AN EVALUATION OF INSTREAM FLOW METHODS FOR USE IN WEST VIRGINIA

REPORT FROM

DIVISION OF WILDLIFE RESOURCES
WEST VIRGINIA DEPARTMENT OF NATURAL RESOURCES
ELKINS, WEST VIRGINIA

TO

OHIO RIVER BASIN COMMISSION
CINCINNATI, OHIO

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PREFACE

The West Virginia Department of Natural Resources, Division of Wildlife Resources, evaluated three methods for determining the instream flow needs of selected fishes and how they will be affected by alterations in stream hydrology. The methods evaluated were: (1) the Cooperative Instream Flow Service Group's (IFG) Incremental method, (2) the Montana (Tennant) method, and (3) the Idaho method. The IFG method was of primary interest, and problems encountered during its use, possible management applications, and potential for use in other eastern streams are discussed.

The following persons were the chief participants in the project:

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Personnel of the Cooperative Instream Flow Service Group, United States Fish and Wildlife Service, provided advice and assistance as well as computer software and documentation, and publications describing procedures for stream flow measurement and development of habitat suitability curves for fishes.

ABSTRACT

The incremental method developed by the Cooperative Instream Flow Service Group (IFG) for determining instream flow needs of fishes was tested for applicability in the Greenbrier, Meadow and New Rivers of West Virginia and compared to the Montana and Idaho methods. Requirements for gathering physical data for the hydraulic simulations were more easily met on smaller streams than on large rivers such as the New. The IFG-4 hydraulic simulation program was judged superior to the IFG-2 program in accuracy and convenience of use, its single disadvantage being that it required three sets of field measurements for calibration as compared to one set for the latter program. Curves were constructed depicting the suitability as habitat of various substrates and of increments of depth and current velocity for life stages of smallmouth bass (*Micropterus dolomieui*), brook trout (*Salvelinus fontinalis*), stoneroller, (*C~~o~~ampostoma anomalum*), fantail darter (*Eth~~o~~eostoma flabellare*), and striped shiner (*Notropis chrysocephalus*). No curves were developed for spotted bass (*Micropterus punctulatus*) or channel catfish (*Ictalurus punctatus*). Most habitat preference data collected in different streams could not be combined. Many of the habitat suitability curves constructed in this study did not resemble curves developed by the IFG but were often similar to curves developed by other investigators. The curves developed in this study probably contain biases inherent in the method of data collection and curve construction. The Montana (Tennant) method gave results which compared favorably with results obtained with the IFG method, but results obtained with the Idaho (wetted perimeter) method were erratic.

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INTRODUCTION

Increased withdrawal of water from streams or alteration of hydrologic conditions as a result of development projects will pose a serious threat to fish and wildlife resources and will necessitate decisions on water allocations which will have major long-range implications. Such decisions should be based upon sound biological data. The need for methods to determine instream flow requirements for aquatic life has long been recognized (Stalnaker and Arnette 1976). Most of the methods developed have been used in the West in response to problems associated with water use and allocation. However as the country moves toward energy self-sufficiency, the methods will be employed nationwide. Their use in the East will occur primarily as a result of hydrologic alteration due to new hydroelectric projects and modifications of existing structures to produce electric power. Also, the development of coal conversion plants potentially may place a burden upon water resources in eastern states.

West Virginia and most eastern states aside from the populated eastern seaboard have rarely experienced the need for severe water conservation measures. With recognition of the increased water demands for social needs, cooling purposes, industrial processes, and energy development an obvious concern becomes apparent (Cairns 1972, Orsborn and Allman 1976a & b). Projected needs indicate a 254% increase in energy use from 1977 to 1996 (U.S. Department of Energy Newsletter 1977). The relatively unpopulated Kanawha Basin could eventually be used to fulfill these needs. As of 1970 at least 9 potential hydro-electric power plant sites were being considered in the Kanawha Basin (U.S. Dept. Interior 1971). Proposed coal gasification energy systems will also use immense amounts of water not directly returnable to the ecosystem due to rapid evaporation. With such demands, instream flow data will be required in order to permit the efficient use of available water resources, and the simultaneous protection of aquatic life.

The development of methods for assessing instream flow needs in the western states has been described by Stalnaker and Arnette (1976), Orsborn and Allman (1976a, 1976b), and Ott and Tarbox (1977).

Instream flow studies were conducted in the Connecticut River Basin Robinson 1969) and in West Virginia (Pierce 1969). Robinson's (1969) method was based on historic flow records. It required the use of average monthly, median, and minimum flows and estimated preservation and optimum flows for fisheries. West Virginia used a reconnaissance type study which determined optimum fishing flows and flows deleterious to bottom fauna.

Studies are in progress or in the planning stage in Pennsylvania, Maryland, Massachusetts, Vermont, and Virginia (G. Taylor, U.S. Fish and Wildl. Serv., Boston, Mass., Pers. Comm.). These studies will use the Instream Flow Group Incremental Method. Studies using the basic IFG method have recently been completed in Illinois (Herricks et al. 1980) and British Columbia (Newcombe 1981).

The purpose of this report is to present the results of the Instream Flow study performed in the Kanawha Basin, West Virginia and to evaluate the potential of three instream flow methods for use on eastern streams. Although data were presented describing habitat availability at various flows in the study streams, no attempt was made to define instream flow needs for the streams. The reader should keep in mind that the primary objective was to compare methods.

BACKGROUND

Under a contract with the Ohio River Basin Commission, The West Virginia Department of Natural Resources has completed a two phase study (Cincotta 1978). The primary purposes of Phase I were to identify existing means for reserving stream-flows for protection of fish and to assess the various methods for applicability in West Virginia. The Phase II study segment outlined in detail a work plan for determining fish and wildlife instream flow needs on three streams in the Kanawha Basin (Cincotta 1978). The project as outlined in Phase II was funded by the O.R.B.C. with matching funds provided by the State of West Virginia.

The present report covers Phase II of the study which extended from 1 June 1979 to 30 June 1981. In Phase II, a promising method for determining instream flow needs of fishes was tested which was developed by the Cooperative Instream Flow Service Group (IFG) of the U.S. Fish and Wildlife Service. Phase II objectives included selection of study reaches, measurement of hydraulic parameters related to stream flows and fish habitats, analysis of data, preparation of a report evaluating the IFG (or Incremental) method, comparison of that method with the Montana (Tennant) and Idaho methods, and assessment of its suitability for employment in West Virginia waters.

DESCRIPTIONS OF STUDY STREAMS

The study is restricted to the Kanawha River Basin in West Virginia, exclusive of the main channel Kanawha River (Fig. 1). Approximately 70% of the Kanawha Basin is found within the boundaries of West Virginia with the remaining portions located in Virginia and North Carolina. The Kanawha River and its major tributaries, the Coal, Elk, Gauley, New and Poctalico drain approximately 12,252 mi^2, 8417 mi^2 of which are in West Virginia.

The New and Gauley Rivers join at Gauley Bridge, West Virginia, to form the mainstem Kanawha River. The Kanawha then flows in a northwesterly direction for approximately 93.6 mi to its confluence with the Ohio River at Point Pleasant, West Virginia. Elevations within the basin range from above 4900 ft in sections of the Blue Ridge Mountains of North Carolina to 533 ft at the junction of the Kanawha and Ohio River.

Detailed information concerning all aspects of the Kanawha Basin can be found in the Kanawha River Comprehensive Basin Study (U.S. Dept. Inter. 1971, Vols. I-VII) and the Basin Water Quality Management Plan for the Kanawha River Basin (WV DNR 1974). Three locations within the Kanawha Basin were chosen for study. These were: (1) the upper Greenbrier River including the East Fork; (2) Meadow River; and (3) New River from Bluestone Dam to Sandstone Falls (Fig. 1). These areas were chosen because they represented diverse habitat types and ranged in size from small streams (East Fork) to large rivers (New River). They also provided the opportunity for comparison of methods and results obtained in different watersheds. The three areas are in the Kanawha Authorization Study for possible water projects which will have an impact on instream flows (U.S. Fish and Wildlife Service 1976; U. S. Department of Interior 1978). A description of the three study areas follows:

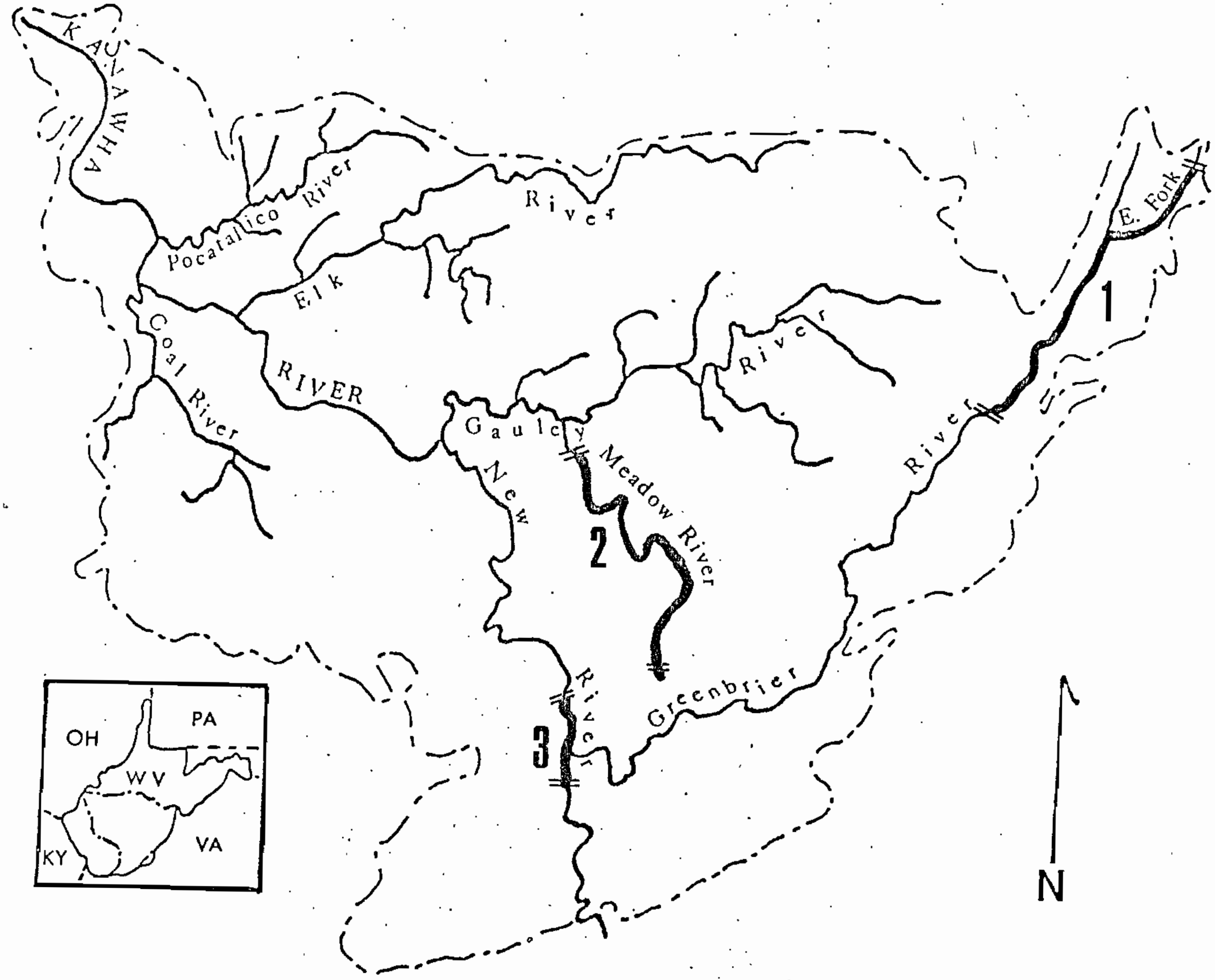


Figure 1. The Kanawha River Basin, West Virginia with study sites indicated (1 = upper Greenbrier River including East Fork; 2 = Meadow River; 3 = New River between Sandstone Falls and Bluestone Dam).

Upper Greenbrier River including East Fork

The Greenbrier River is located in eastern West Virginia, flows 164.8 mi from northern Pocahontas County and enters the New River at Hinton, West Virginia, just below Bluestone Dam (Hocutt, et al. 1978) (Fig. 1). It drains over 1634 mi^2 and is associated with several sink areas, including the Karst region of Greenbrier County (Jones 1973). The average gradient over its length is 15 ft/mi. The gradient for various sections of the river is shown in Figure 2. Reed (1974) reported widths from 45 ft to over 200 ft and depths to 15 ft. There are few surface tributaries on the West and almost none of any size. The study area includes the entire East Fork and that portion of the mainstem Greenbrier from the confluence of the East and West Forks down stream to the town of Marlinton (Fig. 3).

Water quality in the Greenbrier Drainage is generally good. The upper Greenbrier downstream to Marlinton is of high quality with conductivity usually near 70 micromhos, dissolved solids less than 100 mg/l, pH 7.5-8.3, and BOD less than 0.5 mg/l. The East Fork is normally alkaline and of a calcium carbonate nature (Hocutt et al. 1978). Dissolved solids are near 35 mg/l, BOD less than 0.5 mg/l, and pH 7.9-8.3. Pollution influencing water quality within the study area is limited to the tannery at Frank and untreated domestic sewage from the towns of Bartow, Frank, and Durbin. Large sections of the East Fork from near Thornwood to Durbin have been channelized.

The drainage area of the Greenbrier River above Marlinton is 408 mi^2. Flows range from a maximum of 21,700 cfs to a minimum of 12 cfs. The average discharge is 751 cfs. At Durbin flows have ranged from a high of 9900 cfs to a low of 0.5 cfs with an average of 248 cfs. Flow in the Greenbrier is near average for the Kanawha River basin during periods of high flow and tends to be greater than average when basin flows are intermediate or low. The flow of the

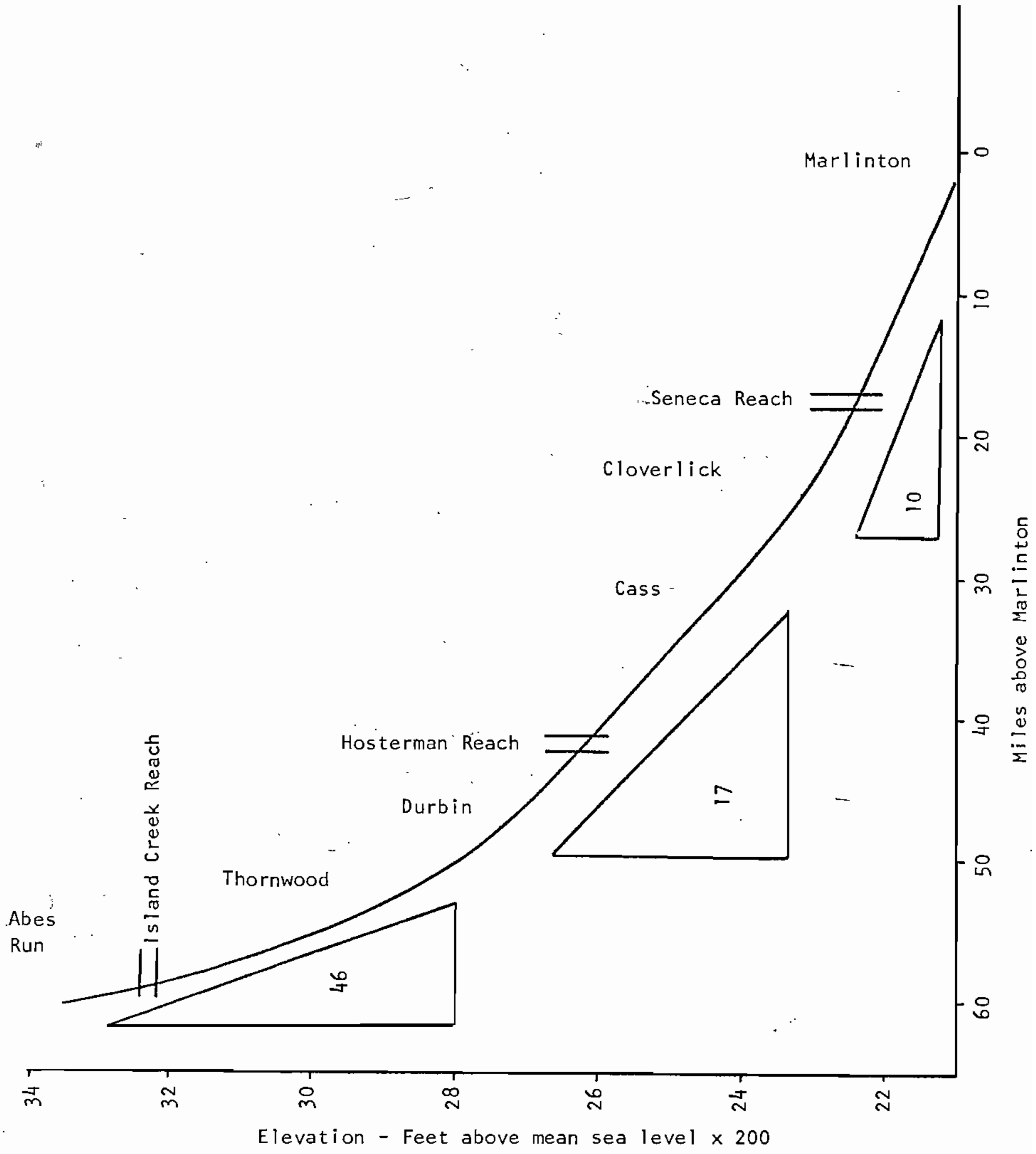


Figure 2. Bed profile of the Greenbrier River. Bed slopes in feet per mile shown in triangles for the 3 study reaches of the river.

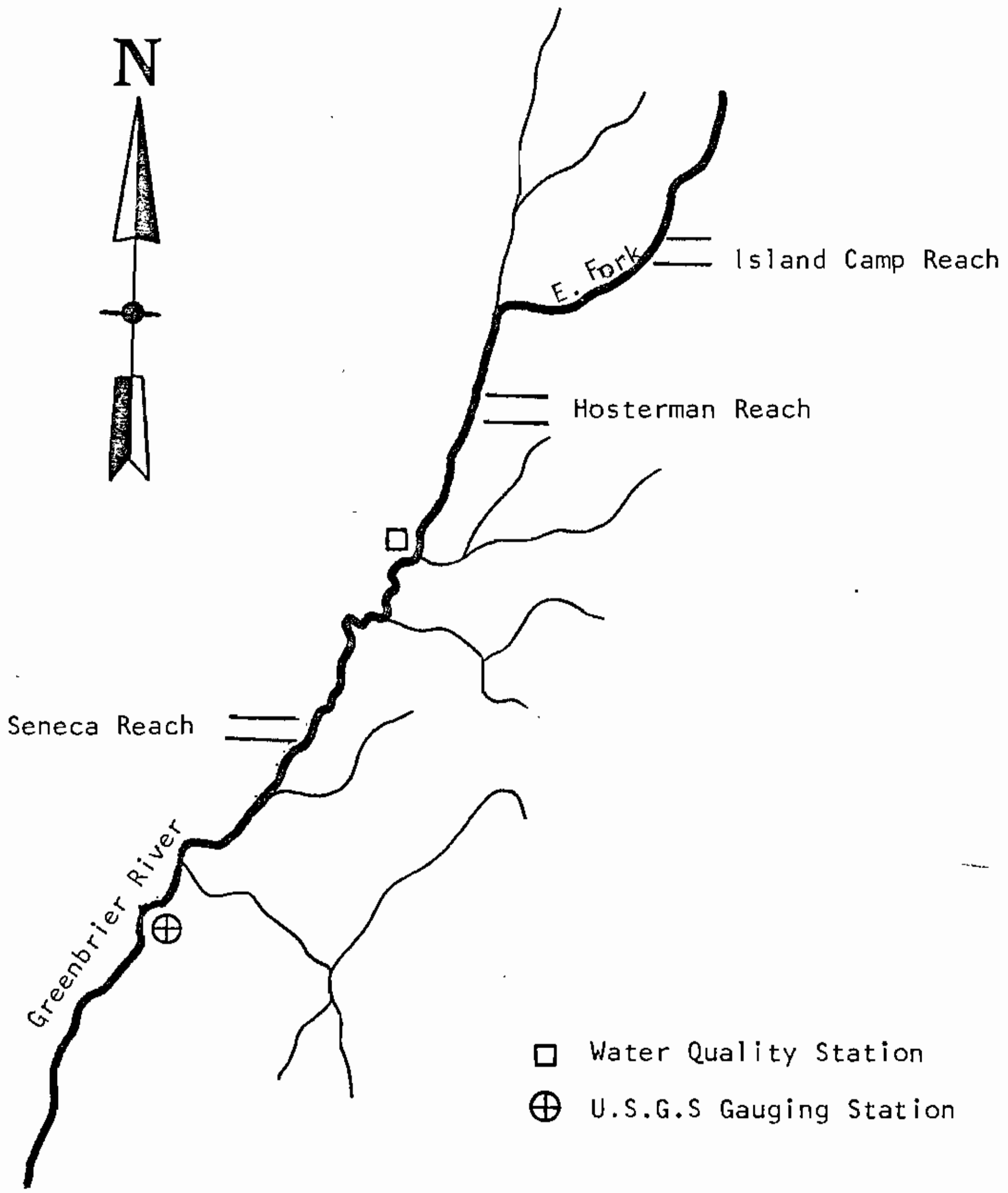


Figure 3. Map of Greenbrier River showing locations of Study Reaches.

Greenbrier is well above average for the basin during periods of extreme low flow. The flow duration data for Durbin and Marlinton is shown in Table 1.

Fish species found within the proposed study area are generally of the warmwater varieties, with exception of the East Fork which contains coldwater habitat (Reed 1974). Table 2 provides a list of species collected in the Greenbrier drainage.

A number of species found in the study area are of "concern" to the state, however their actual status is unknown. These include the tonguetied minnow (Exoglossum laurae), New River shiner (Notropis scabriceps), Kanawha minnow (Phenacobius teretulus), mountain redbelly dace (Phoxinus oreas), and the finescale saddled darter (Etheostoma osburni).

Meadow River

The Meadow River is a major tributary to the Gauley River, rising in eastern Summers County at approximately 3900 ft and flowing north to northwest along the Fayette-Greenbrier and Fayette-Nicholas County lines to its mouth at Carnifex Ferry (Fig. 4). Its total length is approximately 48 mi and the drainage basin is 332 mi^2. The gradient of Meadow River varies considerably over its length and ranges from 1.7 ft/mi in the upper reaches to 70 ft/mi near its mouth (Fig. 5). Rapids are common and pools are usually short and deep.

Flows on the Meadow as measured at Nallen range from a high of 11,200 cfs to a low of zero cfs. Average discharge is 529 cfs. Flow duration data for the Meadow are shown in Table 1.

Water quality in the Meadow and its tributaries is good (U.S. Dept. of Interior 1977). Mine acids are not a major problem at this time. Nevertheless, some pollution can be attributed to untreated domestic sewage, coal mining and related activities and poor forestry and agricultural activities. The last three activities introduce silt and sediments into the river.

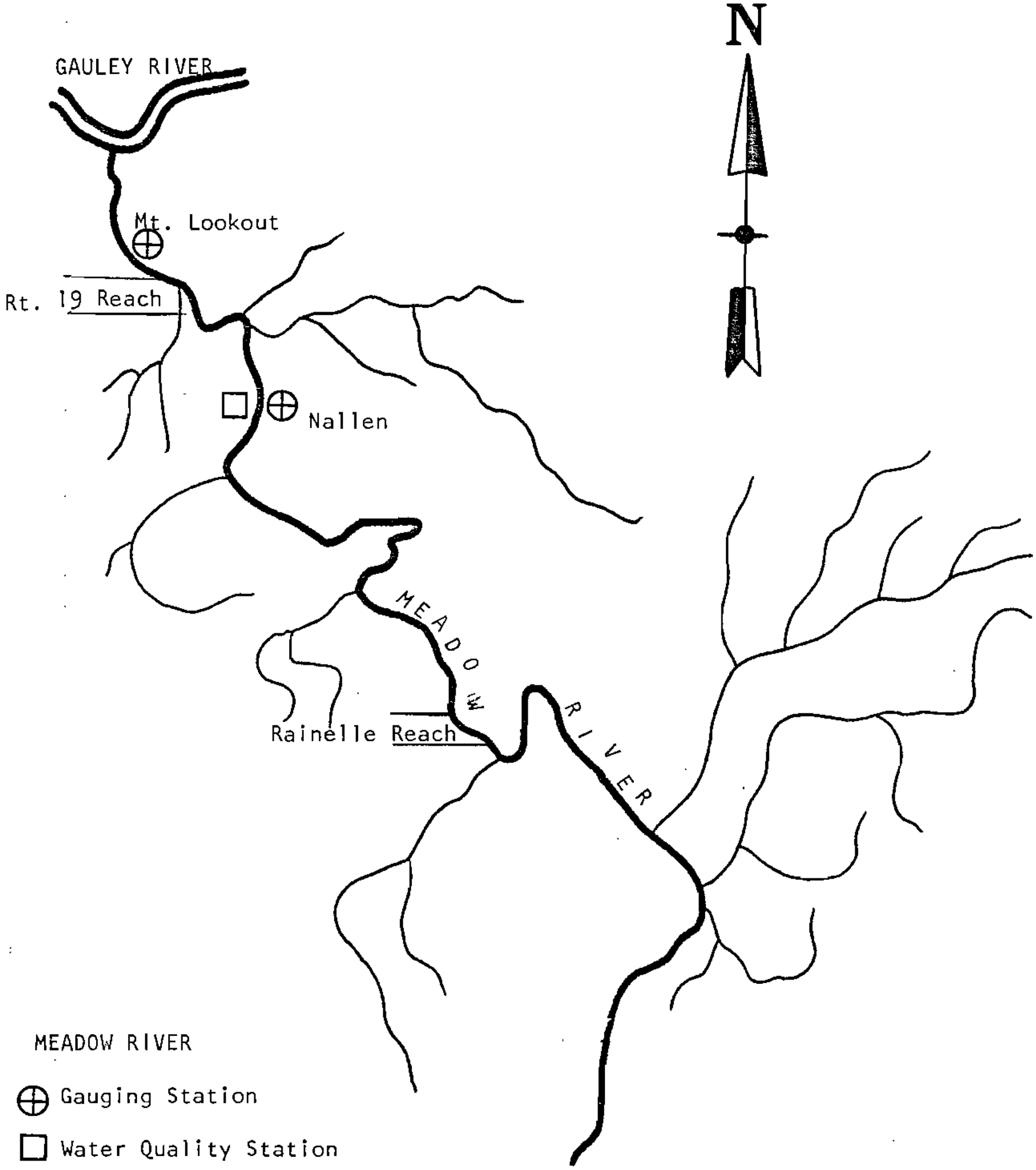


Figure 4. Map of Meadow River showing location of Study Reaches.

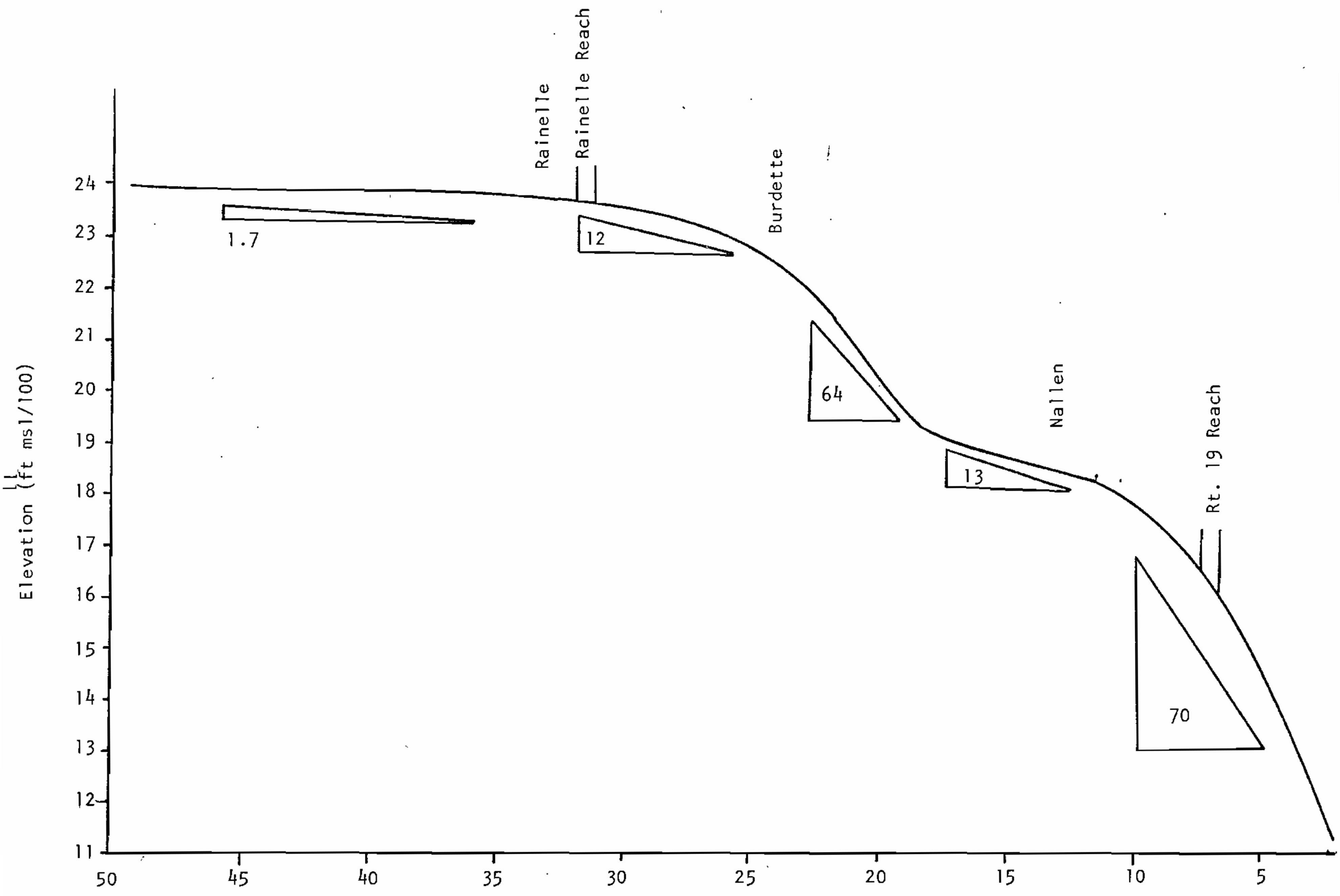


Figure 5. Bed profile of Meadow River. Bed slope in feet per mile is shown in triangles.

Table 1. Flow duration of the three study streams. Data obtained from U.S. Geological Survey.

Stream & Station Name	Drainage Area Sq. Mi.	Percent of time discharge equals or exceeds that shown (c.f.s./sq. mi.)										
		2	5	10	20	30	50	70	80	90	95	98
Greenbrier R. - Durbin	134	7.25	5.40	3.50	2.10	1.42	.690	.292	.170	.078	.041	.021
Greenbrier R. - Marlinton	408	9.08	5.98	3.96	2.28	1.55	.742	.336	.194	.090	.048	.026
Meadow River - Nallen	287	10.2	6.80	4.65	2.80	1.90	.910	.320	.170	.071	.034	.023
New R. - Bluestone Dam	4604	5.05	3.40	2.45	1.69	1.30	.863	.593	.445	.345	.290	.245
New R. - Hinton	6257	5.30	3.70	2.60	1.75	1.28	.788	.530	.410	.312	.260	.220

Table 2. Fish species collected in the Greenbrier drainage in the general vicinity of the study area, 1972 and 1974. (after Hocutt et al., 1978)

Scientific Name	Common Name
Salvelinus fontinalis	brook trout
Campostoma anomalum	stoneroller
Exoglossum laurae	tonguetied minnow
Nocomis platyrhynchus	bigmouth chub
Notropis chrysocephalus	striped shiner
N. photogenis	silver shiner
N. rubellus	rosyface shiner
N. scabriceps	New River shiner
Phenacobius teretulus	Kanawha minnow
Phoxinus oreas	mountain redbelly dace
Pimephales notatus	bluntnose minnow
Rhinichthys atratulus	blacknose dace
R. cataractae	longnose dace
Semotilus atromaculatus	creek chub
Catostomus commersoni	white sucker
Hypentelium nigricans	hogsucker
Ambloplites rupestris	rock bass
Lepomis cyanellus	green sunfish
Micropterus dolomieui	smallmouth bass
Etheostoma blennioides	greenside darter
E. flabellare	fantail darter
E. osburni	finescale saddled darter
Percina "maculata-type"	blackside darter
Cottus bairdi	mottled sculpin
C. carolinae	banded sculpin

The Meadow River is a warmwater stream supporting a good sport fishery primarily for smallmouth bass and rock bass. Several streams in the drainage are stocked with trout by the West Virginia Department of Natural Resources. Table 3 provides a list of fish species collected from the Meadow River.

The bigmouth chub (Nocomis platyrhynchus) is the only fish species of "special concern" known from the Meadow River. However, several other "concern" fishes are found in the remaining Gauley Drainage waters (Hocutt et al. 1979).

New River

The New River rises in the Blue Ridge Mountains of North Carolina, flows generally northward across North Carolina, Virginia, and West Virginia and joins the Gauley River in Fayette County to form the Kanawha River (Fig. 1). The elevation at its source is 3800 ft and at its mouth, 653 ft. Over the total distance of 250 mi, the average rate of fall is 13 ft/mi. Figure 6 shows the profile for the New River below Bluestone Dam. The study area on the New extends from Bluestone Reservoir to Sandstone Falls (Fig. 7).

The New River at Hinton has one of the smallest ranges of flow in cfs/mi^2 of the streams in the State owing to its large drainage area combined with stream regulation and reservoir storage. Average annual flow in the Bluestone Tailwaters is 5584 cfs while at Hinton below the confluence of the Greenbrier the average annual flow is 7723 cfs. The flow duration data for both gauges is shown in Table 1.

The New River provides a good to excellent warmwater fishery which receives heavy fishing pressure. From Bluestone Dam to its mouth at Gauley Bridge, the river flows through the spectacular New River Gorge. A portion of this area has been included as a component of the National Wild and Scenic River System.

Table 3. Fish species collected in the Meadow River (after Hocutt et al. 1979).

Scientific Name	Common Name
Salmo gairdneri	rainbow trout
Salvelinus fontinalis	brook trout
Salmo trutta	brown trout
Campostoma anomalum	stoneroller
Clinostomus funduloides	rosyside dace
Ericymba buccata	silverjaw minnow
Nocomis platyrhynchus	bigmouth chub
Notropis albeolus	white shiner
N. rubellus	rosyface shiner
Pimephales notatus	bluntnose minnow
Rhinichthys atratulus	blacknose dace
R. cataractae	longnose dace
Semotilus atromaculatus	creek chub
Catostomus commersoni	white sucker
Hypentelium nigricans	hog sucker
Ictalurus natalis	yellow bullhead
Ambloplites rupestris	rock bass
L. macrochirus	bluegill
L. cyanellus	green sunfish
L. gibbosus	pumpkinseed
Micropterus dolomieui	smallmouth bass
M. punctulatus	spotted bass
Etheostoma blennioides	greenside darter
E. flabellare	fantail darter
E. nigrum	johnny darter
Percina oxyrhyncha	sharpnose darter
P. caprodes	log perch
Stizostedion vitreum	walleye

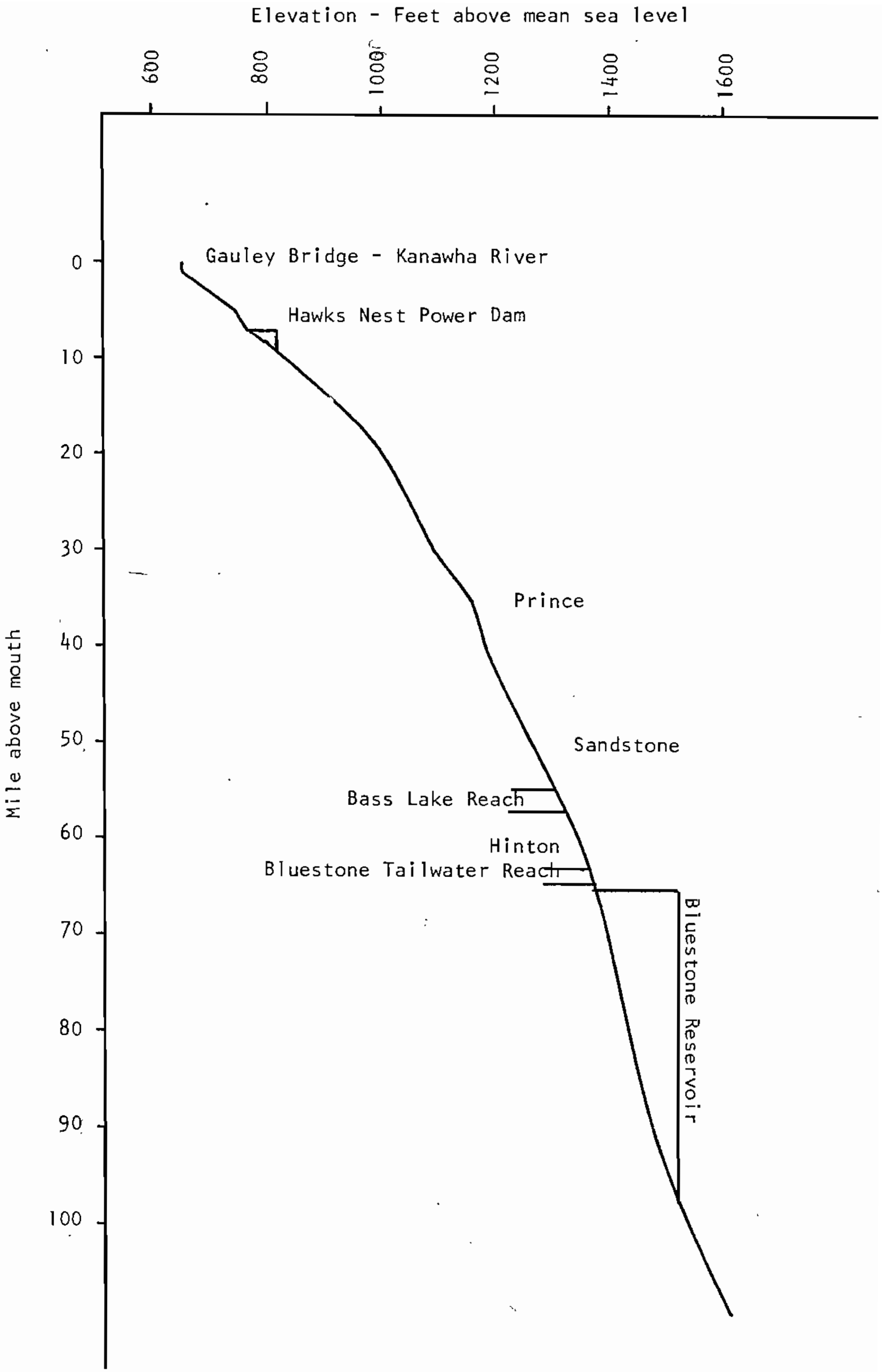


Figure 6. Bed profile of the New River.

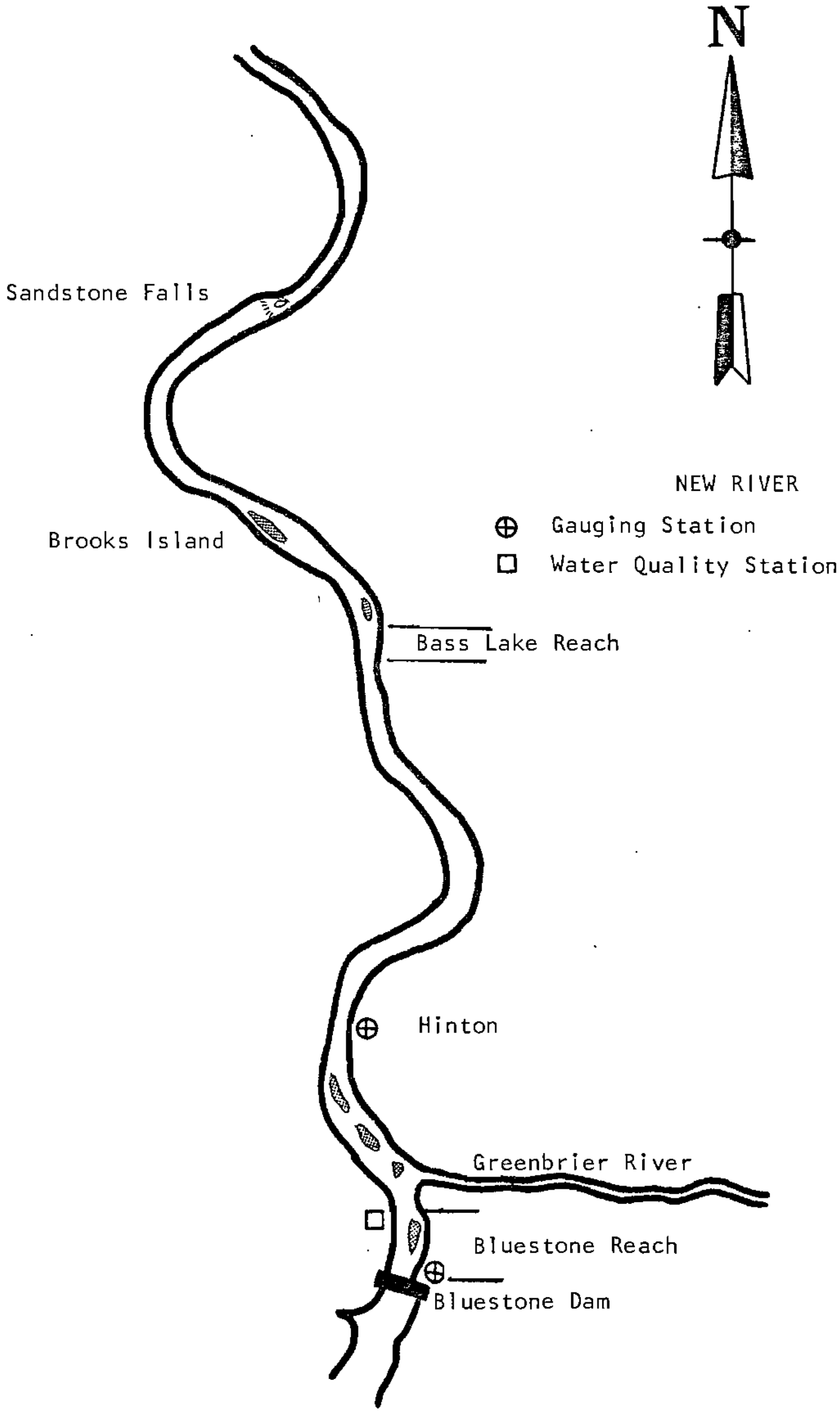


Figure 7. Map of New River showing location of Study Reach.

Water quality in New River is affected by mineral resources and manufacturing activities which contribute a wide variety of pollutants to the watershed. Mining operations near Austinville, Virginia increase copper, iron, lead, manganese, and zinc levels in the river. The Blacksburg-Radford-Pulaski industrial area of Virginia discharges arsenic, cobalt, iron, lead, magnesium, nitrogen, phosphorus, sulfur, and organics. The wastewater treatment plant located in Princeton, West Virginia has been identified as the major discharger of phosphorus into the watershed (U.S. Department of Interior 1978).

Major sources of water quality problems occur above the study area in a tributary, the Bluestone River, and include mine runoff, coal fines, and sedimentation as a result of deep and surface coal mining and coal washing operations in the headwaters (U.S. Department of Interior 1978).

Although many pollutants enter the watershed, the overall water quality is satisfactory, and the environment contains a varied aquatic fauna. Nearly all species of warmwater game fish found in the state are present in the study area. The most common game species include smallmouth bass, spotted bass, largemouth bass, musky, walleye, white bass, rock bass, crappie, sunfish and channel catfish. In addition, striped bass and sunshine bass (striped bass x white bass hybrid) have been stocked in Bluestone Reservoir and occur in the study area.

The New River below Bluestone Reservoir provides excellent fish habitat. The combination of runs, riffles, and pools found in these reaches of the river is near the optimum. The physical habitat of the river bottom is characterized by ledges, boulders, cobbles and sand with silt occurring in some pool areas.

A list of fish species present in the New or expected to be found there is given in Table 4.

Table 4. Checklist of known and expected fish species for the New River, West Virginia. (Compiled by Dan Cincotta, Wildlife Resources Division, WV Department of Natural Resources).

Scientific Name	Common Name
Lampetra aepyptera	Least brook lamprey
Amia calva	Bowfin
Anguilla rostrata	American eel
Alosa pseudoharengus	Alewife
Dorosoma petenense	Threadfin shad
Salmo gairdneri	Rainbow trout
S. trutta	Brown trout
Salvelinus fontinalis	Brook trout
S. trutta x S fontinalis	Tiger trout
Esox lucius	Northern pike
E. masquinongy	Muskellunge
E. niger	Chain pickerel
E. lucius x E. masquinongy	Tiger muskellunge
Campostoma anomalum	Central stoneroller
Carassius auratus	Goldfish
Clinostomus funduloides	Rosyside dace
Ctenopharyngodon idella	Grass carp
Cyprinus carpio	Common carp
Ericymba buccata	Silverjaw minnow
Exoglossum laurae	Tonguetied minnow
E. maxillingua	Cutlips minnow
Hybopsis dissimilis	Streamline chub
Nocomis leptocephalus	Bluehead chub
N. platyrhynchus	Bigmouth chub

Table 4. (cont'd.)

Scientific Name	Common Name
Notemigonus crysoleucas	Golden shiner
Notropis albeolus	White shiner
N. ardens	Rosefin shiner
N. cerasinus	Crescent shiner
N. chrysocephalus	Striped shiner
N. galacturus	Whitetail shiner
N. hudsonius	Spottail shiner
N. photogenis	Silver shiner
N. procne	Swallowtail shiner
N. rubellus	Rosyface shiner
N. scabriceps	New River shiner
N. spilopterus	Spotfin shiner
N. stramineus	Sand shiner
N. telescopus	Telescope shiner
N. volucellus	Mimic shiner
Phenacobius teretulus	Kanawha minnow
Phoxinus oreas	Mountain redbelly dace
Pimephales notatus	Bluntnose minnow
P. promelas	fathead minnow
Rhinichthys atratulus	Backnose dace
R. cataractae	Longnose dace
Semotilus atromaculatus	Creek chub
Catostomus commersoni	White sucker
Hypentelium nigricans	Northern hog sucker
Moxostoma erythrurum	Golden redhorse

Table 4. (cont'd.)

Scientific Name	Common Name
M. rhothoecum	Torrent sucker
Ictalurus furcatus	Blue catfish
I. melas	Black bullhead
I. natalis	Yellow bullhead
I. nebulosus	Brown bullhead
I. punctatus	Channel catfish
Noturus insignis	Margined madtom
Pylodictis olivaris	Flathead catfish
Percopsis omiscomaycus	Trout perch
Labidesthes sicculus	Brook silverside
Morone chrysops	White bass
M. saxatilis	Striped bass
M. chrysops x M. saxatilis	Sunshine bass
Ambloplites rupestris	Rock bass
Lepomis auritus	Redbreast sunfish
L. cyanellus	Green sunfish
L. gibbosus	Pumpkinseed
L. macrochirus	Bluegill
L. megalotis	Longear sunfish
Micropterus dolomieui	Smallmouth bass
M. punctulatus	Spotted bass
M. salmoides	Largemouth bass
Pomoxis annularis	White crappie
P. nigromaculatus	Black crappie
Etheostoma blennioides	Greenside darter
E. caeruleum	Rainbow darter

Table 4. (cont'd.)

Scientific Name	Common Name
E. flabellare	Fantail darter
E. kanawhae	Kanawha darter
E. nigrum	Johnny darter
E. osburni	Finescale saddled darter
E. swannanoa	Swannanoa darter
Perca flavescens	Yellow perch
Percina caprodes	Logperch
P. roanoka	Roanoke darter
P. gymnocephla	Appalachia darter
P. oxyrhyncha	Sharpnose darter
Stizostedion vitreum	Walleye
Cottus bairdi	Mottled sculpin
C. carolinae	Banded sculpin

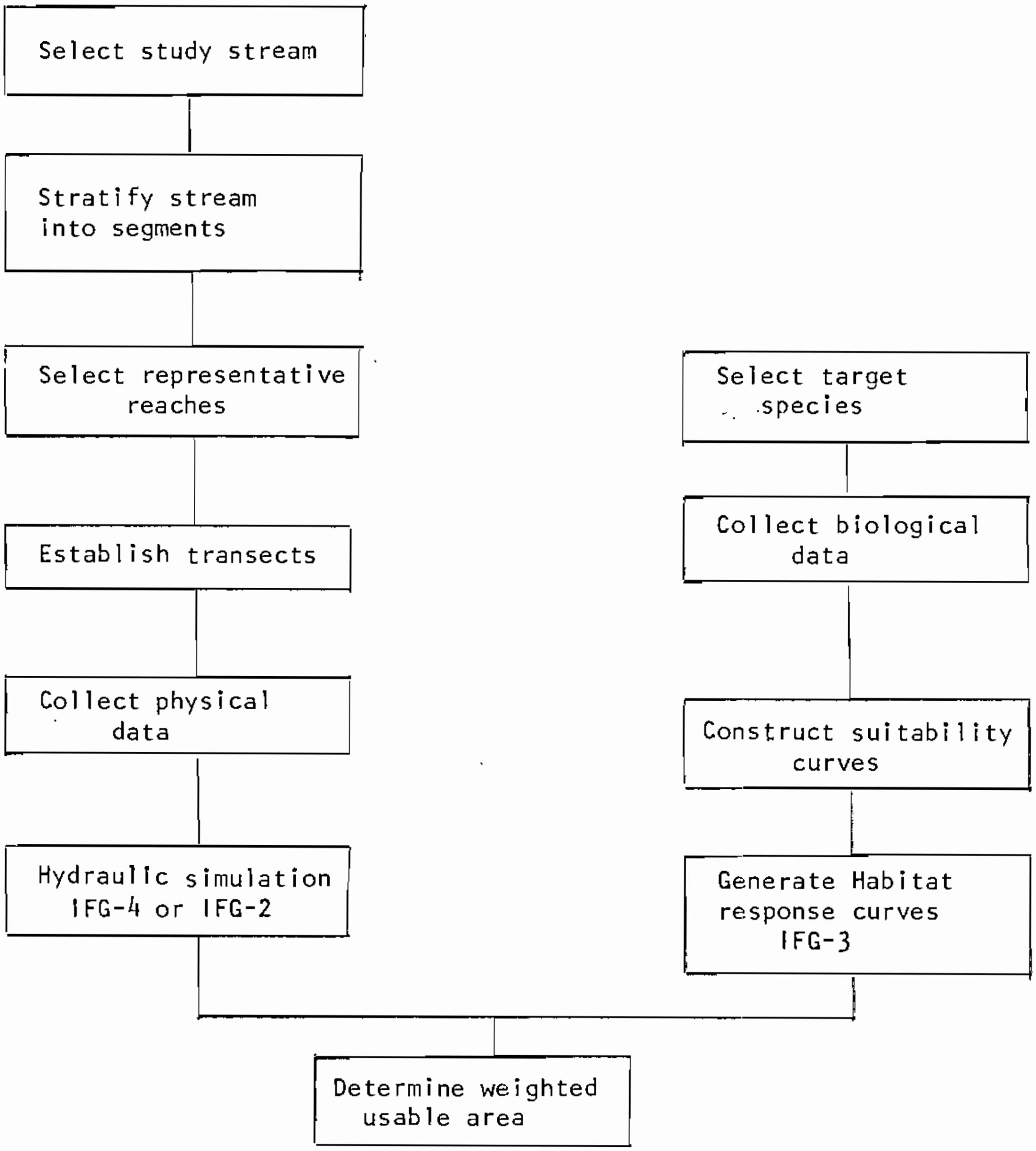
METHODS

IFG Method

The IFG method consists of four steps: (1) field measurement of the physical habitat variables depth, current velocity, and substrate, (2) construction of a computer model to predict the distribution of the variables by area over a range of flows at a chosen site in a study stream, (3) construction of a separate curve for each hydraulic parameter to represent the parameter's changing suitability as habitat with changes in its magnitude for each species and life history stage under investigation, and (4) calculation of a weighted usable area (i.e. an estimate of the habitat's suitability for fish use based on physical conditions alone) for each discharge, species, and life history stage under investigation (Stalnaker 1978; 1979). The sequence of events necessary to carry out the IFG analysis is shown in Table 5.

The IFG method uses several computer programs. Two are hydraulic simulation programs. The IFG-2 Water Surface Profile Program calculates velocities and water surface elevations at a number of flows from a set of measurements taken at a single flow. SUBMODC is a program used to modify the output of the IFG-2 program by entering substrate data and by changing transect weighting factors. The IFG-4 Hydraulic Simulation Program is the main program used for hydraulic simulation in the IFG method. It empirically simulates velocity distributions at a number of flows, but it requires two or, preferably, three sets of velocity and water surface elevation measurements made at different flows. The output of the IFG-2 and IFG-4 programs are used by the IFG-3 (HABTAT) Habitat Simulation Program to simulate the physical habitat available to a species in terms of weighted usable area per 1000 feet of stream. The data used are the habitat suitability curves, the stream channel geometry, water surface elevations, and mean column current velocities in the stream.

Table 5. Procedural steps necessary to carry out the instream flow incremental analysis.



IFG procedures were followed throughout the study. Study sites were selected by the technique of implicit zonation within the explicit zone as described by Bovee and Milhous (1978). Study reaches on the Greenbrier and Meadow Rivers were first viewed from the air. No physical characteristics were observed on the Greenbrier which could serve as a basis for dividing the study reaches. Therefore, a stream profile was constructed and the reach divided into four segments on the basis of gradient. A site was selected at random within each segment. One site was considered superfluous and was not used, leaving a total of three study sites on the Greenbrier study reach (Fig. 2). On the Meadow River, two areas of high gradient and two low gradient areas with differing physical characteristics made up most of the river. A study site was selected at random within each kind of area giving a total of two study sites on the Meadow River (Fig. 5). The New River study reach was not surveyed from the air, but it was easily observed from shore to be divided into two distinct areas: the Bluestone Dam tailwaters and the riffle-pool sequences typical of the rest of the reach. Workability was the overriding consideration when selecting study sites on the New, but those selected were apparently typical of their respective areas.

Data used in the hydraulic simulation were collected by methods described by Bovee and Milhous (1978). An average of six transects were established at each study site across hydraulic controls and various habitat types. Headpins made of 18-inch lengths of ½-in concrete reinforcing rod were driven flush with the ground to mark the endpoints of each transect. A wooden, 18-inch surveyor's stake was driven into the ground behind each headpin to about half its length. Taglines made of ¼-in and 3/8-in twisted nylon rope were attached to the headstakes and used to measure transect distances on Greenbrier and Meadow River stations. Stadia and a level rod were used to measure most distances on New River stations. Physical habitat variables were measured at about 20 to 40 points across each transect. The average current velocity was measured with Teledyne-Gurley Pygmy current meters in 1979 and 1980. In 1981, electronic current meters were used. Depth was measured to the nearest 0.1 foot with the current meter wading rods. Substrate was classified subjectively with reference to the Modified Wentworth Particle Size Scale presented by Bovee and Milhous (1978, p.67). Mixed substrates could be included as data in the IFG method only if they were adjacent to each other on the scale. Therefore, if two substrates were present but were not adjacent on the scale, only the predominant or most biologically important was recorded. Cover data were not recorded because of the difficulty of evaluating cover as a variable, and our unfamiliarity with the necessary procedure for incorporating it into the IFG method. Leveling to determine headpin and water surface elevations was done with a transit in 1979 and the spring of 1980. Later, a self-leveling engineer level was used. All elevations were referenced to a permanent benchmark which was selected at each study site.

Data were coded for input to the IFG-2 and IFG-4 computer programs. Programs were calibrated according to techniques described in the IFG's "Users Guide to the Physical Habitat Simulation Model". The SUBMODC program was obtained from the IFG, rewritten for use on an IBM computer, and used to enter substrate data and change transect weightings in the IFG-2 program.

Fish habitat preference data were collected by two methods. In the first method, the fish were captured and either returned to the stream after identification and measurement or placed in labeled, perforated plastic bags, preserved in a 10% formalin solution and returned to the laboratory for identification, counting, and measurement. Physical habitat variables of depth, velocity, substrate, and temperature were measured and recorded at the point of capture. The several types of gear used to capture fish were, in descending order of importance:

backpack 115/230V, AC electrofishing unit, nylon seine of ¼-in mesh, trot line (minnows and pork liver used for bait), hoop net, gill net, and a boat-mounted 230V DC electrofishing unit. The second method consisted of walking along the stream banks or floating the stream in a canoe. When a fish or nest was observed which could be positively identified, numbers of fish and estimates of length were recorded along with physical data at the point of observation. Attempts were made to sample and observe fish in a wide range of habitats, but water depth, velocity, turbidity, gear selectivity and site accessibility were limiting.

Target Species

Seven target species were initially selected for study; these were: smallmouth bass (*Micropterus dolomieui*), spotted bass (*M. punctulatus*), channel catfish (*Ictalurus punctatus*), brook trout (*Salvelinus fontinalis*), stoneroller (*Campostoma anomalum*), greenside darter (*Etheostoma blennioides*), and striped shiner (*Notropis chrysocephalus*). Too few data were collected for three of the species to enable habitat suitability curves to be constructed. Therefore, the fantail darter (*E. flabellare*) was substituted for the greenside darter as a target species, and suitability curves developed by the IFG were used to determine weighted usable areas for channel catfish and spotted bass.

Fish were assigned to life stages on the basis of length in accordance with age, growth, and maturity data found in the literature, as follows:

Smallmouth bass: Smallmouth bass were considered to become adults and therefore, sexually mature, at age IV (Coble 1975; Carlander 1977) at a total length of about 10 inches (Hess undated). Juveniles were defined as fish which had lost the black coloration of fry but which were less than 10 inches in length. Fry were defined as black fry. Identification of nests was based on criteria given by Coble (1975).

Brook trout: Brook trout were considered to be adults at age I (McFadden 1961; Carlander 1969; Scott and Crossman 1973; R. Menendez, WV Dept. Nat. Resour., Elkins, WV, pers. comm.) at a total length of about 5 inches as determined by analysis of length frequency distributions. Juveniles ranged from about 1.5 to 4.8 inches in total length. Fish smaller than 1.5 inches were classified as fry. Brook trout nests, or redds, were easily identified by the disturbed gravel on the stream bottom or by actual observation of spawning fish.

Stoneroller: Adults were defined as fish of age II or older as determined by anlaysis of length frequency distributions. Stoneroller reportedly mature at age II or III (Eddy and Underhill 1974). Stoneroller less than two years old and longer than 0.8 in in total length were classed as juveniles. No stoneroller fry were collected.

Fantail darter: No data on the age of maturity of fantail darter could be found in the literature. However, several darters in the same genus mature at age I including *Etheostoma smithi* (Page and Burr 1976), *E. gracile* (Braasch and Smith 1967), and the closely related *E. squamiceps* (Page 1974). Therefore, adult fantail darter were defined as individuals age I or older as determined by analysis of length frequency distributions. All age 0 fantails were classified as juveniles. No fantail darter fry were captured, and no nests were observed.

Striped shiner: Striped shiners were classified as adults at age II (Carlander 1969; Pflieger 1975) as determined by length frequency distribution analysis when they had reached a total length of about 2.8 inches. All smaller striped shiners were classed as juveniles. No striped shiner fry were identified. Spawning was not observed during this study although reportedly it often occurs over the gravel nests of hornyhead chub and creek chub (Carlander 1969; Pflieger 1975).

Suitability Curve Construction

Fish habitat preference data, collected by several methods from 42 areas on 27 streams, were coded for computer processing. Data from the same stream were combined to construct habitat suitability curves according to the sampling method used. When the data collected from a given stream were insufficient to construct curves, data from various streams and sampling gears were combined untested to increase sample size. Frequency distributions of each life stage of a species were constructed by determining numbers of fish associated with each increment of depth, velocity, and substrate, and the data were clumped as described by Bovee and Cochnauer (1977). For a given life stage of a given species for each parameter, a curve was fitted by examination to the clumped data for the largest sample. The other sets of clumped data for that life stage, species, and parameter were compared to the curve using a Chi-square test of goodness of fit; the expected values were interpolated from the curve. When differences were not significant ($\alpha = .10$), data were combined, and final suitability curves were constructed as described by Bovee and Cochnauer (1977). By repeating this procedure, each time using the data sets that could not be combined in the previous trial, all possible combinations of the data were tested.

Habitat response curves were generated for several target species in each study reach using the curves which were thought to be most appropriate for a given species in that reach (Figs. 10 through 44). The curves were not intended to be taken as precise evaluations of available habitat for the target species in a study reach, but rather, they were intended as demonstrations of the end product of the IFG method.

Montana Method

The Montana Method (Tennant 1975) is a quick and easy method for determining flows necessary to protect the aquatic resources in both warmwater and coldwater streams based on their average flow. This method allows for rapid assessment of many stream segments by reference to the flow regimes presented in Table 6 and surface water records of the U.S. Geological Survey.

Table 6. Instream flow Regimes for Fish, Wildlife, Recreation and related Environmental Resources.

Narrative Description of Flows	Recommended Base Flow Regimes Oct.-March	April-Sept.
Flushing or Maximum	200% of Average Flow	
Optimum Range	60%-100% of the Average Flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	10% of Average Flow to Zero Flow	

This method is based upon annual flow records obtained from the U.S. Geological Survey or by on-site sampling. The average annual flow at the locations of interest is determined. Then values for 10%, 30%, and 60% of the average annual flow are determined. Work is documented with photographs, physical, and hydraulic measurements (i.e. depth, velocity, etc.) in order that comparisons can be made involving bank exposure wetted perimeter, substrate and other hydraulic parameters.

The 10% of mean annual flow represents poor or degradated habitat; 30% of mean annual flow is necessary for good habitat, and 60% represents flow necessary for excellent habitat. The Montana method is fast and requires no additional field work.

Idaho Method

White (1975) developed this approach primarily for use on large, unwadable rivers. This technique was applied by Cochnauer (1977). A description of the method from Cochnauer (1976) and White (1976) follows: (1) at each station (minimum of 4) a line of sight transect is drawn at right angles to the stream via a transit/level and permanently marked at the high water mark; (2) velocity and depth measurements are taken at a minimum of 20 points along the transect from a boat capable of being stabilized on the river (according to standards found in U.S. Geological Survey 1969); (3) relative elevations of water level at every transect along the thalweg and distances between transects are recorded (Fig. 8); (4) streambed materials are categorized by observation, and changes in types along the stream bottom noted; (5) photographs are taken at each transect; (6) channel profiles are prepared and bottom materials noted along the transect (Fig. 9); (7) information is coded and run on the U.S. Bureau of Reclamation's computer program (U.S. Bureau of Reclamation 1968). Velocity, discharge, and wetted perimeter are estimated by the computer for a range of water surface elevations. Curves are then prepared and correlations with biological data for fish species in the locality are made.

White (1975) with the aid of available life history literature on smallmouth bass, channel catfish, and white sturgeon (Acipenser transmontanus) was able to predict necessary flow values for fish and wildlife maintenance. "Usable widths" concerning passage, spawning, and rearing were the focal points of this approach which is basically similar to the "Oregon Method" described by Cincotta (1978). Due to the difficulties encountered in the collection of the field data on a large river, Idaho personnel collected only one set of field data.

The fact that large difficult river waters along with their warmwater fish species can be assessed is a marked advantage of this methodology. Another advantage is the low cost of one set of field data. However, reliability could be decreased when the same data is applied to other locations. The resolution of analyzed data is dependent on the life history information, thus restricting this approach to only the most important game species.

This method as originally developed made use of the Water Surface Profile (WSP) computer program to physically model the stream. The WSP program, adapted for use in the IFG method, became the IFG-2 program. In determining instream flow needs, the Idaho method made use of usable widths and increases in wetted perimeter, whereas the IFG method incorporates the IFG-2 program with the HABTAT program to generate weighted useable areas.

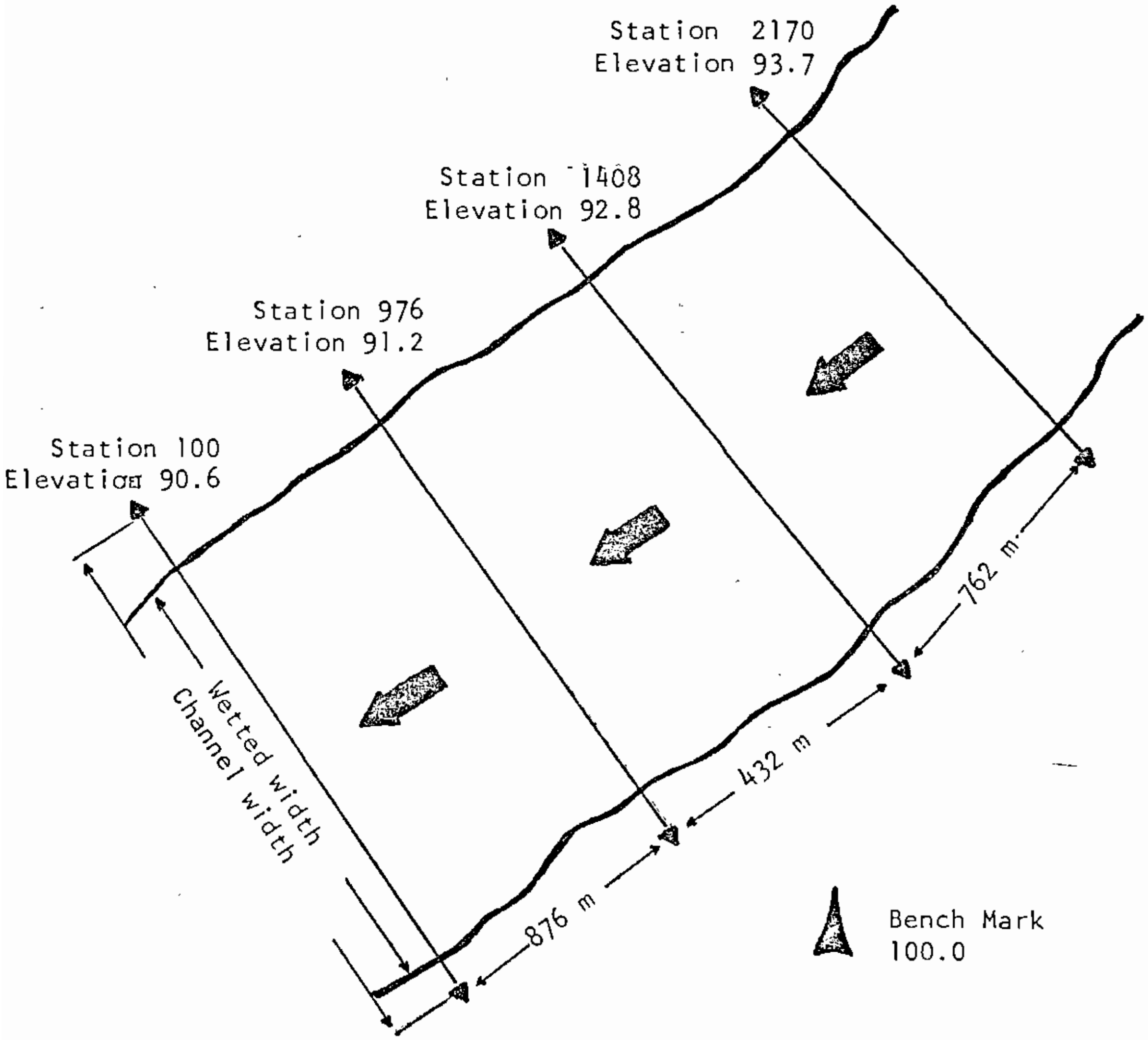


Figure 8. Typical stream study site with the proper information recorded at and between each transect (Cochnauer 1976).

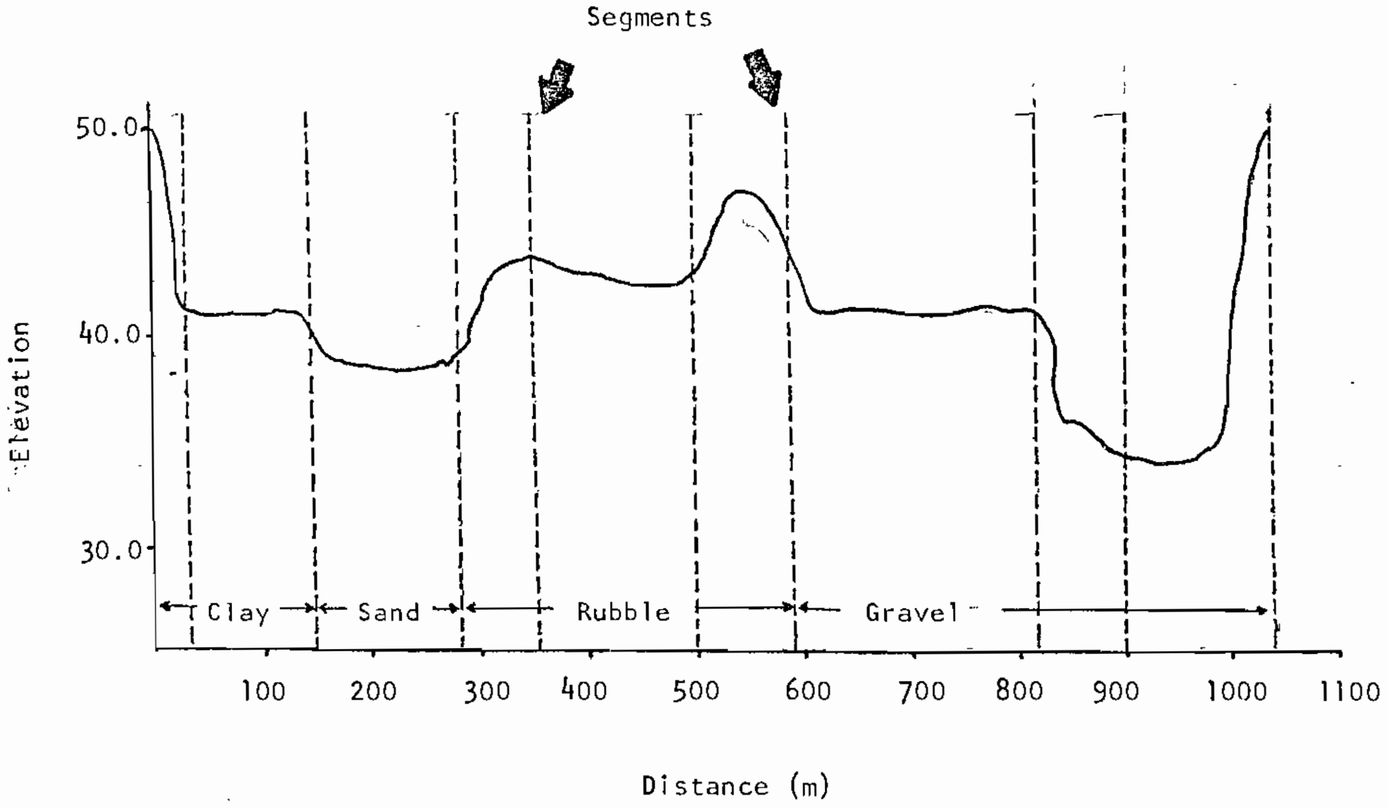


Figure 9. Stream channel configuration with substrate types noted along the transect (Cochnauer 1976).

RESULTS

IFG Method

Calibration

Both the IFG-2 and IFG-4 computer programs had to be calibrated to produce valid hydraulic simulations. IFG-2 programs were considered calibrated when, for a given discharge, water surface elevation predictions were within 0.1 ft of measured elevations and predicted velocities were within 0.2 fps of measured velocities at each transect. It was not possible to achieve that level of accuracy in all cases, but 93% of the water surface elevations and 95% of the velocities were within the desired limits. One average discharge of 66 cfs at the Rainelle study site on the Meadow River could not be calibrated. An IFG-4 program was considered calibrated when the mean difference between three observed and three predicted discharges was less than or equal to five percent of the mean observed discharge at each transect in a study site. If the mean difference was between five and 10% of the mean discharge, the data were reviewed, and the program was considered calibrated if no errors were discovered in the field measurements. Using these criteria, the IFG-4 programs were calibrated at 93%, or 27 of 29, of the transects measured. IFG-4 programs could not be calibrated at the initial transects on the two Meadow River study sites apparently because of difficulties encountered in measuring velocities at identical points at successive discharges. Although mean differences were 17.5% and 19.5%, respectively, of the mean discharges, both transects were included in the hydraulic simulations. Hydraulic simulation data consisting of depth, velocity, and substrate distributions were input directly to the HABTAT (IFG-3) program which used these data and the habitat suitability curves to produce weighted usable area estimates for each species.

Suitability Curves

The process of constructing suitability curves from habitat preference data varied somewhat for each species with results described below:

Smallmouth bass

Adult: A total of 49 smallmouth bass classed as adult were sampled in the New, Tygart, and Greenbrier Rivers by use of a boat-mounted electroshocker, trammel net, and observation. Sample sizes were too small to permit comparisons of habitat preferences to be made between streams. Data from all streams and sampling techniques were combined untested to construct one set of habitat suitability curves for all adult smallmouth bass (Table 7).

Velocity suitability was optimal from zero to 0.05 fps, and velocities beyond 1.05 fps were apparently unsuitable. Depth suitability was optimum between 1.55 and 2.35 ft., and it declined to zero at 6.7 ft. Cobble with small amounts of gravel or boulders was the optimum substrate.

Juvenile: A total of 631 smallmouth bass classed as juveniles were sampled in the New, Greenbrier, Tygart, Meadow, and Dry Fork Rivers, and in Middle Island Creek. Juvenile smallmouth were sampled by observation, use of backpack, boat-mounted, and parallel-wire electroshockers, and by seining. Comparisons were made between observed habitat preferences of juvenile smallmouth bass sampled by observation in the New, Greenbrier, Tygart, and Meadow Rivers (Table 8).

Velocity preference curves were more similar than those of depth and substrate, but a combined velocity curve could be constructed only for the Tygart and Meadow Rivers (Table 9). Separate suitability curves for all parameters were constructed for the New (Table 10) and Greenbrier (Table 11) Rivers, and separate depth and substrate curves were constructed for the Tygart

(Table 12) and Meadow (Table 13) Rivers. Velocity optima were similar in the Meadow-Tygart (0.00 to 0.35 fps) and Greenbrier (0.15 to 0.35 fps) Rivers but were higher in the New River (0.15 to 0.55 fps). Maximum suitable velocity was lowest in the Greenbrier River (1.00 fps), intermediate in the Meadow-Tygart Rivers (1.20 fps), and highest in the New River (1.60 fps). Optimal depth was greatest in the Meadow River (3.25 to 3.65 ft), and decreased progressively in the Tygart and New Rivers to a minimum of 0.35 to 0.55 ft in the Greenbrier River. Optimal substrate in the Meadow River was boulder with some cobble or bedrock; in the Tygart it was a gravel-cobble mixture; in the New River it was gravel with some sand or cobble, and optimal substrate for juvenile smallmouth bass in the Greenbrier River was cobble with some gravel or boulders.

Fry: A total of 916 black fry were observed in the Meadow, Greenbrier and the Dry Fork Rivers. Although many more fry were observed in the Meadow River than in the Greenbrier River a comparison was made between habitat preferences in the two streams (Table 14). Habitat preferences for all parameters were significantly different. Therefore, separate suitability curves were constructed for the Meadow (Table 15) and Greenbrier (Table 16) Rivers. Velocity optima were identical (0.00 to 0.15 fps) in both streams, but the maximum suitable velocity was greater in the Greenbrier (0.80 fps) than in the Meadow (0.60 fps) River. Optimal depth was also greater in Greenbrier River (0.50 to 1.55 ft) than in the Meadow River (0.65 to 0.85 ft), although maximum suitable depths were similar (1.60 to 1.70 ft, respectively). Optimal substrates were boulders mixed with some cobble or bedrock in the Greenbrier River and a cobble-boulder mixture in the Meadow River.

Nests: A total of 14 smallmouth bass nests were observed on the South Branch of the Potomac River and the Meadow River. No between-stream comparisons of habitat preference were made because so few nests were observed, and all data were combined to construct habitat suitability curves (Table 17). Most nests were constructed in velocities of 0.00 to 0.15 fps. Maximum suitable velocity was 0.85 fps. Optimal depth for nests was from 0.45 to 2.75 ft. The maximum suitable depth was 2.80 ft. Optimal substrate for nest construction was sand or gravel with some cobble.

Brook trout

Adult: A total of 174 brook trout classed as adults were sampled by observation in twelve streams. All data were combined untested to construct habitat suitability curves (Table 18). Optimal current velocity for adult brook trout was from 0.00 to 0.15 fps, and maximum suitable velocity was 1.60 fps. Depth suitability increased to an optimum at 0.45 to 0.65 ft and maximum suitable depth was 2.90 ft. Optimal substrate was gravel with cobble or sand in varying amounts.

Juvenile: A total of 52 brook trout classed as juveniles were sampled in eleven streams. Approximately equal numbers of fish were sampled by observation and electrofishing, and data obtained from fish sampled by the two methods in all streams were combined untested to construct habitat suitability curves (Table 19). Optimal velocity for juvenile brook trout ranged from 0.00 to 0.15 fps. The maximum suitable current velocity was 1.05 fps. Optimal depths ranged from 0.35 to 1.15 ft, and maximum suitable depth was 1.80 ft. Optimal substrate was a gravel-cobble mixture.

Fry: A total of 57 brook trout fry were sampled in four streams. Data from individuals observed or captured by backpack electroshocker were combined untested from all streams to construct habitat suitability curves (Table 20). Most brook trout fry were found at current velocities near zero (0.00 to 0.15 fps), and the maximum suitable velocity was 0.80 fps. The optimum depth ranged from 0.05 to 0.65 ft and the maximum suitable depth was 1.25 ft. The optimal substrate was silt with some sand or mud.

Nests: A total of 127 brook trout redds were observed in nine streams. Data from all streams were combined untested to construct habitat suitability curves for nesting brook trout (Table 21). Optimal current velocity for brook trout redds was 0.00 to 0.15 fps, and maximum suitable velocity was 1.05 fps. The optimal depth for nest construction was between 0.15 and 0.75 ft, and maximum suitable depth was 2.0 ft. Most nests were constructed in gravel mixed with small amounts of cobble or sand.

Stoneroller

Adult: A total of 34 stoneroller classed as adults were sampled in the Greenbrier River, Tygart River, Gandy Creek, and Twelve Pole Creek. Adult stoneroller were sampled by use of a backpack electroshocker and by seining. Data collected from the Greenbrier and Tygart Rivers by electrofishing were combined untested to construct habitat suitability curves (Table 22). Velocity suitability for adult stoneroller increased from zero at 0.00 fps to an optimum at 0.75 to 0.95 fps. The maximum suitable current velocity was 1.90 fps. The optimum depth was from 1.05 to 1.25 fps, and maximum suitable depth was 2.80 ft. The optimum substrate was boulder with some cobble or bedrock.

Juvenile: A total of 322 stoneroller classed as juveniles were sampled in the Twelve Pole Creek drainage, Chenoweth Creek, and in the Greenbrier, Tygart, New, and Meadow Rivers. Juvenile stoneroller were sampled in all of the above streams by use of a backpack electroshocker, by seining, and by observation. Comparisons were made between observed habitat preference of juvenile stoneroller sampled by electrofishing in the Twelve Pole Creek drainage. Greenbrier River, and Tygart River (Table 23). Habitat preferences for all parameters were significantly different. Therefore, separate suitability curves were constructed for the Twelve Pole Creek drainage (Table 24), Greenbrier River (Table 25), and Tygart River (Table 26). Optimal current velocity was greater in the Tygart River (0.15 to 0.35 fps) than in the Greenbrier River and Twelve Pole Creek drainage (0.00 to 0.15 fps), but maximum suitable velocity was greatest in the Greenbrier River (2.30 fps), intermediate in the Tygart River (1.80 fps), and least in the Twelve Pole Creek drainage (1.40 fps). Optimal depths were similar in the Greenbrier (0.35 to 0.75 ft) and Tygart (0.45 to 0.65 ft) Rivers, but were not as great in the Twelve Pole Creek drainage (0.25 to 0.45 ft). However, maximum suitable depth was greater in the Twelve Pole Creek drainage (2.70 ft) than in the Tygart (2.10 ft) or Greenbrier (2.00 ft) Rivers. The optimal substrate was gravel-cobble in the Greenbrier River, gravel-cobble with some bedrock in the Tygart River, and sand with some silt or gravel in the Twelve Pole Creek drainage.

Nests: A total of 37 active and inactive stoneroller nests were observed in the Greenbrier River and Chenoweth Creek, and the observed spawning habitat preferences of stonerollers in the two streams were compared (Table 27). Velocity preference data were not significantly different and were combined. Separate suitability curves were constructed for depth and substrate, preferences for which were significantly different in the two streams. Optimal velocities for nest location in both streams ranged from 0.45 to 1.25 fps. Maximum suitable velocity was 1.55 fps (Table 28). Optimal depths ranged from 0.35 to 1.75 ft in the Greenbrier River where the maximum suitable depth was 1.85 ft (Table 29). In Chenoweth Creek, optimal depths were 0.35 to 1.35 ft, and maximum suitable depth was 1.45 ft (Table 30). The optimal substrate for nest-building in both streams was gravel with some sand or cobble although a wider range of substrate was used in Chenoweth Creek (Table 30) than in the Greenbrier River (Table 29).

Fantail darter

Adult: A total of 290 fantail darter classed as adults were sampled in the Greenbrier River, Twelve Pole Creek drainage, Tygart River, Middle Island Creek, and Seneca Creek. Adult fantail darter were sampled by use of a backpack electroshocker and by seining. Comparisons were made between observed habitat preferences of adult fantail darter sampled by electrofishing in the Greenbrier River and the Twelve Pole Creek drainage (Table 31). Velocity preferences of fantail darter adults were not significantly different; therefore, data were combined and one velocity suitability curve constructed for fantail darter in the Greenbrier River and the Twelve Pole Creek drainage (Table 32). Optimal velocities were near zero (0.00 to 0.15 fps) and maximum suitable velocity was 1.95 fps. Separate suitability curves were constructed for depth and substrate in the Greenbrier River (Table 33) and the Twelve Pole Creek drainage (Table 34) due to significant differences in preference between those streams (Table 31). Optimal depths ranged from 0.35 to 0.55 ft in the Greenbrier River, and maximum suitable depth was 2.25 ft. In the Twelve Pole Creek drainage, optimal depths had a wider range (0.15 to 0.55 ft) than in the Greenbrier River, but the maximum suitable depth was much lower (0.65 ft). In the Greenbrier River, most adult fantails were found over gravel-cobble substrate, but in the Twelve Pole Creek drainage, optimal substrates included sand, gravel, and cobble, with some silt or boulders.

Juvenile: A total of 109 fantail darter classed as juveniles were sampled in the Greenbrier River and the Twelve Pole Creek drainage. Habitat suitability curves were constructed only for juveniles from the Greenbrier River (Table 35). All of the fish were caught with a backpack electroshocker. Velocity suitability was optimal from 0.00 to 0.15 fps, and maximum suitable velocity was 1.00 fps. Optimal depths ranged from 0.15 to 0.35 ft; and maximum suitable depth was 1.60 ft. Most juvenile fantail darter were found over gravel-cobble substrate in the Greenbrier River.

Striped shiner

Adult: A total of 137 striped shiner classed as adults were sampled in the Twelve Pole Creek drainage, Chenoweth Creek, Tygart River, and Middle Island Creek. Comparisons (Table 36) were made between observed habitat preferences of striped shiner of the Twelve Pole Creek drainage which were sampled both by seining and by backpack electrofishing unit and shiners of Chenoweth Creek where data were obtained by observation. Habitat preferences of adult striped shiner were significantly different between streams, so separate suitability curves were constructed for the Twelve Pole Creek drainage (Table 37) and Chenoweth Creek (Table 38). Velocity optima differed strongly. In the Twelve Pole Creek drainage optimal velocities were near zero (0.00 to 0.15 fps) with a maximum suitable velocity of 0.70 fps. In Chenoweth Creek, optimal velocities were higher, ranging from 0.45 to 0.65 fps with a maximum suitable velocity of 1.10 fps. Optimal depths ranged from 0.95 to 1.15 ft in the Twelve Pole Creek drainage, with a maximum suitable depth of 3.00 ft. In Chenoweth Creek, optimal depths ranged from 0.65 to 1.25 ft, with a maximum suitable depth of 2.30 ft. In the Twelve Pole Creek drainage, most adult striped shiner were found over a substrate of sand mixed with some gravel or silt. In Chenoweth Creek, however, the optimum substrate was a gravel-cobble mixture.

Juvenile: A total of 74 striped shiner classed as juveniles were sampled in Twelve Pole Creek, Chenoweth Creek, Greenbrier River, New River, Middle Island Creek, and Tygart River. Juvenile shiners were sampled by seining, by parallel wires, backpack electroshocker, and by observation. Data collected from all streams and by all sampling methods were combined untested, and habitat suitability curves were constructed (Table 39). Optimal velocities for juvenile striped shiner were near zero (0.00 and 0.15 fps) and the maximum suitable velocity was 1.30 fps. Optimal depths ranged from 1.45 to 1.85 ft with a maximum suitable depth of 2.80 ft. Most juvenile striped shiner were caught over a substrate of silt mixed with some mud or sand.

Table 7. Habitat suitability curves for smallmouth bass (adult) in all streams. Data collected by observation, shock boat, and trammel net. N = 49.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.05	1.00	.90	0.00	3.00	0.00
.25	.54	1.10	.06	4.00	.03
.45	.23	1.20	.12	5.00	.08
.65	.08	1.30	.23	5.25	.11
.85	.04	1.40	.40	5.50	.18
1.05	0.00	1.50	.66	5.75	1.00
100.00	0.00	1.55	1.00	6.25	1.00
		2.35	1.00	6.75	.31
		2.40	.73	7.00	.19
		2.60	.42	7.50	0.00
		2.80	.27	100.00	0.00
		3.00	.19		
		3.40	.11		
		3.80	.07		
		4.20	.03		
		4.80	.01		
		6.70	0.00		
		100.00	0.00		

Table 8. Summary of results of Chi-square comparisons of clumped habitat preference data for smallmouth bass juveniles. Data collected by observation. * = not significantly different (α = .10); data combined. NC = not compared because of obvious difference.

Reference curve (expected)			Data compared (observed)			X^2, d.f.
Stream	Parameter	N	Stream	Parameter	N	
New R.	Velocity	200	Greenbrier R.	Velocity	176	75.6, 4
			Tygart R.		166	52.8, 4
			Meadow R.		65	8.0, 3
Greenbrier R.		176	Tygart R.		166	6.9, 3
			Meadow R.		65	17.9, 3
Tygart R.		166	Meadow R.		65	6.0, 3*
New R.	Depth	200	Greenbrier R.	Depth	176	3036.7, 10
			Tygart R.		166	62.3, 11
			Meadow R.		65	62.8, 8
Greenbrier R.		176	Tygart R.		166	729.0, 11
			Meadow R.		65	NC
Tygart R.		166	Meadow R.		65	NC
Tygart R.	Substrate	166	Greenbrier R.	Substrate	180	206.2, 6
			New R.		200	58.4, 6
			Meadow R.		65	128.5, 4
Greenbrier R.		180	New R.		200	1478.1, 7
			Meadow R.		65	138.4, 4
New R.		200	Meadow R.		65	57.8, 4

Table 9. Habitat suitability curves for smallmouth bass (juvenile) in Meadow River and Tygart River combined. Data collected by observation. N = 231.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00				
.35	1.00				
.40	.80				
.50	.42				
.60	.20				
.70	.09				
.80	.04				
.85	.02				
.95	.01				
1.15	.01				
1.20	0.00				
100.00	0.00				

Table 10. Habitat suitability curves for smallmouth bass (juvenile) in New River. Data collected by observation. N = 200.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	.65	0.00	0.00	0.00	0.00
.05	.65	.30	0.00	2.50	0.00
.10	.79	.40	.01	3.00	.01
.15	1.00	.60	.02	4.00	.01
.55	1.00	.80	.05	4.50	.09
.60	.69	.90	.10	4.75	1.00
.70	.46	1.00	.20	5.25	1.00
.80	.32	1.20	.43	5.50	.71
.90	.24	1.40	.69	6.00	.50
1.00	.18	1.50	.85	6.50	.38
1.10	.13	1.55	1.00	7.00	.35
1.20	.08	1.75	1.00	7.50	.33
1.30	.05	1.80	.60	8.00	.32
1.40	.02	1.90	.43	100.00	0.00
1.50	.02	2.00	.35		
1.60	0.00	2.20	.23		
100.00	0.00	2.40	.13		
		2.60	.07		
		2.80	0.00		
		100.00	0.00		

Table 11. Habitat suitability curves for smallmouth bass (juvenile) in Greenbrier River. Data collected by observation. N = 180.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	.62	0.00	0.00	0.00	0.00
.05	.62	.20	.40	2.00	0.00
.10	.74	.35	1.00	2.25	.01
.15	1.00	.55	1.00	4.00	.01
.35	1.00	.60	.85	4.25	.04
.40	.42	.80	.50	4.50	.09
.50	.21	1.00	.27	5.00	.22
.60	.12	1.20	.12	5.50	.28
.70	.06	1.30	.07	5.75	1.00
.80	.03	1.40	.05	6.25	1.00
.90	.02	2.60	.05	6.50	.35
1.00	0.00	2.80	0.00	7.00	.16
100.00	0.00	100.00	0.00	7.50	.05
				8.00	.01
				100.00	0.00

Table 12. Habitat suitability curves for smallmouth bass (juvenile) in Tygart River. Data collected by observation. N = 166.

Velocity		Depth		Substrate	
V	s	D	s	S	s
		0.00	0.00		
		.30	0.00	0.00	0.00
		.40	.19	2.50	0.00
		.50	.27	3.00	.01
		.60	.30	3.50	.06
		.70	.34	4.00	.20
		.80	.40	4.50	.50
		.90	.55	5.00	.80
		.95	1.00	5.25	1.00
		2.35	1.00	5.75	1.00
		2.40	.95	6.00	.71
		2.50	.29	6.50	.35
		2.60	.25	7.00	.10
		2.80	.23	7.50	0.00
		3.00	.22	100.00	0.00
		3.20	.17		
		3.40	.10		
		3.60	.06		
		4.00	.05		
		4.10	.04		
		4.20	.00		
		100.00	0.00		

Table 13. Habitat suitability curves for smallmouth bass (juvenile) in Meadow River. Data collected by observation. N = 65.

Velocity		Depth		Substrate	
V	s	D	s	S	s
				0.00	0.00
		0.00	.00	1.00	0.00
		.20	.00	1.50	.01
		.40	.00	5.00	.01
		.60	.05	5.50	.03
		.80	.05	6.00	.23
		1.00	.05	6.50	.40
		1.20	.11	6.75	1.00
		1.40	.24	7.25	1.00
		1.60	.37	7.50	.11
		1.80	.43	8.00	0.00
		2.00	.45	100.00	0.00
		2.60	.48		
		2.80	.50		
		3.00	.56		
		3.20	.76		
		3.25	1.00		
		3.65	1.00		
		3.70	.40		
		3.80	.10		
		3.90	.05		
		4.10	0.00		
		100.00	0.00		

Table 14. Summary of results of Chi-square comparisons of clumped habitat preference data for smallmouth bass fry. Data collected by observation. * = not significantly different ($\alpha = .10$); data combined. NC = not compared because of obvious difference in data.

Reference curve (expected)			Data compared (observed)			χ^2, d.f.
Stream	Parameter	N	Stream	Parameter	N	
Greenbrier R.	Velocity	28	Meadow R.	Velocity	876	96.1, 3
Greenbrier R.	Depth	28	Meadow R.	Depth	876	400.8, 4
Greenbrier R.	Substrate	28	Meadow R.	Substrate	876	673.5, 2

Table 15. Habitat suitability curves for smallmouth bass (fry) in Meadow River. Data collected by observation. N = 876.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.40	0.00	5.50	0.00
.20	.60	.50	.32	6.00	.15
.30	.29	.60	.67	6.25	1.00
.40	.10	.65	1.00	6.75	1.00
.45	.03	.85	1.00	7.00	.28
.60	0.00	.90	.72	7.50	0.00
100.00	0.00	1.00	.49	100.00	0.00
		1.10	.30		
		1.20	.17		
		1.30	.08		
		1.40	.04		
		1.70	0.00		
		100.00	0.00		

Table 16. Habitat suitability curves for smallmouth bass (fry) in Greenbrier River. Data collected by observation. N = 28.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.50	1.00	4.50	0.00
.20	.45	1.55	1.00	5.00	.01
.30	.24	1.60	0.00	5.50	.09
.40	.14	100.00	0.00	6.00	.22
.50	.09			6.50	.46
.80	0.00			6.75	1.00
100.00	0.00			7.25	1.00
				7.50	.37
				7.75	.23
				8.00	.23
				100.00	0.00

Table 17. Habitat suitability curves for smallmouth bass (nests) in Meadow River and South Branch of the Potomac River. Data collected by observation. N = 14.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.40	0.00	4.00	0.00
.20	.50	.45	1.00	4.25	1.00
.25	.38	2.75	1.00	5.25	1.00
.85	0.00	2.80	0.00	5.50	0.00
100.00	0.00	100.00	0.00	100.00	0.00

Table 18. Habitat suitability curves for brook trout (adult) in all streams. Data collected by observation. N = 147.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.15	.12	1.00	.02
.20	.35	.35	.35	2.00	.02
.30	.18	.40	.46	2.50	.05
.40	.10	.45	1.00	3.00	.10
.45	.07	.65	1.00	3.50	.16
.65	.05	.70	.66	4.00	.26
1.15	.01	.80	.57	4.50	.43
1.55	.01	.90	.50	4.75	1.00
1.60	0.00	1.00	.43	5.75	1.00
100.00	0.00	1.10	.40	6.00	.40
		1.20	.38	6.50	.28
		1.40	.36	6.75	.26
		1.70	.36	7.00	.30
		1.80	.34	7.50	.46
		1.90	.30	7.75	.67
		2.00	.20	8.00	.67
		2.10	.12	100.00	0.00
		2.20	.10		
		2.80	.06		
		2.90	0.00		
		100.00	0.00		

Table 19. Habitat suitability curves for brook trout (juvenile) in all waters. Data collected by backpack shocker and observation. N = 52.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.05	.16	2.50	0.00
.20	.55	.10	.19	2.75	.08
.25	.42	.25	.19	3.00	.10
.30	.30	.30	.25	4.50	.12
.35	.23	.35	1.00	4.75	.18
.40	.17	1.15	1.00	5.00	.44
.45	.13	1.20	.25	5.25	1.00
.55	.11	1.30	.19	5.75	1.00
.65	.10	1.45	.19	6.00	.39
.85	.04	1.50	.17	6.25	.19
1.05	0.00	1.65	.09	6.50	.15
100.00	0.00	1.75	.06	8.00	.15
		1.80	0.00	100.00	0.00
		100.00	0.00		

Table 20. Habitat suitability curves for brook trout (fry) all streams. Data collected by backpack shocker and observation. N = 57.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.05	1.00	1.00	.08
.20	.20	.65	1.00	1.75	.08
.25	.10	.70	.40	2.25	.12
.30	.07	.75	.21	2.50	.19
.35	.05	.80	.15	2.70	1.00
.40	.04	.90	.10	3.25	1.00
.55	.03	1.05	.06	3.50	.58
.70	.03	1.25	0.00	3.75	.44
.75	.02	100.00	0.00	4.00	.35
.80	0.00			4.25	.28
100.00	0.00			4.50	.24
				5.00	.22
				5.50	.22
				5.75	.18
				6.75	.01
				8.00	.01
				100.00	0.00

Table 21. Habitat suitability curves for brook trout (nests) all streams. Data collected by observation. N = 127.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.05	.04	3.50	0.00
.20	.77	.10	.14	4.00	.01
.25	.60	.15	1.00	4.50	.07
.30	.48	.75	1.00	4.75	1.00
.35	.37	.80	.54	5.25	1.00
.40	.29	.85	.48	5.50	.17
.45	.22	.90	.42	6.00	.01
.50	.17	1.05	.35	6.50	0.00
.60	.09	1.15	.22	100.00	0.00
.70	.05	1.25	.10		
.75	.03	1.65	.05		
1.00	.02	1.95	.03		
1.05	0.00	2.00	0.00		
100.00	0.00	100.00	0.00		

Table 22. Habitat suitability curves for stoneroller (adult) Greenbrier River and Tygart River. Data collected by backpack shocker. N = 31.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	0.00	0.00	0.00	0.00	0.00
.50	.20	.30	0.00	4.50	0.00
.70	.30	.40	.02	4.75	.11
.75	1.00	.60	.09	6.00	.11
.95	1.00	.80	.18	6.50	.18
1.00	.32	.90	.23	6.75	1.00
1.10	.23	1.00	.35	7.25	1.00
1.20	.18	1.05	1.00	7.50	0.00
1.30	.12	1.25	1.00	100.00	0.00
1.50	.06	1.30	.30		
1.70	.02	1.40	.20		
1.90	0.00	1.60	.12		
100.00	0.00	1.80	.09		
		2.60	.07		
		2.80	0.00		
		100.00	0.00		

Table 23. Summary of results of Chi-square comparisons of clumped habitat preference data for stoneroller juveniles. Data collected by backpack shocker. * = not significantly different (α = .10); data combined. NC = not compared because of obvious differences in data.

Reference curve (expected)			Data compared (observed)			χ^2, d.f.
Stream	Parameter	N	Stream	Parameter	N	
Twelve Pole Ck.	Velocity	101	Greenbrier R.	Velocity	93	52.2, 6
			Tygart R.		47	50.7, 5
Greenbrier R.		93	Tygart R.		47	62.9, 5
Twelve Pole Ck.	Depth	101	Greenbrier R.	Depth	94	57.8. 4
			Tygart R.		47	47.8, 7
Greenbrier R.		94	Tygart R.		47	18.4, 4
Twelve Pole Ck.	Substrate	101	Greenbrier R.	Substrate	94	NC
			Tygart R.		47	NC
Greenbrier R.		94	Tygart R.		47	165.7, 3

Table 24. Habitat suitability curves for stoneroller (juvenile) in Twelve Pole Creek drainage. Data collected by backback shocker. N = 101.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.10	.07	2.50	0.00
.20	.30	.15	.13	2.75	.30
.30	.15	.20	.29	3.00	.42
.40	.13	.25	1.00	3.50	.64
.70	.13	.45	1.00	3.75	1.00
.90	.10	.50	.47	4.25	1.00
1.15	.02	.60	.30	4.50	.78
1.35	.02	.70	.20	5.00	.59
1.40	0.00	.80	.12	5.50	.46
100.00	0.00	1.00	.04	6.00	.27
		1.10	.01	6.50	0.00
		2.70	0.00	100.00	0.00
		100.00	0.00		

Table 25. Habitat suitability curves for stoneroller (juvenile) in Greenbrier River. Data collected by backpack shocker. N = 94.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.10	.02	2.50	0.00
.20	.23	.20	.05	3.00	.01
.30	.15	.25	.09	4.50	.03
.95	.15	.30	.19	5.00	.07
1.10	.12	.35	1.00	5.25	1.00
1.40	.03	.75	1.00	5.75	1.00
1.80	.01	.80	.55	6.00	.23
2.20	.01	.85	.40	6.50	.17
2.30	0.00	.90	.33	7.00	.13
100.00	0.00	1.00	.22	7.25	.10
		1.10	.14	7.50	0.00
		1.20	.11	100.00	0.00
		1.30	.08		
		1.40	.06		
		1.80	.05		
		2.00	0.00		
		100.00	0.00		

Table 26. Habitat suitability curves for stoneroller (juvenile) in Tygart River. Data collected by backpack shocker. N = 47.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	.21	0.00	0.00	0.00	0.00
.05	.21	.10	.14	5.00	0.00
.10	.35	.20	.23	5.25	1.00
.15	1.00	.30	.29	6.25	1.00
.35	1.00	.35	.32	6.50	0.00
.40	.39	.40	.40	100.00	0.00
.45	.21	.45	1.00		
.60	.10	.65	1.00		
.70	.06	.70	.27		
.80	.04	.75	.17		
1.70	.04	.80	.12		
1.80	0.00	.90	.07		
100.00	0.00	1.00	.05		
		2.00	.05		
		2.10	0.00		
		100.00	0.00		

Table 27. Summary of results of Chi-square comparisons of clumped habitat suitability data for stoneroller nests. Data collected by observation. * = not significantly different ($\alpha = .10$); data combined. NC = not compared because of obvious differences in data.

Reference curve (expected)			Data compared (observed)			χ^2, d.f.
Stream	Parameter	N	Stream	Parameter	N	
Greenbrier R.	Velocity	20	Chenoweth Ck.	Velocity	17	4.2, 4*
Greenbrier R.	Depth	20	Chenoweth Ck.	Depth	17	16.7, 5
Greenbrier R.	Substrate	20	Chenoweth Ck.	Substrate	17	17.1, 4

Table 28. Habitat suitability curves for stoneroller (nests) in Greenbrier River and Chenoweth Creek. Data collected by observation. N = 37.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	0.00				
.15	0.00				
.25	.04				
.30	.07				
.35	.11				
.40	.27				
.45	1.00				
1.25	1.00				
1.30	.27				
1.35	.11				
1.45	.04				
1.55	0.00				
100.00	0.00				

Table 29. Habitat suitability curves for stoneroller (nests) in Greenbrier River. Data collected by observation. N = 20.

Velocity		Depth		Substrate	
V	s	D	s	S	s
		0.00	0.00	0.00	0.00
		.25	0.00	4.50	0.00
		.30	.10	4.75	1.00
		.35	1.00	5.25	1.00
		1.75	1.00	5.50	0.00
		1.80	.10	100.00	0.00
		1.85	0.00		
		100.00	0.00		

Table 30. Habitat suitability curves for stoneroller (nests) in Chenoweth Creek. Data collected by observation. N = 17.

Velocity		Depth		Substrate	
V	s	D	s	S	s
		0.00	0.00	0.00	0.00
		.25	0.00	4.00	0.00
		.30	.05	4.50	.25
		.35	1.00	4.75	1.00
		1.35	1.00	5.25	1.00
		1.40	.05	5.50	.17
		1.45	0.00	5.75	.05
		100.00	0.00	6.00	0.00
				100.00	0.00

Table 31. Summary of results of Chi-square comparisons of clumped habitat preference data for fantail darter adults. Data collected by backpack shocker. * = not significantly different ($\alpha = .10$); data combined. NC = not compared because of obvious difference in data.

Reference curve (expected)			Data compared (observed)			χ^2, d.f.
Stream	Parameter	N	Stream	Parameter	N	
Greenbrier R.	Velocity	196	Twelve Pole Ck.	Velocity	27	4.2, 6*
Greenbrier R.	Depth	204	Twelve Pole Ck.	Depth	27	10.6, 2
Greenbrier R.	Substrate	204	Twelve Pole Ck.	Substrate	27	24.1, 6

Table 32. Habitat suitability curves for fantail darter (adult) in Greenbrier River and Twelve Pole Creek drainage. Data collected by backpack shocker. N = 230.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1,00				
0.15	1.00				
0.20	.80				
.25	.70				
.30	.61				
.35	.54				
.40	.49				
.45	.44				
.50	.40				
.60	.32				
.65	.29				
.70	.26				
.80	,22				
.90	.18				
1.00	.15				
1.10	.12				
1.20	.10				
1.30	.07				
1.40	.05				
1.50	.03				
1.60	.02				
1.70	.01				
1.90	.01				
1.95	0.00				
100.00	0.00				

Table 33. Habitat suitability curves for fantail darter (adult) in Greenbrier River. Data collected by backpack shocker. N = 204.

Velocity		Depth		Substrate	
V	s	D	s	S	s
		0.00	0.00	0.00	0.00
		.05	.06	2.50	0.00
		.10	.13	3.00	0.01
		.15	.20	3.50	.03
		.20	.28	3.75	.05
		.25	.38	4.00	.09
		.30	.60	4.25	.14
		.35	1.00	4.50	.20
		.55	1.00	4.75	.29
		.60	.72	5.00	.38
		.65	.57	5.25	1.00
		.70	.45	5.75	1.00
		.75	.38	6.00	.24
		.80	.34	6.25	.18
		.85	.31	6.50	.13
		.90	.29	6.75	.10
		1.00	.25	7.00	.08
		1.65	.11	7.75	.02
		2.05	.01	8.00	.02
		2.20	.01	100.00	0.00
		2.25	0.00		
		100.00	0.00		

Table 34. Habitat suitability curves for fantail darter (adult) in Twelve Pole Creek drainage. Data collected by backpack shocker. N = 27.

Velocity		Depth		Substrate	
V	s	D	s	S	s
		0.00	0.00	0.00	0.00
		.05	.35	2.50	0.00
		.15	1.00	2.75	.05
		.55	1.00	3.00	.08
		.65	0.00	3.25	.10
		100.00	0.00	3.50	.55
				3.75	1.00
				6.25	1.00
				6.50	0.00
				100.00	0.00

Table 35. Habitat suitability curves for fantail darter (juvenile) in Greenbrier River. Data collected by backpack shocker. N = 106.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	.60	0.00	0.00
0.15	1.00	.05	.60	2.50	0.00
.20	.72	.10	.78	3.00	.01
.25	.55	.15	1.00	3.50	.03
.30	.37	.35	1.00	4.00	.05
.35	.24	.40	.78	4.25	.09
.40	.13	.45	.65	4.50	.15
.45	.06	.50	.55	4.75	.24
.55	.02	.55	.46	5.00	.44
.60	.01	.65	.32	5.25	1.00
.90	.01	.70	.27	5.75	1.00
1.00	0.00	.75	.22	6.00	.20
100.00	0.00	.80	.18	6.25	.09
		.90	.13	6.50	0.00
		1.00	.09	100.00	0.00
		1.40	.02		
		1.50	.02		
		1.60	0.00		
		100.00	0.00		

Table 36. Summary of results of Chi-square comparisons of clumped habitat preference data for striped shiner adults. Data collected by observation in Chenoweth Creek and by a combination of methods in Twelve Pole Creek. * = not significantly different ($\alpha = .10$); data combined. NC = not compared because of obvious difference in data.

Reference curve (expected)			Data compared (observed)			χ^2. d.f.
Stream	Parameter	N	Stream	Parameter	N	
Twelve Pole Ck.	Velocity	84	Chenoweth Ck.	Velocity	51	NC
Twelve Pole Ck.	Depth	84	Chenoweth Ck.	Depth	51	21.9, 5
Twelve Pole Ck.	Substrate	84	Chenoweth Ck.	Substrate	51	NC

Table 37. Habitat suitability curves for striped shiner (adult) in Twelve Pole drainage. Data collected by backpack shocker and seine. N = 84.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.45	.04	3.00	0.00
.20	.04	.60	.14	3.25	.03
.25	.01	.70	.28	3.50	.17
.70	0.00	.80	.50	3.75	1.00
100.00	0.00	.90	.79	4.25	1.00
		.95	1.00	4.50	.29
		1.15	1.00	4.75	.18
		1.20	.70	5.00	.13
		1.25	.46	5.25	.10
		1.30	.30	6.00	.08
		1.35	.22	6.25	.06
		1.50	.16	6.50	0.00
		1.60	.15	100.00	0.00
		2.70	.15		
		2.80	.13		
		2.90	.09		
		2.95	.06		
		3.00	0.00		
		100.00	0.00		

Table 38. Habitat suitability curves for striped shiner (adult) in Chenoweth Creek. Data collected by observation. N = 51.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	0.00	0.00	0.00	0.00	0.00
.20	0.00	.35	.06	5.00	0.00
.25	.04	.40	.09	5.25	1.00
.35	.08	.45	.13	5.75	1.00
.40	.13	.50	.18	6.00	.12
.45	1.00	.55	.25	6.50	0.00
.65	1.00	.60	.37	100.00	0.00
.70	.31	.65	1.00		
.75	.21	1.25	1.00		
.80	.16	1.30	.34		
.85	.13	1.35	.25		
.90	.12	1.40	.22		
1.00	.10	1.50	.20		
1.05	.08	2.00	.19		
1.10	0.00	2.10	.16		
100.00	0.00	2.20	.12		
		2.30	0.00		
		100.00	0.00		

Table 39. Habitat suitability curves for striped shiner (juvenile) in all streams. Data collected by backpack shocker, seine, parallel wires, and observation. N = 74.

Velocity		Depth		Substrate	
V	s	D	s	S	s
0.00	1.00	0.00	0.00	0.00	0.00
.15	1.00	.10	0.00	2.50	0.00
.20	.32	.20	.15	2.75	1.00
.30	.18	.30	.28	3.25	1.00
.40	.15	.40	.35	3.50	.60
.75	.15	.60	.40	3.75	.48
.85	.13	1.20	.43	4.00	.43
.90	.11	1.30	.46	4.50	.40
1.30	0.00	1.40	.58	5.75	.40
100.00	0.00	1.45	1.00	6.00	.38
		1.85	1.00	6.50	.18
		1.90	.56	6.75	.05
		2.00	.20	7.50	0.00
		2.10	.12	100.00	0.00
		2.20	.09		
		2.80	0.00		
		100.00	0.00		

Weighted Usable Area Analysis

Weighted usable area (WUA) was evaluated at twelve discharges in each study reach and expressed as ft^2/1000 ft of stream.

Not all of the habitat suitability curves that were constructed were used to obtain predictions of WUA in the study reaches. Suitability curves used to obtain the data to construct a particular set of habitat response curves (i.e. curves depictcting how WUA varied with discharge) are listed on each figure. They are the suitability curves which were thought most appropriate for use with the species, stream, and study reach involved.

Habitat response curves for species in the Greenbrier and Meadow Rivers were generated using the IFG-4 computer program which requires for optimal performance data measured at three discharges. The IFG-2 program was used to generate habitat response curves for species in the New River because hydraulic parameters had been measured at only one discharge.

Greenbrier River

Island Camp Study Reach: WUA/1000 ft of stream was evaluated on the Island Camp study reach on the East Fork of the Greenbrier River (Fig. 3) for brook trout (Fig. 10), stoneroller (Fig. 11), and fantail darter (Fig. 12). The IFG-4 hydraulic simulation program was used with twelve flows ranging from 10 to 160 cfs.

WUA's were generally highest for adults at the lowest flows. WUA was lowest for adult stoneroller with a value of less than 25 ft^2 at flows over 50 cfs. WUA for adult fantail darter was between 200 and 400 ft^2 at flows over 55 cfs, whereas WUA for adult brook trout fluctuated between about 300 to 600 ft^2 over the range fo discharges tested.

WUA's for juveniles, as for adults, were greatest at low flows. WUA declined to lower levels for juvenile stoneroller than for juvenile brook trout or fantail darter. For juvenile stoneroller, WUA declined from an initial value of about 500 ft^2 to less than 100 ft^2 at 100 cfs and higher flows. WUA for juvenile fantail darter declined from over 1100 ft^2 at 10 cfs to less than 300 ft^2 at 40 cfs, and it further declined to less than 200 ft^2 at discharges of 140 and 160 cfs. WUA for juvenile brook trout did not decline below 400 ft^2 until discharges were greater than 80 cfs. Its value never was less than 200 ft^2, and it increased to more than 300 ft^2 at discharges of 140 and 160 cfs.

Brook trout was the only one of the three species for which a habitat suitability curve was constructed for fry. The habitat response curve generated for brook trout fry declined from a WUA of over 300 ft^2 at 10 cfs to less than 100 ft^2 at 20 cfs. Thereafter, it increased steadily until the WUA was again greater than 300 ft^2 at 160 cfs.

The habitat response curves for brook trout and stoneroller nesting were very dissimilar. WUA for brook trout nests generally fluctuated between 200 and 300 ft^2 over most of the range of flows. The WUA for stoneroller nests, on the other hand, increased from zero at 10 cfs to almost 500 ft^2 at 60 cfs. It then declined to about 220 ft^2 at 120 cfs and remained near that value at higher flows.

Hosterman Study Reach: WUA/1000 ft of stream was evaluated on the Hosterman study reach of the Greenbrier River (Fig. 3) for smallmouth bass (Fig. 13), stoneroller (Fig. 14), fantail darter (Fig. 15), and striped shiner (Fig. 16). The IFG-4 hyrdraulic simulation program was used with twelve flows ranging from 25 to 1000 cfs.

WUA for adult lifestages was greatest for fantail darter and stoneroller, intermediate for striped shiner, and least for smallmouth bass. Except for higher values at flows of 25 and 50 cfs, WUA for fantail darter fluctuated between about 250 to 600 ft^2. WUA for stoneroller adults peaked at 2200 ft^2 at 100 cfs, fluctuated between 900 and 300 ft^2 at discharges of 175 to about 400 cfs, and ranged from about 150 to 300 ft^2 at higher flows. WUA for adult striped shiner rose from near zero at 400 cfs to almost 400 ft^2 at 1000 cfs. WUA for adult smallmouth bass was highest (530 ft^2) at 24 cfs but declined to almost zero at 200 cfs and reamined at that level to a discharge of 600 cfs. It was still less than 175 ft^2 at 1000 cfs.

WUA for juveniles was highest for smallmouth bass, intermediate for stoneroller, and lowest for fantail darter and striped shiner. Except for higher values at discharges of 50 cfs or less, WUA's for juvenile smallmouth bass fluctuated between about 800 ft^2 to 1400 ft^2. WUA's for juvenile stoneroller fluctuated between 200 and 700 ft^2 over all flows. WUA's for juvenile fantail darter and striped shiner generally varied between 100 and 400 ft^2 over all flows, but WUA's were greater below 400 cfs for fantail darter and above 400 cfs for striped shiner.

The only fry lifestage for which a habitat response curve was generated in the Hosterman study reach was smallmouth bass. WUA for fry was almost 3800 ft^2 at 25 cfs. It dropped to less than 600 ft^2 at 100 cfs, then increased to more than 1100 ft^2 at 600 cfs and remained at that level at higher flows.

Spawning habitat availability was very low in the Hosterman study reach. WUA for smallmouth bass nests was zero to a discharge of 700 cfs and it increased to only 25 ft^2 at 1000 cfs. WUA for stoneroller nests was 1 ft^2 at 200 cfs, 19 ft^2 at 1000 cfs, and zero at all other flows.

Seneca State Forest Study Reach: WUA/1000 ft of stream was evaluated on the Seneca State Forest study reach of the Greenbrier River (Fig. 3) for smallmouth bass (Fig. 17), stoneroller (Fig. 18), fantail darter (Fig. 19), and striped shiner (Fig. 20). The IFG-4 hydraulic simulation program was used with twelve discharges ranging from 25 to 1000 cfs.

Habitat availability for adult lifestages was greatest for stoneroller, intermediate for fantail darter, and least for smallmouth bass and striped shiner. WUA for adult stoneroller declined steadily from over 5000 ft^2 at 100 cfs to about 500 ft^2 at 1000 cfs. After declining from about 2500 ft^2 at 100 cfs to about 400 ft^2 at 600 cfs, WUA for adult fantail darter ranged between 400 and 600 ft^2 at higher discharges. WUA for adult smallmouth bass generally was between 100 and 200 ft^2 at all flows, whereas for adult striped shiner it remained below 30 ft^2 to 760 cfs then rose to about 100 ft^2 at 1000 cfs.

WUA for juvenile lifestages was greatest for smallmouth bass, intermediate for fantail darter and stoneroller, and least for striped shiner. WUA for smallmouth bass juveniles declined from over 6000 ft^2 at 50 cfs to about 450 ft^2 at 600 cfs then gradually increased to about 650 ft^2 at 1000 cfs. WUA for juvenile fantail darter fluctuated more, but was generally similar to WUA for stoneroller at discharges up to 500 cfs. At higher discharges, both varied between about 200 to 400 ft^2. WUA for juvenile striped shiner varied between 200 and 700 ft^2 over all flows, with peaks at 100 and 1000 cfs.

Habitat availability for smallmouth bass fry, the only fry for which habitat response was evaluated in the Seneca State Forest study reach, declined from almost 9000 ft^2 at 25 cfs to almost 400 ft^2 at 500 cfs and remained near that level at higher flows.

Habitat availability for smallmouth bass and stoneroller nests was rather low as WUA's were generally less than 250 ft^2 at all flows.

Meadow River

Rainelle Study Reach: WUA/1000 ft of stream was evaluated on the Rainelle study reach of the Meadow River (Fig. 4) for smallmouth bass (Fig. 21), spotted bass (Fig. 22), channel catfish (Fig. 23), stoneroller (Fig. 24), fantail darter (Fig. 25), and striped shiner (Fig. 26). The IFG-4 hydraulic simulation program was used with eight discharges ranging from 10 to 300 cfs.

Habitat availability for adult lifestages was greatest for spotted bass and was successively less for channel catfish, stoneroller, fantail darter, smallmouth bass, and striped shiner. WUA for adult spotted bass increased from about 200 ft^2 at 150 cfs to almost 15,000 ft^2 at 300 cfs. WUA for channel catfish increased from about 200 ft^2 at 100 cfs to about 4700 ft^2 at 300 cfs. For adult stoneroller, WUA rose from less than 200 ft^2 at 10 cfs to a peak of about 2300 ft^2 at 150 cfs then declined to about 300 ft^2 at 300 cfs. WUA for adult fantail darter declined from 3200 ft^2 at 10 cfs to 175 ft^2 at 300 cfs, whereas WUA for adult smallmouth bass first declined from 700 ft^2 at 10 cfs, rose to 800 ft^2 at 200 cfs, then declined again to 200 ft^2 at 300 cfs. WUA for striped shiner adults initially declined from over 1100 ft^2 to about 100 ft^2 at 50 cfs and then remained below 200 ft^2 at higher flows.

Habitat availability for juvenile lifestages was greatest for spotted bass and channel catfish, intermediate for striped shiner and smallmouth bass, and least for fantail darter and stoneroller. WUA for juvenile spotted bass increased from about 1500 ft^2 at 25 cfs to over 12,000 ft^2 at 300 cfs while for juvenile channel catfish, it increased from about 50 to 1600 ft^2 over the same range of discharges. For juvenile striped shiner, WUA descended from over 3400 ft^2 at 10 cfs to 1100 ft^2 at 50 cfs rose again to about 1400 ft^2 at 250 cfs then dropped to around 750 ft^2 at 300 cfs. WUA for juvenile smallmouth bass descended from almost 1800 ft^2 at 25 cfs to about 400 ft^2

at 100 cfs; it varied around that level before descending to about 150 ft^2 at 300 cfs. Habitat availability was similar for juvenile fantail darter and stoneroller. WUA's for both descended from values of 2200 and 2500 ft^2, respectively, at 10 cfs to less than 30 ft^2 at 300 cfs.

WUA's for fry lifestages were highest for channel catfish, intermediate for spotted bass, and least for smallmouth bass. For channel catfish fry, WUA's rose from 13,000 ft^2 at 10 cfs to 28,000 ft^2 at 300 cfs, while for spotted bass fry they rose from about 900 ft^2 at 10 cfs to 15,500 ft^2 at 300 cfs. WUA's for smallmouth bass fry descended from about 1300 ft^2 at 10 cfs to 50 ft^2 at 100 cfs and to 1 ft^2 at 300 cfs.

Availability of nesting habitat was greatest for spotted bass, as WUA's rose from almost 1400 ft^2 at 10 cfs to more than 16,000 ft^2 at 300 cfs. WUA was greater for smallmouth bass than for channel catfish at discharges below 200 cfs, but at 300 cfs, WUA's for smallmouth bass nesting had increased only to about 1600 ft^2 whereas for channel catfish nesting it had increased to 3200 ft^2.

Rt. 19 Bridge Study Reach: WUA/1000 ft of stream was evaluated on the Rt. 19 bridge study reach of the Meadow River (Fig. 4) for smallmouth bass (Fig. 27), spotted bass (Fig. 28), channel catfish (Fig. 29), stoneroller (Fig. 30), fantail darter (Fig. 31), and striped shiner (Fig. 32). The IFG-4 hydraulic simulation program was used with flows ranging from 10 to 500 cfs.

Habitat availability for adults was highest for smallmouth bass and stoneroller, intermediate for spotted bass and fantail darter and lowest for channel catfish and striped shiner. Although WUA for stoneroller rose to almost 4000 ft^2, it declined to less than 1000 ft^2 at 500 cfs while WUA for smallmouth increased steadily to over 2000 ft^2 at 500 cfs. WUA for adult spotted bass was between 1100 and 1300 ft^2 at discharges greater than 100 cfs whereas WUA for fantail darter was over 1300 ft^2 at 100 cfs but declined almost to 700 ft^2 at 500 cfs. WUA for adult channel catfish increased from 200 to 400 ft^2 over the range of flows, and WUA for striped shiner was usually less than 100 ft^2.

Habitat availability for juveniles was greatest for spotted and smallmouth bass, intermediate for channel catfish, stoneroller, and striped shiner, and least for fantail darter. WUA for smallmouth bass reached almost 6000 ft^2 at 50 cfs, but it generally remained between 1700 and 2000 ft^2 at discharges greater than 200 cfs. WUA for spotted bass approached 4000 ft^2 at 50 cfs, but it ranged between 2500 and 3000 ft^2 at flows of 2000 cfs and greater. For juvenile channel catfish WUA increased steadily from almost zero at 10 cfs to about 1500 ft^2 at 500 cfs. WUA for juvenile stoneroller and striped shiner, was between 600 and 1000 ft^2 at flows above 100 cfs although habitat availability was more variable for the latter. WUA for juvenile fantail darter rose from more than 500 ft^2 at 25 cfs to about 800 ft^2 at 100 cfs then declined to less than 300 ft^2 at 500 cfs.

Habitat availability for fry lifestages was greatest for channel catfish, intermediate for spotted bass, and least for smallmouth bass. WUA for channel catfish fry rose from about 1000 ft^2 at 10 cfs to almost 5000 ft^2 at 500 cfs. For spotted bass fry, WUA declined from a peak of almost 4500 ft^2 at 100 cfs to less than 1500 ft^2 at 300 cfs after which it rose to almost 1900 ft^2 at 500 cfs. WUA for smallmouth bass fry declined from 2700 ft^2 at 10 cfs to just over 500 ft^2 at 200 cfs and remained near that level at higher discharges.

Nesting habitat was most plentiful for smallmouth bass, reaching levels of 500 ft^2 at 190 cfs and 1000 ft^2 at 500 cfs. It was rather limited for spotted bass and channel catfish, as WUA values never rose above 100 ft^2 for either species.

New River

Bluestone Tailwaters Study Reach: WUA/1000 ft of stream was evaluated on the Bluestone tailwaters study reach of the New River (Fig. 7) for smallmouth bass (Fig. 33), spotted bass (Fig. 34), channel catfish (Fig. 35), stoneroller (Fig. 36), fantail darter (Fig. 37), and striped shiner (Fig. 38). The IFG-2 hydraulic simulation program was used with nine discharges ranging from 250 to 3500 cfs.

Habitat availability for adults was highest for spotted bass, followed by smallmouth bass, channel catfish, fantail darter, stoneroller, and striped shiner. WUA for spotted bass rose from zero at 1000 cfs to 250,000 ft^2 at 3500 cfs. Smallmouth bass WUA rose from about 3000 ft^2 at 250 cfs to 26,000 ft^2 at 2000 cfs then declined to about 4500 ft^2 at 3500 cfs, whereas for adult channel catfish, WUA rose steadily from zero at 250 cfs to 24,600 ft^2 at 3500 cfs. WUA for fantail darter declined from over 11,000 ft^2 at 250 cfs to less than 100 ft^2 at 2500 cfs and remained at that level. Stoneroller WUA rose to a maximum of almost 5500 ft^2 from 1000 to 1500 cfs and declined to less than 200 ft^2 at 3000 and 3500 cfs. WUA for striped shiner declined rapidly from 17,000 ft^2 at 250 cfs to less than 100 ft^2 at 500 cfs and was almost zero at flows of 2500 to 3500 cfs.

Habitat availability for juvenile life stages was greatest for spotted bass and smallmouth bass, intermediate for channel catfish, stoneroller, and striped shiner, and least for fantail darter. WUA for juvenile spotted bass rose from 4500 to 272,000 ft^2 at flows of 250 and 3500 cfs, respectively. WUA for juvenile smallmouth bass rose from 15,000 ft^2 at 250 cfs to 81,000 ft^2 at 750 cfs after which it declined to 1400 ft^2 at 3500 cfs. WUA for juvenile channel catfish rose from about 100 ft^2 at 250 cfs to 8200 ft^2 at 3500 cfs.

For juvenile stoneroller, WUA varied from about 2000 to 7500 ft^2 at discharges less than 1500 cfs, then declined from 600 ft^2 at 1500 cfs to less than 10 ft^2 at 3500 cfs. For juvenile fantail darter, WUA declined from over 2000 ft^2 at 250 cfs to 200 ft^2 at 750 cfs and continued a more gradual decline to zero at 3500 cfs.

WUA for fry lifestages was greatest for spotted bass, intermediate for channel catfish, and least for smallmouth bass. WUA for spotted bass fry rose from 2000 ft^2 at 250 cfs to 268,000 ft^2 at 3500 cfs, whereas for channel catfish fry it rose from 30,000 ft^2 at 250 cfs to 51,600 ft^2 at 3500 cfs. WUA for smallmouth bass fry descended from 74,000 ft^2 at 250 cfs to about 600 ft^2 from 2000 to 3500 cfs.

Availability of nesting habitat was greatest for spotted bass, intermediate for smallmouth bass and channel catfish, and least for stoneroller. WUA for spotted bass nests rose from 4900 ft^2 at 250 cfs to 29,500 ft^2 at 1500 cfs and remained near that level at higher flows. The habitat response curves for smallmouth bass and channel catfish nesting were almost mirror images of each other; the former declined from 24,000 ft^2 at 250 cfs to about 300 ft^2 at 3500 cfs, whereas the latter increased from zero at 500 cfs to 24,000 ft^2 at 3500 cfs. WUA for stoneroller nests rose to a peak of 2800 ft^2 at 750 cfs, declined to about 450 ft^2 at 1500 cfs, rose again almost to 1000 ft^2 at 2500 and 3000 cfs then declined to almost 200 ft^2 at 3500 cfs.

Bass Lake Study Reach: WUA/1000 ft of stream was evaluated on the Bass Lake study reach of the New River (Fig. 7) for smallmouth bass (Fig. 39), spotted bass (Fig. 40), channel catfish (Fig. 41), stoneroller (Fig. 42), fantail darter (Fig. 43), and striped shiner (Fig. 44). The IFG-2 hydraulic simulation program was used with seven discharges ranging from 250 to 2500 cfs.

Habitat suitability for adult lifestages was greatest for spotted bass, followed in order by stoneroller, smallmouth bass, channel catfish, fantail darter, and striped shiner. WUA for adult spotted bass rose from 60,500 ft^2 at 250 cfs to 138,500 ft^2 at 2500 cfs. WUA for adult stoneroller rose from 2200 ft^2 at 250 cfs to 21,600 ft^2 at 750 cfs, declined to 2000 ft^2 at 1500 cfs and to 1400 ft^2 at 2500 cfs. For adult smallmouth bass, WUA rose from less than 100 ft^2 at 250 cfs to 4000 ft^2 at 1500 cfs before declining to 1500 ft^2 at 2500 cfs. WUA for adult channel catfish rose from zero at 250 cfs to 2100 ft^2 at 2500 cfs. From 250 to 1000 cfs, WUA for adult fantail darter fluctuated between 1800 and 2500 ft^2 after which it declined to about 500 ft^2 at 2500 cfs. WUA for adult striped shiner was extremely low, never reaching more than 10 ft^2 at any flow.

Habitat availability for juvenile lifestages was greatest for spotted bass, followed in order by smallmouth bass, channel catfish, fantail darter, striped shiner, and stoneroller. WUA for juvenile spotted bass increased from 72,000 ft^2 at 250 cfs to 125,500 ft^2 at 2500 cfs. For juvenile smallmouth bass, WUA increased from 11,000 ft^2 at 250 cfs to 17,000 ft^2 at 1000 cfs; it then declined to 7300 ft^2 at 1500 cfs and rose again to 18,000 ft^2 at 2500 cfs. WUA for juvenile channel catfish rose from 50 ft^2 at 250 cfs to 2200 ft^2 at 2500 cfs. WUA for juvenile fantail darter rose from zero at 250 cfs to 1200 ft^2 at 750 cfs before declining to near zero at 2500 cfs. For juvenile striped shiner, WUA rose from about 300 ft^2 at 250 cfs to 1000 ft^2 at 750 cfs; it then declined to 600 ft^2 at 2000 cfs before rising to 800 ft^2 at 2500 cfs. WUA for juvenile stonerollers declined from 2900 ft^2 at 250 cfs to less than 100 ft^2 at 2500 cfs.

WUA for fry lifestages was greatest for spotted bass, intermediate for smallmouth bass, and least for channel catfish. WUA for spotted bass fry rose from 67,000 ft^2 at 250 cfs to 141,500 ft^2 at 2500 cfs. WUA for smallmouth bass fry declined from 29,000 ft^2 at 500 cfs to about 6000 ft^2 at 1500 to 2500 cfs, whereas for channel catfish fry, WUA increased from zero at 250 cfs to 15,000 ft^2 at 2500 cfs.

Availability of nesting habitat was limited in the Bass Lake study reach, being zero at all flows for spotted bass and stoneroller. WUA for channel catfish nests increased from zero at 250 cfs to about 900 ft^2 at 2500 cfs.

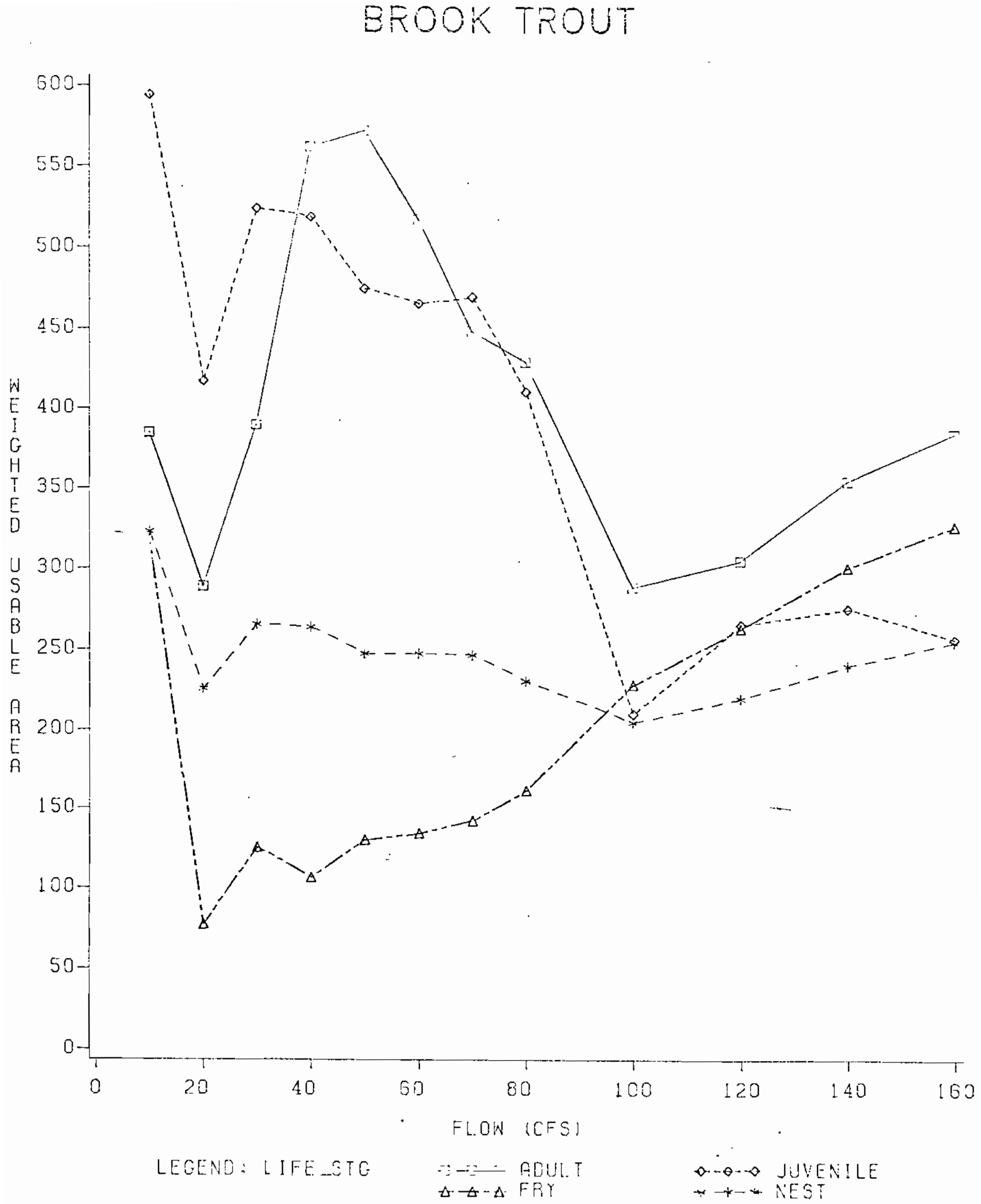


Figure 10. Habitat response curves for brook trout in the Greenbrier River (Island Camp study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 18; juveniles, Table 19; fry, Table 20; nests, Table 21.

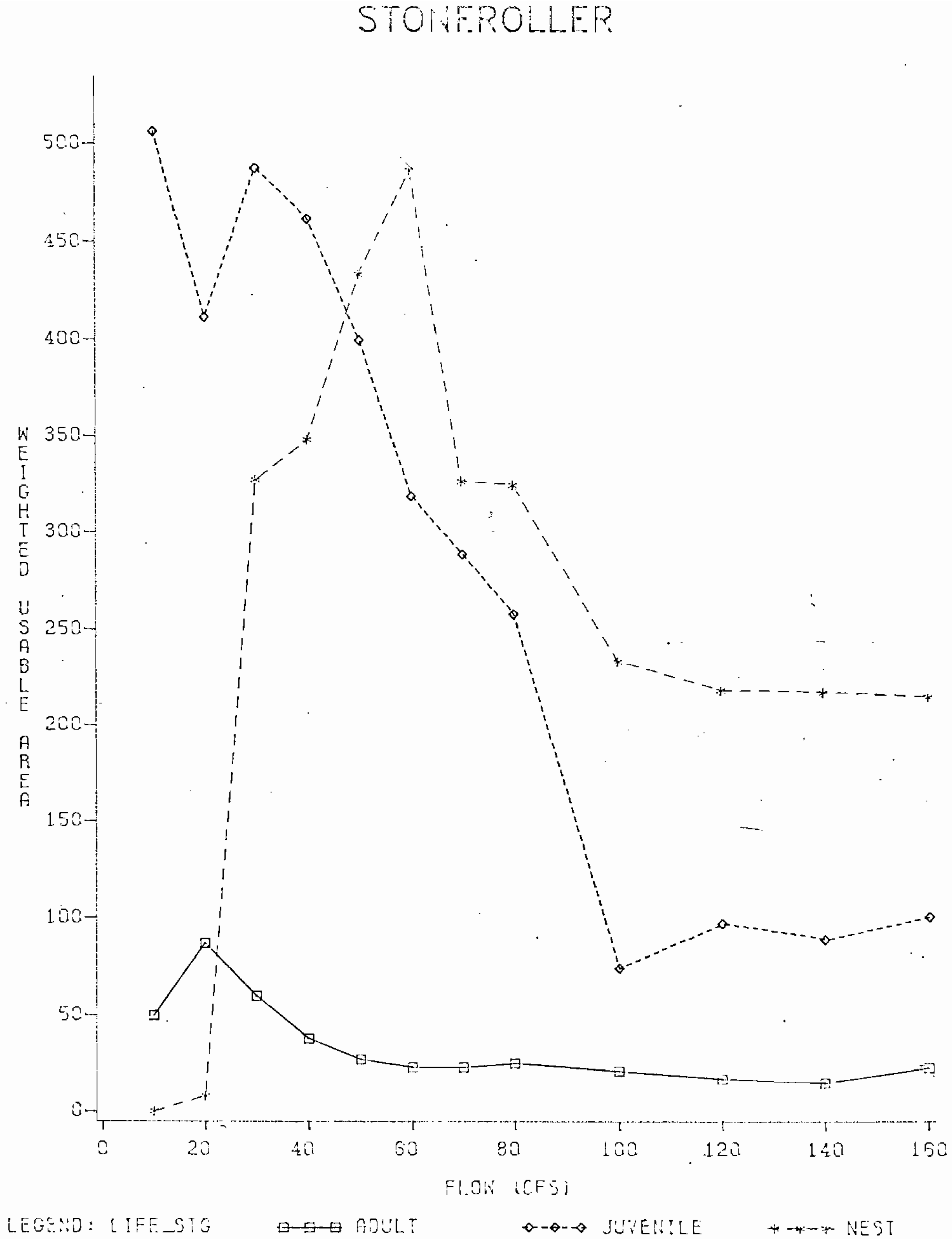


Figure 11. Habitat response curves for stoneroller in the Greenbrier River (Island Camp study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 22; juvenile, Table 25; nests, Tables 28 and 29.

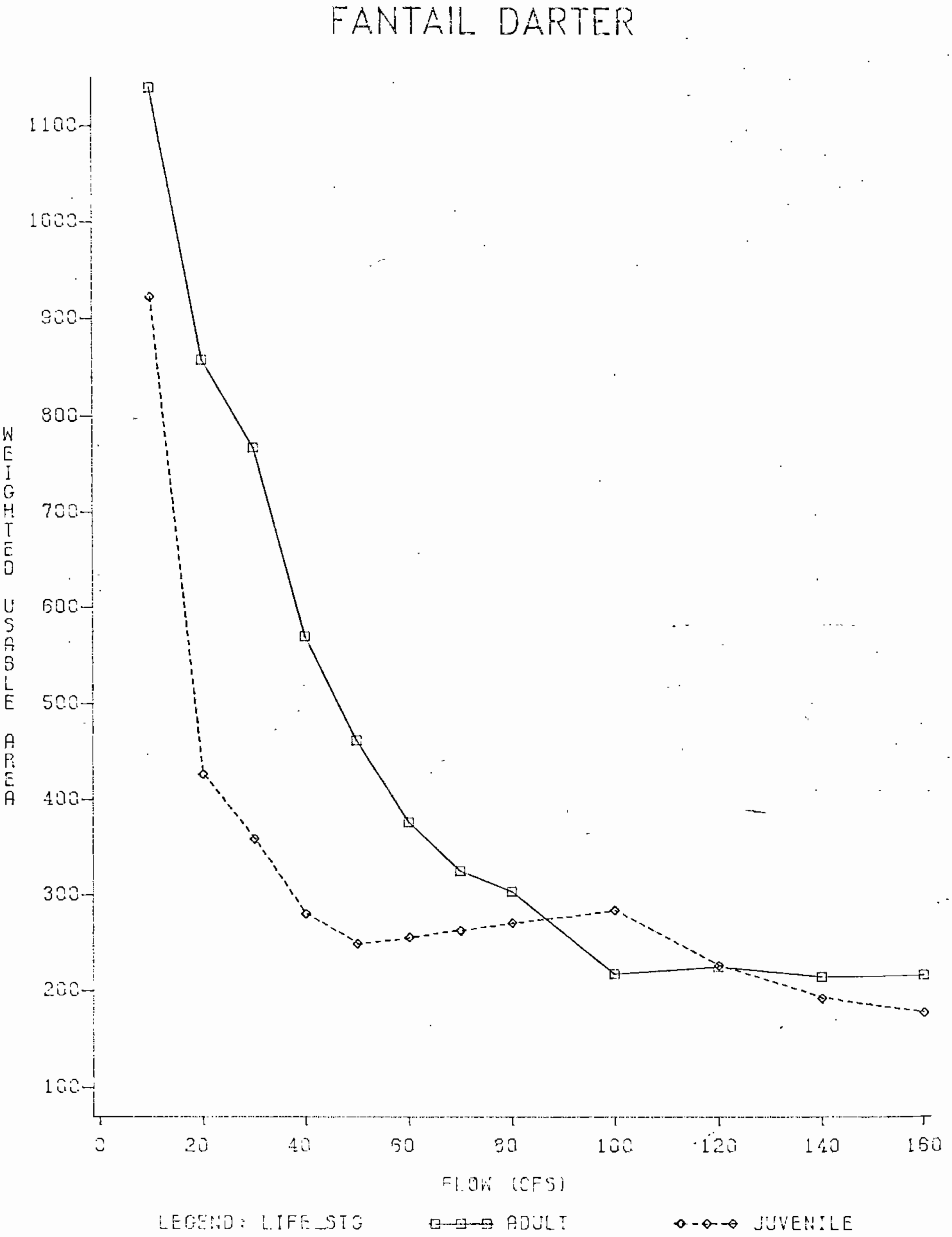


Figure 12. Habitat response curves for fantail darter in the Greenbrier River (Island Camp study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Tables 32 and 33; juvenile, Table 35.

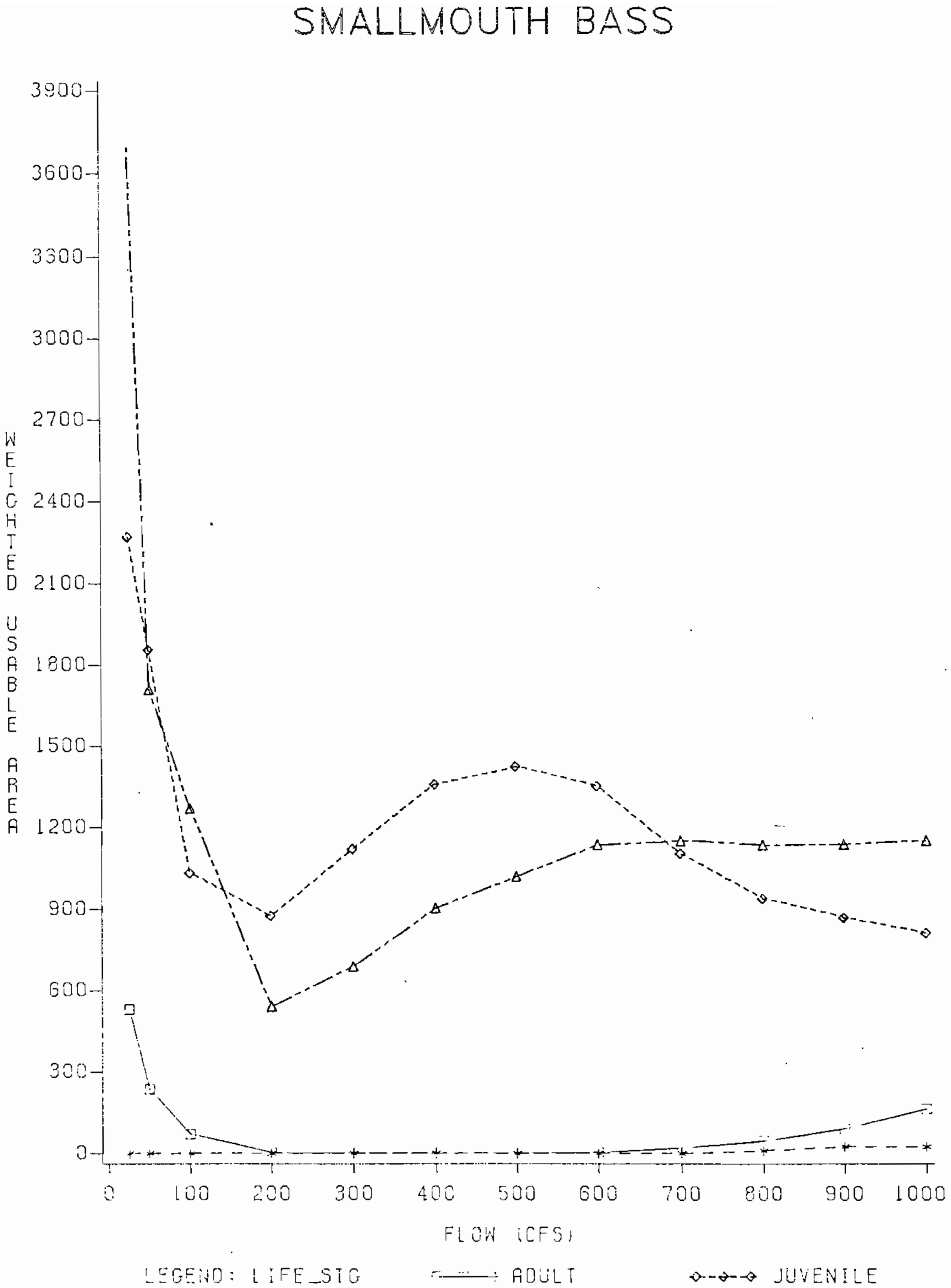


Figure 13. Habitat response curves for smallmouth bass in the Greenbrier River (Hosterman study reach) based on the IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 7; juvenile, Table 11; fry, Table 16; nests, Table 17.

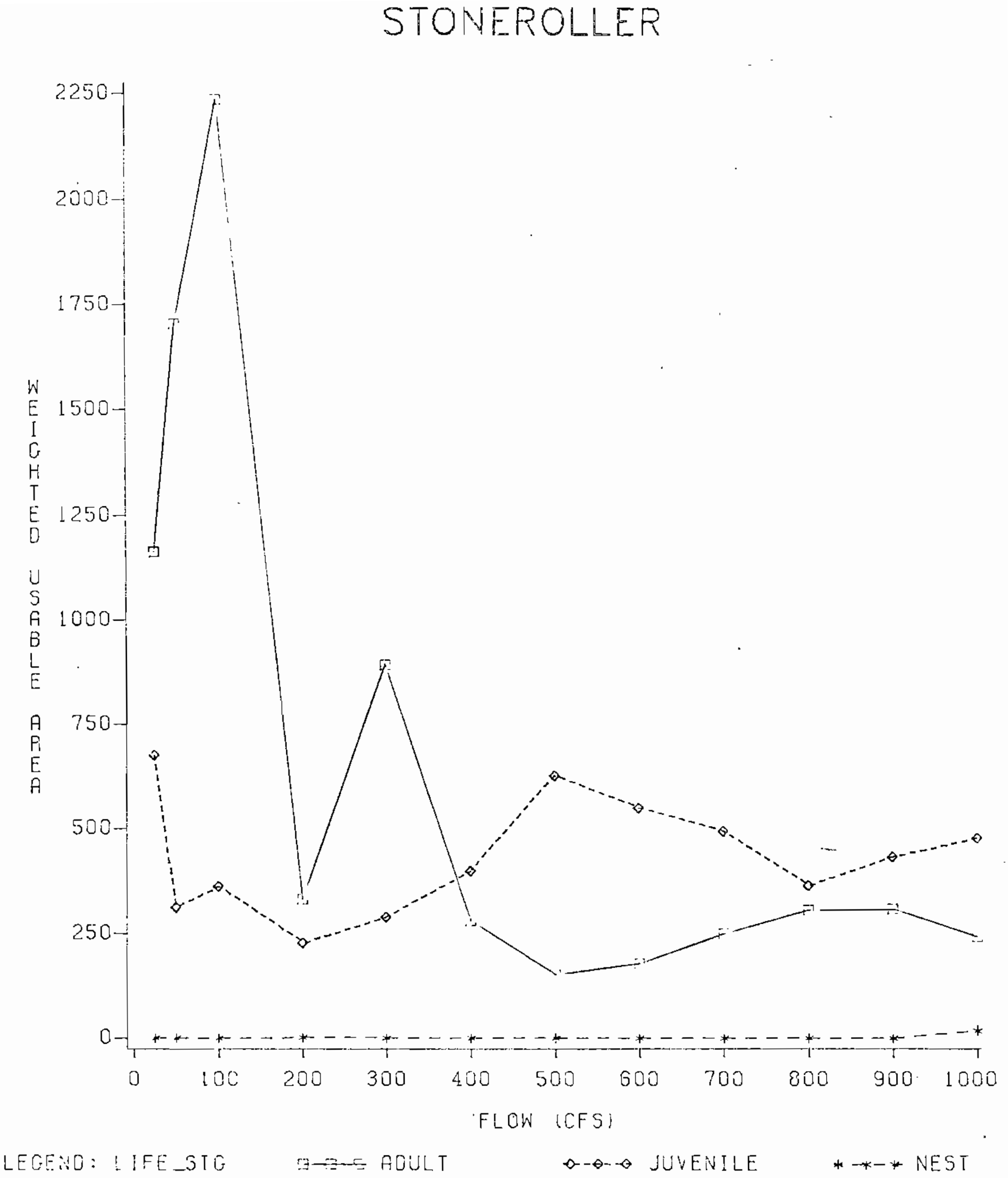


Figure 14. Habitat response curve for stoneroller in the Greenbrier River (Hosterman study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 22; juvenile, Table 25.

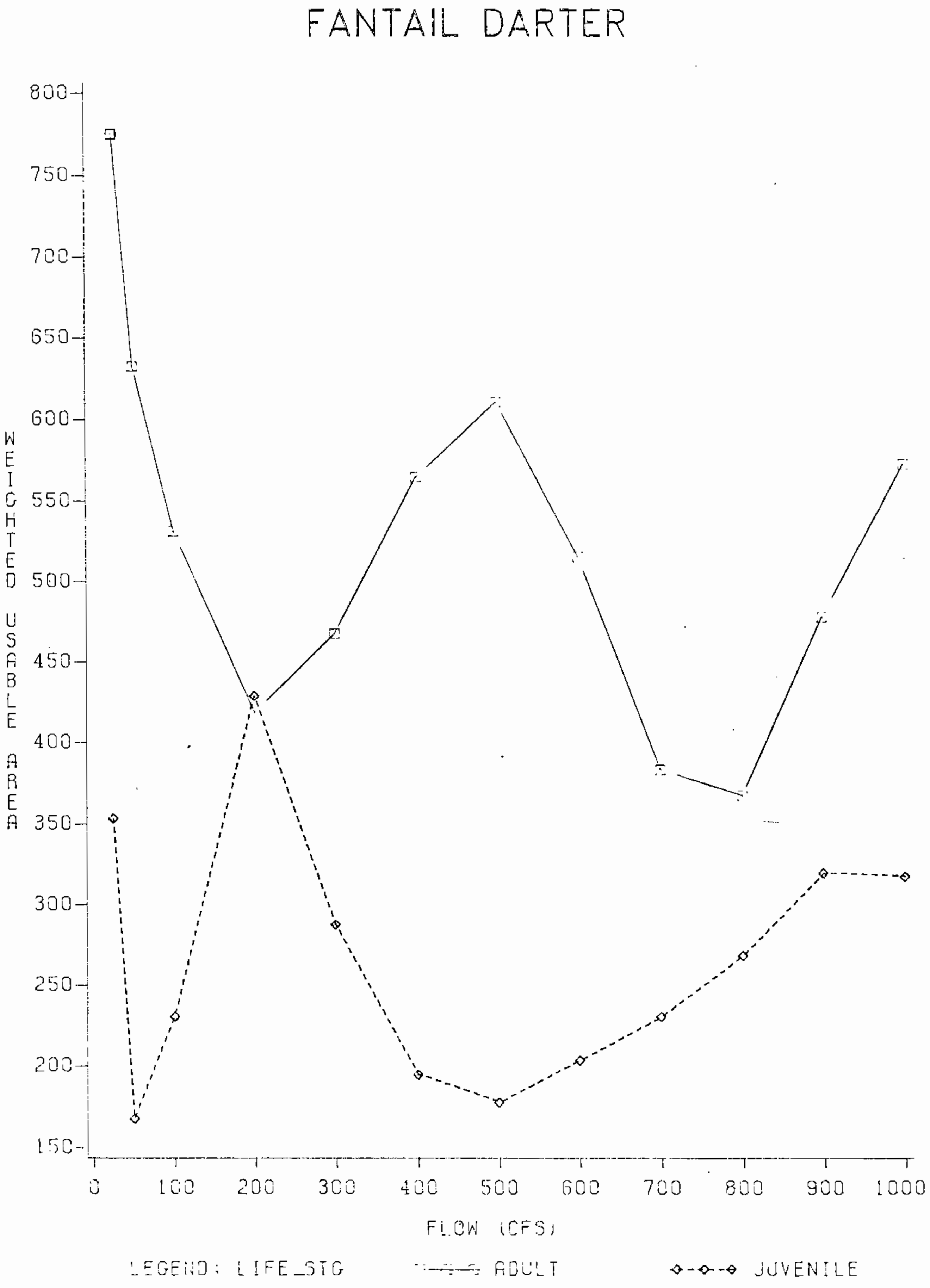


Figure 15. Habitat response curves for fantail darter in the Greenbrier River (Hosterman study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Tables 32 and 33; juvenile, Table 35.

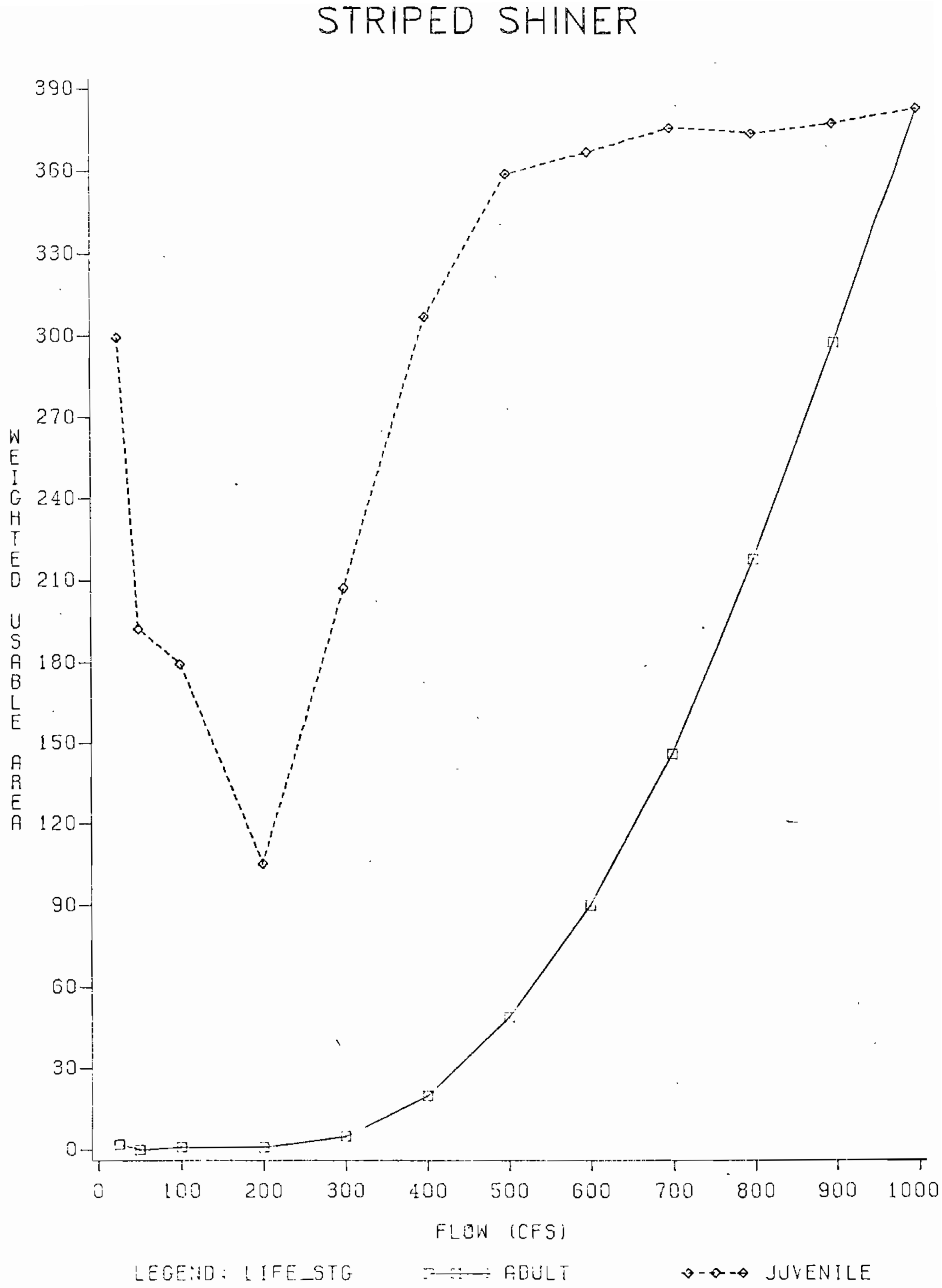


Figure 16. Habitat response curves for striped shiner in the Greenbrier River (Hosterman study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 37; juvenile, Table 39.

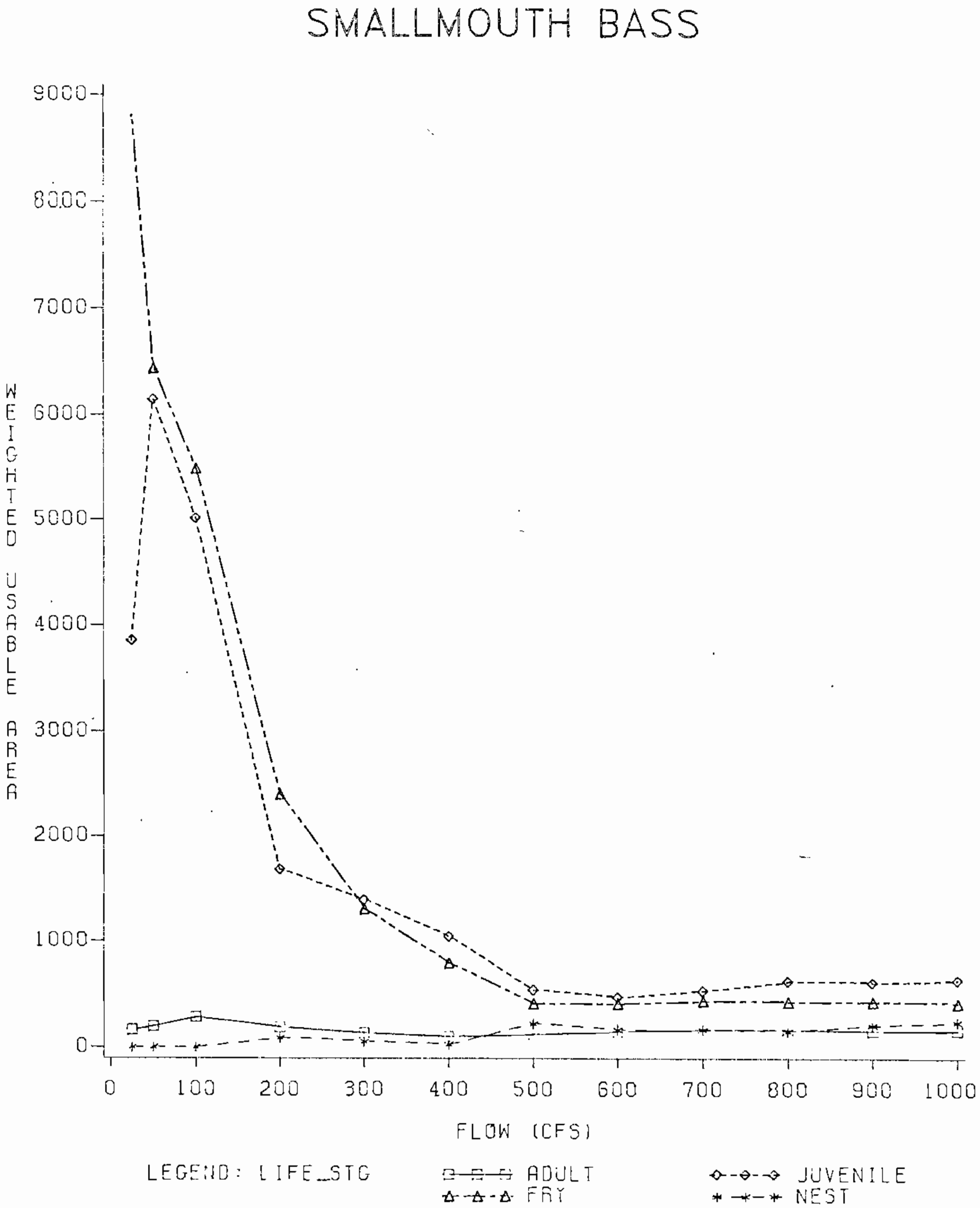


Figure 17. Habitat response curves for smallmouth bass in the Greenbrier River (Seneca State Forest study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 7 ; juvenile, Table 11; fry, Table 16; nests, Table 17.

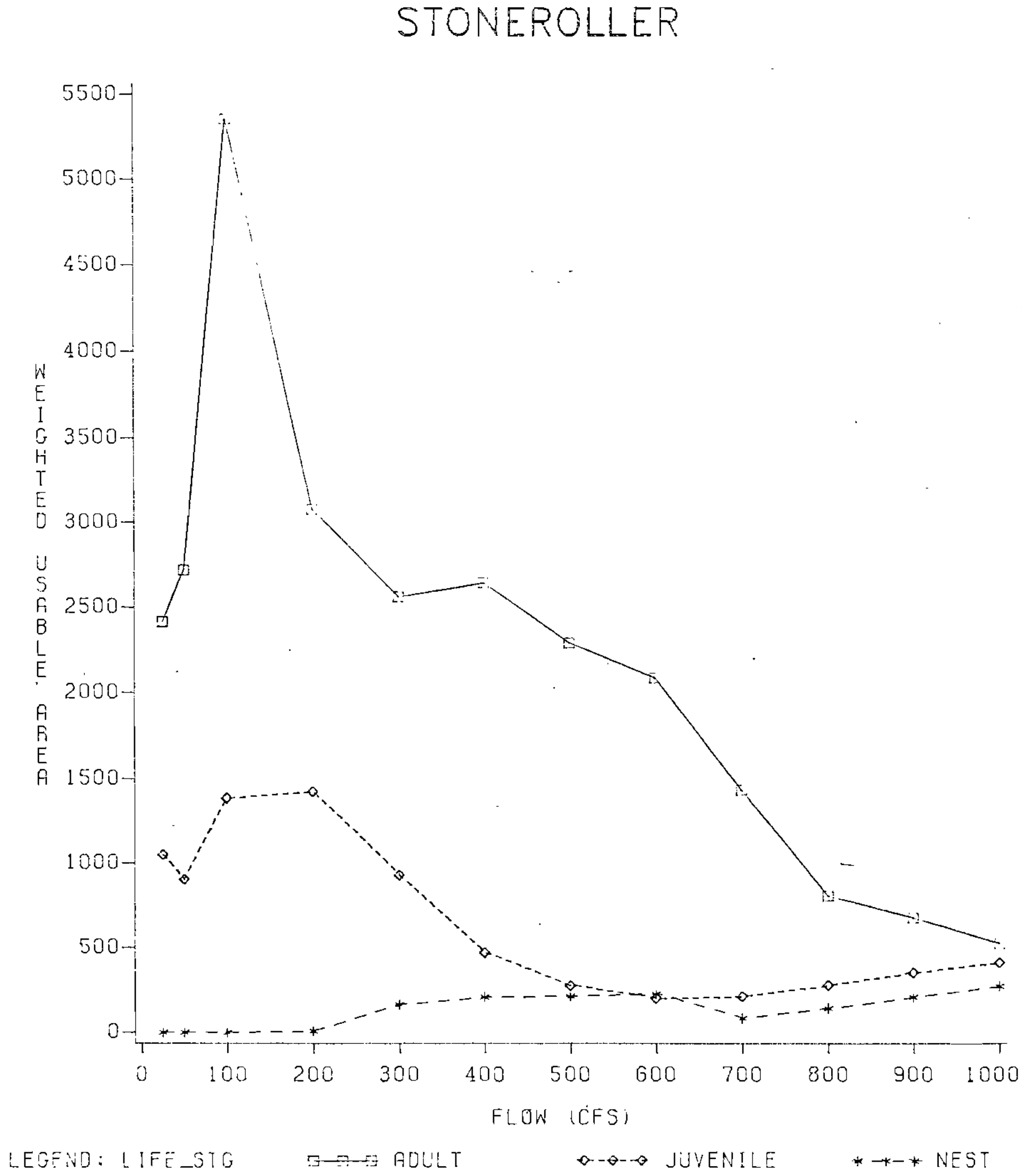


Figure 18. Habitat response curves for stoneroller in the Greenbrier River (Seneca State Forest study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 22; juvenile, Table 25; nests, Tables 28 and 29.

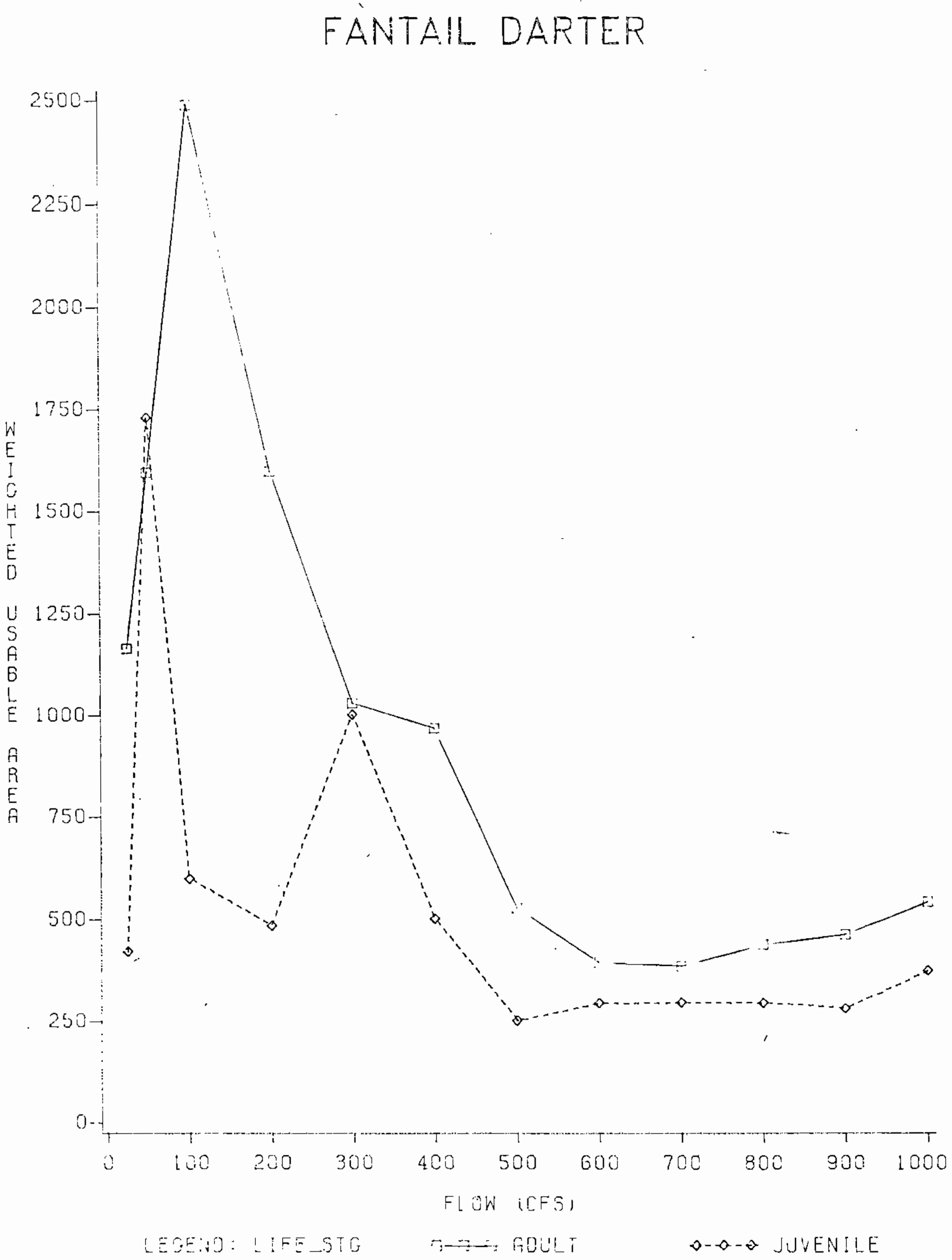
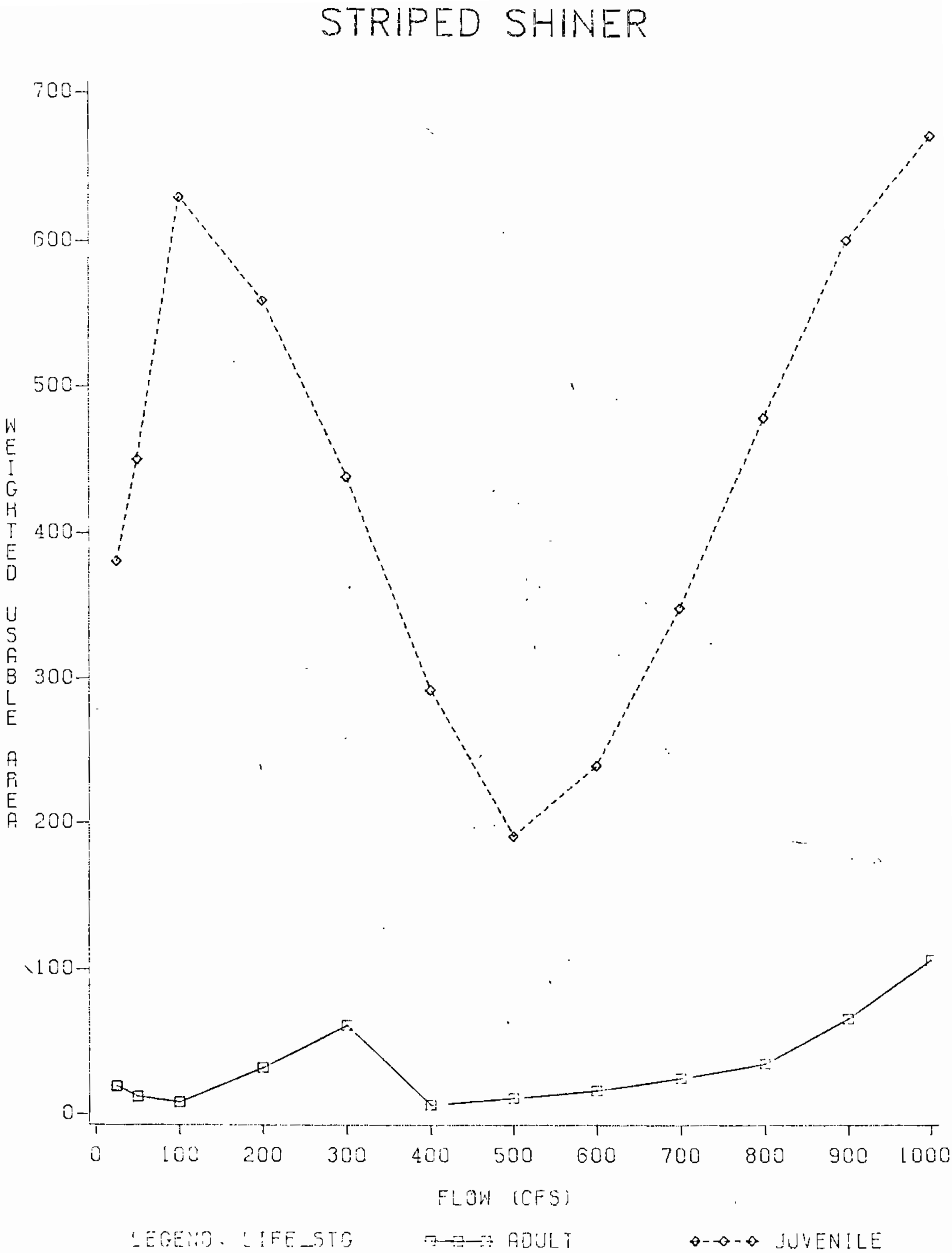


Figure 19. Habitat response curves for fantail darter in the Greenbrier River (Seneca State Forest study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Tables 32 and 33; juvenile, Table 35.



Figures 20. Habitat response curves for striped shiner in the Greenbrier River (Seneca State Forest study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 37; juvenile Table 39.

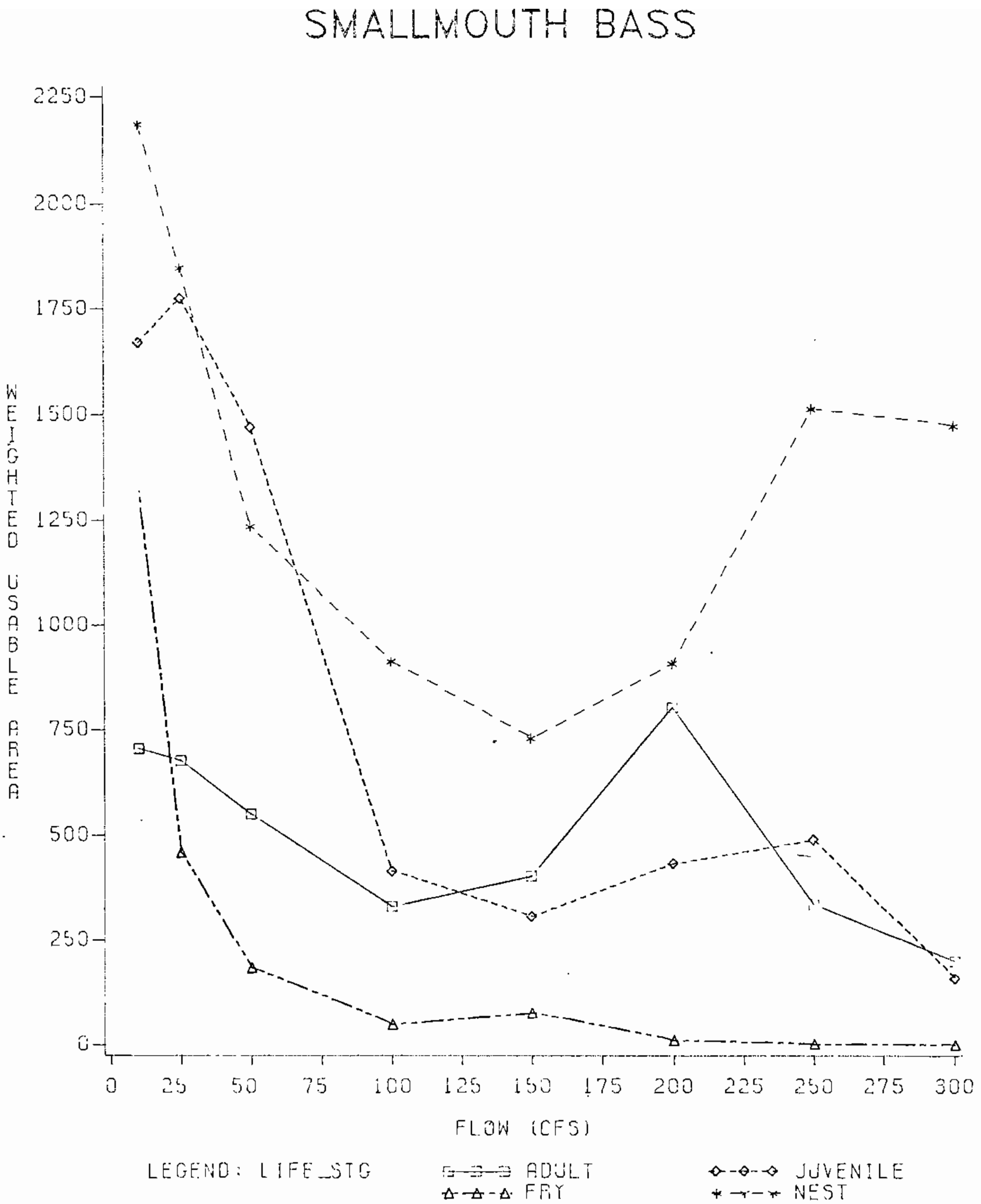


Figure 21. Habitat response curves for smallmouth bass in the Meadow River (Rainelle study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 7; juvenile Tables 9 and 13; fry, Table 15; nests, Table 17.

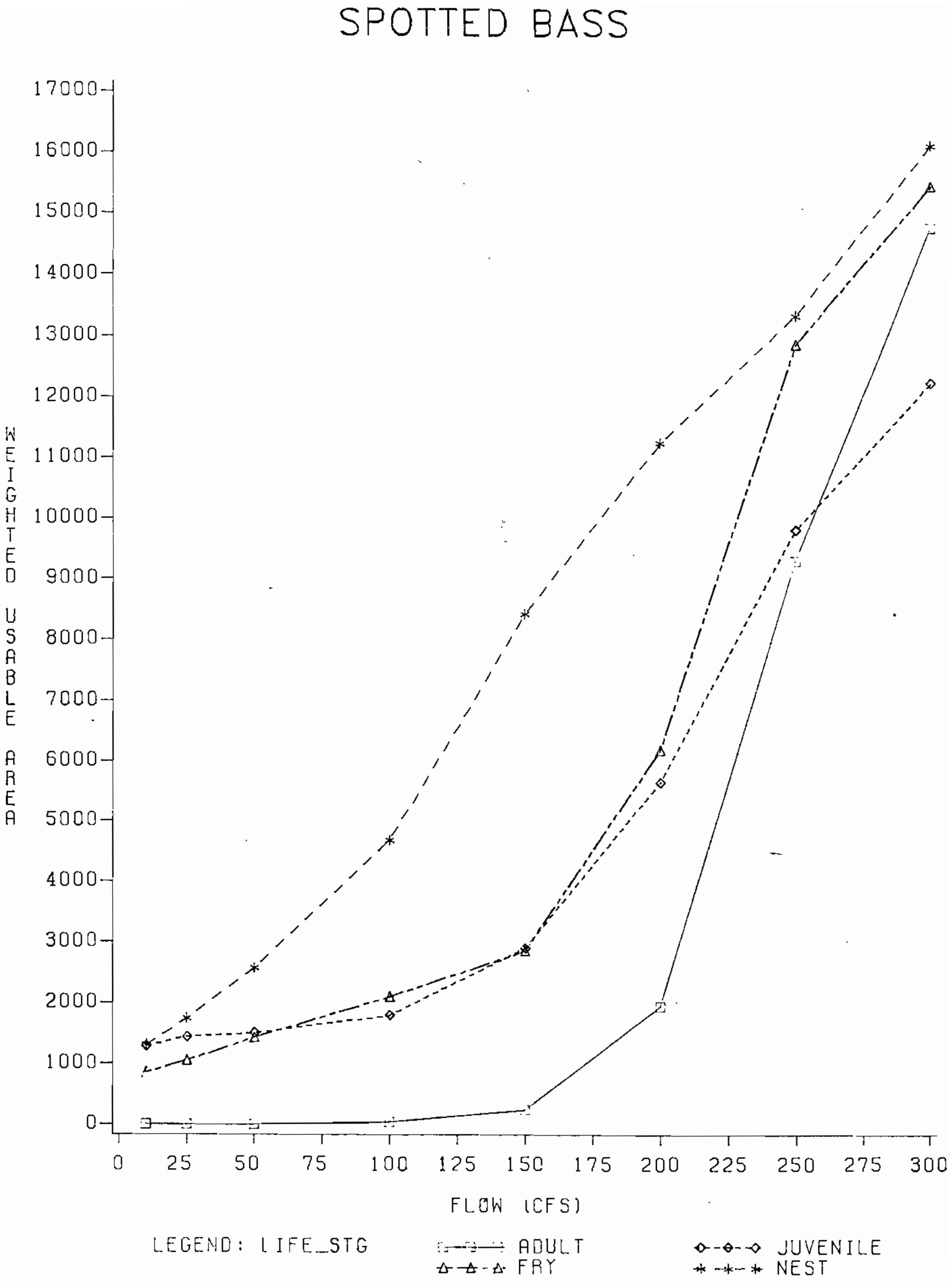


Figure 22. Habitat response curves for spotted bass in the Meadow River (Rainelle study reach) based on IFG-4 hydraulic simulation. IFG suitability curves were used.

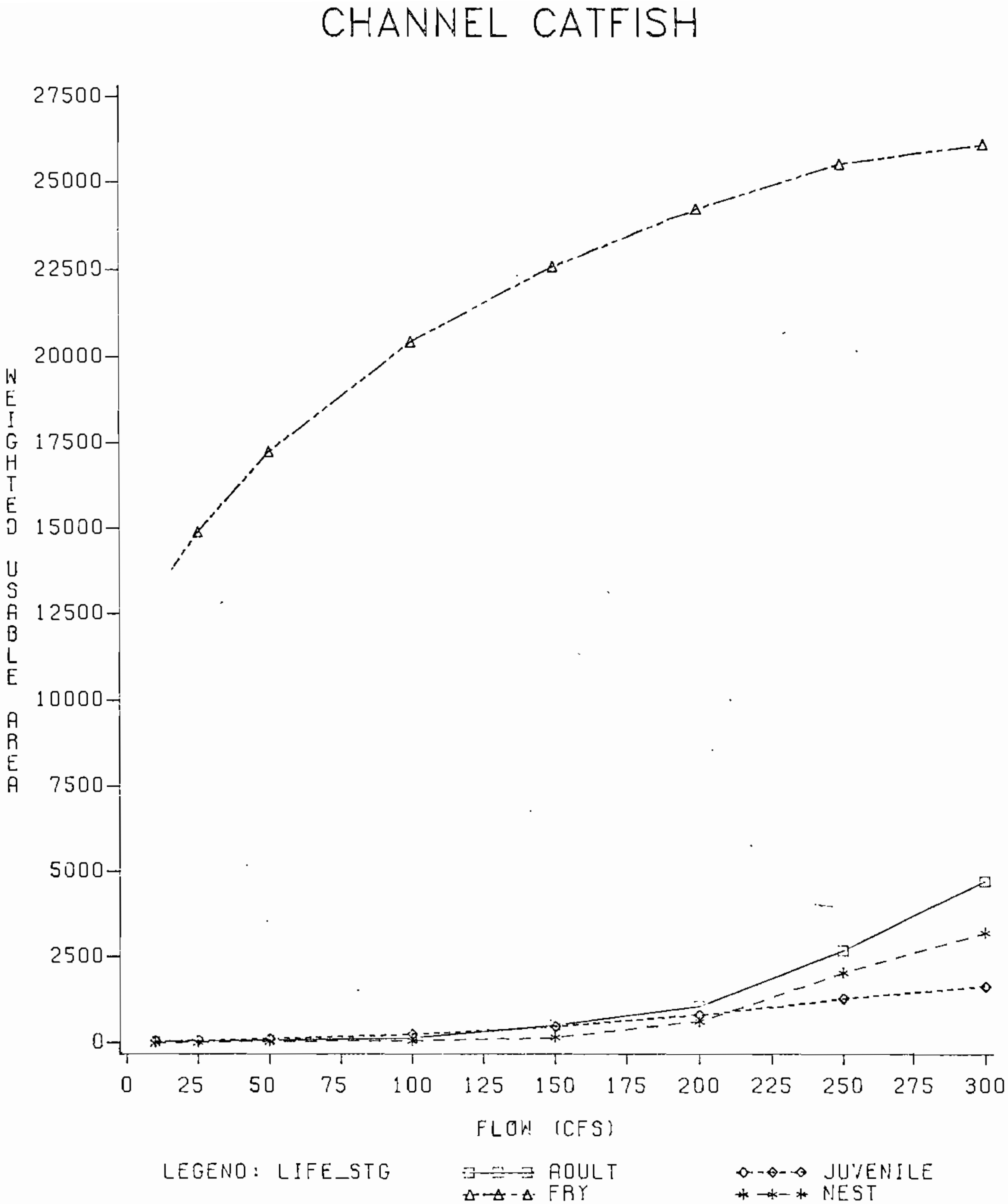


Figure 23. Habitat response curves for channel catfish in the Meadow River (Rainelle study reach) based on IFG-4 hydraulic simulation. IFG suitability curves were used.

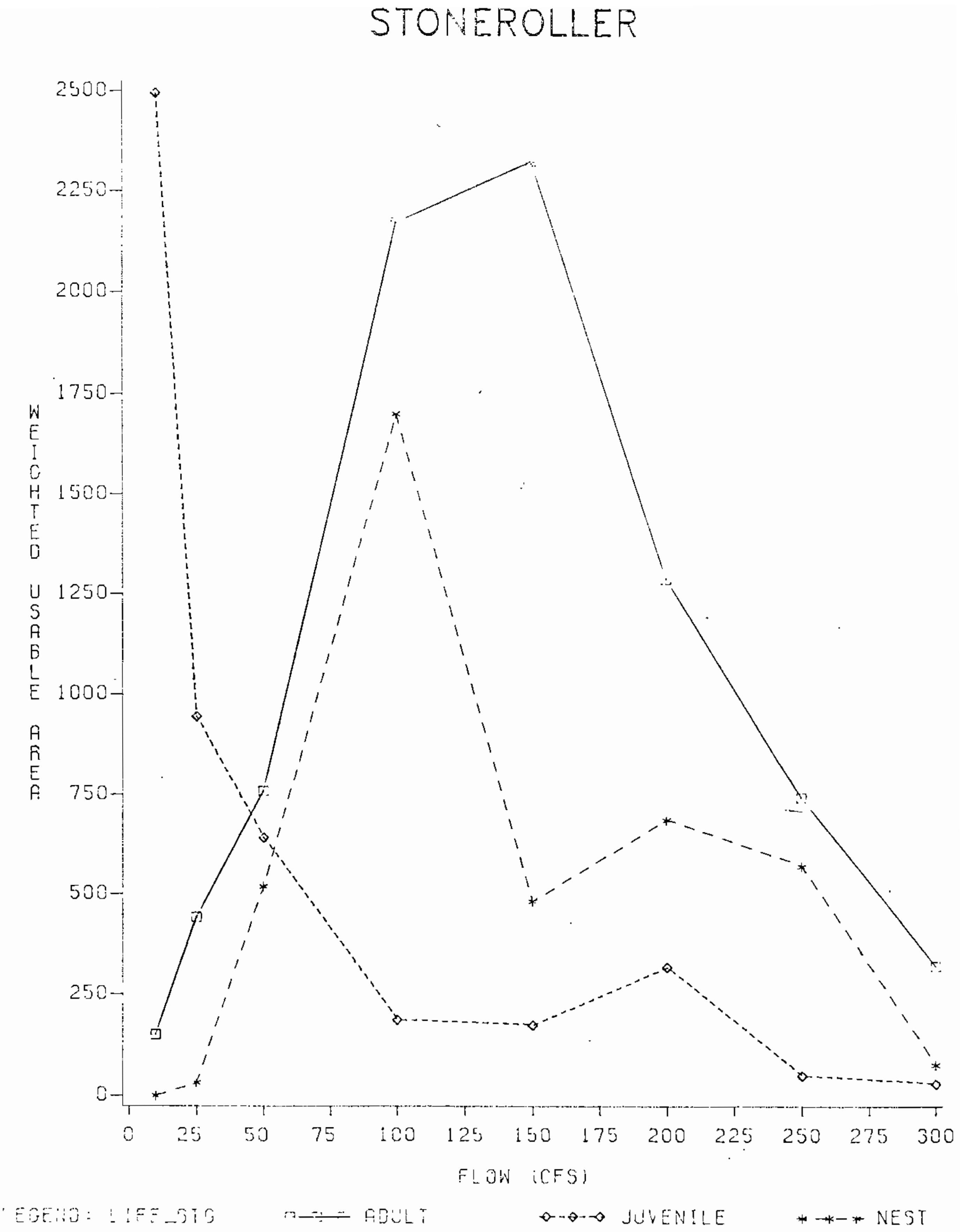


Figure 24. Habitat response curves for stoneroller in the Meadow River (Rainelle study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 22; juvenile, Table 25; nests, Tables 28 and 29.

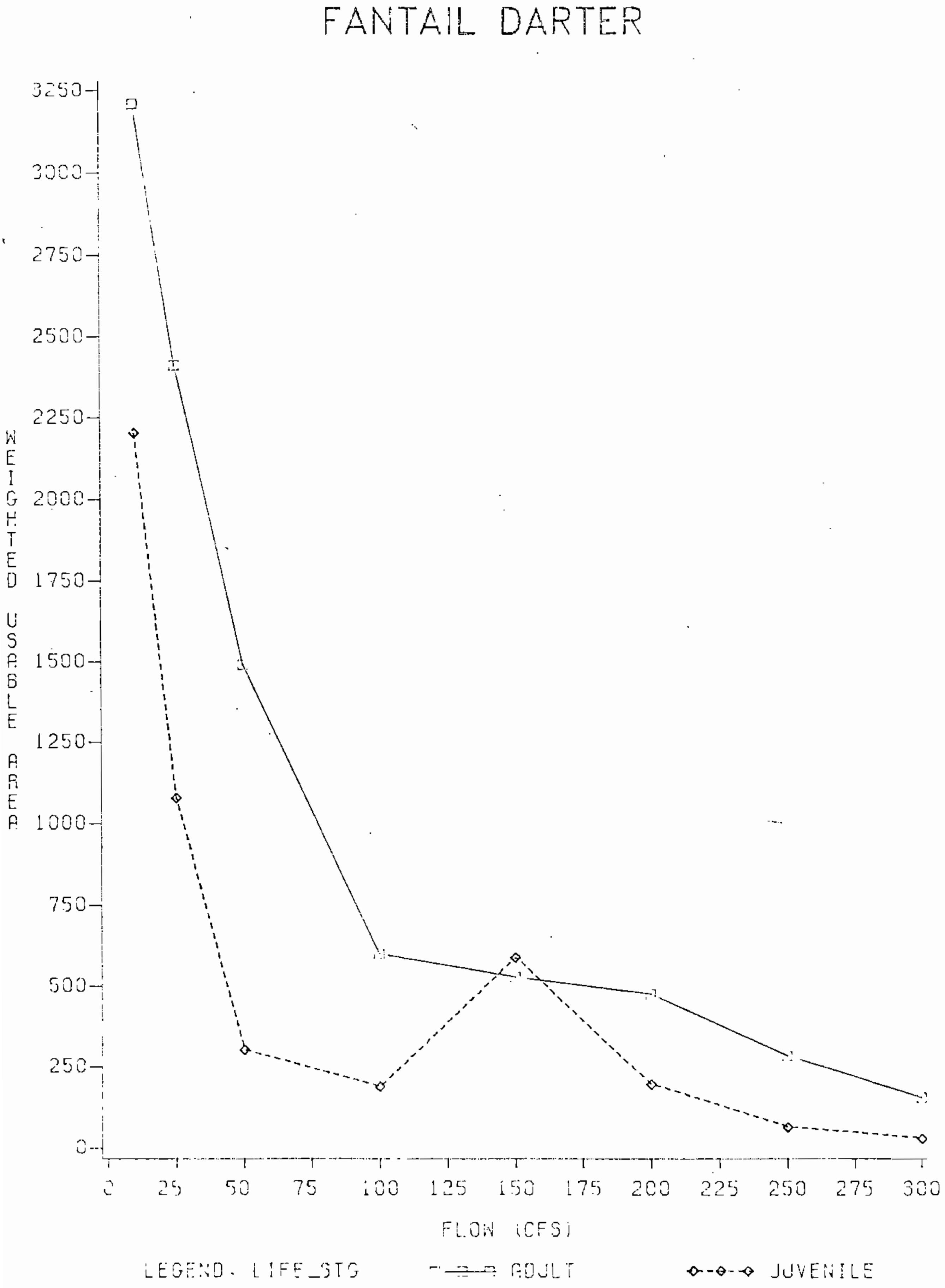


Figure 25. Habitat response curves for fantail darter in the Meadow River (Rainelle study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Tables 32 and 33; juvenile, Table 35.

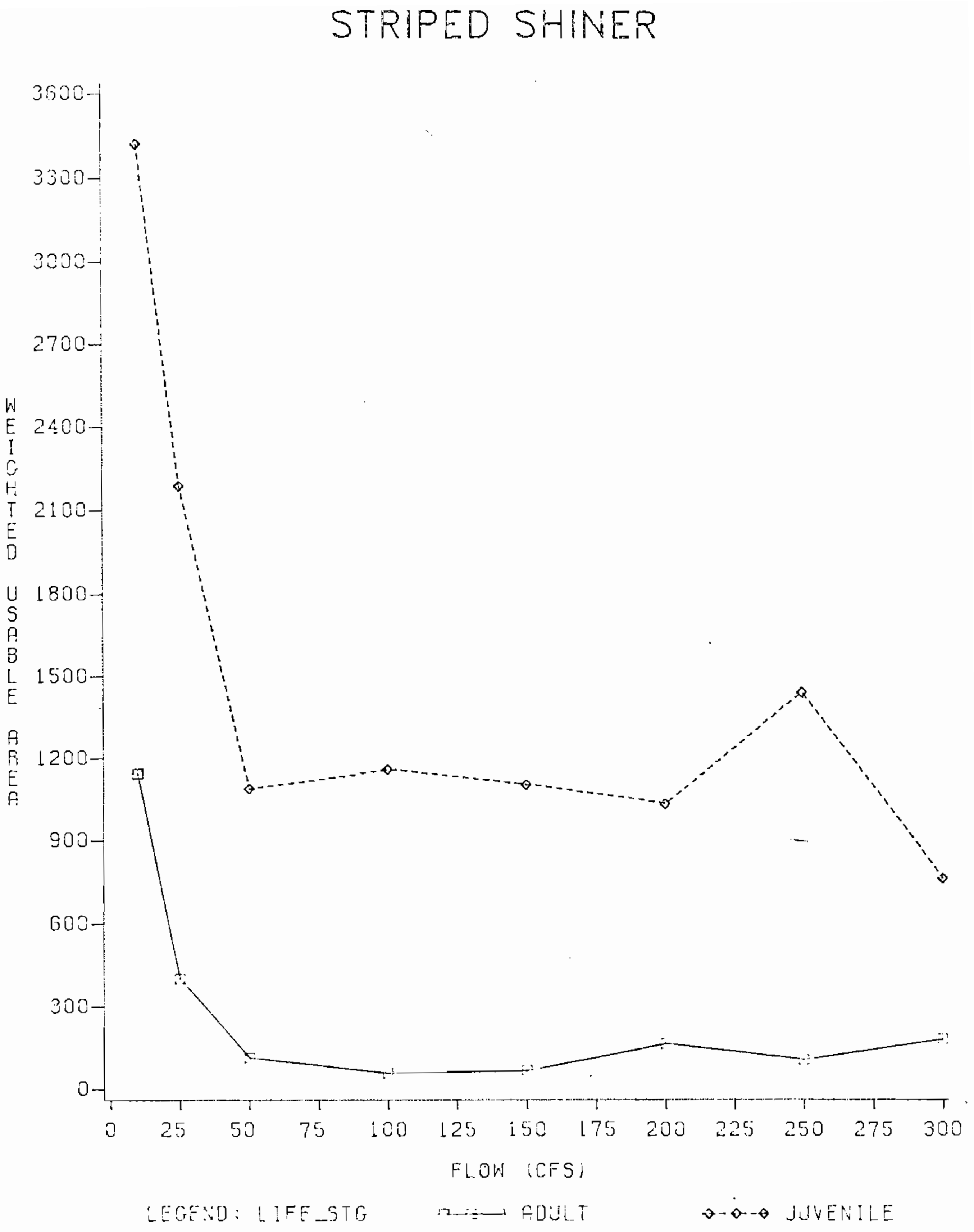


Figure 26. Habitat response curves for striped shiner in the Meadow River (Rainelle study reach) based on IFG-4 hydraulic simulation. Suitability curves used were : adult, Table 37 ; juvenile, Table 39.

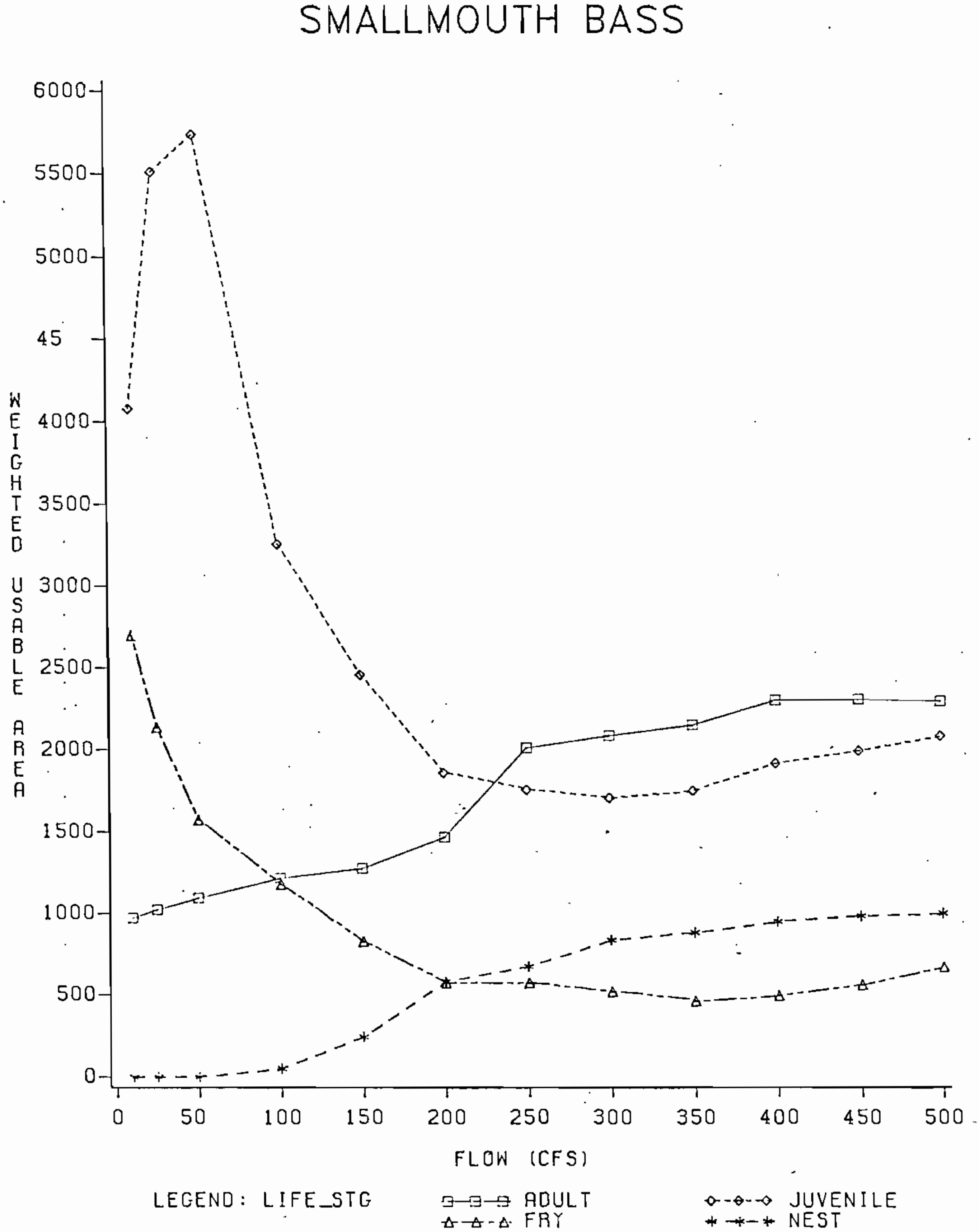


Figure 27. Habitat response curves for smallmouth bass in the Meadow River (Rt. 19 bridge study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 7; juvenile, Tables 9 and 13; fry, Table 15; nests, Table 17.

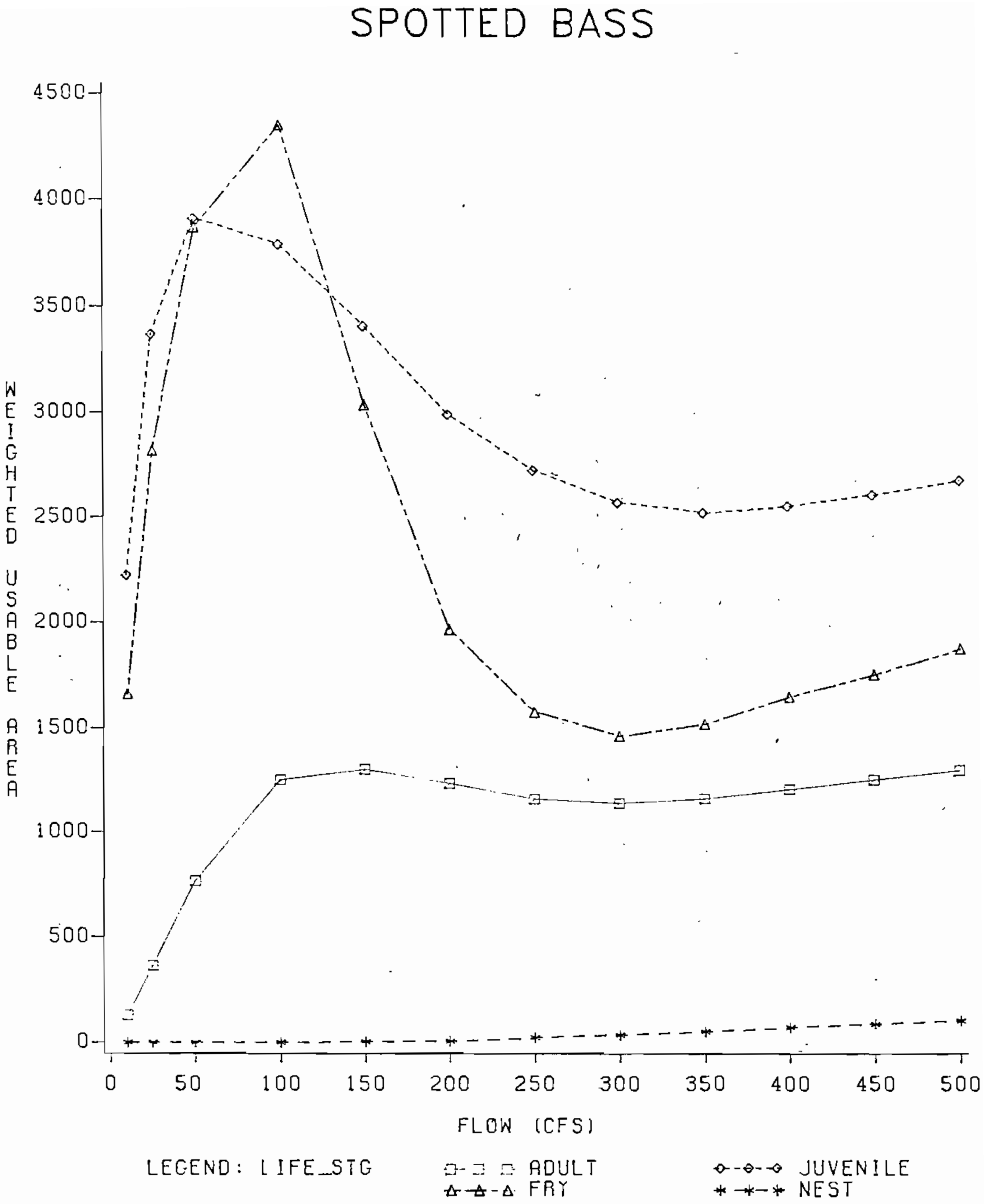


Figure 28. Habitat response curves for spotted bass in the Meadow River (Rt. 19 bridge study reach) based on IFG-4 hydraulic simulation. IFG suitability curves were used.

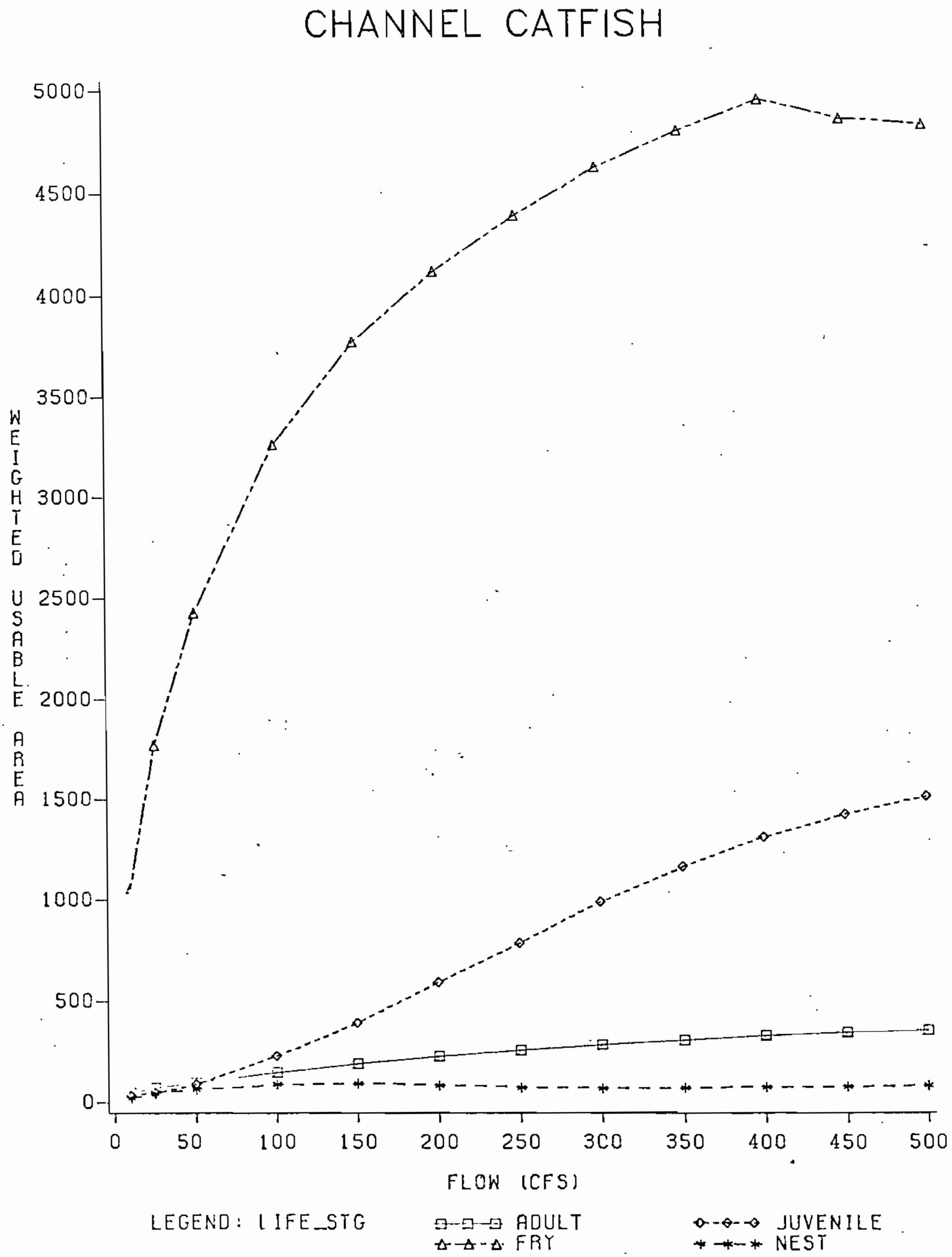


Figure 29. Habitat response curves for channel catfish in the Meadow River (Rt. 19 bridge study reach) based on IFG-4 hydraulic simulation. IFG suitability curves were used.

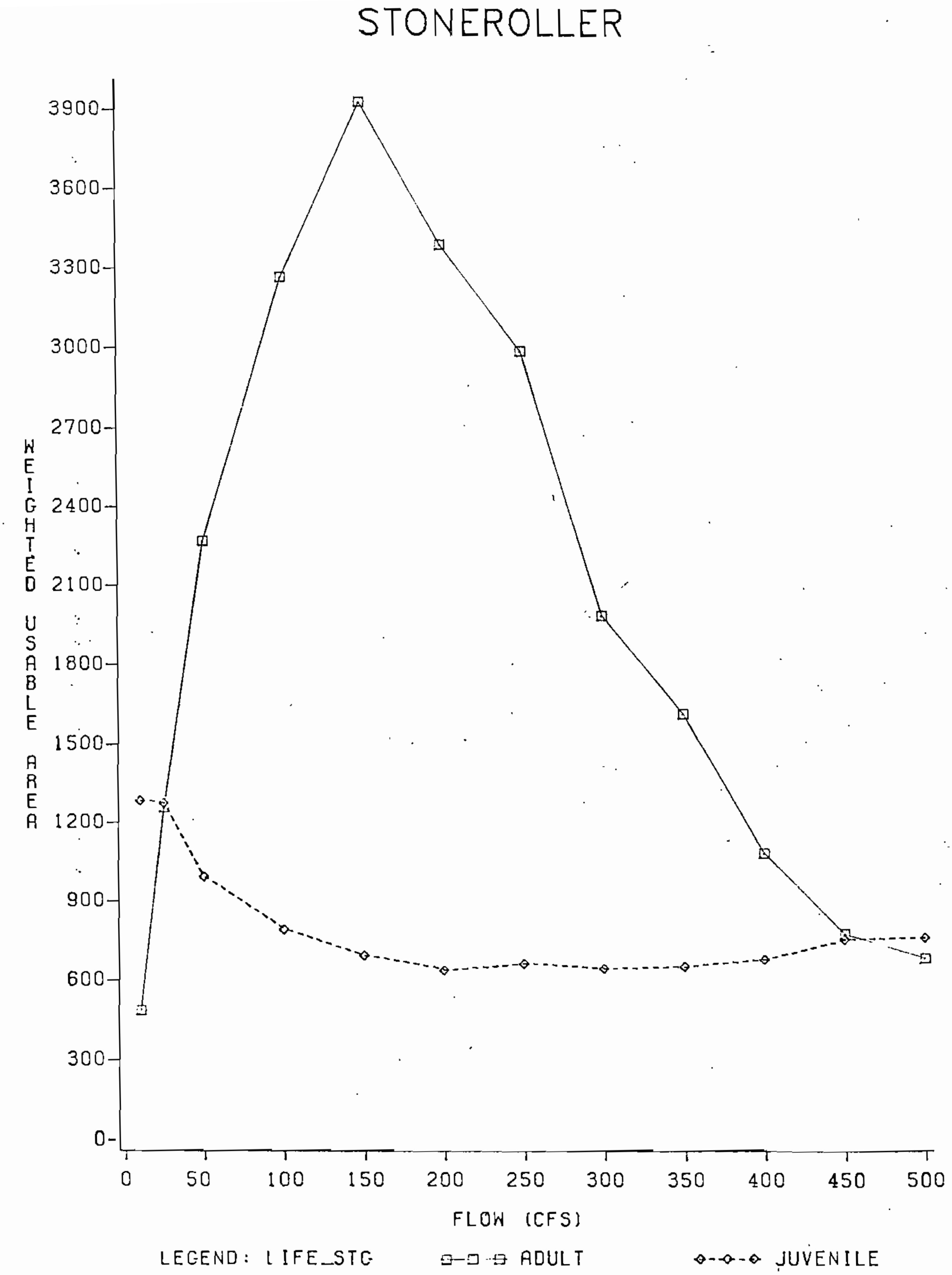


Figure 30. Habitat response curves for stoneroller in the Meadow River (Rt. 19 bridge study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 22; juvenile, Table 25.

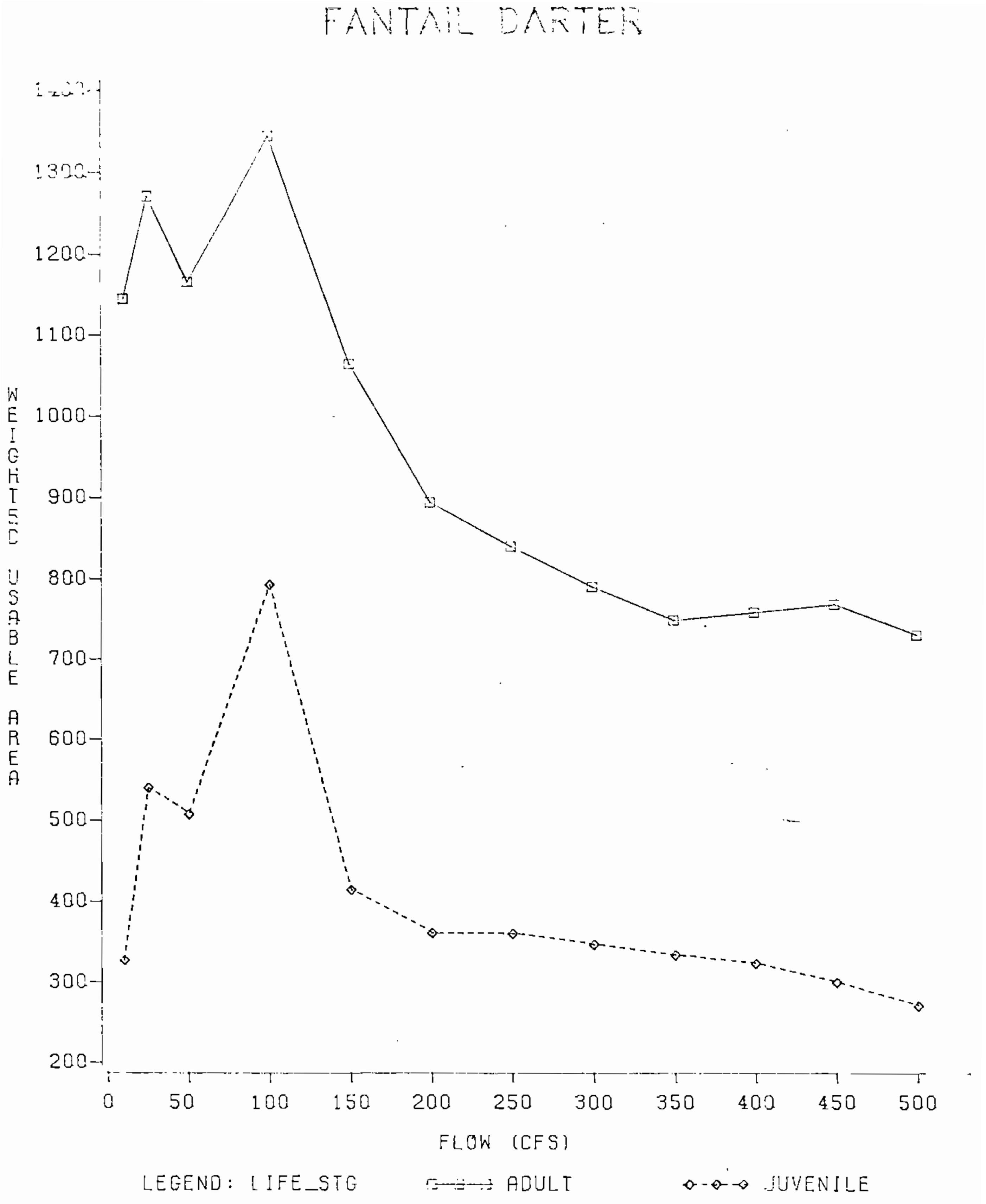


Figure 31. Habitat response curves for fantail darter in the Meadow River (Rt. 19 bridge study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult; Tables 32 and 33; juvenile, Table 35.

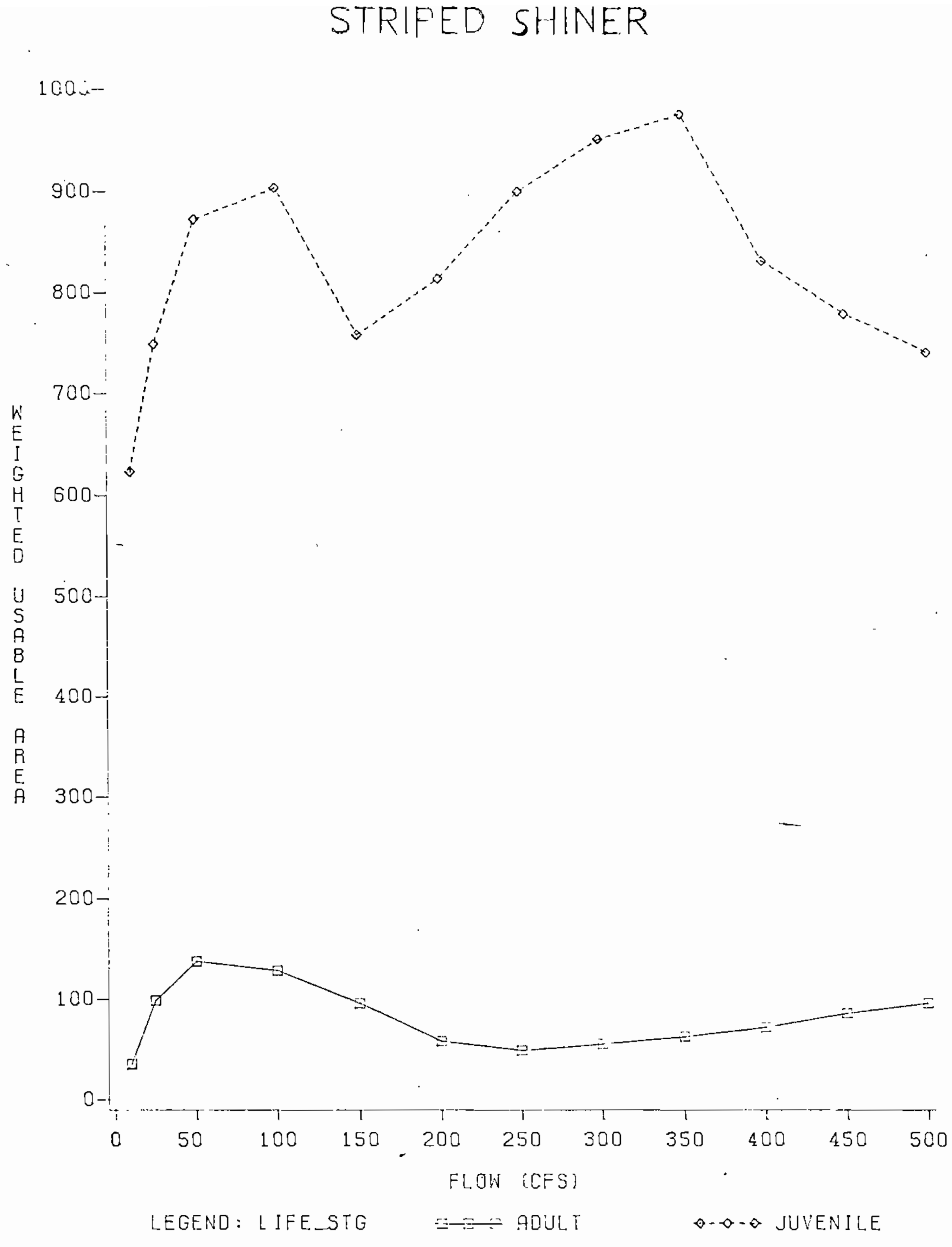


Figure 32. Habitat response curves for striped shiner in the Meadow River (Rt. 19 bridge study reach) based on IFG-4 hydraulic simulation. Suitability curves used were: adult, Table 37; juvenile, Table 39.

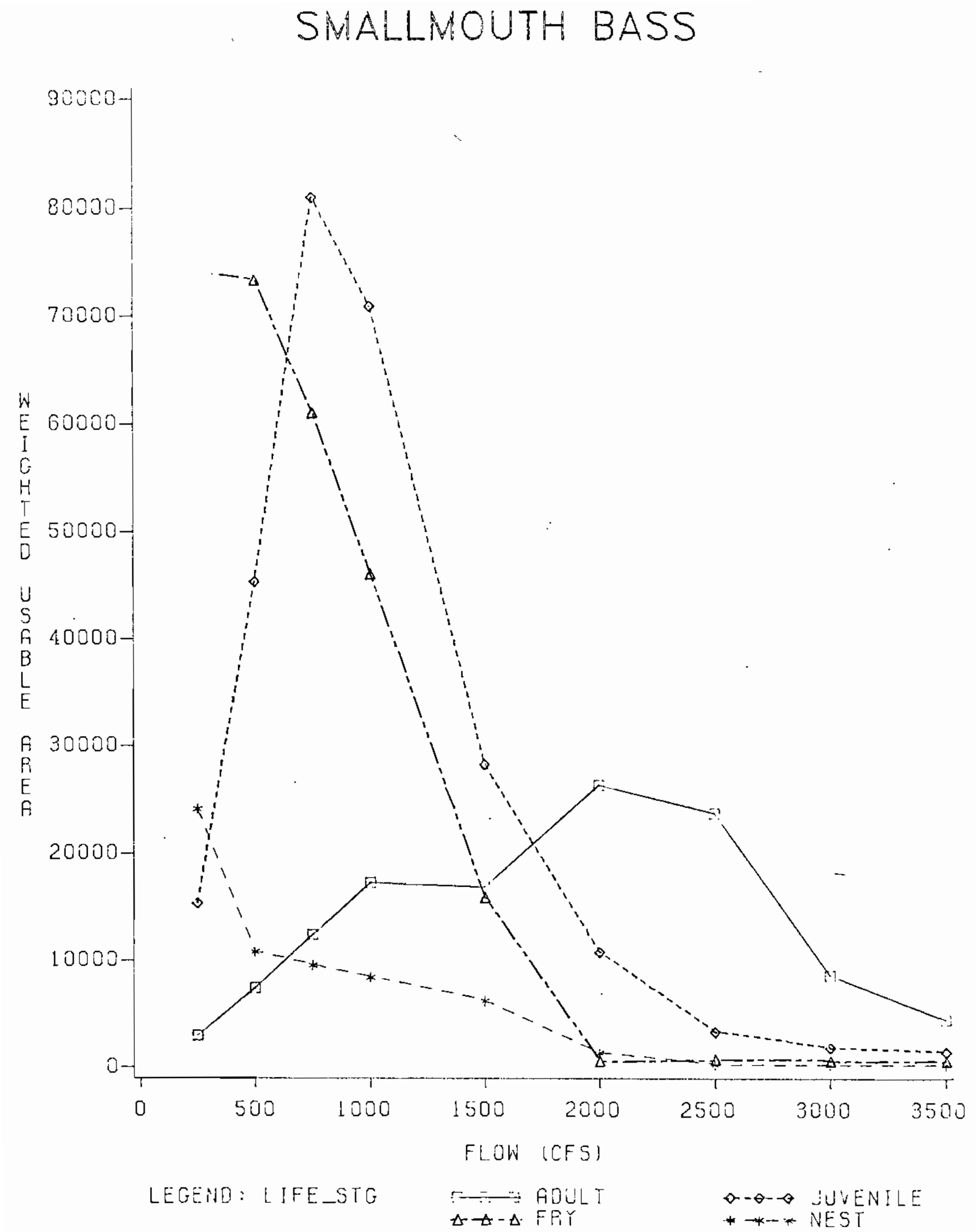


Figure 33. Habitat response curves for smallmouth bass in the New River (Bluestone tailwaters study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Table 7; juvenile, Table 10; fry, Table 16 nests, Table 17.

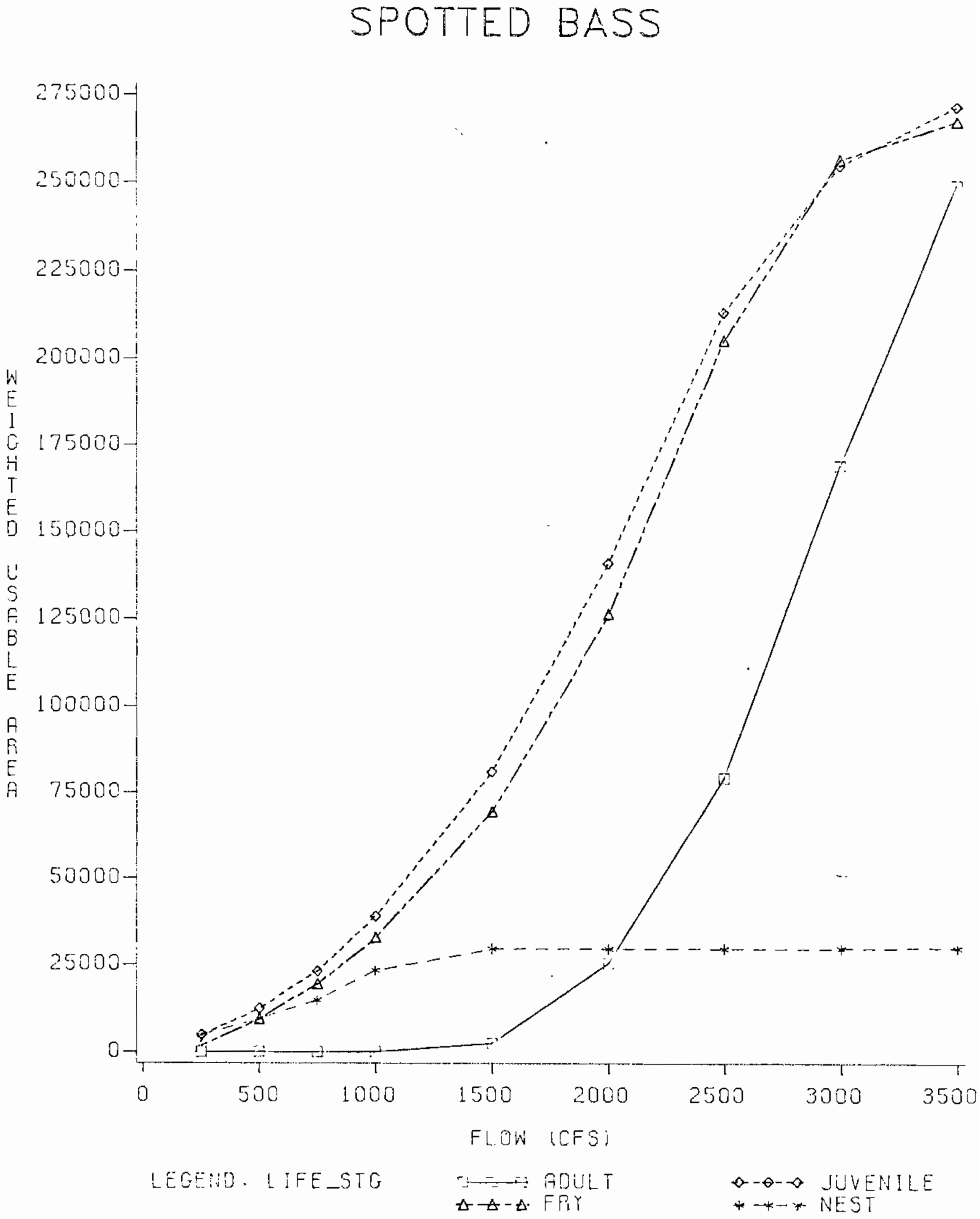


Figure 34. Habitat response curves for spotted bass in the New River (Bluestone tailwaters study reach) based on IFG-2 hydraulic simulation. IFG suitability curves were used.

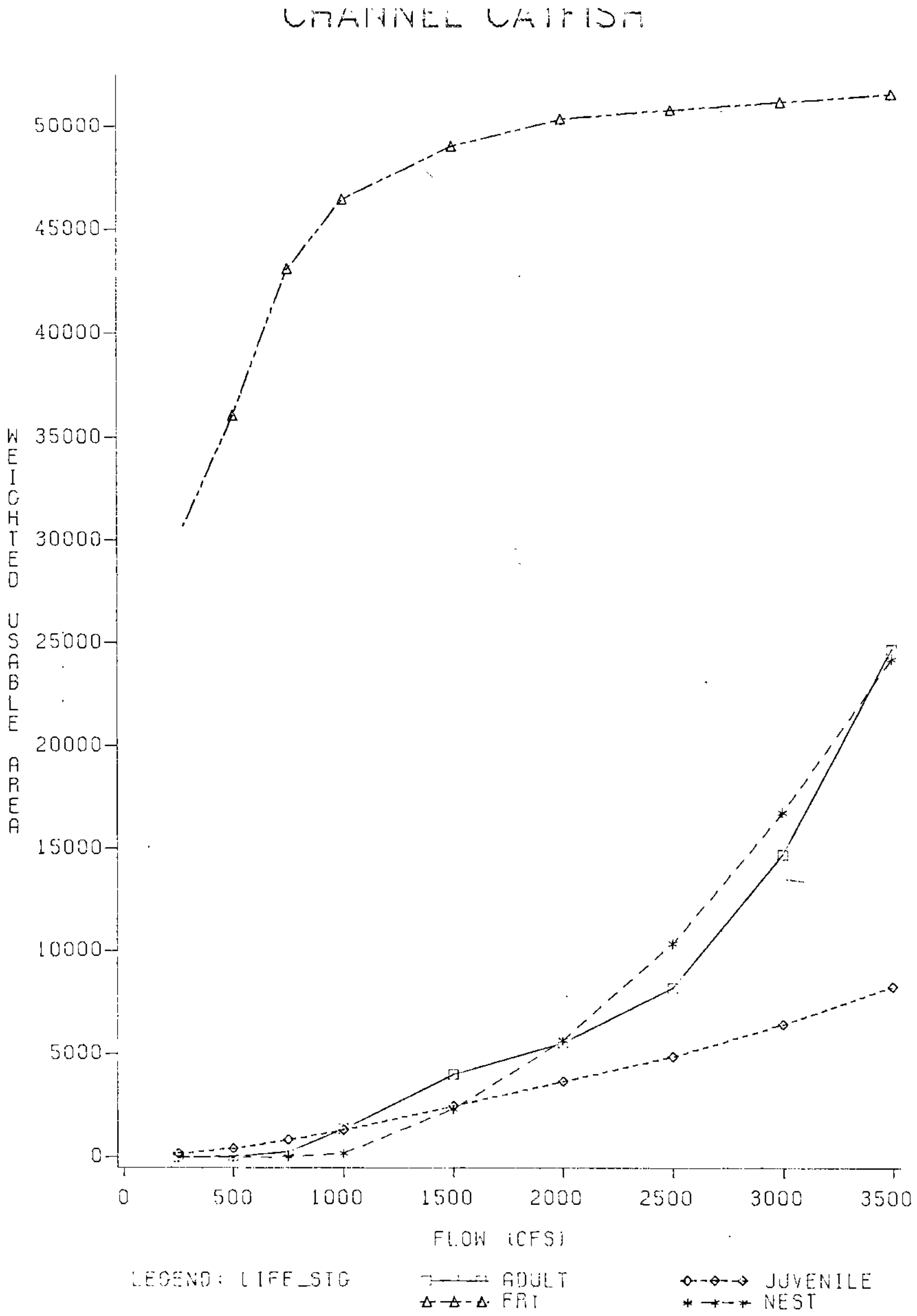


Figure 35. Habitat response curves for channel catfish in the New River (Bluestone tailwaters study reach) based on IFG-2 hydraulic simulation. IFG suitability curves were used.

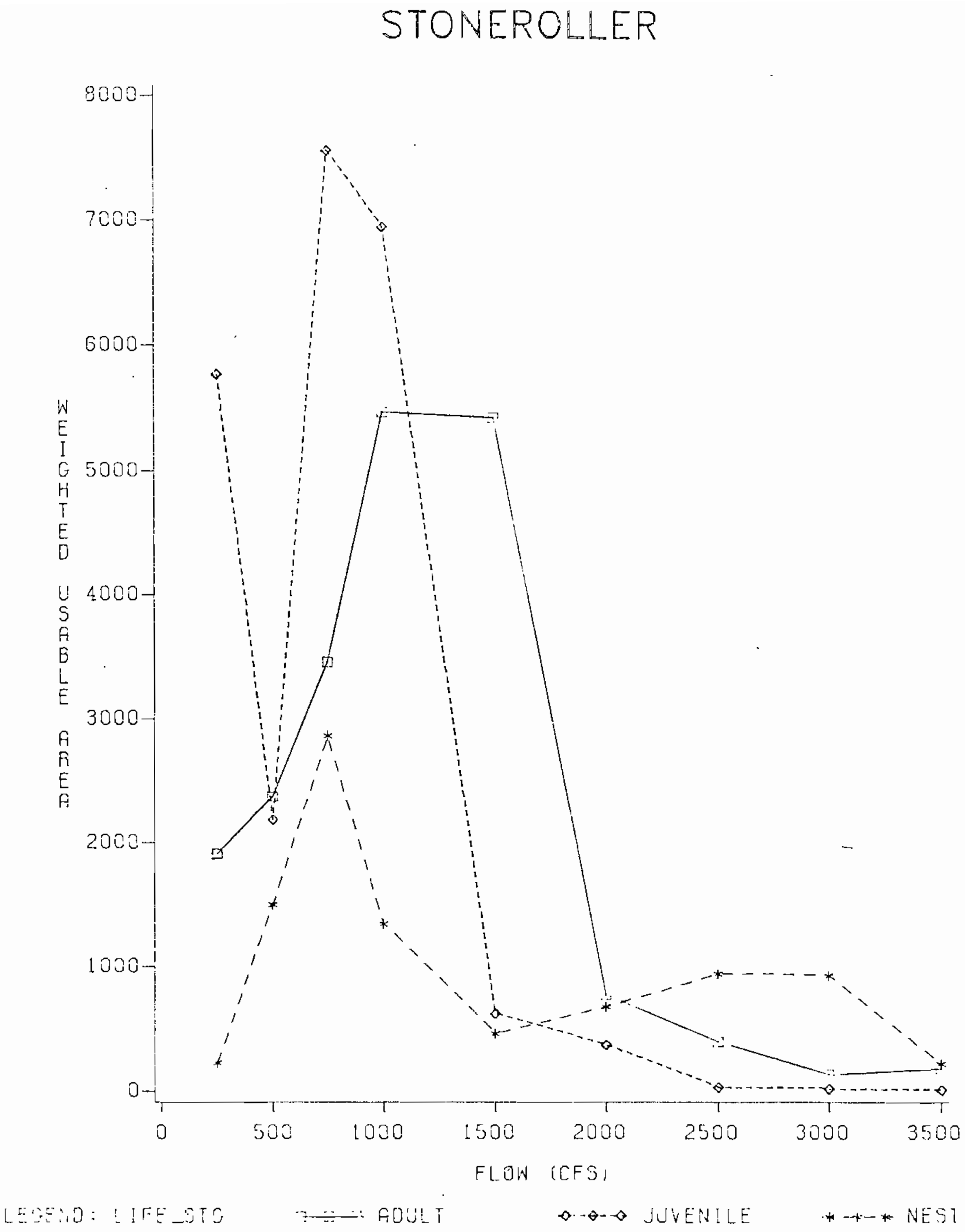


Figure 36. Habitat response curves for stoneroller in the New River (Bluestone tailwaters study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Table 22; juvenile, Table 25; nests, Tables 28 and 29.

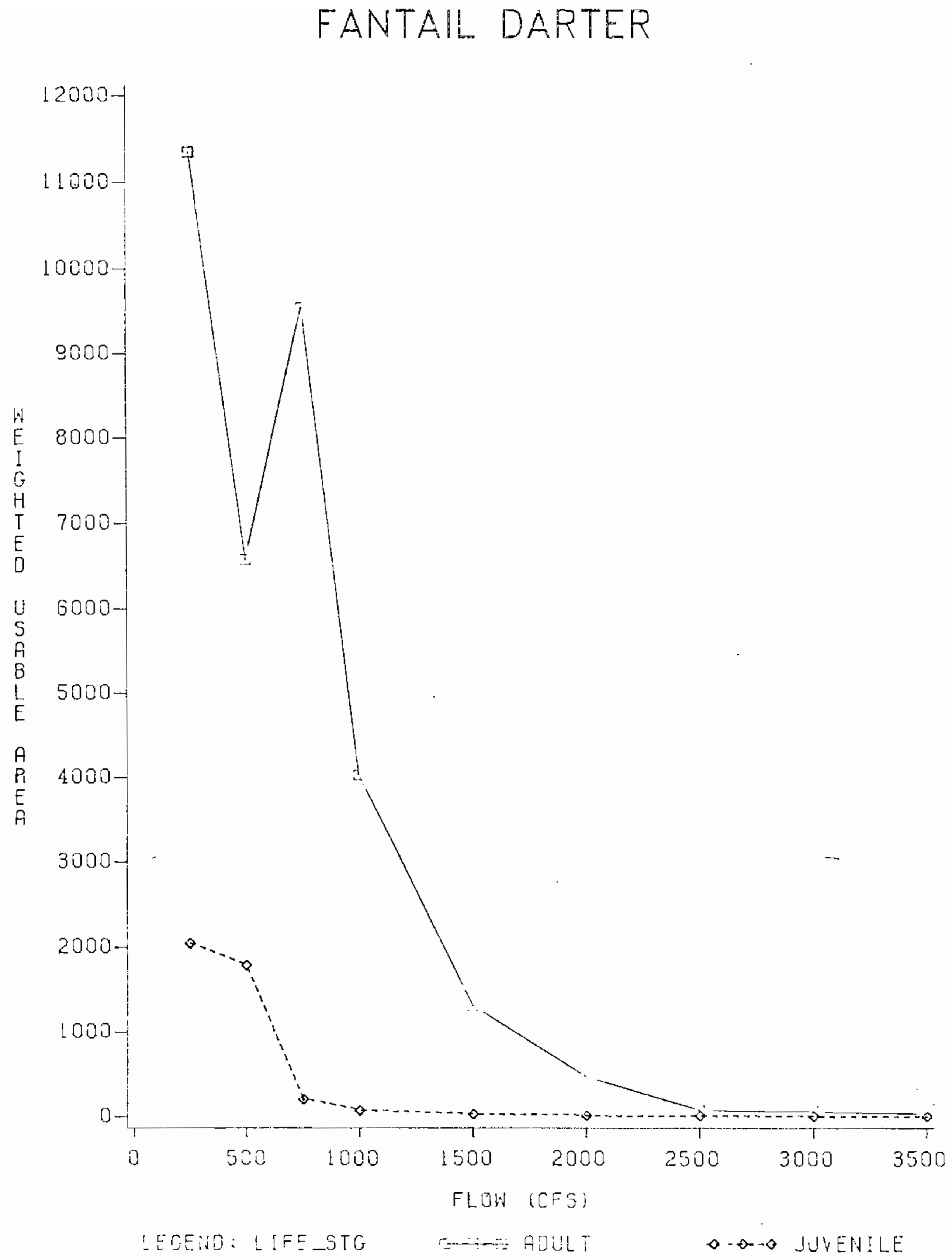


Figure 37. Habitat response curves for fantail darter in the New River (Bluestone tailwaters study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Tables 32 and 33; juvenile, Table 35.

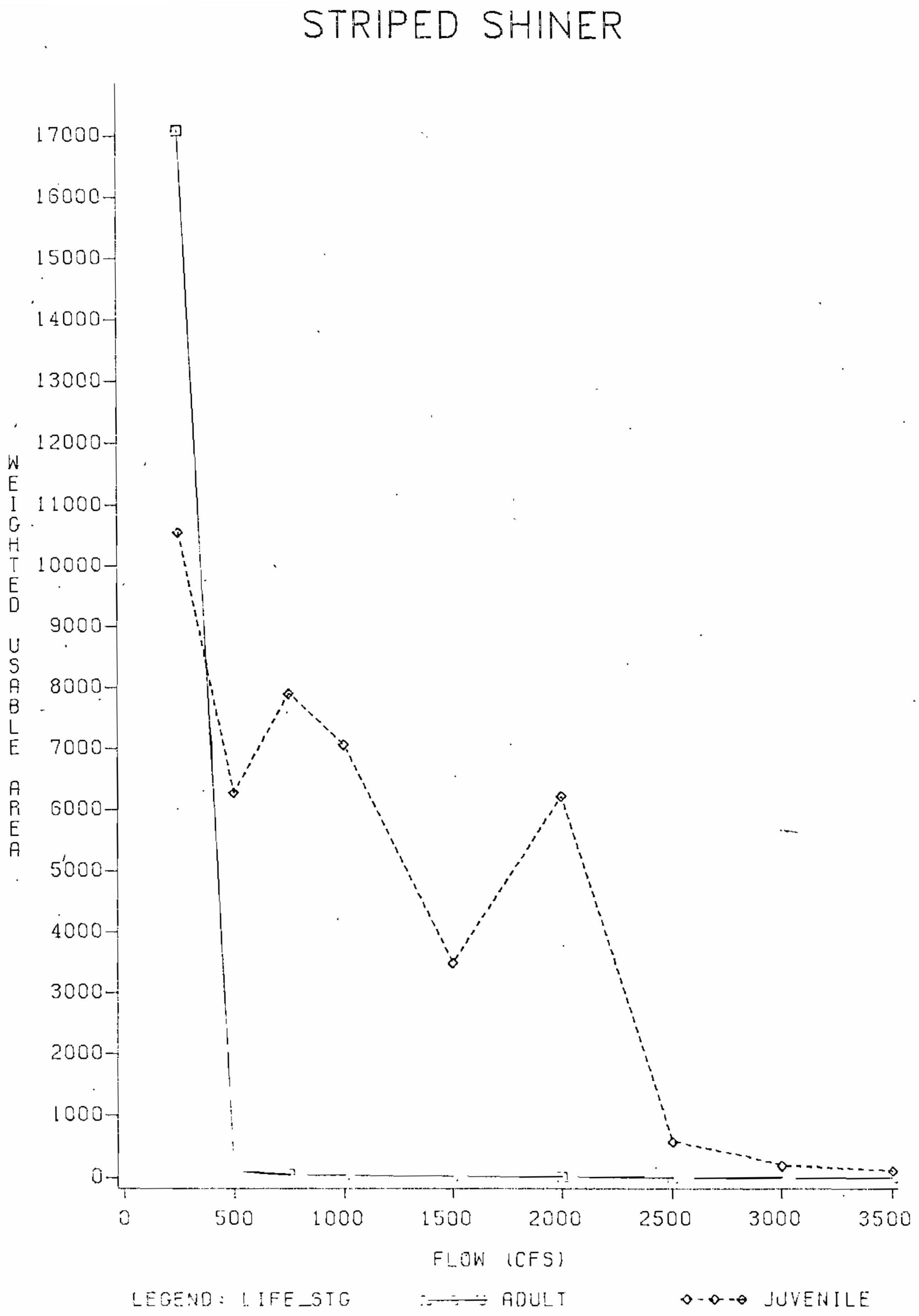


Figure 38. Habitat response curves for striped shiner in the New River (Bluestone tailwaters study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Table 37; juvenile, Table 39.

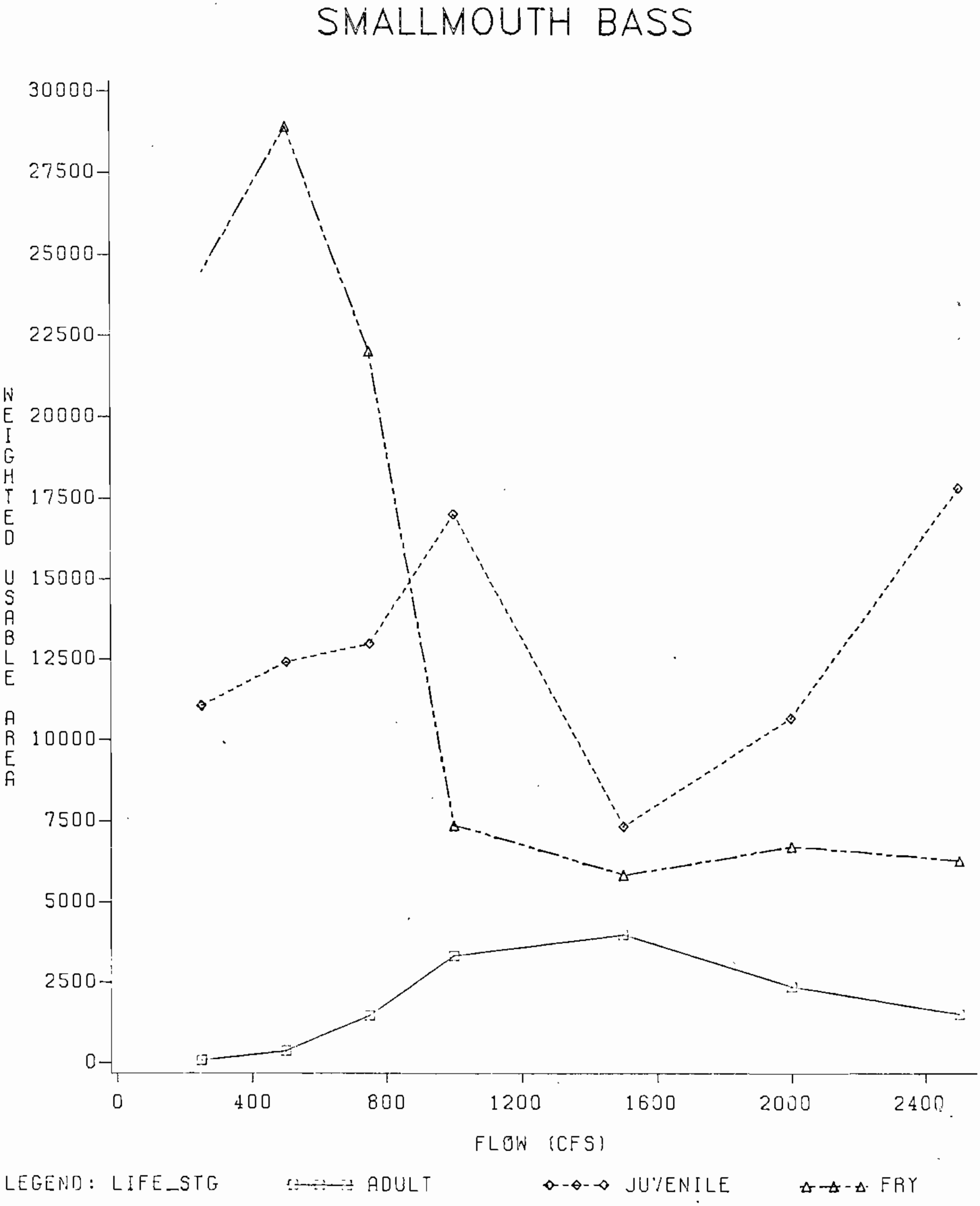


Figure 39. Habitat response curves for smallmouth bass in the New River (Bass Lake study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Table 7; juvenile, Table 10; fry, Table 16.

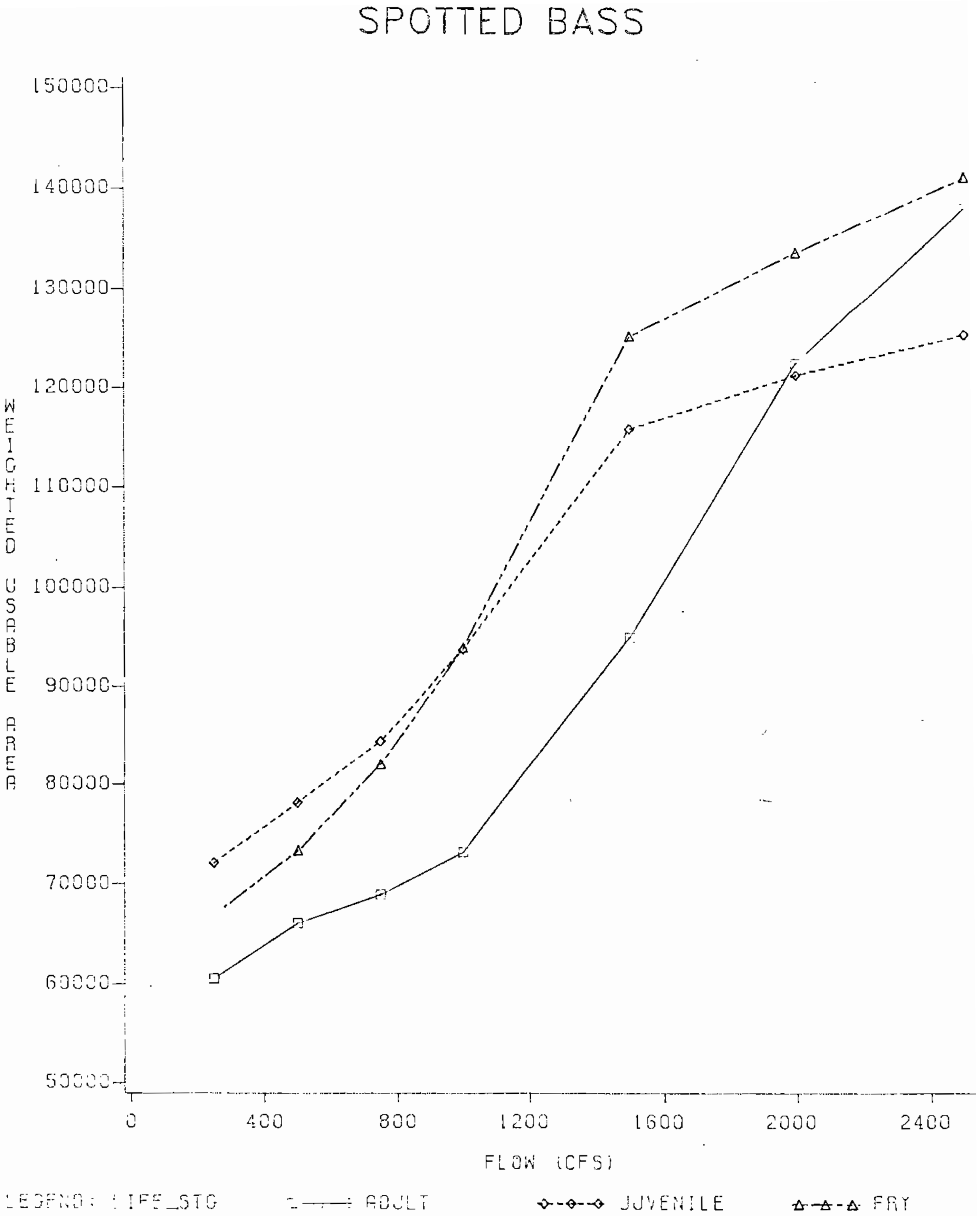


Figure 40. Habitat response curves for spotted bass in the New River (Bass Lake study reach) based on IFG-2 hydraulic simulation. IFG suitability curves were used.

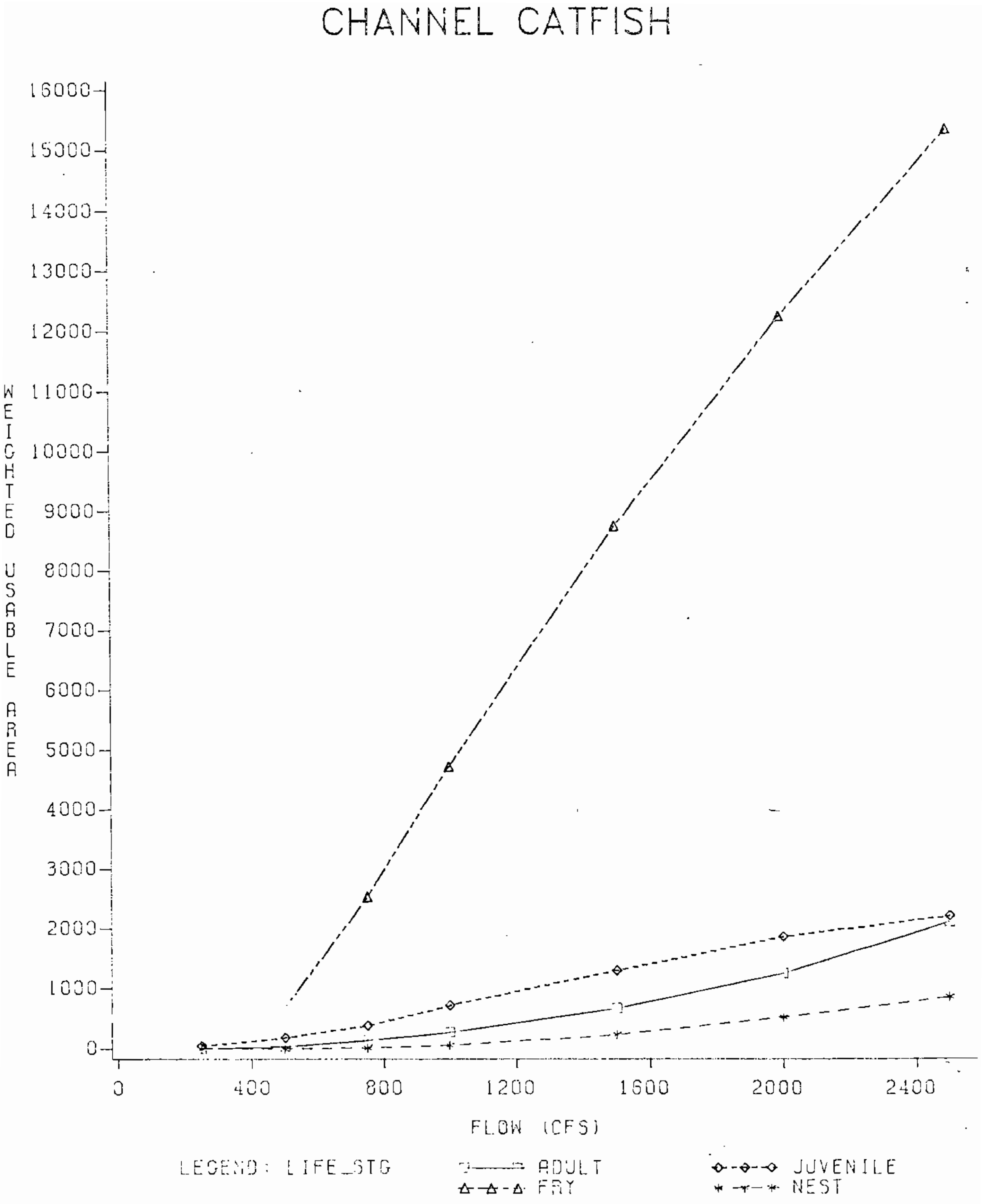


Figure 41. Habitat response curves for channel catfish in the New River (Bass Lake study reach) based on IFG-2 hydraulic simulation. IFG suitability curves were used.

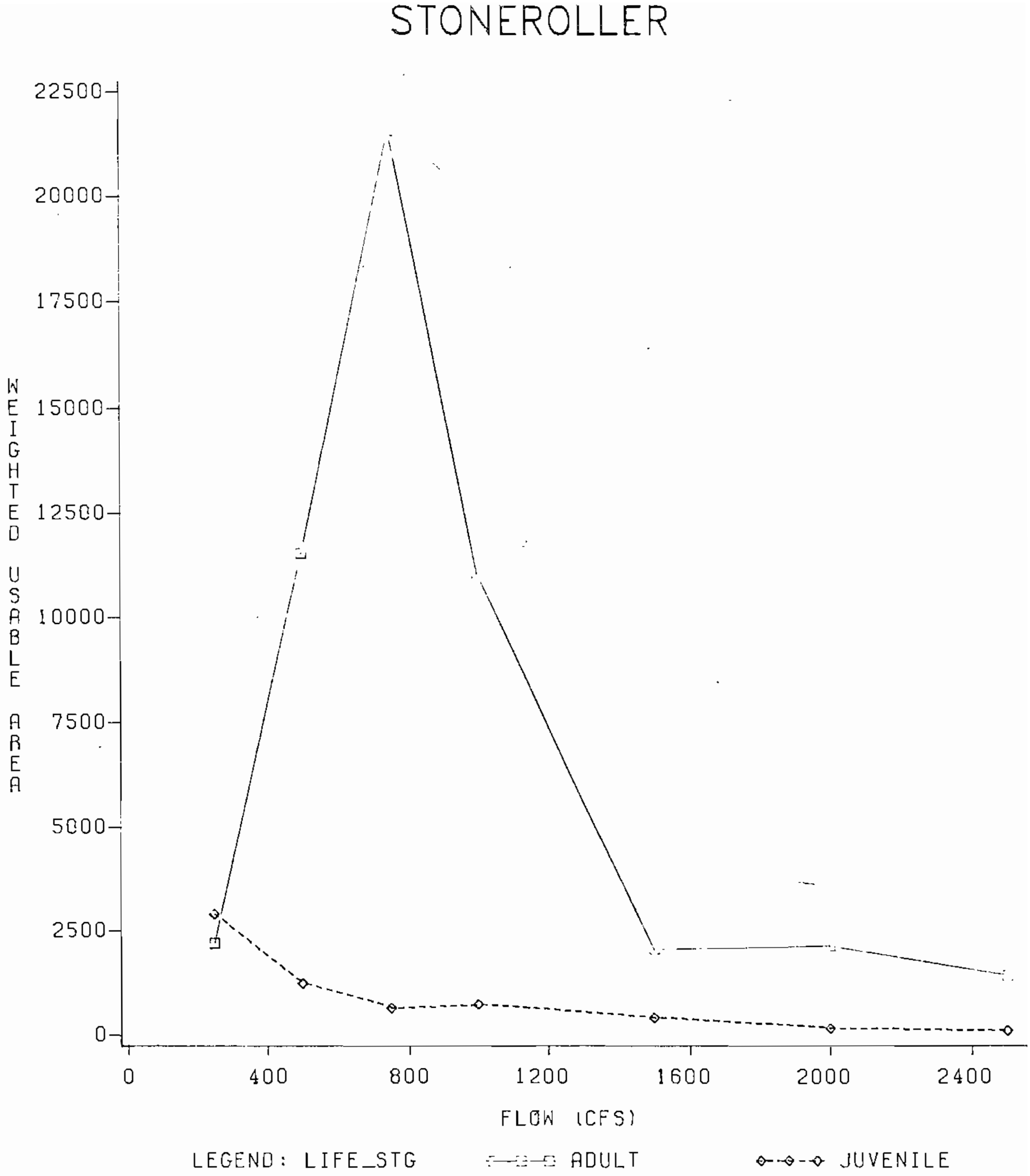


Figure 42. Habitat response curves for stoneroller in the New River (Bass Lake study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Table 22; juvenile, Table 25.

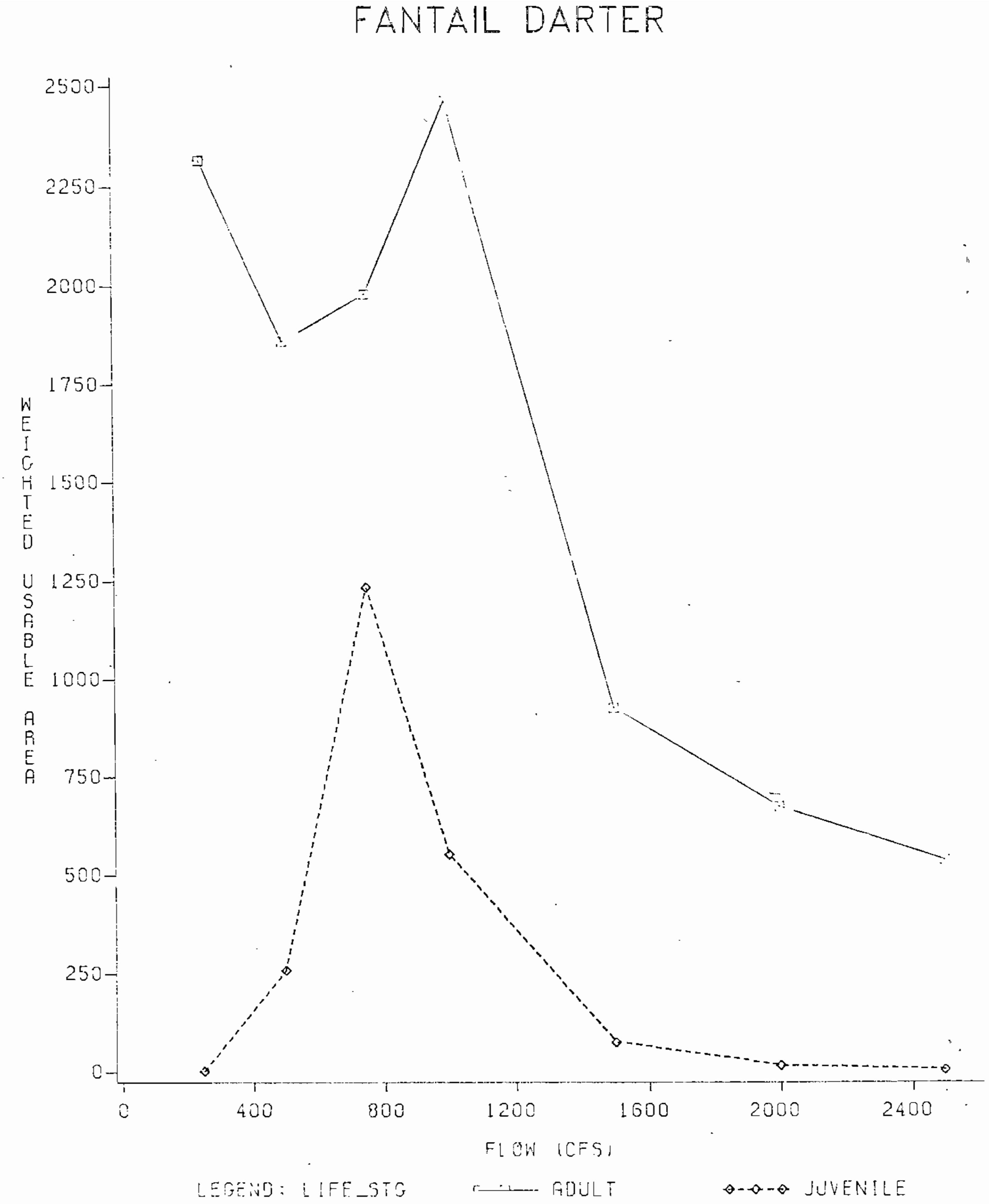


Figure 43. Habitat response curves for fantail darter in the New River (Bass Lake study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Tables 32 and 33; juvenile, Table 35.

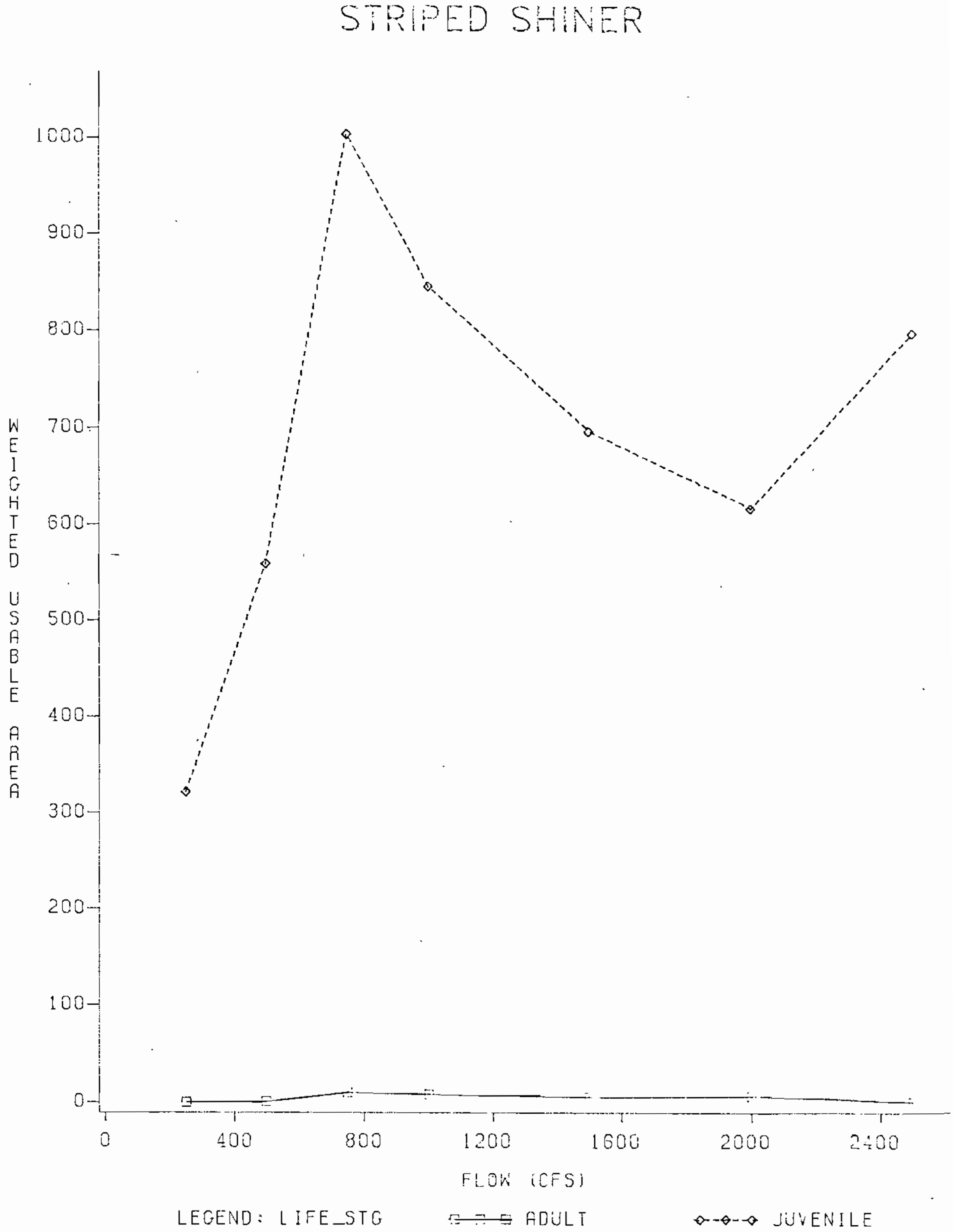


Figure 44. Habitat response curves for striped shiner in the New River (Bass Lake study reach) based on IFG-2 hydraulic simulation. Suitability curves used were: adult, Table 37; juvenile, Table 39.

Montana Method

Greenbrier River

The determination of instream flow needs for fishes in the Greenbrier River using the Montana Method are shown in Table 40. In the East Fork, the optimum range was 44 cfs to 73 cfs. The good to outstanding range during the October to March period was 15 cfs to 29 cfs with degrading conditions beginning at 7 cfs. During the April to September period, the good to outstanding range was 29 cfs to 44 cfs with degrading conditions occurring as flows fell below 22 cfs.

At the Hosterman station on the main Greenbrier, the optimum range for fishery habitat was from 146 cfs to 244 cfs. The good to outstanding range during the October-March period was 48 cfs to 98 cfs, with degrading conditions occurring below 24 cfs. During the April-September period, the good to outstanding range was 98 cfs to 146 cfs with degrading conditions occurring below 73 cfs.

The optimum flow range determined for the Seneca Station on the Greenbrier was 463 cfs to 773 cfs. In the October to March period, the good to outstanding range was 155 cfs to 293 cfs with degrading conditions occurring below 77 cfs. The good to outstanding flows during the April to September period ranged from 293 cfs to 464 cfs, with degrading conditions occurring below 232 cfs.

Meadow River

The instream flow needs for fishes on the Meadow River as determined by the Montana Method are given in Table 41. At Rainelle, the optimum ranged from 317 cfs to 528 cfs. During the October-March period the good to outstanding flows ranged from 105 cfs to 211 cfs with conditions degrading below 53 cfs. The good to outstanding flows during the April to September period ranged from 211 cfs to 317 cfs with degrading conditions occurring below 158 cfs.

The optimum flow range at the Rt. 19 bridge station was 457 cfs to 761 cfs. The October to March good to outstanding flows ranged from 152 cfs to 304 cfs with conditions degrading below 76 cfs. During the April to September period the good to outstanding flow range was 304 cfs to 457 cfs, with degrading conditions occurring below 228 cfs.

New River

Instream flows necessary to protect fishes in the New River are shown in Table 42. Optimum flows for the Bluestone Dam Tailwaters ranged from 3314 cfs to 5523 cfs. Good to outstanding flows for the October to March period were 1105 cfs to 2209 cfs. Degrading conditions began to occur below 552 cfs. For the April to September flow period, good to outstanding flow were 2209 cfs to 3314 cfs, with degrading conditions occurring below 1657 cfs.

At the Bass Lake station, the optimum flows ranged from 4547 cfs to 7579 cfs. The October to March good to outstanding flows are 1516 cfs to 3032 cfs with degrading conditions occurring below 758 cfs. The good to outstanding flows for the April to September period were 2209 cfs to 4547 cfs with degrading conditions occurring below 1657 cfs.

Table 40. Instream flow regimens for fish in the Greenbrier River as determined using the Montana Method (Tennant 1976).

	East Fork		Greenbrier - Hosterman		Greenbrier - Seneca	
Description of Flows	Oct.-Mar	Apr.-Sept.	Oct.-Mar.	Apr. Sept.	Oct.-Mar.	Apr.-Sept.
Flushing or Maximum	146		188		1546	
Optimum Range	44-73		146-244		463-773	
Outstanding	29	44	98	146	293	463
Excellent	22	36	73	122	232	386
Good	15	29	48	98	155	293
Fair or Degrading	7	22	24	73	77	232
Poor or Minimum	7	7	24	24	77	77
Severe Degradation	7.0-0		24-0		77-0	

Table 41. Instream flow regimes for fish in Meadow River as determined using the Montana Method (Tennant 1976).

Description of Flows	Meadow R. - Rt. 19 Bridge Oct.-Mar.	Meadow R. - Rt. 19 Bridge Apr.-Sept.	Meadow R. - Rainelle Oct.-Mar.	Meadow R. - Rainelle Apr.-Sept.
Flushing or Maximum	1522		1056	
Optimum Range	457-761		317-528	
Outstanding	304	457	211	317
Excellent	228	380	158	264
Good	152	304	105	211
Fair or Degrading	76	228	53	158
Poor or Minimum	76	76	53	53
Severe Degradation	46-0		53-0	

Table 42. Instream flow regimens for fish in the New River as determined using the Montana Method (Tennant 1976).

Description of flow	New R. - Bluestone Tailwaters Oct.-Mar.	New R. - Bluestone Tailwaters Apr.-Sept.	New River - Bass Lake Oct.-Mar.	New River - Bass Lake Apr.-Sept.
Flushing or Maximum	11046		15158	
Optimum Range	3314-5523		4547-7579	
Outstanding	2209	3314	3032	4547
Excellent	1657	2762	2274	3789
Good	1105	2209	1516	3032
Fair or Degrading	552	1657	758	1657
Poor or Minimum	552	552	758	758
Severe Degradation	552-0		758-0	

Idaho Method

The Idaho method was designed to predict instream flow needs for fishes of large rivers, particularly, flows needed for rearing and passage (White 1975; Cochnauer 1976). Since passage flows are more important to migratory salmonids than to warmwater fish populations, they will not be considered in this report. In the Idaho method, rearing success is assumed to be directly proportional to the ability of the stream to produce food organisms which is in turn assumed to be directly proportional to wetted perimeter. When wetted perimeter is plotted against discharge, the curve rises steeply until the river channel nears its maximum width. At that point, wetted perimeter begins to increase less rapidly with respect to discharge, and the curve begins to level off. White (1975) considered that this inflection point indicated the minimal rearing discharge. Wetted perimeter-discharge relationships are depicted in Figs. 45, 46, and 47 for the Greenbrier, Meadow, and New Rivers, respectively. Predictions were based on IFG-2 programs calibrated at the highest flow measured at each study site.

Greenbrier River

Minimum rearing flows were predicted to be 170 cfs for the Hosterman study reach and 200 cfs for the Seneca State Forest study reach.

Meadow River

Minimum rearing flows were predicted to be 60 cfs for the Rt. 19 bridge study reach and 180 cfs for the Rainelle study reach.

New River

Minimum rearing flows were predicted to be about 700 cfs for the Bass Lake study reach. No inflection point was apparent for the wetted perimeter-discharge relationship on the Bluestone tailwaters study reach, so no minimum rearing flow could be predicted.

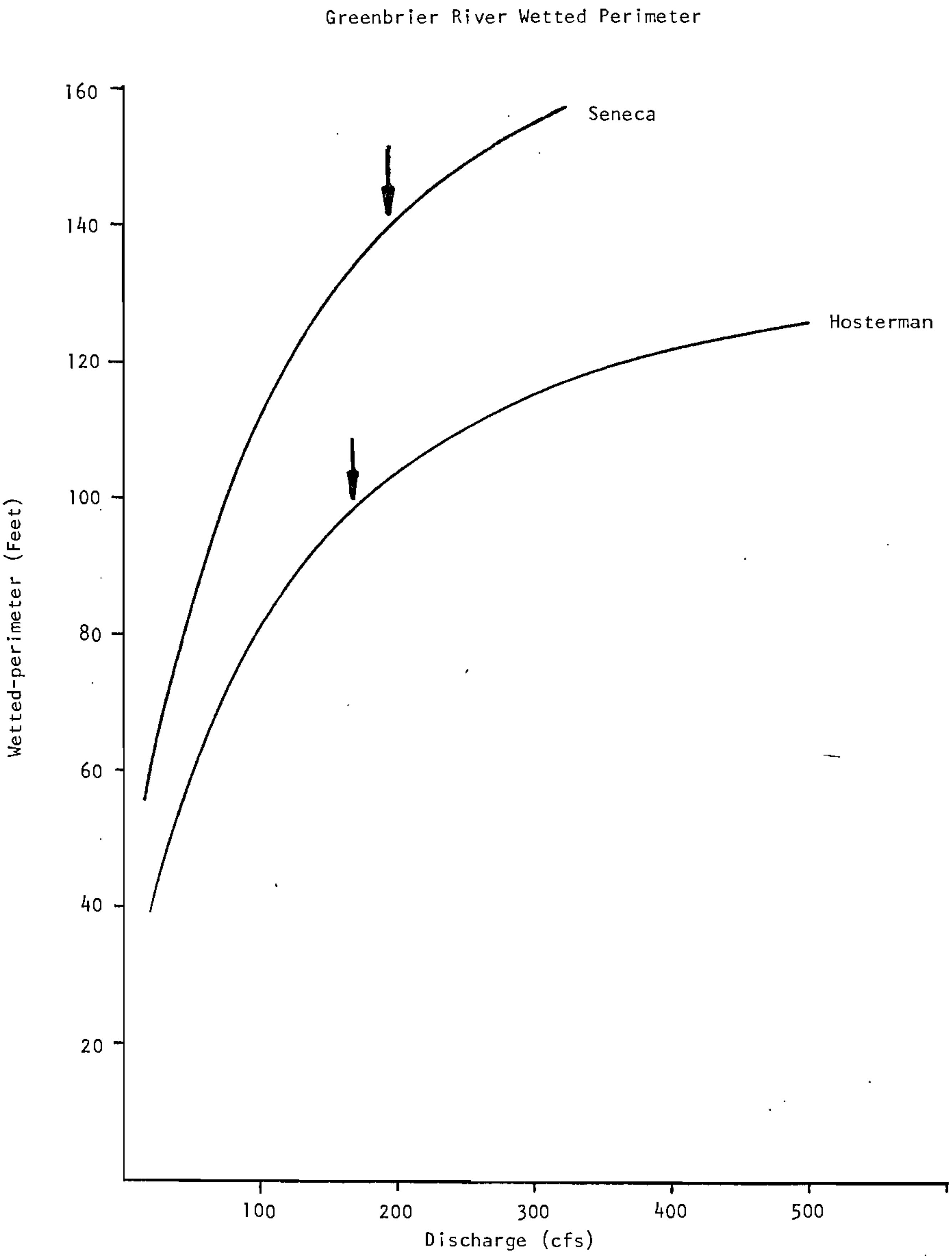


Figure 45. Representation of the wetted perimeter-discharge relationship for two Greenbrier River study reaches. Arrow approximates the recommended rearing discharge.

Meadow River Wetted Perimeter

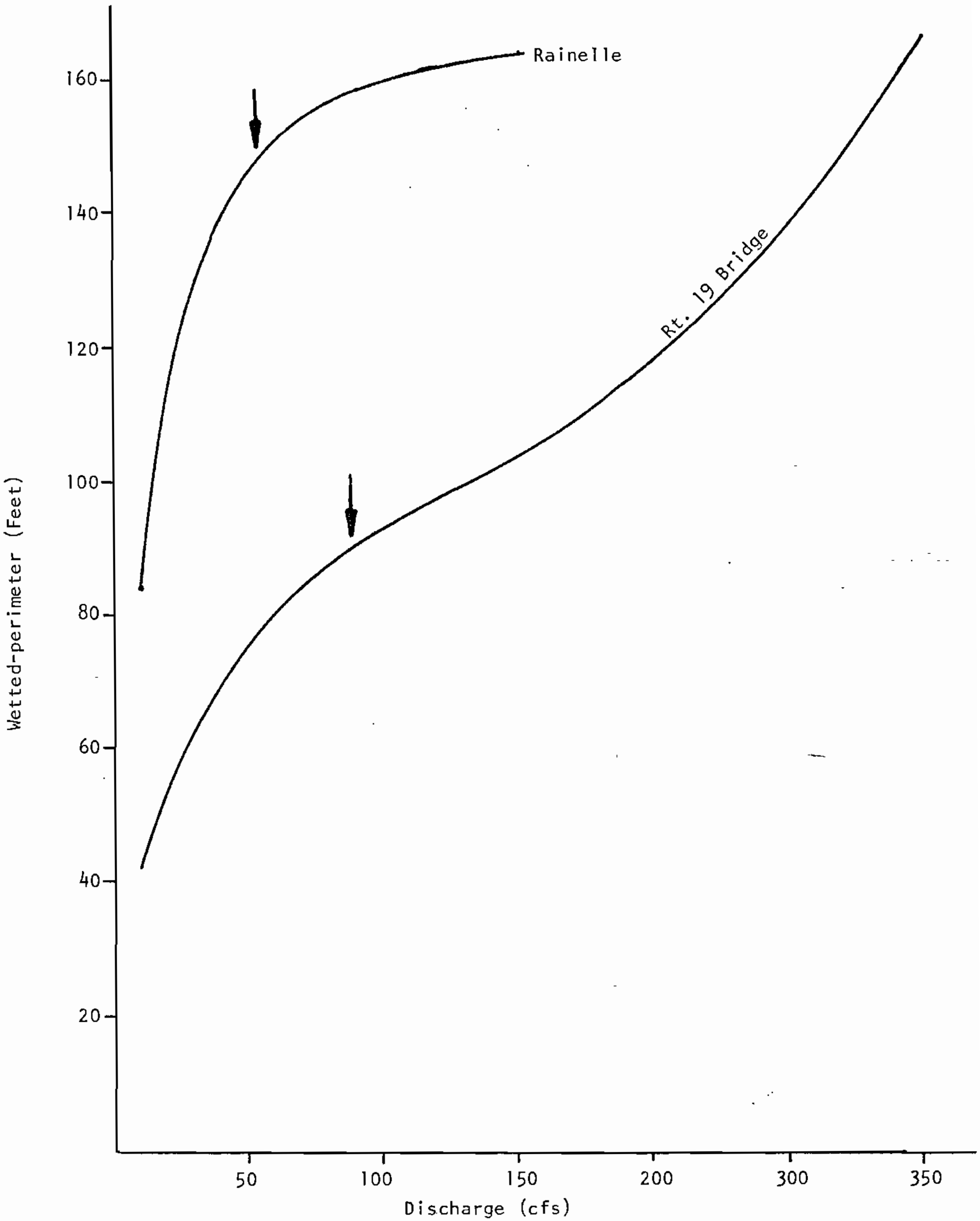


Figure 46. Representation of the wetted perimeter-discharge relationship of two Meadow River study reaches. Arrow approximates the recommended rearing discharge.

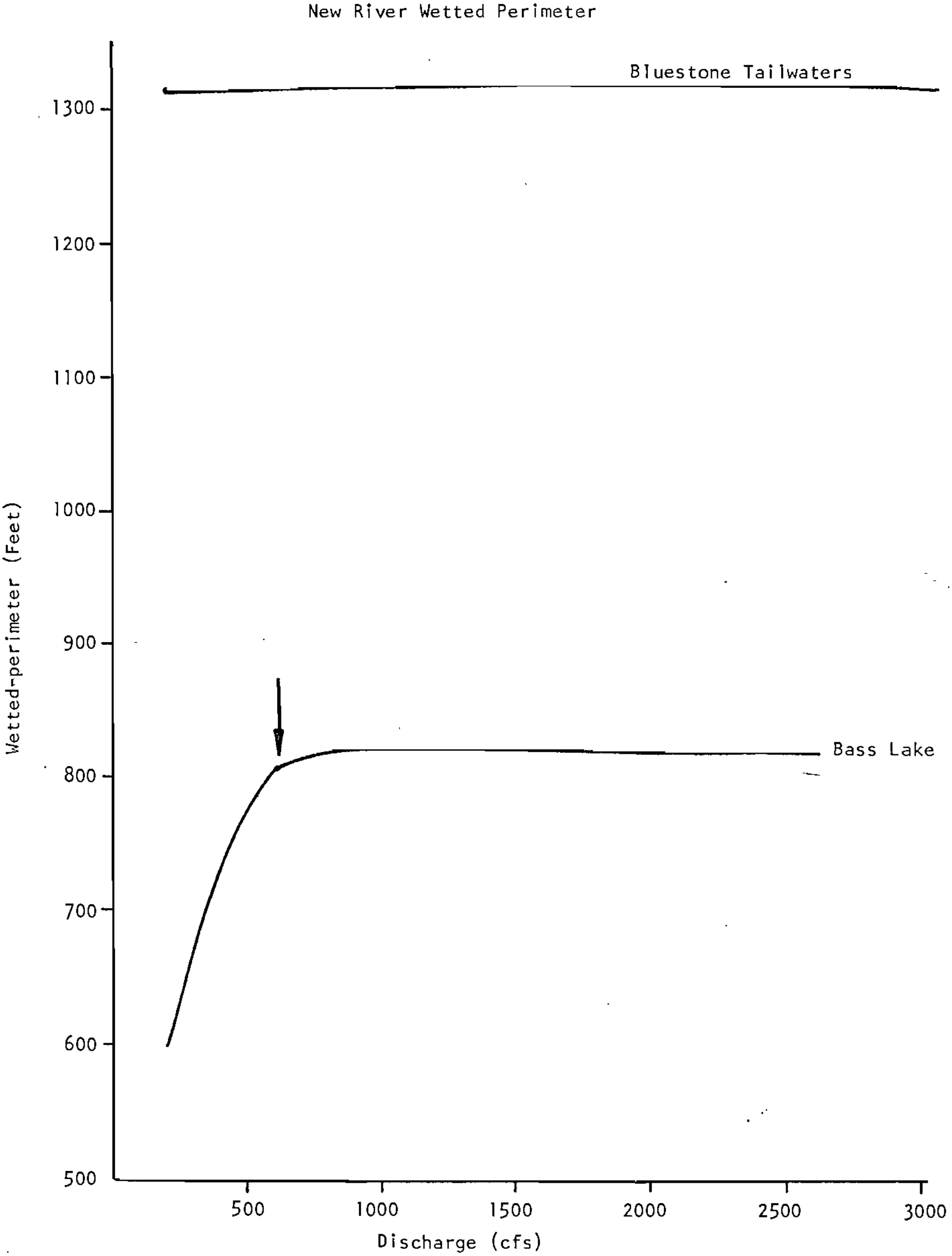


Figure 47. Representation of the wetted perimeter-discharge relationship of two New River study reaches. Arrow approximates the recommended rearing discharge.

DISCUSSION

IFG Method

The IFG method is based on several assumptions: (1) depth, velocity, substrate (and cover where applicable) are the primary habitat variables determining fish production and standing crop in an otherwise suitable stream; (2) the structure of the stream channel does not change with changing flows; (3) a selected segment of a river may be modeled by using a representative sample reach of that river; (4) the suitability of one primary variable as habitat is not affected by the suitability of the other variables (i.e. suitabilities are independent); and (5) there is a direct and postive relationship between the calculated suitability of habitat and the use of that habitat by selected fish species (Stalnaker 1978). Another assumption basic to the IFG method is that habitat suitability functions developed for a given species in one stream are valid for that species in another stream.

It is beyond the scope of this study to attempt to prove or disprove these assumptions although many of the questions they raise are being addressed by IFG personnel and by other investigators. Jackson (1980a; b) and Railsbach, et al. (1980) have pointed out some weaknesses in the physical model. Orth (1980) found that some of the assumptions on which the biological component of the IFG method is based do not always hold true. He found that the assumption of independence of variables in habitat selection by fishes was often invalid, and that a population of adult and juvenile smallmouth bass was not limited by usable habitat as defined by WUA although WUA was limiting during the summer to freckled madtom stoneroller, and orangebelly darter.

We have attempted to apply the IFG method to West Virginia streams while adhering as closely as possible to the methods recommended by the IFG (Bovee and Cochnauer 1977; Bovee and Milhous 1978) in order to assess the practicality of the method. The investigators who participated in this study were biologists rather than hydrologists. Therefore, when questions of theory arose they primarily concerned the biological rather than the hydrological component of the IFG method.

Some difficulties were encountered in the transect placement process. Initially, low flows were required so that hydraulic controls could be located when transects were being placed. In the first year of the study, an unusually wet summer caused delays in the process. High stream levels and turbidities not only made it difficult to set up stations, they also made working conditions dangerous.

When stations had been set up on all of the study streams, it was necessary to collect physical data at three discharges. In some instances, it was difficult to measure depths and velocities at identical points across the transect on successive visits. This was a particular problem when a transect crossed boulders or large elements of cobble. Small errors in horizontal measurement or in tagline placement could result in large variations in depth and/or velocity at what was assumed to be the same point. This was apparently a factor in the failure to calibrate the IFG-4 program at the initial transects of the two Meadow River study sites. The difficulties in making accurate horizontal measurements at successive flows were magnified as stream size increased, and on a wide, high-volume river such as the New, they became prohibitive. For this reason, only one set of flow data were collected at the two New River study sites, and the IFG-2 program was used for the hydraulic simulation.

When the physical data collection phase of the project had been completed, the data were coded for input to the IFG-2 and IFG-4 hydraulic simulation programs. The programs initially had been written for use on a CDC computer. Before they could be used, they had to be rewritten for use on an IBM computer.

The two programs each had advantages and disadvantages to their use, but on the whole, the IFG-4 program was much easier to calibrate and to use than the IFG-2 program. The main disadvantage of the IFG-4 program was that it required data measured at three different flows in order to be calibrated. Once the necessary data were obtained, the IFG-4 program was easily calibrated, and by use of the control card, considerable output flexibility was obtainable. It was simple to obtain output for mulitple discharges using IFG-4, and the program apparently adhered well to the empirical stage-discharge relationship. Discharges modeled with IFG-4 remained within transect endpoints on all study sites except the Rainelle study site on the Meadow River, where transect endpoints were inundated at flows of 250 cfs and greater.

The single advantage in using the IFG-2 program lay in the fact that it only required one set of flow measurements for calibration. However, it was sometimes difficult to calibrate IFG-2. Some calibrations required that several artificial transects be added to the data, and as many as 30 trials were sometimes needed for calibration. A separate program, SUBMODC, had to be acquired and rewritten in order to remove the effects of the artificial transects and to add substrate values (for which no provisions were made in the unmodified IFG-2 program). There were also situations where IFG-2 could not be calibrated over all the transects at a study site. At the Rt. 19 bridge study site on the Meadow River, only the lower four transects could be used for IFG-2 hydraulic simulations. The IFG-2 program also apparently did not model stage-discharge relationships as well as the IFG-4 program. Transect endpoints were inundated at all study sites before the final flows of interest had been modeled. In general, the higher the calibration flow, the higher the flow of interest at which endpoints were inundated. The IFG-2 program also was very tedious and time-consuming to use for modeling a large number of flows of interest. It had no flexibility of output so that it required a complete printout of all calibration data for each flow of interest.

In order to assess the reliability of the IFG-2 model, its predictions of WUA were compared to those obtained by using the IFG-4 program which were assumed to be accurate. Suitability curves for smallmouth bass were used, since that species was considered the most important game fish in the study streams. Comparisons were made at two stations each on the Greenbrier and Meadow Rivers. Some IFG-2 predictions were relatively close to IFG-4 predictions on the Hosterman (Fig. 48) and Seneca State Forest (Fig. 49) study reaches on the Greenbrier River. In both cases, predictions based on IFG-2 programs calibrated at high flows (416 and 378 cfs, respectively) were most accurate. At both stations, IFG-4 flows modeled to 1000 cfs remained within transect endpoints. Discharges modeled with IFG-2 programs calibrated at high flows inundated endpoints at 600 and 400 cfs at the Hosterman and Seneca study sites respectively, and those modeled with programs calibrated at lower flows flooded endpoints at even lower flows. On the Meadow River on the Rainelle study reach, models calibrated at only two flows could be tested (Fig. 50). The model calibrated at low flow (12 cfs) inundated transect endpoints at all higher discharges, and could not be plotted, and the predictions of the program calibrated at high flow (160 cfs) did not resemble the IFG-4 predictions. At the intermediate flow (68 cfs), the program could not be calibrated. At the Rt. 19 bridge study site, the program calibrated at the intermediate flow (105 cfs) gave WUA predictions closest to the IFG-4 model (Fig. 51). The IFG-2 predictions for the Meadow River should probably be disregarded. Therefore, based on the Greenbrier observations, it probably can be said that IFG-2 predictions will approximate IFG-4 predictions most closely if they are based on models calibrated at the highest possible flows.

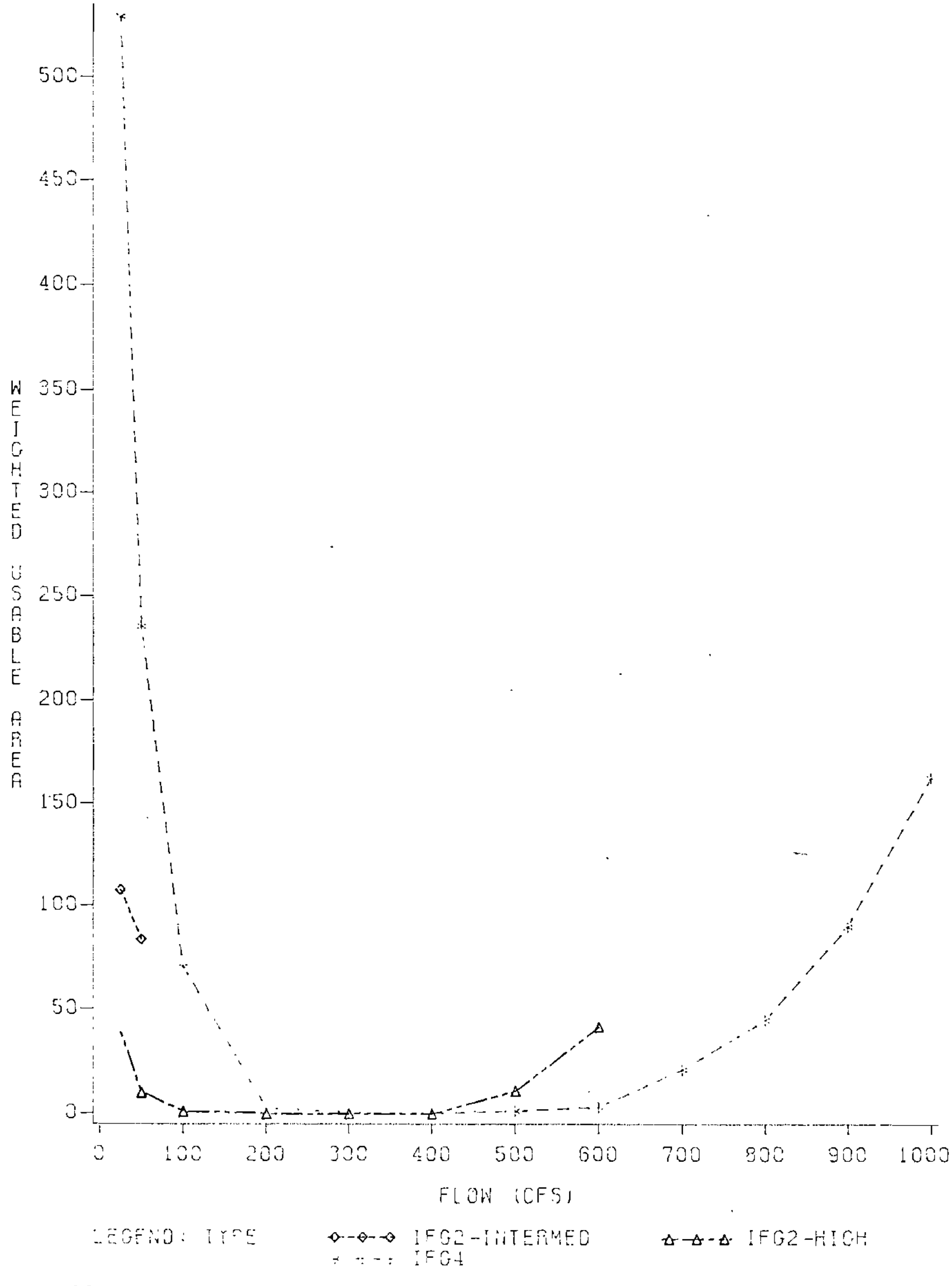


Figure 48. Comparison of IFG-2 and IFG-4 habitat response curves for adult smallmouth bass in the Greenbrier River (Hosterman study reach). IFG-2 programs calibrated at low (12 cfs), intermediate (45 cfs), and high (416 cfs) discharges. Curves extrapolated to 1000 cfs unless transect endpoints inundated at lower flows.

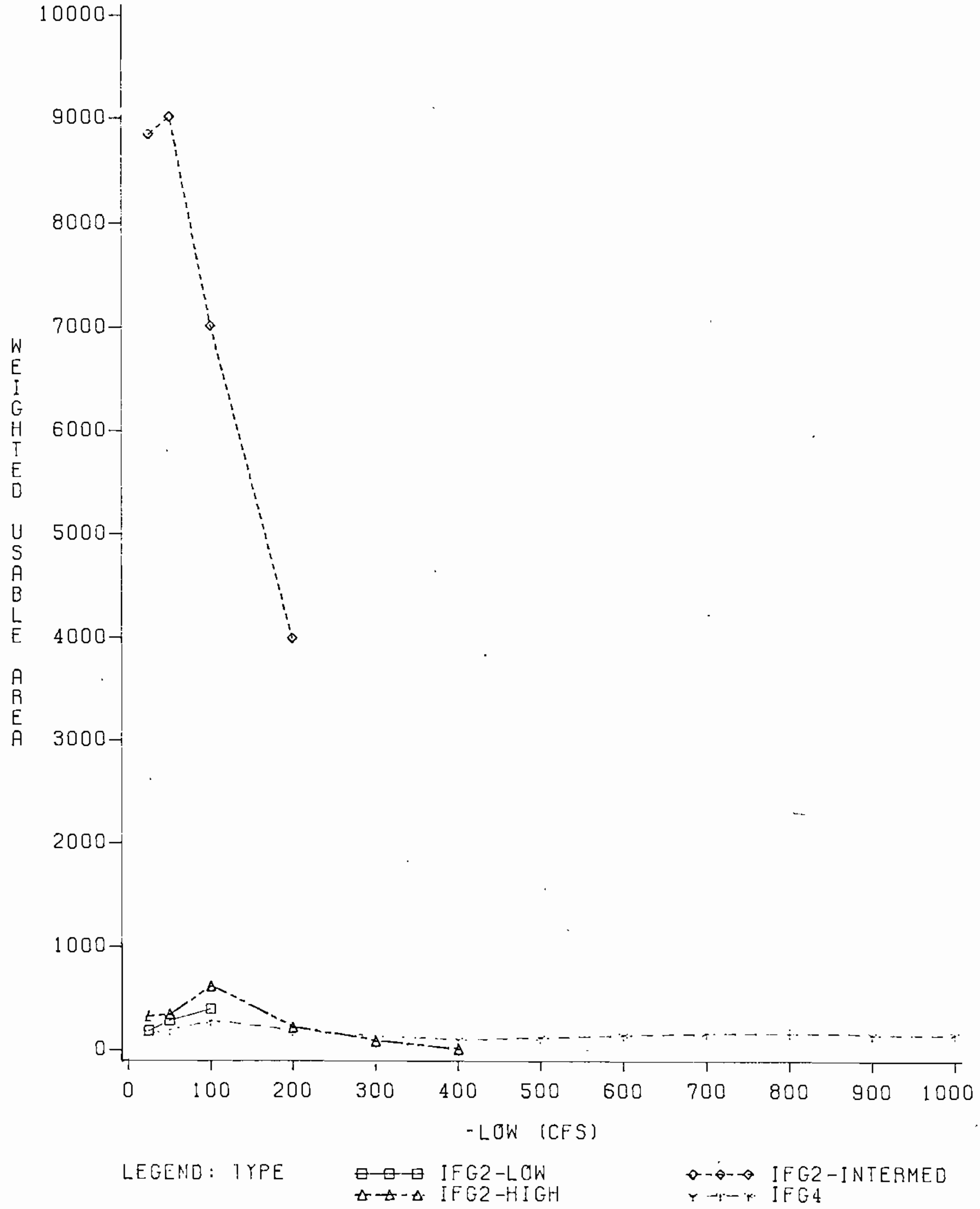


Figure 49. Comparison of IFG-2 and IFG-4 habitat response curves for adult smallmouth bass in the Greenbrier River (Seneca State Forest study reach). IFG-2 programs were calibrated at low (51 cfs), intermediate (252 cfs) and high (378 cfs) discharges. Curves, extrapolated to 1000 cfs unless transect endpoints inundated at lower flows.

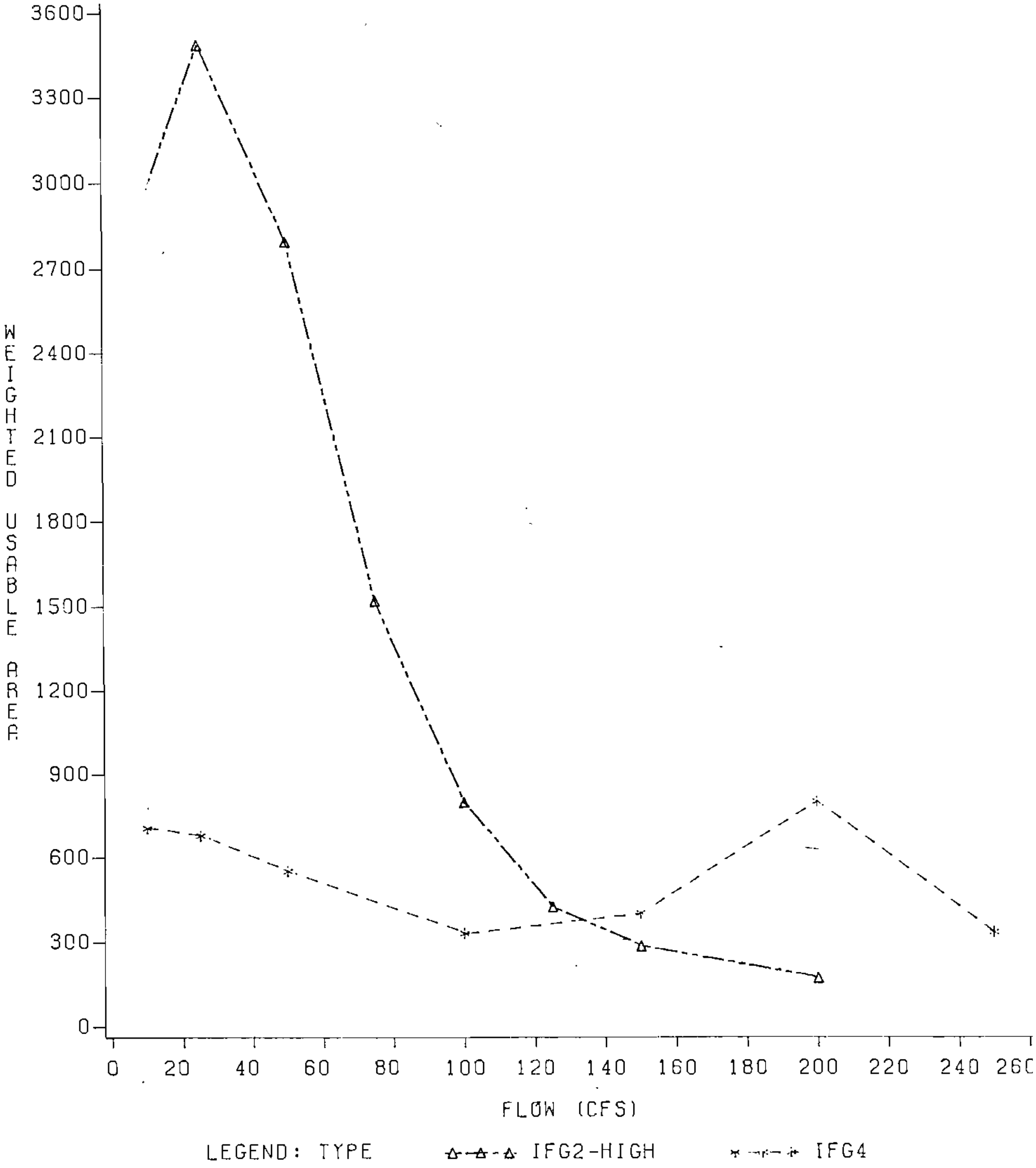


Figure 50. Comparison of IFG-2 and IFG-4 habitat response curves for adult smallmouth bass in the Meadow River (Rainelle study reach). IFG-2 programs calibrated at low (12 cfs), intermediate (68 cfs), and high (160 cfs) discharges. Curves extrapolated to 400 cfs unless transect endpoints inundated at lower flows.

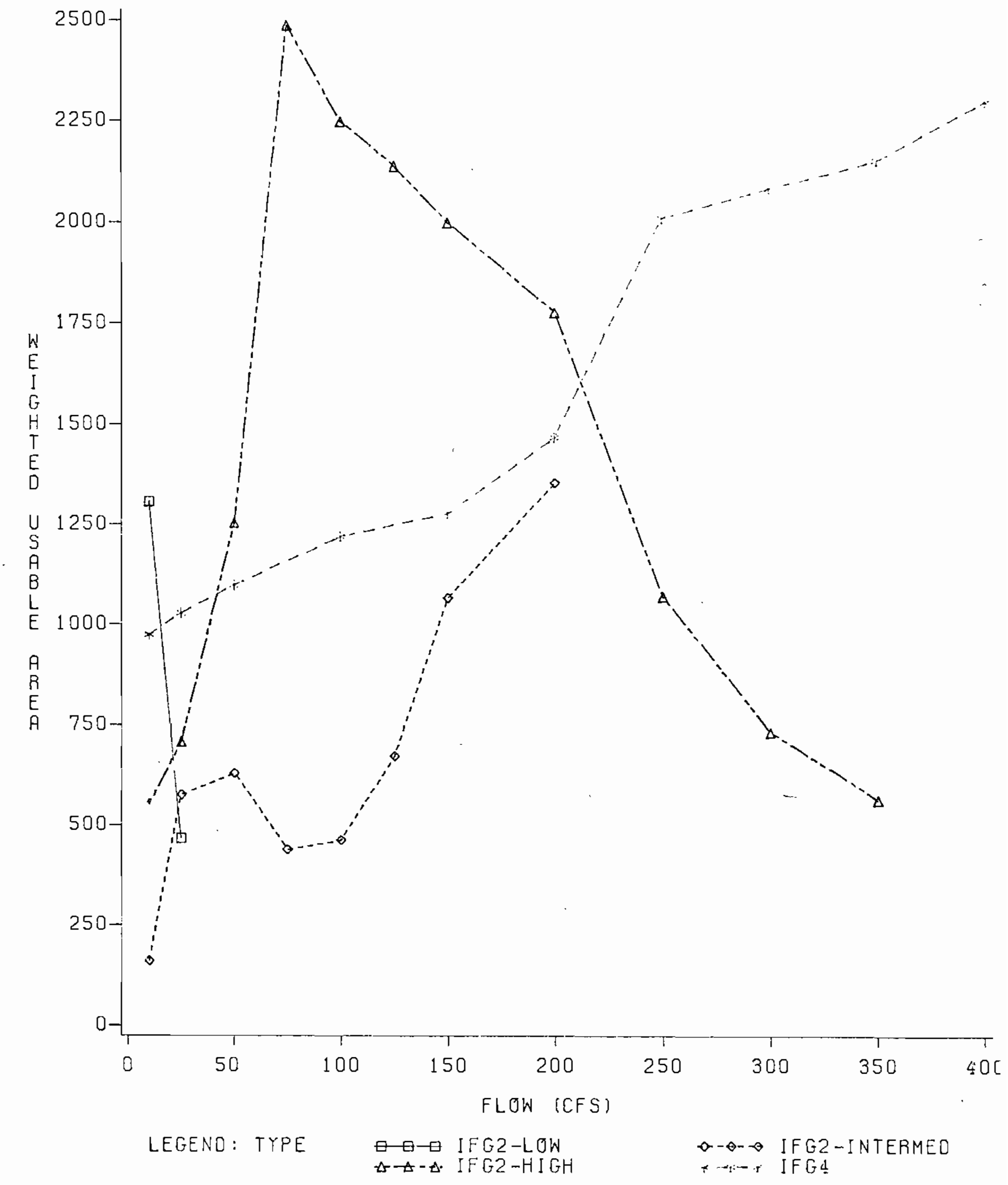


Figure 51. Comparison of IFG-2 and IFG-4 habitat response curves for adult smallmouth bass in the Meadow River (Rt. 19 bridge study reach). IFG-2 programs calibrated at low (27 cfs), intermediate (105 cfs), and high (210 cfs) discharges. Curves extrapolated to 400 cfs unless transect endpoints inundated at lower flows.

The development of habitat suitability curves probably is the one point at which bias can be introduced most easily into the IFG method. Orth (1980) noted two types of bias. The first occurred when existing habitat was sampled non-randomly and the resulting frequency of capture distributions were used to derive habitat suitability curves. He adjusted for the bias by dividing the frequencies by the area of each kind of habitat sampled. No such correction process was described by Bovee and Milhous (1978) and therefore was not applied when curves were derived from data collected in the present study. Although attempts were made to sample all available habitats it is certain that fish inhabiting waters deeper than about 2 ft or with current velocities greater than about 1.0 fps were underrepresented in our samples. Therefore, this bias must be present in the suitability curves derived in this study.

The second type of bias recognized by Orth was bias due to "differential sampling efficiencies over the range of the particular habitat variable being considered". Orth suggested that this bias could be minimized by using several different sampling techniques. Most of the suitability curves derived during the present study are based on data collected by one method. Therefore, the curves must also contain the second kind of bias. It seems questionable that such bias can be much reduced by use of several capture methods. It is difficult to think of a sampling gear that is more efficient in deep water than in shallow or in fast current than in slow even though the relative efficiencies of different gear might differ in each habitat. Therefore, by combining data collected by several methods one might simply subsitute one source of bias for another.

Other possible sources of bias were evident when data were being collected to construct habitat suitability curves. The physical necessity of entering the stream to capture fish often resulted in frightening them. Thus the physical habitat parameters measured were often those of the final refuge rather than the preferred habitat of a fish. For this reason, curves based on observation were probably biased to a lesser extent than those based on physical capture methods.

The limitations imposed on sampling by depth, current velocity, turbidity, and gear efficiency however, resulted in suitability curves that often bore little resemblance to curves developed by the IFG. Velocity suitability curves for adult smallmouth bass are shown in Fig. 52. The suitabilities as determined by the IFG were higher at all velocities than those found in the present study. Maximum suitable velocity based on the IFG curve (2.55 fps) was 2.5 times as great as in West Virginia (WV), and the IFG optimum extended from 0.0 to 0.32 fps whereas the WV optimum extended only to 0.05 fps. The velocity curve developed by Orth (1980) resembled the IFG curve with an optimum of 0.0 to 0.23 fps and a maximum of about 2.30 fps. However, a curve developed by Herricks and Klopke (1980) in Illinois more closely resembled the WV curve as its optimum apparently was almost 0.0 fps and its maximum about 1.10 fps.

Depth suitability curves for adult smallmouth bass are shown in Fig. 53. The WV and IFG curves are very dissimilar. The IFG-4 curve ascends from a suitability of zero at a depth of 1.0 ft to an optimum at all depths of 4.0 ft or greater, whereas the WV curve rises from a suitability of zero at 0.9 ft to an optimum between 1.55 and 2.35 ft, then declines to a maximum suitable depth of about 6.70 ft. The curve of Orth (1980) more closely resembles the WV curve as does the depth suitability curve developed by Herricks and Klopke (1980). The former has an optimum between about 0.8 and 3.6 ft and a maximum of about 8.7 ft, whereas the latter has an optimum of about 1.25 to 1.35 ft and a maximum of about 3.0 ft.

Velocity suitability curves for adult fantail darter are compared in Fig. 54. The WV and IFG curves bear no resemblance to each other. The IFG curve does not even reach its optimum between 2.33 and 3.50 fps before the WV curve reaches maximum suitable velocity of 1.95 fps.

Depth suitability curves for adult fantail darter are compared in Fig. 55. The WV and IFG curves are similar at shallow depths but the IFG curves indicates a much wider optimum and a much greater maximum suitable depth than the WV curve.

The IFG and WV curves for velocity suitability for adult brook trout also show considerable difference although their shapes are similar. The WV curve (Table 18) has an optimum from 0.0 to 0.15 fps and a maximum of 1.60 fps, whereas the IFG curve (Bovee 1978 p. 70) has an optimum of 0.0 to 0.25 fps and a maximum of 4.00 fps. The depth suitability curves are even less similar. The WV curve rises to an optimum of 0.45 to 0.65 ft and then declines to a maximum suitable depth of 2.90 ft. The IFG curve, on the other hand, rises from a suitability of 0.0 at 0.1 ft to an optimum at all depths of 0.90 ft or greater.

It is evident from the above that the habitat suitability curves developed in the present study generally are not similar to IFG curves; however, they are often similar to curves developed by other investigators. They have been constructed by applying as closely as possible the techniqes described by the IFG, and it is probable that any biases they contain are to a greater or lesser extent, inherent in the method.

The results of Chi-square tests applied to data collected in this study suggest that habitat suitability curves developed in one stream should be used with caution when modeling habitat response in other streams. In most instances, sets of habitat preference data for a given species, life stage and parameter collected in different streams were significantly different and could not be combined. Chi-square values for the comparisons are given in Tables 8, 14, 23, 27, and 31. Velocity preferences seemed to be most similar in various streams followed by depth preferences with substrate preferences being least similar. All of the three data sets which could be combined (Tables 9, 28, and 32) were velocity preferences. If too few fish of a given lifestage of a species were collected in a stream, the data were combined untested with similar data from other streams to construct a habitat suitability curves. The curves, although they represent maximum use of the data may contain biases associated with their multi-stream origins.

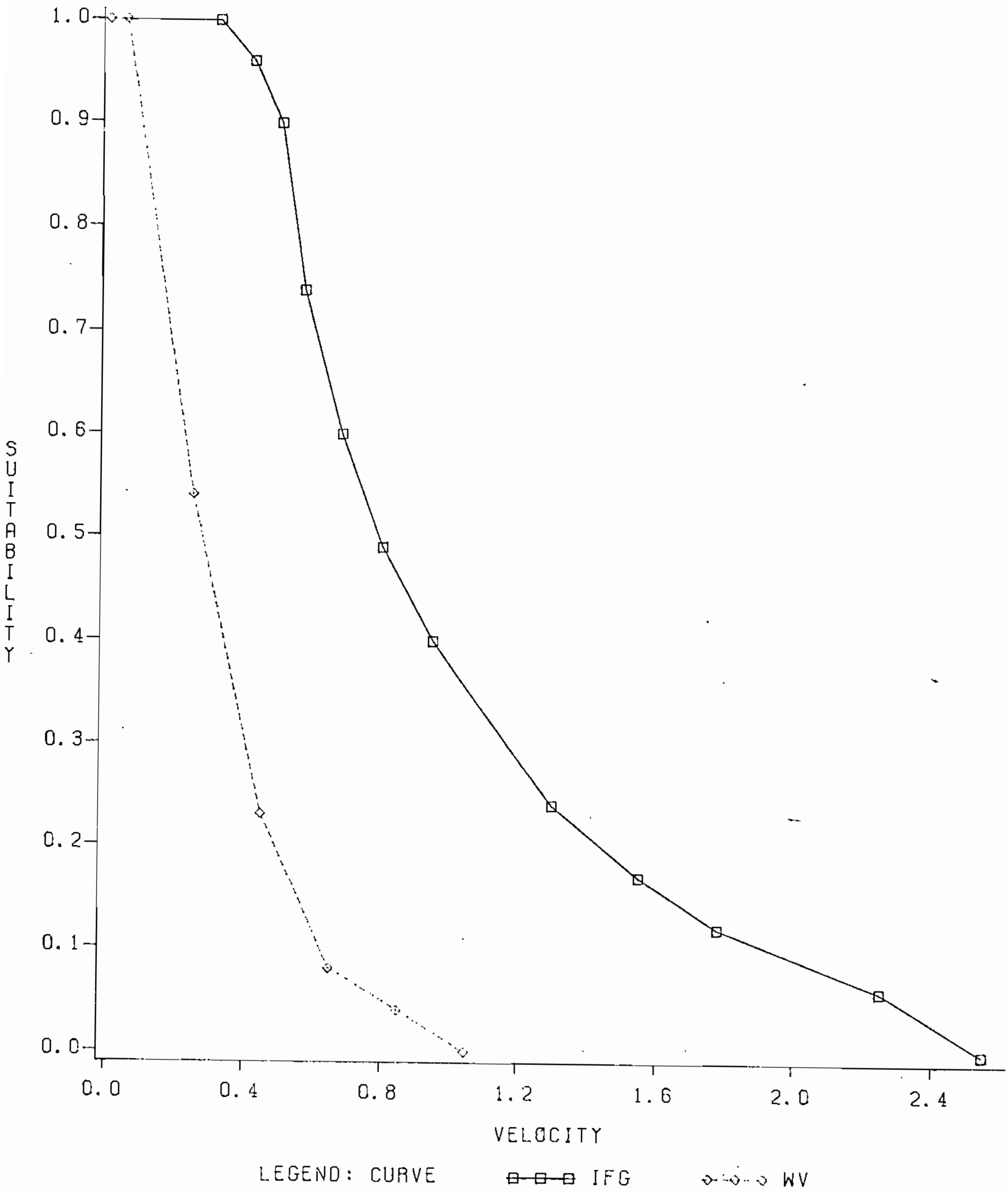


Figure 52. Comparison of habitat suitability curves developed in this study (WV) with curves developed by the IFG. Smallmouth bass, Adult, Velocity.

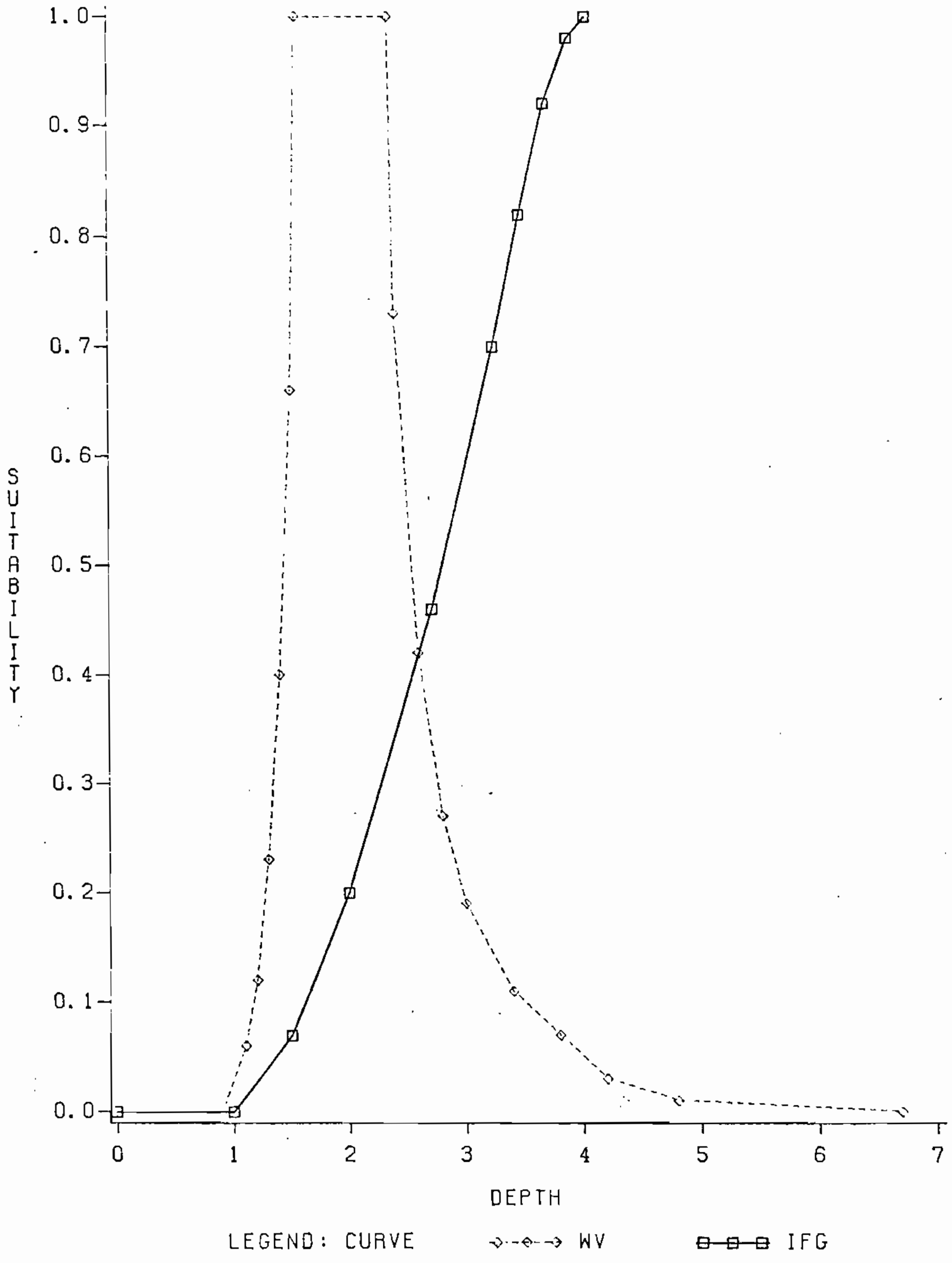


Figure 53. Comparison of habitat suitability curves developed in this study (WV) with curves developed by the IFG. Smallmouth bass. Adult, Depth.

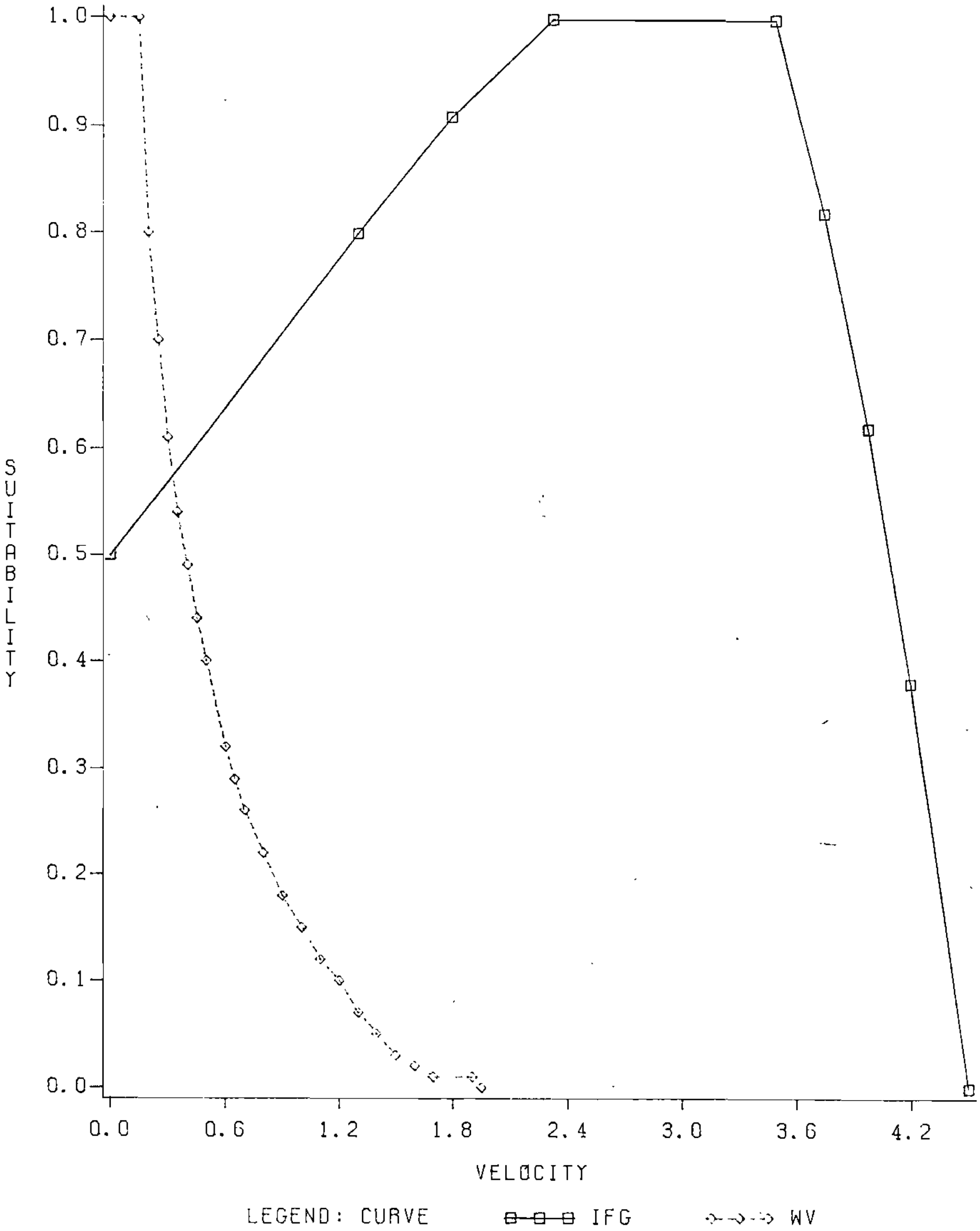


Figure 54. Comparison of habitat suitability curves developed in this study (WV) with curves developed by the IFG. Fantail darter, Adult. Velocity.

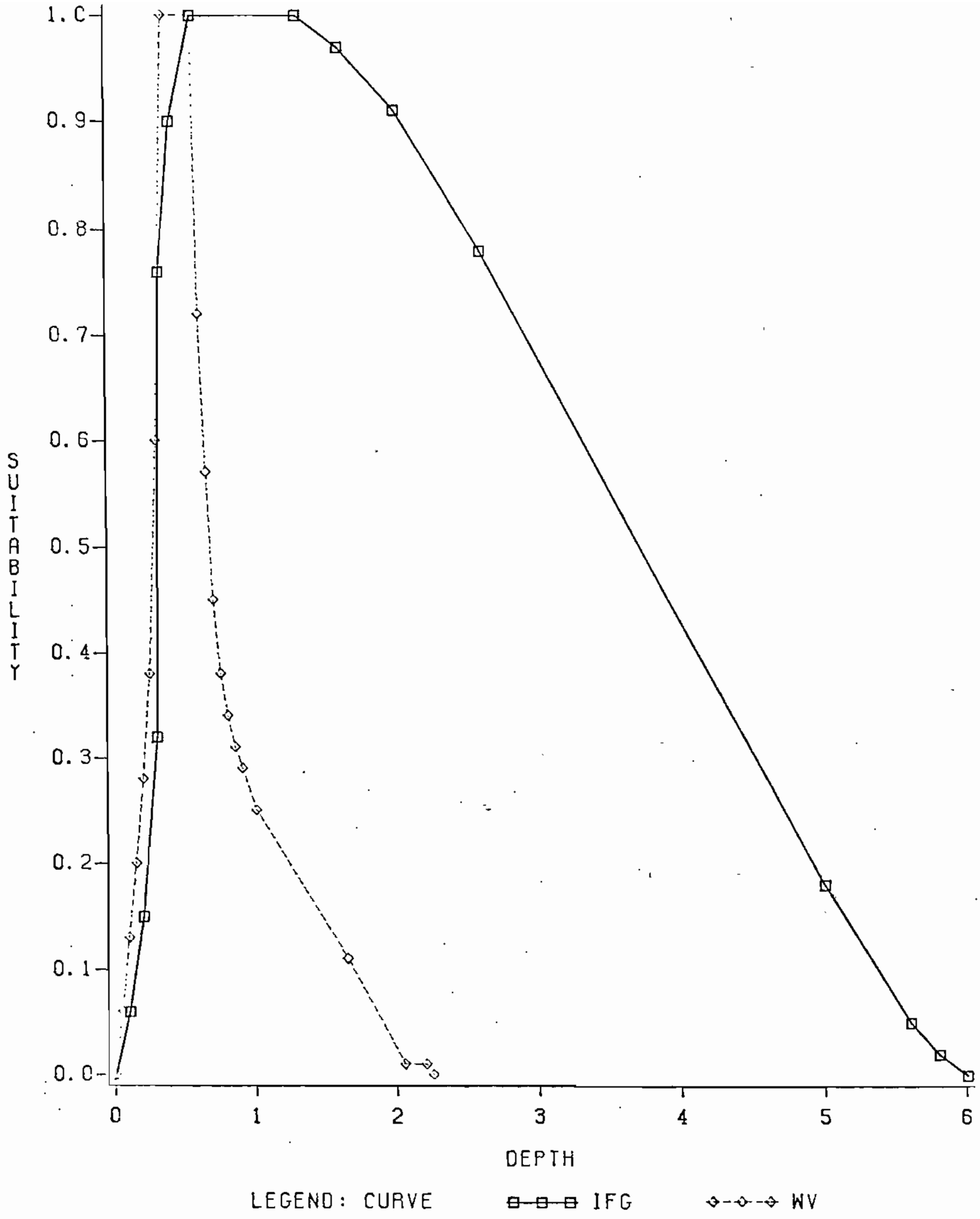


Figure 55. Comparison of habitat suitability curves developed in this study (WV) with curves developed by the IFG. Fantail darter. Adult. Depth.

Comparison of the Montana and IFG Methods

In order to compare the Montana and IFG Methods, some generalizations must be made. First it was necessary to select a range of flows from the habitat response curves generated by the IFG HABTAT program which provides the greatest WUA for each species considered. Since the IFG program considers each life history stage independently, some of these may not fall within this range; however it is felt that the flows selected will provide good to excellent habitat. In addition, the fact that it is possible for habitat to decrease for a certain life history stage with changing flows while increasing for another stage adds to the problem of making exact comparisons. Finally, one must consider the accuracy of the species criteria curves used to generate the WUA's in the IFG Method. There is a considerable amount of bias built into these curves and differences between the two methods can in many instances be the result of this.

Table 43 provides the ranges of flow as selected using the IFG Method compared to those derived from the Montana Method (using the April to September period). As can be seen from this table, most of the ranges derived from IFG at least overlap the Montana flows and in most cases are lower. Exceptions to this are the striped shiner at the Hosterman stations on the Greenbrier the optimum range of which greatly exceeds the range of the Montana Method; the range of smallmouth bass at Rainelle on the Meadow which is considerably less; and the ranges of most of the species on the New River which are lower.

Whether or not the data derived from the IFG Method represent a range of flows which are more suitable for fishes can not be easily determined. Athough the IFG Method represents the current state of the art, as noted above it may contain biases introduced in the construction of habitat suitability curves.

Based upon the data, and upon the writers' knowledge of the streams and species involved, it is felt that the Montana Method will provide reasonable results and compares favorably with the IFG Method. An additional check on this can be made by comparing the results of a West Virginia instream flow study conducted in the Bluestone Tailwaters (Pierce 1971). That study recommended that a minimum flow of 1000 cfs was necessary to protect aquatic life. It further suggested that a range of flows from 1000 cfs to 3000 cfs provided excellent fishing opportunity, and that conditions for both fishing and aquatic life deteriorated rapidly at higher flows. Flows in the good to excellent range were 600 cfs to 1400 cfs in riffle areas and between 2000 cfs and 4000 cfs in pool areas. These results compare favorably with data derived from the Montana Method.

The Montana Method has virtues other than being quick and easy to use. It assures consistency from stream to stream, from state to state, and from biologist to biologist. Using this method, it is easy to adjust to above or below normal water years and maintain stream flows that are appropriate portions of monthly, quarterly, or annual instream supplies of water.

Table 43. Comparison of good to outstanding flows (in cfs) selected from the IFG habitat response curves for the various species compared to the good to outstanding flow range determined using the Montana method.

Stream and Station	Smallmouth Bass	Brook Trout	Stoneroller	Fantail Darter	Striped Shiner	Channel Catfish	Spotted Bass	Montana Method
Greenbrier River								
Island Camp	-	25-50	20-30	10-30	-	-	-	29-44
Hosterman	25-100	-	25-150	100-300	600-1000	-	-	98-146
Seneca	50-100	-	100-300	50-250	25-300	-	-	293-463
Meadow River								
Rainelle	10-50	-	100-200	10-25	10-25	250-300	250-300	211-317
Rt. 19 Bridge	250-500	-	250-500	250-500	250-450	3000-3500	3000-3500	2209-3314
New River								
Bluestone Tailwaters	500-1000	-	500-1000	250-500	250-450	3000-3500	3000-3500	2209-3314
Bass Lake	750-1250	-	500-1000	500-1000	500-1000	2000-2500	2000-2500	3032-4547

Comparison of IFG and Idaho Methods

About 28% of the time, minimum rearing flows predicted by the Idaho method were within the range of flows selected from IFG WUA-discharge curves as providing optimum habitat response for the target species (Table 44). It should be remembered that the optimal discharge ranges selected from the IFG curves represent compromises between the predicted flow needs of all the life stages of a species for which habitat responses were modeled. Although higher or lower flows might not cause severe harm to a species, they would benefit certain life stages at the expense of others.

On the Greenbrier River, no wetted perimeter calculations were made for the Island Camp study reach, so no comparison of methods could be made. On the Hosterman and Seneca State Forest study reaches the minimum rearing flow was within the optimum ranges for three of four species.

On the Meadow River, the Idaho method prediction was not within the optimum flow range for any of the species. On the Rt. 19 bridge study reach the minimum rearing flow was well below the optimum range for all six target species.

On the New River, no minimum rearing flow could be predicted for the Bluestone tailwaters study reach, but on the Bass Lake study reach the predicted minimum rearing flow was within the optimum for three species and below it for three species.

The Idaho method was essentially a step in the development of the IFG method. The WSP (Water Surface Profile) program used in the Idaho method and modified for use with HABTAT, became the IFG-2 program used in the IFG method. Both the WSP and IFG-2 programs require similar input data requiring the same amount of effort to gather, but the former used in the Idaho method yields less detailed information on which to base decisions than the latter used in the IFG method. Therefore, in most situations in which the Idaho method might once have been employed, the IFG method would probably now be the method of choice.

Table 44. Comparison of optimum flows (cfs) selected from the IFG habitat response curves for the target species with minimum rearing flows determined using the Idaho method.

Stream and Station	Smallmouth Bass	Brook Trout	Stoneroller	Fantail Darter	Striped Shiner	Channel Catfish	Spotted Bass	Idaho Method
Greenbrier River								
Island Camp	-	25-50	20-30	10-30	-	-	-	-
Hosterman	25-100	-	25-150	100-300	600-1000	-	-	170
Seneca	50-100	-	100-300	50-250	25-300	-	-	200
Meadow River								
Rainelle	10-50	-	100-200	10-25	10-25	250-300	250-300	60
Rt. 19 Bridge	250-500	-	250-500	250-500	250-450	3000-3500	3000-3500	180
New River								
Bluestone Tailwaters	500-1000	-	500-1000	250-500	250-450	3000-3500	3000-3500	-
Bass Lake	750-1250	-	500-1000	500-1000	500-1000	2000-2500	2000-2500	700

PROBLEMS

A number of unanticipated problems caused delays in the completion of this project. Most of the major problems were associated with the computer programs required for the study. The IFG-4 program used in this study was an early version written for use on CDC computers which was not well documented. When the program was rewritten for IBM computers, it was compiled and stored on tape. When input data were coded according to documentation supplied by the IFG for later versions of IFG-4, the program would not run. Since the original program was not available, much trial and error effort was required to discover the coding mistakes.

More delays were caused by the difficulty of calibrating the IFG-2 program. A total of 17 flows were modeled using IFG-2. A few of them required only 3 to 4 runs to calibrate, but most required more, and a few required as many as 30 runs for calibration. In addition, artificial transects had to be added to the data in order to calibrate many of the flows. When the IFG-2 program was run with HABTAT, the effect of the added transects had to be removed so as not to influence WUA predictions. An additional program, SUBMODC, had to be acquired from the IFG to do this and also to add substrate values which could otherwise not be input to IFG-2.

The SUBMODC program, once acquired, had to be rewritten for IBM computers. The necessity of adapting, debugging and coding data for SUBMODC probably resulted in a 3 to 4 week delay in itself.

The revised SUBMODC program can be obtained by writing to:

Mr. Craig W. Stihler
West Virginia Dept. of Natural Resources
Box 67, Ward Road
Elkins, WV 26241

Management Applications

The IFG incremental method was developed to quantify the impact on fish species resulting from modification in stream flow (Stalnaker 1978). In the past, instream flow methods have tended to specify minimum flow requirements for fishes. The IFG method predicts what will happen to habitat with an increase or decrease in flow by any given increment. It makes these predictions for each life history stage and for each month of the year. Thus the IFG method is not restricted to single-value minimum flows. It is useful for predicting and quantifying impacts and establishing instream flow regimes for specific management objectives.

The IFG method provides information of physical impacts of altered stream flows on fish habitat. These impacts are expressed as an index of surface area of usable habitat for each reach of stream considered. This index relates a particular stream reach to a reach of the same surface area with optimal habitat. These results help the fishery manager determine the potential impact of flow changes on fish habitat and to make judgements about which stream flows meet his management objectives. The IFG method can also be used to predict the environmental impact of water development activities on fisheries by identifying life stages and times of the year which may become limiting to the well-being of a fish species.

The IFG method is well suited for the planning requirements under the Water Resources Council's Principles and Standards. It can be used both for the National Economic Development (NED) account and for the Environmental Quality (EQ) account (Stalnaker 1978). For the NED account, the IFG method quantifies benefits to fish which would result from alternative flow regimes.

These may be translated into monetary benefits by water planners. For EQ accounts the method provides a meaningful measurement of impacts on fish in non-monetary terms.

The IFG method is not designed to generate a minimum flow recommendation. It will not predict the actual numbers or production of fish that will occur in a stream under given conditions. It does predict and quantify the changes in suitability of the physical habitat for various species and life stages under differing flow conditions. The method is not designed to consider chemical or water quality changes.

The Montana method can be applied much the same as the IFG incremental method. Although it does not generate as much empirical data it is felt that it produces good results. It assures consistency from stream to stream, and it will not produce a zero flow recommendation as can occur with the use of other methods (e.g. use of 7-day or 3-day minimum or historic minimum flow criteria). With the Montana method it is easy to adjust to above or below normal water years and to maintain stream flows that are appropriate portions of monthly, quarterly, or annual instream supplies.

SUMMARY

This report has attempted to compare several instream flow methods on West Virginia streams. Data compilation includes a description of the Kanawha Basin and the three streams involved including a brief discussion of stream hydrology and biology. Data necessary for the IFG incremental method and the Idaho method included reach selection, surveying, and physical data collection including velocity, depth and substrate measurements. Data for the determination of flow values used in the Montana method were obtained from the U.S. Geological Survey. The IFG analysis used the IFG-2 and IFG-4 programs to generate habitat estimates. Comparisons were made between the IFG-2, IFG-4, Montana, and Idaho methods.

The following conclusions resulted from this study:

1. The IFG method should be employed in situations where changes in fish habitat due to flow alterations must be quantified and/or reduced to monetary terms or where it is necessary to know the effect of flow alterations on a particular lifestage of a species. The IFG method provides data in a form which can be readily understood by engineers, hydrologists, and water planners.
2. Up-to-date programs and documentation should be obtained from the Instream Flow Group before the IFG method is employed.
3. The IFG-4 hydraulic simulation program was the program most suitable for use with the IFG method. Although it required at least three sets of field measurements at varying flows for accuracy, it provided more accurate models of physical habitat and was easier to use than the IFG-2 program.

4. The IFG-2 model was difficult and time-consuming to calibrate and awkward to use, but it required only one set of field data. Although it was less accurate than the IFG-4 program in modeling physical habitat, it gave the most comparable results when calibrated at high flows.
5. Emphasis should be placed on the elimination of bias from habitat suitability curves as these may represent a large source of potential bias in the IFG method. They should be used with caution in streams other than the one for which they were developed.
6. When simple maintenance of adequate fish habitat is of primary concern, the Montana method is recommended for use. It provided results which apparently were comparable to those obtained from IFG-4, and it was easy to use and apply.
7. The Idaho method is not recommended for use. It made use of the IFG-2 program, but it yielded less information for the same amount of work than the IFG method.
8. In all the methods employed, field data could be collected adequately by field biologists with a minimum of training.

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