg	0%	Base, Alt =0
System Storage, bg	0%	-2358.70			

Figure 54. Expanded view of the global scores box of the DRDSS, showing changes in system drought designations under Revision1 and Revision7 alternatives.

The trigger levels for each of the drought contingency rules, along with a recent history of system storage volume, can be viewed on the web page for the Delaware River Basin Commission (*http://www.state.nj.us/drbc/nyc.htm*). The reader is advised, however, that this display and all information derived as OASIS output refer to system-wide storage rather than for individual reservoirs.

For a normal operating scenario in the DRDSS, one of the primary changes customarily made will be seasonal or monthly release targets to maintain or improve habitat and temperature conditions. These targets will likely need to be modified as part of a contingency plan. In most cases, the releases would be reduced in order to conserve storage. However, if such reductions result in unacceptable decreases in habitat it may be necessary to revise the rule curves themselves. One potential modification would be to initiate the release reduction earlier, so that the impact to habitat is less in magnitude but longer in duration. To some extent, it may also be possible to spread the impact of drought to different locations in the system by reducing releases from one reservoir in order to allow near-normal releases from another. Under true drought conditions, however, this option would necessarily be considered a short-term solution because normal releases would eventually draw the reservoir down to its drought trigger anyway.

Model Limitations and Assumptions

Since the inception of this study, we have attempted to respond to suggestions provided by the Commission and the Subcommittee to make the DRDSS relevant, realistic, and accurate. We have also strived to produce accurate and realistic input data in the form of hydraulic simulations, habitat maps, and temperature predictions. Regardless of their complexity or sophistication, all models are simplifications of the real world. In application, they may be further simplified or limited by assumptions made by their users.

In this application, we have assumed that the channels of all measured rivers are currently in a state of dynamic equilibrium as described by Leopold and others (1964). We have taken a snapshot of the stream bathymetry as it existed in 2004 and 2005. When we suspected that a site might have been altered by a large flood event, the site was resurveyed. Nonetheless, if the channels are not in dynamic equilibrium, the results of our models will become less representative of the rivers with the passage of time.

We have also assumed that our selection process produced study sites that were representative of the stream segments, that the boundary conditions we obtained from gaging station rating curves closely approximated those at the sites, and that our survey data were accurate depictions of site bathymetry. To some extent, the validity of these assumptions was supported by the similarity of the normalized flow versus habitat functions. Each stream was sampled, measured, and modeled independently. If the bathymetric and hydraulic characteristics for a site were markedly different from those of other sites in comparable settings, its response functions would have been noticeably different from the others. The similarity of the functions suggests that errors associated with sampling and data collection were consistent across all the sites, final model outputs were insensitive to these errors, or both. It is important to remember that the comparative statistics generated in the DRDSS are relative, not absolute. The advantage of relative scoring is that any inaccuracies of the models will be equally distributed in both the baseline and alternative simulations. In that sense, the effects of modeling inaccuracies are neutral.

Decision Support and Adaptive Management

A fundamental paradigm underlying the entire habitat analysis portion of the DRDSS is that fish populations respond somehow to changes in habitat. The general hypothesis is that more habitat has the potential to support more fish (or mussels or aquatic insects). Relations between habitat dynamics and population responses are more complex, however, because populations can be affected by variables not included in the habitat models, at spatial and temporal scales that are different from those incorporated in this study. As previously mentioned, conditions favoring an increase in habitat for adults of a species commonly correspond to a reduction in habitat for young of the year. As a result, an increase in adult habitat may have the unintended consequence of reducing recruitment, thereby causing a reduction in adult population over time. Indeed, the few empirical studies that have examined linkages between habitat and biology have failed to identify a unifying connection between the two. Some studies have shown strong relations between fish population size and habitat dynamics (Jowett, 1993; Nehring and Anderson, 1993; Bovee and others, 1994; Bowen, 1996; Freeman and others, 2001; Capra and others, 2003; Fjellheim and others, 2003; Souchon and Capra, 2004). Some have found no relation at all (Irvine and others, 1987; Scott and Shirvell, 1987; Zorn and Seelbach, 1995), and at least one indicated a negative relation (Garciá de Jalón and others, 1996). Dunham and others (2002) noted that the relations between habitat and fish populations in individual streams could be variable depending on biological factors, such as presence of non-native species, or spatial factors such as habitat connectivity.

Given the uncertainties of how populations or communities are influenced by habitat dynamics, the DRDSS should not be viewed as a precise indicator of population response to flow regime. The DRDSS, in its present form, can be used as a tool for strategic planning by the Commission, the Subcommittee, and the Decree parties. The DRDSS was not designed to perform as a tactical tool for daily operations and should not be used as such. Its strength is as a "hypothesis screener." The DRDSS can be used to distinguish among alternatives that may be effective or ineffective, feasible or infeasible, high-risk or low-risk. In many decision environments, such information is sufficient for policy makers to decide on a course of action and implement it. Derivation of a "good enough" solution may be "good enough," even though it may not be the most effective or lowest risk alternative.

To improve and refine the information base, the DRDSS could be used as a precursor to a process of adaptive management by identifying promising operational alternatives that could be implemented and monitored to determine outcomes. In a setting such as the upper Delaware, limited reservoir capacity and uncertain and water supplies hinder full experimental control, but partial control is possible. Experimental control could be established by implementing the baseline operations of the reservoirs as depicted in the DRDSS for several years. During that time, reservoir releases, stream discharge, habitat dynamics, and population or community-level characteristics (for example, year class strength, growth rates, condition, adult populations, and size structure) would be monitored. The experimental treatment would consist of monitoring the same variables for a similar length of time, but operating the reservoirs according the alternative depicted in the DRDSS, such as those used to generate Revision 7. Advantages to this strategy include:

1. Follow-up monitoring of flows and population dynamics could provide validation of the physical models used in the DRDSS and help define habitat and biological linkages.
2. The feasibility of implementing the operational rules of the alternative could be physically tested through day-to-day operations. Furthermore, actual operations can be compared with simulated (OASIS) operations to monitor compliance and deviations thereof.
3. Ecological resets, such as catastrophic floods, could be adapted into the experimental design. A deficiency of "natural" experiments is that they cannot always be completely or rigorously controlled. Deviations from an experimental release plan can create serious problems with a purely empirical adaptive management study because the treatment may be overridden by an uncontrolled event. The habitat impacts of such deviations predicted with the DRDSS models could be compared with biological responses as part of a revised experiment.
4. The addition of information to the body of knowledge regarding habitat dynamics and biological responses is invaluable. Not only would such knowledge benefit stakeholders and decisionmakers in the Delaware River system, it would undoubtedly be of value to others facing similar situations elsewhere.

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We received a great deal of help from a vast array of agency personnel, nongovernmental organizations, landowners, and private citizens. We are grateful to the USGS New York Water Resources Science Center in Troy, N.Y., for providing us with the rating tables we used to establish the boundary conditions at many our study sites. Logistical and field survey support was provided by the National Park Service, New York Department of Environmental Conservation, the Delaware River Foundation, the USGS Connecticut Water Resources Science Center, and the Susquehanna River Basin Commission. In particular, we acknowledge the assistance of Don Hamilton, Alan Ellsworth, Jamie Meyers, Rich Evans, Jeff Shriner, Jim Serio, Wayne Elliot, Elizabeth Ahern, Remo Mondazzi, and Krista Nelson. Leanne Hanson, Kathryn Holland, and Julie Roth from the USGS Fort Collins Science Center were mainstays during the field surveys, data preparation, and hydraulic simulations involved with this study. Our temperature analysis benefited from the contributions of many individuals, including Robert Angyal, Alan Ellsworth, Colin Apse, Jerry Butch, Wayne Elliot, Glenn Horton, Robert Klosowski, Bill Lellis, Rick Naro, Charles Olson, Margaret Phillips, Don Pierson, and Hernan Quinodoz. Thank you all for your dedication and hard work.

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Appendix 1. Proportional Planform Comparisons for Sites and Segments of the Upper Delaware River.

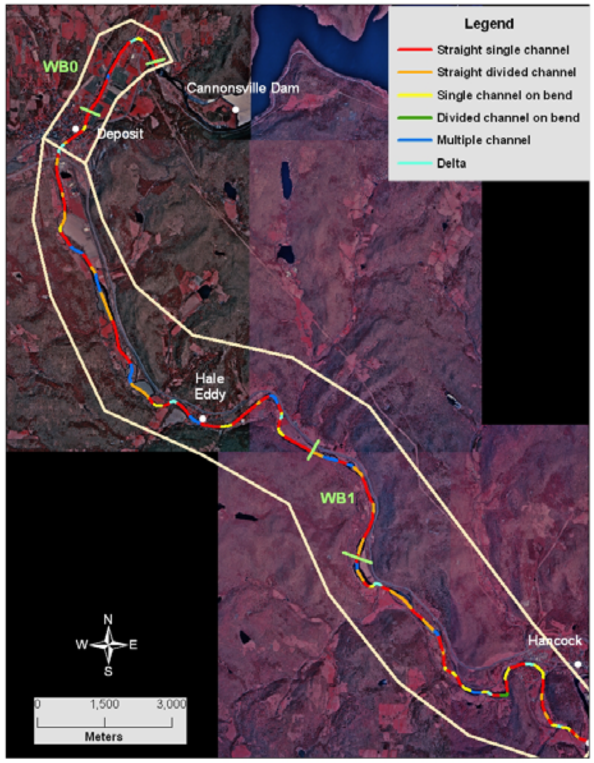
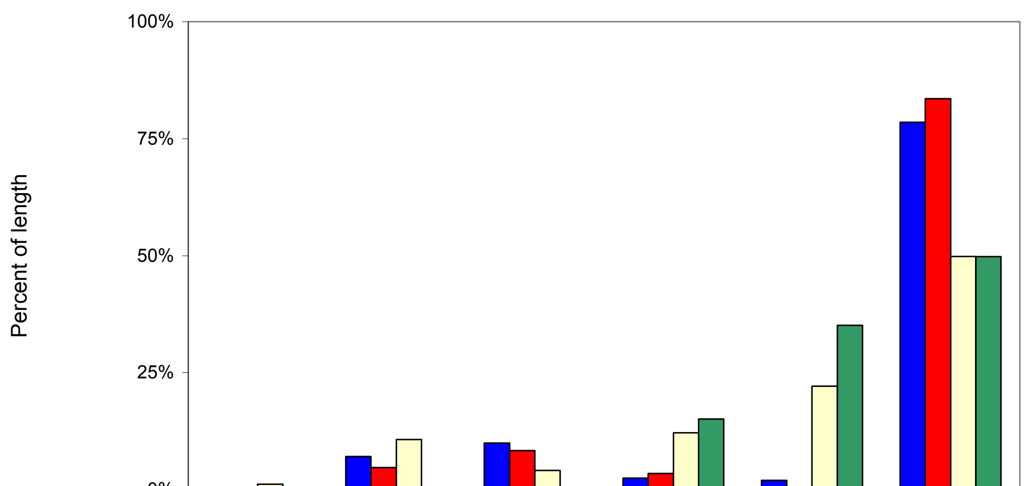


Figure 1-1. Planform map of segments and sites for the West Branch Delaware River.



	Percent divided channel, on bend	Percent single channel, on bend	Percent delta	Percent multiple channel	Percent straight divided channel	Percent straight single channel
WB0_segment	0.00	0.07	0.10	0.02	0.02	0.79
WB0_site	0.00	0.05	0.08	0.03	0.00	0.84
WB1_segment	0.01	0.11	0.04	0.12	0.22	0.50
WB1_site	0.00	0.00	0.00	0.15	0.35	0.50

Planform Type

Figure 1-2. Comparison of planform distributions between segments and sites for the West Branch Delaware River.

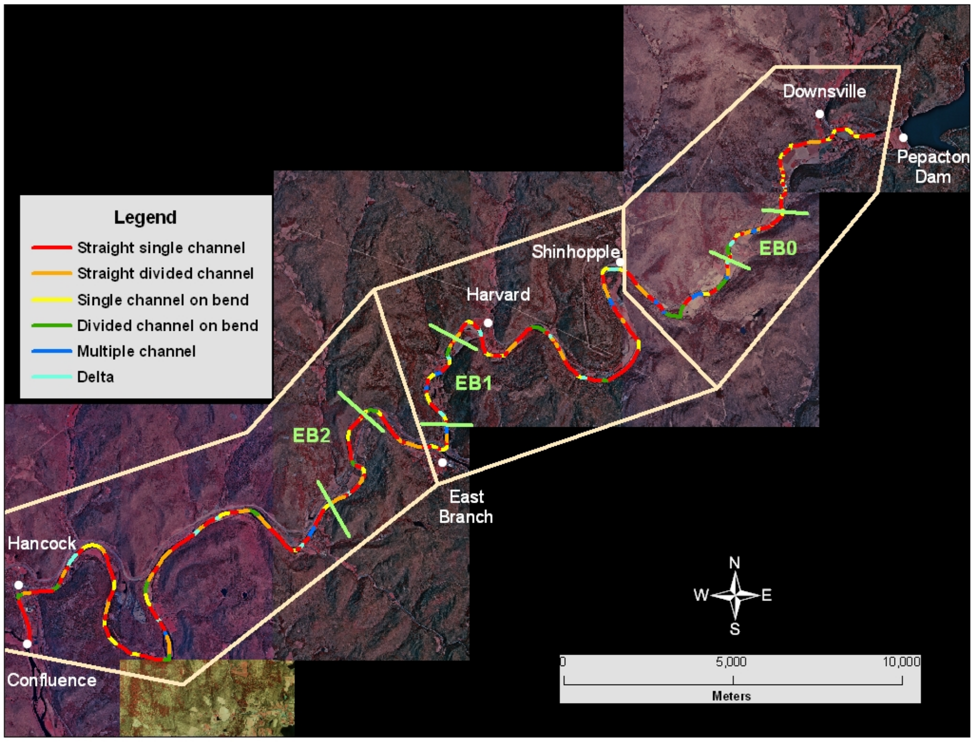
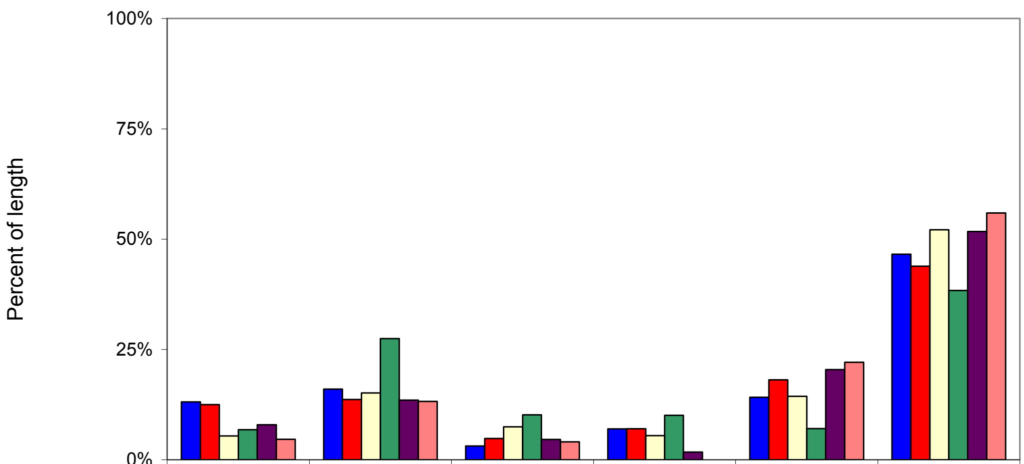


Figure 1-3. Planform map of segments and sites for the East Branch Delaware River.



	Percent divided channel, on bend	Percent single channel, on bend	Percent delta	Percent multiple channel	Percent straight divided channel	Percent straight single channel
EB0_segment	0.13	0.16	0.03	0.07	0.14	0.47
EB0_site	0.13	0.14	0.05	0.07	0.18	0.44
EB1_segment	0.05	0.15	0.07	0.05	0.14	0.52
EB1_site	0.07	0.27	0.10	0.10	0.07	0.38
EB2_segment	0.08	0.14	0.05	0.02	0.20	0.52
EB2_site	0.05	0.13	0.04	0.00	0.22	0.56

Planform Type

Figure 1-4. Comparison of planform distributions between segments and sites for the East Branch Delaware River.

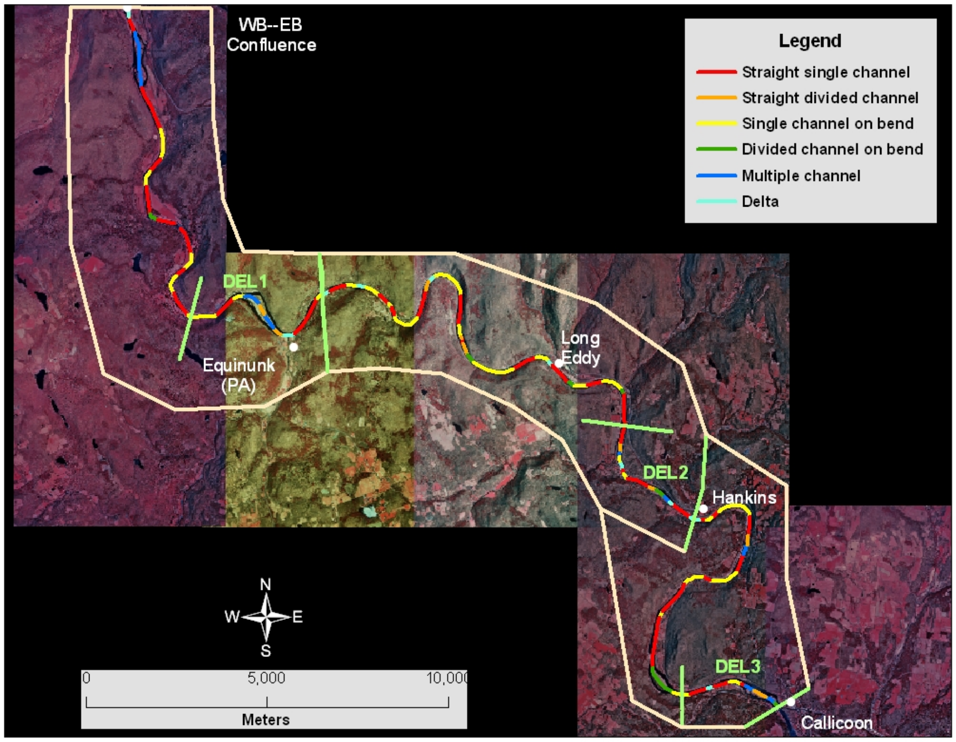
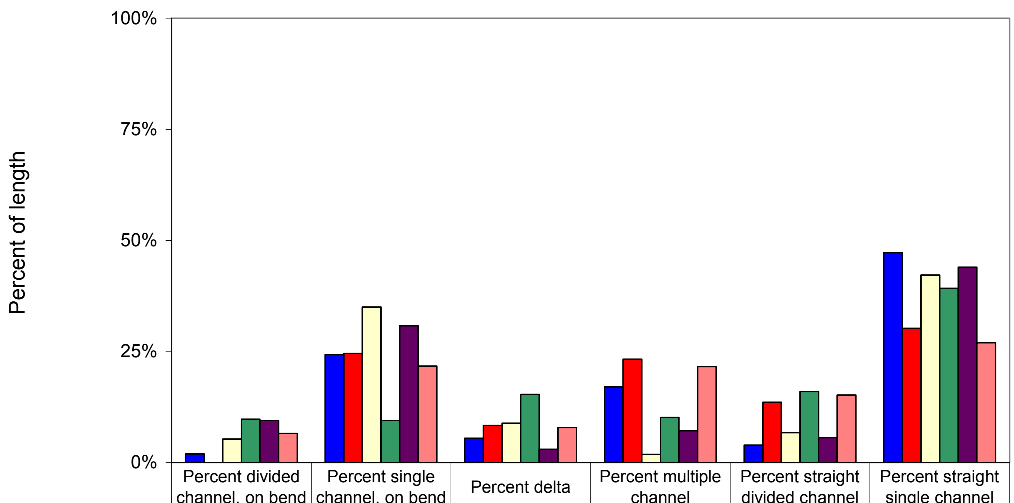


Figure 1-5. Planform map of segments and sites for the main stem Delaware River.



	Percent divided channel, on bend	Percent single channel, on bend	Percent delta	Percent multiple channel	Percent straight divided channel	Percent straight single channel
DEL1_segment	0.02	0.24	0.05	0.17	0.04	0.47
DEL1_site	0.00	0.25	0.08	0.23	0.14	0.30
DEL2_segment	0.05	0.35	0.09	0.02	0.07	0.42
DEL2_site	0.10	0.09	0.15	0.10	0.16	0.39
DEL3_segment	0.09	0.31	0.03	0.07	0.06	0.44
DEL3_site	0.07	0.22	0.08	0.22	0.15	0.27

Planform Type

Figure 1-6. Comparison of planform distributions between segments and sites for the main stem Delaware River.

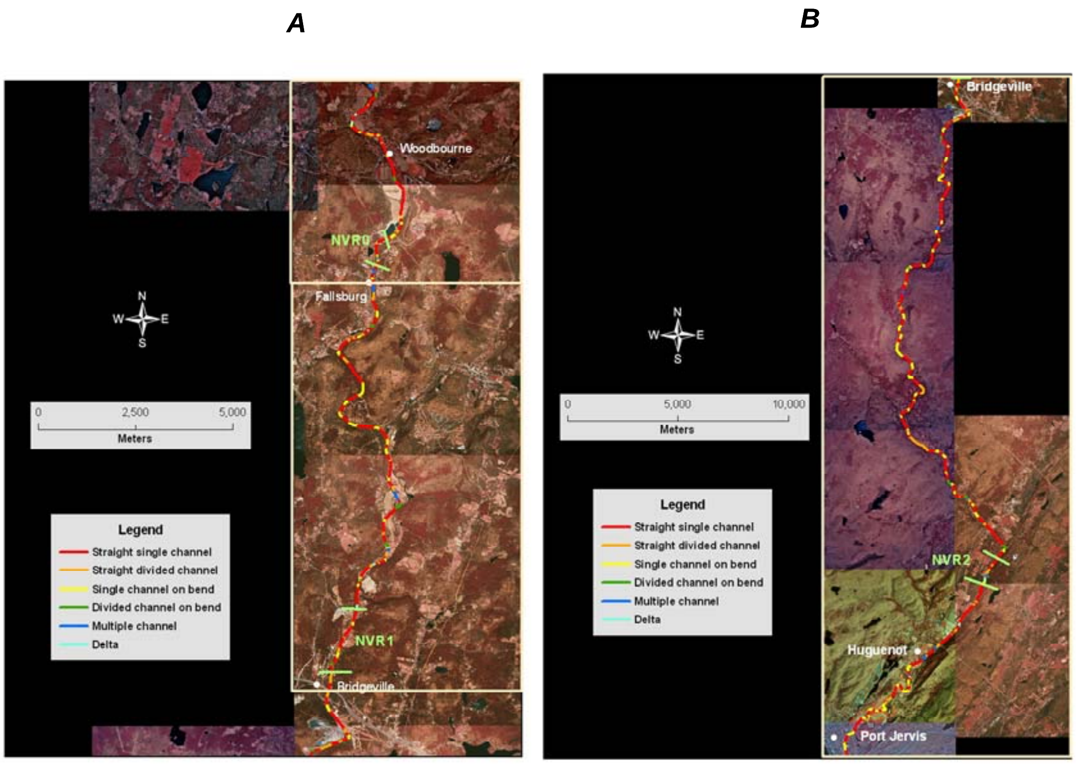
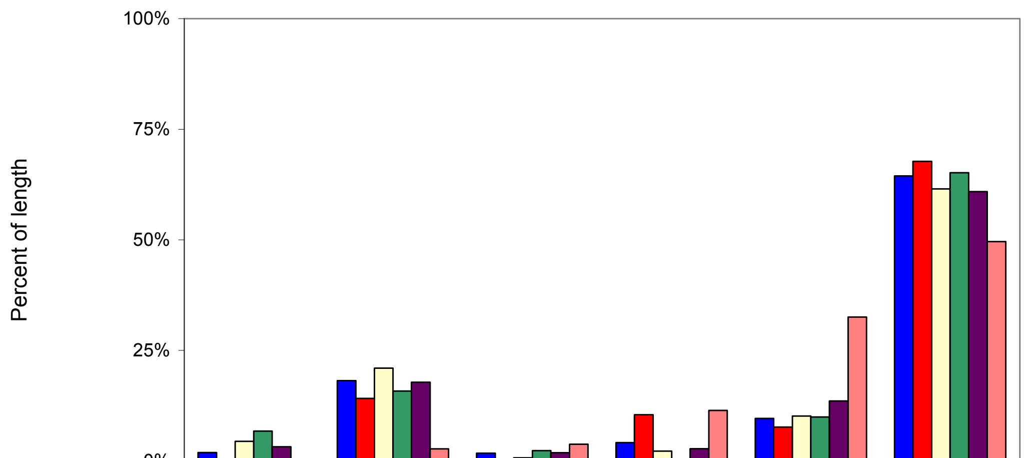


Figure 1-7. Planform maps of segments and sites for the upper (*A*) and lower (*B*) Neversink River.



	Percent divided channel, on bend	Percent single channel, on bend	Percent delta	Percent multiple channel	Percent straight divided channel	Percent straight single channel
NVR0_segment	0.02	0.18	0.02	0.04	0.10	0.64
NVR0_site	0.00	0.14	0.00	0.10	0.08	0.68
NVR1_segment	0.04	0.21	0.01	0.02	0.10	0.61
NVR1_site	0.07	0.16	0.02	0.00	0.10	0.65
NVR2_segment	0.03	0.18	0.02	0.03	0.14	0.61
NVR2_site	0.00	0.03	0.04	0.11	0.33	0.50

Planform Type

Figure 1-8. Comparison of planform distributions between segments and sites for the Neversink River.

Appendix 2. Final Calibration Results for the River2D Hydraulic Simulation Model at Study Sites in the Upper Delaware River.

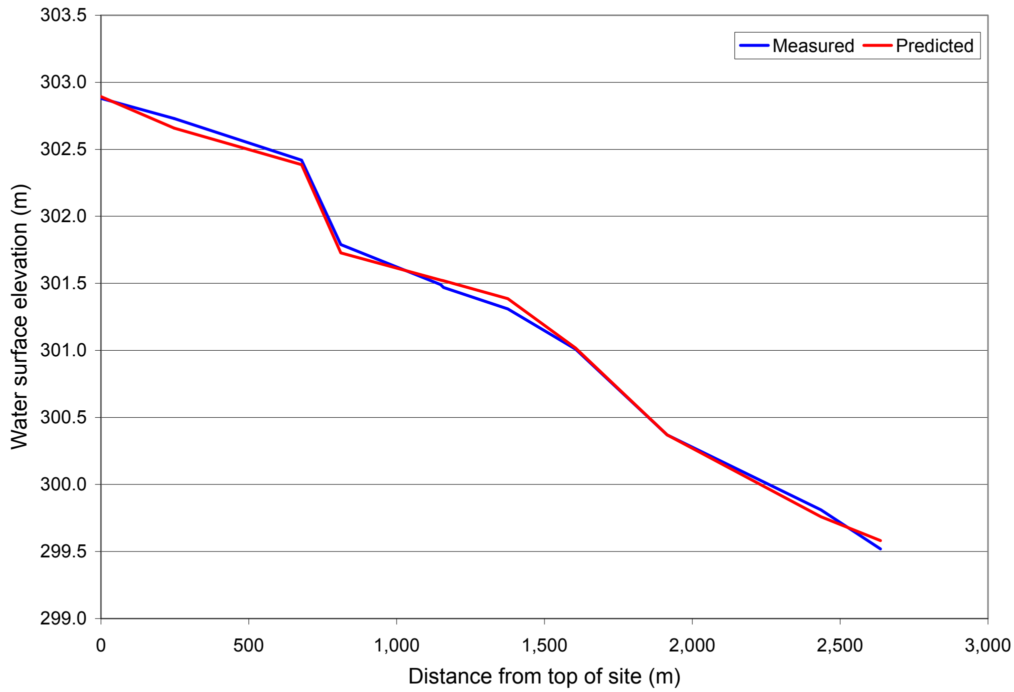


Figure 2-1. Comparison of predicted and measured water surface profiles for the final calibration run at site WB0.

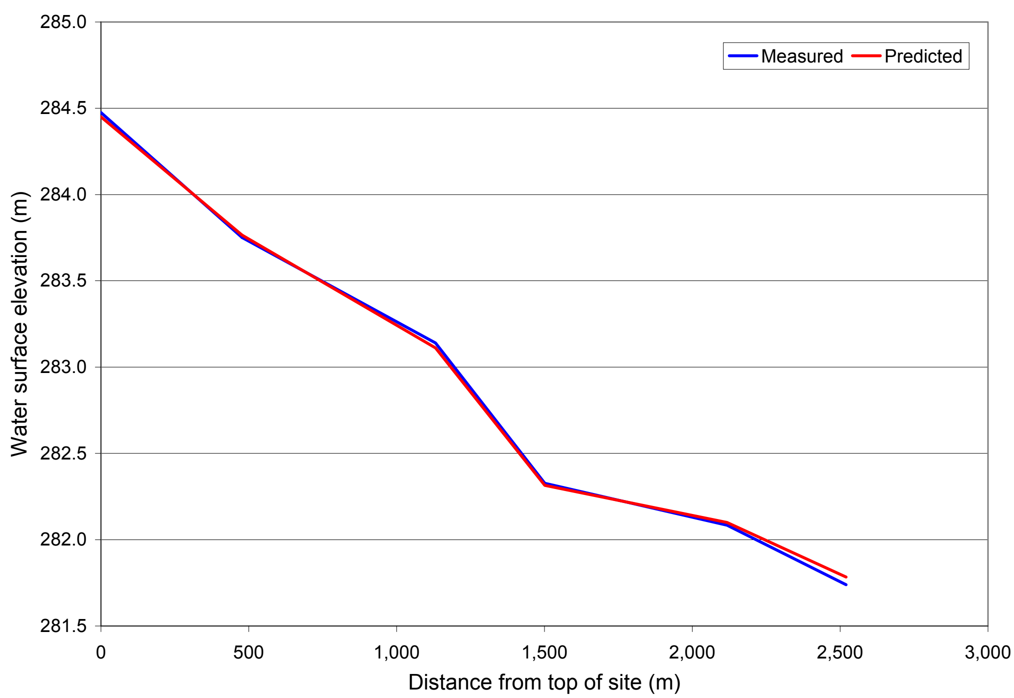


Figure 2-2. Comparison of predicted and measured water surface profiles for the final calibration run at site WB1.

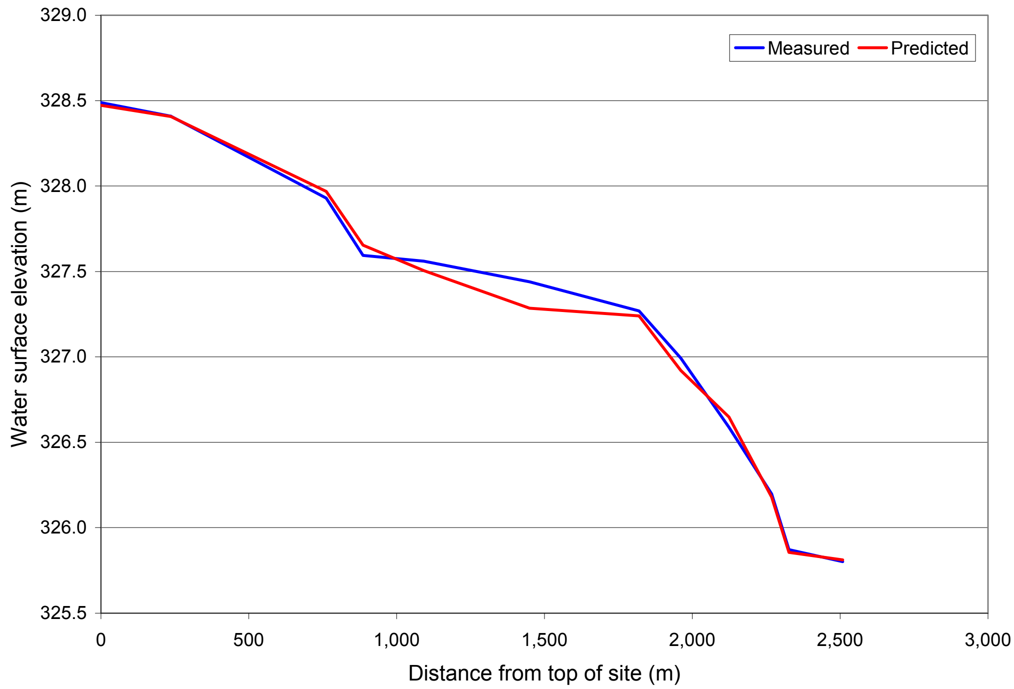


Figure 2-3. Comparison of predicted and measured water surface profiles for the final calibration run at site EB0.

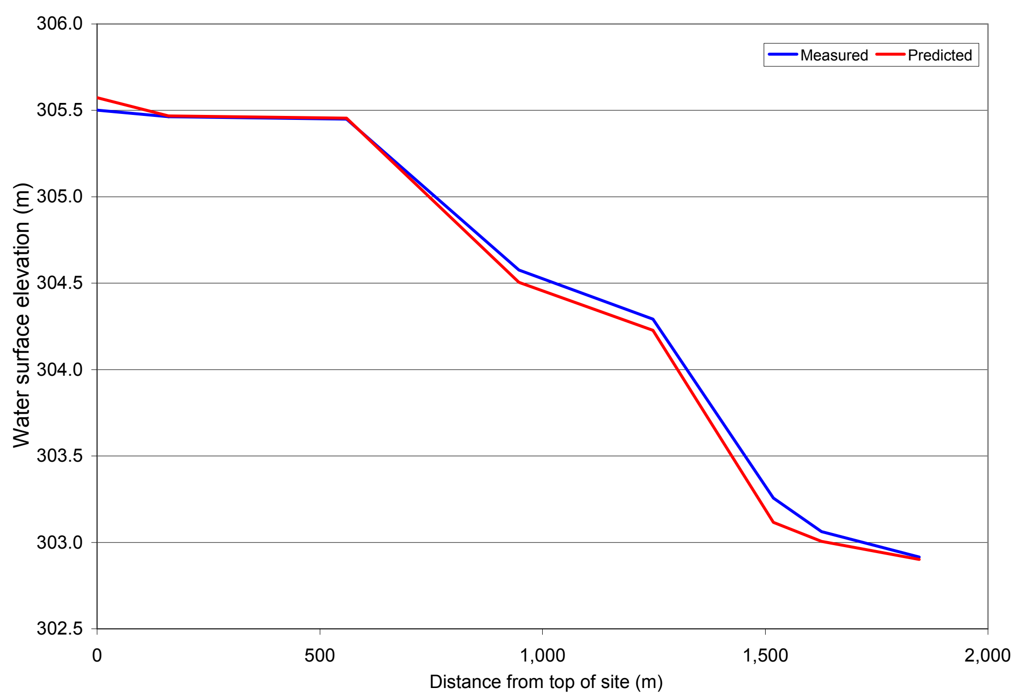


Figure 2-4. Comparison of predicted and measured water surface profiles for the final calibration run at site EB1.

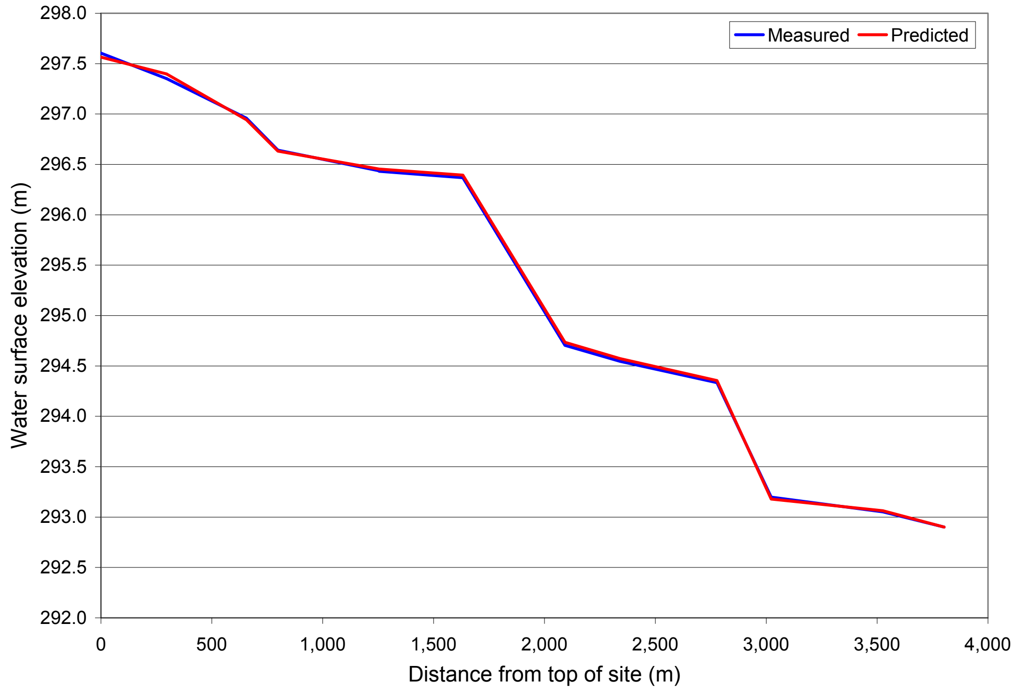


Figure 2-5. Comparison of predicted and measured water surface profiles for the final calibration run at site EB2.

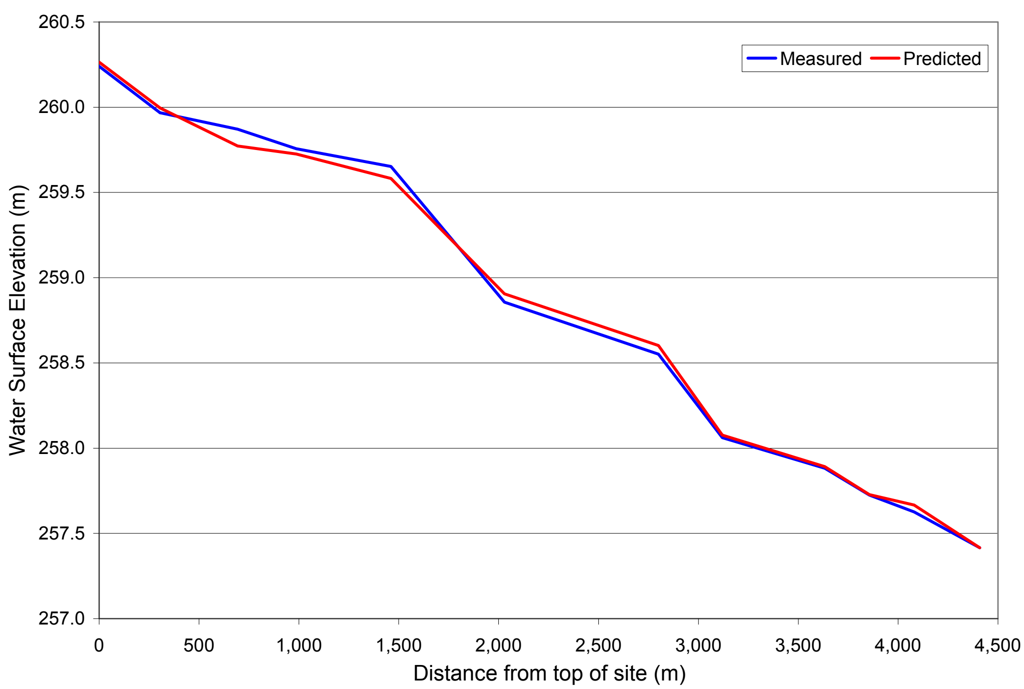


Figure 2-6. Comparison of predicted and measured water surface profiles for the final calibration run at site DEL1.

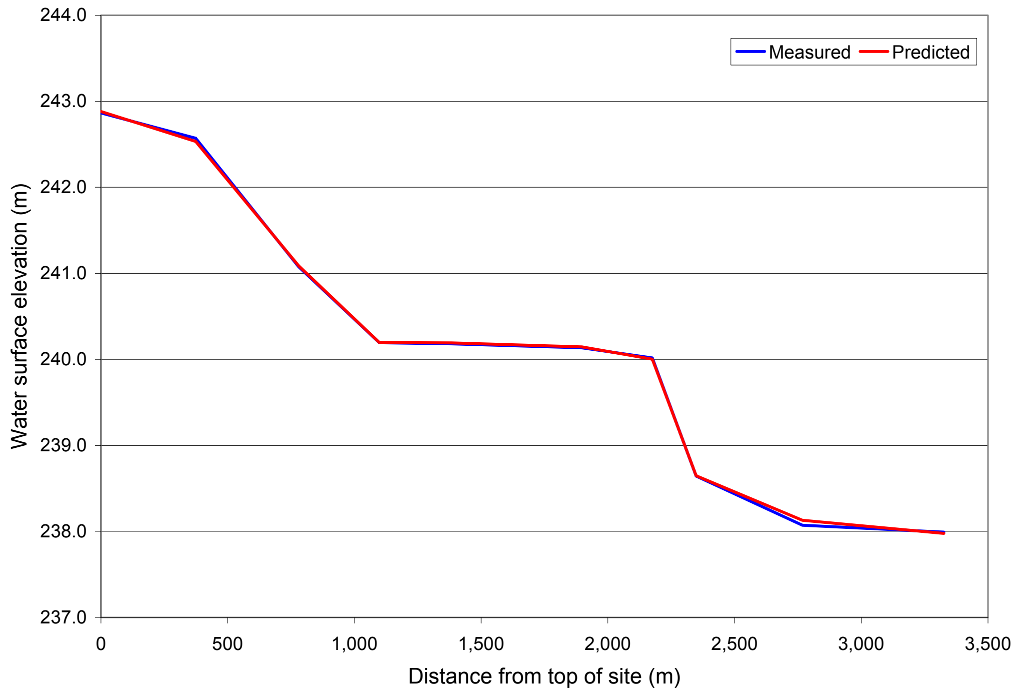


Figure 2-7. Comparison of predicted and measured water surface profiles for the final calibration run at site DEL2.

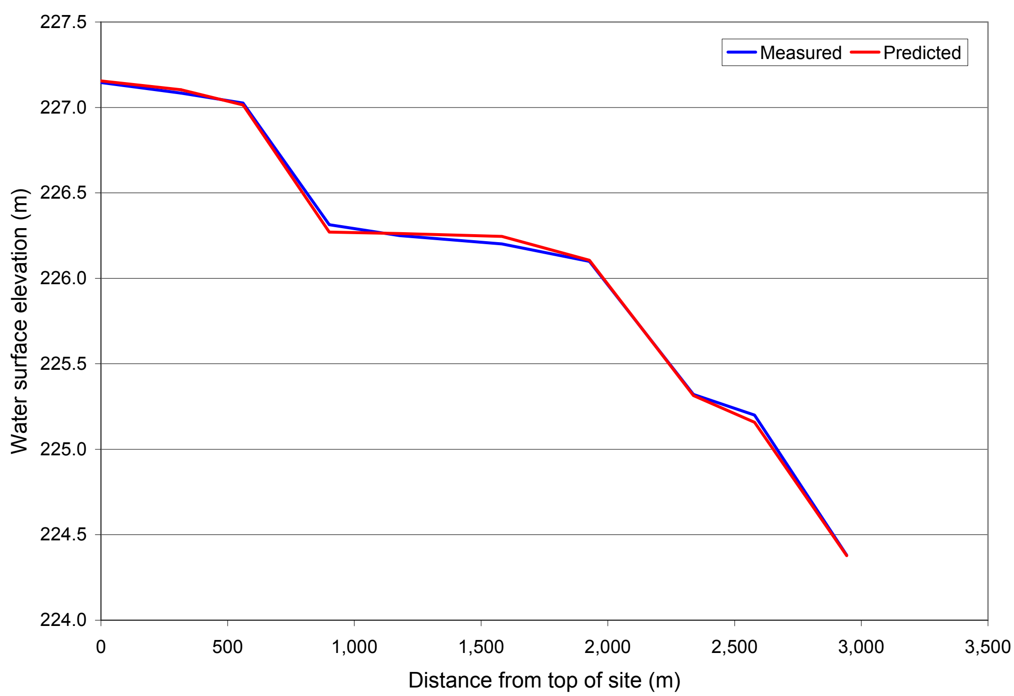


Figure 2-8. Comparison of predicted and measured water surface profiles for the final calibration run at site DEL3.

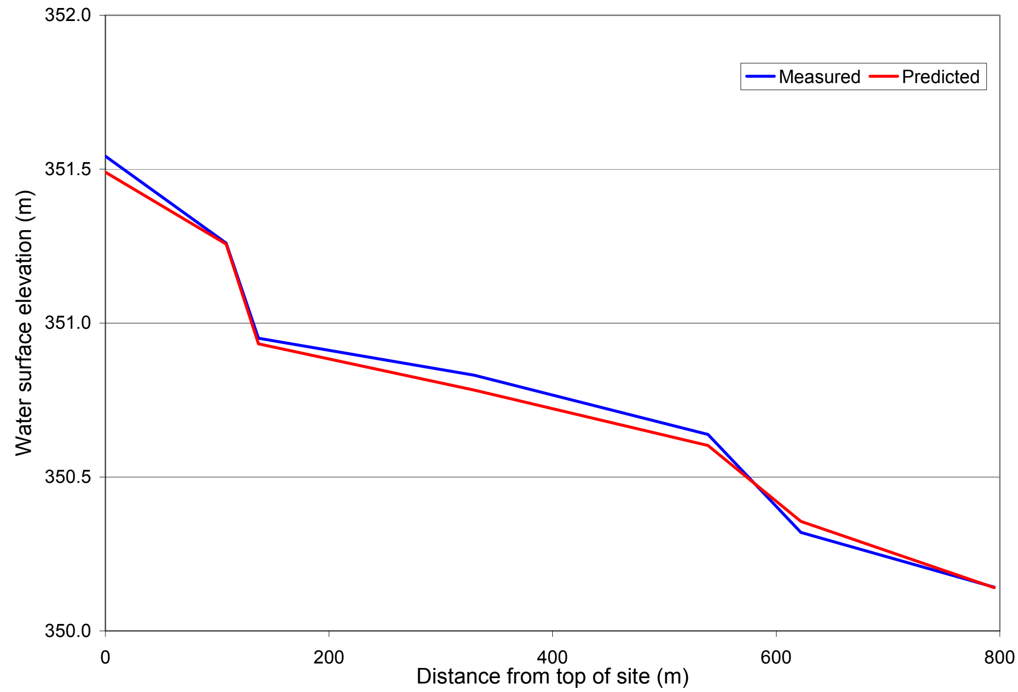


Figure 2-9. Comparison of predicted and measured water surface profiles for the final calibration run at site NVR0.

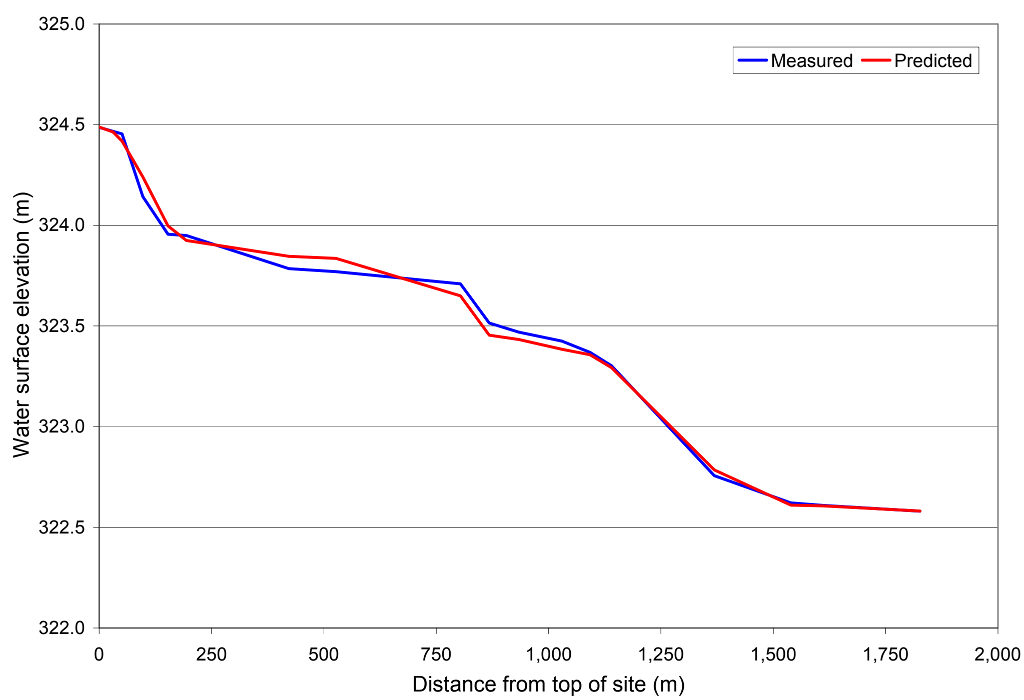


Figure 2-10. Comparison of predicted and measured water surface profiles for the final calibration run at site NVR1.

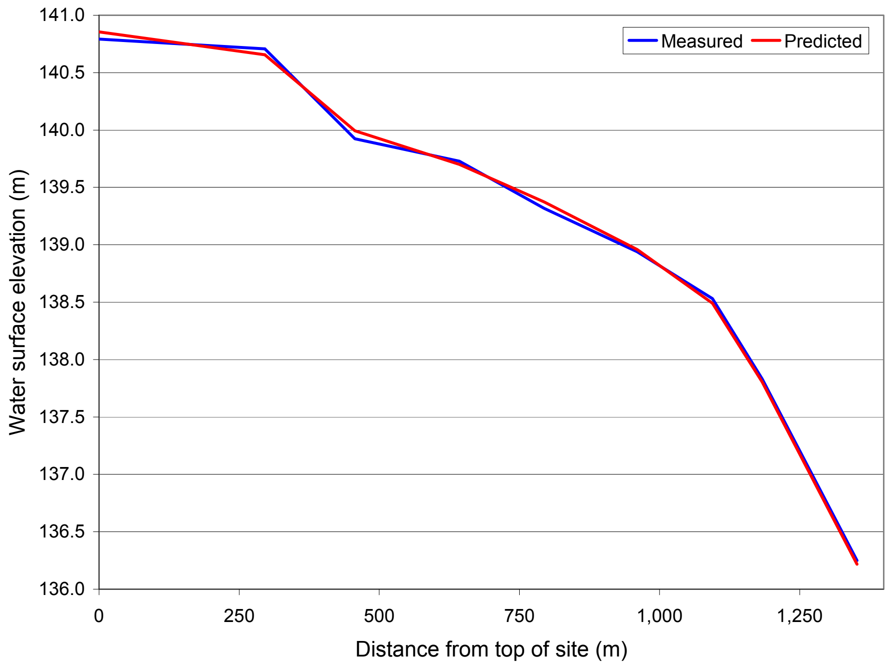


Figure 2-11. Comparison of predicted and measured water surface profiles for the final calibration run at site NVR2.

Appendix 3. Discharge Versus Habitat Area Statistics for Study Sites in the Upper Delaware River.

Table 3-1. Habitat versus discharge relations for segment 0 West Branch Delaware River (WB0).

Discharge		Brown trout adult		Brown trout juveniles		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
9	0.02	1.09	2,786	2.23	5,720	0.09	218	3.48	8,913
14	0.03	1.26	3,242	2.75	7,047	0.27	686	3.65	9,364
21	0.05	1.49	3,826	3.27	8,395	0.59	1,505	3.74	9,587
32	0.07	2.10	5,375	4.17	10,686	1.10	2,830	4.05	9,983
53	0.11	3.04	7,790	5.38	13,785	2.44	6,264	4.48	10,379
81	0.17	4.08	10,460	7.20	18,451	3.96	10,159	4.70	11,486
124	0.27	5.11	13,091	10.78	27,647	6.14	15,734	4.76	12,059
191	0.41	7.70	19,751	15.16	38,871	7.88	20,202	3.96	12,196
297	0.64	11.72	30,041	19.13	49,048	8.92	22,870	3.10	10,160
462	0.99	18.83	48,283	19.91	51,040	4.90	12,557	2.40	7,946
717	1.54	23.11	59,255	16.40	42,046	1.90	4,877	1.68	6,158
1,112	2.39	23.06	59,119	10.81	27,710	1.56	4,011	1.37	4,304
1,730	3.72	18.57	47,611	5.56	14,263	1.15	2,937	1.29	3,523
2,683	5.77	12.07	30,938	3.67	9,418	0.65	1,675	1.09	3,302
4,165	8.96	6.90	17,688	2.60	6,666	0.26	659	0.00	2,792

[1]Constrained by 5-m shoreline buffer.

Table 3-2. Habitat versus discharge relations for segment 1 West Branch Delaware River (WB1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
46	0.08	40.39	1,7410	61.24	2,6399	0.01	6	26.07	11,235
64	0.11	45.72	1,9706	69.05	2,9765	9.10	3,923	29.11	12,547
88	0.15	52.29	2,2537	79.88	3,4429	14.65	6,316	30.01	12,934
125	0.21	61.75	2,6618	90.57	3,9041	20.66	8,904	29.79	12,842
177	0.30	73.47	3,1670	103.67	4,4685	27.31	11,772	29.22	12,594
247	0.42	89.91	3,8756	116.92	5,0398	30.97	13,349	28.38	12,233
353	0.59	110.98	4,7835	128.78	5,5511	28.88	12,447	26.10	11,251
494	0.83	132.19	5,6978	133.01	5,7331	22.80	9,827	23.14	9,973
706	1.19	153.12	6,6000	123.96	5,3433	15.10	6,507	18.11	7,805
953	1.60	170.43	7,3459	96.25	4,1488	6.14	2,648	13.52	5,827
1,341	2.25	174.09	7,5040	66.27	2,8563	1.98	853	10.44	4,499
1,906	3.20	153.29	6,6075	42.51	1,8322	1.30	558	9.90	4,265
2,683	4.51	123.01	5,3024	30.01	1,2933	1.95	841	9.53	4,107
3,777	6.35	88.13	3,7986	26.44	1,1395	2.76	1,189	9.90	4,266
5,330	8.96	71.82	3,0959	26.02	1,1216	3.12	1,346	6.43	2,773

[1]Constrained by 5-m shoreline buffer.

Table 3-3. Habitat versus discharge relations for segment 0 East Branch Delaware River (EB0).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
7	0.02	11.10	9,096	9.85	8,071	0.08	63	11.56	9,477
11	0.03	11.83	9,700	11.05	9,053	0.25	208	11.60	9,511
18	0.05	13.12	10,755	13.05	10,699	0.71	585	11.64	9,542
25	0.07	14.28	11,703	14.48	11,866	1.12	917	11.82	9,687
39	0.10	16.70	13,691	17.79	14,586	1.95	1,597	11.85	9,716
56	0.15	18.95	15,531	21.73	17,808	2.81	2,305	11.86	9,720
88	0.24	22.13	18,142	25.90	21,229	3.85	3,154	10.74	8,805
131	0.35	28.66	23,493	28.90	23,685	4.33	3,553	10.58	8,675
201	0.54	36.48	29,898	32.42	26,570	2.32	1,905	8.38	6,867
304	0.82	42.53	34,862	32.89	26,961	1.06	867	6.90	5,657
462	1.24	46.70	38,278	29.82	24,443	0.68	558	5.67	4,645
702	1.89	49.55	40,617	20.82	17,067	0.73	599	5.48	4,493
1,070	2.88	50.66	41,526	14.06	11,523	1.39	1,141	5.84	4,790
1,627	4.37	49.06	40,216	15.14	12,414	1.61	1,323	6.43	5,274
2,471	6.64	50.97	41,778	19.11	15,665	1.73	1,421	5.52	4,524

[1]Constrained by 5-m shoreline buffer.

Table 3-4. Habitat versus discharge relations for segment 1 East Branch Delaware River (EB1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-fast guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
38	0.08	37.17	24,615	30.53	20,221	2.31	1,527	11.70	7,748
53	0.12	40.00	26,490	33.33	22,074	3.54	2,347	11.67	7,727
74	0.16	43.15	28,575	35.95	23,807	4.76	3,152	11.39	7,543
103	0.22	46.76	30,967	38.10	25,231	5.39	3,569	10.96	7,257
143	0.31	51.89	34,362	39.62	26,237	4.74	3,137	10.60	7,017
199	0.43	56.43	37,372	40.50	26,819	3.63	2,402	10.18	6,741
277	0.60	61.14	40,492	39.41	26,098	2.06	1,361	9.40	6,223
385	0.84	63.68	42,175	37.77	25,016	1.36	898	8.56	5,667
537	1.17	66.44	44,003	34.46	22,821	0.77	513	8.22	5,443
746	1.63	65.89	43,638	29.10	19,274	0.78	514	8.03	5,317
1,039	2.27	67.22	44,517	24.36	16,133	1.28	847	7.90	5,230
1,446	3.16	67.03	44,391	21.32	14,117	2.32	1,537	7.40	4,901
2,012	4.39	63.75	42,220	20.17	13,355	2.81	1,864	7.06	4,678
2,802	6.12	58.49	38,736	23.87	15,811	3.29	2,179	6.96	4,611
3,901	8.52	58.17	38,524	33.36	22,090	8.88	5,883	7.03	4,658

[1]Constrained by 5-m shoreline buffer.

Table 3-5. Habitat versus discharge relations for segment 2 East Branch Delaware River (EB2).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
100	0.13	77.55	30,292	77.74	30,366	13.73	5,364	21.81	8,519
150	0.19	85.28	33,313	82.97	32,411	17.04	6,657	21.63	8,447
200	0.25	91.92	35,908	85.31	33,325	18.15	7,089	21.04	8,218
300	0.38	104.82	40,947	85.69	33,473	17.36	6,782	18.90	7,382
450	0.57	118.20	46,170	83.68	32,687	15.69	6,130	16.87	6,589
700	0.89	131.09	51,206	76.43	29,855	11.82	4,616	14.09	5,502
1,000	1.28	139.34	54,430	65.34	25,524	7.02	2,744	11.35	4,435
1,399	1.78	140.32	54,812	51.67	20,185	3.41	1,331	10.35	4,045
1,539	1.96	143.28	55,967	49.72	19,424	2.27	887	10.35	4,042
2,099	2.68	127.04	49,623	35.34	13,804	1.07	418	8.78	3,428
3,199	4.08	100.25	39,159	23.74	9,274	0.86	336	8.06	3,149
4,598	5.87	65.68	25,656	20.27	7,919	0.76	298	8.63	3,369
6,697	8.54	49.51	19,338	21.72	8,484	0.49	193	9.70	3,787
9,896	12.62	48.71	19,028	28.87	11,279	0.25	98	10.47	4,090
21,191	27.03	73.87	28,855	42.89	16,753	0.12	48	12.15	4,748

[1]Constrained by 5-m shoreline buffer.

Table 3-6. Habitat versus discharge relations for segment 2 East Branch Delaware River (EB2) – Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km
100	0.13	84.58	33,038	9.31	3,636
150	0.19	91.86	35,884	19.69	7,690
200	0.25	97.95	38,263	30.36	11,858
300	0.38	105.93	41,377	60.60	23,673
450	0.57	110.72	43,250	83.21	32,503
700	0.89	110.25	43,067	96.55	37,716
1,000	1.28	98.42	38,445	97.06	37,914
1,399	1.78	75.53	29,506	84.93	33,176
1,539	1.96	77.25	30,175	85.74	33,490
2,099	2.68	50.26	19,632	56.64	22,123
3,199	4.08	36.37	14,206	32.79	12,808
4,598	5.87	29.65	11,582	22.32	8,719
6,697	8.54	27.54	10,759	21.06	8,226
9,896	12.62	31.17	12,176	22.99	8,982
21,191	27.03	51.77	20,224	38.07	14,870

Table 3-7. Habitat versus discharge relations for segment 1 Delaware River main stem (DEL1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
344	0.22	107.70	72,285	88.74	59,555	5.70	3,828	18.09	12,142
426	0.27	118.24	79,355	97.15	65,201	7.38	4,955	16.74	11,234
568	0.36	130.34	87,475	104.20	69,931	9.64	6,472	14.91	10,004
746	0.47	146.05	98,019	107.20	71,944	7.73	5,187	14.21	9,540
959	0.60	160.33	107,607	107.41	72,085	4.25	2,855	13.62	9,141
1,243	0.78	171.07	114,810	102.51	68,800	2.07	1,388	13.04	8,752
1,598	1.00	179.58	120,526	93.54	62,780	0.75	506	11.12	7,464
2,095	1.32	185.92	124,779	79.78	53,544	1.10	737	9.65	6,476
2,698	1.70	190.73	128,004	60.87	40,851	1.50	1,007	8.12	5,449
3,515	2.21	194.99	130,866	45.84	30,768	1.52	1,021	7.70	5,167
4,544	2.86	197.91	132,824	38.27	25,686	1.69	1,136	7.46	5,007
5,893	3.71	189.00	126,843	40.36	27,084	1.23	828	7.60	5,103
7,597	4.78	177.78	119,318	48.36	32,457	0.80	536	7.35	4,933
9,869	6.21	176.79	118,653	56.94	38,216	2.52	1,690	5.94	3,989
12,780	8.04	176.06	118,163	64.34	43,182	0.27	181	3.50	2,349

[1]Constrained by 5-m shoreline buffer.

Table 3-8. Habitat versus discharge relations for segment 1 Delaware River main stem (DEL1) – Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km
344	0.22	109.52	73,505	31.53	21,163
426	0.27	119.34	80,092	43.29	29,056
568	0.36	130.70	87,718	64.02	42,969
746	0.47	140.62	94,373	89.16	59,837
959	0.60	144.41	96,918	109.30	73,355
1,243	0.78	143.68	96,427	123.69	83,010
1,598	1.00	135.79	91,137	132.97	89,244
2,095	1.32	124.12	83,304	137.40	92,215
2,698	1.70	110.12	73,909	133.57	89,641
3,515	2.21	90.82	60,953	113.43	76,125
4,544	2.86	78.96	52,992	91.08	61,126
5,893	3.71	70.55	47,348	76.91	51,618
7,597	4.78	67.45	45,268	68.70	46,106
9,869	6.21	73.77	49,508	72.20	48,460
12,780	8.04	82.60	55,435	84.22	56,521

Table 3-9. Habitat versus discharge relations for segment 2 Delaware River main stem (DEL2).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
466	0.28	95.35	55,758	58.95	34,476	100.23	6,898	12.46	6,441
597	0.36	99.94	58,445	57.13	33,410	108.08	6,765	12.23	9,405
762	0.46	104.11	60,884	54.55	31,900	117.15	6,185	11.95	11,885
974	0.58	107.93	63,118	50.78	29,697	125.80	5,745	11.42	13,104
1,243	0.74	110.74	64,761	48.12	28,143	134.33	5,509	10.75	13,836
1,585	0.95	114.57	67,000	44.99	26,308	144.52	4,165	10.38	14,460
2,023	1.21	117.90	68,950	40.17	23,490	155.00	2,133	9.57	14,660
2,577	1.54	116.63	68,207	34.56	20,208	161.68	1,589	9.79	13,404
3,297	1.98	114.98	67,241	29.26	17,110	168.35	1,466	8.86	10,232
4,208	2.52	107.75	63,009	25.82	15,101	175.28	1,288	8.67	7,459
5,373	3.22	90.36	52,839	22.66	13,252	181.96	1,062	8.85	5,640
6,855	4.11	72.83	42,589	21.13	12,359	189.35	1,091	8.90	4,645
8,751	5.25	62.12	36,328	20.63	12,067	199.07	1,485	8.96	4,016
11,172	6.70	62.93	36,799	21.13	12,356	210.90	2,181	8.70	4,497
14,261	8.55	57.39	33,559	17.67	10,332	222.47	2,381	7.40	4,116

[1]Constrained by 5-m shoreline buffer.

Table 3-10. Habitat versus discharge relations for segment 2 Delaware River main stem (DEL2) – Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km
466	0.28	77.03	47,917	11.80	19,969
597	0.36	75.98	49,255	11.57	29,156
762	0.46	74.28	49,822	10.58	36,845
974	0.58	71.82	49,080	9.82	40,624
1,243	0.74	68.20	47,903	9.42	42,892
1,585	0.95	64.58	47,155	7.12	44,826
2,023	1.21	56.52	43,229	3.65	45,446
2,577	1.54	49.79	35,338	2.72	41,552
3,297	1.98	43.02	29,567	2.51	31,721
4,208	2.52	36.30	25,347	2.20	23,122
5,373	3.22	31.36	22,408	1.82	17,484
6,855	4.11	28.14	20,771	1.87	14,401
8,751	5.25	28.33	20,429	2.54	12,449
11,172	6.70	28.67	21,547	3.73	13,939
14,261	8.55	23.75	17,409	4.07	12,760

Table 3-11. Habitat versus discharge relations for segment 3 Delaware River main stem (DEL3).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
505	0.28	90.42	89,632	83.19	78,648	0.25	9,616	17.87	13,671
650	0.36	102.83	101,955	82.78	82,072	9.00	8,919	13.85	11,834
833	0.46	113.78	112,806	86.01	85,280	9.24	9,164	13.57	11,595
1,059	0.58	123.76	122,705	88.18	87,425	8.71	8,640	13.21	11,289
1,377	0.76	133.47	132,326	87.64	86,890	7.56	7,499	12.24	10,460
1,779	0.98	143.03	141,805	81.59	80,888	5.76	5,707	10.57	9,035
2,291	1.26	148.64	147,369	70.45	69,846	2.84	2,812	8.76	7,484
2,951	1.62	149.26	147,980	56.07	55,590	1.27	1,255	7.71	6,592
3,798	2.09	145.95	144,705	38.16	37,837	1.16	1,154	6.85	5,858
4,889	2.69	136.23	135,066	24.66	24,445	1.17	1,162	6.37	5,441
6,294	3.46	113.46	112,489	17.66	17,511	0.97	961	6.05	5,171
8,105	4.45	91.62	90,842	15.90	15,767	1.08	1,067	6.13	5,242
10,435	5.73	67.99	67,408	16.26	16,118	1.52	1,504	6.54	5,586
13,435	7.38	54.46	53,994	16.64	16,493	1.68	1,664	6.57	5,612
17,297	9.50	44.30	43,922	16.87	16,725	2.22	2,201	6.58	5,624

[1]Constrained by 5-m shoreline buffer.

Table 3-12. Habitat versus discharge relations for segment 3 Delaware River main stem (DEL3) – Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km
505	0.28	114.55	91,086	97.72	42593
650	0.36	78.13	98,197	99.04	54535
833	0.46	74.04	103,348	104.24	69793
1,059	0.58	68.30	106,551	107.47	86566
1,377	0.76	59.22	107,856	108.79	98783
1,779	0.98	43.01	100,496	101.36	107196
2,291	1.26	32.63	88,923	89.69	105451
2,951	1.62	27.03	76,806	77.47	94660
3,798	2.09	23.01	62,344	62.88	78693
4,889	2.69	18.81	46,805	47.21	58188
6,294	3.46	16.80	35,255	35.56	37469
8,105	4.45	17.69	33,698	33.99	30722
10,435	5.73	19.93	31,471	31.74	27913
13,435	7.38	17.22	25,411	25.63	23804
17,297	9.50	13.71	20,891	21.07	19517

Table 3-13. Habitat versus discharge relations for segment 0 Neversink River (NVR0).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
14	0.12	13.01	10,084	15.11	11,709	13.01	711	9.43	7,311
18	0.16	13.42	10,400	15.58	12,080	13.42	1,060	9.72	7,534
25	0.22	14.17	10,985	16.75	12,987	14.17	1,708	9.68	7,505
32	0.28	14.87	11,531	18.43	14,284	14.88	2,298	9.62	7,458
42	0.37	15.83	12,270	19.68	15,259	15.84	2,995	9.25	7,168
56	0.50	17.17	13,312	20.70	16,048	17.20	3,896	8.79	6,811
74	0.66	19.34	14,996	22.33	17,312	19.41	4,434	7.98	6,189
99	0.87	22.22	17,225	23.18	17,965	22.34	3,784	6.96	5,393
134	1.19	24.62	19,085	23.73	18,396	24.80	3,482	6.09	4,720
177	1.56	27.26	21,130	22.99	17,824	27.63	2,783	4.93	3,820
233	2.06	29.64	22,974	21.89	16,969	30.74	1,811	4.33	3,356
307	2.72	30.69	23,791	19.89	15,415	33.32	1,235	4.06	3,145
406	3.59	30.11	23,339	17.18	13,320	35.43	969	3.98	3,082
540	4.78	29.71	23,030	13.99	10,846	37.13	1,219	3.95	3,063
713	6.31	29.17	22,614	11.53	8,937	38.88	2,004	4.33	3,356

[1]Constrained by 5-m shoreline buffer

Table 3-14. Habitat versus discharge relations for segment 1 Neversink River (NVR1).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
28	0.17	24.39	9,380	37.46	14,408	3.35	1,288	17.00	6,538
39	0.23	27.96	10,752	41.44	15,938	4.97	1,911	16.75	6,443
54	0.32	34.36	13,214	46.27	17,798	6.28	2,416	16.39	6,303
76	0.44	40.48	15,571	51.27	19,720	8.35	3,211	15.44	5,938
105	0.62	47.54	18,286	55.78	21,455	8.38	3,224	14.04	5,401
146	0.85	55.93	21,510	59.11	22,733	7.89	3,035	10.91	4,198
203	1.19	64.85	24,943	58.63	22,551	4.58	1,761	8.53	3,282
282	1.65	71.24	27,399	54.83	21,087	1.89	728	6.47	2,489
393	2.30	73.69	28,343	47.31	18,196	0.81	310	5.72	2,202
545	3.19	73.82	28,391	34.03	13,090	0.67	258	5.52	2,125
758	4.43	74.96	28,830	20.85	8,019	0.79	302	6.40	2,463
1,053	6.16	68.65	26,402	14.66	5,639	1.32	506	6.40	2,463
1,463	8.55	65.71	25,275	15.02	5,777	1.03	398	6.64	2,556
2,032	11.88	104.13	40,048	32.93	12,665	0.92	352	6.59	2,536
2,824	16.51	47.30	18,194	17.87	6,872	0.38	146	6.56	2,525

[1]Constrained by 5-m shoreline buffer

Table 3-15. Habitat versus discharge relations for segment 2 Neversink River (NVR2).

Discharge		Brown trout adult		Brown trout juvenile		Shallow-fast guild		Shallow-slow guild[1]	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km	Ha	m^2/km
70	0.23	36.96	15,597	40.63	17,145	8.62	3,637	18.28	7,715
90	0.29	40.42	17,056	43.62	18,405	10.14	4,276	19.02	8,023
117	0.38	44.88	18,938	46.01	19,414	11.19	4,720	17.25	7,277
151	0.49	49.27	20,788	47.59	20,079	12.55	5,293	16.77	7,076
195	0.63	53.59	22,610	46.70	19,704	14.07	5,937	16.17	6,823
252	0.82	59.83	25,246	46.26	19,520	12.36	5,214	15.66	6,609
325	1.06	63.51	26,797	43.83	18,494	11.28	4,761	14.53	6,130
420	1.37	64.81	27,345	40.90	17,255	10.47	4,418	13.62	5,746
543	1.77	63.42	26,758	37.05	15,632	9.92	4,184	12.59	5,311
701	2.28	61.46	25,932	29.70	12,533	10.67	4,503	10.80	4,557
905	2.95	59.83	25,246	25.91	10,932	10.06	4,243	9.56	4,032
1,169	3.81	54.71	23,084	22.72	9,585	6.90	2,909	8.50	3,585
1,511	4.92	46.97	19,817	19.54	8,245	4.09	1,724	7.90	3,335
1,951	6.36	38.52	16,253	17.22	7,264	2.37	1,000	7.44	3,141
2,859	9.31	29.61	12,492	15.25	6,434	3.04	1,282	6.54	2,760

[1]Constrained by 5-m shoreline buffer.

Table 3-16. Habitat versus discharge relations for segment 2 Neversink River (NVR2) – Continued.

Discharge		American shad juvenile		American shad spawning	
Q (ft^3/s)	Q ($ft^3/s/mi^2$)	Ha	m^2/km	Ha	m^2/km
70	0.23	47.33	16,503	10.92	3,809
90	0.29	51.06	17,806	14.99	5,228
117	0.38	54.92	19,152	21.20	7,394
151	0.49	57.37	20,006	28.22	9,839
195	0.63	56.31	19,638	33.73	11,761
252	0.82	56.90	19,842	40.90	14,263
325	1.06	55.24	19,262	44.48	15,509
420	1.37	52.47	18,295	48.10	16,773
543	1.77	44.21	15,416	47.18	16,453
701	2.28	39.70	13,844	40.89	14,258
905	2.95	34.32	11,969	37.20	12,971
1,169	3.81	29.06	10,134	31.38	10,942
1,511	4.92	24.89	8,681	22.66	7,902
1,951	6.36	22.85	7,969	17.61	6,142
2,859	9.31	21.30	7,427	13.57	4,733

Appendix 4. Habitat Persistence Tables for Brown Trout (*Salmo trutta*) Spawning – Incubation and Dwarf Wedgemussels (*Alasmidonta heterodon*).

Table 4-1. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site WB0. Units of habitat are m^2/km.

			Incubation flow														
	(ft^3/s/mi^2)		0.02	0.03	0.05	0.07	0.12	0.18	0.27	0.42	0.65	1.02	1.58	2.45	3.81	5.92	9.19
		(ft^3/s)	9	14	21	32	53	82	124	192	298	465	721	1,118	1,740	2,698	4,189
	0.02	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.03	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.05	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.07	32	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0
	0.12	53	2	26	39	51	126	126	124	126	126	126	126	123	89	82	2
	0.18	82	2	30	40	74	173	327	324	328	328	328	328	320	266	226	4
	0.27	124	2	29	40	81	210	488	748	748	749	748	748	738	672	476	5
Spawning flow	0.42	192	2	21	29	82	277	599	1,113	2,205	2,206	2,206	2,206	2,194	2,033	1,494	0
	0.65	298	1	12	22	72	295	724	1,605	3,160	4,105	4,103	4,094	4,092	3,932	2,619	826
	1.02	465	0	2	11	51	232	581	1,529	3,221	4,375	4,748	4,702	4,742	4,635	3,272	696
	1.58	721	0	0	3	31	151	425	1,280	2,756	3,848	4,225	4,634	4,629	4,604	3,321	649
	2.45	1,118	0	0	0	3	8	12	50	485	1,144	1,527	1,883	2,273	2,273	2,099	617
	3.81	1,740	0	0	0	0	0	0	0	0	47	119	211	406	486	486	266
	5.92	2,698	0	0	0	0	0	0	0	0	2	5	15	39	75	107	94
	9.19	4,189	0	0	0	0	0	0	0	0	0	0	0	0	0	8	17

Table 4-2. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site WB1. Units of habitat are m^2/km.

Spawning flow		Incubation flow														
(ft^3/s/mi^2)		0.08	0.11	0.15	0.21	0.30	0.42	0.59	0.83	1.19	1.60	2.25	3.20	4.51	6.35	8.96
	(ft^3/s)	46	64	88	125	177	247	353	494	706	953	1,341	1,906	2,683	3,777	5,330
0.08	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.11	64	0	58	59	59	59	59	59	59	59	59	59	45	23	23	13
0.15	88	0	233	482	483	483	483	483	483	483	483	483	405	107	80	39
0.21	125	0	493	862	1,153	1,152	1,153	1,152	1,153	1,153	1,153	1,152	933	280	192	92
0.30	177	0	1,077	1,606	2,095	2,530	2,530	2,530	2,532	2,531	2,531	2,530	2,242	844	420	173
0.42	247	0	1,505	2,661	3,403	3,979	4,603	4,600	4,602	4,602	4,601	4,598	4,300	2,063	695	307
0.59	353	0	1,422	2,647	3,952	4,838	5,705	6,645	6,643	6,645	6,642	6,632	6,338	3,851	1,381	436
0.83	494	0	1,266	2,421	3,767	5,381	6,888	8,172	9,044	9,043	9,041	9,028	8,742	6,143	3,329	824
1.19	706	0	849	1,844	2,978	4,550	6,127	7,791	8,939	9,644	9,640	9,625	9,506	7,002	4,438	1,495
1.60	953	0	411	932	1,521	2,614	3,758	5,195	6,413	7,276	7,608	7,593	7,590	6,481	4,515	1,808
2.25	1,341	0	120	263	410	686	1,217	2,114	2,992	3,834	4,260	4,298	4,295	4,275	3,483	1,661
3.20	1,906	0	0	0	1	21	71	212	512	1,020	1,336	1,405	1,429	1,429	1,369	850
4.51	2,683	0	0	0	0	0	0	0	1	76	191	236	257	262	260	234
6.35	3,777	0	0	0	0	0	0	0	0	0	2	3	8	12	13	13
8.96	5,330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-3. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site EB0. Units of habitat are m^2/km.

			Incubation flow														
	($ft^3/s/mi^2$)		0.02	0.03	0.05	0.07	0.10	0.15	0.24	0.35	0.54	0.82	1.25	1.90	2.89	4.40	6.68
		(ft^3/s)	7	11	18	25	39	57	89	131	202	305	465	706	1,076	1,637	2,485
Spawning flow	0.02	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.03	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.05	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.07	25	0	3	6	6	6	6	6	6	6	6	6	6	4	0	0
	0.10	39	0	13	27	30	32	32	32	32	32	32	32	31	26	10	0
	0.15	57	0	28	108	150	186	190	190	190	190	190	190	179	125	84	0
	0.24	89	0	35	211	481	797	840	849	849	849	849	849	838	702	535	0
	0.35	131	0	35	210	524	1,412	2,134	2,891	2,940	2,940	2,940	2,940	2,928	2,785	2,509	0
	0.54	202	0	25	155	368	1,217	2,339	3,621	3,873	3,949	3,949	3,949	3,949	3,899	3,511	0
	0.82	305	0	0	63	183	871	1,933	3,213	3,668	3,963	3,991	3,991	3,991	3,965	3,618	0
	1.25	465	0	0	0	18	523	1,393	2,406	2,776	3,096	3,210	3,215	3,215	3,207	3,008	0
	1.90	706	0	0	0	0	0	0	0	86	223	312	327	338	338	322	0
	2.89	1,076	0	0	0	0	0	0	0	0	0	0	1	6	9	9	0
	4.40	1,637	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
	6.68	2,485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-4. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site EB1. Units of habitat are m^2/km.

			Incubation flow													
	(ft^3/s/mi^2)		0.08	0.12	0.15	0.22	0.31	0.43	0.60	0.84	1.17	1.61	2.23	3.14	4.38	6.07	8.45
		(ft^3/s)	35	53	70	102	141	197	275	384	535	739	1,021	1,440	2,006	2,781	3,872
Spawning flow	0.08	35	91	91	91	91	91	91	91	91	82	50	40	26	17	11	5
	0.12	53	176	289	289	289	289	289	289	289	265	206	186	160	112	102	57
	0.15	70	333	474	599	600	600	600	600	600	571	478	447	408	265	228	98
	0.22	102	525	709	893	1,003	1,003	1,003	1,003	1,003	975	866	825	763	487	382	141
	0.31	141	629	906	1,148	1,324	1,439	1,440	1,439	1,440	1,413	1,295	1,211	1,121	791	581	266
	0.43	197	670	1,009	1,303	1,560	1,725	1,862	1,859	1,862	1,857	1,741	1,619	1,501	1,119	878	482
	0.60	275	598	938	1,328	1,635	1,868	2,087	2,194	2,194	2,193	2,120	2,010	1,869	1,453	1,168	715
	0.84	384	269	496	831	1,149	1,455	1,751	1,966	2,014	2,015	1,991	1,936	1,804	1,457	1,248	846
	1.17	535	59	139	257	478	815	1,158	1,435	1,570	1,642	1,626	1,631	1,569	1,342	1,215	905
	1.61	739	0	0	2	28	73	151	359	488	637	813	802	802	740	616	412
	2.23	1,021	0	0	0	0	0	15	103	186	341	539	701	701	686	607	468
	3.14	1,440	0	0	0	0	0	0	0	2	33	184	374	815	813	777	630
	4.38	2,006	0	0	0	0	0	0	0	0	0	45	117	537	740	739	693
	6.07	2,781	0	0	0	0	0	0	0	0	0	0	0	144	253	262	261
	8.45	3,872	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Table 4-5. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site EB2. Units of habitat are m^2/km.

			Incubation flow														
	($ft^3/s/mi^2$)		**0.13**	**0.19**	**0.25**	**0.38**	**0.57**	**0.89**	**1.28**	**1.78**	**1.96**	**2.68**	**4.08**	**5.87**	**8.54**	**12.62**	**27.03**
		(ft^3/s)	**100**	**150**	**200**	**300**	**450**	**700**	**1,000**	**1,399**	**1,539**	**2,099**	**3,199**	**4,598**	**6,697**	**9,896**	**21,191**
Spawning flow	**0.13**	**100**	543	543	543	543	543	543	543	543	543	475	166	121	7	0	0
	0.19	**150**	1,185	1,437	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,292	362	249	42	0	0
	0.25	**200**	1,919	2,244	2,408	2,409	2,409	2,409	2,409	2,409	2,409	2,234	753	342	92	2	0
	0.38	**300**	2,499	3,089	3,319	3,546	3,547	3,547	3,547	3,547	3,547	3,363	1,689	514	157	14	0
	0.57	**450**	1,868	2,872	3,538	4,200	4,666	4,667	4,667	4,667	4,667	4,487	2,899	1,238	435	30	0
	0.89	**700**	1,068	1,882	2,599	3,935	4,977	5,675	5,676	5,676	5,676	5,546	4,069	2,533	713	63	0
	1.28	**1,000**	124	422	790	1,813	3,130	4,192	4,375	4,375	4,375	4,375	3,664	2,533	793	111	0
	1.78	**1,399**	0	20	54	422	1,312	2,518	2,810	2,859	2,859	2,859	2,678	1,982	784	122	0
	1.96	**1,539**	0	5	18	242	990	2,146	2,431	2,473	2,473	2,474	2,294	1,698	663	89	0
	2.68	**2,099**	0	0	0	0	10	328	489	571	573	606	604	572	263	57	0
	4.08	**3,199**	0	0	0	0	0	0	0	1	1	16	22	22	20	0	0
	5.87	**4,598**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8.54	**6,697**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12.62	**9,896**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	27.03	**21,191**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-6. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site DEL1. Units of habitat are m^2/km.

			Incubation flow														
	($ft^3/s/mi^2$)		**0.22**	**0.27**	**0.36**	**0.47**	**0.60**	**0.78**	**1.00**	**1.31**	**1.69**	**2.20**	**2.84**	**3.69**	**4.75**	**6.17**	**7.99**
		(ft^3/s)	**342**	**424**	**565**	**741**	**953**	**1,236**	**1,589**	**2,083**	**2,683**	**3,495**	**4,518**	**5,860**	**7,554**	**9,813**	**12,708**
Spawning flow	**0.22**	**342**	431	1,831	1,833	1,833	1,833	1,832	1,832	1,831	1,832	1,832	1,833	1,820	1,818	1,597	1,314
	0.27	**424**	2,603	2,643	2,644	2,644	2,644	2,643	2,642	2,641	2,642	2,642	2,643	2,630	2,625	2,397	2,057
	0.36	**565**	3,710	3,803	3,841	3,841	3,842	3,841	3,840	3,838	3,839	3,838	3,840	3,828	3,813	3,612	3,210
	0.47	**741**	4,886	5,092	5,188	5,227	5,227	5,226	5,225	5,223	5,223	5,222	5,224	5,214	5,188	5,015	4,451
	0.60	**953**	4,859	5,357	5,565	5,643	5,662	5,660	5,660	5,658	5,657	5,655	5,658	5,651	5,625	5,414	4,666
	0.78	**1,236**	4,199	5,062	5,722	5,949	6,018	6,028	6,026	6,024	6,025	6,022	6,025	6,018	5,994	5,611	4,456
	1.00	**1,589**	2,912	3,699	4,484	4,952	5,086	5,151	5,169	5,165	5,167	5,163	5,166	5,164	5,144	4,831	3,510
	1.31	**2,083**	1,318	1,768	2,279	2,600	2,786	2,908	3,006	3,040	3,040	3,039	3,039	3,038	3,030	2,857	2,089
	1.69	**2,683**	314	435	605	772	880	992	1,125	1,250	1,270	1,270	1,270	1,270	1,266	1,223	1,060
	2.20	**3,495**	0	9	64	132	192	244	335	509	589	613	613	612	611	602	556
	2.84	**4,518**	0	0	0	0	0	5	20	120	193	241	253	253	253	251	220
	3.69	**5,860**	0	0	0	0	0	0	5	47	84	117	126	126	126	126	119
	4.75	**7,554**	0	0	0	0	0	0	0	2	12	20	22	22	22	22	22
	6.17	**9,813**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7.99	**12,708**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-7. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site DEL2. Units of habitat are m^2/km.

			Incubation flow														
	(ft^3/s/mi^2)		0.28	0.36	0.46	0.58	0.74	0.95	1.21	1.54	1.98	2.52	3.22	4.11	5.25	6.70	8.55
		(ft^3/s)	466	597	762	974	1,243	1,585	2,023	2,577	3,297	4,208	5,373	6,855	8,751	11,172	14,261
Spawning flow	0.28	466	2,219	2,220	2,220	2,220	2,219	2,214	2,201	2,147	1,801	1,195	457	361	239	82	29
	0.36	597	2,216	2,380	2,381	2,381	2,380	2,380	2,375	2,330	1,985	1,355	629	500	335	124	63
	0.46	762	2,009	2,478	2,716	2,716	2,716	2,716	2,715	2,687	2,380	1,785	1,097	852	539	139	88
	0.58	974	1,625	2,294	2,661	2,836	2,836	2,836	2,835	2,835	2,617	2,101	1,467	1,126	690	133	94
	0.74	1,243	1,114	1,771	2,297	2,727	3,117	3,118	3,117	3,118	3,100	2,682	2,065	1,566	929	114	85
	0.95	1,585	531	1,091	1,549	2,032	2,480	3,215	3,214	3,215	3,214	3,123	2,587	1,951	1,139	101	75
	1.21	2,023	95	287	655	1,044	1,487	2,246	2,428	2,428	2,427	2,428	2,175	1,635	944	62	57
	1.54	2,577	0	6	72	319	694	1,421	1,609	1,798	1,798	1,797	1,779	1,327	748	9	9
	1.98	3,297	0	0	0	10	143	561	743	986	1,219	1,219	1,219	922	433	45	23
	2.52	4,208	0	0	0	0	0	8	86	307	668	833	833	821	607	272	162
	3.22	5,373	0	0	0	0	0	0	0	57	330	790	844	844	975	678	245
	4.11	6,855	0	0	0	0	0	0	0	0	33	275	592	867	867	695	91
	5.25	8,751	0	0	0	0	0	0	0	0	0	10	137	480	727	687	123
	6.70	11,172	0	0	0	0	0	0	0	0	0	0	4	32	183	345	304
	8.55	14,261	0	0	0	0	0	0	0	0	0	0	0	0	0	17	34

Table 4-8. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site DEL3. Units of habitat are m^2/km.

			Incubation flow													
	(ft^3/s/mi^2)		0.28	0.36	0.46	0.58	0.76	0.98	1.26	1.62	2.09	2.69	3.46	4.45	5.73	7.38	9.50
		(ft^3/s)	505	650	833	1,059	1,377	1,779	2,291	2,951	3,798	4,889	6,294	8,105	10,435	13,435	17,297
Spawning flow	0.28	505	8,678	8,678	8,678	8,678	8,678	8,678	8,678	8,678	8,678	8,670	8,224	5,091	840	79	0
	0.36	650	10,362	10,546	10,546	10,546	10,546	10,546	10,546	10,546	10,546	10,538	10,153	6,691	1,501	273	33
	0.46	833	10,604	11,079	11,270	11,270	11,270	11,270	11,270	11,270	11,270	11,262	11,023	7,980	2,599	687	212
	0.58	1,059	9,535	10,381	10,889	11,338	11,669	11,729	11,729	11,729	11,729	11,724	11,532	8,377	3,978	1,169	380
	0.76	1,377	7,111	8,806	9,819	11,433	12,231	12,376	12,376	12,376	12,376	12,373	12,247	8,818	5,804	1,942	599
	0.98	1,779	4,006	5,665	9,796	11,554	12,943	13,195	13,195	13,195	13,195	13,195	13,153	12,114	10,209	4,566	832
	1.26	2,291	591	1,400	3,163	6,015	8,729	9,230	9,357	9,342	9,348	9,355	9,357	9,130	8,589	5,008	1,203
	1.62	2,951	73	309	710	2,141	5,455	6,377	6,598	6,746	6,747	6,747	6,747	6,722	6,534	4,443	1,508
	2.09	3,798	0	0	38	244	1,095	1,821	2,237	2,485	2,586	2,586	2,584	2,577	2,499	1,560	560
	2.69	4,889	0	0	0	1	69	400	686	1,051	1,283	1,364	1,358	1,358	1,313	1,000	402
	3.46	6,294	0	0	0	0	0	0	32	215	418	564	668	663	664	642	293
	4.45	8,105	0	0	0	0	0	0	0	0	19	102	211	365	353	365	237
	5.73	10,435	0	0	0	0	0	0	0	0	0	2	32	134	199	198	156
	7.38	13,435	0	0	0	0	0	0	0	0	0	0	0	8	34	61	47
	9.50	17,297	0	0	0	0	0	0	0	0	0	0	0	0	2	7	9

Table 4-9. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site NVR0. Units of habitat are m^2/km.

			Incubation flow													
	(ft^3/s/mi^2)		0.12	0.16	0.22	0.28	0.37	0.50	0.66	0.87	1.19	1.56	2.06	2.72	3.59	4.78	6.31
		(ft^3/s)	14	18	25	32	42	56	74	99	134	177	233	307	406	540	713
Spawning flow	0.12	14	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
	0.16	18	5	10	11	11	11	11	11	11	11	11	10	3	2	1	1
	0.22	25	39	55	81	81	81	81	81	81	81	80	75	64	49	41	34
	0.28	32	82	104	142	170	171	171	172	172	172	170	162	150	96	70	63
	0.37	42	88	128	177	230	273	273	273	273	273	271	263	245	180	112	92
	0.50	56	89	133	209	542	628	721	720	721	720	719	710	688	606	445	391
	0.66	74	89	138	323	873	1,121	1,243	1,559	1,549	1,552	1,534	1,553	1,529	1,436	977	796
	0.87	99	79	125	373	1,134	1,530	1,670	1,964	2,109	2,109	2,084	2,107	2,094	1,992	1,473	1,210
	1.19	134	55	92	362	1,145	1,628	1,934	2,338	2,550	2,604	2,554	2,585	2,602	2,551	2,031	1,764
	1.56	177	28	63	346	1,134	1,650	2,015	2,578	2,818	2,972	3,069	3,070	3,070	3,047	2,553	2,279
	2.06	233	6	27	212	936	1,382	1,663	2,076	2,308	2,558	2,708	2,884	2,884	2,882	2,849	2,659
	2.72	307	0	18	185	815	1,194	1,430	1,769	1,978	2,259	2,496	2,707	2,788	2,789	2,785	2,744
	3.59	406	0	0	1	9	148	286	492	618	847	1,087	1,329	1,463	1,526	1,526	1,525
	4.78	540	0	0	0	0	1	1	27	104	241	411	619	774	897	960	959
	6.31	713	0	0	0	0	0	0	0	1	10	55	176	263	354	433	457

Table 4-10. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site NVR1. Units of habitat are m^2/km.

			Incubation flow														
	(ft^3/s/mi^2)		**0.17**	**0.23**	**0.32**	**0.44**	**0.62**	**0.85**	**1.19**	**1.65**	**2.30**	**3.19**	**4.43**	**6.16**	**8.55**	**11.88**	**16.51**
		(ft^3/s)	**28**	**39**	**54**	**76**	**105**	**146**	**203**	**282**	**393**	**545**	**758**	**1,053**	**1,463**	**2,032**	**2,824**
Spawning flow	**0.17**	**28**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.23	**39**	31	95	95	95	95	95	95	95	95	95	95	95	95	74	41
	0.32	**54**	51	131	161	162	162	162	162	162	162	162	162	158	158	117	51
	0.44	**76**	191	340	400	425	425	425	425	425	425	425	425	237	217	158	58
	0.62	**105**	321	734	817	860	896	896	896	896	896	896	896	521	348	262	74
	0.85	**146**	339	855	1,067	1,166	1,260	1,322	1,322	1,321	1,322	1,322	1,322	943	698	514	133
	1.19	**203**	304	824	1,221	1,932	2,211	2,322	2,343	2,344	2,344	2,344	2,344	1,995	1,729	1,464	222
	1.65	**282**	209	713	1,094	1,919	2,424	2,623	2,663	2,670	2,670	2,670	2,670	2,373	2,129	1,881	381
	2.30	**393**	62	328	558	979	1,451	1,706	1,790	1,827	1,841	1,841	1,841	1,738	1,630	1,397	368
	3.19	**545**	0	0	2	53	365	591	676	751	789	791	791	792	760	583	230
	4.43	**758**	0	0	0	0	0	15	61	104	143	162	165	165	164	136	66
	6.16	**1,053**	0	0	0	0	0	0	0	0	3	5	8	8	8	8	6
	8.55	**1,463**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11.88	**2,032**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16.51	**2,824**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-11. Persistent spawning-incubation habitat for brown trout (*Salmo trutta*) at site NVR2. Units of habitat are m^2/km.

			Incubation flow														
	(ft^3/s/mi^2)		**0.23**	**0.30**	**0.38**	**0.49**	**0.64**	**0.82**	**1.07**	**1.38**	**1.78**	**2.30**	**2.97**	**3.83**	**4.95**	**6.39**	**9.37**
		(ft^3/s)	**70**	**90**	**117**	**151**	**195**	**252**	**325**	**420**	**543**	**701**	**905**	**1,169**	**1,511**	**1,951**	**2,859**
Spawning flow	**0.23**	**70**	995	993	996	996	988	984	970	941	747	483	331	224	34	1	0
	0.30	**90**	1,280	1,370	1,371	1,371	1,371	1,371	1,361	1,333	1,140	757	545	396	60	1	0
	0.38	**117**	1,571	1,708	1,839	1,841	1,841	1,841	1,836	1,809	1,621	1,207	870	669	188	10	0
	0.49	**151**	1,993	2,284	2,507	2,718	2,721	2,721	2,720	2,702	2,518	2,111	1,663	1,393	500	75	6
	0.64	**195**	2,932	3,624	4,094	4,477	4,785	4,788	4,788	4,785	4,624	4,226	3,726	3,358	1,931	159	33
	0.82	**252**	2,717	3,823	4,472	4,982	5,366	5,718	5,720	5,720	5,682	5,347	4,867	4,393	2,673	440	64
	1.07	**325**	2,262	3,314	4,125	4,864	5,407	5,878	6,174	6,177	6,177	6,078	5,694	5,159	3,152	811	120
	1.38	**420**	1,891	2,821	3,531	4,300	4,974	5542	5,920	6,169	6,171	6,171	5,971	5,494	3,329	968	199
	1.78	**543**	1,617	2,397	2,963	3,574	4,174	4,718	5,182	5,514	5,777	5,778	5,776	5,488	3,310	996	253
	2.30	**701**	858	1,389	1,769	2,125	2,563	3,007	3,409	3,725	3,968	4,185	4,187	4,138	2,652	949	293
	2.97	**905**	1	23	67	117	186	310	495	701	890	1,103	1,248	1,250	1,114	751	368
	3.83	**1,169**	0	1	5	15	33	76	133	223	329	486	633	685	685	624	359
	4.95	**1,511**	0	0	0	2	6	21	39	64	109	203	312	398	412	411	321
	6.39	**1,951**	0	0	0	0	1	1	5	15	28	62	118	180	206	209	203
	9.37	**2,859**	0	0	0	0	0	0	0	0	0	4	22	44	56	64	171

Table 4-12. Persistent habitat for dwarf wedgemussels (*Alasmidonta heterodon*) at site DEL1. Units of habitat are hectares.

			Discharge # 2														
	(ft^3/s/mi^2)		0.22	0.27	0.36	0.47	0.60	0.78	1.00	1.31	1.69	2.20	2.84	3.69	4.75	6.17	7.99
		(ft^3/s)	342	424	565	741	953	1,236	1,589	2,083	2,683	3,495	4,518	5,860	7,554	9,813	12,708
Discharge # 1	0.22	342	2.83	2.82	2.82	2.82	2.82	2.79	2.79	2.82	2.72	2.50	2.03	1.73	1.44	0.99	0.79
	0.27	424	2.82	3.04	3.04	3.03	3.03	3.00	3.00	3.03	2.92	2.70	2.22	1.91	1.59	1.11	0.88
	0.36	565	2.82	3.04	3.18	3.18	3.17	3.14	3.14	3.17	3.07	2.84	2.35	2.02	1.69	1.19	0.94
	0.47	741	2.82	3.03	3.18	3.30	3.29	3.27	3.27	3.29	3.18	2.95	2.44	2.11	1.77	1.26	0.99
	0.60	953	2.82	3.03	3.17	3.29	3.39	3.36	3.36	3.38	3.27	3.04	2.52	2.19	1.85	1.32	1.04
	0.78	1,236	2.79	3.00	3.14	3.27	3.36	3.56	3.55	3.56	3.46	3.22	2.70	2.35	2.00	1.46	1.16
	1.00	1,589	2.79	3.00	3.14	3.27	3.36	3.55	3.67	3.67	3.56	3.32	2.79	2.44	2.09	1.54	1.22
	1.31	2,083	2.82	3.03	3.17	3.29	3.38	3.56	3.67	3.82	3.69	3.44	2.91	2.55	2.19	1.63	1.31
	1.69	2,683	2.72	2.92	3.07	3.18	3.27	3.46	3.56	3.69	3.82	3.57	3.02	2.66	2.30	1.74	1.40
	2.20	3,495	2.50	2.70	2.84	2.95	3.04	3.22	3.32	3.44	3.57	3.70	3.12	2.76	2.39	1.82	1.47
	2.84	4,518	2.03	2.22	2.35	2.44	2.52	2.70	2.79	2.91	3.02	3.12	3.29	2.88	2.47	1.86	1.53
	3.69	5,860	1.73	1.91	2.02	2.11	2.19	2.35	2.44	2.55	2.66	2.76	2.88	2.95	2.53	1.89	1.55
	4.75	7,554	1.44	1.59	1.69	1.77	1.85	2.00	2.09	2.19	2.30	2.39	2.47	2.53	2.60	1.91	1.57
	6.17	9,813	0.99	1.11	1.19	1.26	1.32	1.46	1.54	1.63	1.74	1.82	1.86	1.89	1.91	2.03	1.60
	7.99	12,708	0.79	0.88	0.94	0.99	1.04	1.16	1.22	1.31	1.40	1.47	1.53	1.55	1.57	1.60	1.69

Table 4-13. Persistent habitat for dwarf wedgemussels (*Alasmidonta heterodon*) at site DEL2. Units of habitat are hectares.

			Discharge # 2														
	($ft^3/s/mi^2$)		**0.28**	**0.36**	**0.46**	**0.58**	**0.74**	**0.95**	**1.21**	**1.54**	**1.98**	**2.52**	**3.22**	**4.11**	**5.25**	**6.70**	**8.55**
		(ft^3/s)	**466**	**597**	**762**	**974**	**1,243**	**1,585**	**2,023**	**2,577**	**3,297**	**4,208**	**5,373**	**6,855**	**8,751**	**11,172**	**14,261**
Discharge # 1	**0.28**	**466**	5.56	5.56	5.56	5.56	5.56	5.55	5.54	5.33	4.85	4.11	3.23	2.73	2.23	1.51	0.91
	0.36	**597**	5.56	5.71	5.71	5.71	5.71	5.70	5.69	5.47	4.98	4.22	3.32	2.81	2.30	1.56	0.94
	0.46	**762**	5.56	5.71	5.86	5.86	5.86	5.85	5.84	5.62	5.12	4.34	3.42	2.90	2.38	1.62	0.98
	0.58	**974**	5.56	5.71	5.86	6.06	6.06	6.05	6.03	5.81	5.30	4.50	3.55	3.02	2.48	1.69	1.04
	0.74	**1,243**	5.56	5.71	5.86	6.06	6.25	6.25	6.23	5.99	5.47	4.66	3.67	3.13	2.58	1.77	1.09
	0.95	**1,585**	5.55	5.70	5.85	6.05	6.25	6.36	6.34	6.11	5.57	4.75	3.75	3.20	2.64	1.80	1.12
	1.21	**2,023**	5.54	5.69	5.84	6.03	6.23	6.34	6.47	6.23	5.68	4.85	3.83	3.26	2.70	1.84	1.15
	1.54	**2,577**	5.33	5.47	5.62	5.81	5.99	6.11	6.23	6.35	5.78	4.93	3.90	3.33	2.75	1.89	1.19
	1.98	**3,297**	4.85	4.98	5.12	5.30	5.47	5.57	5.68	5.78	5.94	5.06	4.02	3.43	2.84	1.93	1.23
	2.52	**4,208**	4.11	4.22	4.34	4.50	4.66	4.75	4.85	4.93	5.06	5.19	4.10	3.50	2.91	1.95	1.25
	3.22	**5,373**	3.23	3.32	3.42	3.55	3.67	3.75	3.83	3.90	4.02	4.10	4.23	3.60	2.98	1.88	1.23
	4.11	**6,855**	2.73	2.81	2.90	3.02	3.13	3.20	3.26	3.33	3.43	3.50	3.60	3.67	3.05	1.79	1.18
	5.25	**8,751**	2.23	2.30	2.38	2.48	2.58	2.64	2.70	2.75	2.84	2.91	2.98	3.05	3.11	1.70	1.14
	6.70	**11,172**	1.51	1.56	1.62	1.69	1.77	1.80	1.84	1.89	1.93	1.95	1.88	1.79	1.70	2.25	1.28
	8.55	**14,261**	0.91	0.94	0.98	1.04	1.09	1.12	1.15	1.19	1.23	1.25	1.23	1.18	1.14	1.28	1.52

Table 4-14. Persistent habitat for dwarf wedgemussels (*Alasmidonta heterodon*) at site DEL3. Units of habitat are hectares.

			Discharge # 2														
	(ft^3/s/mi^2)		**0.28**	**0.36**	**0.46**	**0.58**	**0.76**	**0.98**	**1.26**	**1.62**	**2.09**	**2.69**	**3.46**	**4.45**	**5.73**	**7.38**	**9.50**
		(ft^3/s)	**505**	**650**	**833**	**1,059**	**1,377**	**1,779**	**2,291**	**2,951**	**3,798**	**4,889**	**6,294**	**8,105**	**10,435**	**13,435**	**17,297**
Discharge # 1	**0.28**	**505**	3.53	3.48	3.39	3.27	3.15	2.97	2.74	2.44	2.06	1.76	1.36	0.90	0.31	0.21	0.24
	0.36	**650**	3.48	3.91	3.80	3.68	3.55	3.14	2.96	2.71	2.36	2.03	1.57	1.04	0.39	0.26	0.28
	0.46	**833**	3.39	3.80	4.29	4.16	4.02	3.49	3.13	2.95	2.68	2.29	1.78	1.16	0.46	0.31	0.32
	0.58	**1,059**	3.27	3.68	4.16	4.59	4.44	3.90	3.40	3.11	2.93	2.48	1.92	1.26	0.50	0.33	0.35
	0.76	**1,377**	3.15	3.55	4.02	4.44	4.72	4.25	3.74	3.29	3.09	2.61	2.01	1.32	0.52	0.35	0.37
	0.98	**1,779**	2.97	3.14	3.49	3.90	4.25	4.52	4.02	3.53	3.15	2.38	1.84	1.19	0.45	0.31	0.34
	1.26	**2,291**	2.74	2.96	3.13	3.40	3.74	4.02	4.14	3.72	3.27	2.26	1.77	1.16	0.46	0.32	0.34
	1.62	**2,951**	2.44	2.71	2.95	3.11	3.29	3.53	3.72	3.95	3.33	2.78	2.11	1.33	0.52	0.35	0.37
	2.09	**3,798**	2.06	2.36	2.68	2.93	3.09	3.15	3.27	3.33	3.49	2.85	2.11	1.31	0.50	0.33	0.36
	2.69	**4,889**	1.76	2.03	2.29	2.48	2.61	2.38	2.26	2.78	2.85	3.02	2.07	1.25	0.49	0.32	0.35
	3.46	**6,294**	1.36	1.57	1.78	1.92	2.01	1.84	1.77	2.11	2.11	2.07	2.39	1.15	0.46	0.32	0.32
	4.45	**8,105**	0.90	1.04	1.16	1.26	1.32	1.19	1.16	1.33	1.31	1.25	1.15	1.59	0.33	0.24	0.24
	5.73	**10,435**	0.31	0.39	0.46	0.50	0.52	0.45	0.46	0.52	0.50	0.49	0.46	0.33	0.76	0.18	0.12
	7.38	**13,435**	0.21	0.26	0.31	0.33	0.35	0.31	0.32	0.35	0.33	0.32	0.32	0.24	0.18	0.58	0.12
	9.50	**17,297**	0.24	0.28	0.32	0.35	0.37	0.34	0.34	0.37	0.36	0.35	0.32	0.24	0.12	0.12	0.64

Appendix 5. User Documentation for the Delaware River Decision Support System

Getting Started

The very first step in using the Delaware River Decision Support System (DRDSS) is to make sure that the computational infrastructure is up to the task. The system appears to run adequately on computers having a 3 GHz processor and at least 1 GB of RAM. In addition, we have found that the DRDSS requires Excel 2003 in order to load all the required spreadsheets. Excel 2002 will open some of them, but not all. Each run of the DRDSS requires a separate directory containing all the spreadsheets and any supporting files. Consequently, the volume of hard drive space consumed by DRDSS directories can accumulate rapidly. A convenient and economical solution to this problem is to store DRDSS directories on an external hard drive. External hard drives provide good system backup as well as ease of transport from one computer to another (especially useful for public hearings or meetings where multiple runs are to be displayed). Although the most of the graphics displays in the DRDSS are formatted to be distinguishable in black and white, a color printer capable of handling tabloid-sized paper (11 x 17 in) or larger will provide greater definition of graphs and charts. In some cases, access to a large-format plotter capable of generating poster-sized printouts may be desirable.

The DRDSS consists of five linked spreadsheets titled DSS_AGG.XLS, DSS_WB.XLS, DSS_EB.XLS, DSS_DEL.XLS, and DSS_NVR.XLS. In addition, there are two utility spreadsheets,"met_data.xls" and "OASIS reformatterV2_1.xls" that are integral components to the DRDSS. "Met_data.xls" contains the meteorological data (historical, normal, and worst-case) needed to perform temperature simulations. The OASIS reformatter converts hydrologic information from OASIS into the format required as input to the DRDSS.

None of these spreadsheets is adequately protected to prevent inadvertent damage caused by keystroke errors or information pasted into the wrong places. Even minor modifications to the code can render the entire system useless, so users are advised to work on copies of the DRDSS master files instead of working on the original version. Before doing anything else, the user should create a directory named according to the alternatives to be tested (for example, REV1_REV7 as a directory name). The DSS_AGG worksheet, all four of the SUBS (DSS_WB.XLS, DSS_EB.XLS, DSS_DEL.XLS, and DSS_NVR.XLS), and the two utility files should be copied into this directory. The DRDSS cannot be run from the native medium (in this case, a CD) and must be copied to a hard drive. It is helpful to include a small "README" file to this directory that describes the OASIS modifications performed for the comparisons embodied in the particular DRDSS run. These two steps will provide backup in the event that the DRDSS files are compromised and will assist the user in recalling the changes made to test an alternative. Describing the characteristics of the run is especially important if multiple runs are made because some of the changes may be subtle. It can be extremely frustrating to arrive at a promising solution and not remember how it was derived.

Preparing Input Data

Importing Data from OASIS to DRDSS

There are several critical details to keep in mind before starting. First, order is critical, both temporally and spatially. If data are not entered in the order expected by the DSS, the results will be incorrect; in such a case, the only way to gain correct results would be to start over. Incorrect or erroneous applications of the DRDSS may be virtually indistinguishable from correct applications. Finding mistakes can be traumatic, especially if they are found during a public hearing or negotiations setting. Fixing them can be time-consuming and frustrating.

> An example of this type of mix-up occurred during the beta-testing of version 2.0, where a user entered OASIS output for the baseline period 1990 – 2000, but used the record from 1960 – 1970 for the alternative. The mistake was detected by the decisionmakers, who realized that the outcome displayed on the summary scoring page was counterintuitive. In this case, the intuition of the decisionmakers was correct and the model results were wrong.

The DRDSS operates on a 10-year period of water years, which begin on October 1 (October 1, 1995, is the first day of water year 1996). Any 10-year period between 1953 and 2000 can be used, so long as it starts on October 1, ends on September 30, and has 10 years of data between the two. Note that OASIS output extends back to 1928. The usable period in the DRDSS extends only to 1953 because of limitations of the meteorological database.

Output derived from OASIS consists of at least two individual text files containing daily flow data, reservoir storage and release data, system-wide drought trigger data, Montague flows, and export data for New York City and the Delaware and Raritan canal diversion in New Jersey. One file contains data for the baseline and the other contains data for the alternative. The spatial order of the data from left to right is the same in the OASIS text files as it is in the DRDSS with one major exception: OASIS does not produce flow statistics for the Beaverkill, but there is a column in the DRDSS “FLOWS” sheet for the Beaverkill. The historical discharges of the Beaverkill have been incorporated in the “OASIS reformatter.xls” spreadsheet, provided to convert OASIS output to the correct spatial order required to the DRDSS.

Preparing Data for Import from OASIS

1. Open the “OASIS formatter.xls” spreadsheet and click on the page labeled “From_OASIS” (Fig. 5-1).
2. Open the first (baseline) OASIS text file in a new Excel workbook as a space delimited file.
3. Go to the first data value (the first Stilesville flow) in the newly opened OASIS workbook. Select and copy all the data values. Do not copy dates or column headers.
4. Open the “From_OASIS” page in the OASIS_formatter spreadsheet and paste the OASIS data to cell B15 (Fig 5-1).
5. As soon as the OASIS data are pasted into the “From_OASIS” sheet, the “To_DSS” sheet is automatically updated.

Exporting Data to the DRDSS

6. Click on the tab “To_DSS” in the OASIS formatter spreadsheet (fig. 5-2).
7. Move the cursor to the first day of the first water year to be processed in the DRDSS (for example, October 1, 1959, for water year 1960).
8. Select and copy the entire block of data (including the date) from this point to the last data column for the last day of the tenth water year from the start date (in this example, September 30, 1969; fig. 5-2).

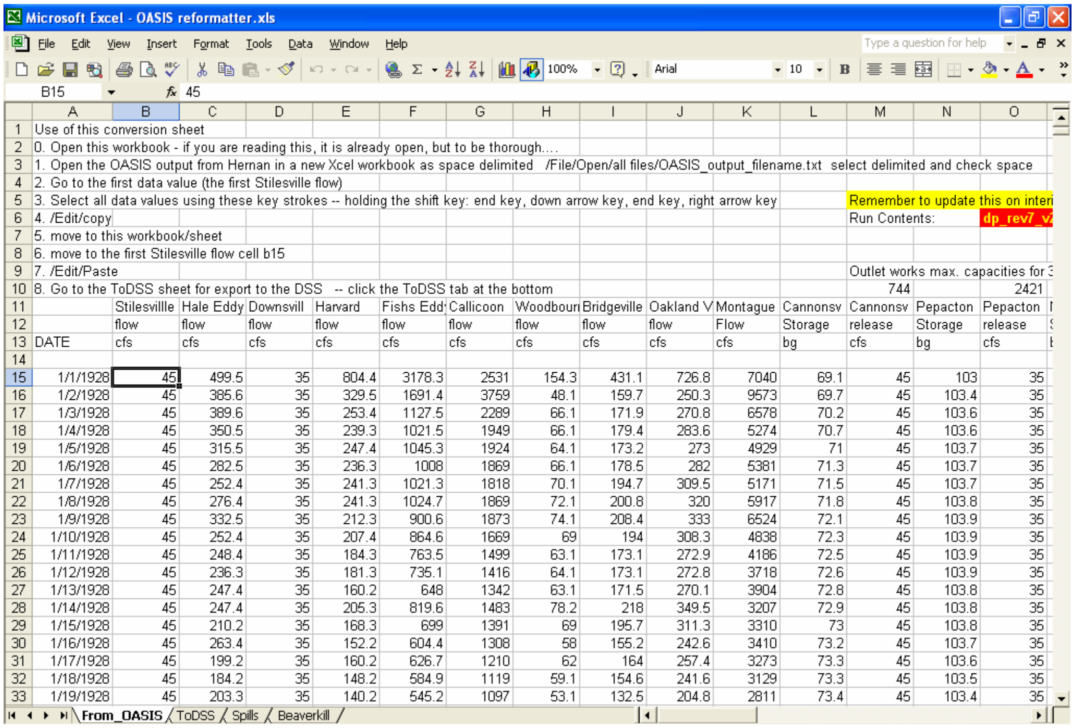


Figure 5-1. The "From_OASIS" page of "OASIS_formatter.xls." Outlined box in figure shows where the data copied from the OASIS text file are to be pasted.

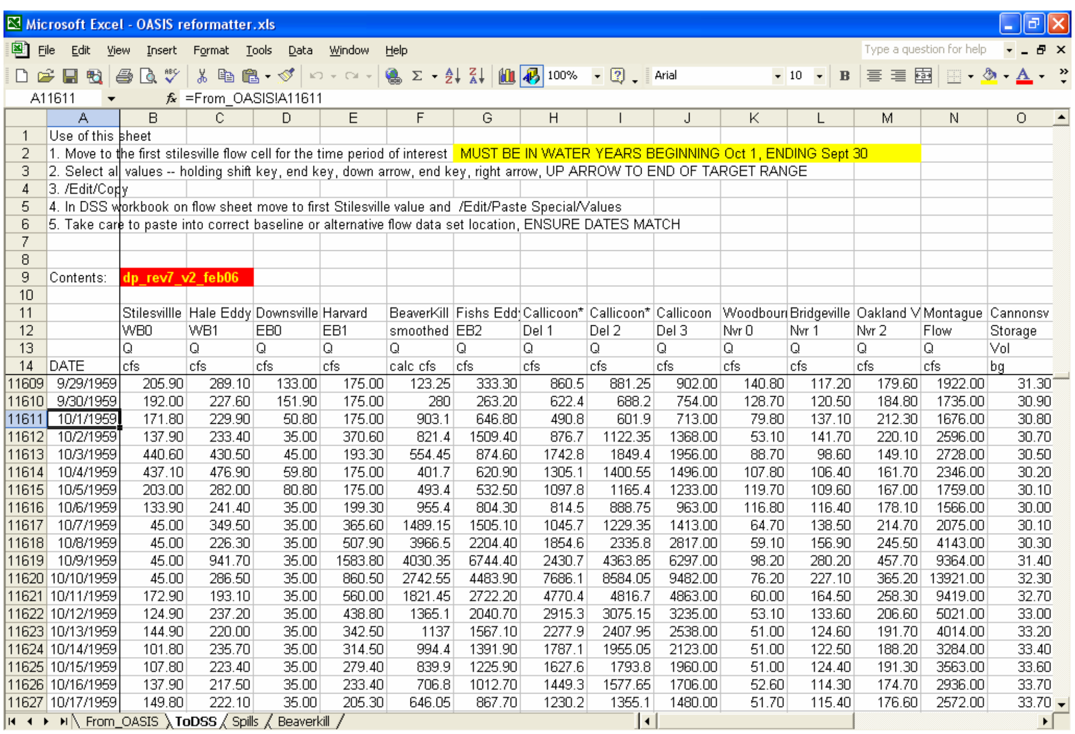
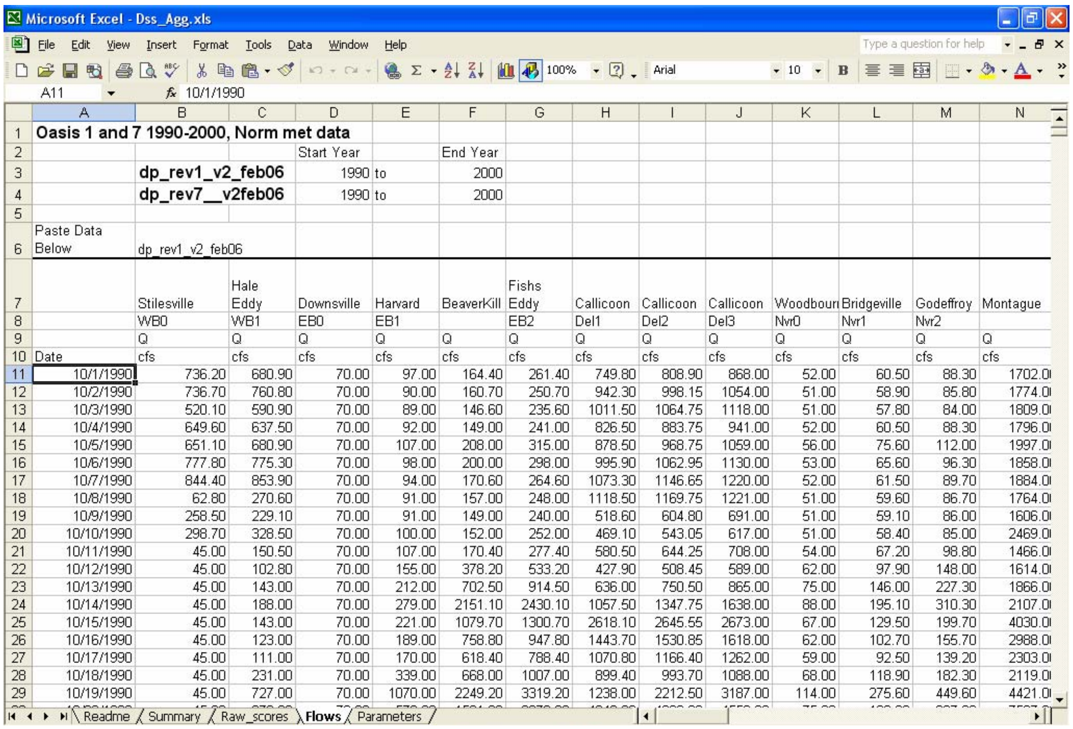


Figure 5-2. The "To_DSS" page of "OASIS formatter.xls." In the example, the first date of the first water year of interest is October 1, 1959, located at cell A11611.

9. In the DSS_AGG.xls workbook, click on the tab labeled "Flows" (fig. 5-3). This worksheet contains the flows, storage volumes, releases, and spills computed by OASIS. Flows are arrayed by date (row) and by study area (column) in two blocks (left and right). The first block pertains to the baseline, and starts at cell A11 (fig 5-3). The second block is for the alternative, and it starts in cell AB11. Do not forget to update the second block with the same period of record as the first one.
10. Having copied the 10-year data baseline block from "OASIS formatter.xls," **SELECT** cell A11 on the "Flows" page of DSS_AGG.xls and **PASTE SPECIAL/VALUES**. The data must be pasted as values because the dates in the data block from "OASIS formatter.xls" are actually formulas.



Microsoft Excel - Dss_Agg.xls

A11 10/1/1990

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Oasis 1 and 7 1990-2000, Norm met data													
2				Start Year		End Year								
3		dp_rev1_v2_feb06		1990	to	2000								
4		dp_rev7__v2feb06		1990	to	2000								
5														
6	Paste Data Below	dp_rev1_v2_feb06												
7		Stilesville	Hale Eddy	Downsville	Harvard	BeaverKill	Fishs Eddy	Callicoon	Callicoon	Callicoon	Woodbourı	Bridgeville	Godeffroy	Montague
8		WB0	WB1	EB0	EB1		EB2	Del1	Del2	Del3	Nvr0	Nvr1	Nvr2	
9		Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
10	Date	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs
11	10/1/1990	736.20	680.90	70.00	97.00	164.40	261.40	749.80	808.90	868.00	52.00	60.50	88.30	1702.0
12	10/2/1990	736.70	760.80	70.00	90.00	160.70	250.70	942.30	998.15	1054.00	51.00	58.90	85.80	1774.0
13	10/3/1990	520.10	590.90	70.00	89.00	146.60	235.60	1011.50	1064.75	1118.00	51.00	57.80	84.00	1809.0
14	10/4/1990	649.60	637.50	70.00	92.00	149.00	241.00	826.50	883.75	941.00	52.00	60.50	88.30	1796.0
15	10/5/1990	651.10	680.90	70.00	107.00	208.00	315.00	878.50	968.75	1059.00	56.00	75.60	112.00	1997.0
16	10/6/1990	777.80	775.30	70.00	98.00	200.00	298.00	995.90	1062.95	1130.00	53.00	65.60	96.30	1858.0
17	10/7/1990	844.40	853.90	70.00	94.00	170.60	264.60	1073.30	1146.65	1220.00	52.00	61.50	89.70	1884.0
18	10/8/1990	62.80	270.60	70.00	91.00	157.00	248.00	1118.50	1169.75	1221.00	51.00	59.60	86.70	1764.0
19	10/9/1990	258.50	229.10	70.00	91.00	149.00	240.00	518.60	604.80	691.00	51.00	59.10	86.00	1606.0
20	10/10/1990	298.70	328.50	70.00	100.00	152.00	252.00	469.10	543.05	617.00	51.00	58.40	85.00	2469.0
21	10/11/1990	45.00	150.50	70.00	107.00	170.40	277.40	580.50	644.25	708.00	54.00	67.20	98.80	1466.0
22	10/12/1990	45.00	102.80	70.00	155.00	378.20	533.20	427.90	508.45	589.00	62.00	97.90	148.00	1614.0
23	10/13/1990	45.00	143.00	70.00	212.00	702.50	914.50	636.00	750.50	865.00	75.00	146.00	227.30	1866.0
24	10/14/1990	45.00	188.00	70.00	279.00	2151.10	2430.10	1057.50	1347.75	1638.00	88.00	195.10	310.30	2107.0
25	10/15/1990	45.00	143.00	70.00	221.00	1079.70	1300.70	2618.10	2645.55	2673.00	67.00	129.50	199.70	4030.0
26	10/16/1990	45.00	123.00	70.00	189.00	758.80	947.80	1443.70	1530.85	1618.00	62.00	102.70	155.70	2988.0
27	10/17/1990	45.00	111.00	70.00	170.00	618.40	788.40	1070.80	1166.40	1262.00	59.00	92.50	139.20	2303.0
28	10/18/1990	45.00	231.00	70.00	339.00	668.00	1007.00	899.40	993.70	1088.00	68.00	118.90	182.30	2119.0
29	10/19/1990	45.00	727.00	70.00	1070.00	2249.20	3319.20	1238.00	2212.50	3187.00	114.00	275.60	449.60	4421.0

Readme / Summary / Raw_scores / Flows / Parameters

Figure 5-3. The "Flows" page of "DSS_AGG.xls," with outlined cell indicating where to paste baseline data from "OASIS formatter.xls."

11. Open the second OASIS text file, containing information for the alternative and repeat steps 1 – 10, but pasting the data from "OASIS_reformatter.xls" in cell AE11 on the "Flows" page of "DSS_AGG.xls" (fig. 5-4). Note that the dates for the baseline and the alternative are copied and pasted into their respective locations independently from each "OASIS_reformatter.xls" scenario. The DRDSS compares the ranges of dates to confirm that the same period of record was used for both cases. The DRDSS will run successfully if mismatched data sets are used, but the user is alerted to the disparity on the scoring pages.

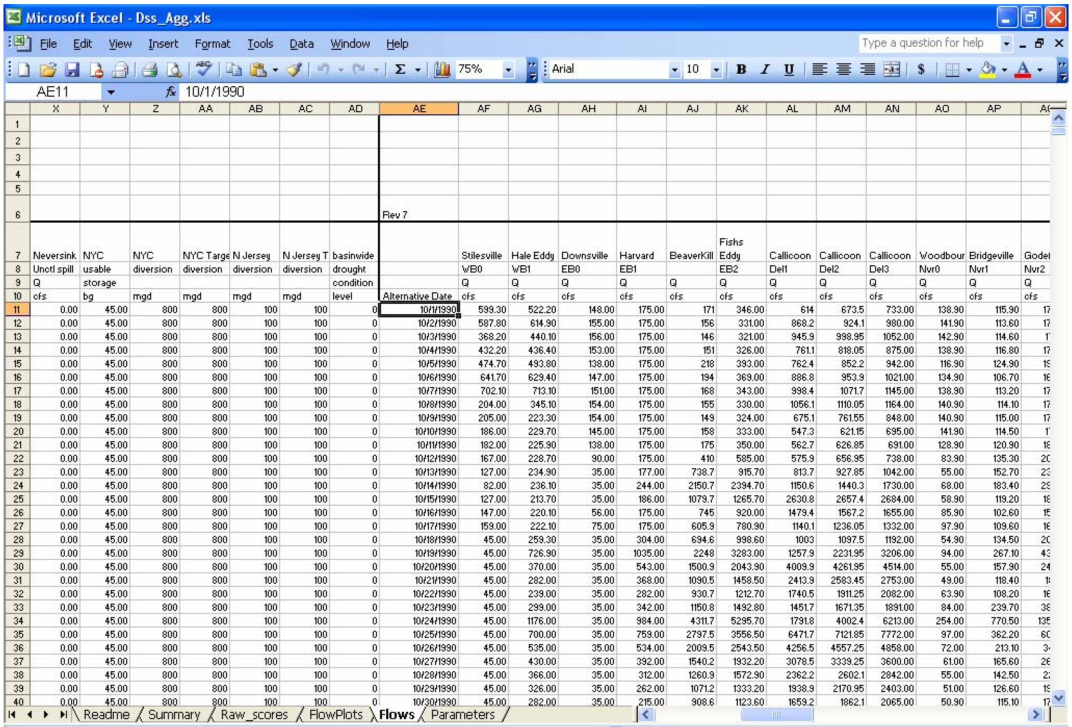


Figure 5-4. The "Flows" page of "DSS_AGG.xls," with outlined cell indicating where to paste data for an alternative from "OASIS formatter.xls."

Importing Meteorological Data

To reiterate, there are three choices with regard to the meteorological data used in the DRDSS temperature calculations: (1) repetitive cycles of the 1993 – 2003 empirical data set from Monticello, (2) normal (average) meteorological values arranged by date, or (3) extreme daily values arranged by date. These data are contained in the file "met_data.xls." Records in this spreadsheet match the period of record applicable to the DSS, extending from October 1, 1953, to September 30, 2003, with daily values filled in accordingly. As with the flow data, it is extremely important to match the dates from which the meteorological data are to be extracted with the dates used for the flow data. However, with the meteorological date, the copy/paste sequence is a little trickier because data are only recorded for the period May 1 – September 30. The rest of the dates have no data, but MUST BE COPIED ANYWAY in order to synchronize properly with the flow data. Furthermore, the dates for the meteorological data are not copied to the "Flows" page, so cross checking is not performed within the DRDSS to ensure synchronization.

1. If not previously done, make a copy of "met_data.xls" and work off the copy.
2. Continuing with our previous example, our period of record is from October 1, 1959, through September 30, 1969. Supposing that we are using "normal" meteorological conditions, the block from cell F2002 to I5854 would be copied (figs. 5-5 and 5-6).

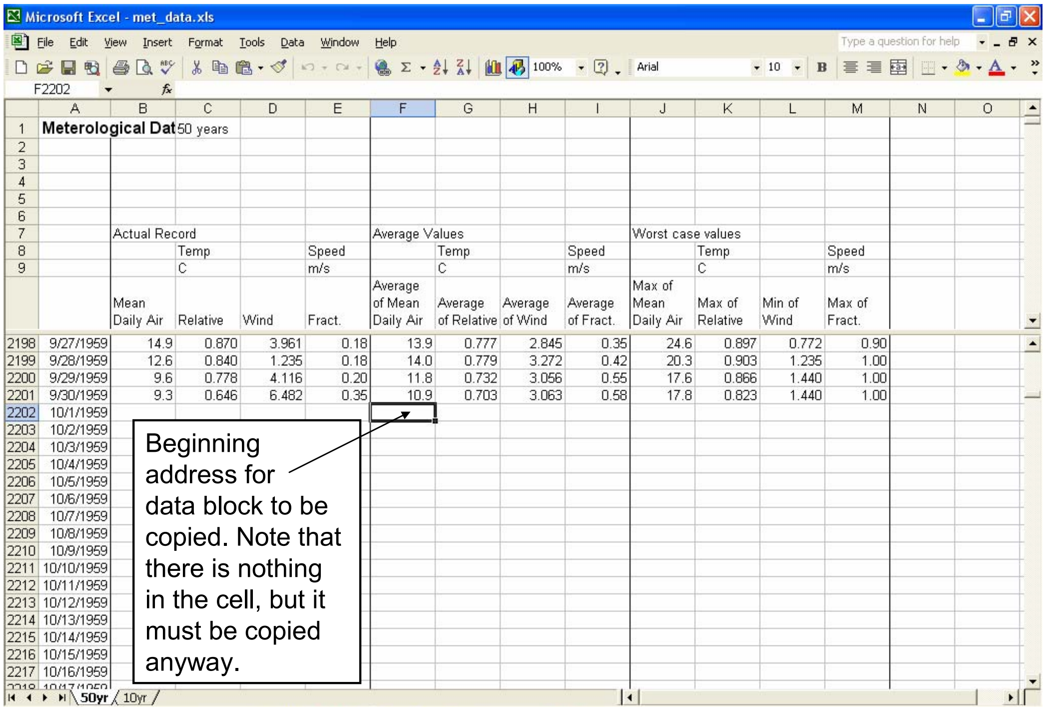


Figure 5-5. Cell F2002 in “met_data.xls,” the starting location for copying a ten-year block of “normal” meteorological data corresponding to the dates and flows previously imported to the “Flows” page of “DSS_AGG.xls.”

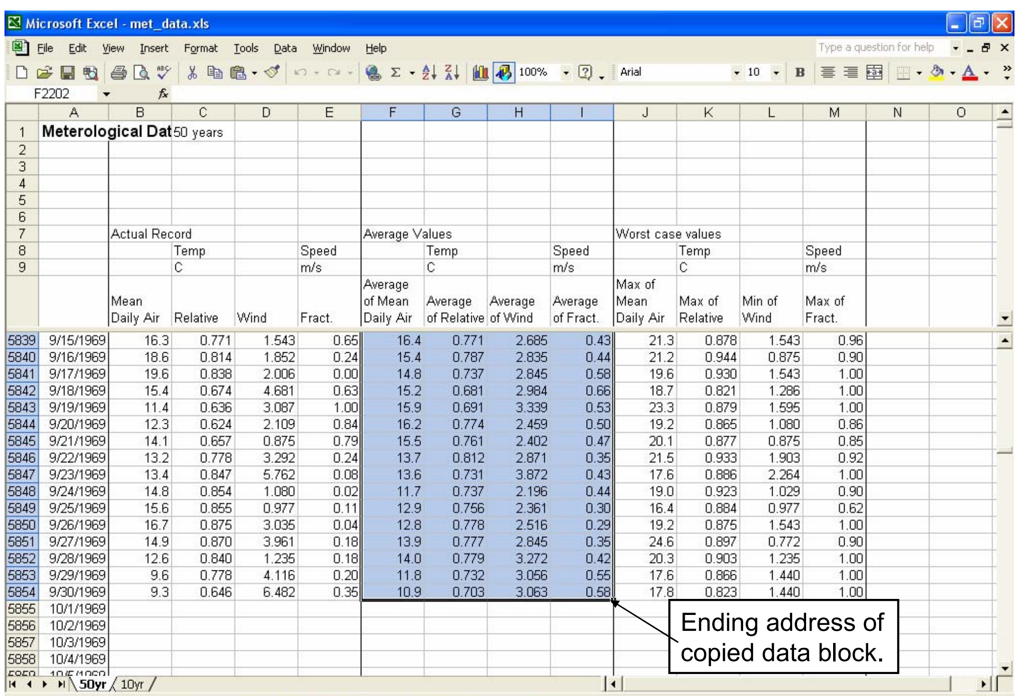


Figure 5-6. Selected block ending at cell I5854 in “met_data.xls,” the ending location for copying a ten-year block of “normal” meteorological data corresponding to the dates and flows previously imported to the “Flows” page of “DSS_AGG.xls.”

3. Once the desired block of meteorological data has been copied, return to the “Flows” page of DSS_AGG.xls, and paste the data to cell BI11 (fig. 5-7).

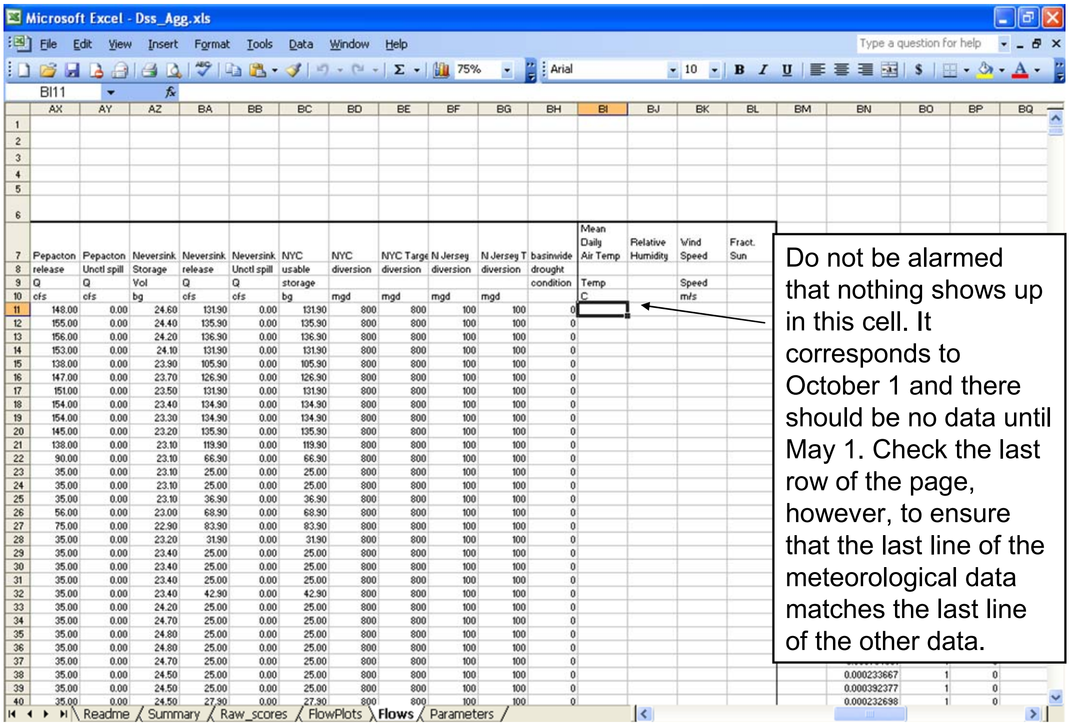


Figure 5-7. Cell BI11 on the “Flows” page of “DSS_AGG.xls” is outlined. This is where the meteorological data originating from the met_data.xls database are pasted.

Setting the Scoring Parameters and Related Information on the “Parameters” Page.

1. Open the DSS_AGG workbook and click on the tab labeled Parameters (fig. 5-8).
2. Update parameters and scoring thresholds as desired. If no data are supplied, the values in the Default column (column C) will be used instead. Any value in column D (as well as E, F, or G in the case of temperature thresholds) will override the Default. User values must be in correct units or formatted as shown in the Units column (column B). Do not overwrite the values in column C as this will replace the defaults. If the default value is acceptable, no entry needs to be made in column D. Otherwise, modify the appropriate values as desired in column D. The exceptions are for entries 4, 5, and 6 (cells D17, D19, D20, and D22), which should be updated to keep track of the specifics of a scenario. The meteorological series entry (D39) is a documentation field only and DOES NOT import the meteorological data automatically. The DRDSS uses the meteorological data from the last run unless new data have been copied and pasted from “met_data.xls.” Run settings, labels for baseline and alternative scenarios, and the period of record are updated automatically on the “Summary” and “Raw Scores” pages of the DSS_AGG.xls spreadsheet as an aid to run documentation.

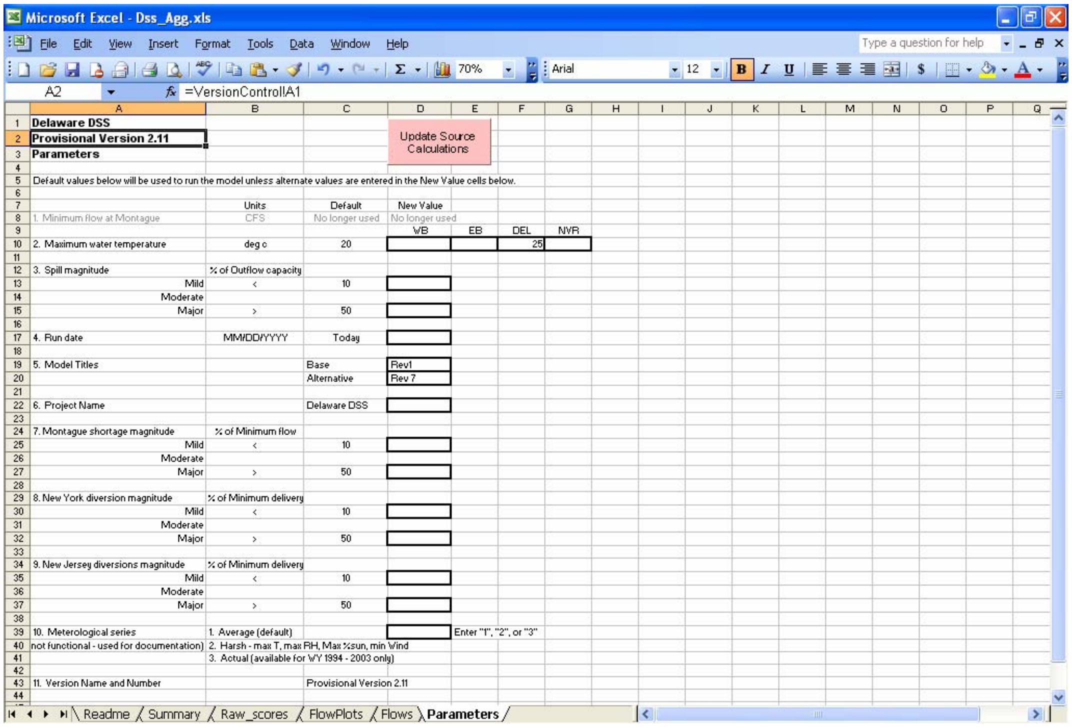


Figure 5-8. Parameters page from "DSS_AGG.xls."

Making a DSS Run

1. Double check all imported data to make sure everything lines up correctly with respect to dates and locations.
2. Review the "Parameters" page to ensure that all the thresholds are correctly set and that the run identification data are entered correctly.
3. Press the pink button labeled "Update Source Calculations" (fig. 5-8). The Update Source Calculations button sequentially opens each of the subsidiary workbooks (DSS_WB.xls, DSS_EB.xls, DSS_DEL.xls, and DSS_NVR.xls); copies the flow, meteorology, and parameter data into them; and recalculates all the values for the stream segment. Links to the stream files are updated in the DSS_AGG.xls file. Typical run times vary from 20 to 40 minutes, depending on processor speed. Do not push this button until all pertinent changes have been made and checked.

Generating Graphics and Displays

The DRDSS can generate a wide variety of graphics, all of which can be useful at different stages of interpreting and evaluating the outcomes of a run. Some displays should be generated for every run, whereas others need only to be generated on a case-by-case basis. Some of the graphics generated by the DRDSS are not automatically saved and can be overwritten. Therefore, it is advisable to save any desired graphics as hard copy, in electronic format (JPEG, TIF, or BMP, for example), or both. In this section, we have arranged the types of graphics and the means of generating them as a hierarchy, starting with graphics that should always be generated.

Scoring Summary and Raw Scores Pages

These scoring pages are actually tables that appear as Excel spreadsheet pages. Neither is a self-contained graphical unit, but must be manipulated to look like one for export, either to a printer or to an electronic graphics file. These pages can be printed directly from Excel to a single sheet, using the page setup and print preview options. Clarity and legibility can be improved by printing on tabloid-sized paper (11 x17 in), or larger. To create an electronic graphics file:

1. Outline the block of cells to be included in the graphics file (cells A1 to Q64 for the summary page or cells B1 to BP103 for the raw scores page). **Copy** the block.
2. Open Microsoft Word or (preferably) Powerpoint, select a new page (Word) or slide (Powerpoint) and click **Edit/Paste Special/Picture**. When the table appears satisfactorily on the page or slide, save the file under a name that reflects the alternatives being compared (for example, Rev1_Rev7_norm_60, for Revision 1 versus Revision 7 using normal year meteorological data for the decade 1960–1970). The advantage of storing these graphics in Powerpoint is that individual slides can be saved as JPEGs or other electronic graphics files. They cannot be saved directly in this format from Word.

Flow, Storage, and Temperature Duration Curves

These graphics are grouped together because they are all generated the same way. Flow and storage curves should be generated for every location and scenario. Temperature curves are optional and the decision to generate them depends on site- or situation-specific circumstances.

1. Generate a duration curve for one of the sites. We will use flows at WB0 for this example. Generation of duration curves for other variables and sites will follow a parallel approach.
    a. Open one of the SUBS spreadsheets (in this example, DSS_WB.xls) and move to the WBDurCurve tab (fig. 5-9).
    b. Select “Flows” from the menu adjacent to the button labeled “Get Variable Plot” and “WB0 from the menu next to the button labeled “Get Study Site” (fig. 5-9).
    c. Press the purple button labeled “Update Data.” The associated macros will proceed to sort the data and update the graph at the “DurCurveChart” page.
    d. As soon as the chart has updated, Excel automatically tabs to the DurCurveChart page, accompanied by an information window stating that the update is complete. Click OK on the information box.
2. If desired, rescale the Y-axis to accentuate the low-flow portion of the curve. Set the cursor over the Y-axis, right click, and select “Format axis.” From the menu, select “Scale” and manually set the limit for the maximum value. Reset the increments between the maximum and minimum values if necessary by manually changing the number in the box labeled “Major Unit.” Click OK. Note that once the scale has been changed, the same scale will be used for all subsequent charts, sometimes with unintelligible results. To avoid such problems, the scale can be reset to automatically adjust after the graph has been printed or saved.

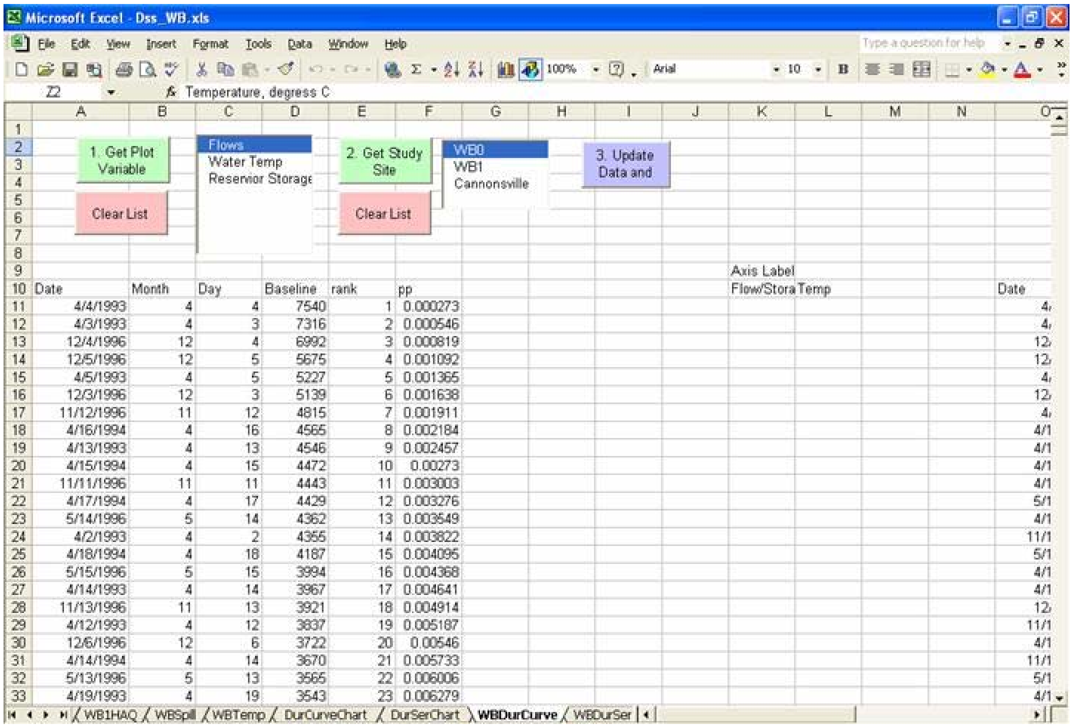


Figure 5-9. Setup to generate a flow duration curve for WB0 on the "WBDurCurve" page of "DSS_WB.xls." Selected Page tab and variables are highlighted.

3. IMMEDIATELY print and/or save the chart.
    a. Left click anywhere on the chart area. Black highlight dots should appear to outline the chart. To print, select **File/Print**. (The default print settings are for letter-sized paper and landscape orientation. Check to ensure that the printer paper matches the size specified in the print settings).
    b. To save the chart electronically, select the chart area as above, and click Edit/Copy. Then open the electronic graphics file (the Word or Powerpoint file) created for the scenario, create a new page or slide, and **Paste Special/Picture** to paste the chart. Save the File and return to the WBDurCurve page in the DSS_WB.xls spreadsheet
4. Select the next site or variable, and repeat steps 1–3 as necessary until all appropriate duration curves have been generated, printed, and saved. When finished, close the DSS_WB.xls workbook **without** saving.
5. Open the next SUB workbook, such as DSS_EB.xls and repeat steps 1–4. Repeat for all the SUBS workbooks until the full complement of duration curves has been generated and saved.

Duration Series Curves

Duration series curves are generated by procedures almost identical to those used to produce the duration curves described in the previous section. The basic differences are that the variables and sites are selected on the <sitename>DurSer page of the SUB workbook (fig. 5-10), and the chart will be updated on the DurSerChart page of that site's workbook. These charts may be considered optional, but should at least be reviewed and those showing "interesting" patterns of habitat availability should be saved or printed. The methods of printing or saving electronic versions of these charts are identical to those described for duration curves in the previous section. Unlike the duration curves, however, it will probably never be necessary to rescale the Y-axis to accentuate a particular portion of the chart.

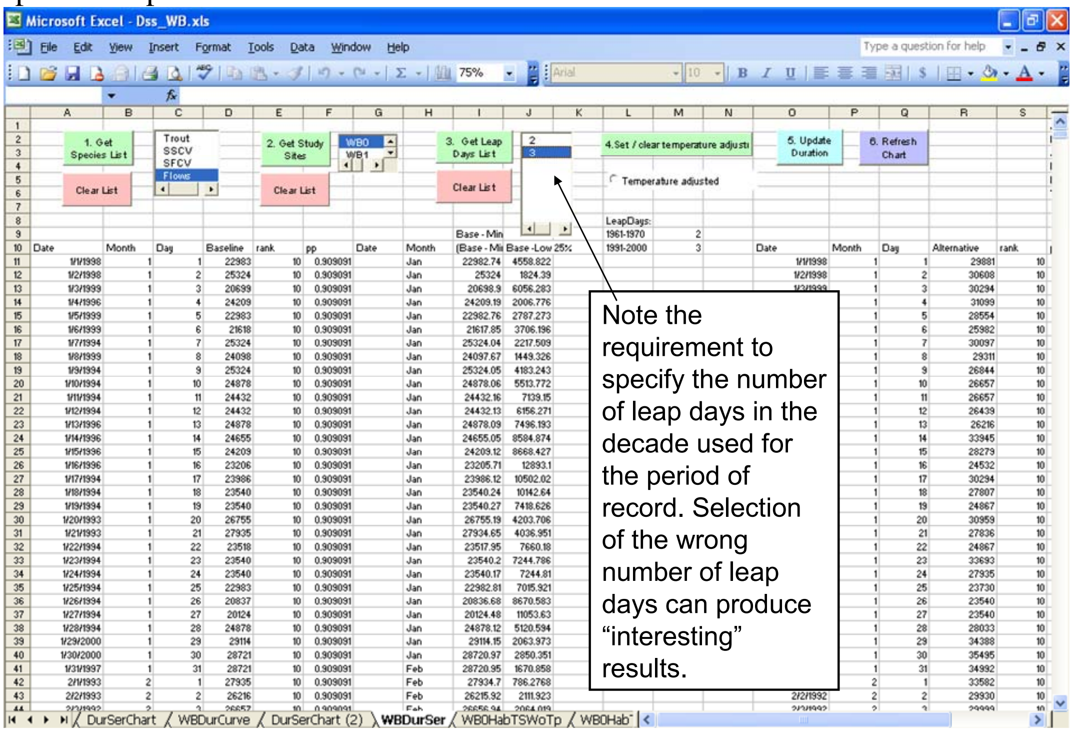


Figure 5-10. Setup to generate a flow duration series curve for WB0 on the "WBDurSer" page of "DSS_WB.xls." Selected Page tab and variables are highlighted.

Flow Plots

The time series plots of flows in each segment and storage volumes in the three reservoirs are found on the "Flow Plots" page of the DSS_AGG workbook. The original intent of incorporating these plots into the DRDSS was to provide a quick on-screen review of the sequence of flows and storage volumes. The charts are set up to lock the window for the Y-axis, allowing the user to scroll back and forth through the sequence. Unfortunately, the sequence is so long that plotting the whole thing compresses the scale so much that the plot is virtually unreadable.

There are several options available, however, in the event that a legible plot is needed. If the user has access to a large format color plotter, such as those used to produce poster presentations, the entire time series can be copied and pasted to a custom-sized (for example, 36 x 48 in) Powerpoint slide and printed in its entirety. Otherwise portions of the series can be copied to a more commonly-used size (either letter or tabloid) in a Powerpoint presentation file. The easiest way to copy a portion of the series is to scroll to the desired part of the sequence and use the "Print Screen" function on the computer. The contents of the clipboard can then be pasted to a Powerpoint slide and trimmed up to make presentable.

The Raw Scores Page

On occasion, it may be desirable to generate the Raw Scores page of the DSS_AGG workbook, especially if there are substantial spatial differences in the habitat responses to a change in operations. For example, the same operating rules might result in an increase of habitat metrics at WB0 and a decrease at WB1. Such a result could be masked on the Summary Scores page, which might indicate little or no change for the West Branch as a whole.

The Raw Scores page is organized in exactly the same format as the Summary Scores page. The difference between the two scoring pages is that the Raw Scores page contains information for each study segment instead of a compilation of scores for each stream. Because the Raw Scores page is so much larger than the Summary Scores page, we encounter the same problem discussed previously for the Flow Plots. The entire Raw Scores page can be copied to a letter-sized slide or document, but no one will be able to read it. Tabloid size is marginally better, but still hard to read.

The best overall option is the use of a custom sized Powerpoint slide that can be printed on a large format color plotter, or viewed as a projected image on a screen. To be as legible as a tabloid-sized version of the Summary Scores page, the page size for Raw Scores should be about three times as large (approximately 36 x 48 in). The same general procedures described for generating the Summary Scores page apply to copying and pasting the Raw Scores page, except that the block to be copied is much larger.

Information Management

The purpose of the DRDSS is to compare operations and results for numerous runs, so data management and organization of tabular and graphical output is of paramount importance. Each run has the potential of generating 89 different graphs and figures:

1. One (1) Summary Scores page,
2. Eleven (11) flow duration plots,
3. Three (3) storage duration plots,
4. Eight (8) temperature duration plots (none for the Neversink),
5. Forty-eight (48) duration series curves (85 if curves including both temperature conditioned and unconditioned habitat are generated),
6. Eleven or more (11+) flow series plots, depending on whether a series of partial plots must be generated,
7. Three or more (3+) storage series plots, with the same caveat as above, and
8. Four (4) Raw Scores pages.

Recall that a DRDSS run represents the outcome for a single OASIS alternative for one decade. If the analyst were only to produce the minimum number of routinely-generated graphics (items 1–3 above) for all five decades in the period of record, there would be at least 45 graphs for each alternative. The need for organization should be obvious to even the most casual of observers.

We have already discussed some of the basics regarding information management, such as setting up individual computer directories for each run. A parallel approach can be followed to organize the results from each run:

1. Create a single directory for each run, named according to the alternative tested and the time period represented by the run (for example, Rev1_Rev7_1960s). The directory can consist of a file folder if all the results are to consist of hard copy. If the directory is to be created electronically, a backup folder should be created on an independent medium such as a CD-ROM or external hard drive.
2. Write a README file containing the specifics of the objectives of the alternative and the operating rules defining the baseline and the alternative in the OASIS run, and put it in the

folder. Over the years, we have witnessed a widespread failure to do this. Universally, everyone who has not documented the alternatives has regretted it later.

3. Generate and save the necessary graphics. It may be convenient to save electronic graphics as a series of slides in an appropriately named Powerpoint presentation file. For hardcopy, it may be worthwhile to segregate graphics of a particular type, such as all the flow duration curves, into a subfolder.
4. To the extent possible, conduct a cause-and-effect analysis of the run and write a brief synopsis of the mechanics leading to particular outcomes. For example, "Spawning-incubation habitat was decreased under the alternative. The probable cause was that streamflow was increased during October and November and remained the same as the baseline from December through April. The net result was that the differential between spawning flows and incubation flows increased, thereby causing a reduction in persistent spawning-incubation habitat." Although this step might be considered optional, documenting the cause-effect mechanisms for both positive and negative outcomes will be extremely useful for developing the next scenario or a contingency plan.

One idea for organizing these materials with consistent format and content is to collect all the aforementioned products into a poster. A primary advantage of the poster format is that the results of multiple runs can be displayed side-by-side for comparison during public hearings or Commission-related meetings. The best information in the world is useless if no one can understand it. It is almost as useless if decisionmakers cannot find or readily identify the information they need to address a particular problem.

The poster option is available only for users having access to a large format color plotter, but it may be of sufficient utility to justify acquiring access to one by purchase, lease, or contract. Figure 5-11 illustrates a basic poster template that accommodates the summary scores page, multiple graphics (in this case, all the flow and storage duration curves), and text boxes describing the conditions and outcomes of a DRDSS run. A similar design can be used for displaying raw scores and additional graphics. The poster shown in figure 5-11 was generated in ArcMap and originally dimensioned to 36 x 74 inches. This seems to be a suitable size because the items on the poster are legible at distances of two to three meters, but the posters are small enough to display several of them side-by-side in a meeting room.

The poster format is a promising technique for consolidating, organizing, and displaying large amounts of information. The advantages of posters are that they can be fairly self-explanatory (not much text required or wanted) and visually stimulating, facilitating "big-picture" comparisons among alternatives. A disadvantage of posters is that it may difficult to anticipate what information the decisionmakers will find the most useful. This can lead the poster designer to try to include everything, at the risk of creating an illegible billboard overloaded with information. It may take several attempts before the most effective combination of design and content is accomplished, but the goal should always be to convey the most information to the most people in the most understandable way possible.

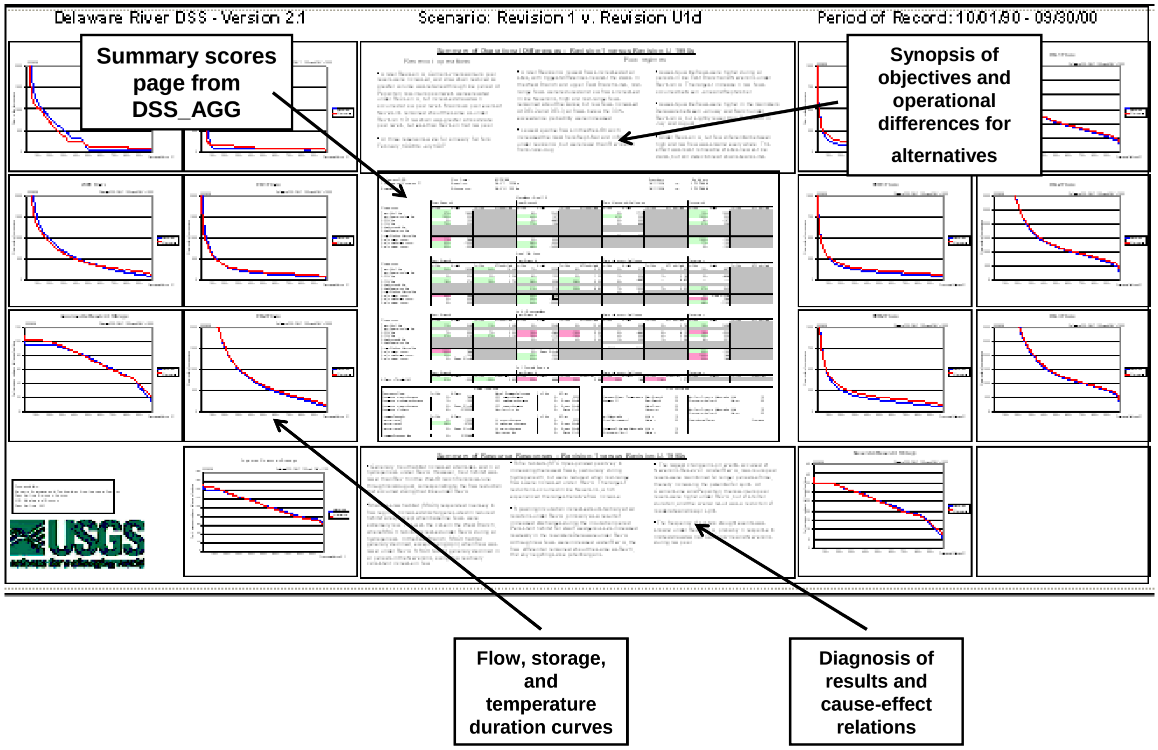


Figure 5-11. Poster template generated for 36 x 74 inch page size in ArcMap, showing locations and relative sizes of components.