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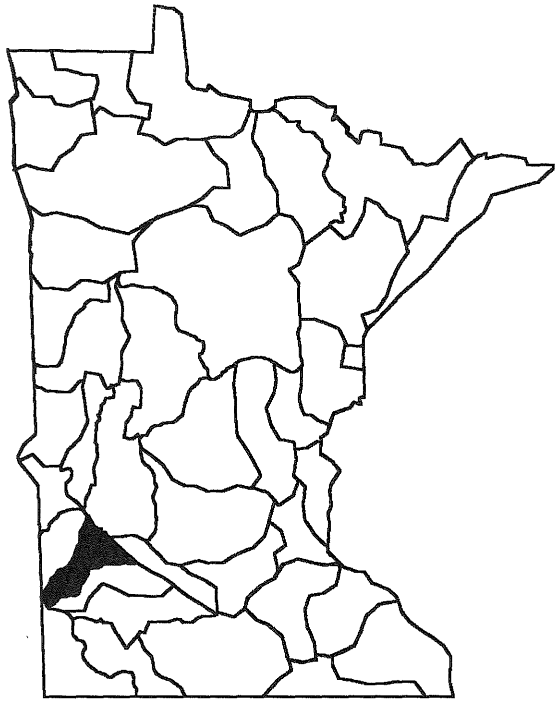
YELLOW MEDICINE RIVER WATERSHED

Recommendations for Streamflow and Habitat Protection



Minnesota Department of Natural Resources
Division of Fish and Wildlife
April 1998

Report to the
Legislative Commission on
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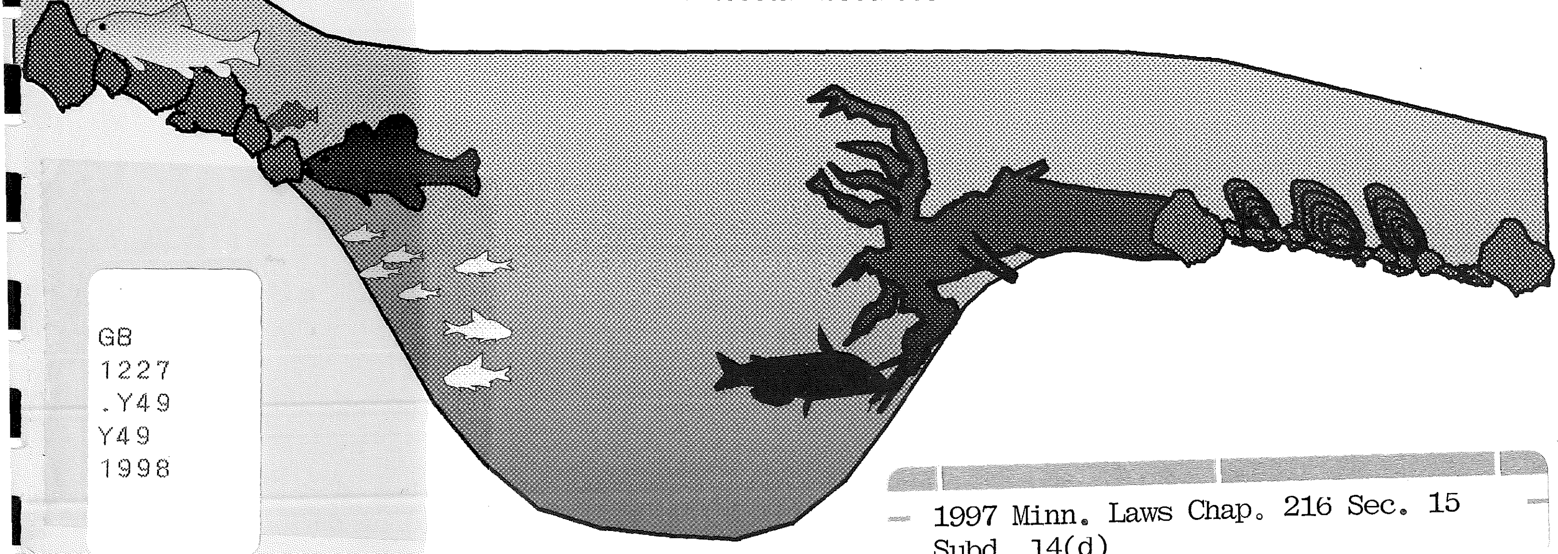

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Yellow Medicine River Watershed: Recommendations for Streamflow and Habitat Protection

Report to the
Legislative Commission on Minnesota Resources

by

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FOREWORD

All Minnesota waters, both running and still, are considered waters of the state, owned by the citizens of Minnesota. Minnesota's "protected waters", however, encompass a more narrow category of lakes, streams, and wetlands, which are regulated by the Minnesota Department of Natural Resources (MNDNR). The rights to extract from these protected waters for offstream uses are reserved primarily for riparian landowners. The MNDNR is mandated (Minnesota Rules 6115.0620) to require riparian landowners to obtain permits for groundwater and surface water appropriations in most situations. Minnesota Statute 116D.04, Subdivision 6 states that "No state action significantly affecting the quality of the environment shall be allowed, nor shall any permit for natural resources management and development be granted, where such action or permit has caused or is likely to cause pollution, impairment, or destruction of the ... natural resources located within the state, so long as there is a feasible and prudent alternative ... Economic considerations alone shall not justify such conduct." When reviewing water appropriation applications, the MNDNR Commissioner is to consider, in part, "the quantity, quality, and timing of any waters returned after use and the impact on the receiving waters involved", historic streamflow records, the "aquatic system of the watercourse, riparian vegetation, and existing fish and wildlife management within the watercourse", and the frequency of occurrence of high and low flows (Minnesota Rules 6115.670, Subpart 2). The commissioner cannot issue a permit if, in part, there is an unresolved conflict between competing users for the waters involved (Minnesota Rules 6115.0670, Subpart 3). Water use permits must be prioritized by the MNDNR according to Minnesota Statute 103G.261 such that certain uses have priority over other uses. Permit applicants are required to either include a contingency plan with their application which describes their planned alternative(s) in the event that appropriations must be restricted to meet instream flow needs or agree to go without appropriating if required.

All permits to appropriate water from rivers must be limited so that consumptive appropriations are not made from rivers during periods of specified low flows to protect instream users (Minnesota Statutes 103G.285, Subdivision 2), and it is the responsibility of the permittee to measure, keep records, and report to the MNDNR the amount of water being appropriated from each source (Minnesota Rules 6115.0750). In addition, the MNDNR's commissioner has been charged (Minnesota Statutes 103G.265) with the responsibility of developing and managing "water resources to assure an adequate supply to meet long-range seasonal requirements for domestic, municipal, industrial, agricultural, fish and wildlife, recreational, power, navigation, and quality control purposes from waters of the state". The commissioner can deem it necessary to terminate a permit(s) "for the conservation of the water resources of the state or in the interest of public health, safety, and welfare" (Minnesota Rules 6115.0750 Subpart 8).

Protection elevations have previously been established for Minnesota lakes. Below the protection elevation, no appropriation from that water basin is allowed. Similarly, the MNDNR was directed in 1977 to set protected streamflows, where a protected flow is defined as the volume of water required to protect instream resources, such as water-based recreation, navigation, aesthetics, fish and wildlife habitat, and water quality. Since streamflows are much more dynamic than are lake levels, determining protected flows is a highly complex task. A survey of MNDNR area fisheries managers showed that low flows are their primary concern in regards to the survival, productivity, or use of the riverine fish community (Olson et al. 1988) so effective protected flows must be established. To date, protected flows have been based on annual hydrologic statistics, usually the annual 90% exceedance flow, which is the flow equaled or exceeded 90% of the time in a river. These flows often provide inadequate protection (Olson et al. 1988; Olson et al. 1989), however, because they are extremely low flows, sometimes drought flows, and do not address the seasonal flow-related needs of the resources they are intended to protect. Therefore, a new method based on protecting stream resources is needed to establish protected flows.

Various methods to establish protected flows were considered by the MNDNR Division of Waters (DOW) (Olson et al. 1988), including Tennant's Method, the Northern Great Plains Resource Program (flow duration analysis), wetted perimeter, and the Instream Flow Incremental Methodology (IFIM). The MNDNR DOW determined that IFIM, the most widely used and accepted instream flow methodology in North America (Reiser et al. 1989), was "the most comprehensive method for predicting changes in habitat from changes in hydraulic and physical parameters" (Olson et al. 1988). Therefore, IFIM is being used by the MNDNR Division of Fish and Wildlife (DFW) to address the flow-related habitat requirements of fish, wildlife, and recreation, and to develop protected flows for Minnesota's streams.

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1.0 INTRODUCTION

The rivers and streams of Minnesota provide an array of resource values, including ecological, recreational, aesthetic, educational, economic, social, and cultural. They harbor a diverse and unique assemblage of habitats and fish and wildlife species which depend upon these habitats. Unfortunately, many resource values are being lost and an alarming number of riverine species are in trouble in Minnesota and across North America due to the degradation of stream habitat (NRC 1992). For example, nearly three fourths of the nearly 200 species of mussels native to North America are considered endangered, threatened, or of special concern, primarily resulting from the loss of riverine habitat (Williams et al. 1993). Similarly, many riverine fishes are vanishing due to degraded habitat (Miller et al. 1989; Williams et al. 1989). The alteration of natural flow regimes has been a major cause of this habitat degradation (Lillehammer and Saltveit 1984; Ward and Stanford 1989; Sparks 1992).

The hydrologic regime of most rivers in North America and throughout the world has been altered by human actions (NRC 1992; Dynesius and Nilsson 1994). Water flowing in rivers has been diverted, abstracted, impounded, regulated by dams, cut-off from floodplains, and altered by land use practices such as wetland drainage and ditching. These alterations have degraded habitat and water quality, created channel instability, altered important ecological processes, interrupted the flux of nutrients and energy, and severed the connectivity among channel, hyporheic, riparian, and floodplain attributes (Junk et al. 1989; Stanford and Ward 1993; Leopold 1994). As a consequence, the biotic communities of rivers have been adversely impacted and resource values have been lost (Bain et al. 1988; Petts 1989).

The goal of the MNDNR Stream Habitat Program is to work with watershed-wide fluvial processes to protect and restore the integrity of riverine habitats and their biotic communities in Minnesota. A major emphasis is on developing a comprehensive approach for establishing protected flows for Minnesota's streams based on the flow-related needs of fish, wildlife, and recreation. This statewide program will provide the necessary framework for setting biologically valid protected flows for water appropriation permits, reservoir and hydropower operations, local water planning, and resource enhancement. Since one of the major impacts of streamflow regulation on instream resources results from changes in habitat conditions, a habitat-based approach, the Instream Flow Incremental Methodology (IFIM)(Bovee 1982), will be used to establish protected flows.

The IFIM, developed by the U.S. Fish and Wildlife Service, is the most widely used method for addressing instream flow issues (Reiser et al. 1989). The Physical Habitat Simulation System (PHABSIM), a group of computer programs within the IFIM, combines hydraulic simulation procedures with species-specific habitat suitability criteria to predict changes in available physical habitat with changes in flow (Milhous et al. 1981; Milhous et al. 1989). Habitat suitability criteria describe the preference of an aquatic organism for the variables depth, velocity, substrate, and cover. These flow-dependent physical habitat features play a vital role in governing the distribution and abundance of stream fishes and macroinvertebrates (Hynes 1970; Gore 1978; Aadland 1993; Hart 1995). Because changes in flow translate into changes in these habitat features, streamflow regulation can adversely alter the structure, function, and composition of stream communities by altering the availability of various habitat types on both spatial and temporal scales (Fisher and LaVoy 1972; Ward 1976; Williams and Winget 1979; Cushman 1985; Bain et al. 1988; Sparks 1992).

Flow recommendations for individual streams will be developed using a community-based approach to IFIM habitat analysis (Leonard and Orth 1988; Aadland 1993). In earlier IFIM work, game fish were typically targeted for modeling in coldwater streams in the western United States, but due to the high diversity of aquatic organisms in the warmwater stream communities in Minnesota, a broader approach must be used. Minnesota's streams may have 45 or more fish species along with a diverse assemblage of mussel and other macroinvertebrate species. Each species-life stage may require a different type of habitat, and preserving these habitats is fundamental in preserving the integrity of the stream ecosystem. Simulating habitat conditions for every species-life stage, however, is not practical. Therefore, representative target species and species-life stages will be selected from each of six habitat-preference guilds identified by Aadland (1993) for Minnesota warmwater streams. This approach assumes that species within a guild have similar habitat versus flow relations so that meeting the flow-related habitat needs of representative target species should also meet the needs of the other species within the same habitat guild. Furthermore, this approach recognizes that certain habitat types (e.g., riffles) are more sensitive to changes in flow than others. By selecting target species and life stages occupying each habitat type, especially flow-sensitive habitat types, the instream flow needs of the entire community can be addressed.

Recommendations for streamflow and habitat protection are being developed for each of Minnesota's 39 major watersheds. This report presents recommendations for the Yellow Medicine

River Watershed. Since it would be impractical to conduct an IFIM analysis for every stream and stream reach within the watershed, flow recommendations developed for individual study sites will be used in conjunction with the stream gaging network to identify and implement protected flows for streams throughout the watershed. Because watershed characteristics (e.g., hydrologic, geologic, climatic, vegetative, land use, and soil characteristics) strongly govern runoff and flow patterns, fish and wildlife assemblages, and recreational opportunities, streams within a watershed should have related instream flow requirements (Leopold and Miller 1956; Platts 1974 and 1979; Burton and Wesche 1977; Bayha 1978; Dunne and Leopold 1978).

2.0 WATERSHED PROFILE

2.1 Watershed Characteristics

The Yellow Medicine River Watershed unit (Figure 1) is one of many within the broad, flat iron-shaped Coteau des Prairies or "highland of the prairies" (Hydrologic Atlas of Minnesota 1959). This plateau, 500 to 800 ft higher than the central plains, "is the most conspicuous surface feature in southwestern Minnesota and sets the topographic stage for the streams of the region" (Waters 1977). Having an area of 1,057 square miles, this watershed unit consists of parts of Lac Qui Parle, Lincoln, Lyon, Redwood, and Yellow Medicine counties. It comprises 670 square miles of the drainage basin of the Yellow Medicine River and 387 square miles that drain directly into the Minnesota River (Hydrologic Atlas of Minnesota 1959).

The Yellow Medicine River originates in Lake Shaokatan at an altitude of about 1776 ft and flows northeast for approximately 110 miles to its junction with the Minnesota River at an altitude of 870 ft. The river has an average fall of 8 ft per mile, with the greatest fall, 350 ft in about 8 miles, occurring along the transition slope from the upland to the lowland plain (Figure 2).

Mean annual precipitation in this watershed is 25.2 inches. The wettest month is June, averaging 4.1 inches of precipitation, and the driest month is January with an average of 0.7 inches. The greatest amount of precipitation to fall in any single month was 13 inches in June of 1890. Several years, however, have had months with zero precipitation; all of these have occurred October - February (Minnesota State Climatology Office 1995).

2.2 Hydrology

Flow data for the Yellow Medicine River were obtained from the United States Geological Survey (USGS) using gage #05313500 near Granite Falls, Minnesota as reported in Gunard et al. (1993). Flow records and hydrologic statistics were available from March 1931 to December 1992 and are summarized in Appendix A. Bankfull flow at the gage is 810 cubic ft per second (cfs).

The river's high gradient combined with a depletion of the watershed's natural storage due to factors such as wetland drainage, conversion of land to row crop agriculture, and a lack of riparian buffer zones has resulted in an unstable hydrologic regime characterized by accentuated high and low flows (Figure 3). Since 1931, 46 days have had zero discharge: one day in 1931, 22 days in 1933, 7 days in 1948, and 16 days in 1959. In contrast, having periods of very high flow is also common for the Yellow Medicine River. The Yellow Medicine River has a mean annual flow of 130 cfs, yet since 1931, 18 years have had periods with recorded flows greater than 2,000 cfs. Indicative of its flashy nature, the Yellow Medicine has a record high flow of 17,200 cfs. For comparison, the Otter Tail River in Otter Tail County, Minnesota is much different than the Yellow Medicine River. The Otter Tail is a very stable river because it still has high natural storage, flowing through several large lakes and wetlands. It has a mean annual discharge of 323 cfs, an unregulated low daily mean of 1.6 cfs, a record high flow of 1,710 cfs, and no zero discharge days (Figure 4). These hydrologic differences among river systems demonstrate the inconsistencies of exceedance statistics when developing flow protection statistics.

2.3 Resource Values

Instream uses within the Yellow Medicine River Watershed include recreational activities such as canoeing, kayaking, tubing, and fishing. Several canoe rental businesses exist in the area. All forms of recreation are limited at times due to the flashy nature of this watershed as both extreme high and low flows can make the rivers unusable to recreationists. The Upper Sioux Agency State Park borders the Yellow Medicine River for approximately three miles, and park users enjoy the river while horseback riding, hiking, and camping. Environmental education groups use the Yellow Medicine River for teaching students through demonstrations and hands-on assignments.

Besides many species of macroinvertebrates, reptiles, amphibians, birds, and mammals, at least

49 species of fish from 11 families and 30 genera (Table 1) and 12 species of mussels (Table 2) depend on rivers in this watershed to meet daily requirements such as food production and cover from predators, and many aquatic species depend on rivers to complete their reproductive cycles. The mussel fauna of the Yellow Medicine River has not been studied in detail, but based on extensive mussel surveys of the Minnesota River (Bright et al. 1990), only one of the 12 species found in the Yellow Medicine River is considered to have a healthy population. Surveys of the Minnesota River from the late 1890s and early 1900s found 39 mussel species, but Bright et al. (1990) found only 20, two of which they classified as healthy populations throughout the river.

Table 1: Fish species present in the Yellow Medicine River in Yellow Medicine County, Minnesota and their habitat guilds by life stage, where YOY=young-of-year, Juv=juvenile, Adt=adult, Spn=spawning, Fing=fingerling, SP=shallow pool, MP=medium pool, DP=deep pool, SR=slow riffle, FR=fast riffle, and RW=raceway.

Common Name	Scientific Name	Habitat Guilds					
		YOY	Juv	Adt	Spn	Fry	Fing
Shortnose gar	*Lepisosteus platostomus*			DP			
Gizzard shad	*Dorosoma cepedianum*		MP	MP			
Northern pike	*Esox lucius*	SP		DP			
Central stoneroller	*Campostoma anomalum*	FR	SR	SR	SR		
Largescale stoneroller	*Campostoma oligolepis*	FR	SR	SR	FR		
Spotfin shiner	*Cyprinella spiloptera*	SR		SR	MP		
Common carp	*Cyprinus carpio*	SP	MP	MP			
Common shiner	*Luxilus cornutus*	SP	DP	MP			
Hornyhead chub	*Nocomis biguttatus*	SP	MP	RW	SP		
Emerald shiner	*Notropis atherinoides*	SP		SR			
River shiner	*Notropis blennius*	FR		SR	FR		
Bigmouth shiner	*Notropis dorsalis*	SP		SR			
Spottail shiner	*Notropis hudsonius*	SP		MP	SP		
Rosyface shiner	*Notropis rubellus*			RW			
Sand shiner	*Notropis stramineus*	SP		SP	SR		
Mimic shiner	*Notropis volucellus*	SP		SR			
Bluntnose minnow	*Pimephales notatus*	SP		SP			
Fathead minnow	*Pimephales promelas*	SP		SP	SP		
Bullhead minnow	*Pimephales vigilax*			FR			
Blacknose dace	*Rhinichthys atratulus*	SP		SR	FR		
Creek chub	*Semotilus atromaculatus*	SP	DP	MP	SR		
River carpsucker	*Carpiodes carpio*	SP	DP	DP	FR		
Quillback	*Carpiodes cyprinus*	SP	MP	MP	SP		
White sucker	*Catostomus commersoni*	SR	SR	RW	DP		
Northern hog sucker	*Hypentelium nigricans*	SP	FR	RW	SR		
Bigmouth buffalo	*Ictiobus cyprinellus*	SP		MP			
Silver redhorse	*Moxostoma anisurum*	SP	DP	RW	FR		
Golden redhorse	*Moxostoma erythrurum*	SP	MP	DP	SR		
Shorthead redhorse	*Moxostoma macrolepidotum*	SR	RW	RW	FR		

Greater redhorse	*Moxostoma valenciennesi*	SP	DP	RW	SR		
Brook stickleback	*Culaea inconstans*	SP		SP			
Black bullhead	*Ameiurus melas*	MP	MP	MP			
Channel catfish	*Ictalurus punctatus*	SR	MP	MP			
Stonecat	*Noturus flavus*	FR	FR	FR			
Flathead catfish	*Pylodictis olivaris*	SR					
Rock bass	*Ambloplites rupestris*	MP	MP	SP	MP		
Green sunfish	*Lepomis cyanellus*	SP	SP	SP			
Orangespotted sunfish	*Lepomis humilis*	SP	SP	SP			
Smallmouth bass	*Micropterus dolomieu*		RW	RW	MP	SP	SR
White bass	*Morone chrysops*	MP		MP			
Rainbow darter	*Etheostoma caeruleum*	FR		FR	FR		
Fantail darter	*Etheostoma flabellare*	SR		FR	FR		
Johnny darter	*Etheostoma nigrum*	SP		SR	SP		
Banded darter	*Etheostoma zonale*	FR		FR	FR		
Blackside darter	*Percina maculata*	SP		SP			
Slenderhead darter	*Percina phoxocephala*	SP		FR	FR		
Sauger	*Stizostedion canadense*	MP	MP	DP	RW		
Walleye	*Stizostedion vitreum*	MP	MP	DP	RW		
Freshwater drum	*Aplodinotus grunniens*	MP	DP	RW			

Table 2: Mussel species present in the Yellow Medicine River in Yellow Medicine County, Minnesota and their habitat guilds where sufficient information has been collected to determine.

Common Name	Scientific Name	Habitat Guild
White heelsplitter	*Lasmigona complanata*	undetermined
Fat mucket	*Lampsilis siliquiodea*	Raceway
Pocketbook	*Lampsilis ovata ventricosa*	Slow riffle
Wabash pigtoe	*Fusconaia flava*	Raceway
Fragile papershell	*Leptodea fragilis*	undetermined
Mucket	*Actinonaias carinata*	Raceway
Threeridge	*Amblema plicata*	Raceway
Mapleleaf	*Quadrula quadrula*	undetermined
Black sandshell	*Ligumia recta*	Raceway
Giant floater	*Anodonta grandis*	undetermined
Squawfoot	*Strophitus undulatus*	Raceway
Cylindrical papershell	*Anodontoides ferussacianus*	undetermined

3.0 METHODS

3.1 Site Selection

In general, the PHABSIM study sites chosen by the Stream Habitat Team for determining protected flow levels and protecting instream habitat are atypical sections of the rivers within a watershed. They do, in fact, represent areas that, while far from pristine, are healthier than much of the watershed. Site selection is based on several criteria including a) ecological context of the river and gradient, b) habitat diversity, c) channel stability, d) resource values, and e) presence of hydraulic controls. Yellow Medicine River Watershed sites were selected based on the following.

a) Ecological context and gradient. The Yellow Medicine River has a valuable fish community, mussel community, and fishery. Just as importantly, it is a key feeder stream for the Minnesota River. The Minnesota, like many larger rivers, is low gradient over much of its length. Consequently, it has few riffles and rapids, most of which were inundated or disconnected from the lower Minnesota River many years ago by the construction of the Granite Falls and Minnesota Falls dams. In addition to being the preferred habitat types for most mussel species, riffles and rapids are important spawning habitats for a large proportion of the fishes in the Minnesota and Yellow Medicine rivers, including walleye, sauger, shovelnose sturgeon, and most of the darter and sucker species. Large numbers of fish migrate up the Yellow Medicine River from the Minnesota River to spawn, and any of these migrating fish species may serve as the hosts necessary to perpetuate specific mussel species. The magnitude of this spawning activity is impressive and illustrates the importance of these high gradient portions of the Yellow Medicine River. The fish spawning extends into August for some species. After the spawning season has ended, the Yellow Medicine provides rearing habitat for the fry and fingerlings. Of the larger tributaries of the Minnesota River, the Lac Qui Parle, Chippewa, and Pomme de Terre are disconnected from the lower Minnesota River by dams at Lac Qui Parle and Granite Falls. The Redwood River would provide similar high gradient habitat as the Yellow Medicine River but has a natural barrier at Redwood Falls. The Cottonwood River, which has recently been reconnected to the lower Minnesota by the removal of Flandrau Dam, is the only large, high gradient tributary which provides ecological functions similar to the Yellow Medicine. Habitat types found in low gradient reaches, such as pools, tend not to change in response to moderate changes in flow (i.e., pools remain pools as flow changes). Higher gradient reaches, which are often composed of riffles, are more sensitive to changes in flow: as flow increases, riffle habitat shifts to raceway habitat, and as flow decreases, riffle habitat becomes shallow pool habitat or dewatered. Therefore, higher gradient reaches are preferable when selecting study sites because they are flow sensitive. Consequently, protection of these sites will protect all of the streams within the watershed as well. If we are to protect stream ecosystems, it is essential that these high gradient reaches be protected.

b) Habitat diversity. Selecting sites with diverse habitat allows for habitat analysis of the diverse fish and other aquatic life in the Yellow Medicine River. This habitat diversity is not found in degraded portions of the river. Therefore, the sites chosen do not represent degraded segments of the Yellow Medicine River Watershed. The riffles and pools found in the sites, however, are representative of riffles and pools found in much of the watershed. The choice of high quality sites for habitat studies is important in all fish and wildlife studies. A big game biologist, for instance, is not likely to focus his or her protection efforts on degraded areas such as parking lots but rather on remaining suitable habitat such as wood lots and meadows.

c) Channel stability. Site stability is important because it is an assumption of the model. While even pristine channels will change over time, these changes are slow, and the channel type and relative proportions of different habitat types remain similar. Degraded, unstable channels change more rapidly, and channel types continue to change until a stable bed form is reached (Leopold et al. 1964). Although neither of the Yellow Medicine sites has an exceptionally stable channel, hydraulic data collection was completed at each site within a field season, thus avoiding major changes which often accompany spring floods.

d) Resource values. Healthier segments of rivers generally have higher resource values than do more degraded segments and are, therefore, more critical to protect. Gradient, habitat diversity, quality of the fishery, and recreational use are all related. The lower Yellow Medicine site has very high resource values due in part to its proximity to the Upper Sioux Agency State Park. This site, which is also high gradient with diverse habitats, is one of the most heavily used portions of the river. The upper site, while not having the high level of recreational use of the lower site, does have high gradient and diverse habitat.

e) Hydraulic controls. Hydraulic controls are an important attribute of a suitable site. Without these controls, calibration of the model is difficult or impossible. Both of the sites chosen had good hydraulic controls, resulting in quality models.

The upper and lower study sites are both on the main stem of the Yellow Medicine River. The upper Yellow Medicine River site is in Alta Vista Township, Lincoln County (T113N R44W S29), about 24 miles downstream from Lake Shaokatan (Figure 1), and has a bankfull flow of 67 cfs. The predominant land use in the area is pasture; the site is on privately owned, pastured land, open and grassy on one side and wooded with mature oaks on the other. Based on Rosgen's (1994) stream classification, this site is in the B6 category because it is moderately entrenched, has a moderate width/depth ratio and moderate sinuosity, and the predominant substrate type is silt/clay. This stream type is dominated by riffles (Rosgen 1994).

The lower site is southeast of the city of Granite Falls in Hawk Creek Township, Yellow Medicine County (T115 R38W S29), approximately two miles above the river's confluence with the Minnesota River (Figure 1). The predominant land use in this area is row crop agriculture and parkland. This site is bordered on the north by the Upper Sioux Agency State Park and on the south by private land in row crops and woods. This site is a C3 stream type, being slightly entrenched and dominated by cobble substrate, and having a high width/depth ratio and high sinuosity. This stream type is characterized by riffle/pool sequences and broad, well-developed floodplains, and they are susceptible to accelerated bank erosion (Rosgen unpublished data), although the bank erosion can be reduced through proper maintenance of riparian vegetation. In addition, the lower site is monitored by a USGS gage, and fish habitat suitability data have been collected at this site since 1988 by the Stream Habitat Program so site specific habitat suitability criteria are available.

3.2 Transect Selection

Transect locations were selected to characterize the hydraulic and microhabitat conditions of each site, and transects were positioned perpendicular to flow across each major habitat type (e.g., pools, riffles). Nine transects were established at the upper site (Figure 5a) and 16 at the lower site (Figure 5b). Transects were numbered consecutively with transect one being the downstream-most transect. Transect descriptions and distances are summarized in Appendices B1 and B2. At the upper site, the distance between the upstream-most and downstream-most transects is 243.0 ft, and the thalweg elevation drops 1.8 ft, making the gradient 39.1 ft per mile. At the lower site, the distance between the upstream-most and downstream-most transects is 1263.5 ft, and thalweg elevation drops 3.6 ft, making the gradient 15.0 ft per mile.

3.3 Field Data

Hydraulic and microhabitat data for use in PHABSIM were collected following the guidelines established by Trihey and Wegner (1981) and Bovee (1982). The standard application of PHABSIM modeling involves collecting stage-discharge data (water surface elevations and corresponding discharges) at three target flows (low, medium, and high) and water velocity, substrate composition, cover, and channel cross section data sets at one or more of these flows. Our study design included collecting complete stage-discharge and water velocity data sets at three target flows and substrate composition, cover, and channel cross section data sets at one flow. When modeled in PHABSIM, measured flows can be extrapolated to simulate flows from 40% lower to 250% higher than the measured flows (Milhous et al. 1981). When selecting target flows, an effort was made to ensure that simulated flows met or overlapped and that, at sites close to a USGS gage, the lowest simulated flow was less than or equal to 10% of the mean annual flow. The three data sets were collected at discharges of 16, 114, and 267 cfs at the lower site, and 7, 12, and 24 cfs at the upper site.

Field data were collected in the following sequence: 1) transects, benchmark, and headstakes were established; 2) a closed level loop was surveyed to establish the elevation of the headstakes; 3) water surface elevations were surveyed at each transect; 4) water velocity and depth were measured along each transect; 5) substrate and cover were measured along each transect; 6) channel cross sections were surveyed at each transect; 7) measurements were taken to prepare a site map so that the site could be reestablished if headstakes were lost; 8) station index values were determined and weighting factors were assigned for each transect, and 9) each transect was photographed. Steps three, four, and nine were repeated at all three target flows. Quality control was ensured by using standardized data sheets, careful review of field data, and professional training of personnel in field data collection techniques.

3.3.1 Transect Measurements

3.3.1.1 Water Surface Elevations and Channel Cross Sections

Water surface elevations and channel cross sections were surveyed along each transect to the nearest 0.01 ft with a level and stadia rod using differential leveling techniques (Brinker and Taylor 1963; Bouchard and Moffitt 1965). All elevations at each study site were referenced to a common benchmark (one at each site) which was assigned an elevation of 100.00 ft. A steel fence post driven into the bank at each site was used as a benchmark for the duration of the study. Permanent headstakes were established at both ends of each transect at an elevation high enough that they would still be above the water level at the highest simulated flow. Headstakes were used as points of known elevations for surveying water surface elevations after a closed level loop was used to establish headstake elevations. The level loop closure error was within the acceptable limits of third order accuracy as defined by the equation: maximum closure error = $0.05(M)^{0.5}$ ft, where M = length of level loop in miles (Trihey and Wegner 1981). Water surface elevations were measured near the water's edge along each transect at all three target flows. A permanent staff gage, established at each study site in a protected area where disturbance by humans or floating debris was not likely, was monitored hourly to ensure that water surface elevations at all transects were surveyed during steady flow. Thalweg elevations and measured water surface elevations at each target flow are provided in Appendices C1 and C2.

Channel cross sections were surveyed at each transect. After stretching a measuring tape across a transect, the elevations of dry cells along the tape from each headstake to the nearer edge of water were surveyed. Substrate and cover (see section 3.3.1.2) were also measured at each cell, where a cell is a square that extends half the distance to each adjacent point at which data were collected. Cells were placed wherever a noticeable change in elevation, substrate, or cover occurred. Channel cross sections for the lower and upper sites are presented in Appendices D1 and D2.

3.3.1.2 Microhabitat

Microhabitat data (depth, velocity, substrate, and cover) were collected at wet cells along each transect. The number and location of cells depended on hydraulic and channel structure characteristics. A minimum of ten to twenty measurements is recommended for determining velocity distributions and 20 to 30 for calculating discharge (Trihey and Wegner 1981). At least 30 measurements were generally taken along each transect. To ensure that habitat measurements were taken during steady flow, a temporary staff gage established at each transect was read immediately before taking and upon completing measurements along each transect.

Mean column velocity was measured at 0.6 of the depth in water less than 2.5 ft deep and at 0.2 and 0.8 of the depth in water 2.5 ft deep and deeper (Buchanon and Somers 1969). Velocity was measured with Price AA or Pygmy current meters attached to top-setting wading rods equipped with digitizers or with Marsh McBirney current meters attached to top-setting wading rods. Price AA meters were equipped with optic units. All meters were spin-tested before each day's use to ensure that they were in good working order. The Marsh McBirney was calibrated prior to use. Water depth was measured to the nearest 0.1 ft with a top setting wading rod. Measured velocities are graphed in Appendices D1 and D2.

Substrate and cover were described according to criteria (Aadland 1993) in Table 3. The percent of the cell area covered by each substrate type was visually estimated to the nearest 10 percent in each cell.

Table 3: Dimensions of substrate categories and descriptions of cover categories (Aadland 1993).

SUBSTRATE	DIMENSION	COVER	DESCRIPTION
Organic detritus	organic matter	Undercut	undercut bank
Silt	<0.0024"	Vegetation	rooted or unrooted plants
Sand	0.0024 - 0.125"	Wood	woody matter
Gravel	0.125 - 2.5"	Boulder	boulders >4" above streambed
Cobble	2.5 - 5"	Flotsam	thick foam on water surface
Rubble	5 - 10"	Overhang	canopy or overhead structure
Small boulder	10 - 20"	Edge	a break from high to low velocities
Large boulder	20 - 40"		
Bedrock	>40"		

3.3.1.3 Station Index Values, Weighting Factors, and Site Maps

Each transect was assigned a station index value and a weighting factor. A station index value identified the distance from a particular transect to the downstream-most transect and was measured between adjacent transects at water's edge along both banks. Station index values were used with channel cross section and water surface elevations to establish gradients. Weighting factors described what percentage of the distance to the adjacent transects upstream and downstream the microhabitat measurements taken along each transect were extended during computer modeling. Station index values and weighting factors are provided in Appendices B1 and B2.

A map was drawn to scale for each study site using the following measurements: 1) distance between headstakes of adjacent transects along both banks, 2) distance between the left and right bank headstakes at each transect, 3) distance between the left bank headstake and the left edge of water, between the right bank headstake and the right edge of water, and between the left and right edges of water at each transect, and 4) diagonal (over water) distances between adjacent headstakes. Photographs were taken of each transect at each flow.

3.4 Computer Modeling

Field data were collected such that any computer model or combination of models within PHABSIM could be used as needed. Models were developed separately for each site. Fifteen flows were simulated at the upper site, ranging from 3 to 60 cfs. Twenty-eight flows were simulated at the lower site, ranging from 7 to 670 cfs. The PHABSIM input files, the final models and options used, and calibration details are available upon request.

3.4.1 Hydraulic Modeling

The first step in hydraulic modeling was to develop a stage-discharge relation using the empirical data collected at the three measured calibration flows. Water surface elevations were then modeled for simulated flows. There are three water surface models available in PHABSIM: IFG4, which uses a stage-discharge regression; MANSQ, which uses Manning's equation; and WSP, which is a step-backwater method. All three models were run and the predicted water surface elevations were compared and scrutinized, and the best model was chosen for each transect at each flow. Decisions were based on the difference between the predicted elevations and the measured elevations at the calibration flows, the orientation of the slope between contiguous transects (the slope must be positive), and comparisons of predicted elevations across the range of flows at each transect (as discharge increases, the predicted water surface elevations must increase).

After the water surface elevation models were developed and calibrated, velocity distributions were simulated using the derived stage-discharge relations and the IFG4 model, which predicts velocities based on Manning's equation. Velocities were simulated three times, using the low, medium, and high measured velocity sets separately. For each velocity data set, the measured and predicted velocities at the calibration flows were compared and the velocity adjustment factors (which compensate for changes in roughness as discharge increases or decreases) were examined to determine which velocity data sets where most reliably predicting velocities at what flows.

For the lower site, each of the three velocity data sets predicted velocities most reliably throughout their respective ranges (i.e., the low flow data set best predicted velocities for low simulated flows, the medium for medium flows, etc.) so all three were used for habitat simulation. For the upper site, each of the three velocity data sets predicted velocities most reliably throughout their respective ranges (i.e., the low flow data set best predicted velocities for low simulated flows) so all three were used for habitat simulation. For the lower site, the high flow data set predicted velocities most reliably; therefore, it was used for habitat simulation at all simulated flows. Weighted distance averages were used to model habitat for simulated flows that overlapped between the data sets.

3.4.2 Habitat Modeling

An ongoing project of the MNDNR Stream Habitat Program is developing habitat suitability criteria for fish, mussels, and other macroinvertebrates. These criteria describe an organisms preference for the habitat variables depth, velocity, substrate, and cover. Habitat preference data have been collected in spring, summer, and winter to develop criteria appropriate to the seasons being modeled. These data have been gathered for 211 fish species-life stages at 20 sampling sites since 1987, and habitat suitability criteria have been developed for 81 species and species-life stages of fish (Aadland et al. 1991; MNDNR, unpub. data). Habitat suitability criteria for nine freshwater mussel species have also been developed at six sampling sites since 1992 for the variables depth, velocity, and substrate, and for other macroinvertebrates at three sampling sites for the variables of depth, velocity, substrate, and cover (MNDNR, unpub. data). For this watershed, suitability curves for larval fish (<25 mm) were created using only data collected at the Yellow Medicine sampling site. This was done because cover preferences seemed unique and enough observations had been made in the Yellow Medicine River to develop site specific criteria. The preference curves and histograms for the guild representatives modeled for the Yellow Medicine River Watershed are shown in Appendix E.

Representative target species-life stages known to occur in the Yellow Medicine River were selected from each of six habitat-preference guilds for habitat modeling in three seasons for the upper site and five seasons for the lower site. Habitat-preference guilds were identified by Aadland (1993) for warmwater and coolwater streams of Minnesota. Species and species-life stages were assigned to a habitat guild based on the habitat type in which their densities (individuals per area sampled) were highest. The habitat types were defined as: slow riffle (<60 cm deep, 30-59 cm/s velocity); fast riffle (<60 cm, ≥60 cm/s velocity); raceway (60-149 cm deep, ≥30 cm/s velocity); shallow pool (<60 cm deep, <30 cm/s velocity); medium pool (60-149 cm deep, < 30 cm/s velocity); and deep pool (≥150 cm deep) (Aadland 1993). These habitat types were also modeled to examine the relation between discharge and the availability of habitat types in the Yellow Medicine River Watershed. Seasons were delineated based on historic regional temperature data combined with known preferred spawning temperatures. Appropriate species-life stages from the target list were selected for each season.

For the upper site, recommendations were made for three seasons: 1 April - 15 May, 16 May - 4 November, and 5 November - 31 March. The 16 May - 4 November season was originally divided into two seasons based on temperature data, but the selected guild representatives were identical so the two seasons were combined. Thirteen guild representatives were selected (Table 4a). Preference curves used for the 5 November - 31 March season are either winter specific curves or winter sampling has verified that summer and winter habitat use are the same. No guild representatives were modeled for deep pool habitat because this habitat type is not present at this site within the range of simulated flows.

For the downstream site, recommendations were made for five seasons: 1 April - 15 May, 16 May - 30 June, 1 July - 31 July, 1 August - 4 November, 5 November - 31 March. The 16 May - 4 November period was divided into three seasons to accommodate spawning, fry, and fingerling life stages of smallmouth bass (*Micropterus dolomieu*), none of which occurs throughout the time period. Spawning smallmouth bass are present in late spring but not during the summer months, and fry, while present from late spring through July, generally achieve fingerling status by 1 August. Smallmouth bass fry were modeled, however, in all four seasons from 16 May - 31 March. While smallmouth bass fry are not present throughout this period, they act as guild representatives for other species that are. Twenty-two guild representatives were selected (Table 4b), but no species life stages were modeled for deep pool habitat because this habitat type is not present within the site until discharge exceeds 400 cfs. As with the upper site, preference curves used for the 5 November - 31 March season are either winter specific curves or winter sampling has verified that summer and winter habitat use are the same.

Table 4a. Habitat-use guild representatives modeled for upper site by season.

Habitat Type	5 November - 31 March	1 April - 15 May	16 May - 4 November
Shallow Pool	Sand shiner, Adult Leopard frog Orange-spotted sunfish, Adult	Hornyhead chub, Spawning	Rock bass, Adult Sand shiner, Adult Sand shiner, YOY Larval fish Orange-spotted sunfish, Adult
Medium Pool	Northern pike, Adult		Northern pike, Adult
Raceway		Walleye, Spawning	
Slow Riffle			Blacknose dace, Adult
Fast Riffle		Slenderhead darter, Spawning	Rainbow darter, Adult

Table 4b. Habitat-use guild representatives modeled for lower site by season.

Habitat Type	5 Nov - 31 Mar	1 Apr - 15 May	16 May - 30 Jun	1 Jul - 31 Jul	1 Aug - 4 Nov
Shallow Pool	Sand shiner, Adult Leopard frog Smallmouth bass, Fry		Bluntnose minnow, YOY Smallmouth bass, Fry Larval fish	Bluntnose minnow, YOY Smallmouth bass, Fry Larval fish	Smallmouth bass, fing. Smallmouth bass, Fry Bluntnose minnow, YOY Larval fish
Medium Pool	Northern pike, Adult Walleye, Adult Walleye, Juv.		Northern pike, Adult Smallmouth bass, Spawning Walleye, Adult Walleye, Juv.	Northern pike, Adult Walleye, Adult Walleye, Juv. Channel catfish, Adult Channel catfish, Juv.	Northern pike, Adult Walleye, Adult Walleye, Juv. Channel catfish, Adult Channel catfish, Juv.
Raceway	Wabash Pigtoe	Walleye, Spawning Wabash Pigtoe	Smallmouth bass, Juv. Wabash Pigtoe	Smallmouth bass, Juv. Wabash Pigtoe	Smallmouth bass, Juv. Smallmouth bass, Adult Wabash Pigtoe
Slow Riffle			Banded darter, YOY Central stoneroller, Adult	Banded darter, YOY Central stoneroller, Adult Channel catfish, YOY	Banded darter, YOY Central stoneroller, Adult Channel catfish, YOY
Fast Riffle		Banded darter, Spawning	Banded darter, Adult Rainbow darter, Adult	Banded darter, Adult Rainbow darter, Adult	Banded darter, Adult Rainbow darter, Adult

The habitat suitability criteria were combined with the results from hydraulic modeling in the HABTAE model to calculate weighted usable area (WUA), an index of habitat availability or quantity, for the selected guild representatives at each simulated flow. WUA was calculated as:

$$\text{WUA} = \sum_{I=1}^{n} S_i \, A_i$$

where: S_i = composite suitability weighting factor,
A_i = surface area of the cell, and
n = total number of cells within the study site.

The composite suitability weighting factor, S_i, was calculated using the multiplicative aggregation function $S_i = S_s * S_v * S_d$ where S_s, S_v, and S_d were suitability criteria values ranging from 0.0 to 1.0 for substrate and cover (combined), velocity, and depth for each individual cell. WUA was normalized on a scale of zero to one so that the WUA versus discharge relation peaked at a value of one for each species-life stage modeled.

3.5 Selecting the Community-based Flow

Our recommended flows are designed to protect the diverse habitat of riverine communities. While a recommended flow will not likely be ideal for all guild representatives, it is the flow that provides the highest diversity of habitat conditions suitable for the entire riverine community. On the normalized WUA graphs, this is the single flow that provides the most habitat for all species life stages modeled in a particular season. The point at which this occurs is termed the community-based flow (CBF), and the two guild representatives that intersect at this point are called the drivers. Guild representatives excluded when choosing the CBF are those whose WUA is bimodal, zero across the range of simulated flows, or does not change across the range of simulated flows. To illustrate this point using figure 6, the CBF occurs at the intersection of WUA for Species A, which is habitat-limited at high flows, and Species C, which is habitat-limited at low flows. In this example, all three species would have at least 75% of their maximum available habitat at 41 cfs. Although none of the species' maximum amount of habitat occurs at 41 cfs, this is the flow that best meets the habitat needs of the entire aquatic community. The seasonal CBFs served as the basis for establishing protected flows.

3.6 Implementing Protected Flows

3.6.1 Relating the CBF to Stream Gages

Because protected flows are going to be monitored and implemented at calibrated stream gages within the watershed, the CBFs developed at the study sites were related to these gages. This was done by relating the drainage area at each study site to the drainage area of the nearest gage. To adjust the CBF discharge to the corresponding discharge at the gage, the CBF was multiplied by the ratio of the drainage area of the gage to the drainage area of each study site. This approach was based on the observation that drainage area influences the water yield from, and the number and size of streams within, a watershed (Gordon et al. 1992). By regressing drainage area against mean annual flow for eleven USGS gage stations in west central Minnesota, we found that 97% of the variability in mean annual flow among these gages could be explained by drainage area. Similarly, we found that 96% of the variability in the annual Q90 and 97% of variability in the annual Q10 could be explained by drainage area. Regressing bankfull flows against drainage area for several southwestern Minnesota streams yielded similar results.

The drainage areas at USGS gages were obtained from the annual Water Resources Data Reports (Mitton et al. 1996), and the drainage area at each study site was calculated using data obtained from the Land Management Information Center (LMIC 1995), which reports the cumulative drainage area at any of more than 5600 minor watersheds in Minnesota. For the Yellow Medicine River Watershed, a watershed-wide recommendation is made by relating the seasonal CBF from each study site to USGS gage #05313500 on the Yellow Medicine River near Granite Falls, Minnesota (Figure 7). At the gage, the drainage area is 417,920 acres (Mitton et al. 1993). At the lower site, which is a short distance below the USGS gage, the drainage area is 429,642 acres, and at the upper site, which is a above the USGS gage, the drainage area is 34,542 acres. The upper site's CBFs were multiplied by 12.099 (417,920 ÷ 34,542) and the lower site's CBFs were multiplied by 0.973 (417,920 ÷ 429,642) to apply the recommendation to the USGS gage.

3.6.2 Bracket Approach for Implementing Protected Flows

The following bracket system for establishing protected flows is being recommended by the

Division of Fish and Wildlife to determine when appropriations would be limited or suspended. When the discharge at the gage is greater than 150% of the CBF (the CBF adjusted to the gage), appropriators upstream from the gage would be allowed to withdraw their total permitted amount. When the discharge at the gage is between 50% and 150% of the CBF, total appropriations upstream from the gage would be limited to 20% of the CBF, or total permitted appropriations, whichever is less. When the discharge at the gage is below 50% of the CBF, all appropriations upstream from the gage would be suspended. The bracket approach was based on analyses of historic flow records and resulting effects of various appropriation scenarios on the flow regime.

4.0 RESULTS

4.1 Habitat versus Discharge Relations

Habitat versus flow relations varied considerably among the species-life stages modeled (Figures 8-15). Most species-life stages relations fell into one of three general categories: 1) WUA peaked at low flows and decreased as flow increased (e.g., rock bass adult, shallow pool guild) 2) WUA increased as flow increased, peaking at a high flow (e.g., longnose dace adult, fast riffle guild), and 3) WUA peaked at an intermediate flow and decreased as flow either increased or decreased (e.g., channel catfish young-of-year, slow riffle guild, lower site). Non-normalized WUA versus discharge relations are provided in appendix F. The diversity of available habitat types was also related to discharge (Figures 16a and 16b): both study sites were dominated by shallow pool habitat at low flows and by raceway and fast riffle habitat at high flows. Habitat diversity was highest at intermediate flows.

4.2 Community-Based Flow

For the 1 April - 15 May season at the upper site, the CBF was 41 cfs. The drivers for this season were spawning walleyes *Stizostedion vitreum*, representing the raceway guild, and spawning hornyhead chubs *Nocomis biguttatus*, representing the shallow pool guild (Figure 8). For both the 16 May - 4 November and the 5 November - 31 March seasons, the CBF was 18 cfs. Drivers for the 16 May - 4 November season were adult rainbow darters *Etheostoma caeruleum*, of the fast riffle guild, and larval fish, of the shallow pool guild (Figure 9). The 5 November - 31

March drivers were adult sand shiners *Notropis stramineus*, of the shallow pool guild, and adult orangespotted sunfish *Lepomis humilis*, of the shallow pool guild (Figure 10).

At the lower site, the CBF for the season 1 April - 15 May was 200 cfs. Drivers for this season were spawning walleyes and spawning banded darters *Etheostoma zonale* (Figure 11). Spawning banded darters represented the fast riffle guild. The drivers for the seasons 16 May - 30 June, 1 July - 31 July, 1 August - 4 November, and 5 November - 31 March were the same; therefore, the CBF was the same: 59 cfs. For these four seasons, the drivers were smallmouth bass fry, representatives of the shallow pool guild, and Wabash pigtoe mussel *Fusconaia flava*, representatives of the raceway guild (Figures 12 -15).

4.3 Relating the CBF to Stream Gages

The CBFs for each season were multiplied by 12.099 at the upper site and by 0.973 at the lower site to determine the corresponding CBFs at the Granite Falls gage (Table 5). For example, the 1 April - 15 May season CBF of 200 cfs at the lower site was multiplied by 0.973 to obtain a CBF value of 195 cfs at the Granite Falls gage. This simply means that when the discharge at the lower study site is 200 cfs, the discharge at the gage is 195 cfs. This relation was established so that bracketed protected flow recommendations could be implemented at this gage.

Table 5. Community-based flows (CBF) by season at the upper and lower Yellow Medicine River study sites, and as adjusted to the Granite Falls stream gage.

	Study Site CBF (cfs)		Granite Falls Gage CBF (cfs)	
Season	Upper	Lower	Upper	Lower
5 Nov - 31 Mar	18	59	218	57
1 Apr - 15 May	41	200	496	195
16 May - 30 Jun	18	59	218	57
1 Jul - 30 Jul	18	59	218	57
1 Aug - 4 Nov	18	59	218	57

4.4 Bracket Approach for Implementing Protected Flows

The Yellow Medicine River Watershed's CBF was based solely on the lower site. This was done for two reasons. First, the extremely flashy flows of the upper site make surface water appropriations impractical. Consequently, the lower site has a greater likelihood of being affected by future appropriations. Second, the fish community of the upper site consists of generalized fishes adapted to flashy flow conditions and recolonization. The lower site has greater habitat and species diversity with more flow-sensitive species. Therefore, we believe that protected flows based on the lower site will adequately protect the upper site.

The seasonal brackets used for determining when appropriations would be limited or suspended upstream from the Granite Falls gage are presented in table 6. Under the bracket system, appropriations will be allowed up to a total of 81 cfs (10% of the bankfull flow) or the total permitted amount, whichever is less, within the Yellow Medicine River Watershed from 1 April through 15 May when the flow at the USGS gage is above 293 cfs (150% of 195 cfs) (Table 6). All appropriators can withdraw up to a total of 39 cfs (20% of 195 cfs) when the discharge is from 98 cfs (50% of 195 cfs) to 293 cfs. As is currently the case here, individual appropriators will be allowed to take their full permitted amounts at flows equal to or greater than 98 cfs if the total appropriations do not exceed 39 cfs. If the flow at the gage is less than 98 cfs, all withdrawals will be suspended.

From 16 May through 31 March, during which the recommended protected flow is 57 cfs, appropriations up to 81 cfs or the total permitted amount, whichever is less, will be allowed when the flow at the gage exceeds 86 cfs. Twenty percent of the recommended flow, or 11 cfs, can be withdrawn when the discharge at the gage is from 29 cfs to 86 cfs. Currently, the total permitted amount does not exceed 11 cfs; therefore, appropriators now permitted could take their full permitted amount at flows greater than or equal to 29 cfs. No appropriations will be allowed when the discharge at the gage drops below 29 cfs (Figure 17).

Table 6. Recommended protected flows and allowable appropriations by season based on the flow at USGS gage #05313500 on the Yellow Medicine River near Granite Falls, Minnesota.

Season:	Recommended flow:	If flow at gage is...:	...then the action is:
		>293 cfs	Appropriators may take a total of 81 cfs or total permitted amount, whichever is less
1 April - 15 May	195 cfs	98-293 cfs	Appropriators may take a total of 39 cfs or total permitted amount, whichever is less
		<98 cfs	Suspend all appropriations
		>86 cfs	Appropriators may take a total of 81 cfs or total permitted amount, whichever is less
16 May - 31 March	57 cfs	29-86 cfs	Appropriators may take a total of 11 cfs or total permitted amount, whichever is less
		<29 cfs	Suspend all appropriations

5.0 DISCUSSION

Many fishes, mussels, and other invertebrates inhabiting the rivers and streams of Minnesota have specific and diverse flow-related habitat needs: e.g., some require riffle habitat (shallow, high velocity, and coarse substrates), others need deep pool habitat (deep, low velocities, and fine substrates) (Aadland et al. 1991; Aadland 1993; Hart 1995; Johnson 1995). The availability of these habitats is largely a function of flow (Trotzky and Gregory 1974; Leonard and Orth 1988; Aadland 1993); consequently, a river's flow regime plays a vital role in structuring fish and invertebrate communities (Schlosser 1982, 1985; Bain and Boltz 1989; Poff and Ward 1989, 1990). Unfortunately, the flow regime of most rivers in North America have been altered by human actions (NRC 1992; Dynesius and Nilsson 1994). Flow regulation, by altering the availability of habitats and creating channel instability, has adversely altered the structure, function, and composition of stream communities (Cummins 1979; Gorman and Karr 1978; Moyle and Baltz 1985). Examples of adverse alterations of stream communities include reduced biodiversity and decreased biological productivity (Bain et al. 1988; Junk et al. 1989; Petts 1989). For many rivers, protected streamflows are therefore vitally needed to restore and maintain the integrity of their habitats and biotic communities. Implementing protected flows has been shown to benefit fish and invertebrate communities (Weisberg et al. 1990; Wolff et al. 1990; Weisberg and Burton 1993). Our recommended flows are designed to protect the flow-related habitat needs of the diverse biotic communities found in Minnesota's rivers and streams.

5.1 Bracket Approach for Implementing Protected Flows

The bracket approach for establishing protected flows is being recommended by the Division of Fish and Wildlife to determine when surface water appropriations (excluding municipal appropriations) from rivers, streams, and ditches would be limited or suspended. Ditches were included because they directly impact streamflows. Although groundwater appropriations would not be limited or suspended under the bracket system at this time, the effects of groundwater appropriations on streamflow need to be carefully assessed and included in flow protection and permitting. Even after surface water appropriations have been suspended to maintain protected flows in a watershed, groundwater withdrawals may continue to deplete streamflows (Olson et al. 1989). Delin (1991) reported that groundwater discharge to streams has decreased by 39% in the Rochester, Minnesota area due to historical groundwater pumping. The Yellow Medicine River is very susceptible to groundwater and surface water appropriations since it has very low base flows; Novitzki et al. (1969) noted that low flows in the Yellow Medicine River result primarily from groundwater storage. Therefore, we recommend that all groundwater permits, both those previously issued and those applied for in the future, be scrutinized on an individual basis by the MNDNR to determine if they have the potential to impact streamflow. Any groundwater permit determined to potentially impact streamflow should be considered as a surface water appropriation.

The middle bracket, when the discharge is between 50% and 150% of the CBF and total appropriations are limited to 20% of the CBF, was chosen because it: 1) is sufficiently wide to be useful as a management tool, 2) encompasses flows that provide the most habitat for most species, and 3) simultaneously allows for some offstream appropriation while protecting instream resources. Abruptly suspending all appropriators within a watershed when the flow at the gage drops below the recommended flow would not be ideal for appropriators, the riverine ecosystem, or regulators. The three tier bracket allows both appropriators and regulators time to adjust operations accordingly as flows drop from one bracket to the next. The brackets were based on analyses of historic flow records and resulting effects of various appropriation scenarios on the flow regime.

The bracket approach could possibly result in a yo-yo effect. When the flow drops below 50% of the recommended flow and all appropriations are suspended, the lack of water withdrawals could cause the flow to increase above the suspension cut-off. Limited appropriations would resume then, but these withdrawals could cause the flow to drop below the suspension cut-off again, creating a yo-yo effect. Pro-rating appropriations within a bracket or suspending appropriations sequentially could eliminate this problem. The need for pro-rating would increase with total appropriation amounts. This may be handled best by the watershed district on a case by case basis.

5.1.1 Bracket Recommendations Compared To Tennant's Method

Next to the IFIM approach used in this study to establish protected flows, the Tennant Method (Tennant 1975, 1976) is the most commonly used technique for establishing protected flows (Reiser et al. 1989). This hydrologic method recommends protected flows based on percentages of the mean annual flow for the river in question. The percentages are broken into two seasons and range from 10 percent for degradation flow to 60-100 percent for optimal flow (Table 7). While the Tennant Method is quick and easy, it lacks the direct tie to the instream resources that it intends to protect. Consequently, there is no way of knowing if the recommended protected flow adequately protects instream resources. Our recommended protected flows as percentages of mean annual flow and corresponding Tennant ratings are provided in Table 8. During the 1 April

- 15 May season, our protected flows fall in Tennant's optimum range. During summer and winter, our protected flows range from poor or minimum to good.

Table 7. Recommended base flow regimes using Tennant's Method (Tennant 1975, 1976). Flows are calculated as a percentage of mean annual flow.

	Recommended Base Flow	
Description of flow	**October through March**	**April through September**
Flushing or Maximum	200%	200%
Optimum range	60 to 100%	60 to 100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	0 to 10%	10%

Table 8. IFIM based recommended protected flows as a percentage of mean annual flow and rated using Tennant's Method (Tennant 1975, 1976). Mean annual flow is 130 cfs at the Granite Falls gage.

Season	IFIM based protected flow recommendations	Recommended flow as % of mean annual flow	Tennant's Oct-March	Rating April-Sept
1 April - 15 May	98	75.4%		optimum
16 May - 31 March	29	22.3%	border between good and excellent	border between poor or minimum and fair or degrading

5.1.2 Frequency of Appropriation Suspension under Bracket System

As discussed earlier, the Yellow Medicine frequently has very low flows that make it an unreliable source of water for appropriations. Flows are very high following heavy rains or snowmelt when little need for irrigation exists and very low during dry periods when demand for irrigation is high. Because of common low flows, appropriations compete directly with instream resources, and the protected flow recommendations in this report will limit periods during which water can be removed for irrigation and other uses. The existing system of suspension would also change. The existing system, under which appropriators are given notice that they have two weeks before they are suspended, encourages appropriators to maximize withdrawals before the deadline. This can be disastrous for the river. We witnessed this on the Pomme de Terre River in 1989 when the river was literally pumped dry following notice of forthcoming suspension. The establishment of protected flows will also protect appropriators from the possibility of excessive future appropriation permits: an increase in appropriation permits or their allowed amounts will decrease the amount present appropriators would be allowed to withdraw. Having established protected flows will limit the amount of water that can be permitted by the MNDNR.

Based on historical flows and the recommended protected flows in this report, appropriators in the past would have been allowed to withdraw water from the Yellow Medicine River 70% of the time in late May, 66% in June, 52% in July, and 31% in August (Appendix G). These percentages do not, however, give a true picture of flow availability and reliability. For instance, during June, July, and August of 1932-1937, average streamflow was 3.9 cfs and appropriators would have been allowed to irrigate only 2% of the time under the recommended protected flows. In contrast, during the same months of 1990-1992, streamflow averaged 384 cfs and appropriators would have been allowed to irrigate 100% of the time. In fact, 34% of the growing seasons (May 15 - August 31) when flow reached our recommended level for suspension, it also reached 2.1 cfs, the existing protected flow. In the remaining 66% of the years when flow reached 29 cfs during the growing season, flows came so close to 2.1 cfs that *any* increase in flow protection would have resulted in significant increases in appropriation suspensions. On the other hand, during the last six years flows have been high, and appropriations would not have been suspended even if our recommended protection levels had been in effect. The last suspension during the growing season would have been in August, 1989, with the exception of August 30 & 31, 1991, when the flow barely dropped below the present recommended flow for the last two days of the growing season.

This instability of streamflow makes any future reliance on the Yellow Medicine River for irrigation tenuous with or without flow protection.

5.1.3 Existing Appropriations

All permitted water appropriations within the Yellow Medicine River Watershed are summarized in Table 9. There are 19 permits for appropriations from streams, ditches, groundwater, and dug pits within the watershed. The total permitted amount of appropriations from streams and ditches is 47.9 million gallons per year (mgy). The majority of this (19.9 mgy) is permitted for major crop irrigation. The remainder of the permits are for pipeline/tank testing (12.0 mgy), temporary uses (10.0 mgy), and industrial processing (6.0 mgy). The potential maximum instantaneous rate of withdrawal of water from streams in the watershed totals 2836 gallons per minute (gpm), or 6.32 cfs.

There is a total of 214.0 mgy of groundwater appropriations in the Yellow Medicine River Watershed with a total pump rate of 2656 gpm (or 5.92 cfs) (Table 9). The two main uses of groundwater are municipal (144.3 mgy, 1756 gpm, 3.91 cfs) and crop irrigation (69.7 mgy, 900 gpm, 2.01 cfs). Three appropriations from dug pits total 29.3 mgy with a combined pump rate of 835 gpm (or 1.86 cfs). These permits are for a golf course (17.0 mgy, 60 gpm, 0.13 cfs), sand and gravel washing (2.3 mgy, 25 gpm, 0.06 cfs), and sand and gravel pit dewatering (10.0 mgy, 750 gpm, 1.67 cfs).

5.2 Additional Considerations for Flow Protection

The greatest demand for offstream uses generally occurs during periods of low flow (e.g., late summer) when meeting the instream habitat needs of aquatic communities is of major concern. The CBFs and bracketed protected flow approach are designed to address this concern. There is typically little conflict between offstream and instream uses during periods of high flow (e.g., spring). It should be emphasized, however, that high flows are extremely important for maintaining the integrity of stream habitats and their biotic communities. Of particular importance are bankfull flows and flows needed for maintaining the connection between a river's channel and its floodplain. For the reasons discussed below, these features of flow regimes need to be protected if future appropriations threaten their occurrence.

Table 9. Summary of all permitted water appropriations for the Yellow Medicine River Watershed. Data provided by MNDNR DOW and summarized by authors.

Resource Type	Description of use	Number of permits	Million of gallons per year (mgy)	Pump rate in gallons per minute (gpm)	Pump rate in cubic feet per second (cfs)
Streams and ditches	Crop irrigation	2	19.9	900	2.01
	Pipeline/tank testing	1	12.0	1000	2.23
	Temporary	2	10.0	136	0.30
	Industrial processing	1	6.0	800	1.78
	Total	**6**	**47.9**	**2836**	**6.32**
Groundwater	Municipal	7	141.4	1716	3.89
	Private waterworks	1	2.9	40	0.09
	Crop irrigation	2	69.7	900	2.01
	Total	**10**	**214.0**	**2656**	**5.92**
Dug pit	Golf course	1	17.0	60	0.13
	Sand and gravel washing	1	2.3	25	0.06
	Sand and gravel pit dewatering	1	10.0	750	1.67
	Total	**3**	**29.3**	**835**	**1.86**
All appropriations combined		**19**	**291.2**	**6327**	**14.10**

5.2.1 Bankfull Flows

Bankfull discharge is the discharge that corresponds to the stage at which the river begins to flow out of its banks and onto its floodplain. Bankfull flows are largely responsible for forming and maintaining the shape of stream channels because they move the most sediment over time, doing most of the work (e.g., forming bars, bends, and meanders) that results in the morphological characteristics of natural channels (Dunne and Leopold 1978; Leopold 1994).

These characteristics include a river's dimension (e.g., width/depth ratio, entrenchment ratio, wetted perimeter), pattern (e.g., sinuosity, meander wavelength and radius of curvature), and profile (e.g., water surface slope, riffle/pool spacing). The dimension, pattern, and profile relations of rivers have been shown to be proportionally related to bankfull flows and are generally described as a function of bankfull channel characteristics (Leopold et al. 1964; Rosgen 1996). Bankfull flows typically have a recurrence interval of 1.5 years based on flood frequency analysis (Leopold et al. 1964; Dunne and Leopold 1978).

Bankfull flows are important for maintaining the stability of stream channels and the diversity of habitats found in river systems. Stability, as used here, is defined as the ability of a stream, over time, to transport the flows and sediment of its watershed in such a manner that the dimension, pattern, and profile of the river is maintained without either aggrading or degrading (Rosgen 1996). Rivers have a natural tendency to seek and maintain their own stability (Leopold et al. 1964). While channel morphology does not adjust with every short-term variation of discharge (Ackers and Charlton 1970), long-term changes in a river's natural flow regime, particularly changes in historical bankfull flows, can lead to instability as the morphology of the channel (i.e., the dimension, pattern, and profile) tries to readjust to its new flow regime. Channel adjustments are often manifested in bank and streambed erosion, sedimentation, land loss, channel aggradation and incision, reduced channel capacity, etc. These adjustments can degrade instream habitat quality, alter biotic communities, and result in lost resource values.

5.2.2 Floodplain-Channel Interactions

Periodic flooding of floodplain habitats plays a vital role in maintaining the health of riverine ecosystems (Hynes 1975; Welcomme 1979; Sparks 1992; Stanford and Ward 1993). Floods facilitate the transfer of sediments, nutrients, and organisms between a river's channel and its floodplain, helping to maintain stream productivity. Indeed, Junk et al. (1989) suggest that most of the riverine animal biomass derives from production within the floodplain. Many aquatic and terrestrial plants and animals have keyed critical life stages to take advantage of the "flood pulse", a natural, predictable, and ecologically critical feature of the annual hydrograph of floodplain rivers (Junk et al. 1989; Sparks 1992). The floodplain-channel connection has been severed for many rivers, interrupting critical processes needed to sustain habitat and biological productivity. Although Minnesota Statutes and Rules encourage appropriations during flood events, eliminating the flood pulse and floodplain-channel interactions could adversely impact river ecosystems.

5.3 Existing Flow Protection

The MNDNR was directed in 1977 to set protected streamflows for the purpose of protecting instream resources, such as water-based recreation, navigation, aesthetics, fish and wildlife habitat, and water quality . To date, protected flows have been established on 45 rivers based primarily on annual hydrologic statistics, usually the annual 90% exceedance flow. These protected flows often provide inadequate protection for instream resources (Olson et al. 1988; Olson et al. 1989) because they are extremely low flows, sometimes drought flows, and they do not address the seasonal flow-related needs of the resources they are intended to protect. Low flows are the primary concern of MNDNR area fisheries managers in regards to the survival, productivity, or use of the riverine fish community (Olson et al. 1988). Protected flows based on hydrologic statistics do not address the flows needed to maintain channel morphology and stability or flows needed to maintain the connection to floodplain habitats. In addition, under the existing system, appropriators are given notice that they have two weeks before they are suspended, encouraging appropriators to maximize withdrawals before the suspension deadline. This can be disastrous for the river, as witnessed on the Pomme de Terre River in 1989 when the river was essentially pumped dry following notice of forthcoming suspension.

The Yellow Medicine River has a protected flow of 2.1 cfs at the Granite Falls gage, which was the 90% exceedance flow when the protected flow was established. While this flow was too low to be reliably simulated with PHABSIM using the field data collected in this study, modeling results at 7 cfs show that there is very little preferred habitat available for most of the guild representatives and that habitat diversity, an important factor governing the diversity of fishes and invertebrates found in warmwater streams (Ward 1976; Gorman and Karr 1978; Schlosser 1982), is very limited at this low flow, consisting almost entirely of shallow pool habitat (Figures 16a and 16b). As flow increases from 7 cfs to 267 cfs, habitat diversity steadily increases (Figure 18).

5.4 Land-use Practices Affecting Flow Regimes

In addition to direct withdrawals, other human actions have also altered the natural flow regime of rivers, including wetland drainage, ditching, and conversion of land to row crop agriculture. Within the Yellow Medicine River Watershed, the drainage of wetlands has likely had the greatest negative effect on the rivers. The percentages of Lac Qui Parle, Lincoln, Lyon, Redwood, and Yellow Medicine counties' wetlands that have been drained are 98.8%, 97.5%, 99.1%, 99.4%, and 99.2%, respectively (Anderson and Craig 1984). One of the functions of wetlands is to provide storage for precipitation and runoff: water storage slows the water's path to the rivers, thus providing a time lag between a large precipitation event or snowmelt and the arrival of the water into the river. This storage, then, helps to dampen the rise of the river (flashiness of flows) and decrease flooding. Closely linked to wetland drainage is the conversion of land to row crop agriculture; 77% of the total 2,319,294 acres in these five counties was classified as cropland in a 1992 census (Minnesota Agricultural Statistics Service 1996). Dense stands of prairie grasses, upland forests, and riparian forests intercept and absorb runoff, whereas row crop agriculture increases surface runoff, resulting in water entering the rivers faster. Once water enters a natural channel, meanders absorb energy from it as it moves downstream, thus lessening the force and the velocity of the water. Channelization, or the removal of meanders from the natural stream channel, results in increased water velocities within the stream. More than 10 miles of river have been lost or degraded due to channelization on the main stem of the Yellow Medicine alone. Row crop agriculture near rivers, filling of wetlands, and channelization can also result in unnaturally high sedimentation rates and decreased water quality.

Wetland drainage, ditching, and conversion of land to row crop agriculture all act together to reduce water storage, increase effective drainage area, and increase runoff rates throughout the watershed. These actions alter the natural flow regimes of streams by increasing the frequency and magnitude of high flows (Moore and Larson 1979) and accentuating periods of low flows (Hey and Wickenkamp 1996). These types of changes in flow regimes can lead to channel instability and associated impacts (see discussion of channel stability in section 5.2.1).

5.5 Additional Factors Impacting Stream Habitat and Biotic Communities

5.5.1 Channelization

Channelizing a stream involves straightening (i.e., removing the meanders), and usually widening, the natural channel. This decreases the river's length and increases its gradient. In short, channelization directly alters most aspects of a river's dimension, pattern, and profile from a stable form to an unstable, transitional form. As with altering natural flow regimes, altering a river's morphology runs contrary to the natural stable tendencies of rivers and sets up a series of systematic channel adjustments as the river tries to regain its stable dimension, pattern, and profile (Rosgen 1996). Channel adjustments are often manifested in bank and streambed erosion, sedimentation, land loss, channel aggradation and incision, reduced channel capacity, etc. Channelization results in the loss of habitat diversity and biological productivity (Funk and Ruhr 1971; Darnell et al. 1976). For example, fish biomass was 280 times higher in an unchannelized reach as compared to a channelized reach of the Whitewater River in Winona County, Minnesota (MNDNR, unpublished data). The diversity of habitats was much greater in the unchannelized reach. At least 10 miles of the Yellow Medicine River have been degraded or lost due to channelization.

5.5.2 Sedimentation

Wetland drainage, ditching, row crop agriculture, loss of riparian vegetation, and channelization have all contributed to the severe bank erosion and sedimentation problems evident throughout the watershed. Severe bank erosion is common where riparian vegetation has been removed and where row crops are grown too close to the stream channel. Sedimentation degrades both water quality and physical habitat. In particular, sedimentation can reduce both invertebrate production and reproductive success of fishes by filling in the interstitial spaces between coarse substrates. The Yellow Medicine has a high sediment load that likely limits the stream's fish and invertebrate community.

5.5.3 Dams

The damming of rivers has profound impacts on the integrity of riverine ecosystems (Stanford and Ward 1979; Petts 1984; Dynesius and Nilsson 1994). Dams alter the flow of water, sediment, nutrient, energy, and biota through the river system: in short, dams interrupt and alter most of a river's important fluvial and ecological processes. As a consequence, dams can initiate long-term and adverse changes in stream habitats (e.g., fragmentation of habitats, destabilizing stream channel morphology, decreased water quality) (Simons 1979; Williams and Wolman 1984; Schmidt et al. 1995; Sear 1995) and their biotic communities (e.g., loss of native species, reduced biodiversity, reduced productivity) (Isom 1971; Ward 1976; Petts 1989; Zincone and Rulifson 1991).

Due to its flashy streamflows, fishes and invertebrates of the Yellow Medicine River Watershed are particularly reliant on connectivity of the river system for recolonization and migration into suitable habitats. Drought results in dewatering of riffle areas and subsequent mortality of riffle-oriented organisms while high velocities associated with floods can cause fry mortality or displacement, cause invertebrates to enter the drift, and dislodge mussels. Our research suggests that migration and recolonization are key factors in preserving a diverse species assemblage in the Yellow Medicine River. Connectivity is not a major problem in the Yellow Medicine River Watershed; at this time, there is only one dam on the main stem of the Yellow Medicine River, and it is at the outlet of Lake Shaokatan. Seven other dams are present on tributaries within the watershed.

Fish populations of the Minnesota River also rely on the Yellow Medicine for reproduction and nursery of young due to its high gradient and abundant riffle habitat. Two municipally-owned hydropower dams on the Minnesota River (the Minnesota Falls Dam and the Granite Falls Dam) block fish passage upstream of Granite Falls. These dams, the downstream-most on the Minnesota River, are upstream of the Yellow Medicine River's confluence with the Minnesota River, making the Yellow Medicine River and others in its watershed particularly important as reproduction and nursery areas. The eight dams within the watershed at the present time, while they are barriers to migrating organisms, are not currently a substantial concern. Any new dams in the watershed could result in severe damage to the ecosystems of the Yellow Medicine and Minnesota rivers.

6.0 RESTORATION OPPORTUNITIES

There are many opportunities to protect and restore the ecological integrity of the rivers and streams of the Yellow Medicine River Watershed. Restoration efforts should focus on protecting streamflows and restoring channel morphology and stability. Flow protection should not only address the range of flows needed to maintain instream habitat but also the flows needed to maintain channel morphology and stability (i.e., bankfull flows), as well as flows needed to maintain floodplain functions. Restoring wetlands, reestablishing meanders, and plugging ditches would help stabilize flows and restore a more natural hydrologic regime. This would not only help improve channel stability, but would also provide the additional benefits associated with wetlands.

Restoration efforts should also focus on restoring stream channel morphology and stability. To achieve long-term stream stability and function, stream channel restoration efforts must incorporate the integrative relations among fluvial processes, stream morphology, and the natural self-stabilizing tendencies of stream channels (Jackson et al. 1995; Kauffman et al. 1997). The stream classification system developed by Rosgen (1996) incorporates these relations and we recommend that it be used to guide and monitor channel restoration efforts. The Rosgen classification system can be used to determine if a stream channel is physically degraded and unstable and, if so, to determine the degraded channel's most probable stable form, or stream type. Once this determination is made, the morphological characteristics of an un-impacted stable reach of the same stream type can be used as a natural stability "blueprint" for guiding the restoration of the degraded, unstable channel. This approach could prove very useful in restoring some of the many miles of channelized, degraded stream channels throughout the Yellow Medicine River Watershed.

This stream classification system can also be used to evaluate a channel in terms of its sensitivity to disturbance, recovery potential, sediment supply, vegetation controlling influence, and streambank erosion potential. These evaluations can be applied to impact assessments and risk analyses associated with proposed development and management activities. Similarly, stream typing can be used to predict a river's behavior or response to some action based on its appearance (i.e., based on its stream type), thus avoiding those actions that create changes in the dimension, pattern, and profile of the natural, stable form. For example, many fish habitat improvement structures (e.g., gabion check dams, overhead bank cover, etc.) have failed because they worked against the tendencies of the natural stable form, resulting in adverse channel adjustments and instability (Beschta et al. 1991; Frissell and Nawa 1992; Kondolf et al. 1996; Kauffman et al. 1997). Rosgen has provided guidelines for evaluating the suitability of various fish habitat improvement structures based on stream type. Finally, this classification system provides a consistent and reproducible frame of reference for communicating among the diverse group of people (hydrologists, fisheries biologists, engineers, range managers, fluvial geomorphologists, foresters, etc.) working with river systems.

A concerted effort to stabilize stream banks needs to be made throughout the watershed. Bank erosion is a severe problem and a major contributor to the high sediment load of the rivers in the watershed. Bank erosion is especially severe in areas where riparian vegetation has been removed and where row crops are grown too close to the stream channel. Cooperative efforts with riparian landowners to restore and manage streamside vegetation and riparian buffers should be pursued to reduce sedimentation and improve habitat and water quality.

7.0 CONCLUSIONS

Restoring and maintaining the integrity of riverine habitats and their biotic communities, as well as meeting the increasing demand for resource values placed on river ecosystems, will require a management approach that works with watershed processes that form and maintain stable river systems (NRC 1992; Rosgen 1996; Kauffman et al. 1997; Roper et al. 1997). A major component of this approach must focus on protecting and restoring natural flow regimes. Indeed, the call for protecting and restoring hydrologic regimes is an emerging paradigm in river management (Junk et al. 1989; NRC 1992; Sparks 1992; Doppelt et al.1993; Dynesius and Nilsson 1994). This paradigm has grown out of the recognition that flow-dependent processes and functions create and sustain both the physical and biological characteristics of rivers.

Healthy river ecosystems are an important component of the quality of life in Minnesota. Wise stewardship of these ecosystems is necessary if future Minnesotans are to enjoy and benefit from the diverse resource values and uses that rivers provide. Conflict between resource protection and development is inevitable given the limited supply and increasing demand for water in Minnesota and the U.S. This reality was forecasted over fifteen years ago by Stalnaker (1981) who stated, as a result of increasing demand, "midwestern and eastern states no longer are considered to have an 'unlimited' water supply". The challenge before us then is to assure that the present use of our rivers will not compromise their health for future generations. The goal of the Stream Habitat Program is to help meet this challenge by providing the information needed to establish biologically sound protected flows for the rivers and streams of Minnesota.

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9.0 LITERATURE CITED

Aadland, L. P. 1993. Stream habitat types: their fish assemblages and relationship to flow. North American Journal of Fisheries Management 13:790-806.

Aadland, L. P., C. M. Cook, M. T. Negus, H. G. Drewes, and C. S. Anderson. 1991. Microhabitat preferences of selected stream fishes and a community-oriented approach to instream flow assessments. Minnesota Department of Natural Resources. Section of Fisheries. Investigation report No. 406.

Ackers, P., and F. G. Charlton. 1970. Meander geometry arising from varying flows. Journal of Hydrology 11:230-252.

Anderson, J. P., and W. J. Craig. 1984. Growing energy crops on Minnesota's wetlands: the land use perspective. Judith H. Weir, editor. Publication of the Center for Urban and Regional Affairs, University of Minnesota, Minneapolis.

Bain, M.B., and J.M. Boltz. 1989. Regulated streamflow and warmwater stream fish: a general hypothesis and research agenda. Biological Report 89(18). U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Bain, M. B., J. T. Finn, and H. E. Booke. 1988. Stream-flow regulation and fish community structure. Ecology 69:382-392.

Bayha, K. D. 1978. Instream flow methodologies for regional and national assessments. Instream flow information paper no. 7. Cooperative Instream Flow Service Group, US Fish and Wildlife Service FWS/OBS-78/61. Ft. Collins, Colorado.

Beschta, R.L., W.S. Platts, and J.B. Kauffman. 1991. Field evaluation of fish habitat improvement projects in the Grande Ronde and John Day River basins of eastern Oregon. DOE / BP-21493-1. U.S. Department of Energy, Bonneville Power Administration, Portland, OR.

Bouchard, H., and F. H. Moffitt. 1965. Surveying. International Textbook Company, Scranton, Pennsylvania.

Bovee, K. D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream flow information paper no. 12. US Fish and Wildlife Service FWS/OBS-82/26. Ft. Collins, Colorado.

Bright, R. O., C. Gatenby, D. Olson, and E. Plummer. 1990. A survey of the mussels of the Minnesota River, 1989. Bell Museum of Natural History, University of Minnesota, Minneapolis, Minnesota. Unpublished report.

Brinker, R. C., and W. C. Taylor. 1963. Elementary Surveying. International Textbook Company, Scranton, Pennsylvania.

Buchanon, T. J., and W. P. Somers. 1969. Discharge measurements at gaging stations. Book 3, Chapter A8, Techniques of water-resources investigations of the US Geological Survey. US government printing offices, Washington, D.C.

Burton, R. A., and T. A. Wesche. 1977. Relationship of duration of flows and selected watershed parameters to the standing crop estimates of trout populations. University of Wyoming, Water Resources Research Institute, Laramie, Wyoming.

Cummins, K.W. 1979. The natural stream ecosystem. Pages 7-24 *In* Ward, J.V. Ward and J.A. Stanford (editors), The ecology of regulated streams. Plenum Press, New York, New York, USA.

Cushman, R. M. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5:330-339.

Darnell, R.M., W.E. Pequegnat, B.M. James, F.J. Benson, and R.E. Defenbaugh. 1976. Impacts of construction activities in wetlands of the United States. 393 pp (+XXII). U.S. EPA, Report No. EPA-600/3-76-045.

Delin, G. N. 1991. Hydrogeology and simulation of groundwater flow in the Rochester area, southeastern Minnesota, 1987-88. USGS Water-Resources Investigations Report 90-4081.

Doppelt, B., M. Scurlock, C. Frissell, and J. Karr. 1993. Entering the watershed: A new approach to save America's river ecosystems. Island Press, Washington, D.C.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Co., San Francisco, California.

Dynesius, M., and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Science 266:753-762.

Fisher, S. G., and A. LaVoy. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. Journal of Fisheries Research Board of Canada 29:1472- 1476.

Frissell and Nawa. 1992. Incidence and cause of physical failures of artificial habitat structures in streams of western Oregon and Washington. North American Journal of Fisheries Management 12:182-197.

Funk, J.L., and C.E. Ruhr. 1971. Stream channelization in the midwest. Pages 5-11, in E. Schneberger and J.L. Funk (editors). Stream channelization: a Symposium. American Fisheries Society Special Publication No. 2, American Fisheries Society, Bethesda, Maryland, USA.

Gordon, N. D., T. A. McMahon, B. L. Finlayson. 1992. Stream Hydrology: An introduction for ecologists. John Wiley and Sons Ltd., New York, New York.

Gore, J. A. 1978. A technique for predicting instream flow requirements of benthic macroinvertebrates. Freshwater Biology 8:141-151.

Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507-515.

Gunard, K. T., J. H. Hess, J. L. Zirbel, and C. E. Cornelius. 1993. Water resources data Minnesota water year 1993 volume 2 upper Mississippi and Missouri river basins. US Geological Survey. Water-data report MINNESOTA-93-2.

Hart, R.A. 1995. Mussel (Bivalva: Unionidae) habitat suitability criteria for the Otter Tail River, Minnesota. M.S. Thesis, Department of Zoology, North Dakota State University, Fargo, North Dakota, USA.

Hey, D.L., and J.A. Wickenkamp. 1996. Some hydrologic effects of wetlands in nine watersheds of southeastern Wisconsin. Great Lakes Wetlands 7:4-9.

Hydrologic Atlas of Minnesota. 1959. Minnesota Conservation Department. Division of Waters. Bulletin no. 10.

Hydrosphere Data Products. 1997. Hydrodata: USGS Daily Values - Central Volume 9.1.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Canada.

Hynes, H. B. N. 1975. The stream and its valley. Verhandlungen der Internationalen Vereinigung fur Theoretische und Angerwandte Limnologie 19:1-15.

Isom, B.G. 1971. Effects of storage and mainstem reservoirs on benthic macroinvertebrates in the Tennessee Valley. Pages 179-192 *In* G.E. Hall (editor), Reservoir fisheries and limnology. Special publication no. 8, American Fisheries Society, Bethesda, Maryland, USA.

Jackson, L.L., N. Lopoukhine, and D. Hillyard. 1995. Ecological restoration: a definition and comments. Restoration Ecology 3:71-75.

Johnson, S.L. 1995. Instream flow requirements of Quadrula fragosa and the aquatic community in the lower St. Croix River downstream of the Northern States Power hydroelectric dam at St. Croix Falls, Wisconsin. Final report submitted to Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, Wisconsin, USA.

Junk, W., Bayley, P. B., and Sparks, R. E. 1989. The flood pulse concept in river-floodplain systems. *In* Proceedings of the International Large River Symposium (LARS). Canadian Special Publication Fisheries Aquatic Science 106:110-127.

Kauffman, J.B., R.L. Beschta, N. Otting, and D. Lytjen. 1997. An ecological perspective of riparian and stream restoration in the western United States. Fisheries 22:12-24.

Kondolf, G.M., J.C. Vick, and T.M. Ramirez. 1996. Salmon spawning habitat rehabilitation on the Merced River, California: An evaluation of project planning and performance. Transactions of the American Fisheries Society 125: 899-912.

Land Management Information Center. 1995. UPSTREAM Watershed Identification Program, part of the Stream Information System. St. Paul, Minnesota.

Leonard, P. M., and D. J. Orth. 1988. Use of habitat guilds of fishes to determine instream flow requirements. North American Journal of Fisheries Management 8(4):399-409.

Leopold, L.B. 1994. A view of the river. Harvard University Press, Cambridge, MA.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W. H. Freeman, San Francisco, California.

Leopold, L. B., and J. P. Miller. 1956. Ephemeral streams: hydraulic factors and their relation to the drainage network. U.S. Geological Society Professional Paper 282-A.

Lillehammer, A., and S.J. Saltveit, editors. 1984. Regulated rivers. Universitetsforlaget As. Oslo.

Milhous, R. T., D. L. Wegner, and T. Waddle. 1981. User's guide to the physical habitat simulation system. Instream flow information paper no. 11. US Fish and Wildlife Service FWS/OBS-81/43. Ft. Collins, Colorado.

Milhous, R. T., M. A. Updike, and D. M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream flow information paper no. 26. US Fish and Wildlife Service. Biological Report 89(16).

Miller, R.R., J.D. Williams, and J.C. Kelly. 1989. Extinctions of North American fishes during the past century. Fisheries 14:22-38.

Minnesota Agricultural Statistics Service. 1996. Unpublished data. St. Paul, Minnesota.

Minnesota State Climatology Office. 1995. Minnesota Department of Natural Resources. Division of Waters. Data supplied by the National Climate Data Center, Asheville, North Carolina.

Mitton, G. B., J. H. Hess, and K. G. Guttormson. 1996. Water resources data water year 1996: volume 1. Upper Mississippi and Missouri river basins. US Geological Survey water-data report MINNESOTA-93-2.

Moore, I.D., and C.L. Larson. 1979. Effects of drainage projects on surface runoff from small depressional watersheds in the north-central region. University of Minnesota, Water Resources Research Center Bulletin 99.

Moyle, P.B. and D.M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.

National Research Council. 1992. Committee on restoration of aquatic ecosystems-science, technology and public policy. Restoration of aquatic ecosystems. National Academy Press, Washington, D.C.

Novitzki, R. P., W. A. Van Voast, and L. A. Jerabek. 1969. Water resources of the Yellow Medicine River Watershed, southwestern Minnesota. Hydrologic Investigations Atlas HA-320. US Geological Survey.

Olson, P.L., H. Drewes, and D. Desotelle. 1988. Statewide instream flow assessment, Technical Report 1985-1987. Minnesota Department of Natural Resources, St. Paul.

Olson, P.L., R. A. Domingue, and G. A. Kruse. 1989. An instream flow program for Minnesota, Main Report. Minnesota Department of Natural Resources, St. Paul.

Petts, G.E. 1984. Impounded rivers: perspectives for ecological management. John Wiley and Sons. Chichester, England.

Petts, G.E. 1989. Perspectives for ecological management of regulated rivers. Pages 3-26 In Gore, J.A. and G.E. Petts (editors). Alternatives in regulated river management, CRC Press, Inc., Boca Raton, Florida, USA.

Platts, W. S. 1974. Geomorphic and aquatic conditions influencing stream classification with application to ecosystem management. US Department of Agriculture, SEAM Program. Billings, Montana.

Platts, W. S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho river drainage. Fisheries 4(2):5-9.

Poff, N. L., and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of regional streamflow patterns. Canadian Journal of Aquatic Sciences 46: 1805-1818.

Poff, N. L., and J.V. Ward. 1990. Physical habitat template of lotic systems: recovery in the context of historical pattern of spatio-temporal heterogeneity. Environmental Management 14:629-645.

Reiser, D. W., T. A. Wesche, and C. Estes. 1989. Status of instream flow legislation and practices in North America. Fisheries 14(2):22-29.

Roper B.B, J.J. Dose, and J.E. Williams. 1997. Stream restoration: is fisheries biology enough? Fisheries 22:6-11.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22:169-199.

Rosgen, D. L. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, Colorado, USA.

Schlosser, I. J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecological Monographs 52:395-414.

Schlosser, I. J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. Ecology 66:1484-1490.

Schmidt, J.C., P.E. Grams, and R.H. Webb. 1995. Comparison of the magnitude of erosion along two large regulated rivers. Water Resources Bulletin 31:617-631.

Sear, D.A. 1995. Morphological and Sedimentological changes in a gravel-bed river following twelve years of flow regulation for hydropower. Regulated Rivers: Research and Management 10:247-264.

Simons, D.B. 1979. Effects of stream regulation on channel morphology. Pages 95-111 In J.V. Ward and J.A. Stanford, editors. The ecology of regulated streams. Plenum Press, New York, New York.

Sparks, R. E. 1992. Risks of altering the hydrologic regime of large rivers. Pages 119-152 in J. Cairns, Jr., B. R. Niederlehner, and D. R. Orvos, editors. Predicting Ecosystem Risk. Advances in Modern Environmental Toxicology. Volume XX. Princeton Scientific Publishing Company, Inc., Princeton, New Jersey.

Stalnaker, C.B. 1981. Low flow as a limiting factor in warmwater streams. Pages 192-199 In Krumholz, L.A. (editor). The warmwater streams symposium. Southern Division of the American Fisheries Society.

Stanford, J.A., and J.V. Ward. 1979. Stream regulation in North America. Pages 215-236 in J.V. Ward and J.A. Stanford (editors). The ecology of regulated streams. Plenum Press, New York.

Stanford, J.A. and J.V. Ward. 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. Journal of North American Benthological Society 12(1):48-60.

Tennant, D.L. 1975. Instream flow regimes for fish, wildlife, recreation and related environmental resources. U.S. Fish and Wildlife Service Report. Billings, Montana, USA. 18 pp.

Tennant, D.L. 1976. Instream flow regimes for fish, wildlife, recreation and related environmental resources. Pages 359-373 In J.F. Orsborn and C.H. Allman (editors). Proceedings of the Symposium and Special Conference on Instream Flow Needs, Volume II. American Fisheries Society, Bethesda, Maryland, USA.

Trihey, E. W., and D. L. Wegner. 1981. Field data collection procedures for use with the Physical Habitat Simulation System of the Instream Flow Group. Cooperative Instream Flow Service Group. US Fish and Wildlife Service. Ft. Collins, Colorado.

Trotzky, H.M., and R.W. Gregory. 1974. The effect of flow manipulation below a hydroelectric power dam on the bottom fauna of the Upper Kennebec River, Maine. Transactions of the American Fisheries Society 103:318-324.

Ward, J. V. 1976. Effects of flow patterns below large dams on stream benthos: a review. Pages 235-253 *in* J.F. Orsborn and C.J. Allman, editors. Instream flow needs symposium, Volume 2. American Fisheries Society, Bethesda, Maryland.

Ward, J.V., and J.A. Stanford. 1989. Riverine ecosystems: The influence of man on catchment dynamics and fish ecology. Canadian Special Publications in Fisheries and Aquatic Sciences 106:56-64.

Waters, T. F. 1977. The streams and rivers of Minnesota. University of Minnesota Press, Minneapolis, Minnesota.

Weisberg, S.B., A.J. Janicki, J. Gerritsen, and H.A. Wilson. 1990. Enhancement of benthic macroinvertebrates by minimum flow from a hydroelectric dam. Regulated Rivers: Research and Management 5:265-277.

Weisberg, S.B., and W. H. Burton. 1993. Enhancement of fish feeding and growth after an increase in minimum flow below the Conowingo Dam. Najfm 13:103-109.

Welcomme, R.L. 1979. Fisheries ecology of floodplain rivers. Longman. 337 pp.

Williams, G.P., and M.G. Wolman. 1984. Downstream effects of dams on alluvial rivers. USGS paper number 1286.

Williams, R. D., and R. N. Winget. 1979. Macroinvertebrate response to flow manipulation in the Strawberry River, Utah. Pages 365-376 in J.V. Ward and J.A. Stanford, editors. The ecology of regulated streams. Plenum Press, New York, New York.

Williams, R.D., and R.N. Winget. 1979. Macroinvertebrate response to flow manipulation in the Strawberry River, Utah. Pages 365-376 in J.V. Ward and J.A. Stanford, editors. The ecology of regulated streams. Plenum Press, New York, New York.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S.C. Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McAllister, and J.E. Deacon. 1989. Fishes of North America: endangered, threatened, or of special concern. Fisheries 14:2-20.

Williams J.D., M.L. Warren, Jr., K.S. Cummings, J.L. Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18 (9):6-22.

Wolff, S.W., T.A. Wesche, D.D. Harris, and W.A. Hubert. 1990. Brown trout population and habitat changes associated with increased minimum low flows in Douglas Creek, Wyoming. U.S. Fish and Wildlife Service, Biological Report 90(11).

Zincone, L.H., and R.A. Rulifson. 1991. Instream flow and striped bass recruitment in the lower Roanoke River, North Carolina. Rivers 2:125-137.

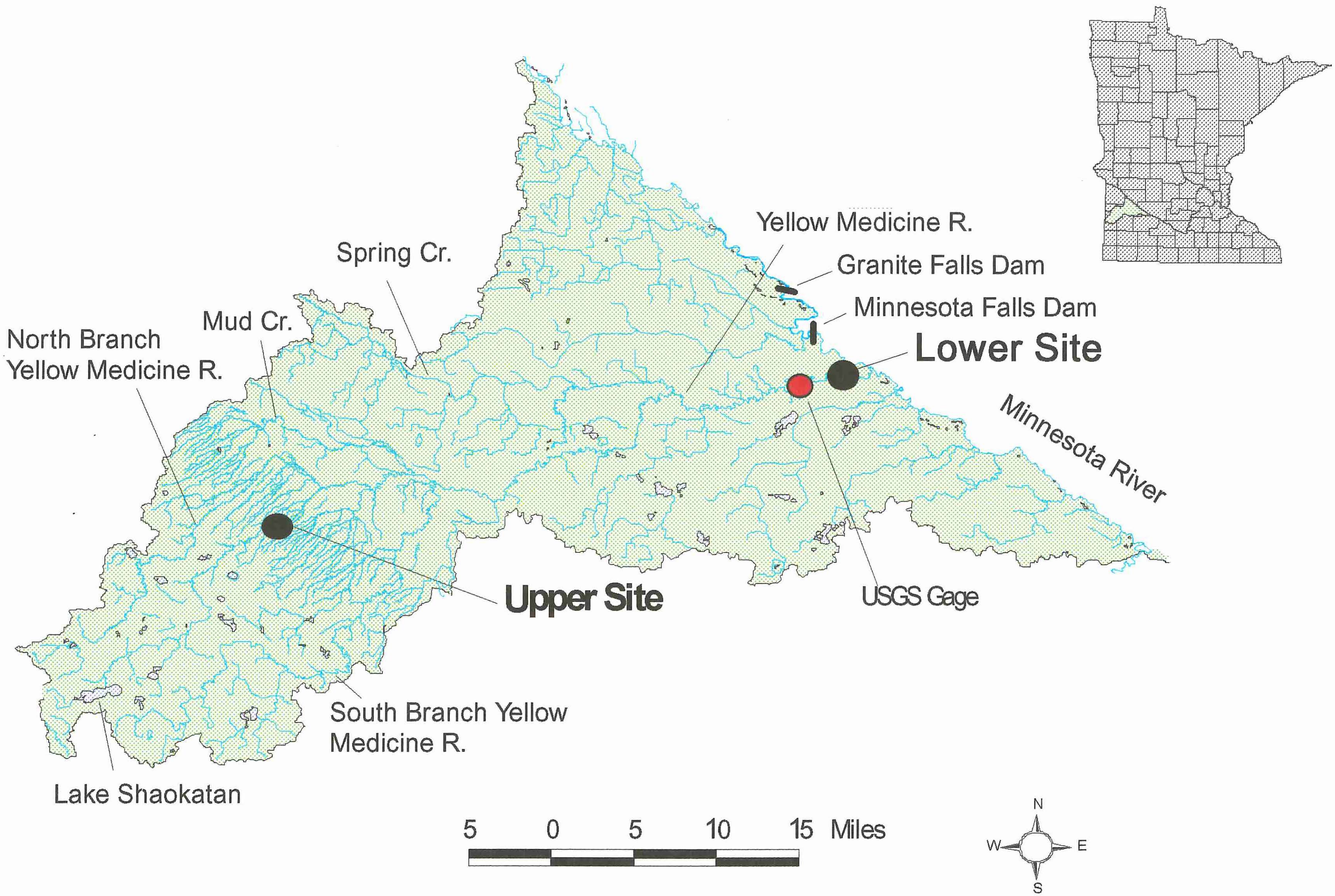


Figure 1. Locations of the Yellow Medicine River Watershed study sites, within the watershed and within the state.

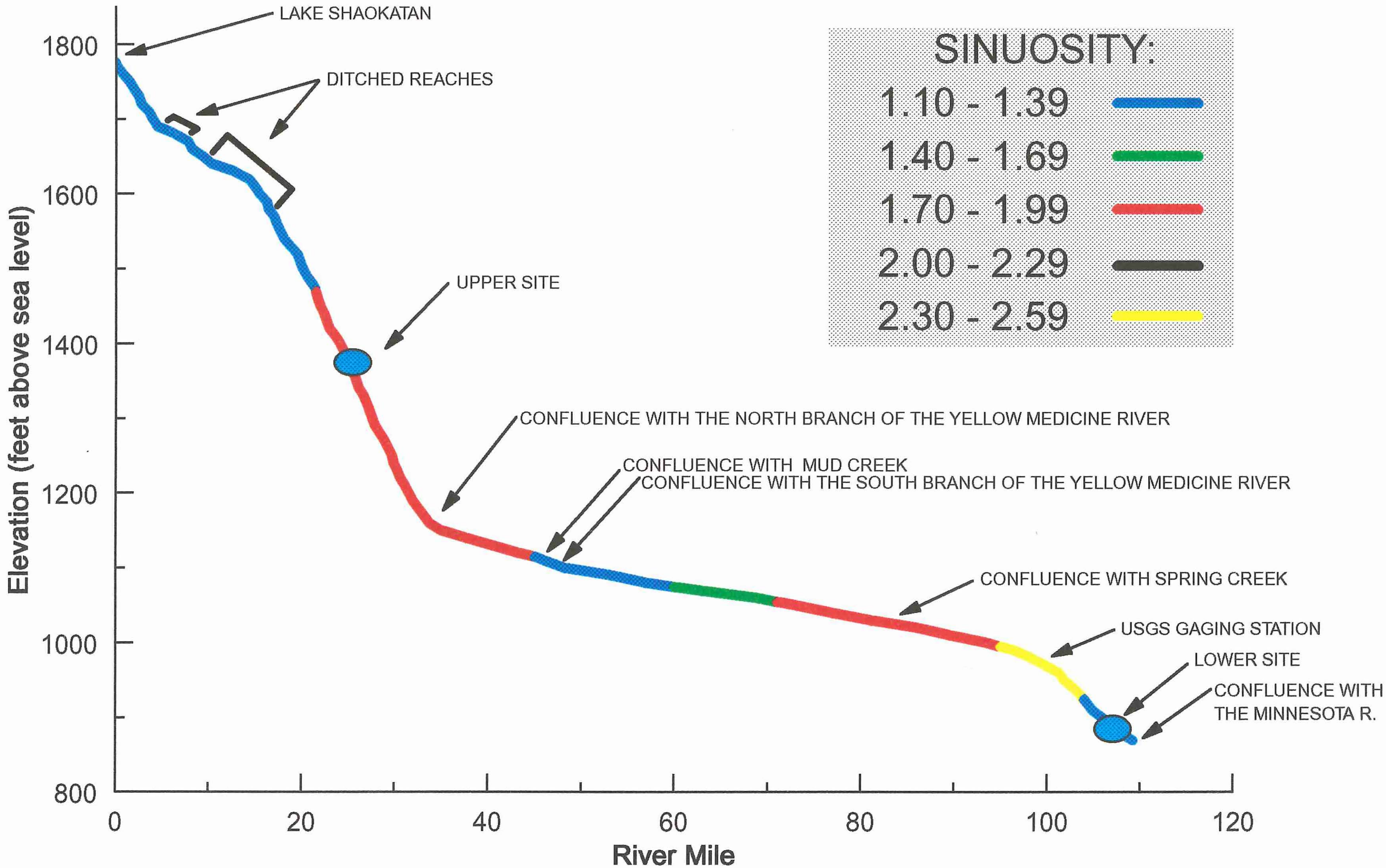


FIGURE 2. Elevation and sinuosity of the Yellow Medicine River from its headwaters to its confluence with the Minnesota River.

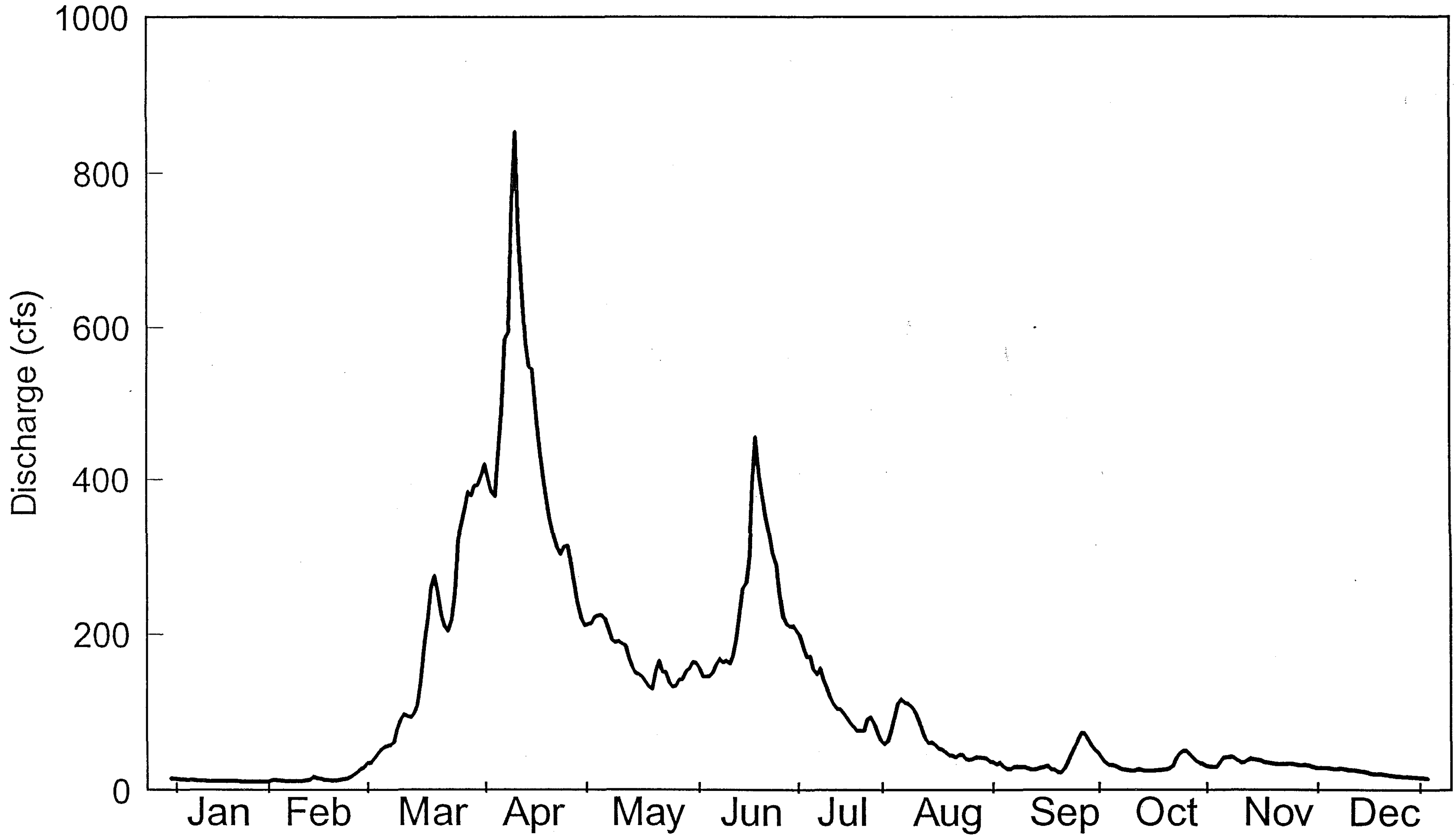


FIGURE 3. Hydrograph of the Yellow Medicine River at Granite Falls, MN based on the mean of mean daily flows from 1931 to 1992.

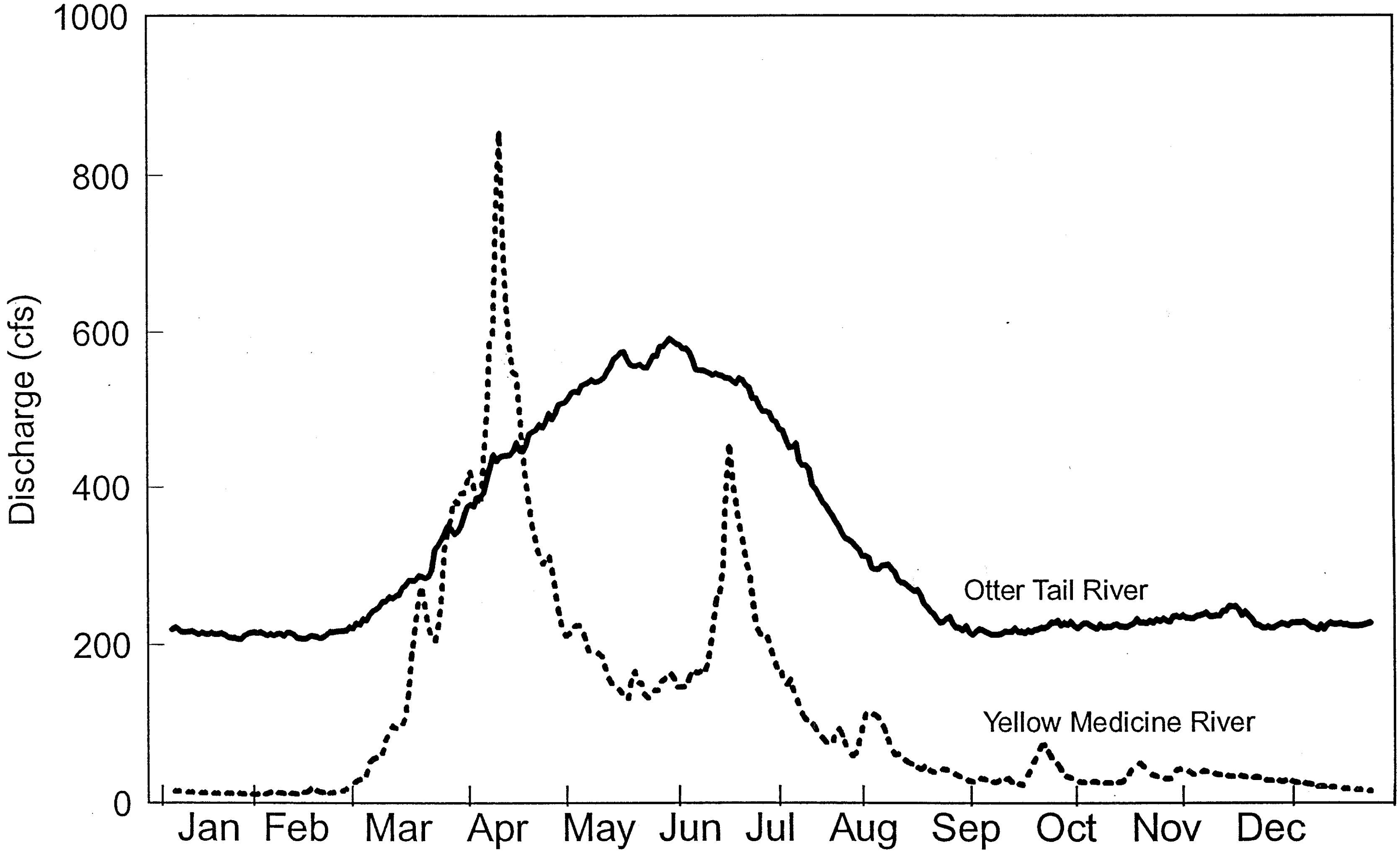


FIGURE 4. Comparison of the mean daily flows of the Otter Tail River and the Yellow Medicine River.

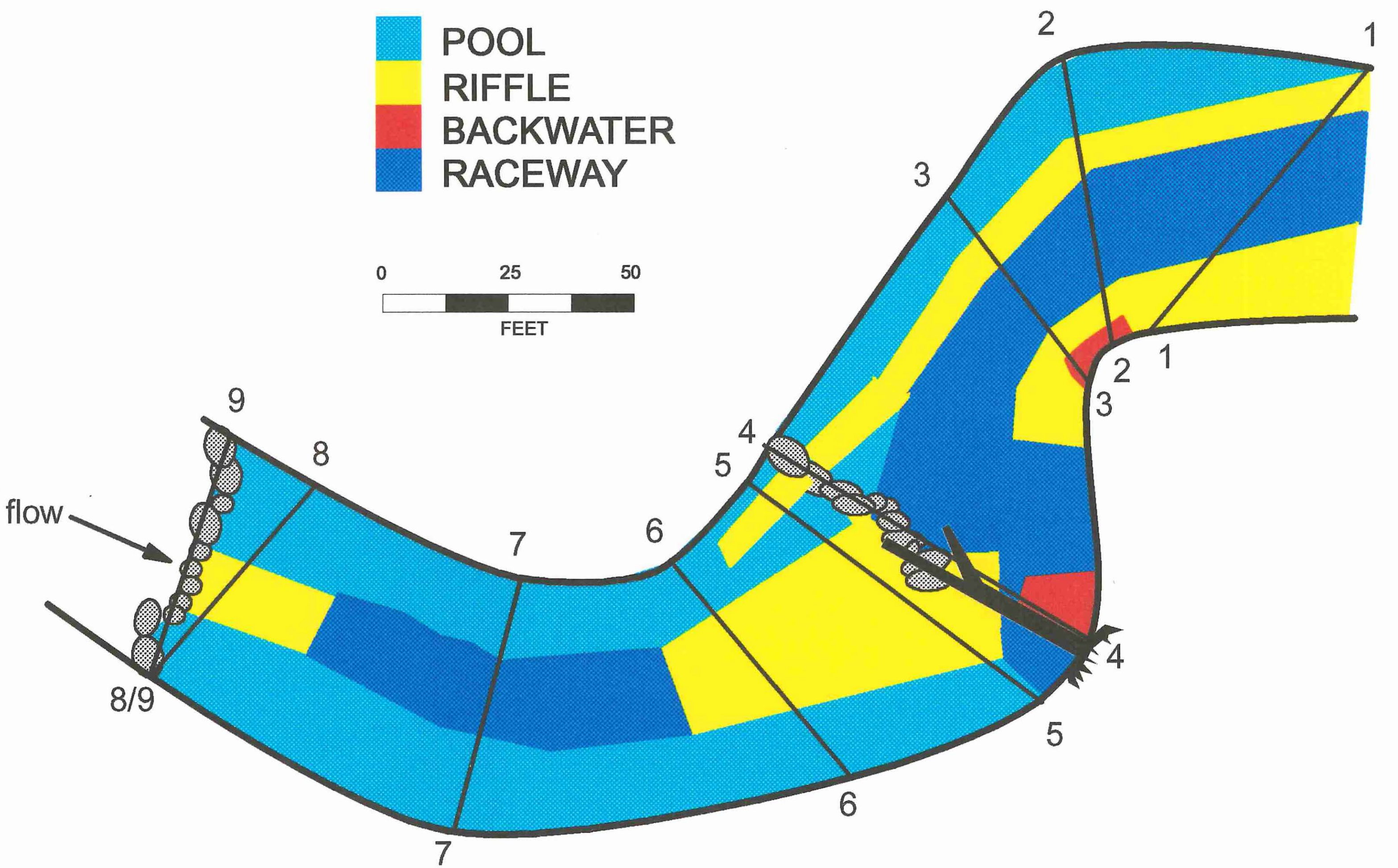


FIGURE 5a. Upper Yellow Medicine study site showing transects and habitat types.

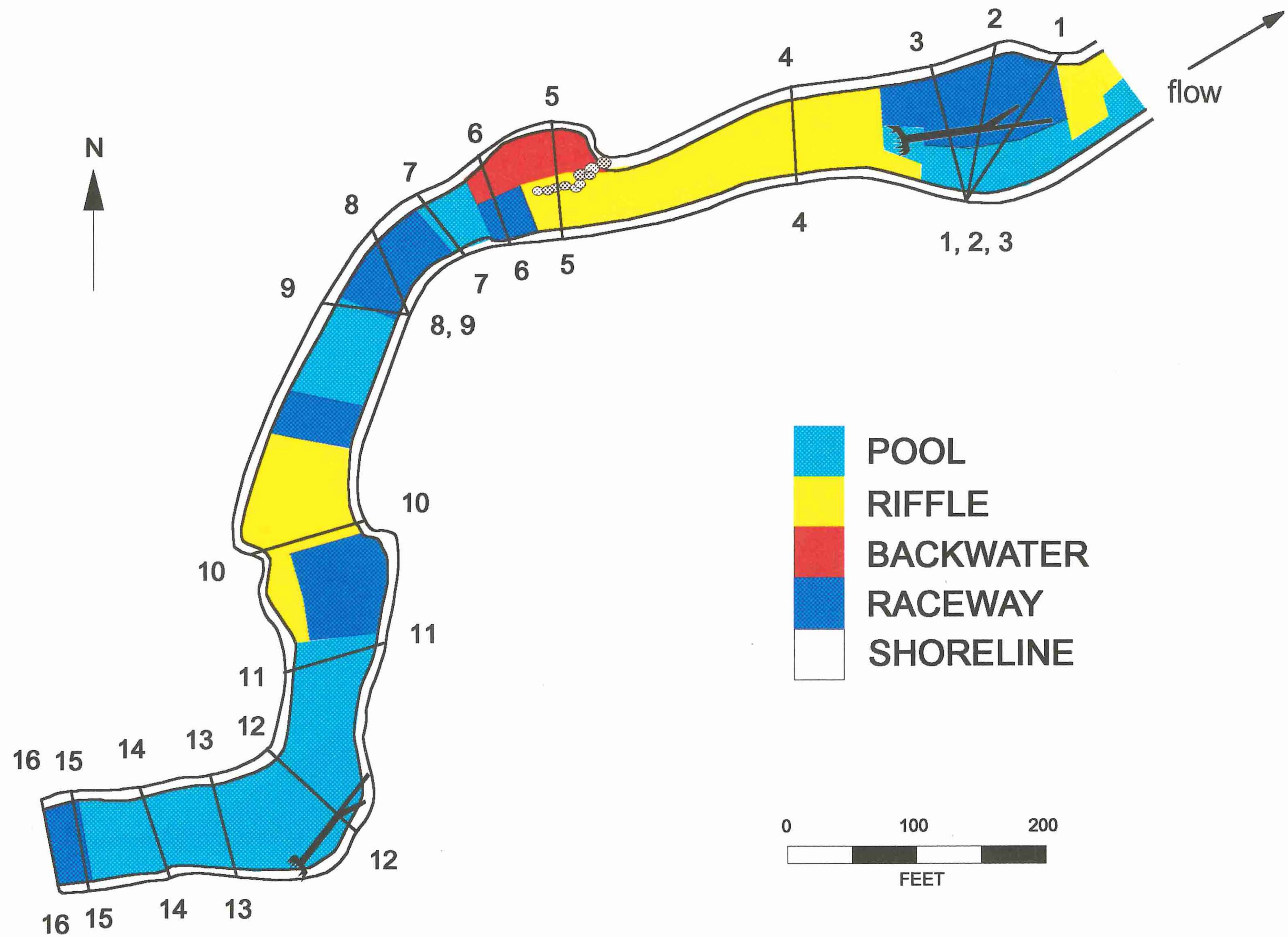


FIGURE 5b. Lower Yellow Medicine study site showing transects and habitat types.

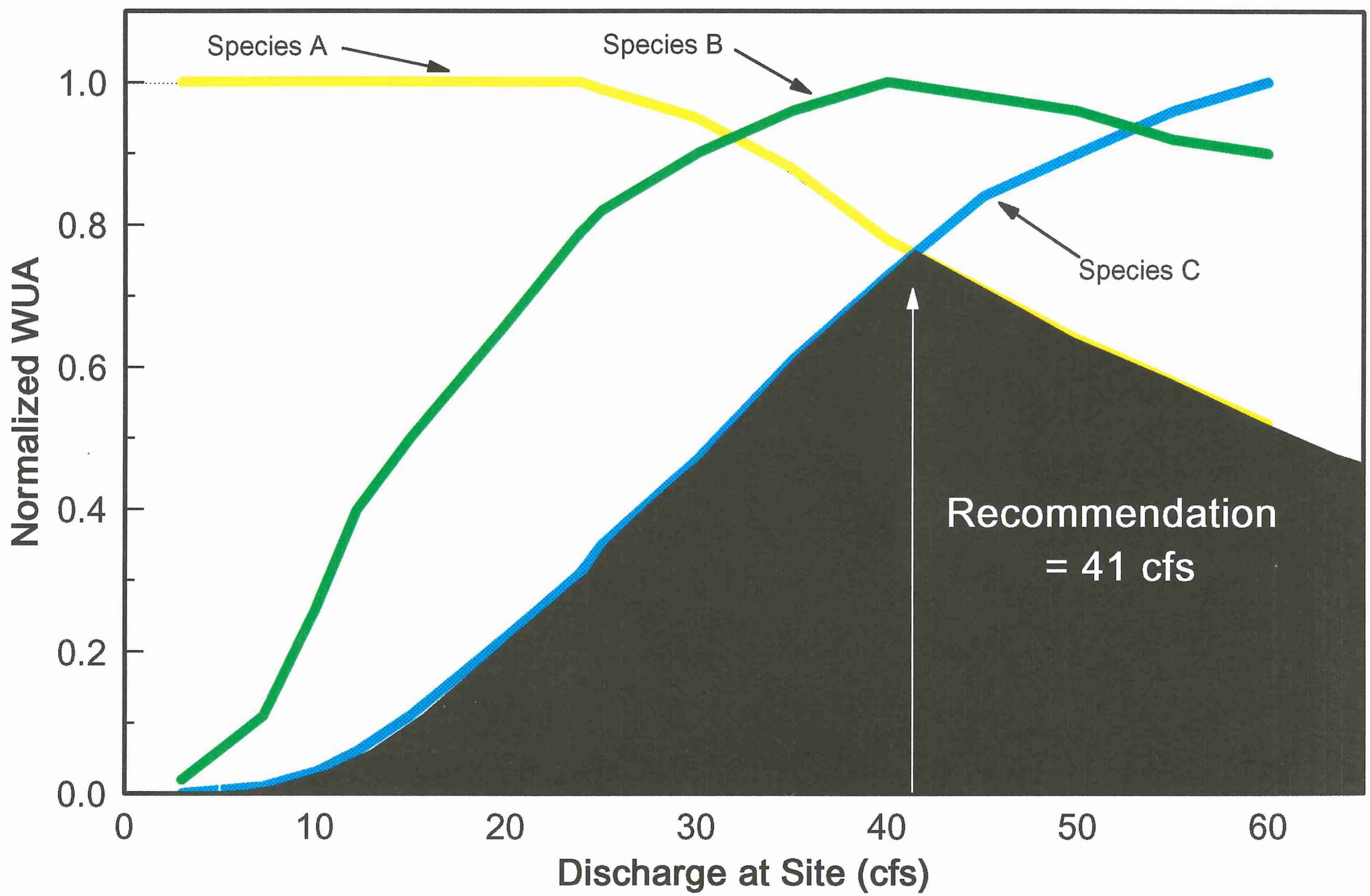


FIGURE 6. Graphical procedure for identifying the community-based flow recommendation (CBFR): generally the highest point of the black area to the right of and below all WUA lines.

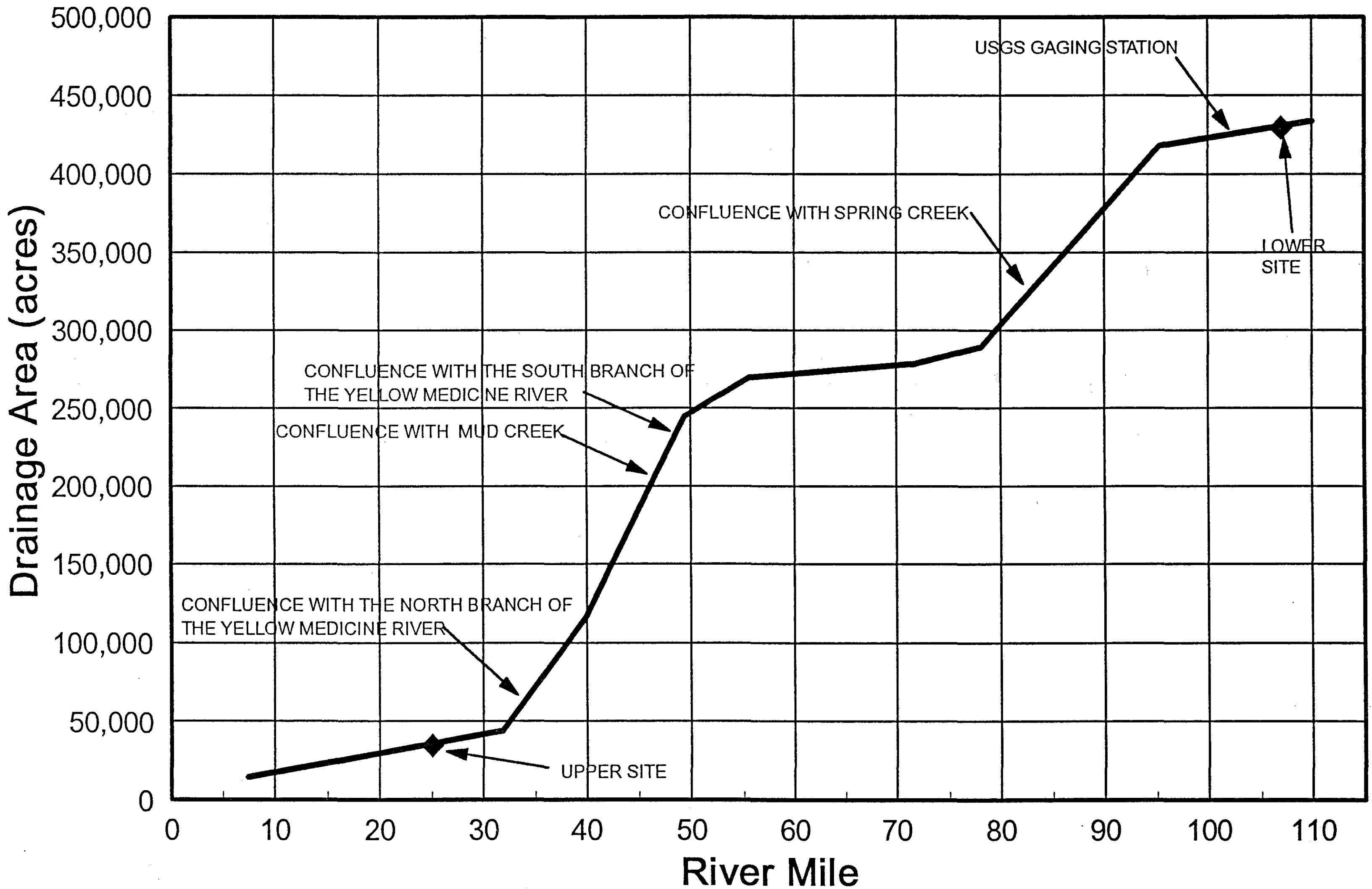


FIGURE 7. Drainage area by river miles for the Yellow Medicine River.

Legend for Figures 8-15

BDDA	BANDED DARTER - ADULT		RBDA	RAINBOW DARTER - ADULT	
BDDS	BANDED DARTER - SPAWNING		RKBA	ROCK BASS - ADULT	
BDDY	BANDED DARTER - YOY		SDSA	SAND SHINER - ADULT	
BNDA	BLACKNOSE DACE - ADULT		SDSA - Winter	SAND SHINER - ADULT WINTER	
BNMY	BLUNTNOSE MINNOW-YOY		SDSY	SAND SHINER - YOY	
CCFA	CHANNEL CATFISH - ADULT		SHDS	SLENDERHEAD DARTER - SPAWNING	
CCFJ	CHANNEL CATFISH - JUVENILE		SMBA	SMALLMOUTH BASS - ADULT	
CCFY	CHANNEL CATFISH - YOY		SMBFi	SMALLMOUTH BASS - FINGERLING	
CSRA	CENTRAL STONEROLLER - ADULT		SMBFr	SMALLMOUTH BASS - FRY	
FROG	LEOPARD FROG		SMBJ	SMALLMOUTH BASS - JUVENILE	
HHCS	HORNYHEAD CHUB - SPAWNING		SMBS	SMALLMOUTH BASS - SPAWNING	
LARVA	ALL LARVAL FISH COMBINED		WAEA	WALLEYE - ADULT	
NOPA	NORTHERN PIKE - ADULT		WAEJ	WALLEYE - JUVENILE	
OSSA	ORANGESPOTTED SUNFISH - ADULT		WAES	WALLEYE - SPAWNING	
PTO	WABASH PIGTOE MUSSEL		INVERTS	MACROINVERTS OTHER THAN MUSSELS	

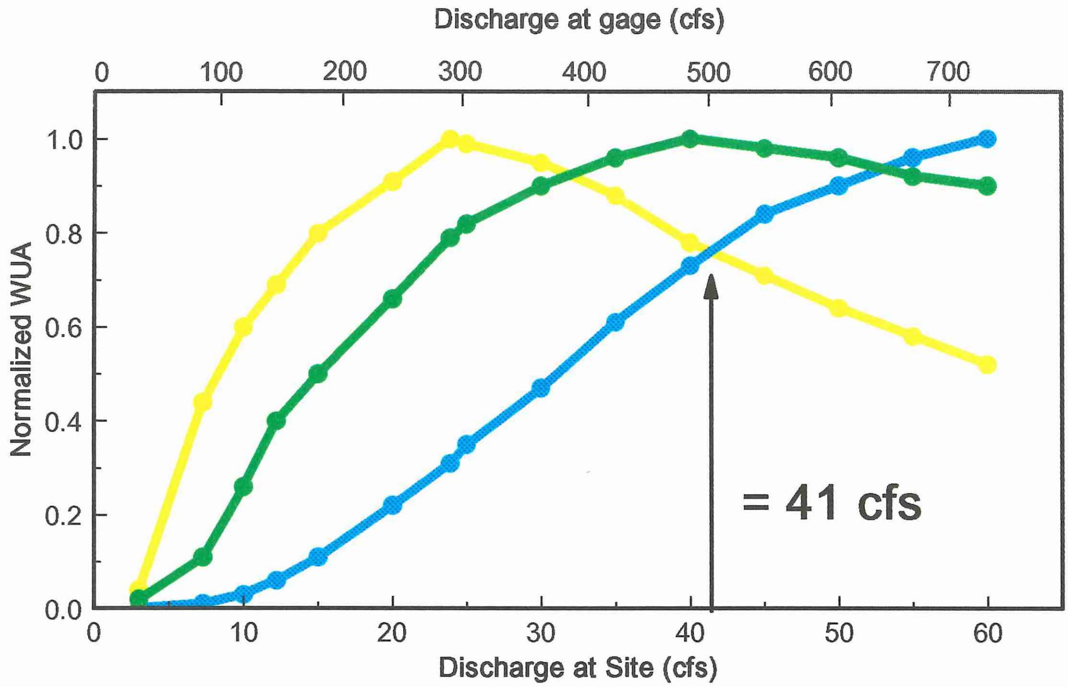


FIGURE 8. Normalized WUA for the upper Yellow Medicine site for the season 1 April - 15 May, where the drivers are spawning walleye and spawning hornyhead chub (see legend between figures 7 and 8).

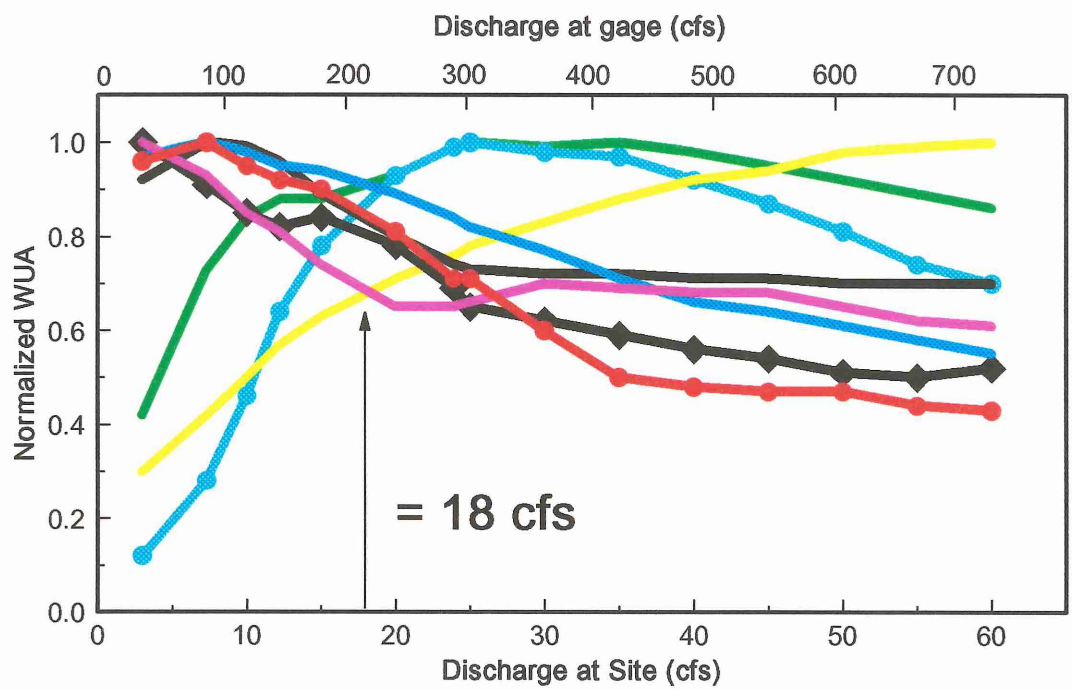


FIGURE 9. Normalized WUA for the upper Yellow Medicine site for the season 16 May - 4 November, where the drivers are adult rainbow darters and larval fish (see legend between figures 7 and 8).

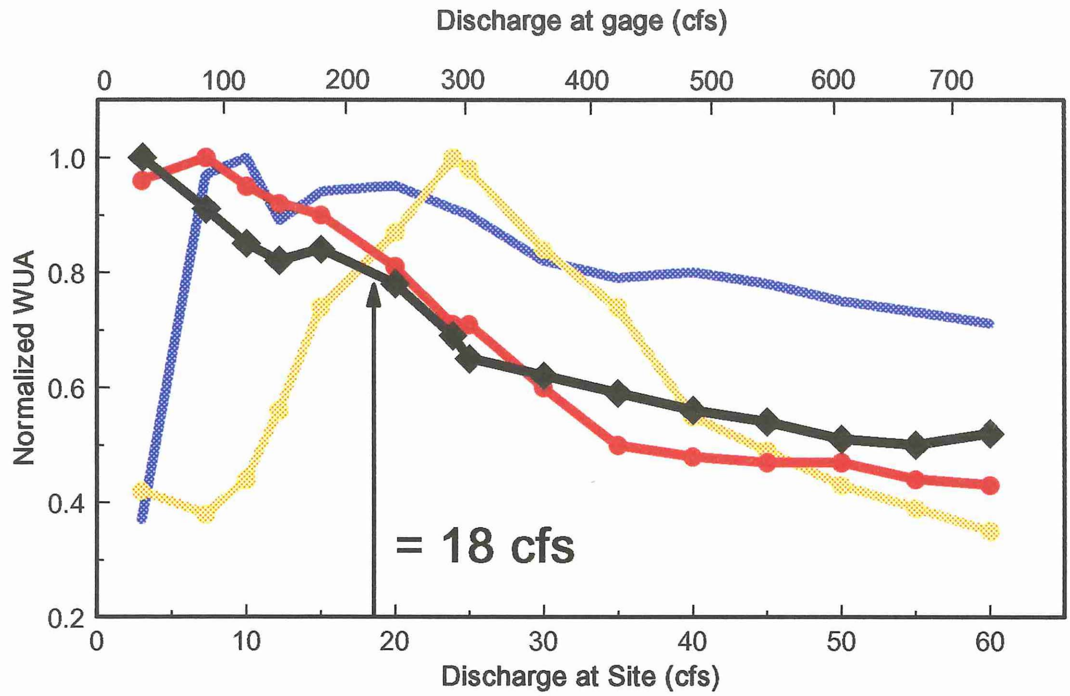


FIGURE 10. Normalized WUA for the upper Yellow Medicine site for the season 5 November - 31 March, where the drivers are adult sand shiners and adult orangespotted sunfish (see legend between figures 7 and 8).

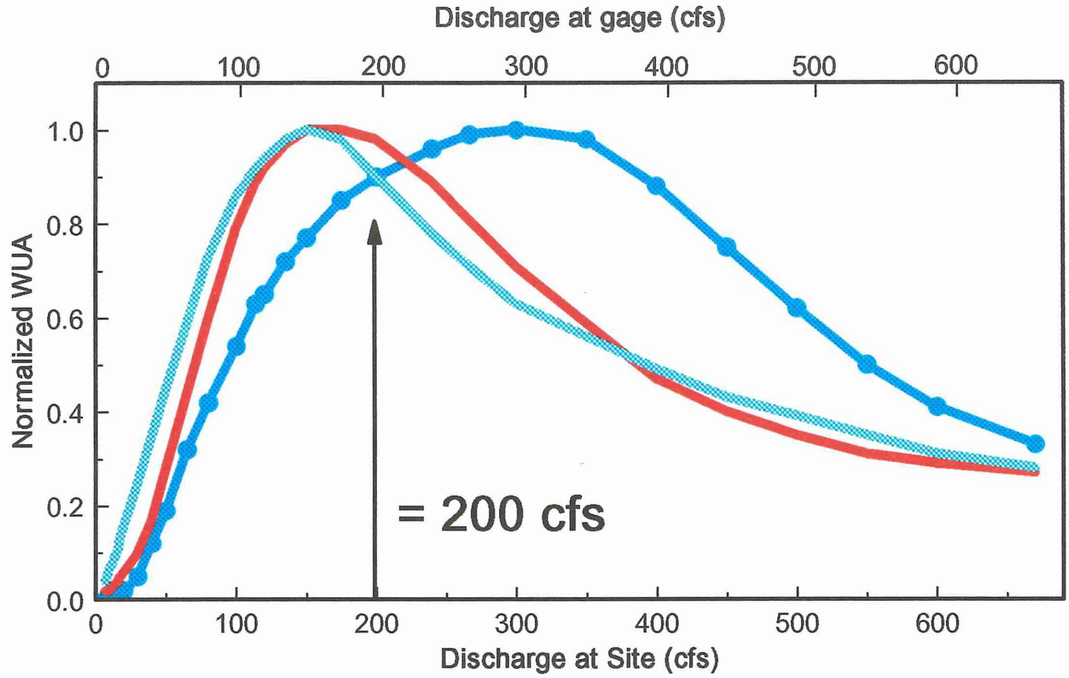


FIGURE 11. Normalized WUA for the lower Yellow Medicine site for the season 1 April - 15 May, where the drivers are spawning walleye and spawning banded darters (see legend between figures 7 and 8).

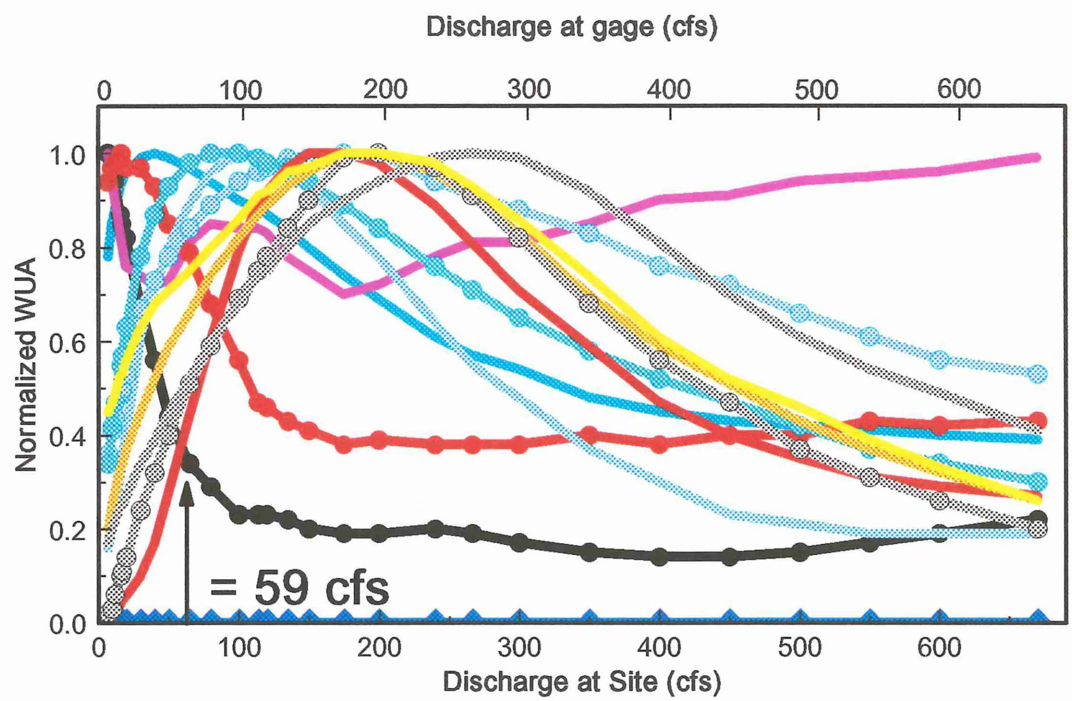


FIGURE 12. Normalized WUA for the lower Yellow Medicine site for the season 16 May - 30 June, where the drivers are Wabash pigtoe mussel and smallmouth bass fry (see legend between figures 7 and 8).

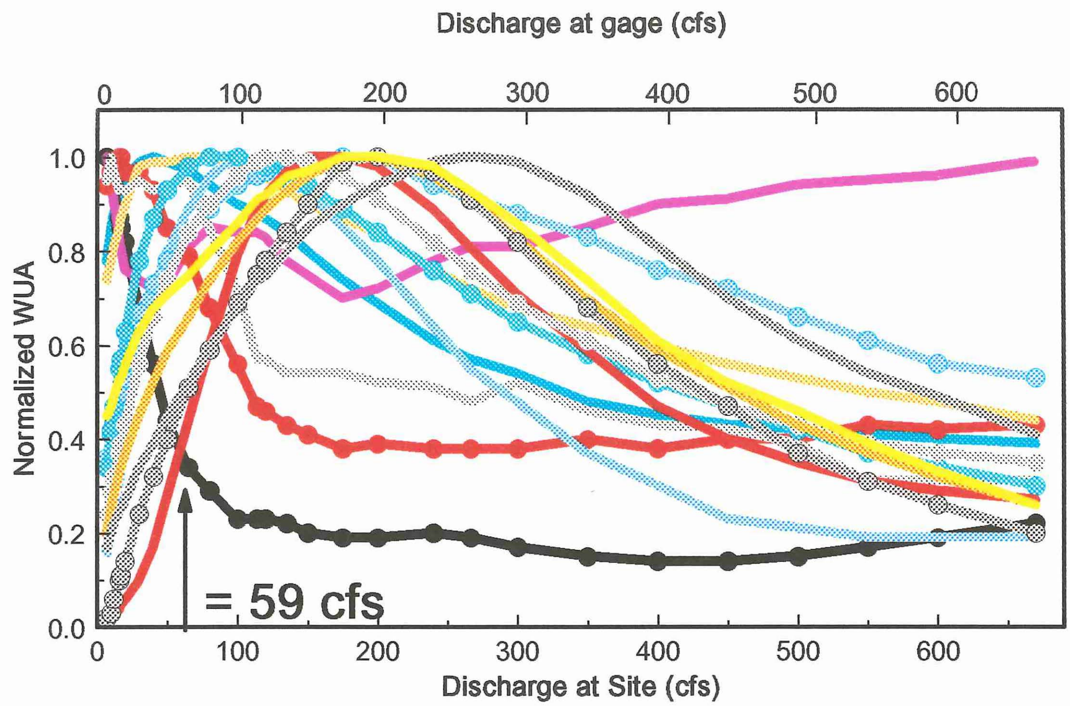


FIGURE 13. Normalized WUA for the lower Yellow Medicine site for the season 1 July - 31 July, where the drivers are Wabash pigtoe mussel and smallmouth bass fry (see legend between figures 7 and 8).

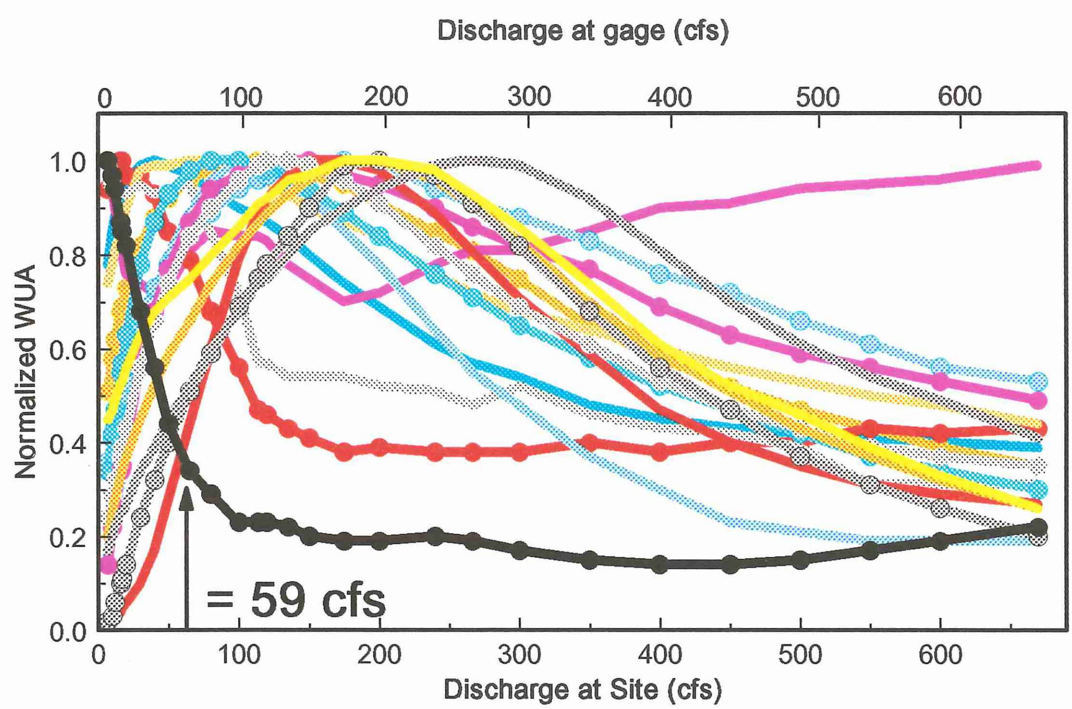


FIGURE 14. Normalized WUA for the lower Yellow Medicine site for the season 1 August - 4 November, where the drivers are Wabash pigtoe mussel and smallmouth bass fry (see legend between figures 7 and 8).

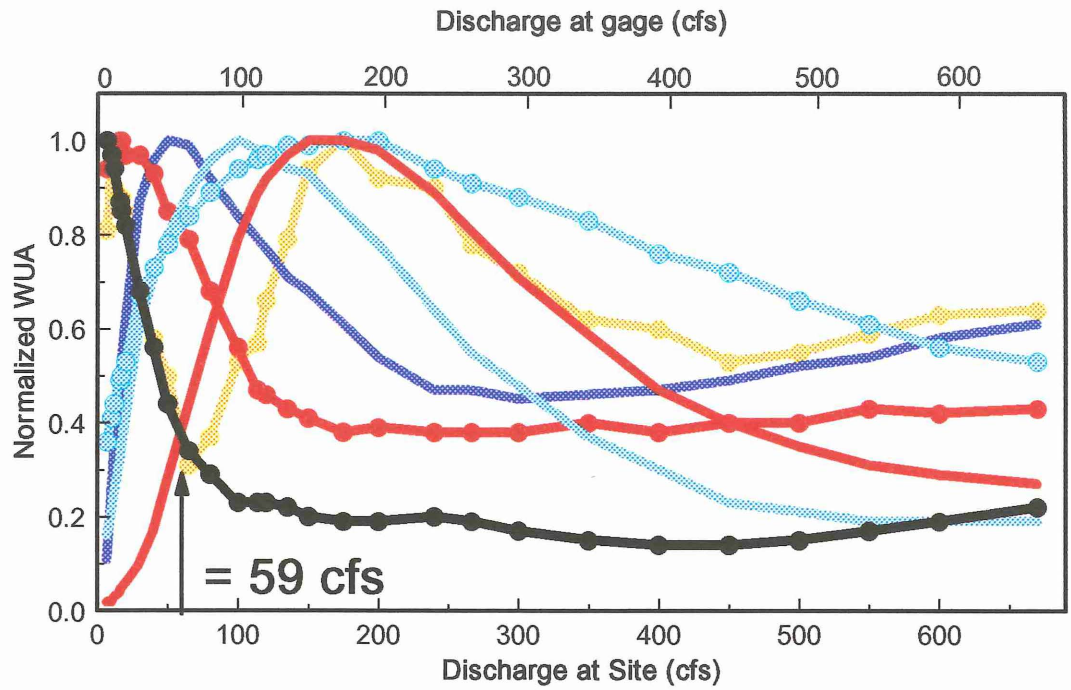


FIGURE 15. Normalized WUA for the lower Yellow Medicine site for the season 5 November - 31 March, where the drivers are Wabash pigtoe mussel and smallmouth bass fry (see legend between figures 7 and 8).

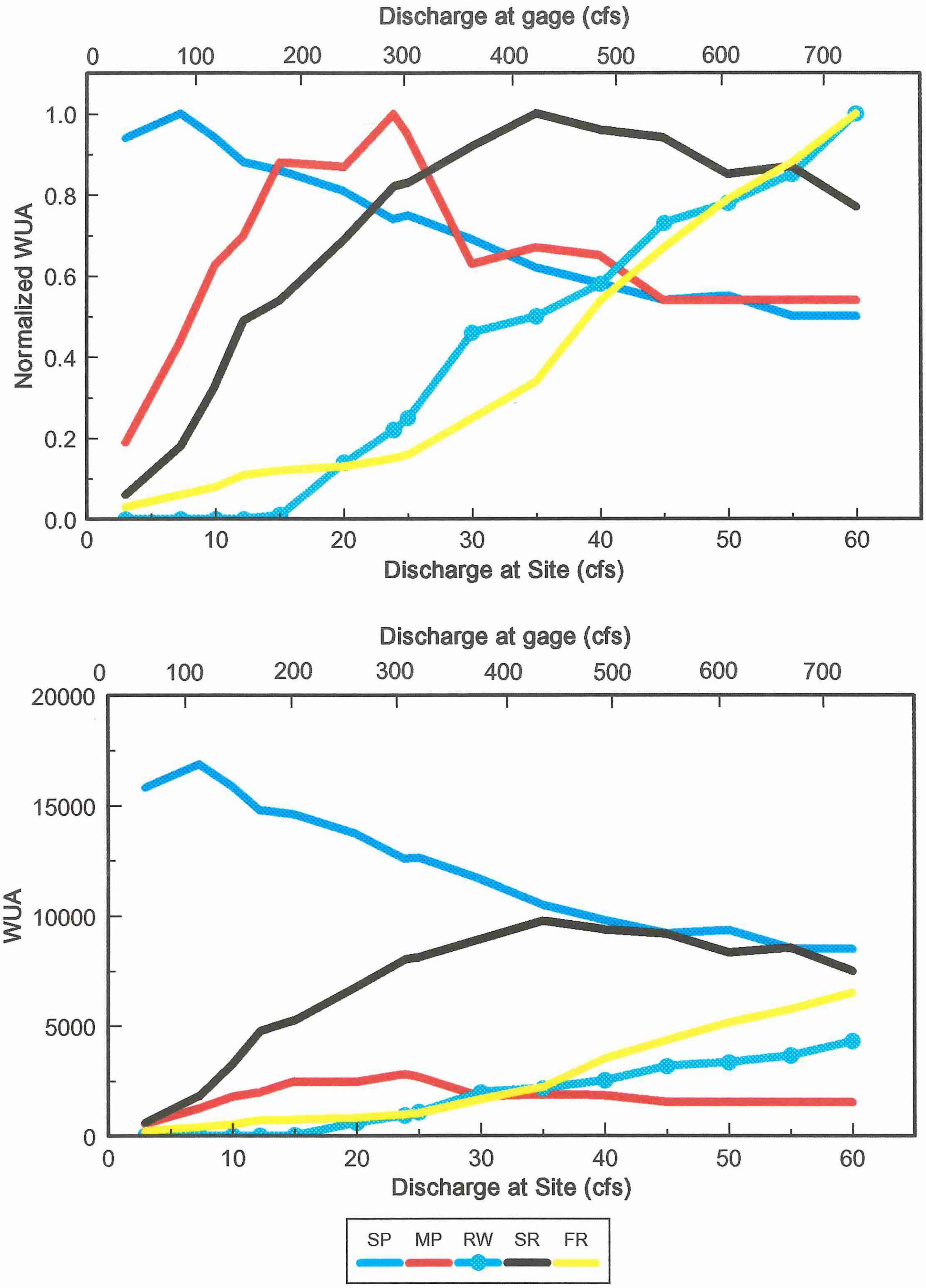


FIGURE 16a. Normalized and non-normalized weighted usable area as a function of discharge for habitat types at the upper Yellow Medicine River site, where SP=shallow pool, MP=medium pool, RW=raceway, SR=slow riffle, and FR=fast riffle. The lower x-axis is the discharge at the site, and the upper x-axis is the extrapolated discharge at the USGS gage near Granite Falls, MN.

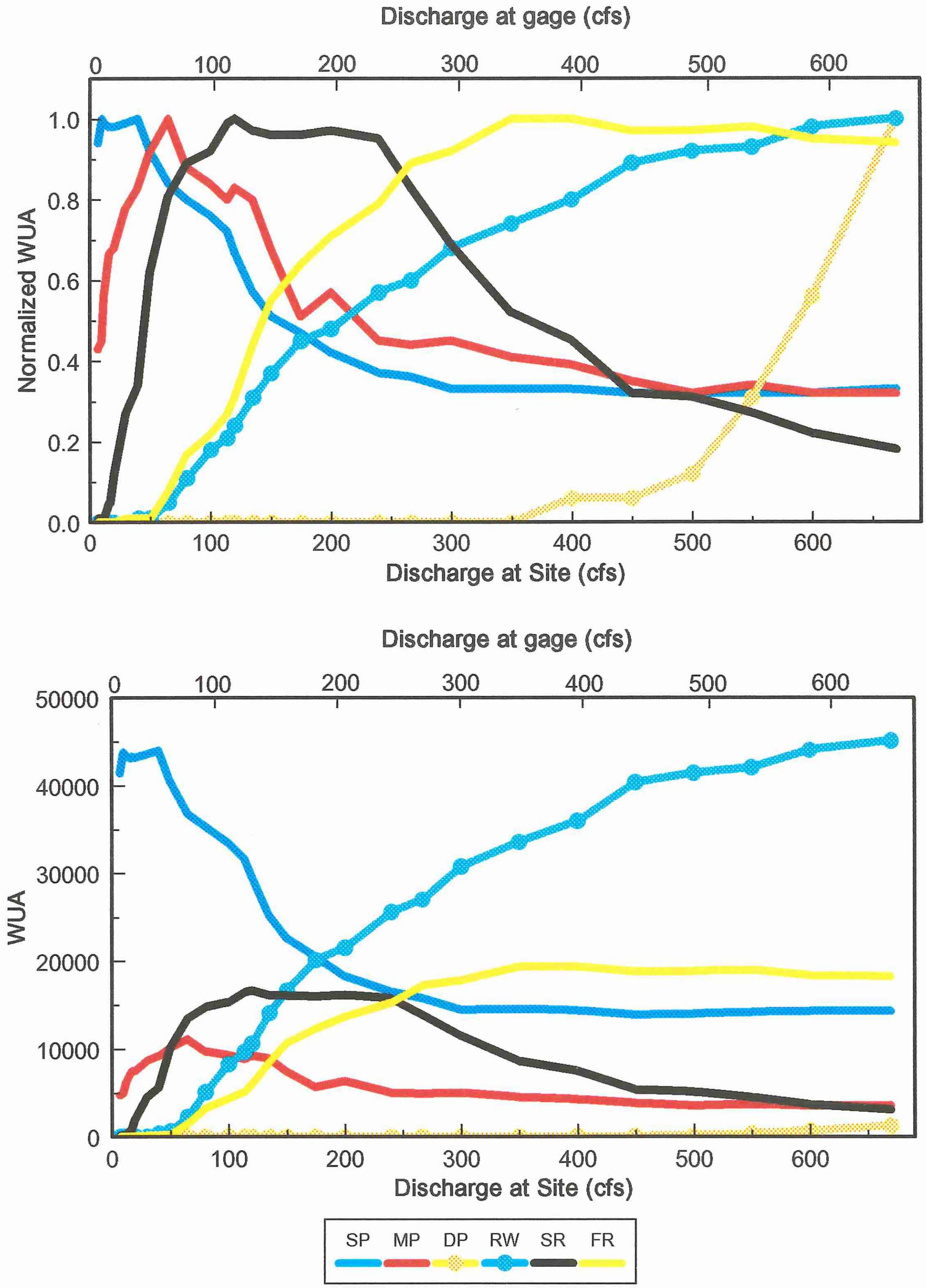


FIGURE 16b. Normalized and non-normalized weighted usable area as a function of discharge for habitat types at the lower Yellow Medicine River site, where SP=shallow pool, MP=medium pool, DP=deep pool, RW=raceway, SR=slow riffle, and FR=fast riffle. The lower x-axis is the discharge at the site, and the upper x-axis is the extrapolated discharge at the USGS gage near Granite Falls, MN.

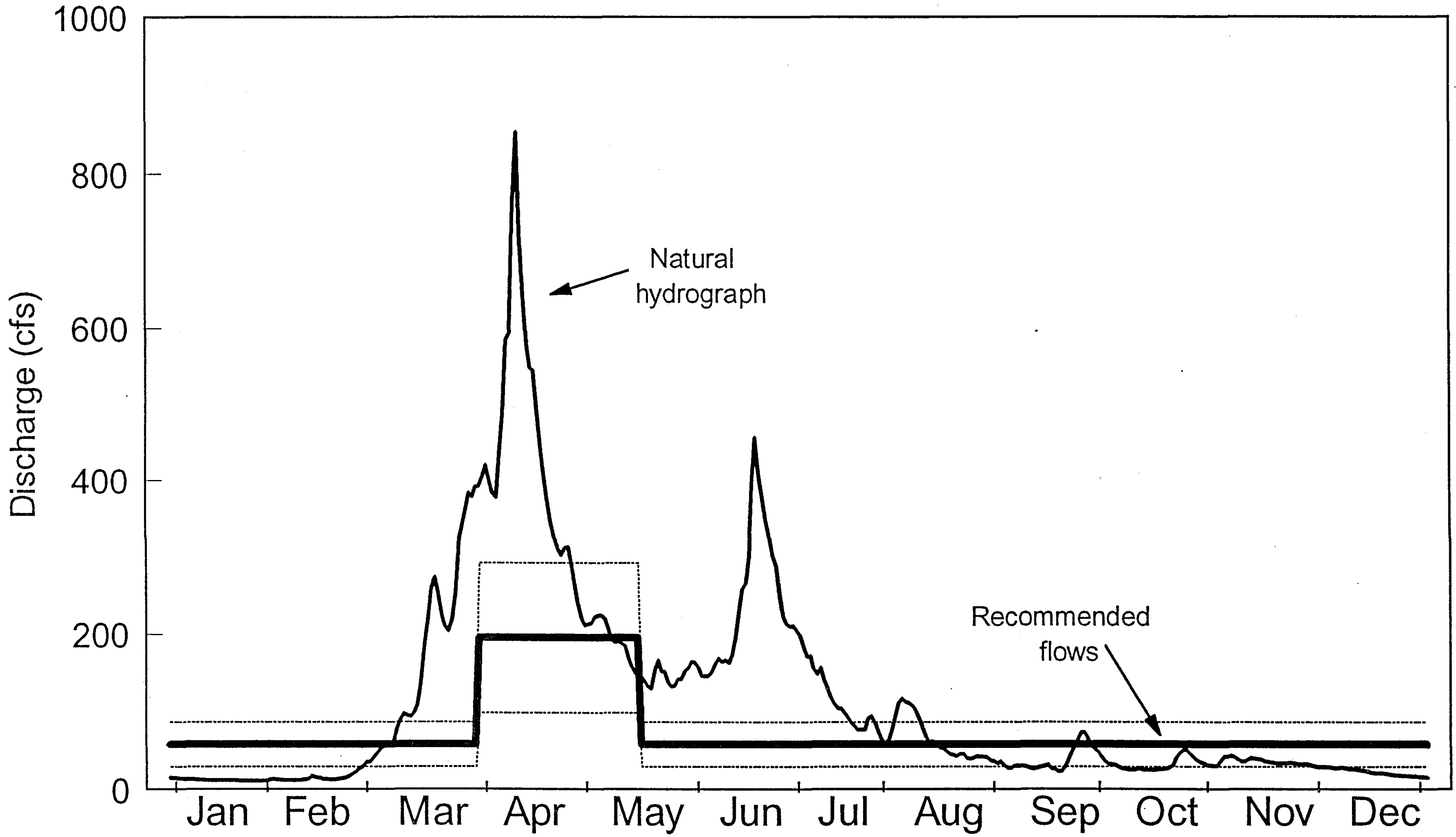


FIGURE 17. Hydrograph of the Yellow Medicine River at Granite Falls, MN based on the mean of mean daily flows from 1931 to 1992, plus the recommended flows and their corresponding brackets.

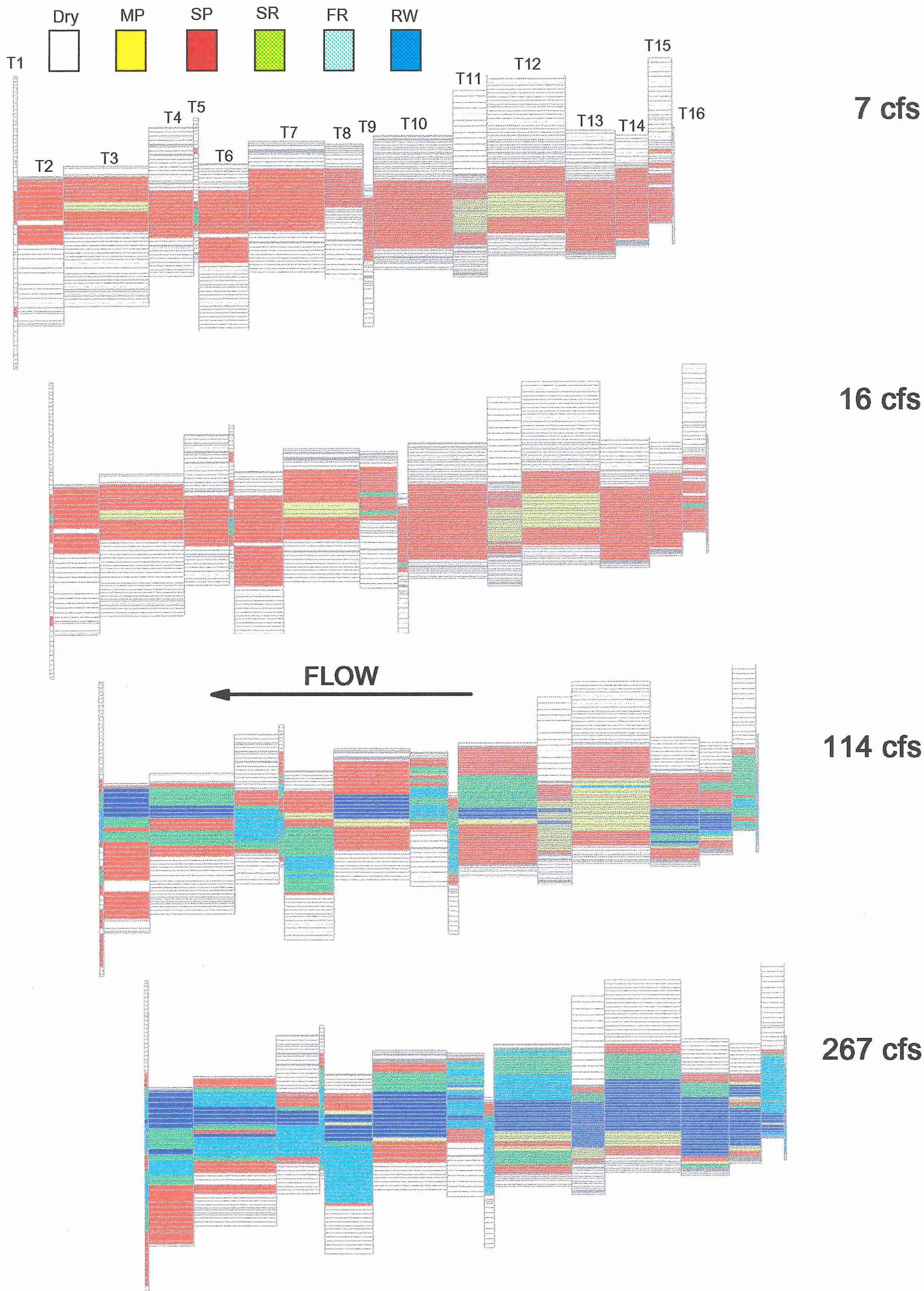


FIGURE 18. Plan view showing the increasing diversity of habitat types available along the 16 transects of the lower Yellow Medicine site at discharges of 7 cfs, 16 cfs, 114 cfs, and 267 cfs, where SP=shallow pool, MP= medium pool, SR=slow riffle, FR=fast riffle, RW=raceway, and white areas are dry. Current protected flow = 2.1 cfs.

Appendix A. Hydrologic statistics for the period of record for the USGS gage (#05313500) on the Yellow Medicine River near Granite Falls, MN (Hydrosphere Data Products 1997). All values are in units of cfs.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Minimum	0.3	0.1	3.7	2.6	1.2	1.2	0.3	0.4	0.5	1.4	1.6	1.4	8.3
Maximum	75.5	97.1	933.5	3302.0	1087.0	2484.0	1600.0	510.4	1005.0	552.8	396.8	289.3	565.7
Median	5.5	5.4	42.0	145.5	82.0	62.0	36.0	13.0	6.7	7.2	12.0	7.5	18.0
Mean	13.7	22.3	226.3	460.3	200.5	280.5	140.4	69.4	43.9	43.6	45.6	28.3	133.9
10% exceedance flow	33.0	45.8	678.1	1180.0	530.5	638.7	361.6	165.0	83.0	105.8	127.0	80.0	318.0
90% exceedance flow	1.7	1.8	3.8	19.0	12.0	6.5	1.9	1.1	1.3	1.8	2.4	2.5	2.2

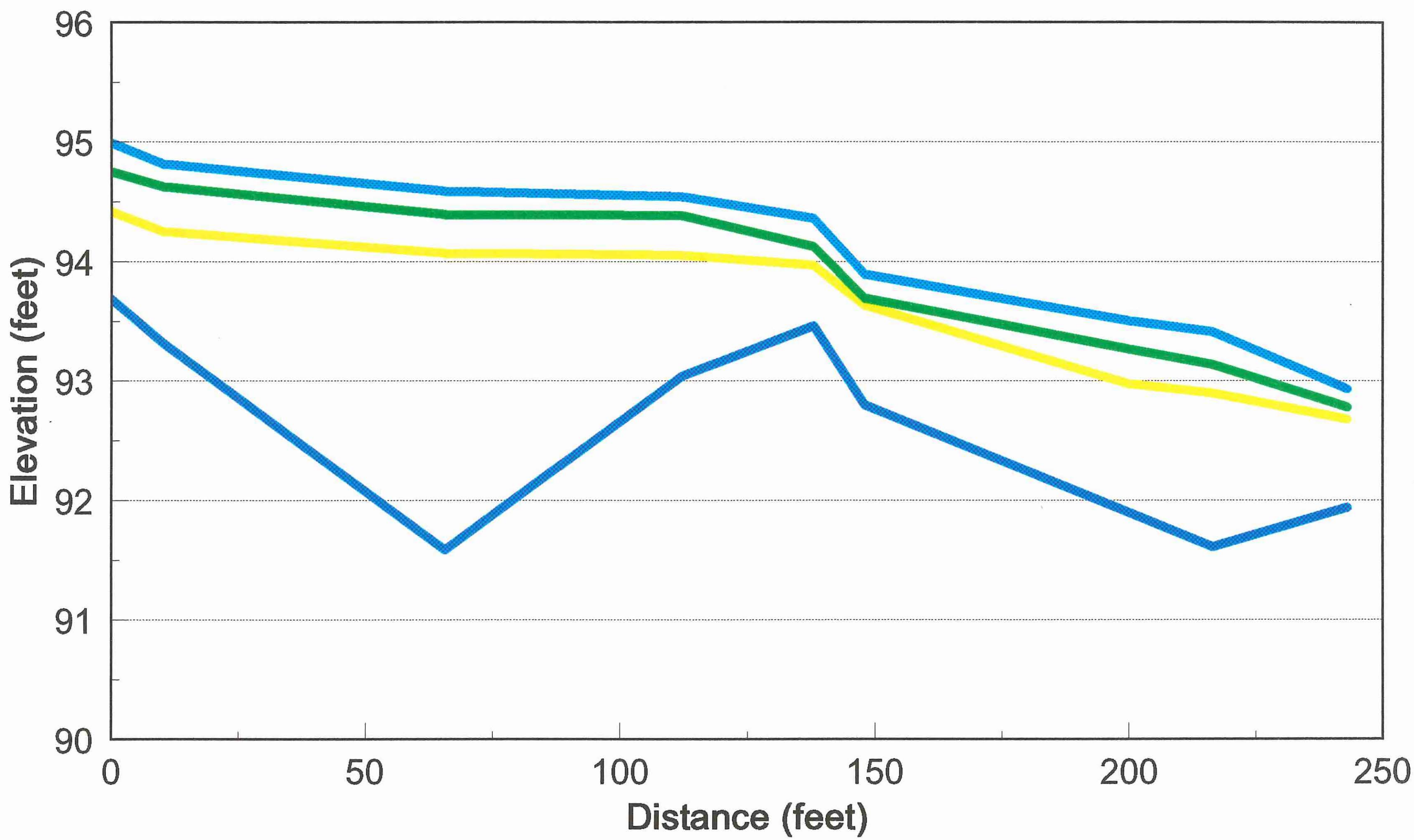
Appendix B1. Transect descriptions and proximity to adjacent transect(s) at the upper Yellow Medicine study site.

Transect Number	Transect Description	Dist. to next transect - left (ft)	Dist. to next transect - right (ft)	Average dist. to next transect (ft)	Cumulative distances (ft)
1	Hydraulic control	37.7	15.2	26.5	0.0
2	Riffle/raceway with backwater	21.7	11.1	16.4	26.5
3	Raceway	55.3	48.8	52.0	42.9
4	Riffle/plunge pool	8.3	11.7	10.0	94.9
5	Hydraulic control	20.6	30.9	25.8	104.9
6	Riffle	35.9	57.3	46.6	130.7
7	Pool	46.5	64.3	55.4	177.3
8	Raceway	20.7	0.0	10.3	232.7
9	Hydraulic control	n/a	n/a	n/a	243.0

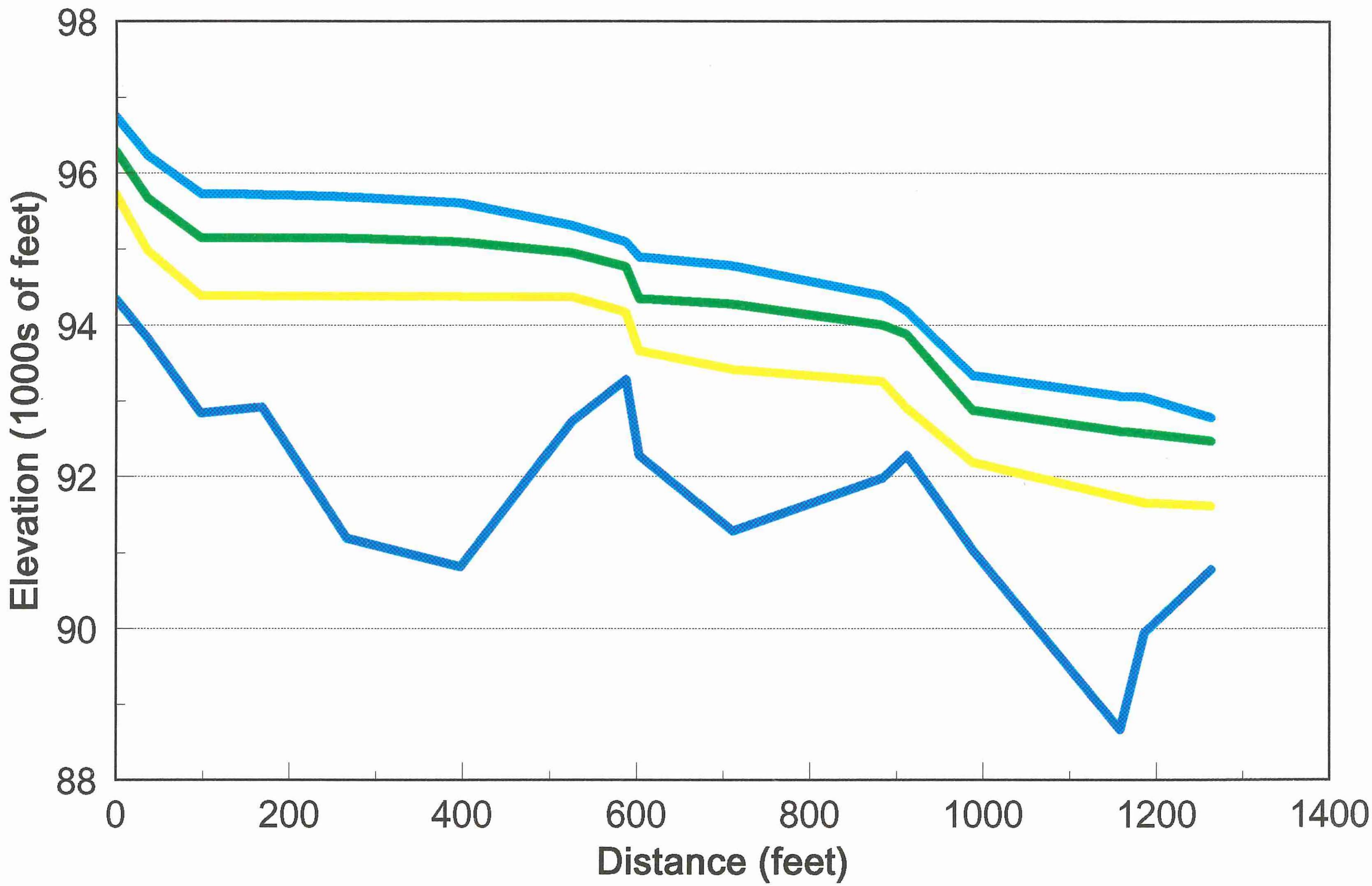
Appendix B2. Transect descriptions and proximity to adjacent transect(s) at the lower Yellow Medicine study site.

Transect Number	Transect Description	Dist. to next transect - left (ft)	Dist. to next transect - right (ft)	Average dist. to next transect (ft)	Cumulative distances (ft)
1	Hydraulic control	154.8	0.0	77.4	0.0
2	Riffle/raceway	55.7	0.0	27.9	77.4
3	Raceway	168.4	171.4	169.9	105.3
4	Riffle/raceway	75.4	77.1	76.3	275.2
5	Control/backwater	37.8	17.3	27.6	351.5
6	Raceway	200.1	146.3	173.2	379.0
7	Pool	112.4	103.2	107.8	552.3
8	Riffle/raceway	30.6	0.0	15.3	660.0
9	Riffle	75.5	48.7	62.1	675.4
10	Hydraulic control	117.4	139.5	128.5	737.5
11	Lower pool	95.2	168.1	131.7	865.9
12	Pool	79.5	115.2	97.4	997.6
13	Upper pool	67.9	74.2	71.1	1095.0
14	Raceway	56.9	65.6	61.3	1166.0
15	Riffle	33.3	39.5	36.4	1227.3
16	Hydraulic control	n/a	n/a	n/a	1263.7

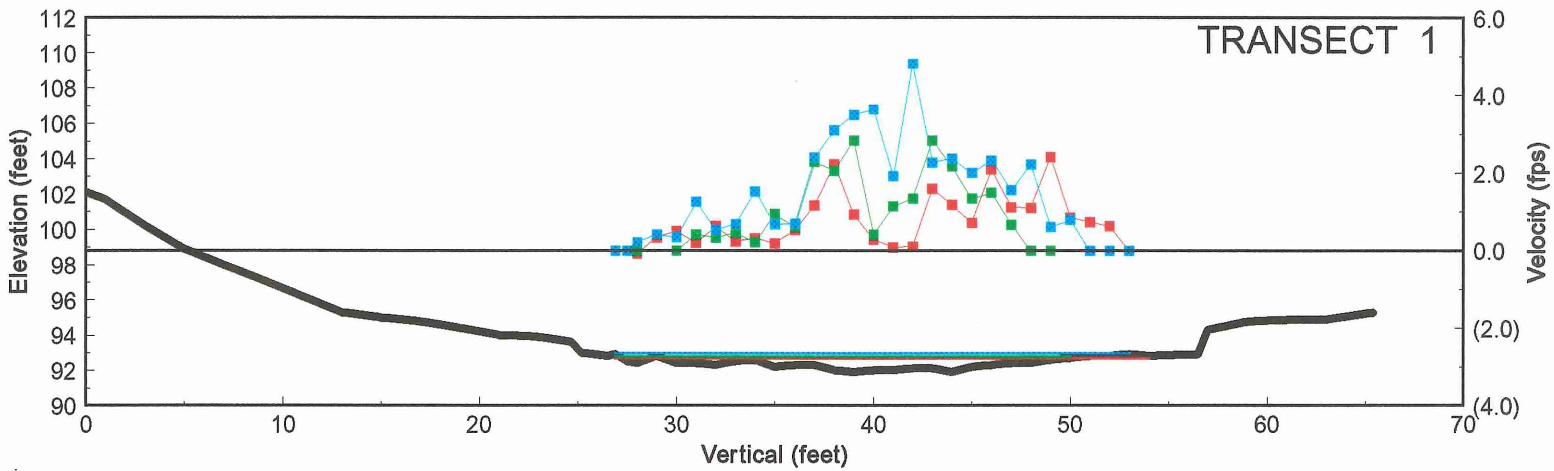
Appendix C1. Longitudinal profile of thalweg and the three measured water surface elevations at the upper Yellow Medicine site.

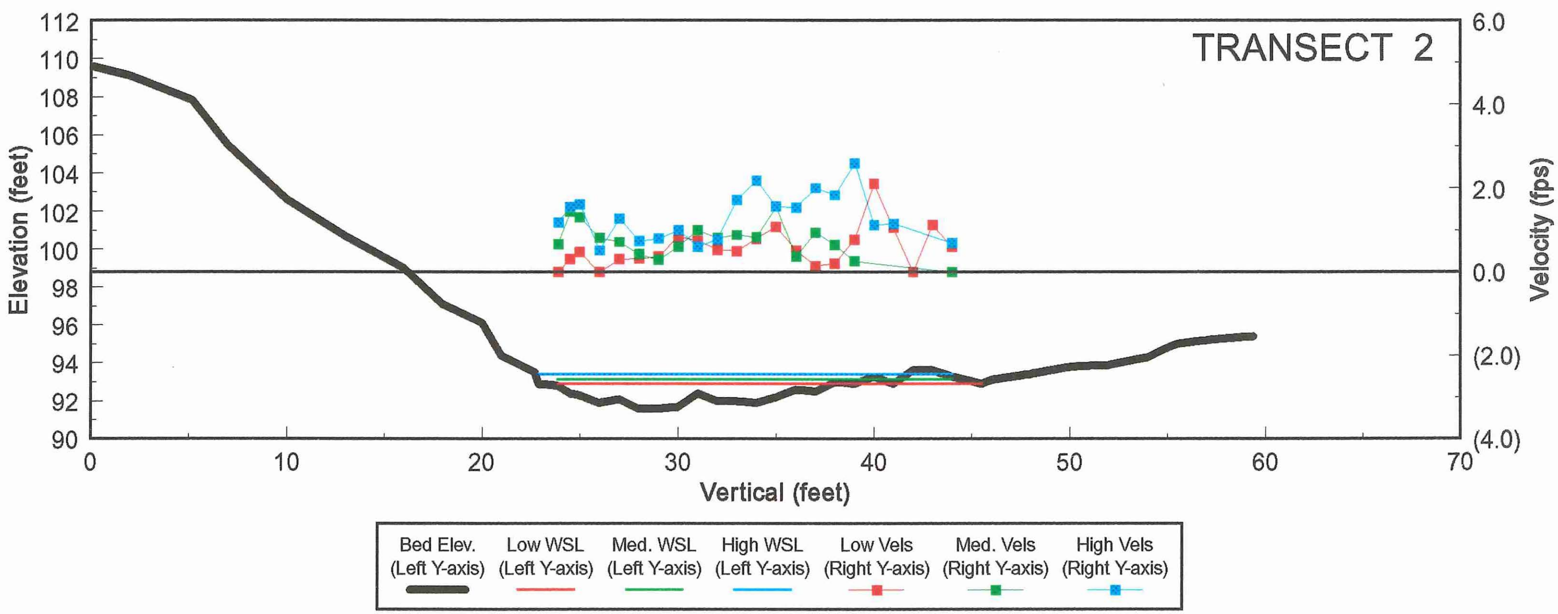


Appendix C2. Longitudinal profile of thalweg and the three measured water surface elevations at the lower Yellow Medicine site.

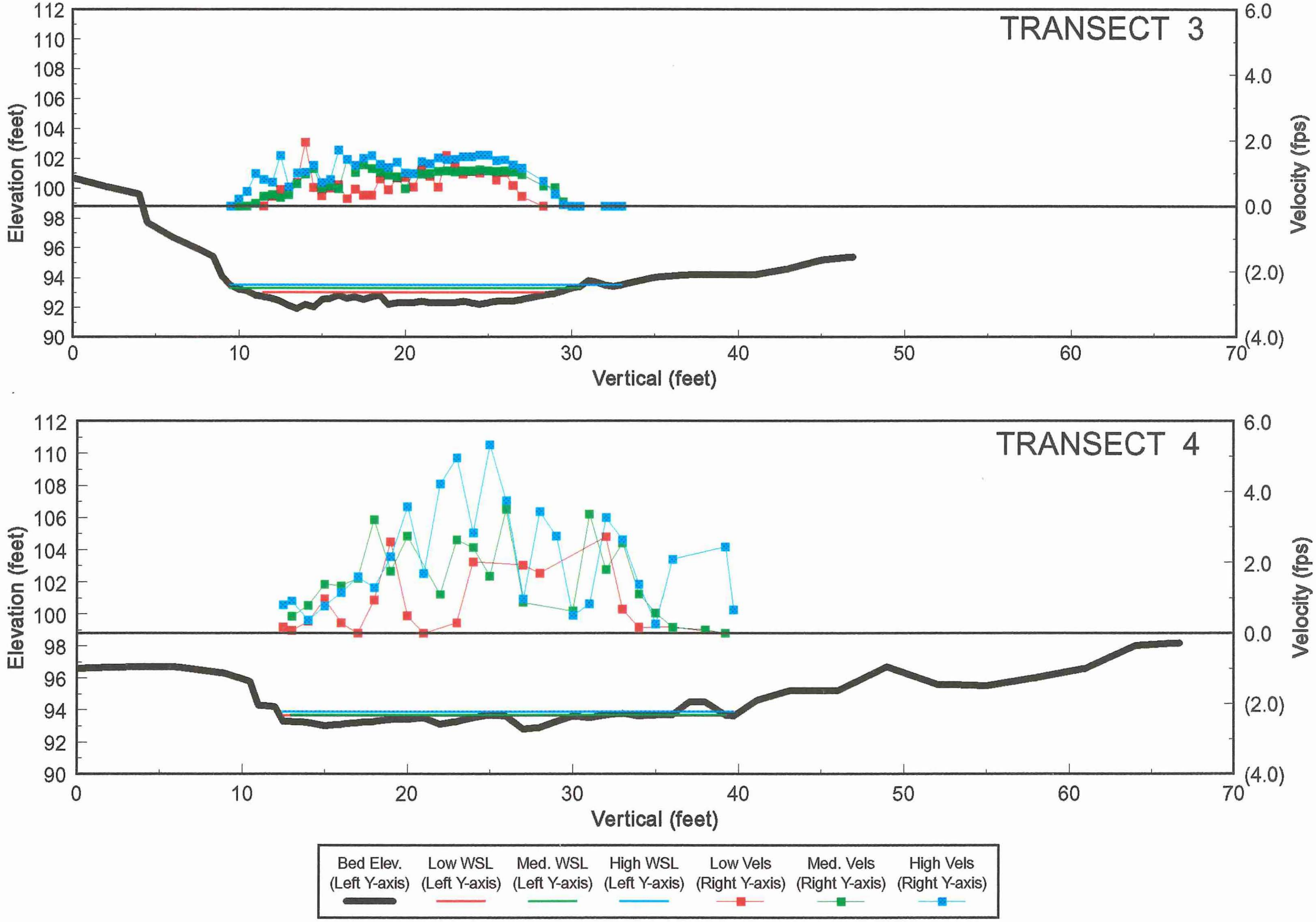


Appendix D1. Cross sections at the upper Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.

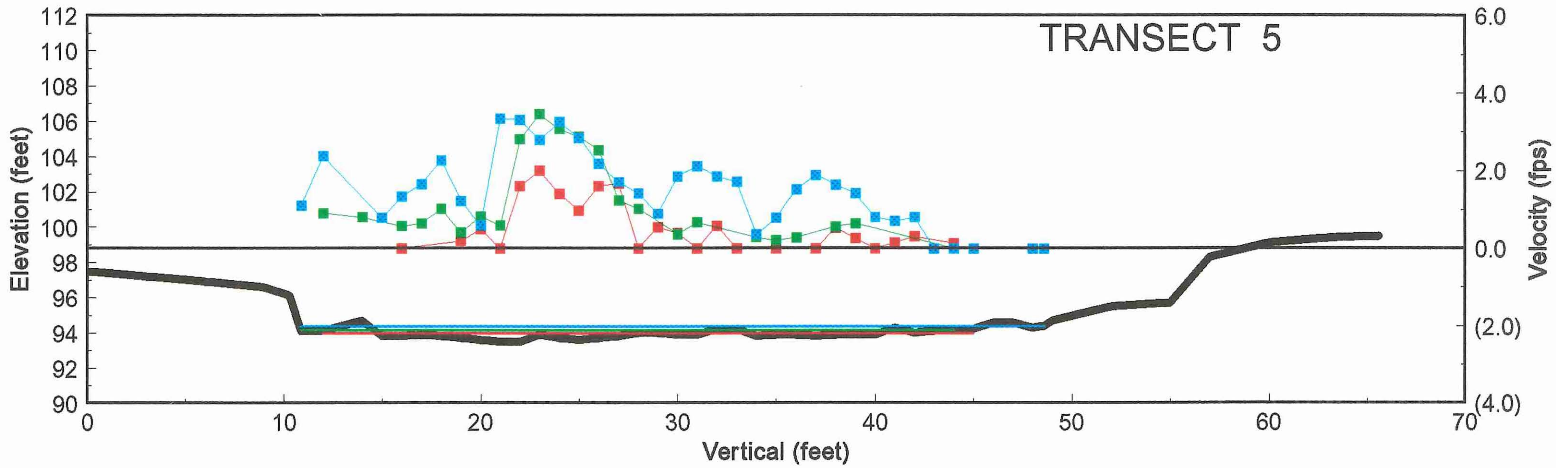


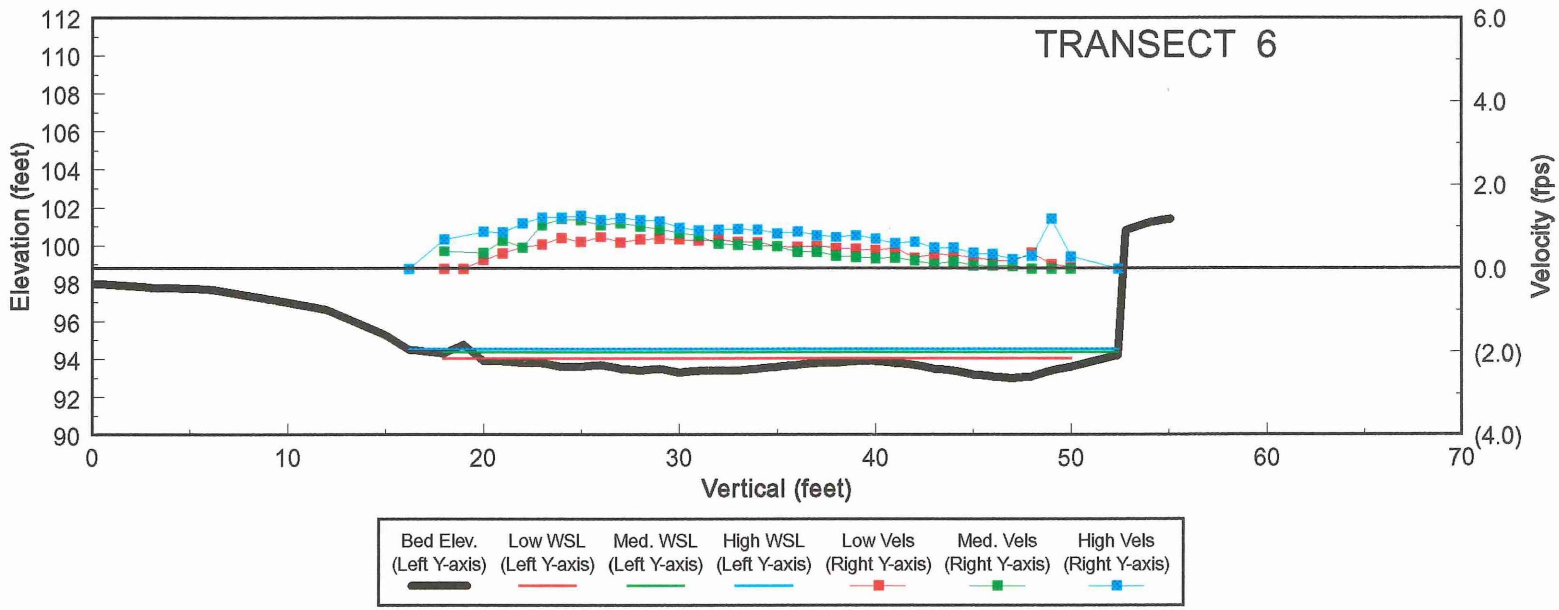


Appendix D1 (cont.). Cross sections at the upper Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.

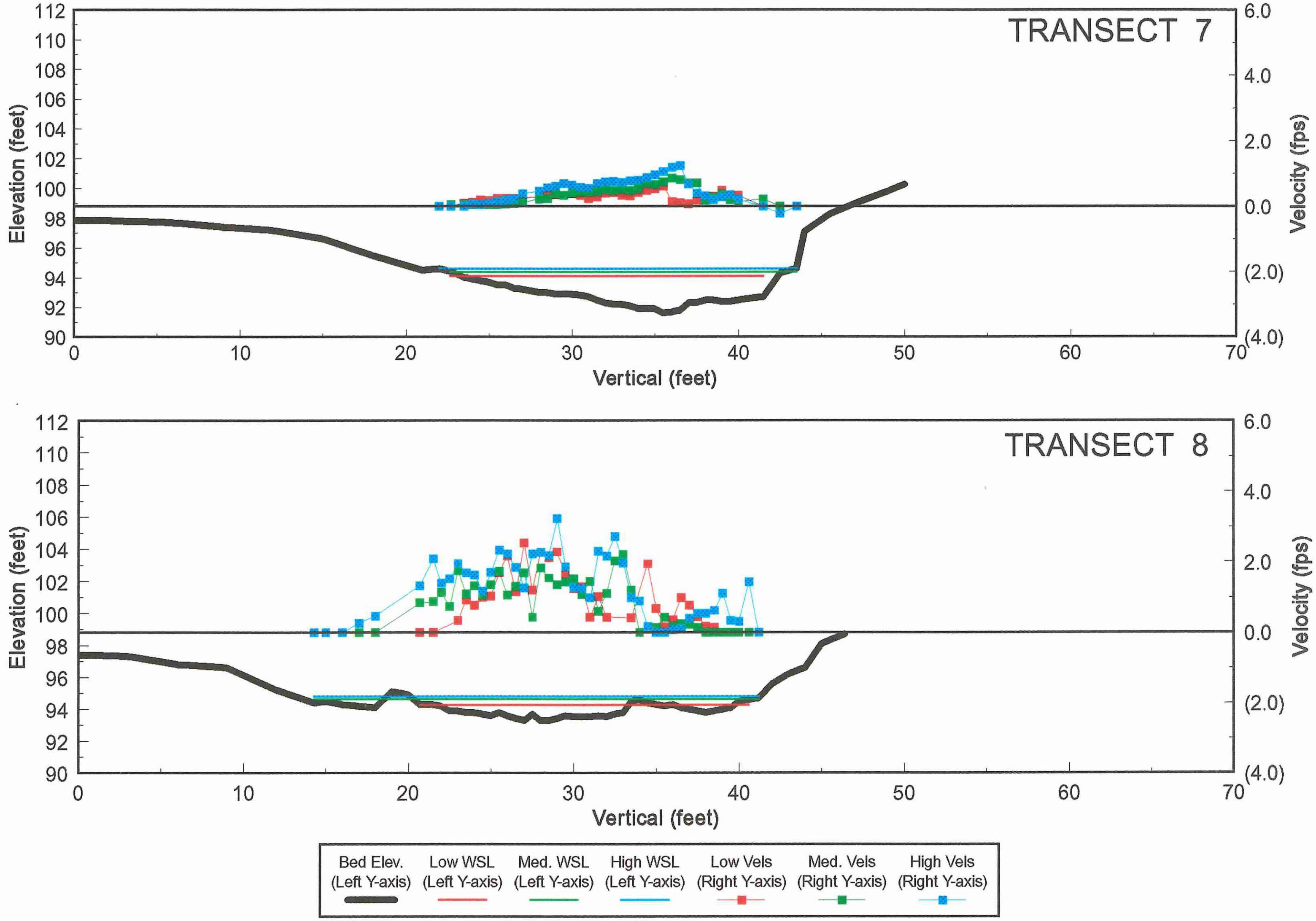


Appendix D1 (cont.). Cross sections at the upper Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.

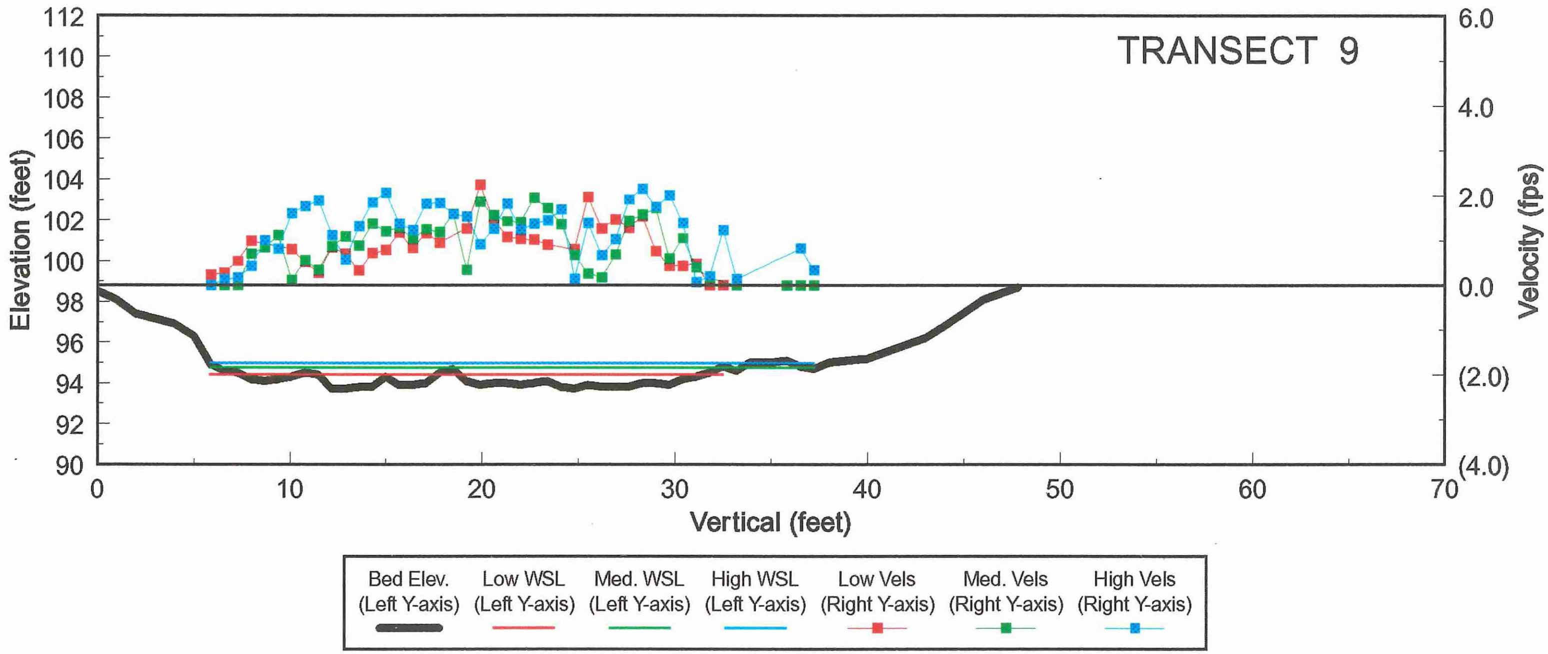




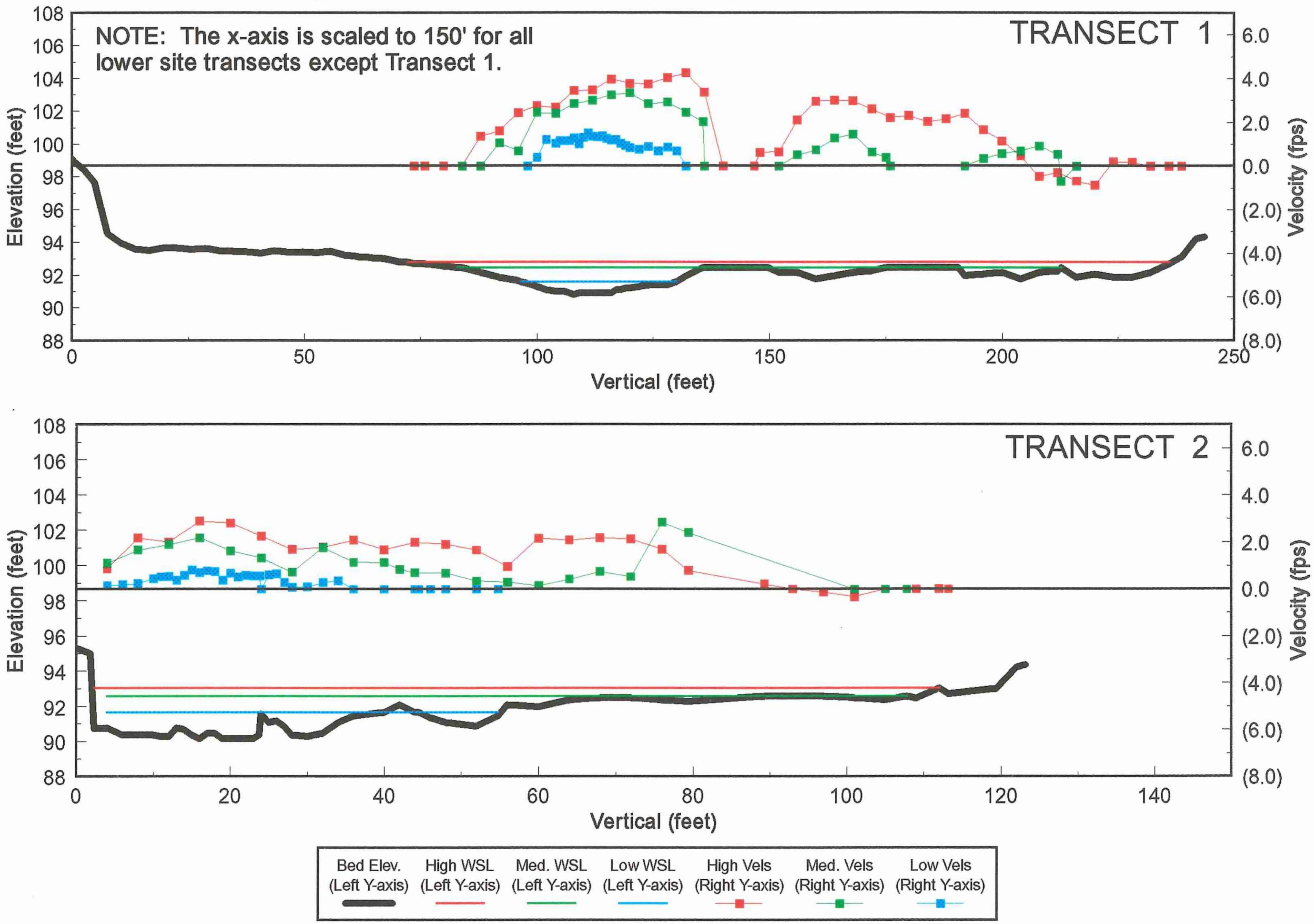
Appendix D1 (cont.). Cross sections at the upper Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



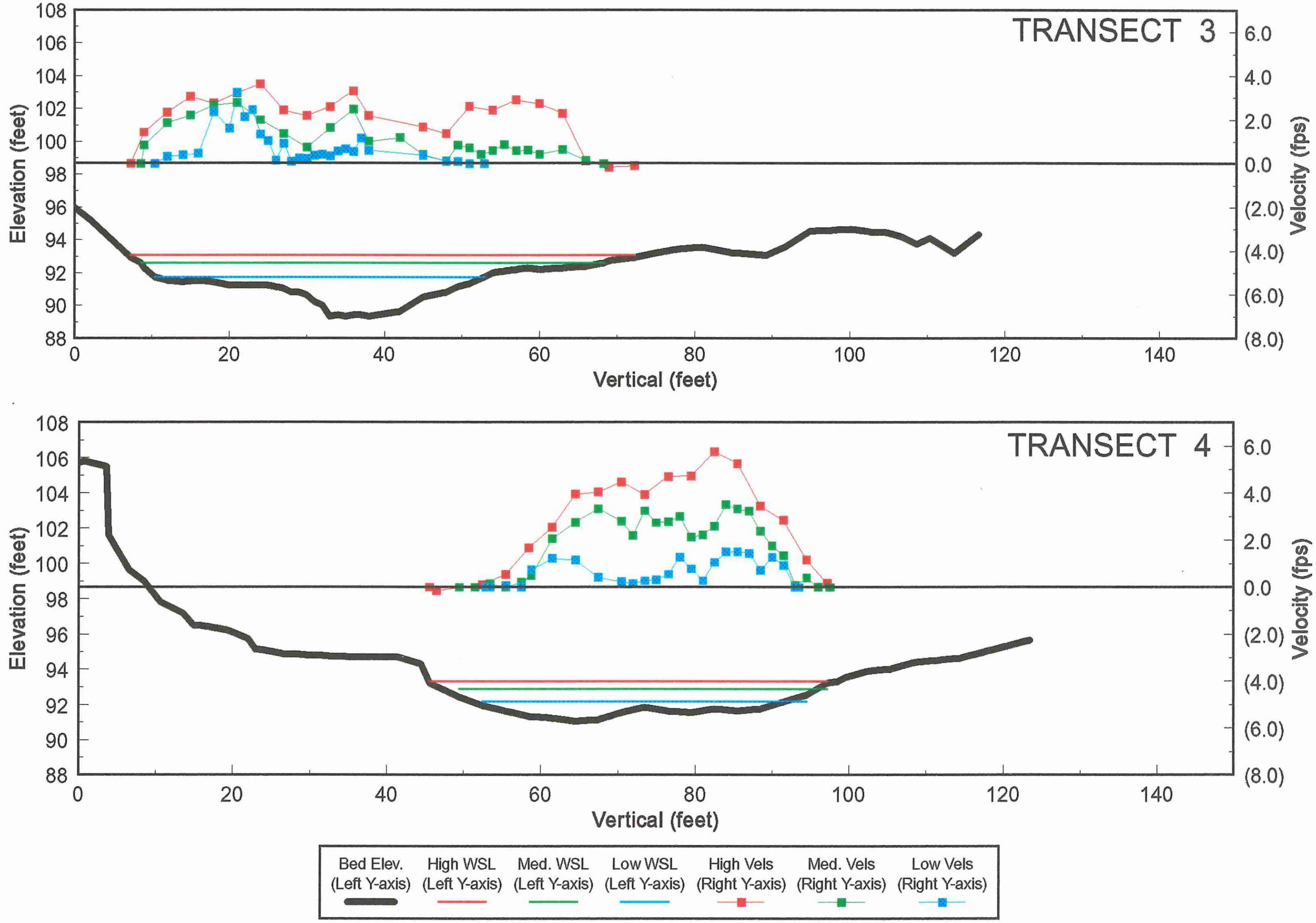
Appendix D1 (cont.). Cross sections at the upper Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



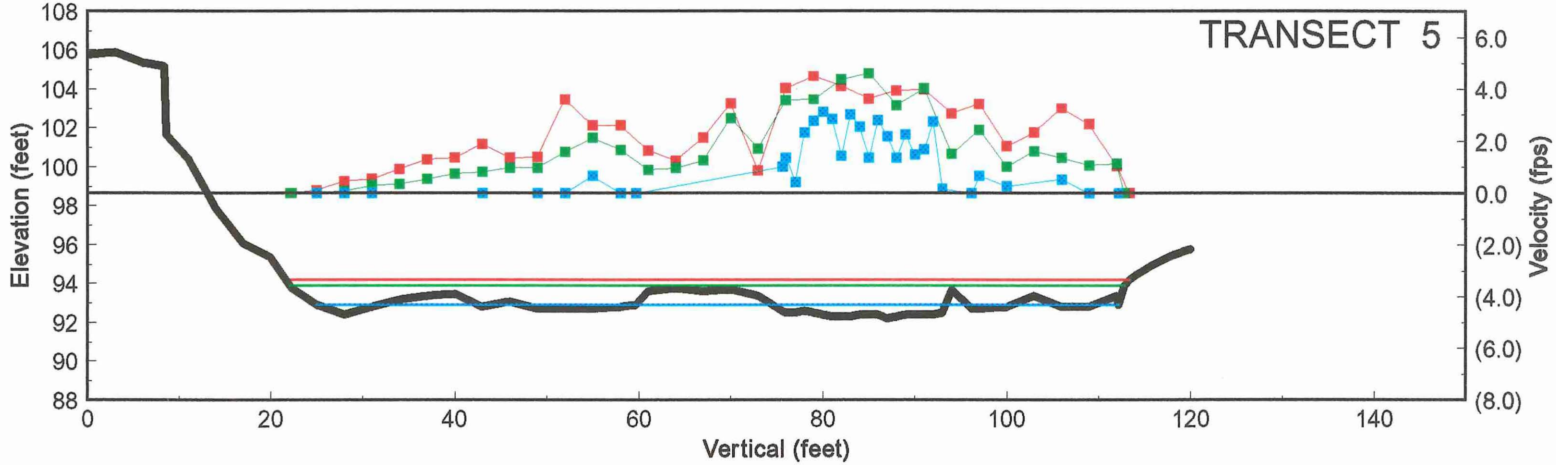
Appendix D2. Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.

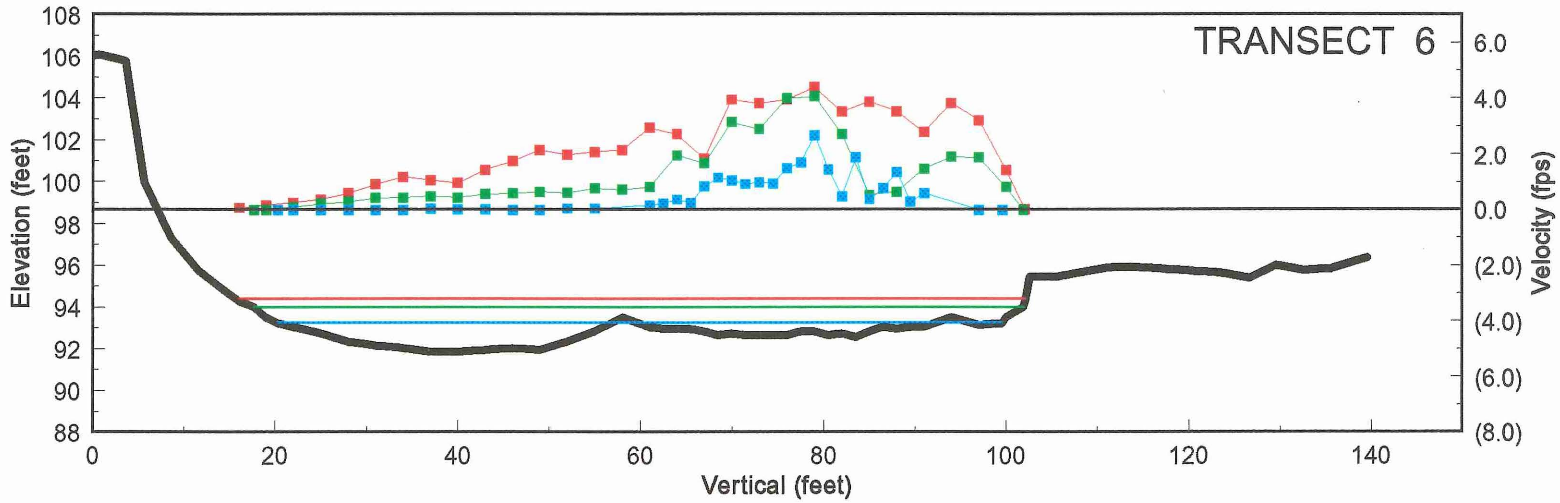


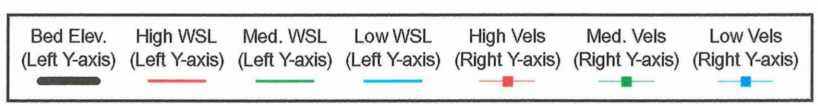
Appendix D2 (cont.). Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



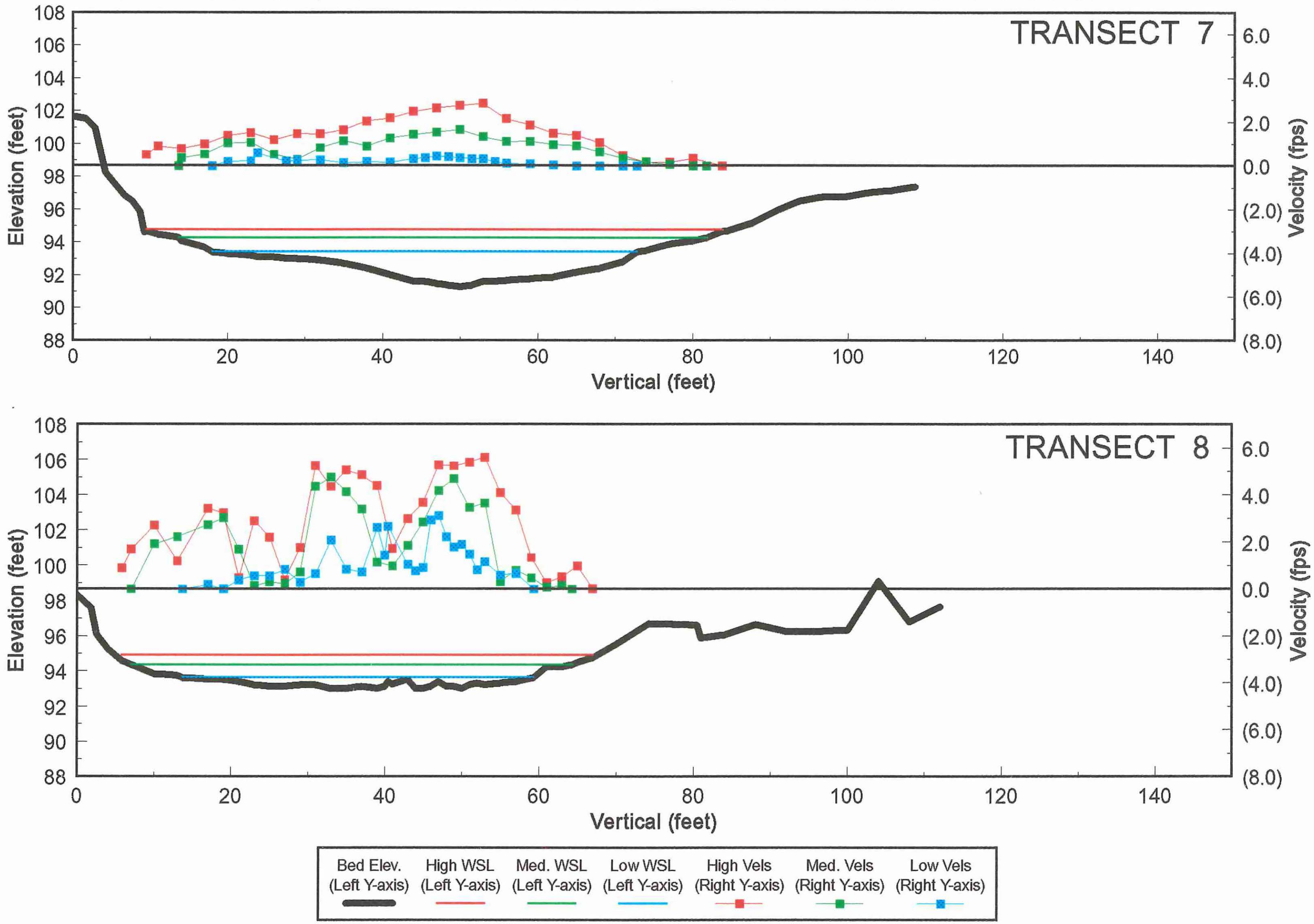
Appendix D2 (cont.). Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



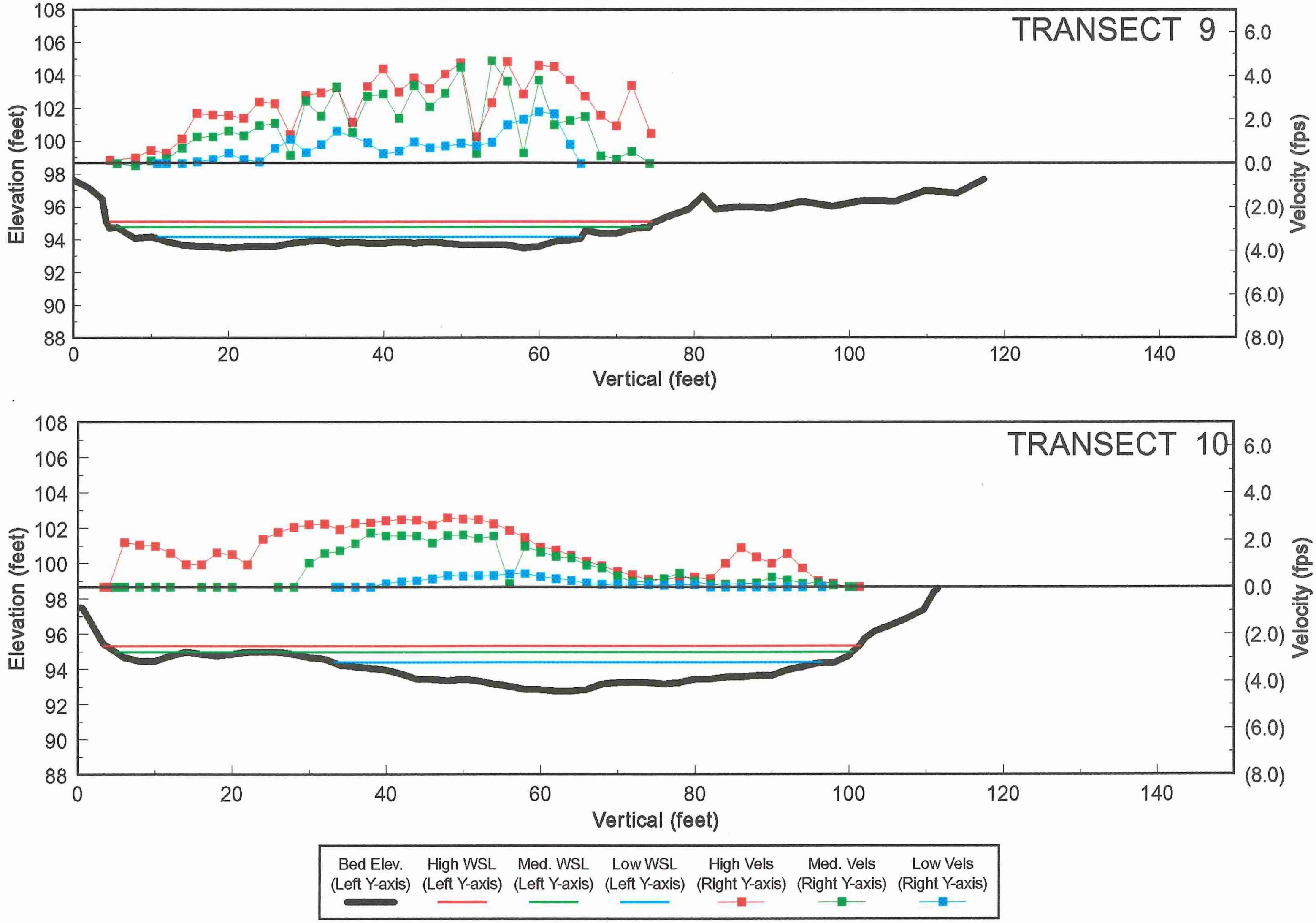




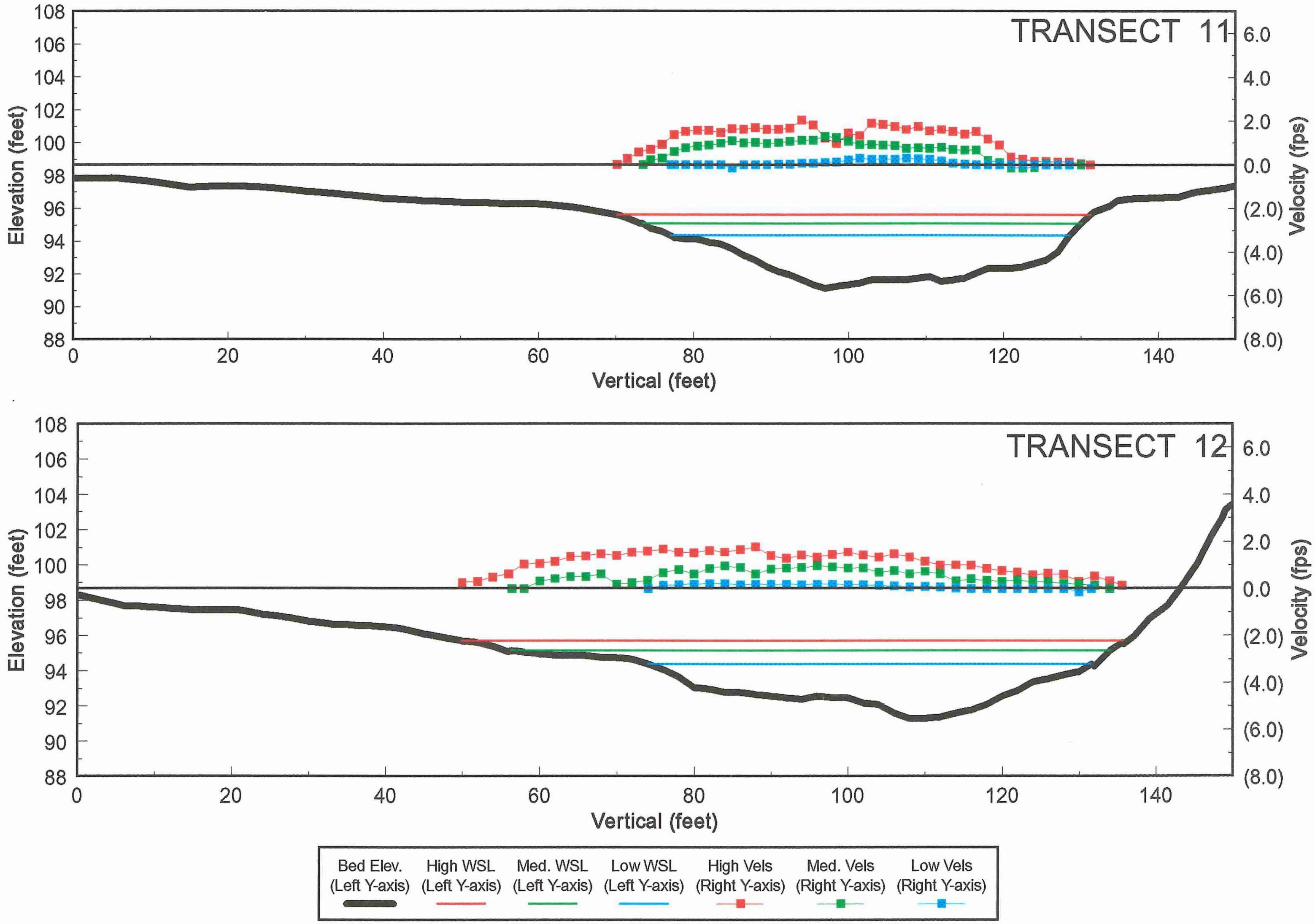
Appendix D2 (cont.). Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



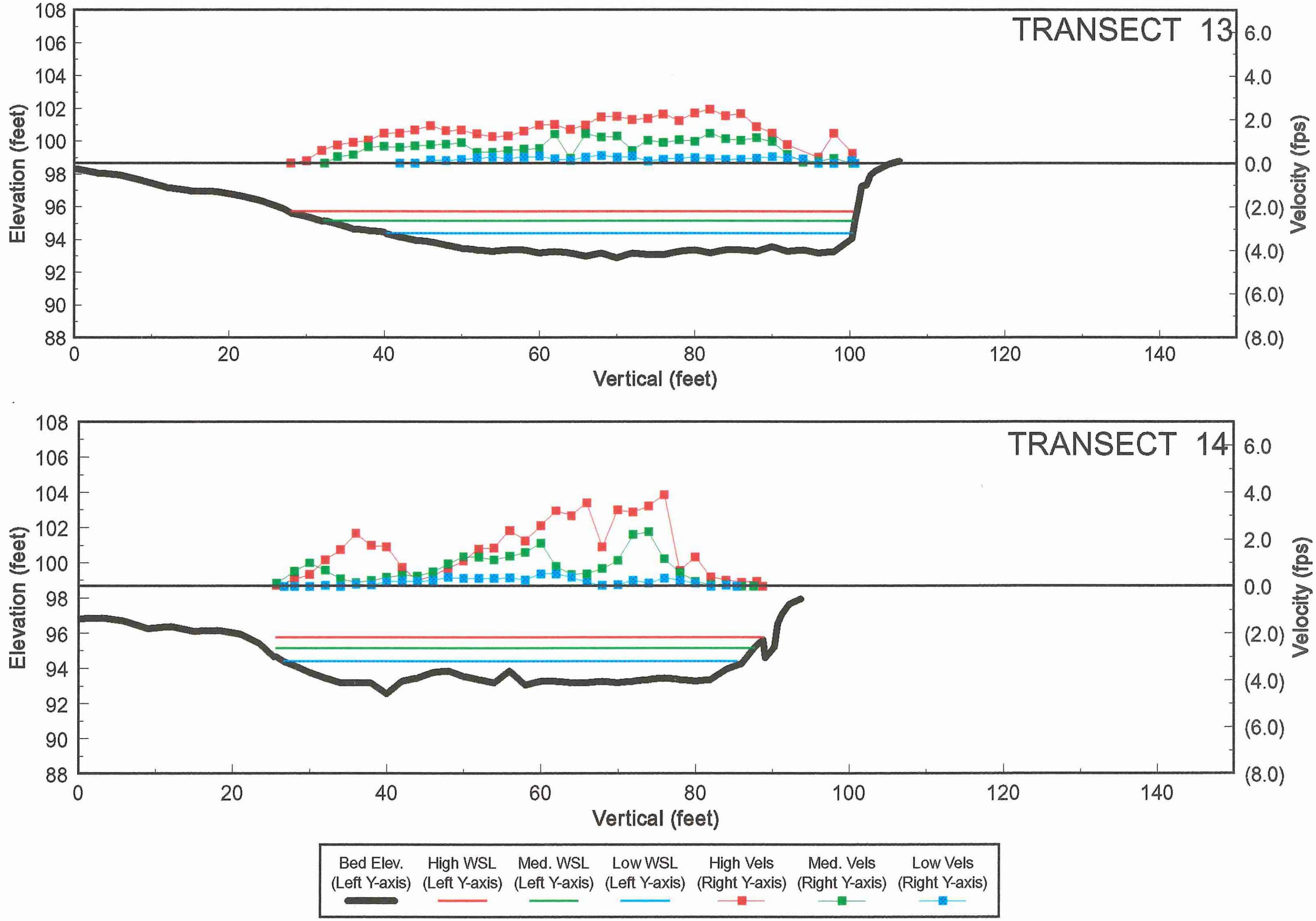
Appendix D2 (cont.). Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



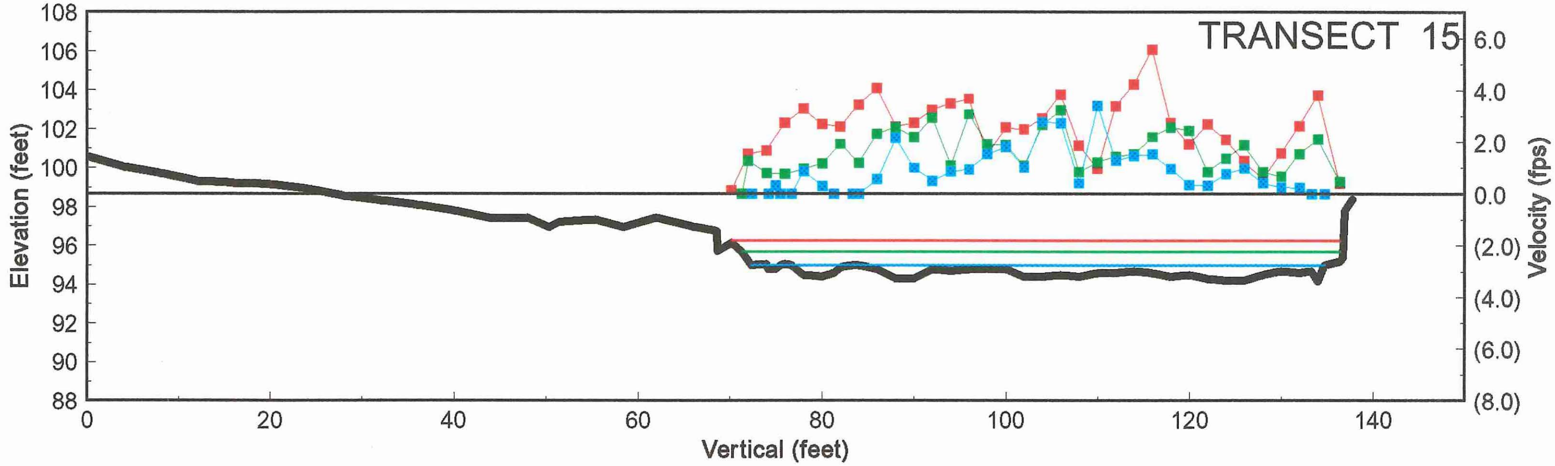
Appendix D2 (cont.). Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.

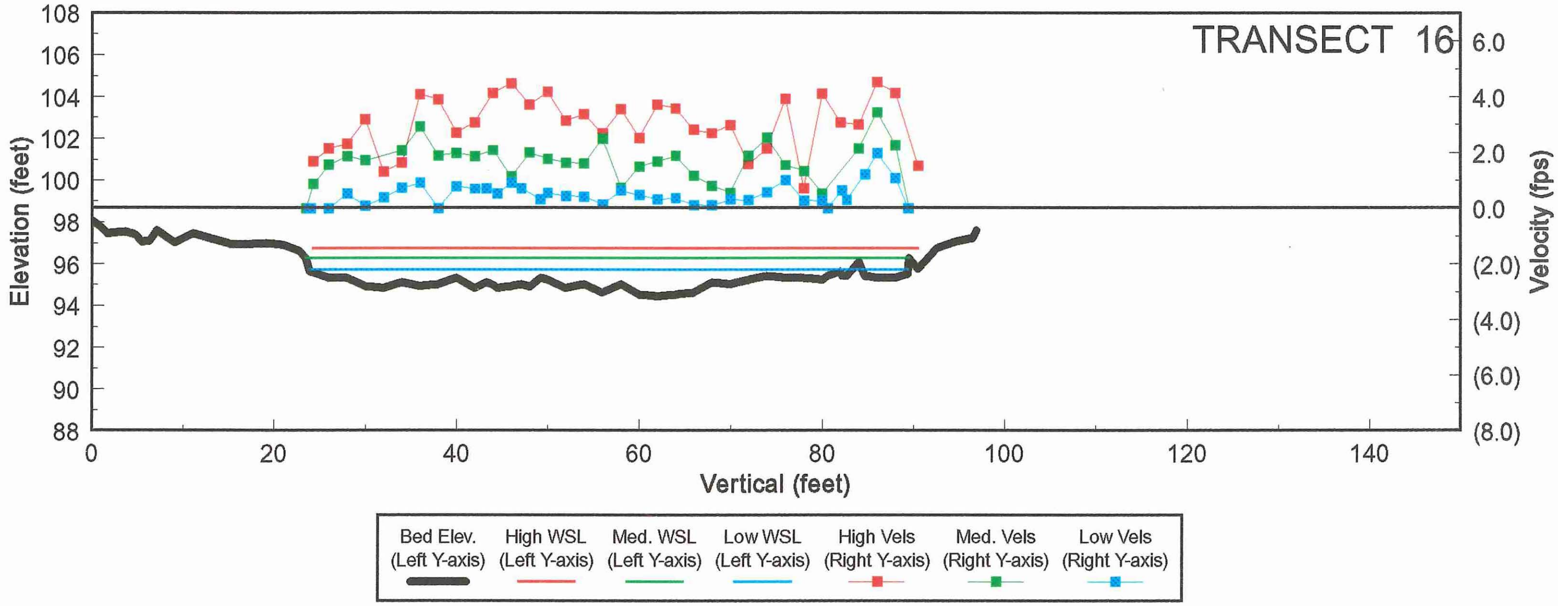


Appendix D2 (cont.). Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



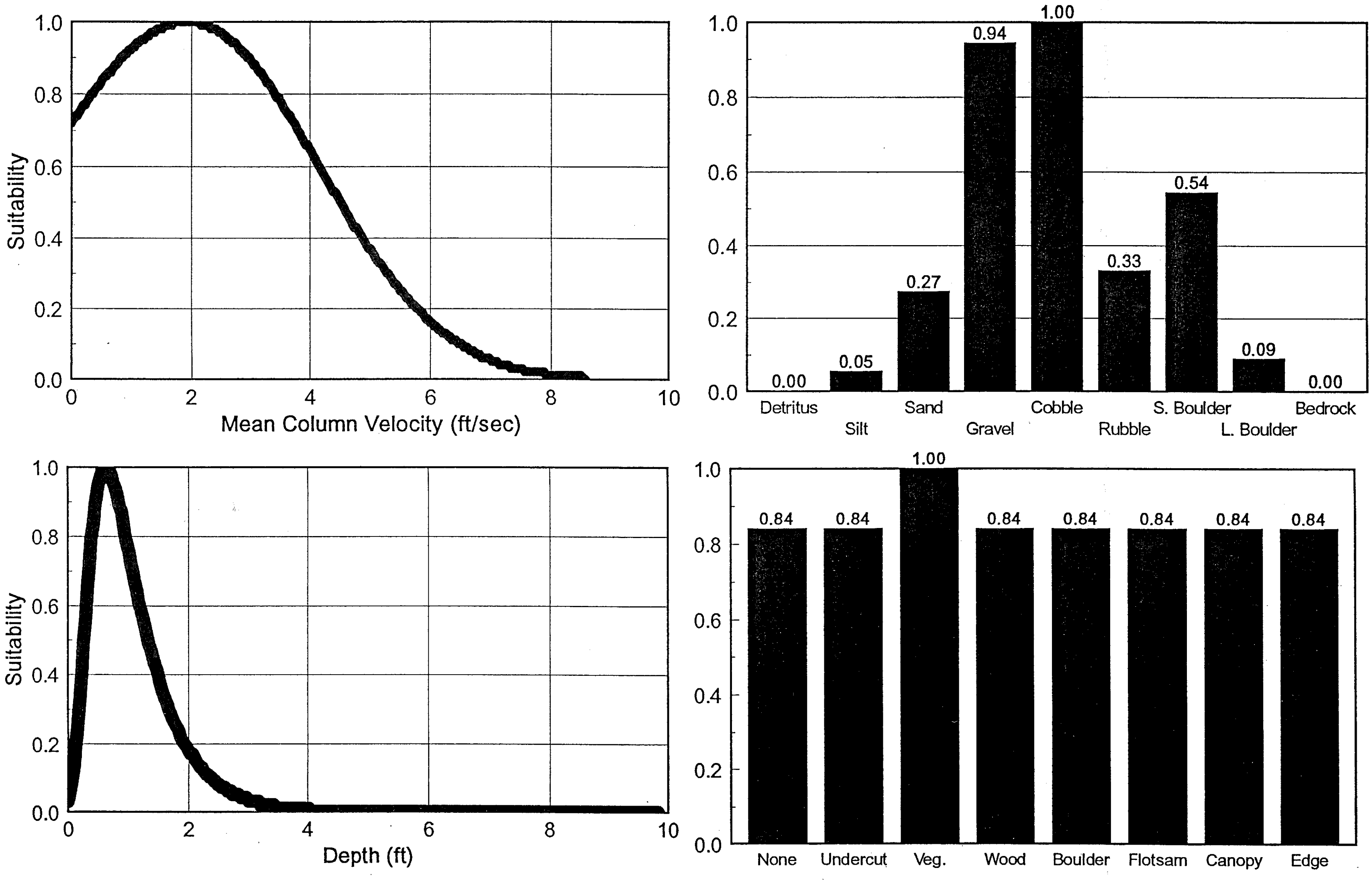
Appendix D2 (cont.). Cross sections at the lower Yellow Medicine site's transects showing channel elevations from headstake to headstake, three measured water surface elevations, and three sets of measured velocities.



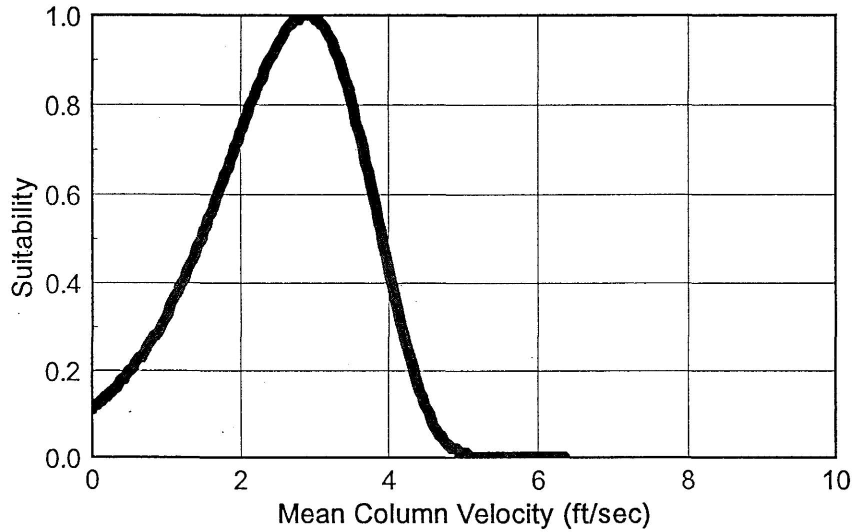


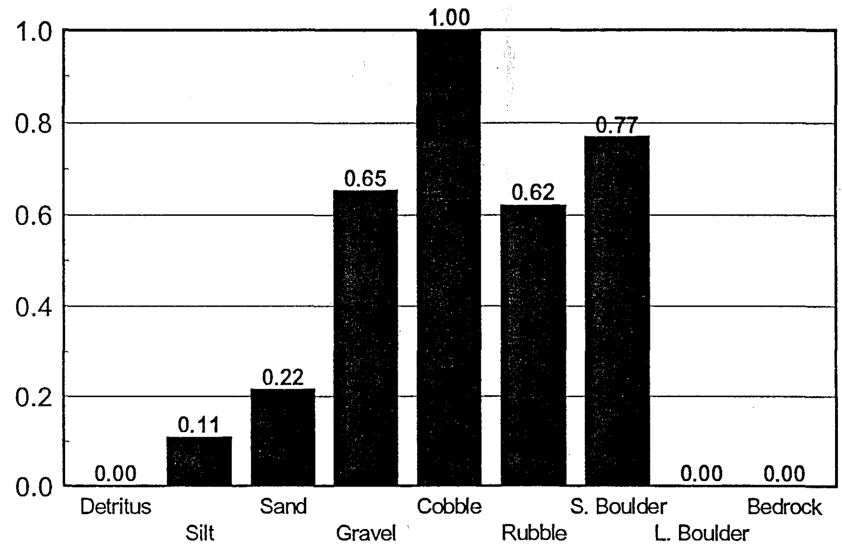
Appendix E. This appendix contains scatter graphs and bar charts showing the depth, velocity, substrate, and cover habitat suitability criteria for each of the 30 species life stages modeled for the upper and lower Yellow Medicine sites.

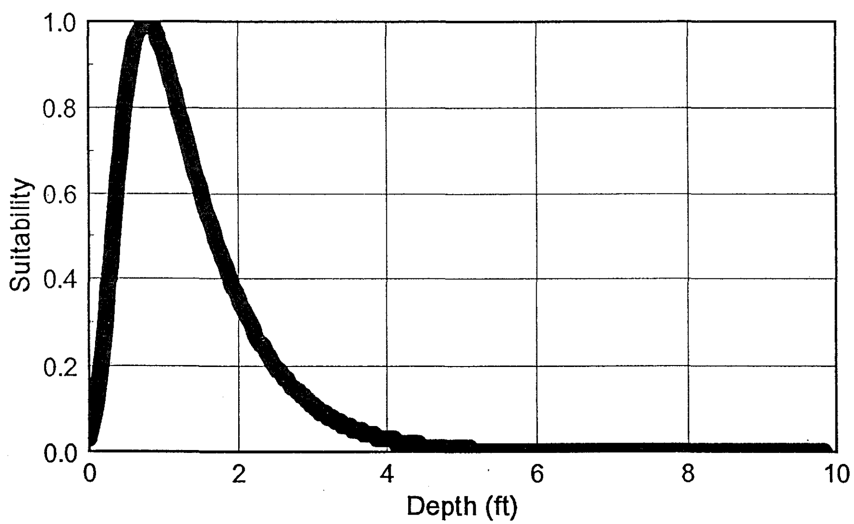
BANDED DARTER YOY

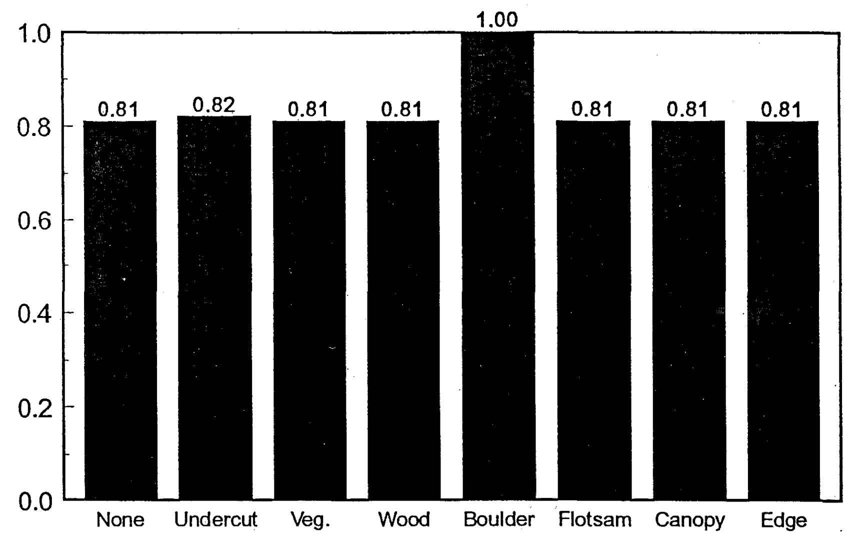


BANDED DARTER ADULT

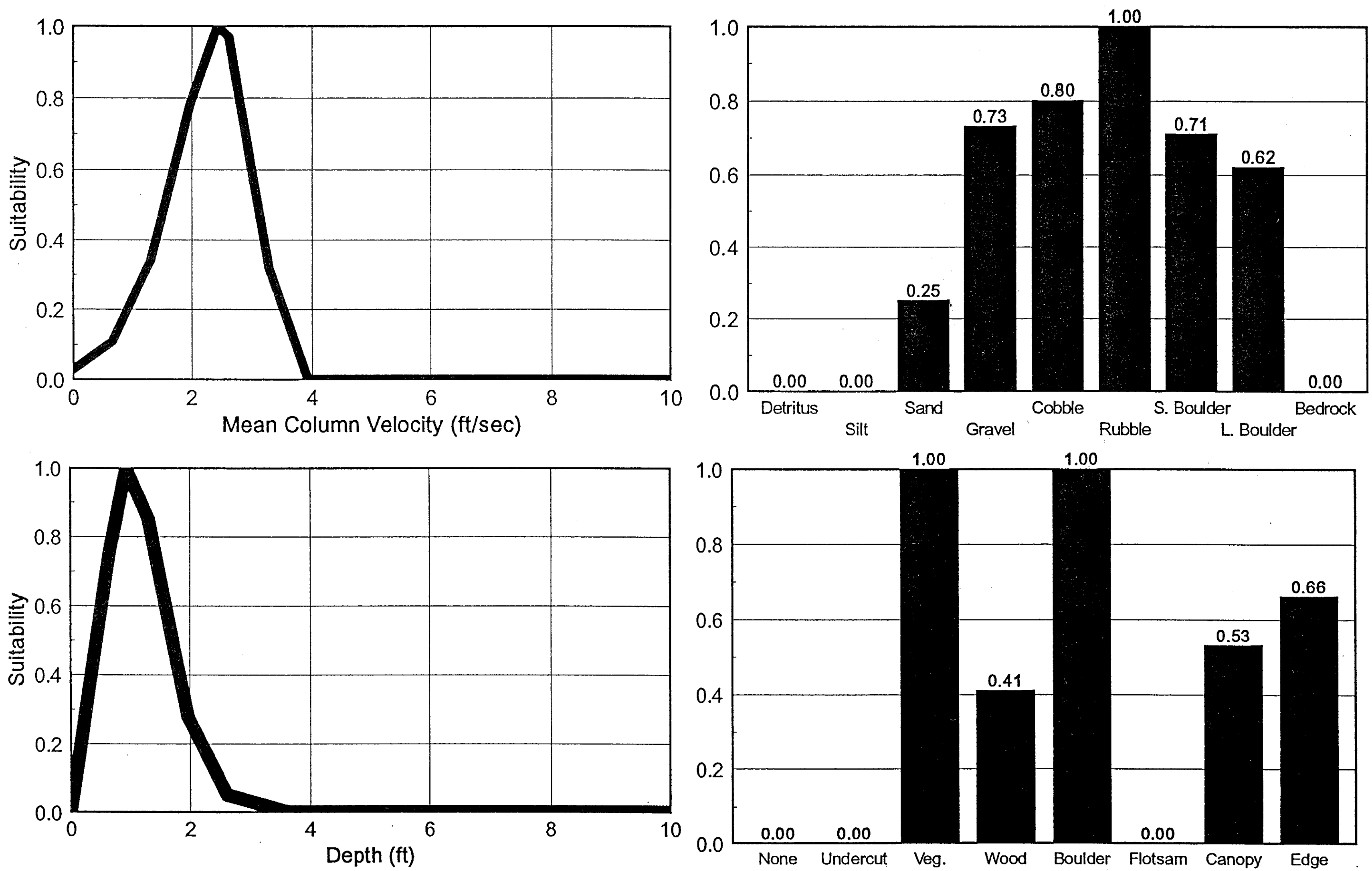




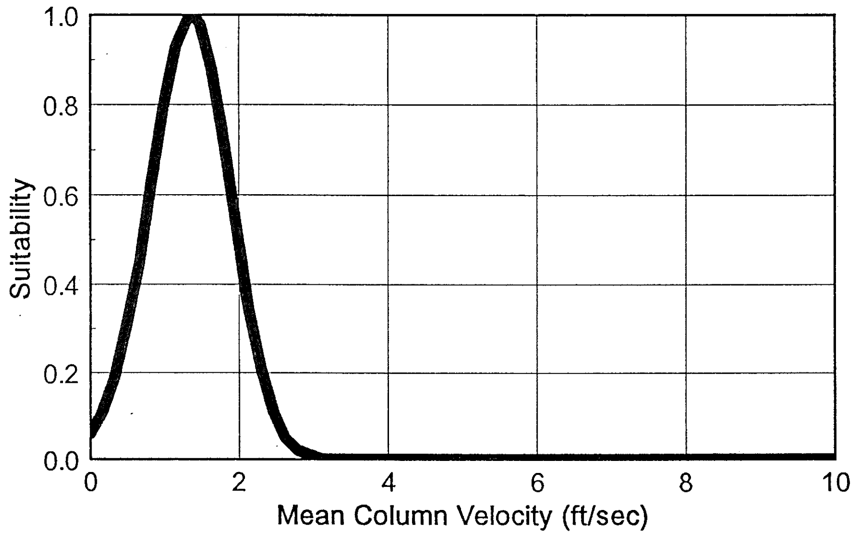


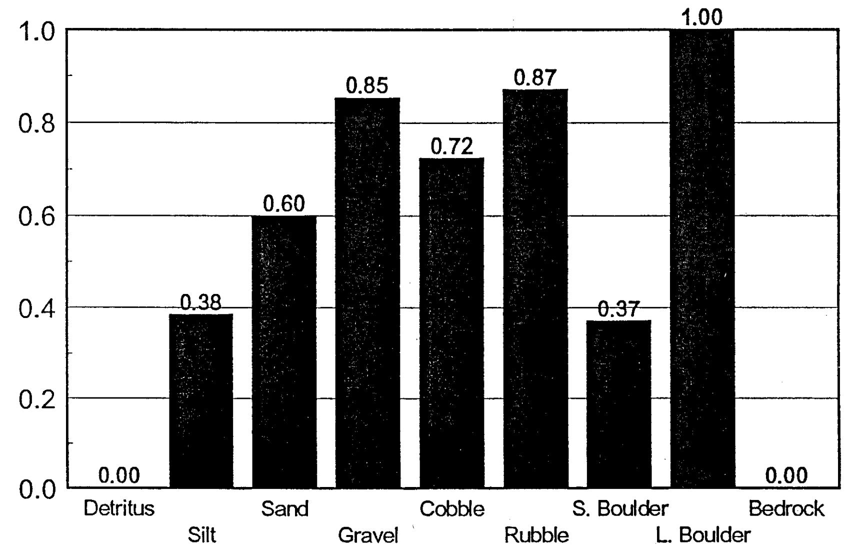


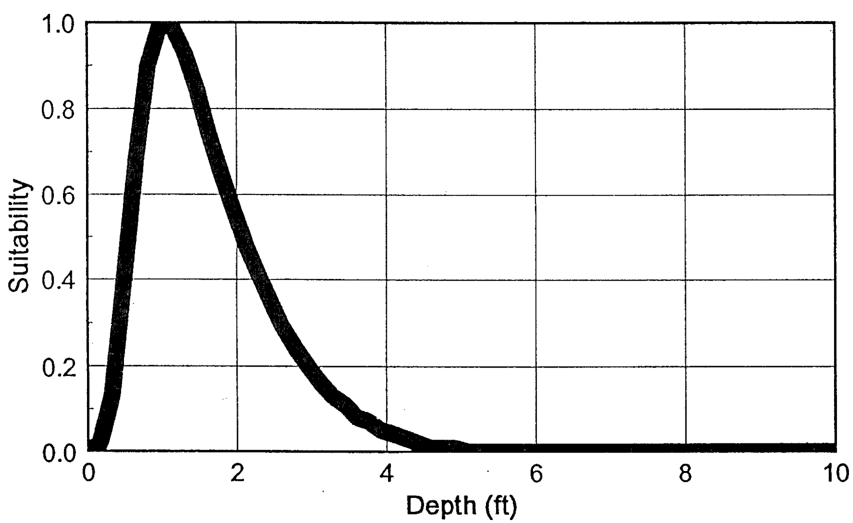
BANDED DARTER SPAWNING

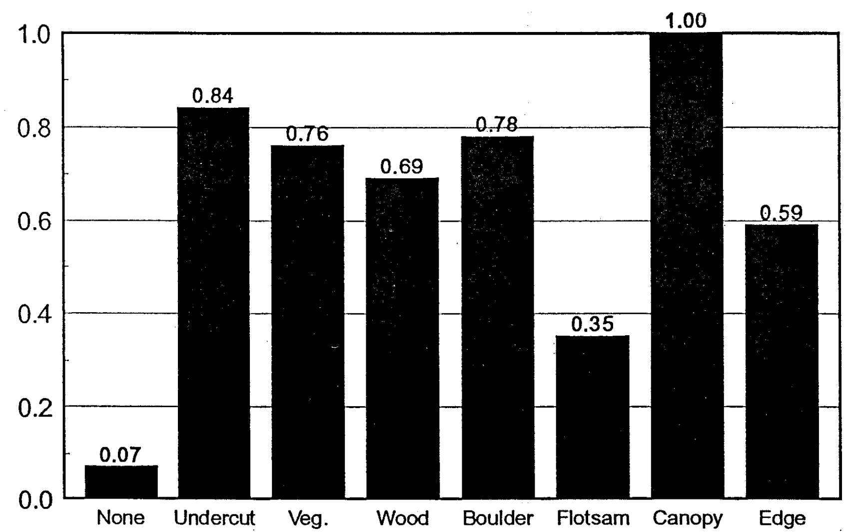


BLACKNOSE DACE ADULT

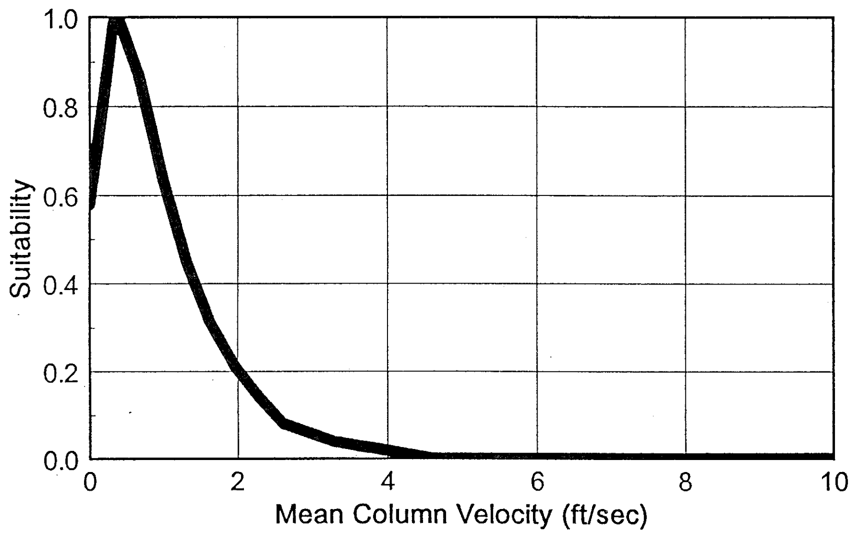


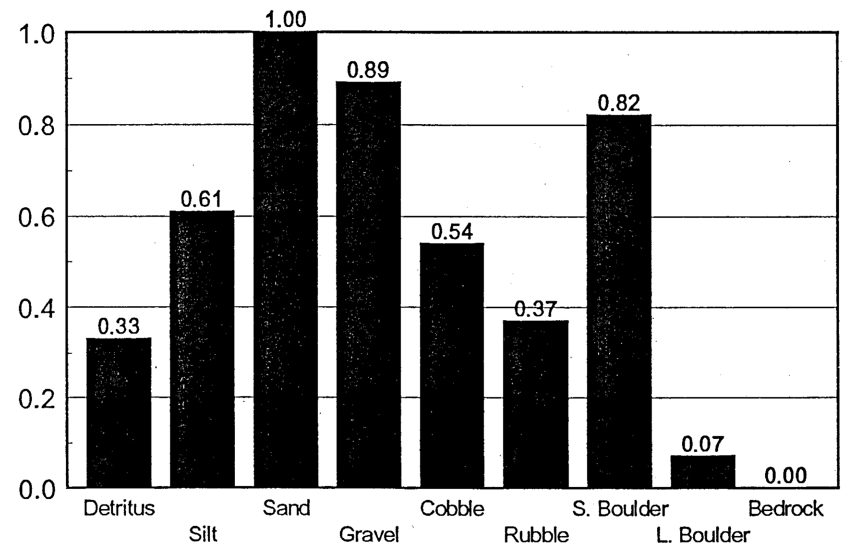


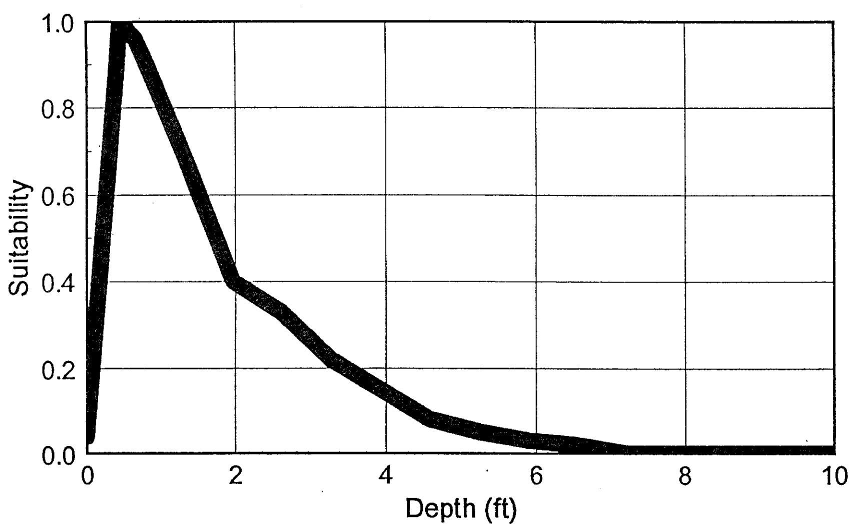


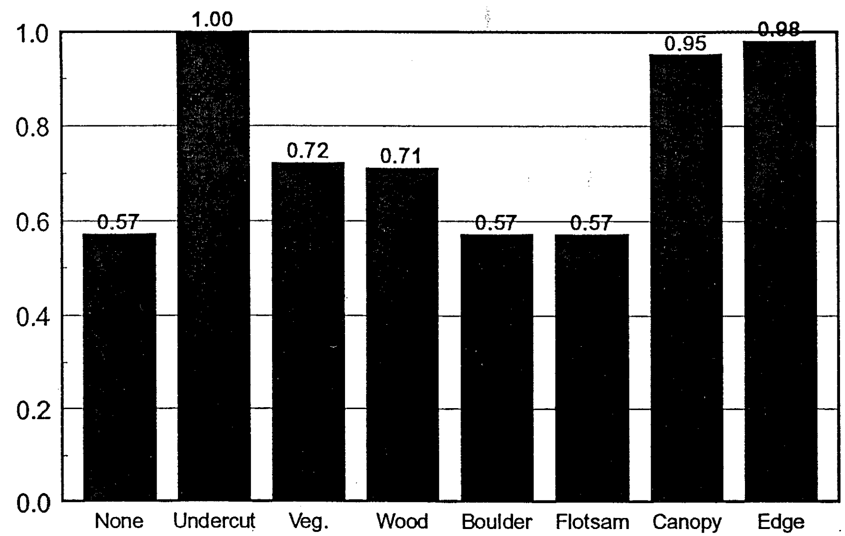


BLUNTNOSE MINNOW YOY

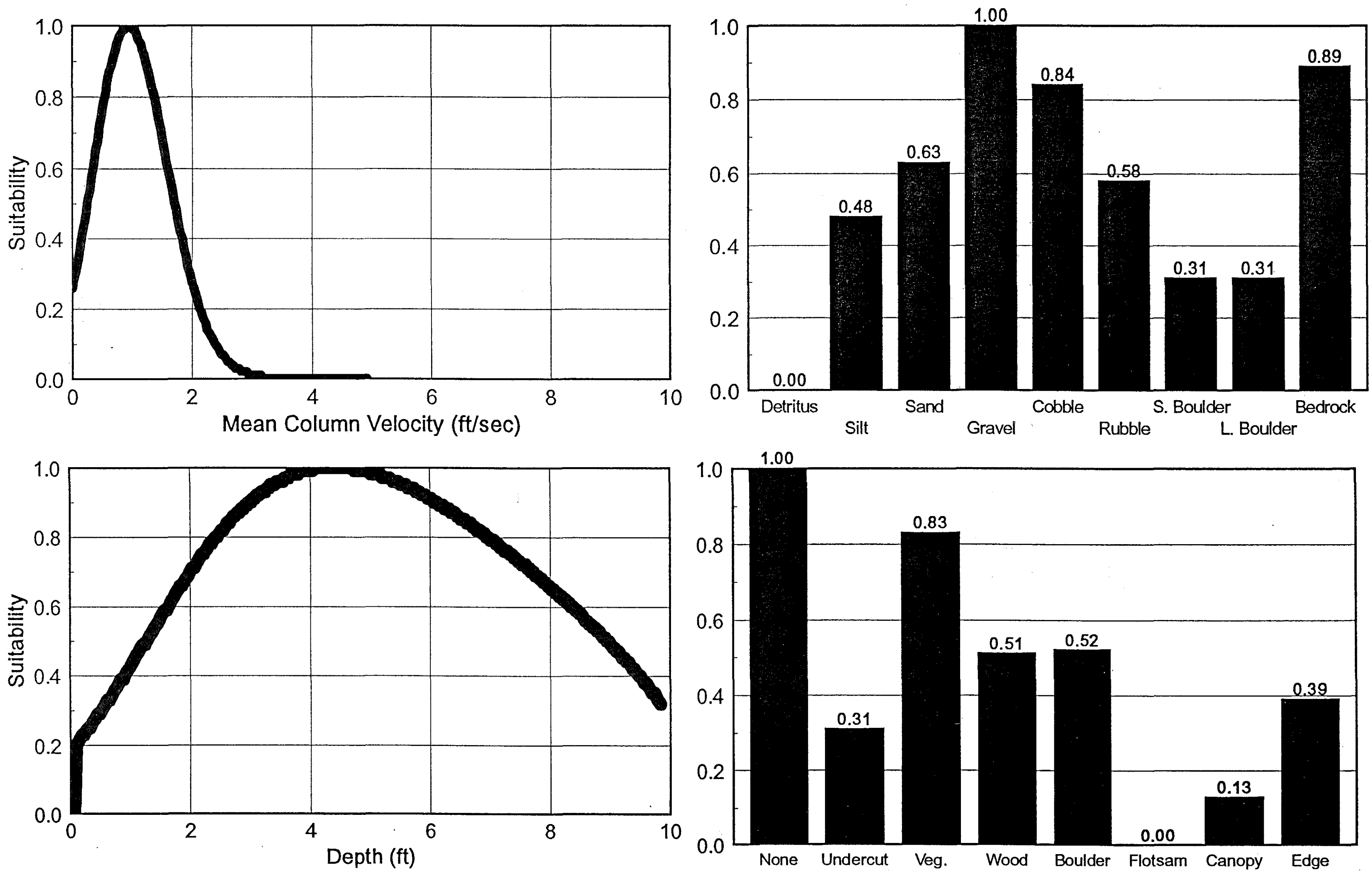




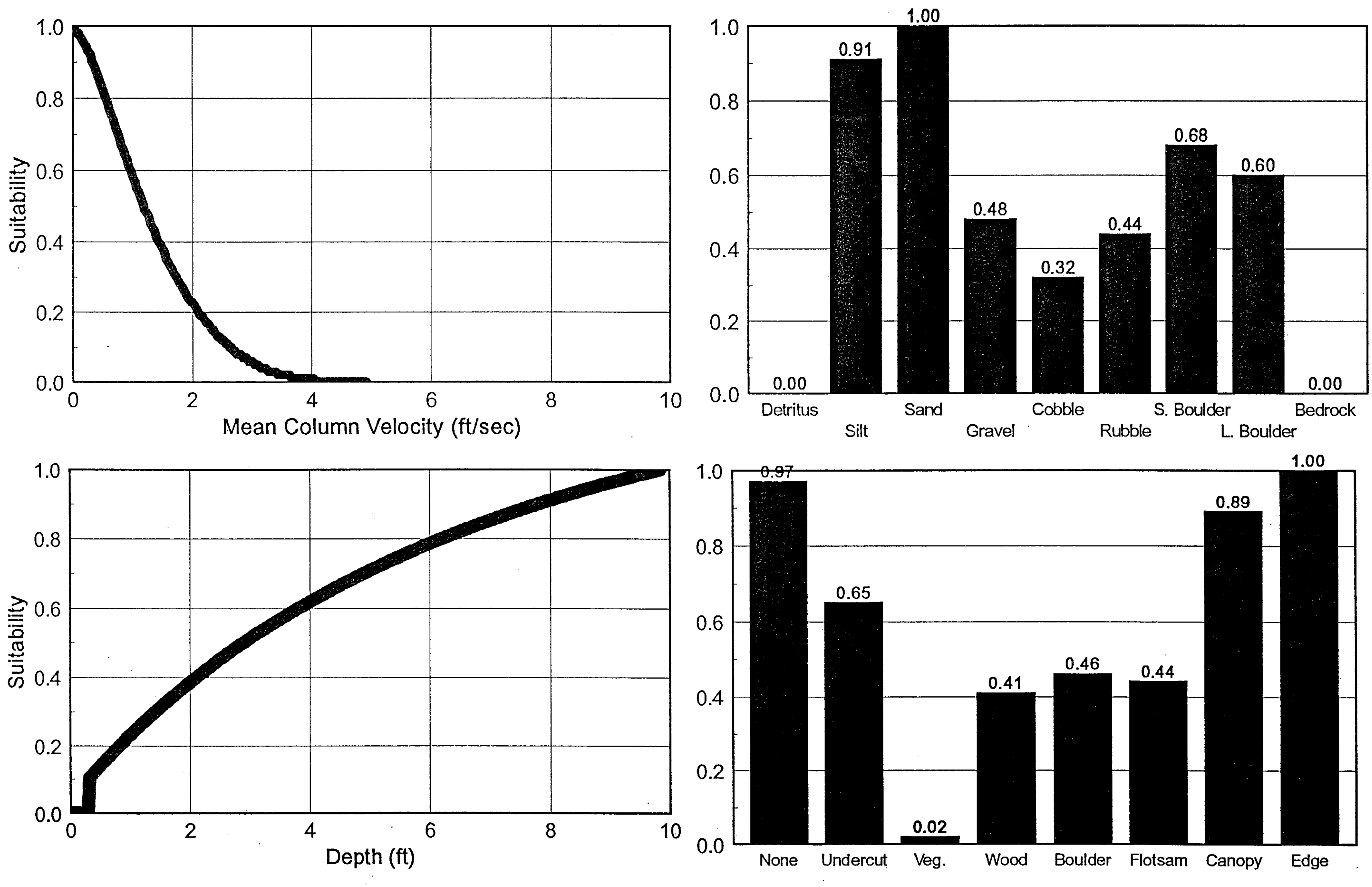




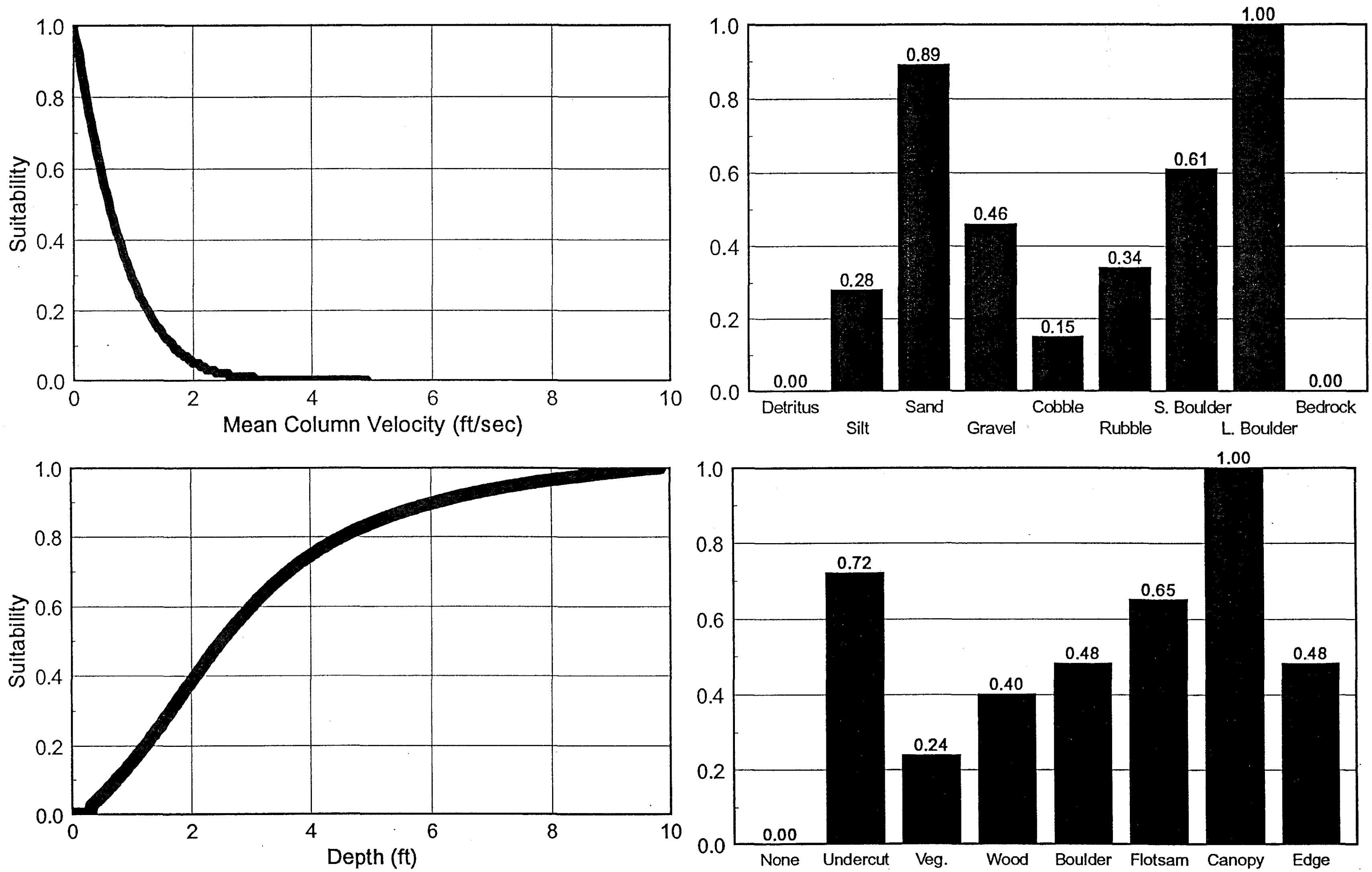
CHANNEL CATFISH YOY



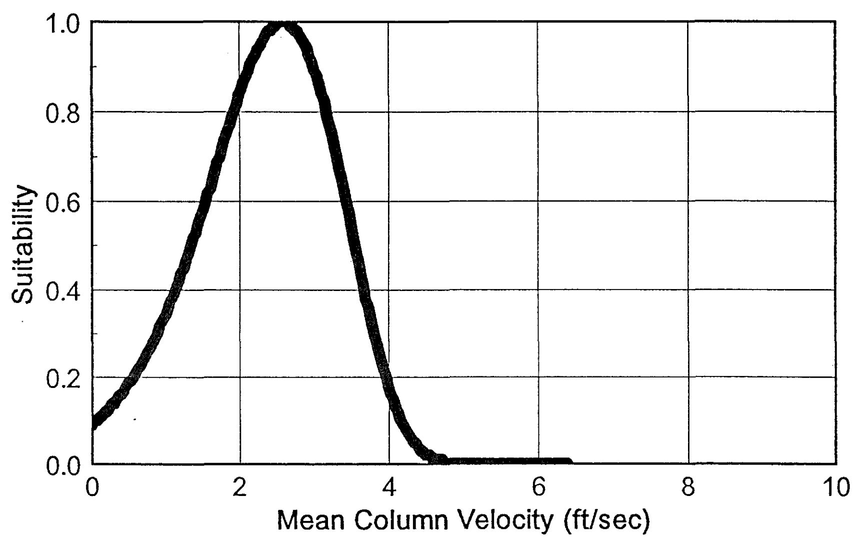
CHANNEL CATFISH JUVENILE

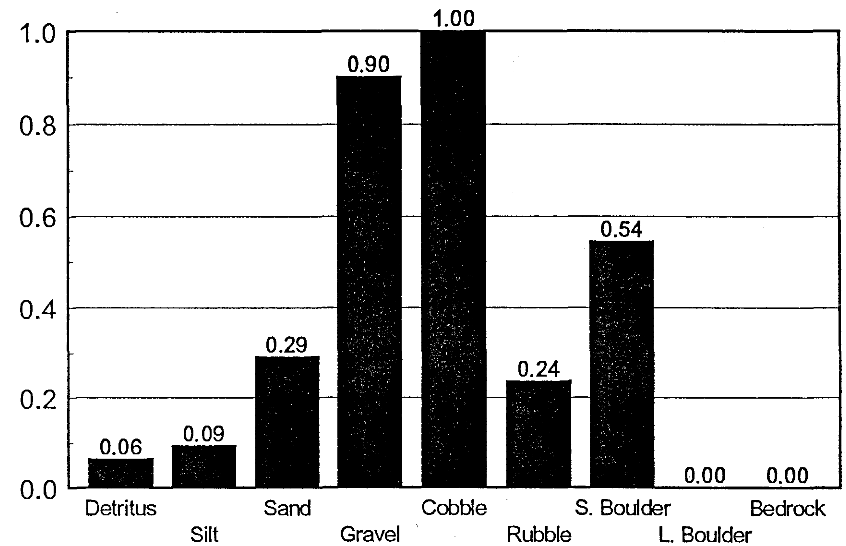


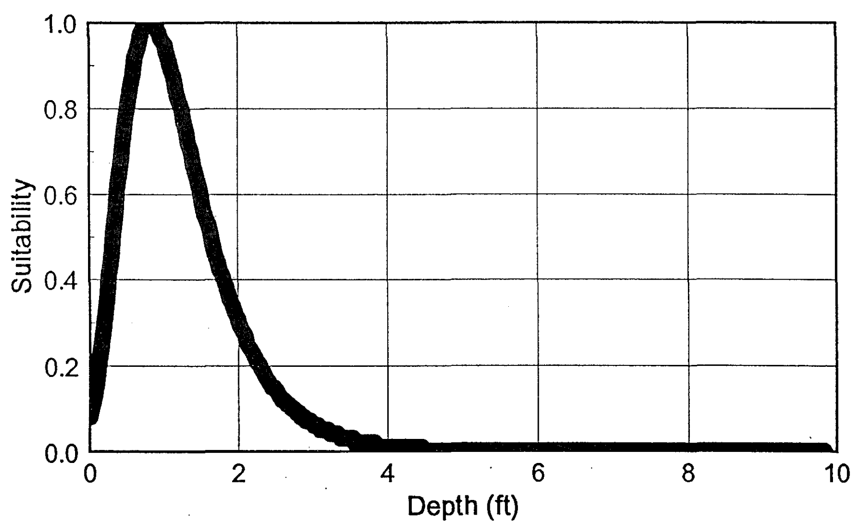
CHANNEL CATFISH ADULT

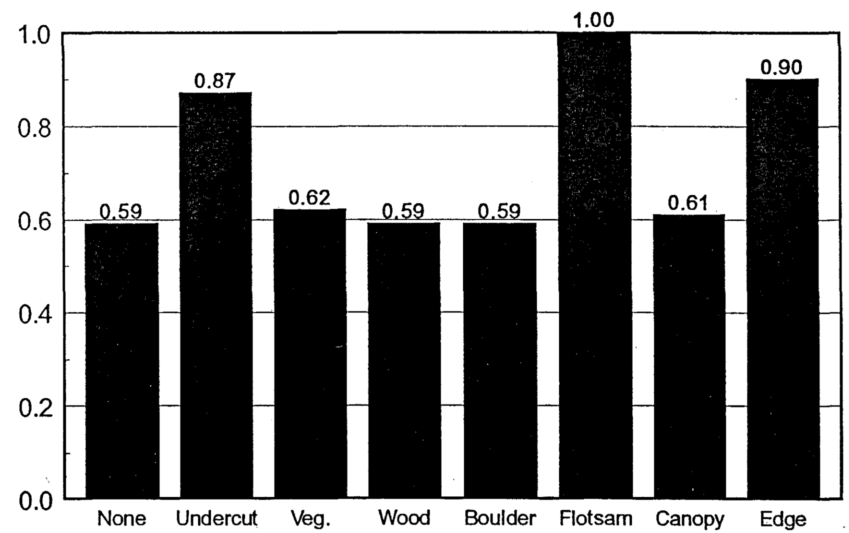


CENTRAL STONEROLLER ADULT

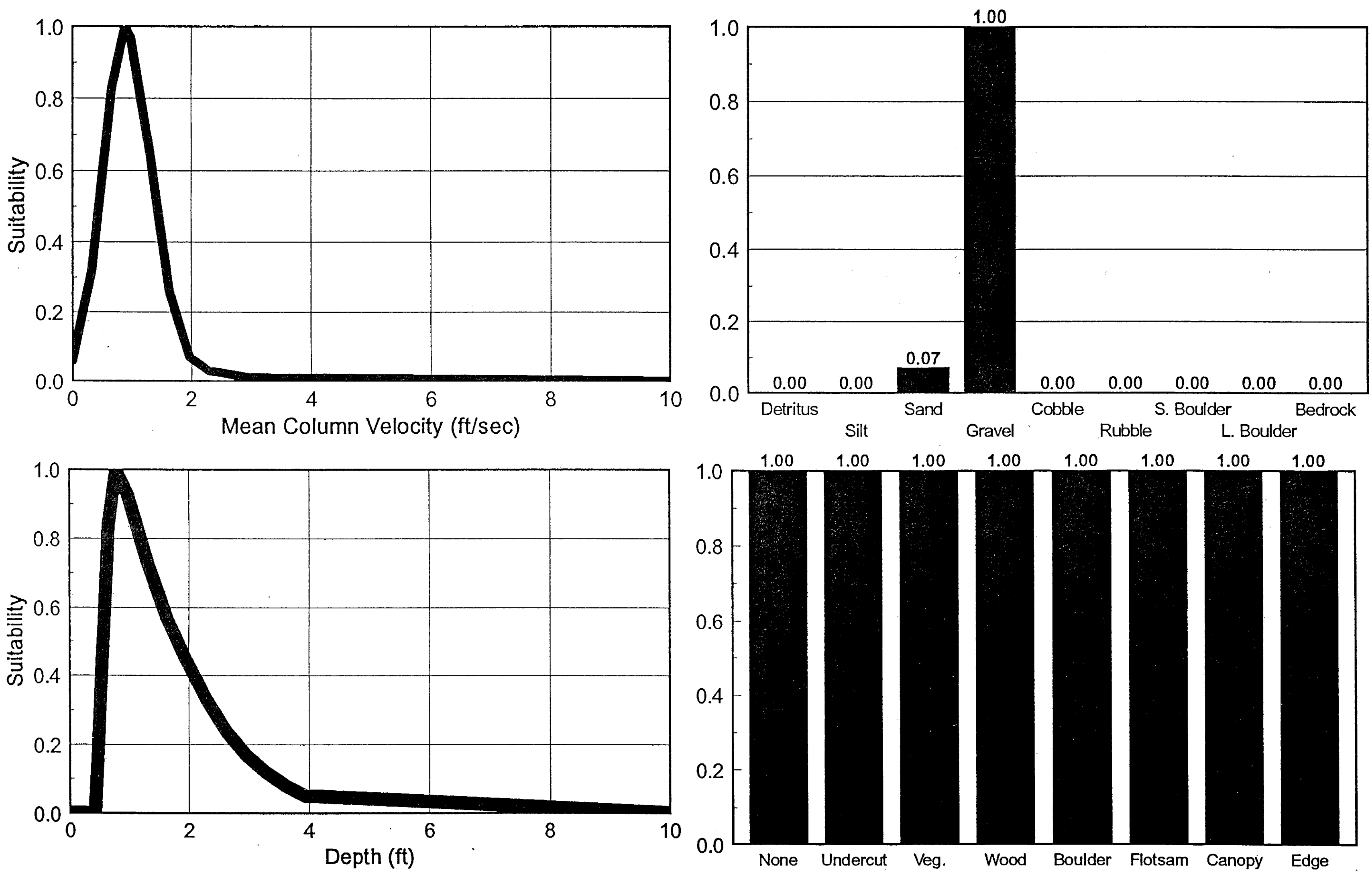




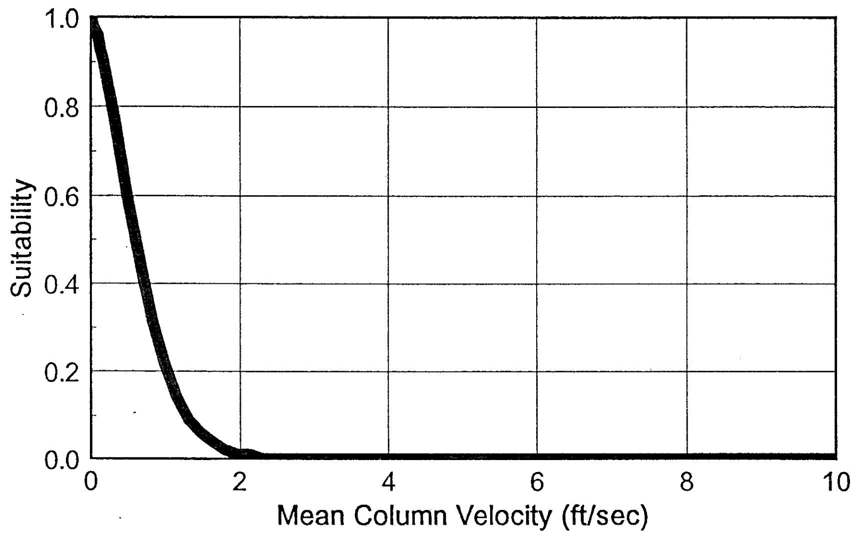


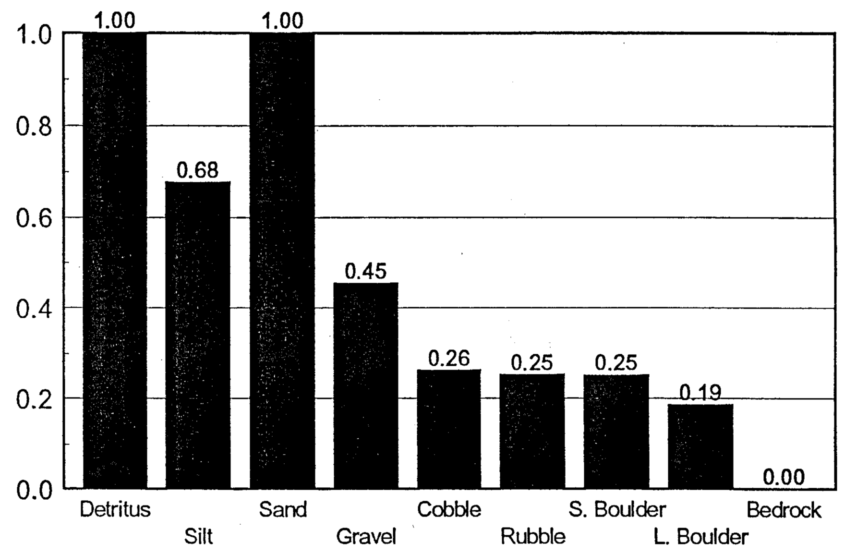


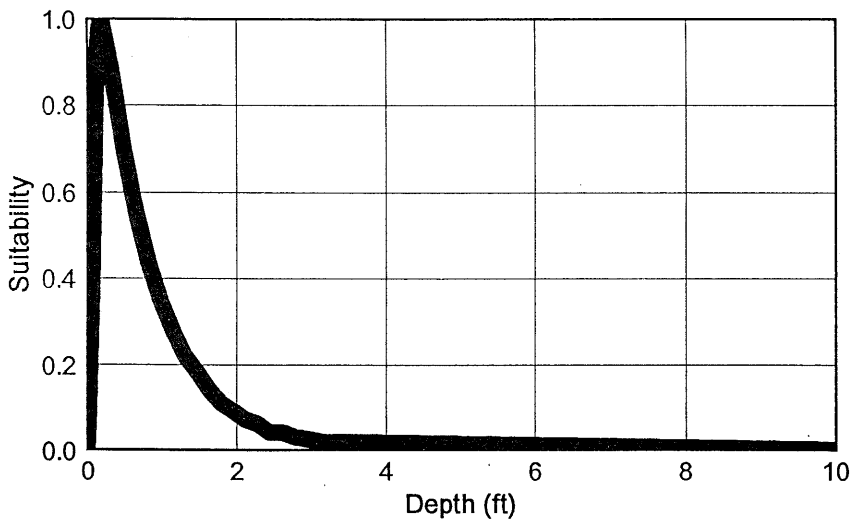
HORNYHEAD CHUB SPAWNING

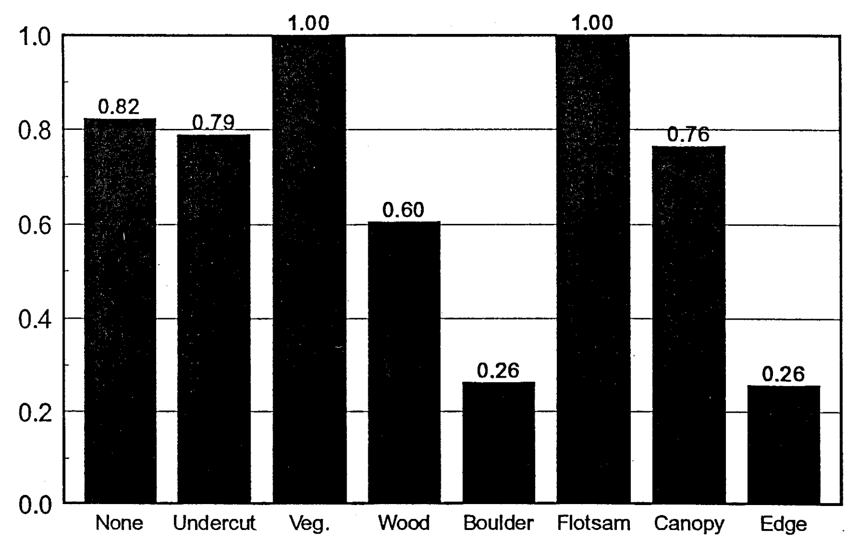


LARVA - YM SPECIFIC

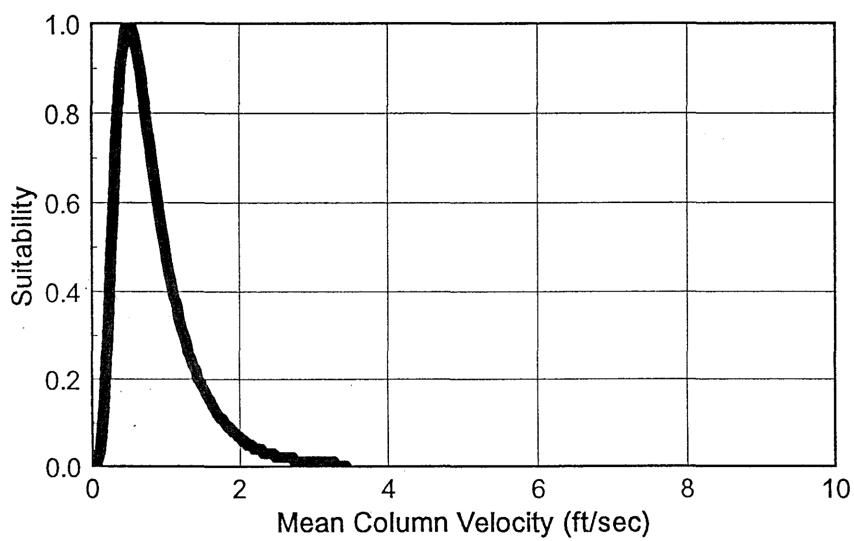


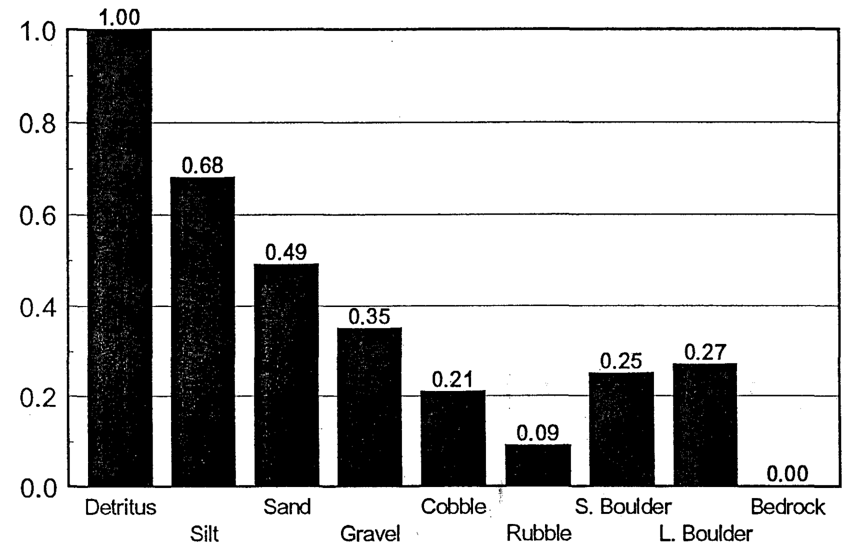


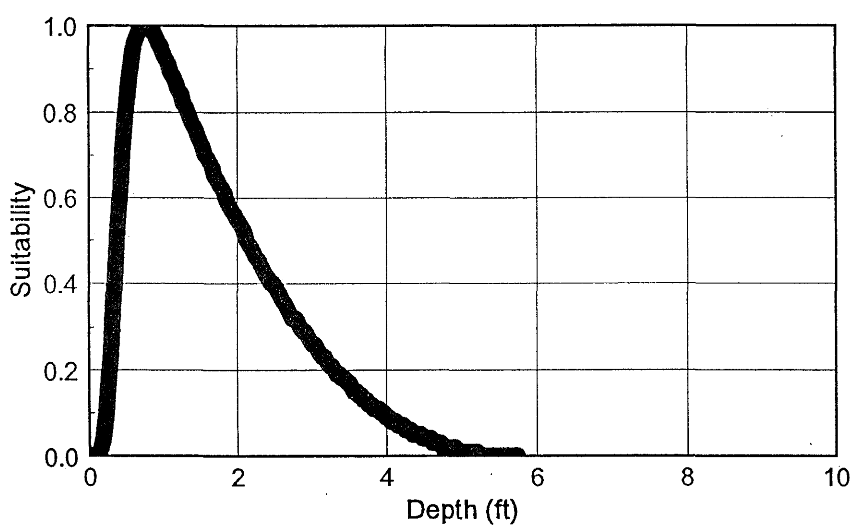


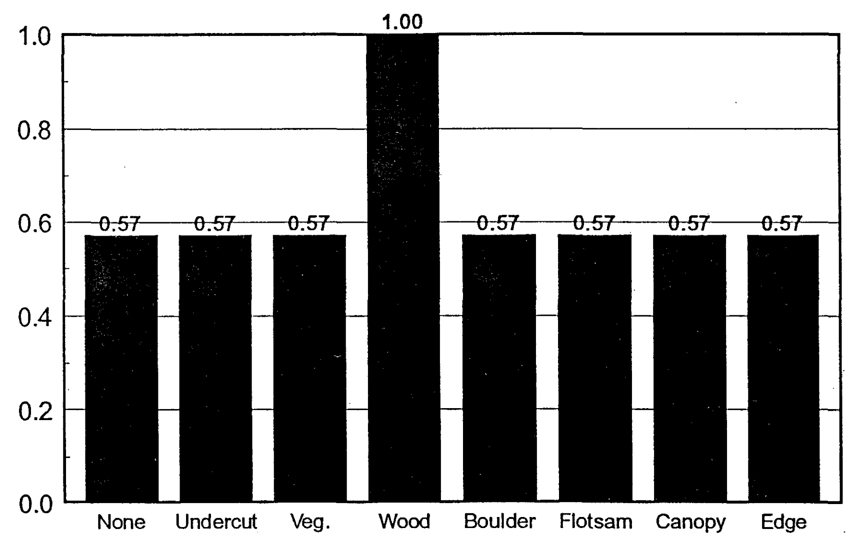


LEOPARD FROG - WINTER

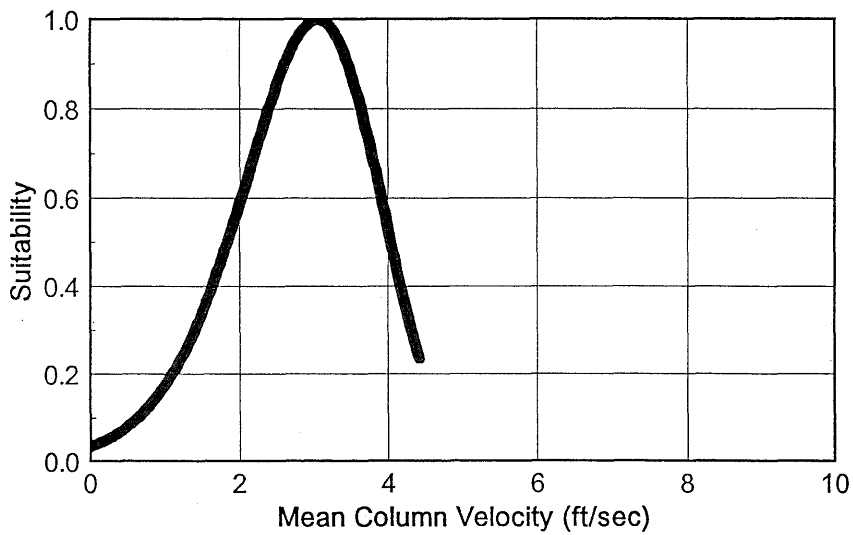


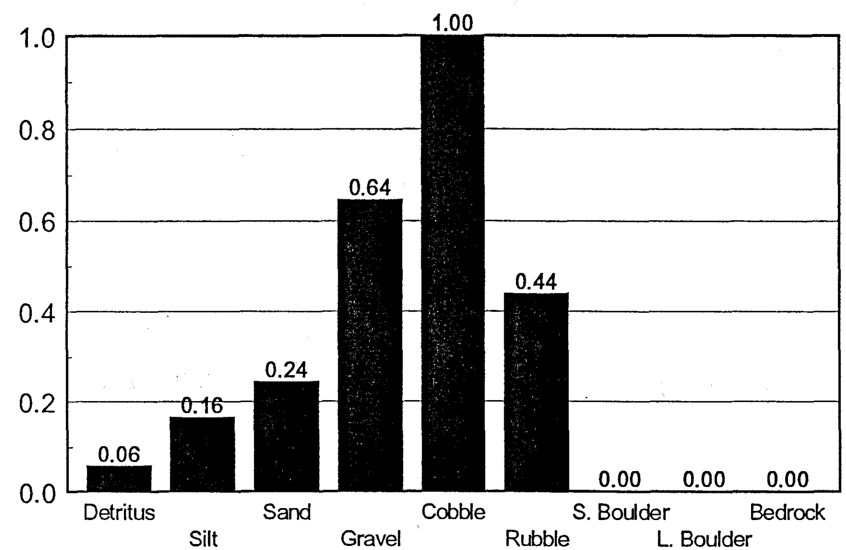


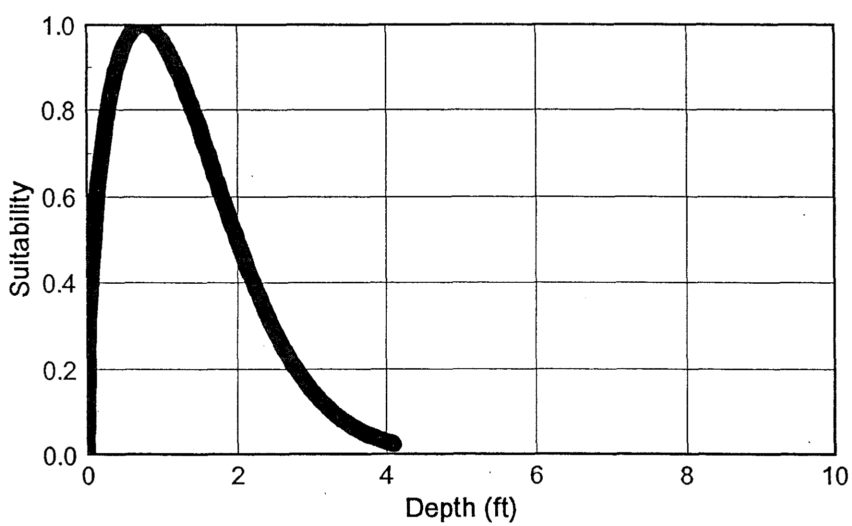


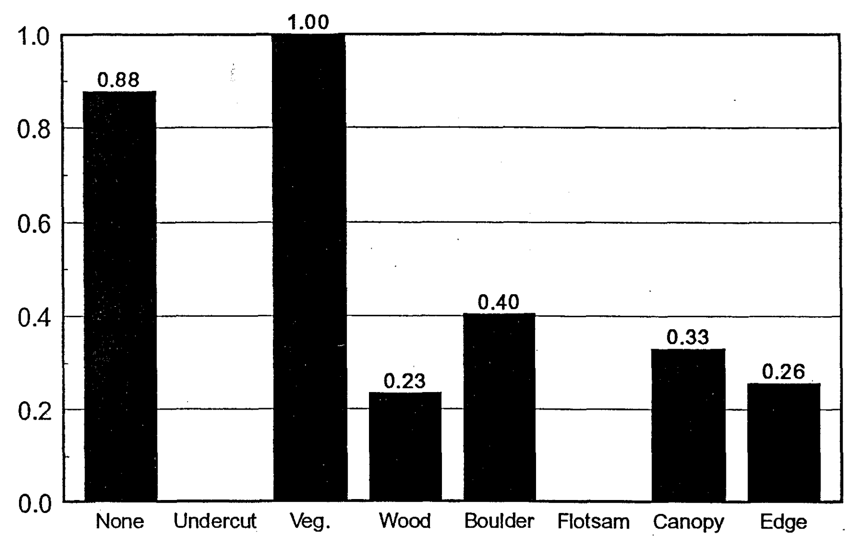


MACROINVERTEBRATES OTHER THAN MUSSELS

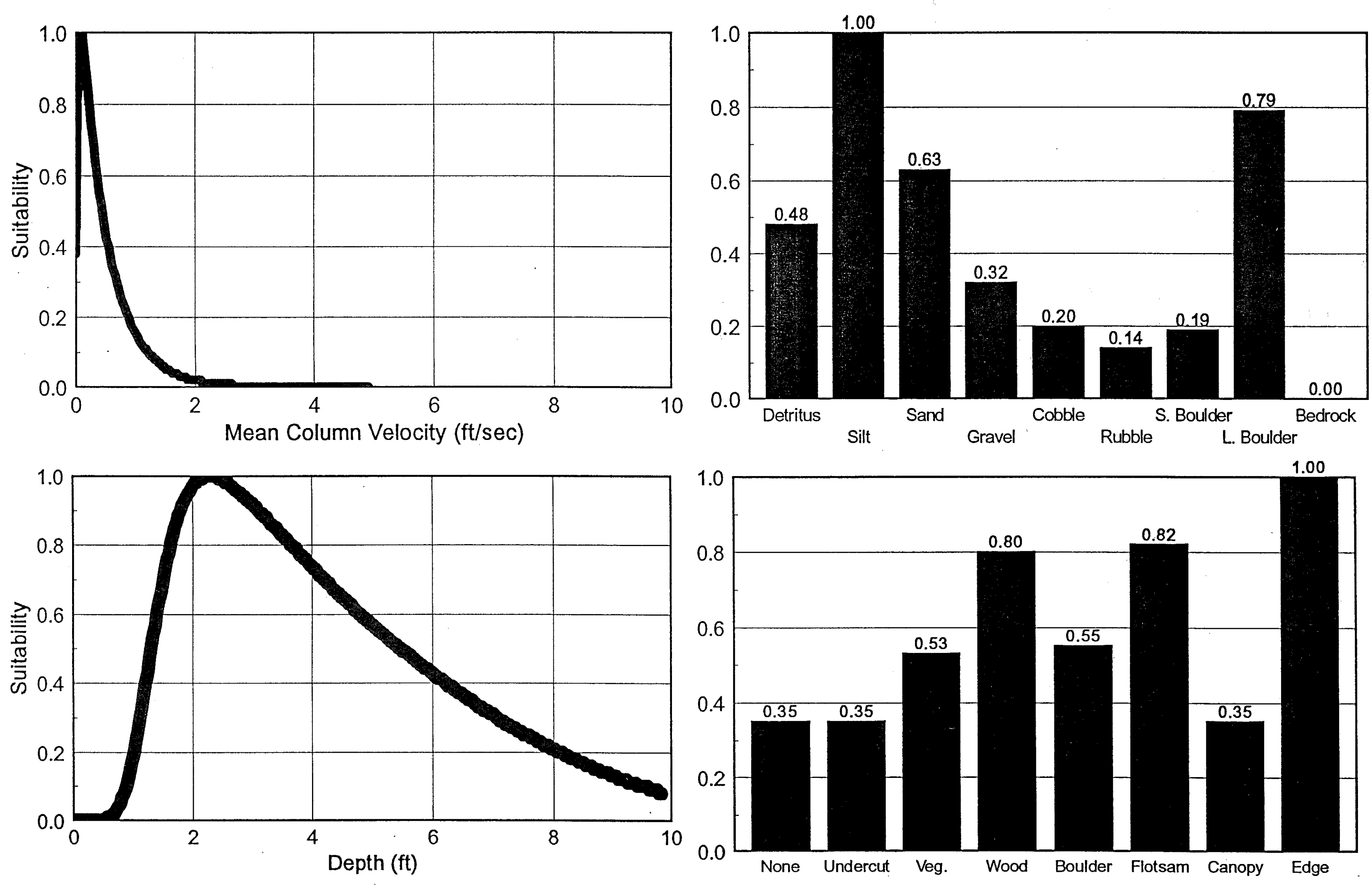




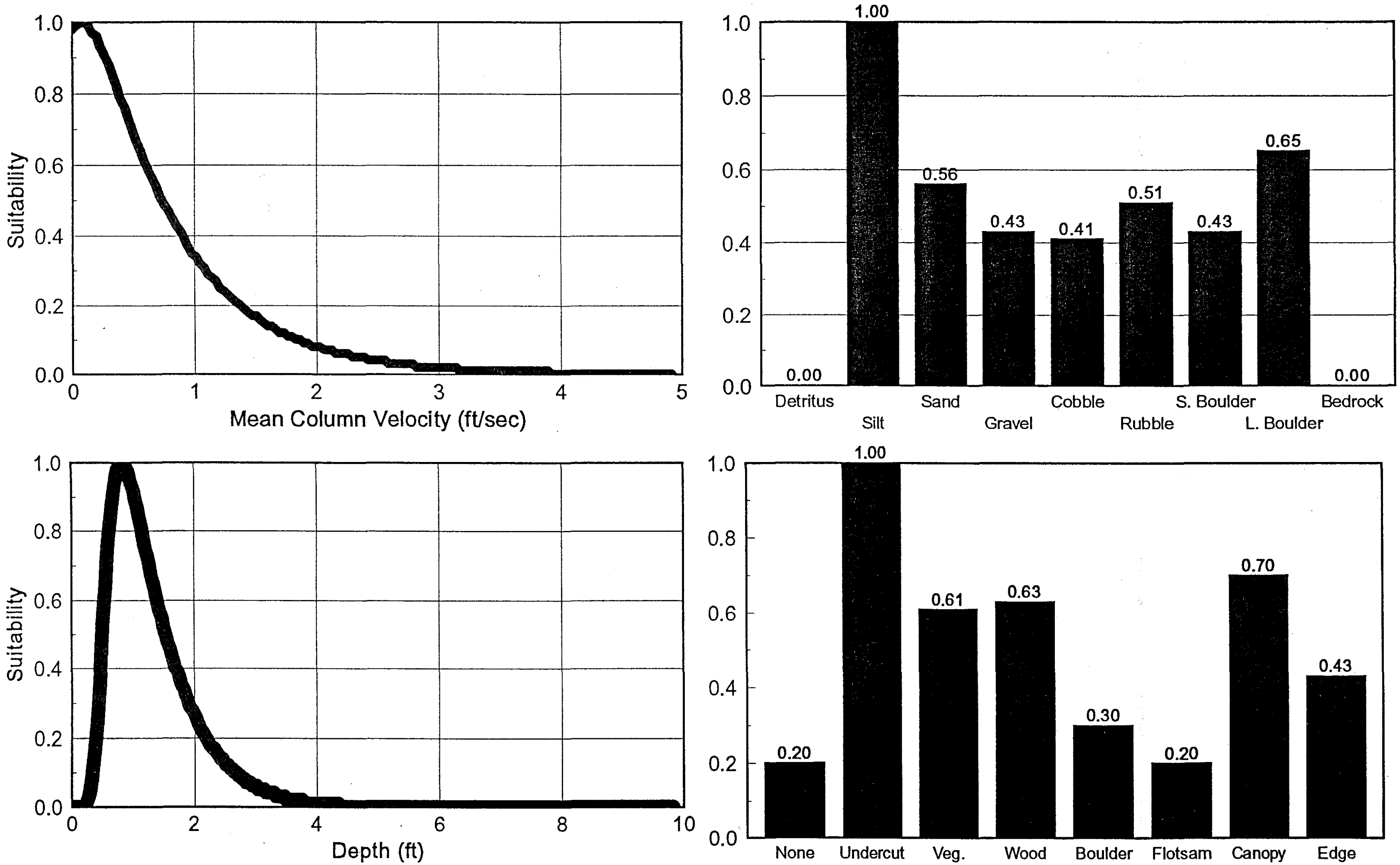




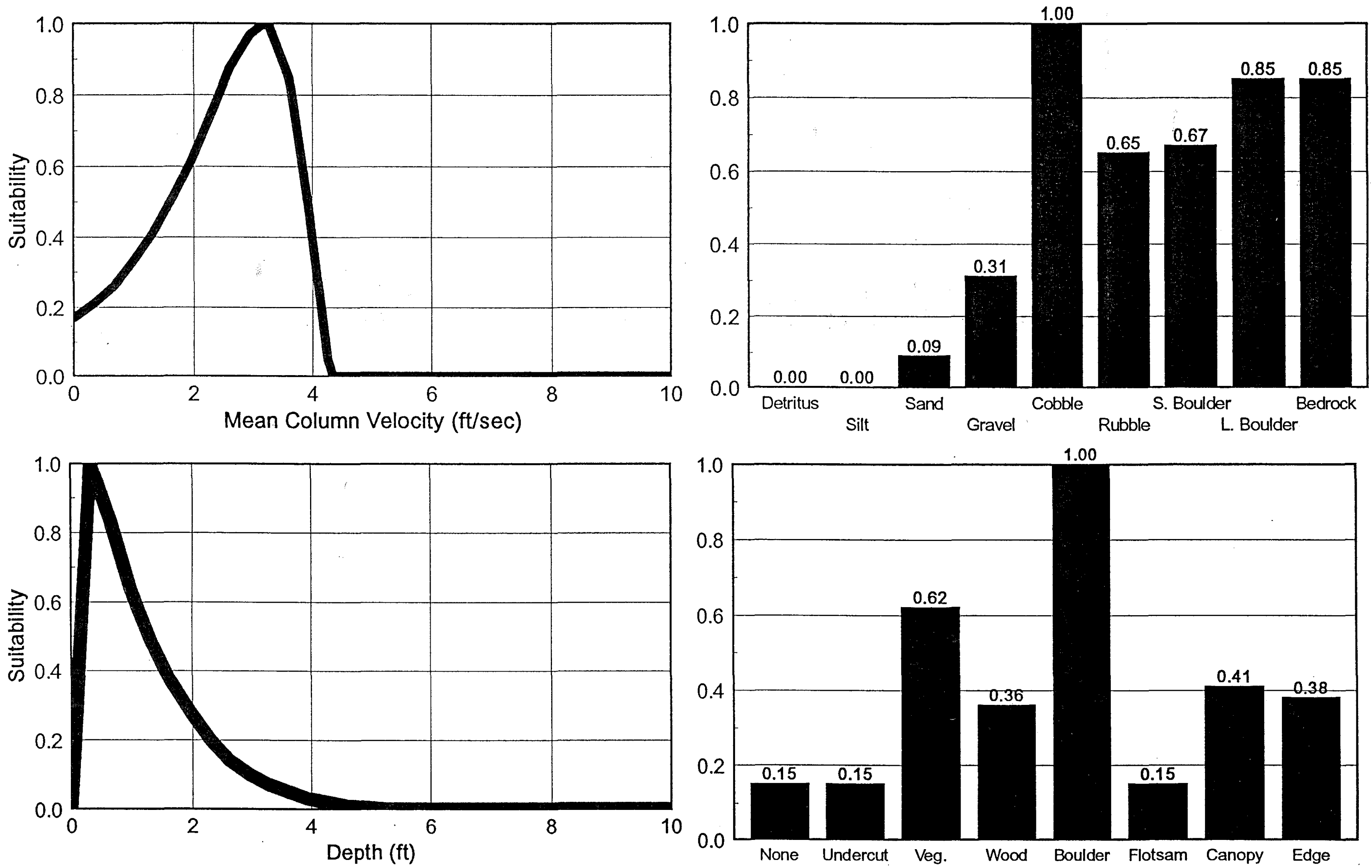
NORTHERN PIKE ADULT



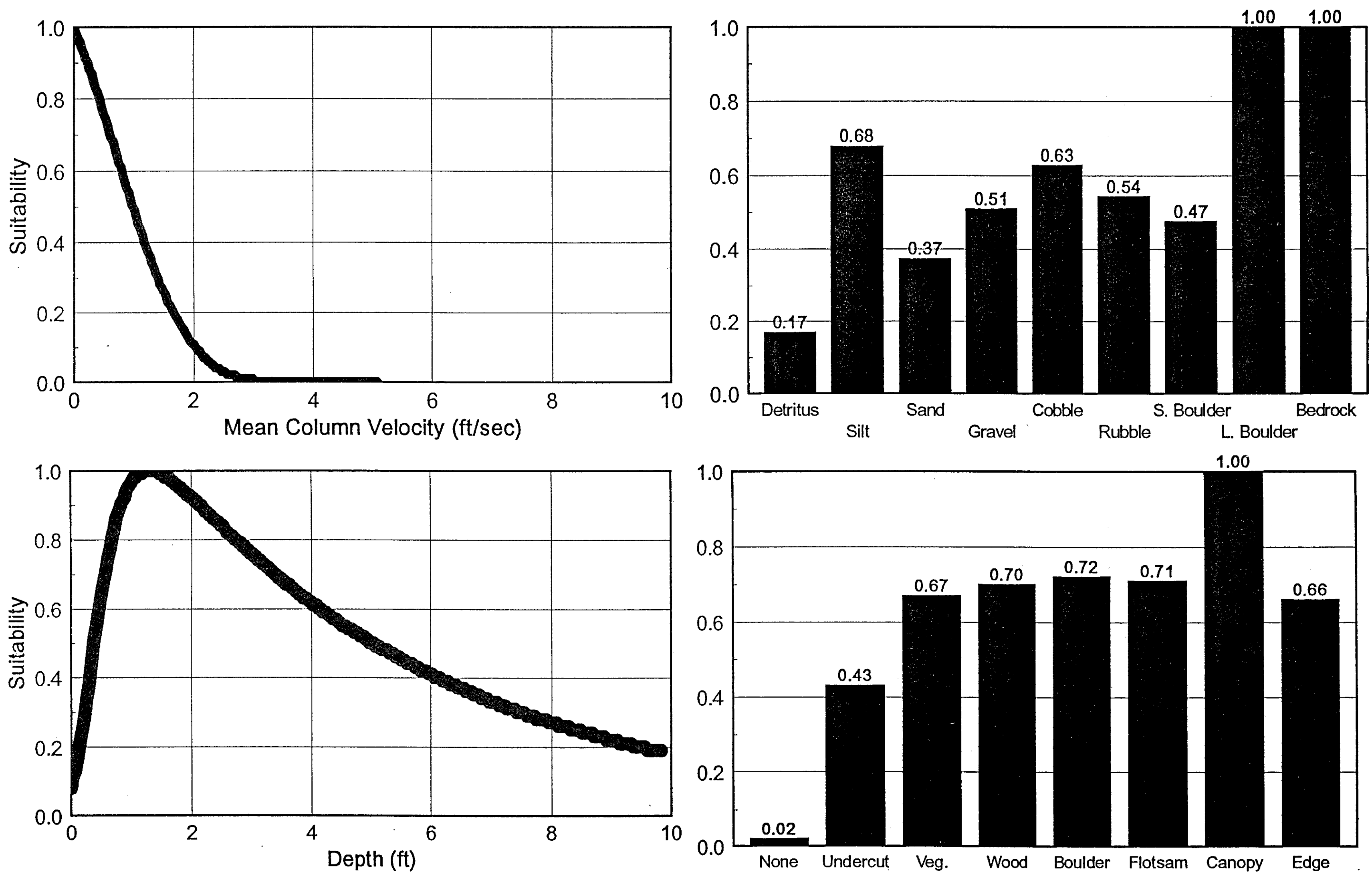
ORANGESPOTTED SUNFISH ADULT



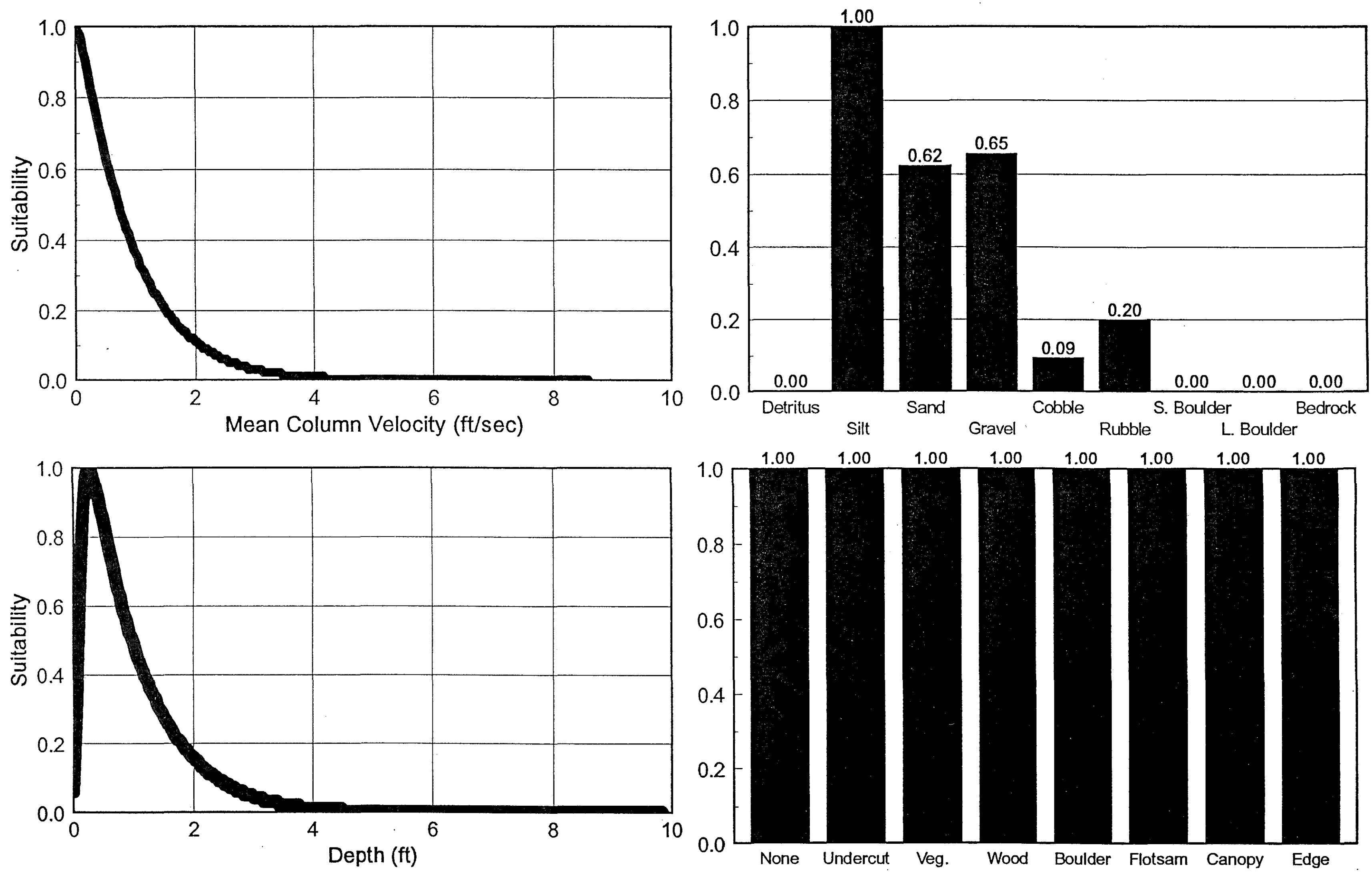
RAINBOW DARTER ADULT



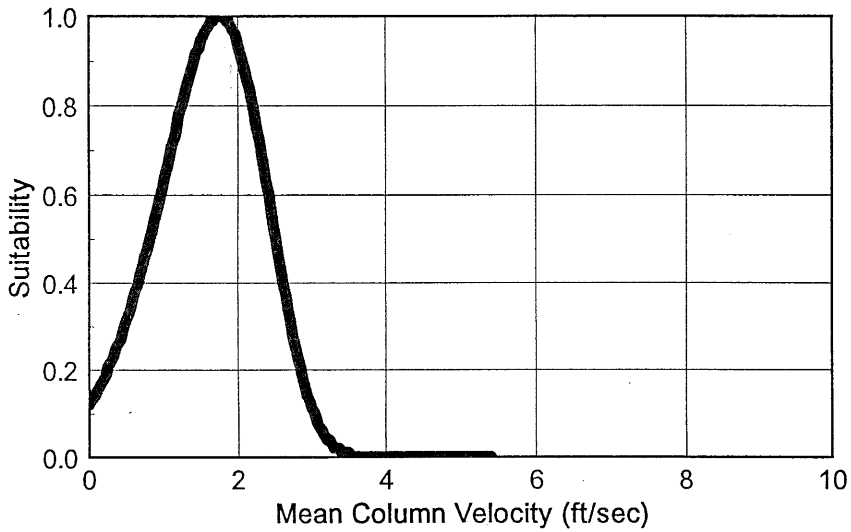
ROCK BASS ADULT

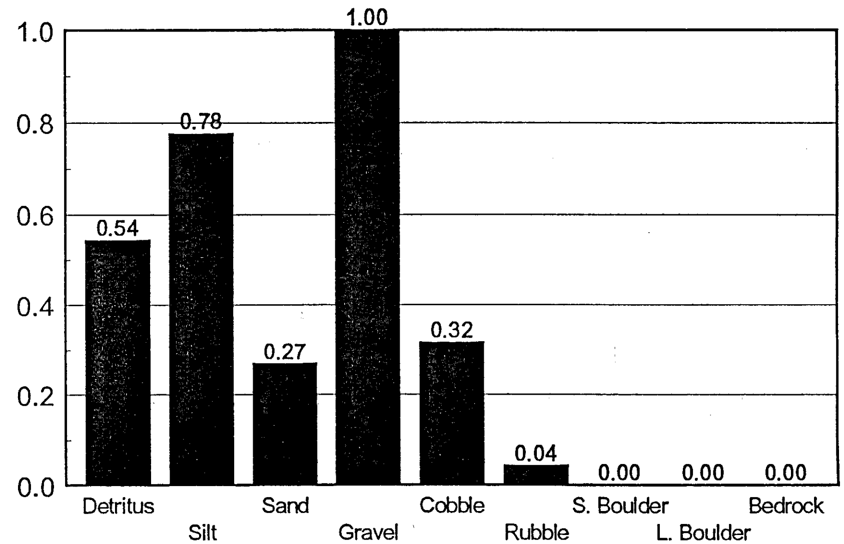


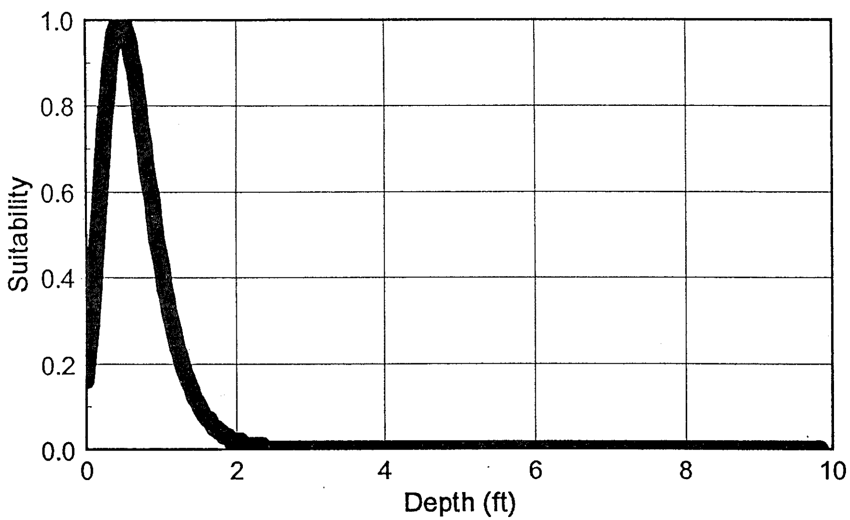
SAND SHINER YOY

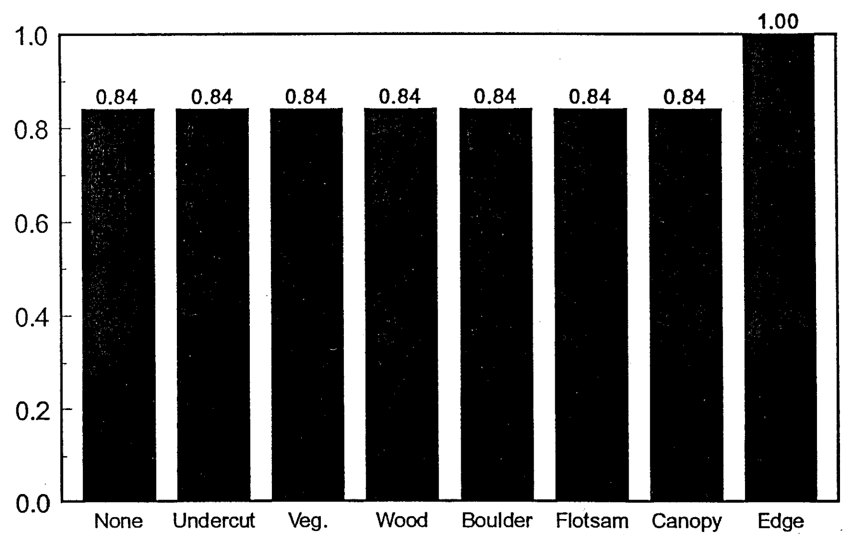


SAND SHINER ADULT

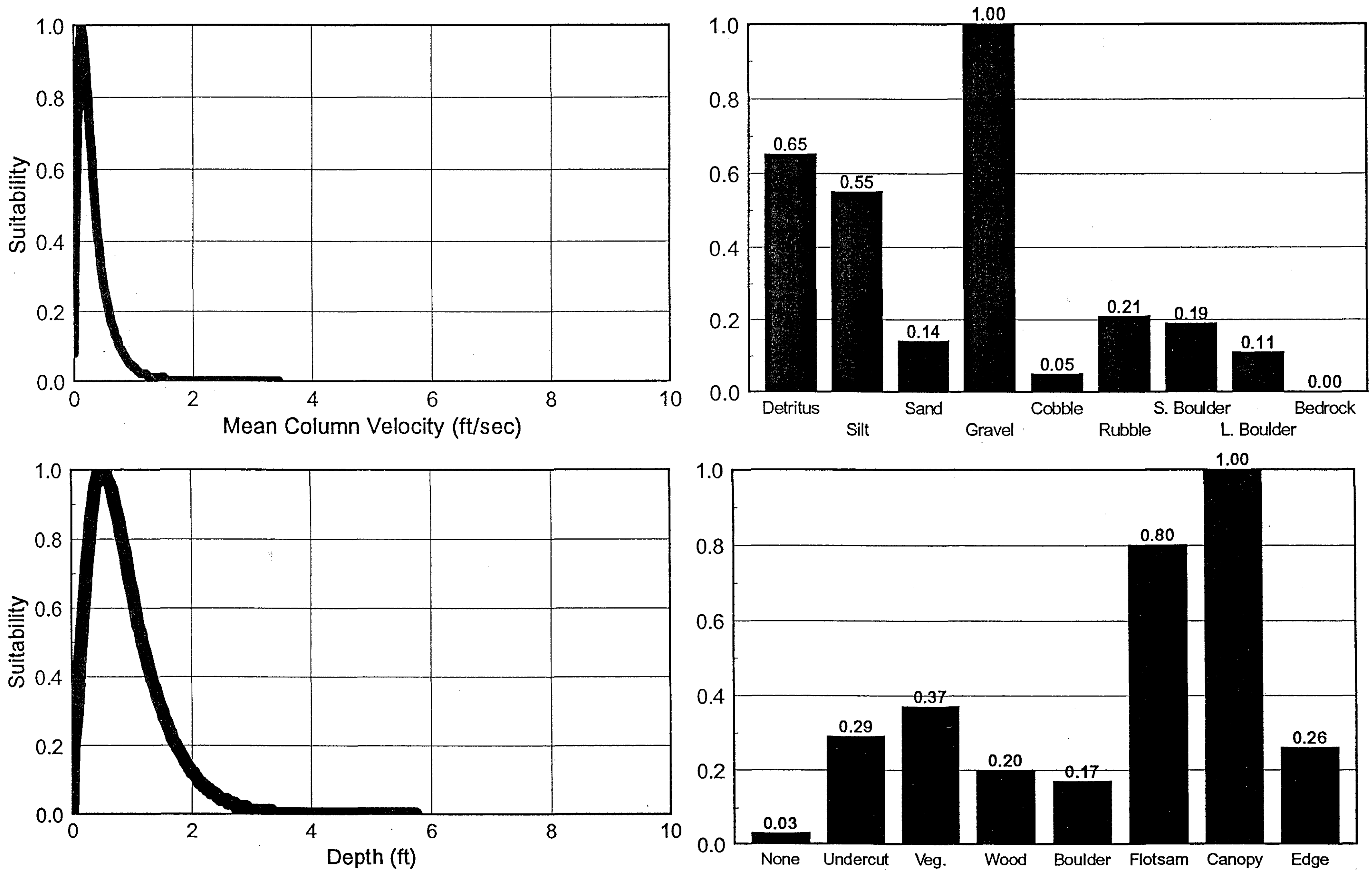




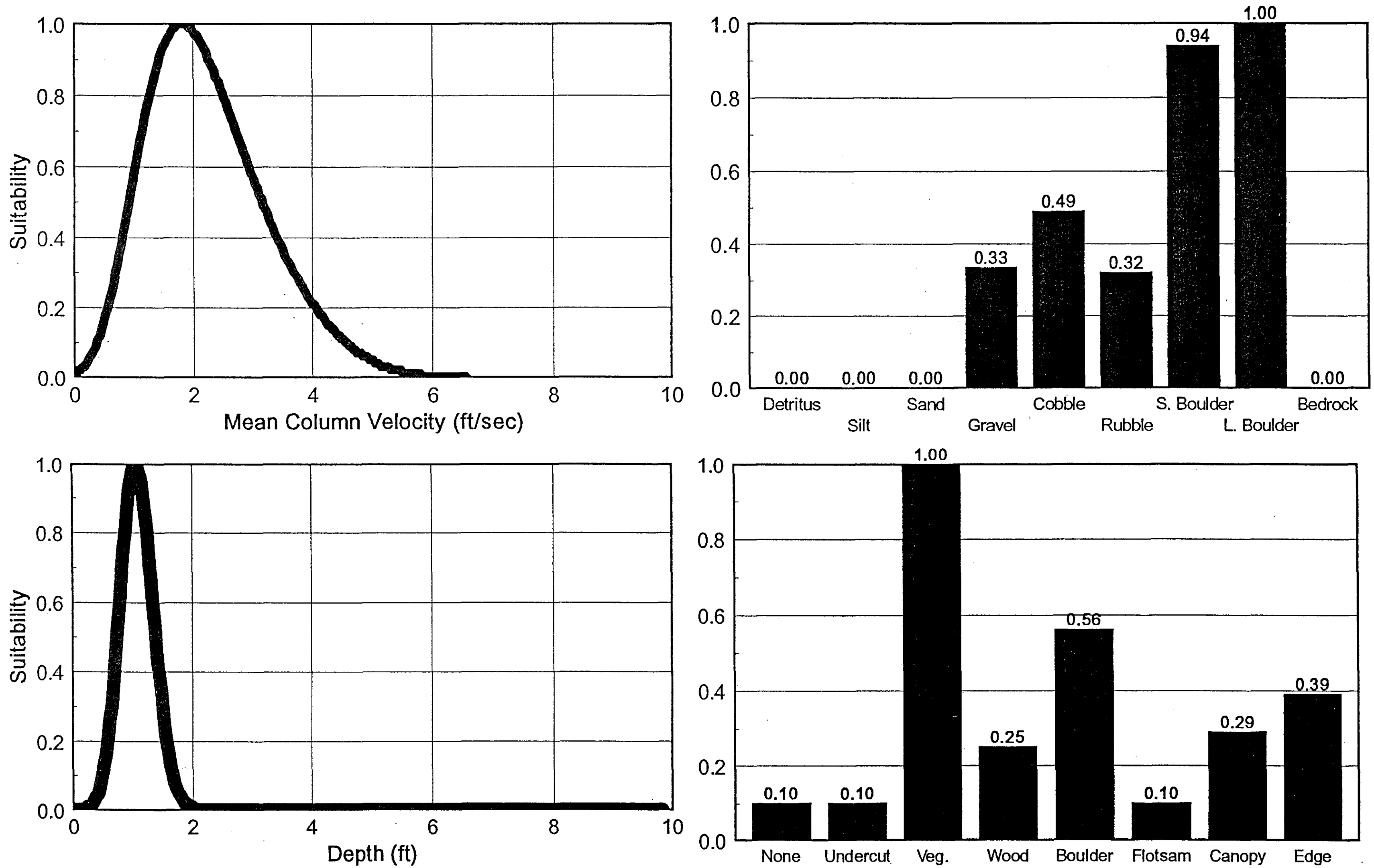




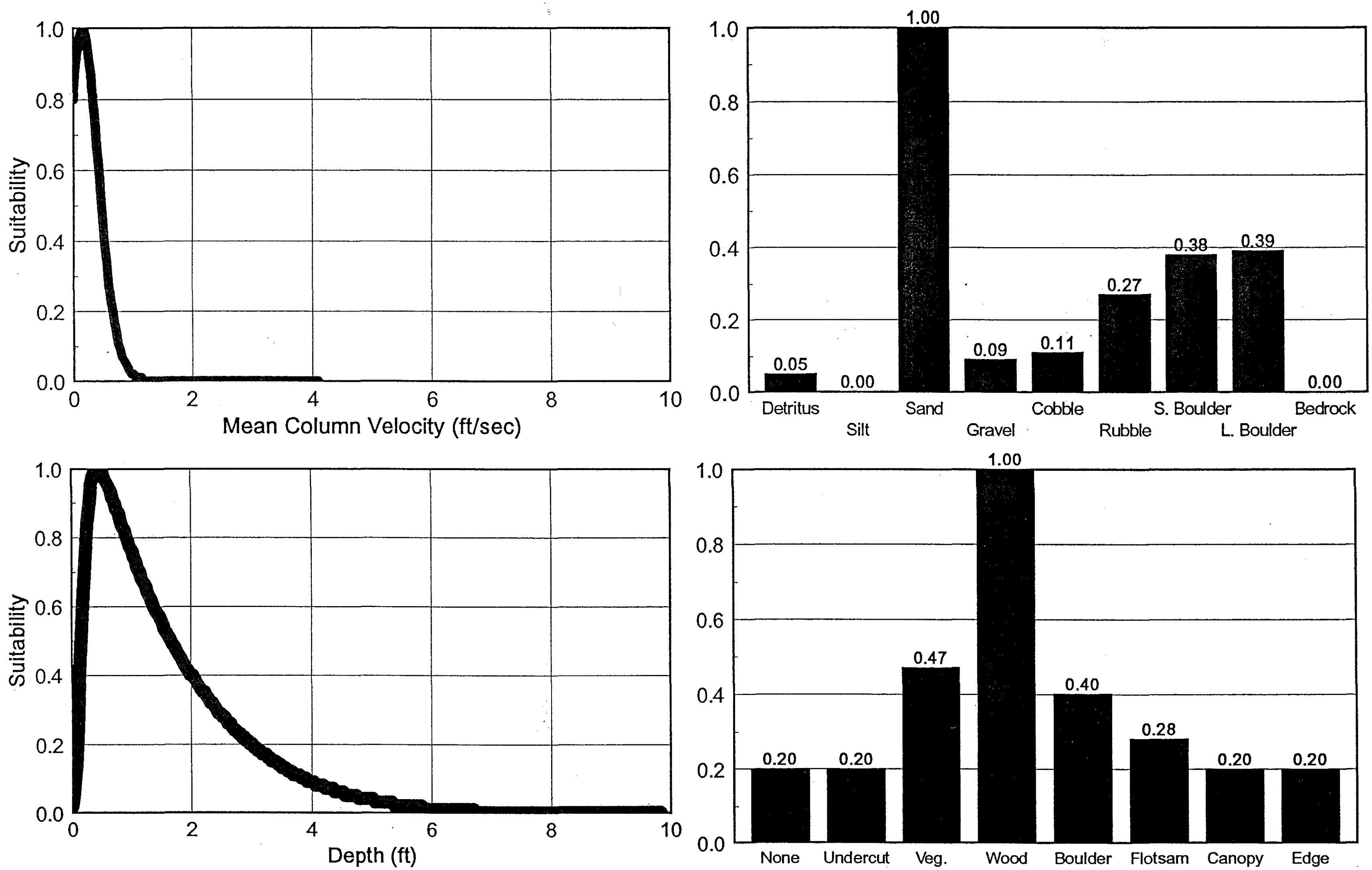
SAND SHINER ADULT - WINTER



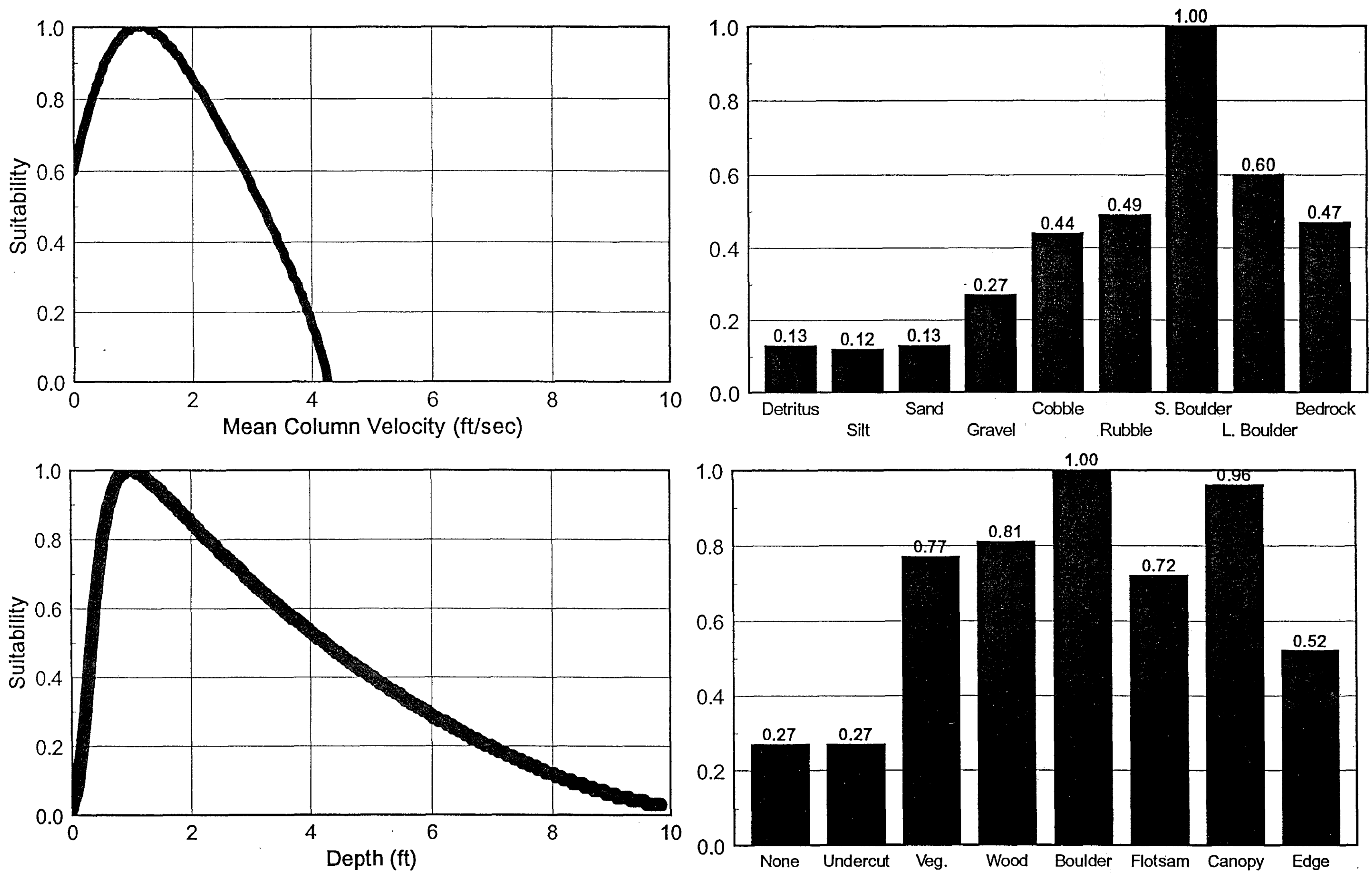
SLENDERHEAD DARTER SPAWNING



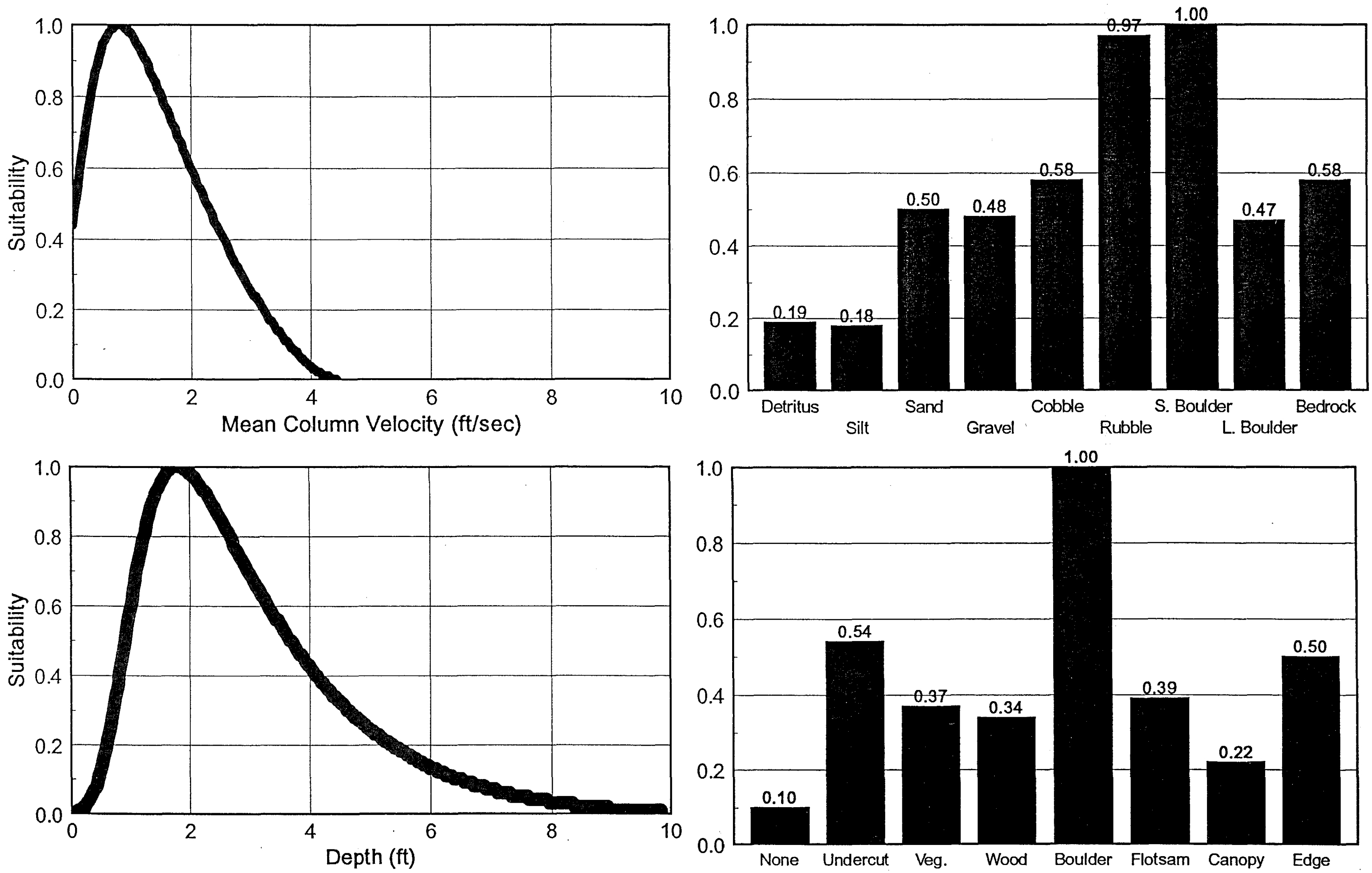
SMALLMOUTH BASS FRY



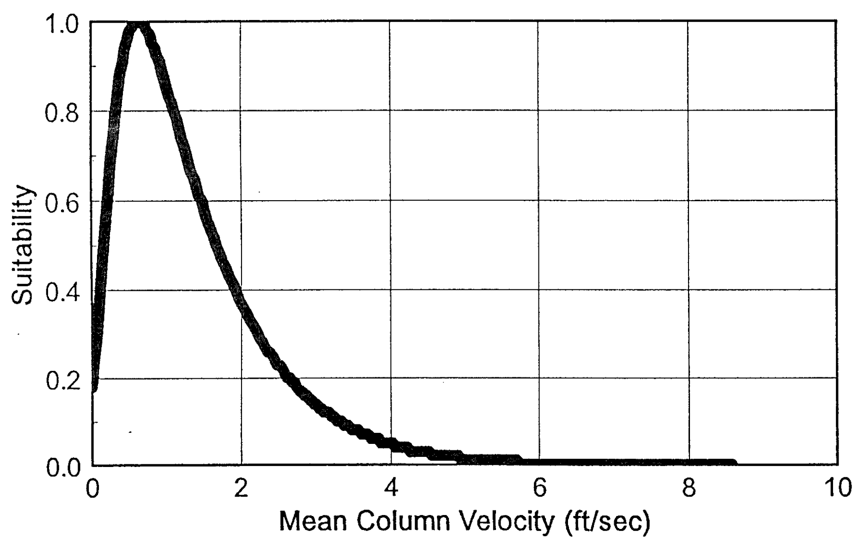
SMALLMOUTH BASS FINGERLING

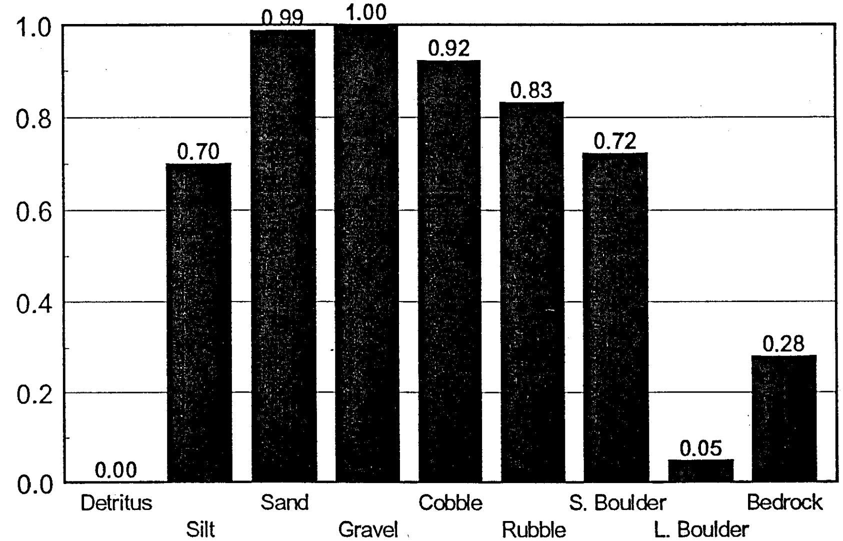


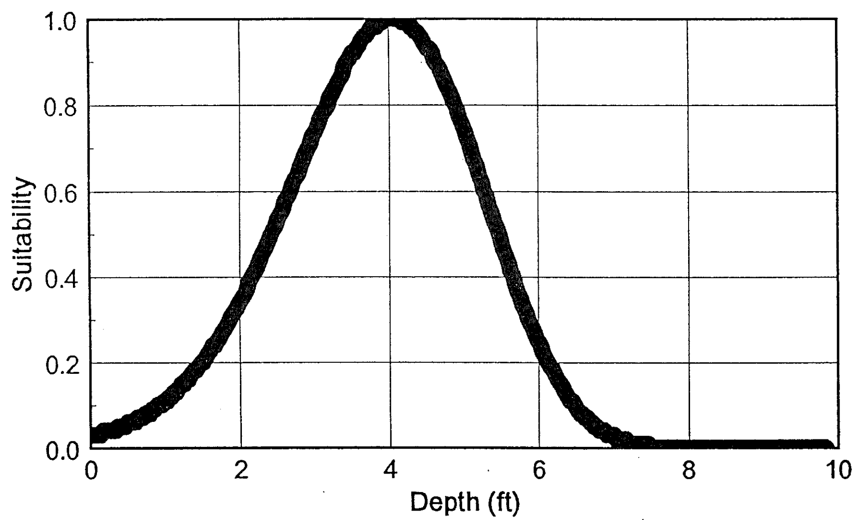
SMALLMOUTH BASS JUVENILE

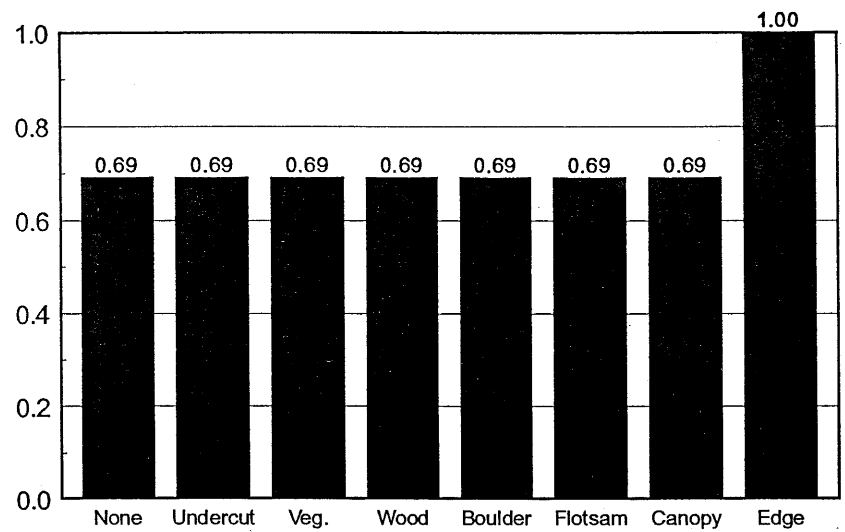


SMALLMOUTH BASS ADULT

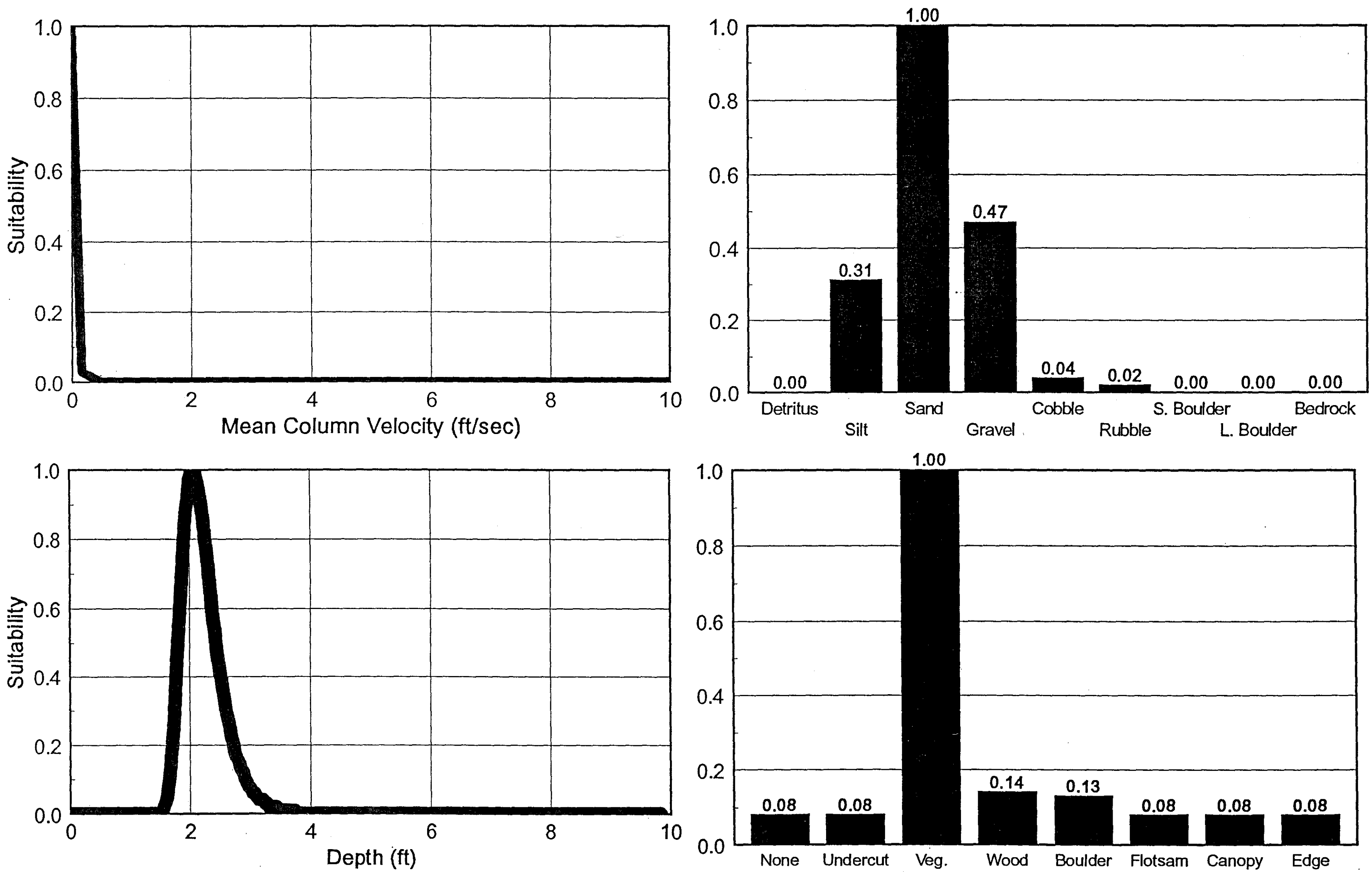




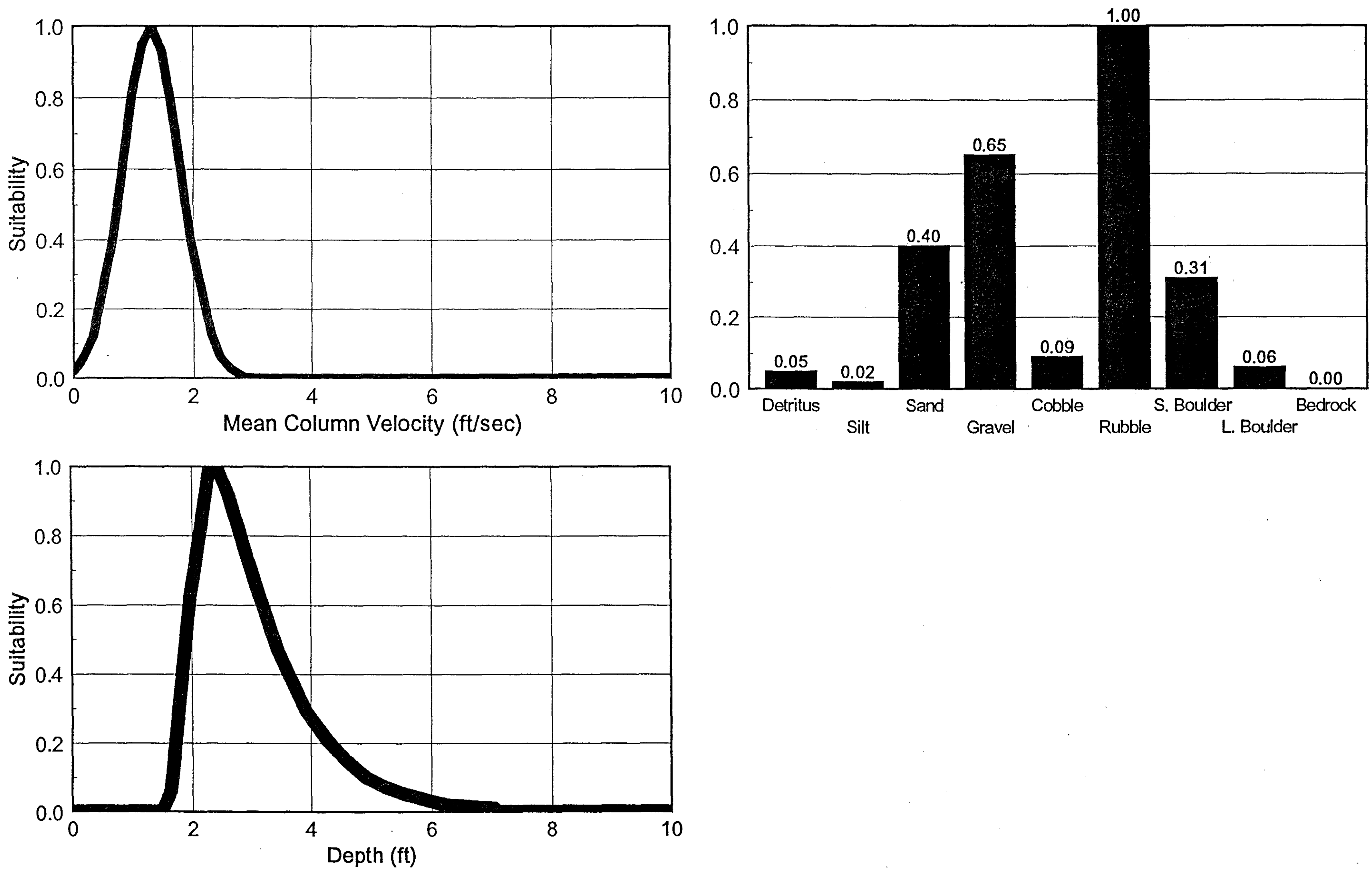




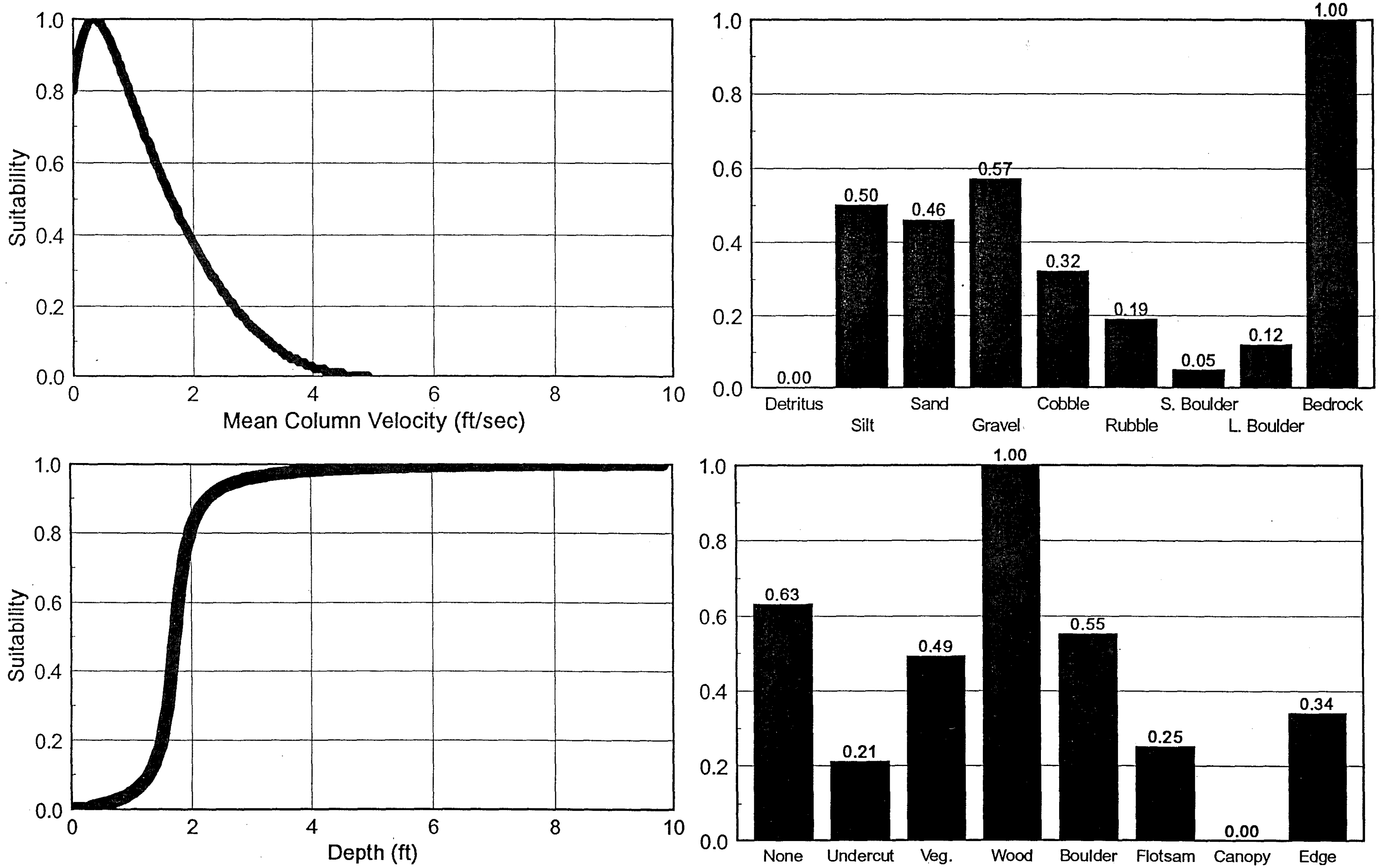
SMALLMOUTH BASS SPAWNING



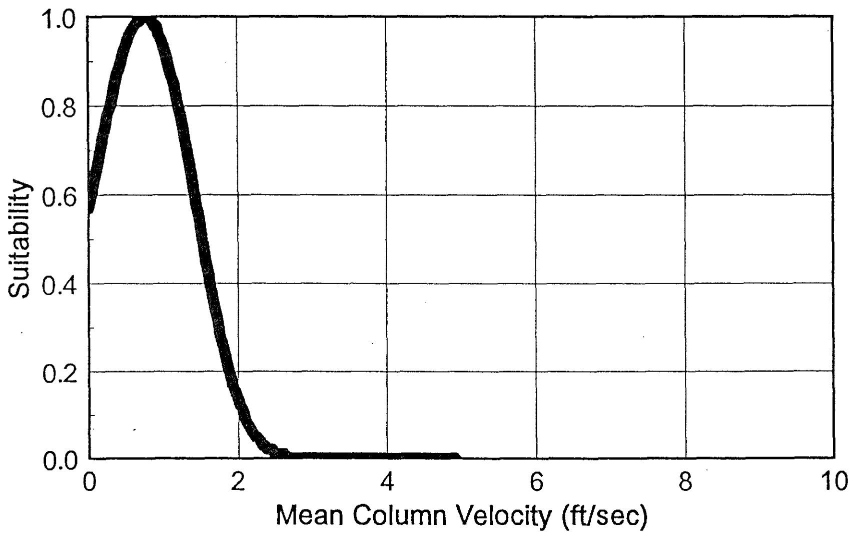
WABASH PIGTOE

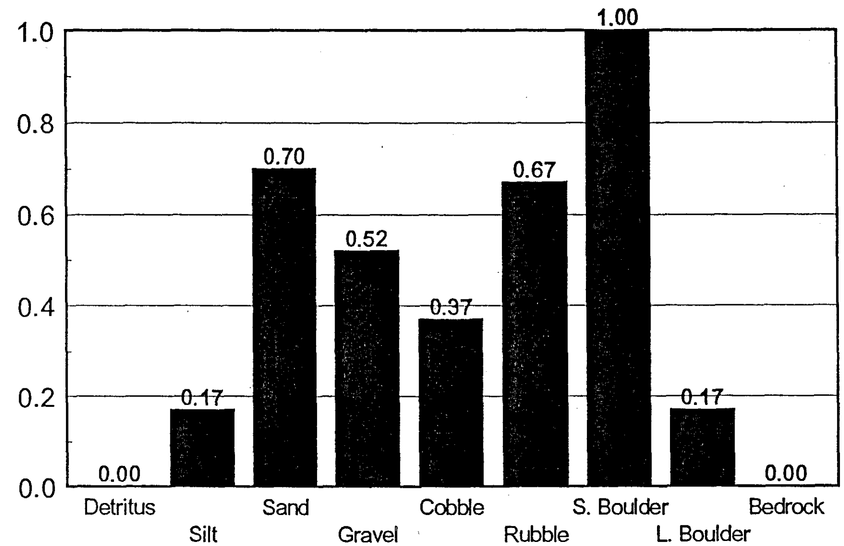


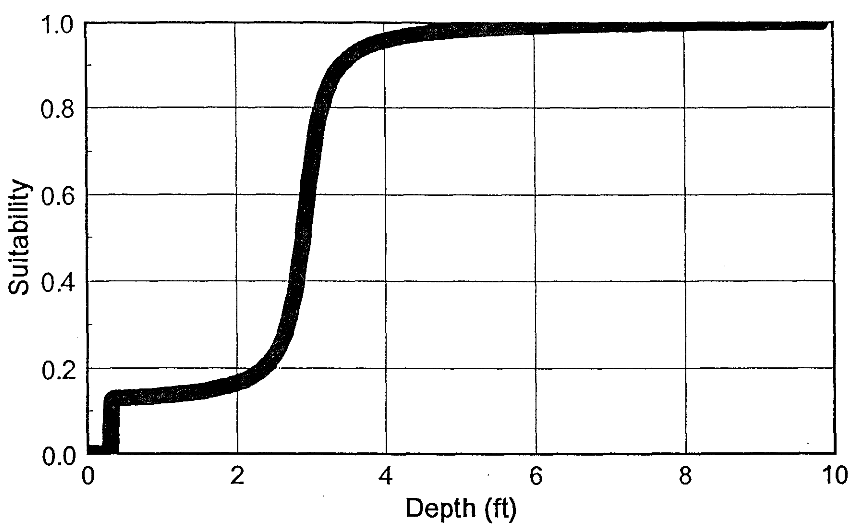
WALLEYE JUVENILE

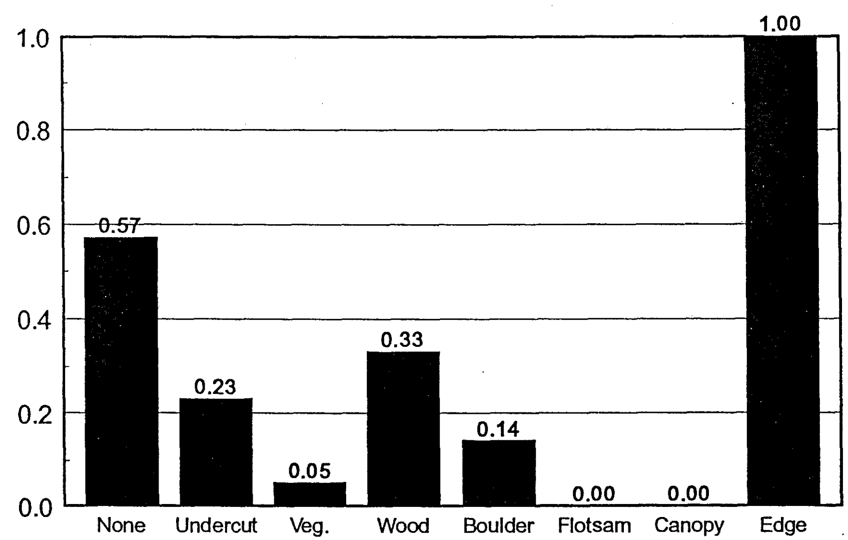


WALLEYE ADULT

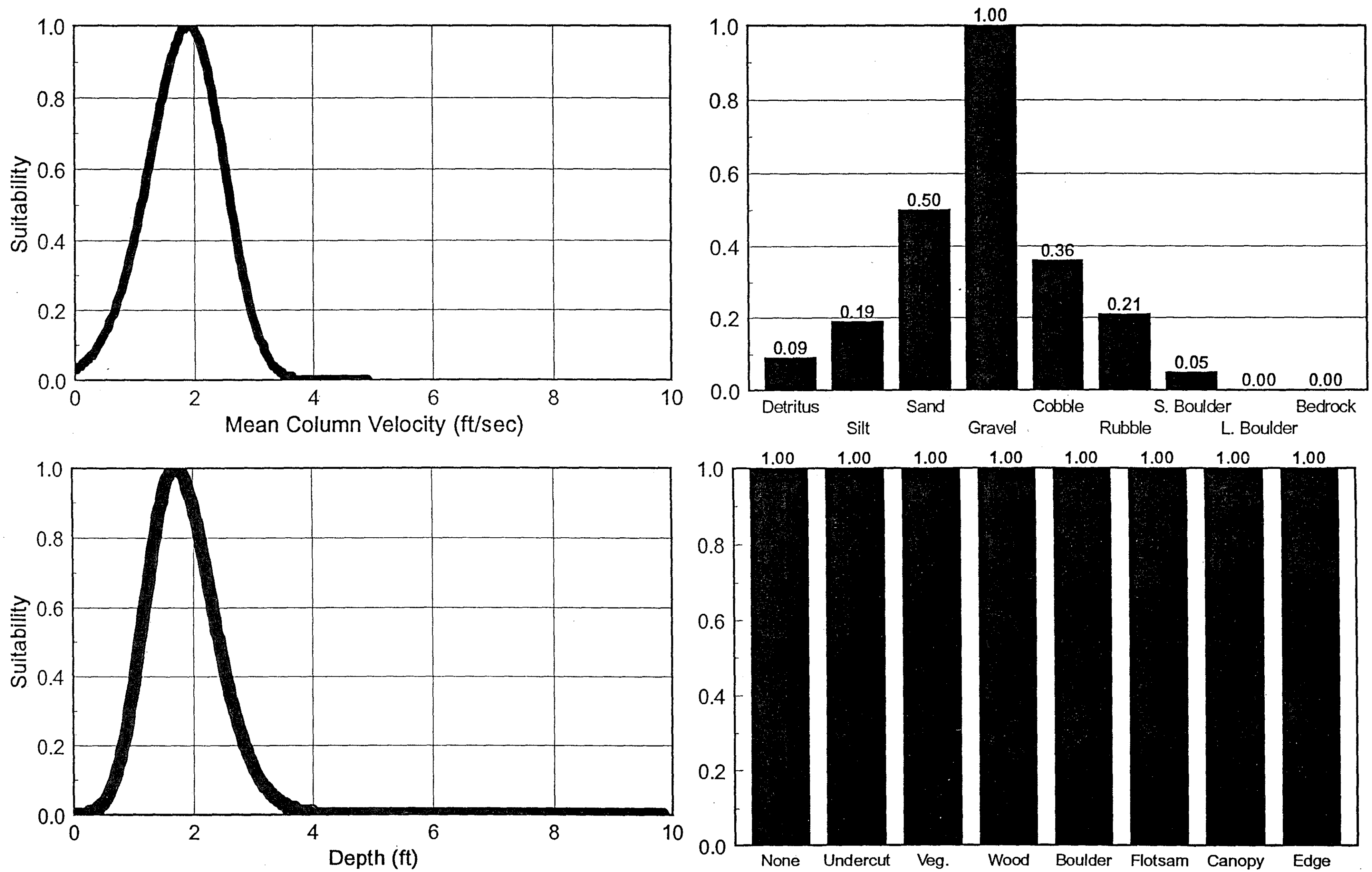




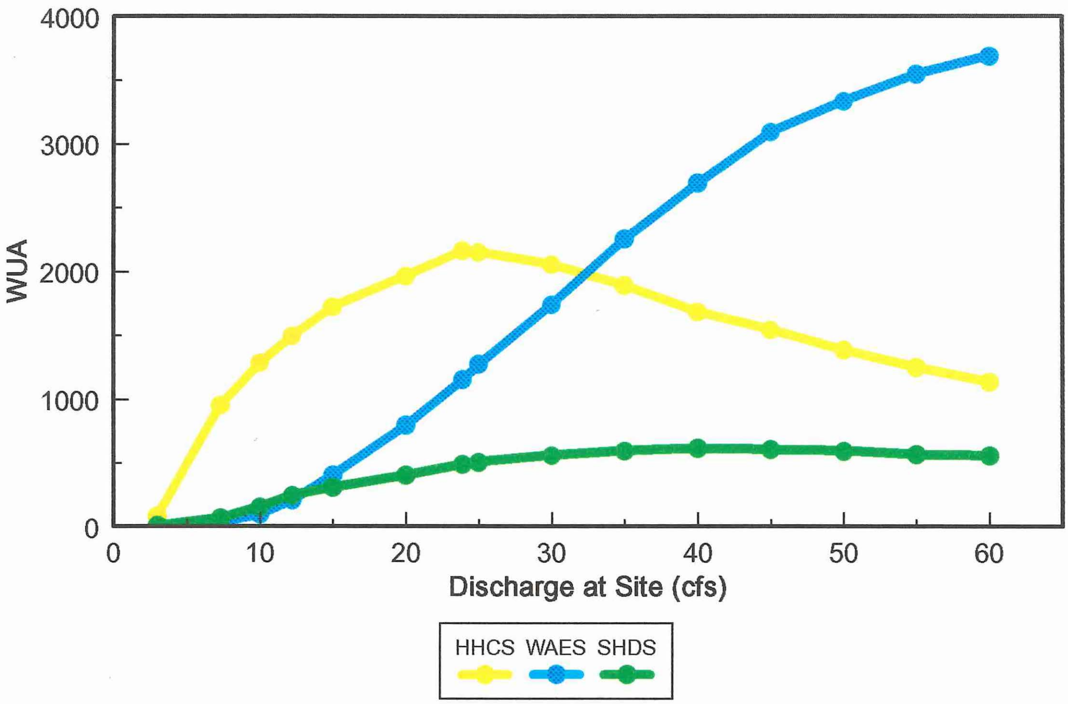


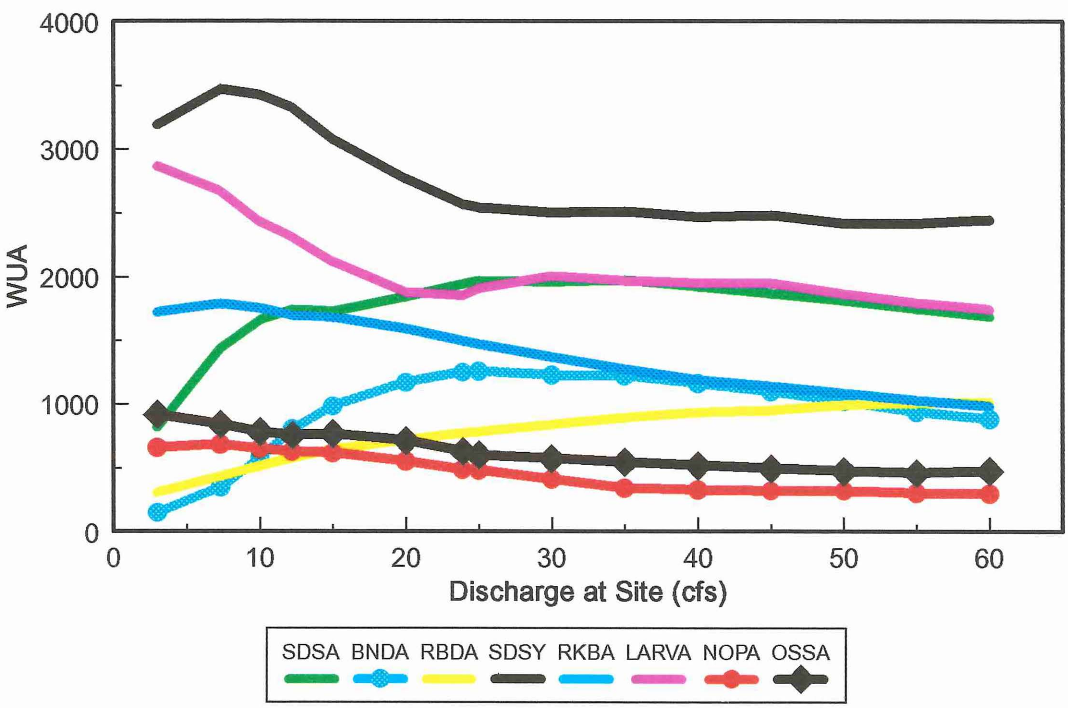


WALLEYE SPAWNING

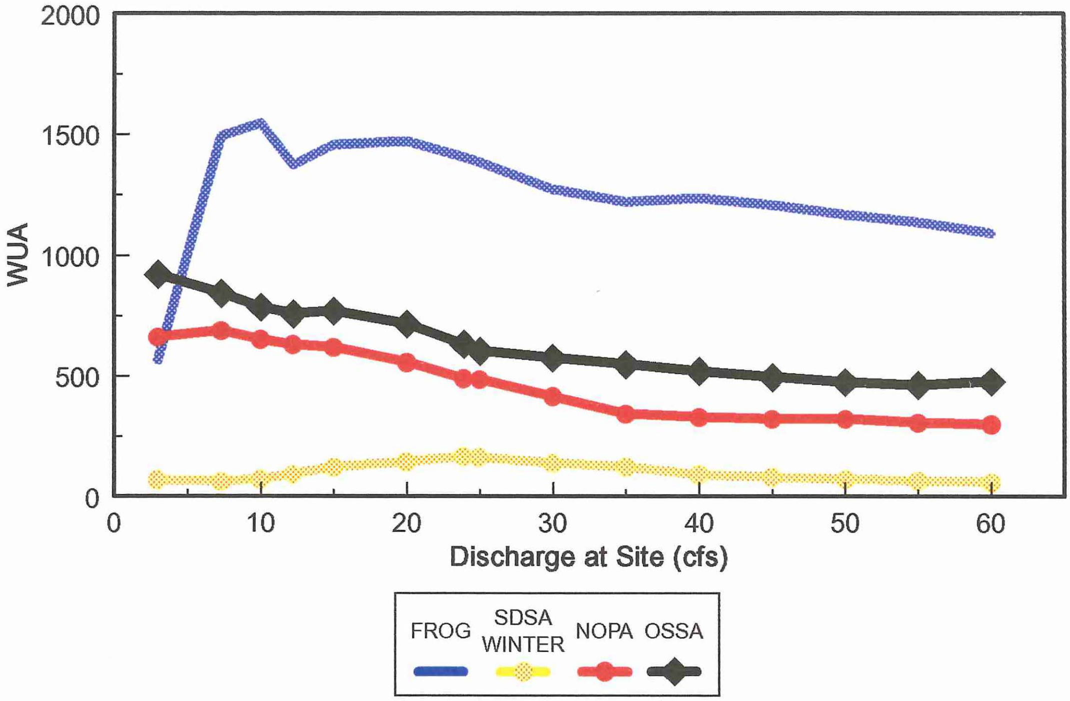


Appendix F1. Non-normalized weighted usable area as a function of discharge for 1 April - 15 May (top) and the 16 May - 4 November (bottom) at the upper Yellow Medicine River site.

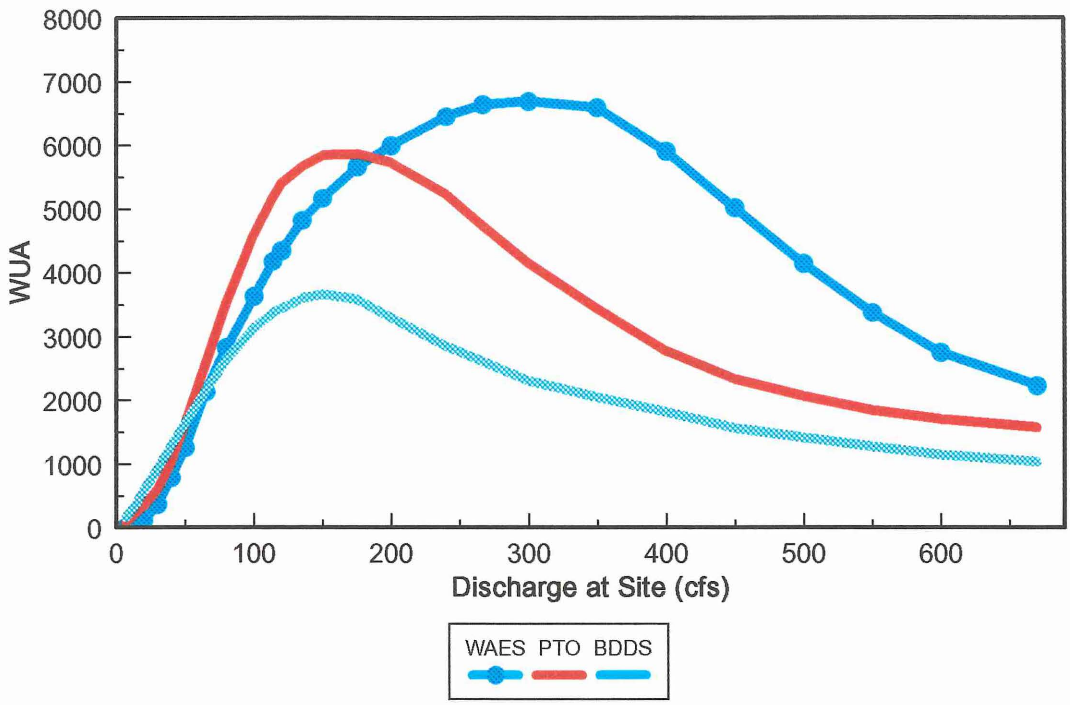


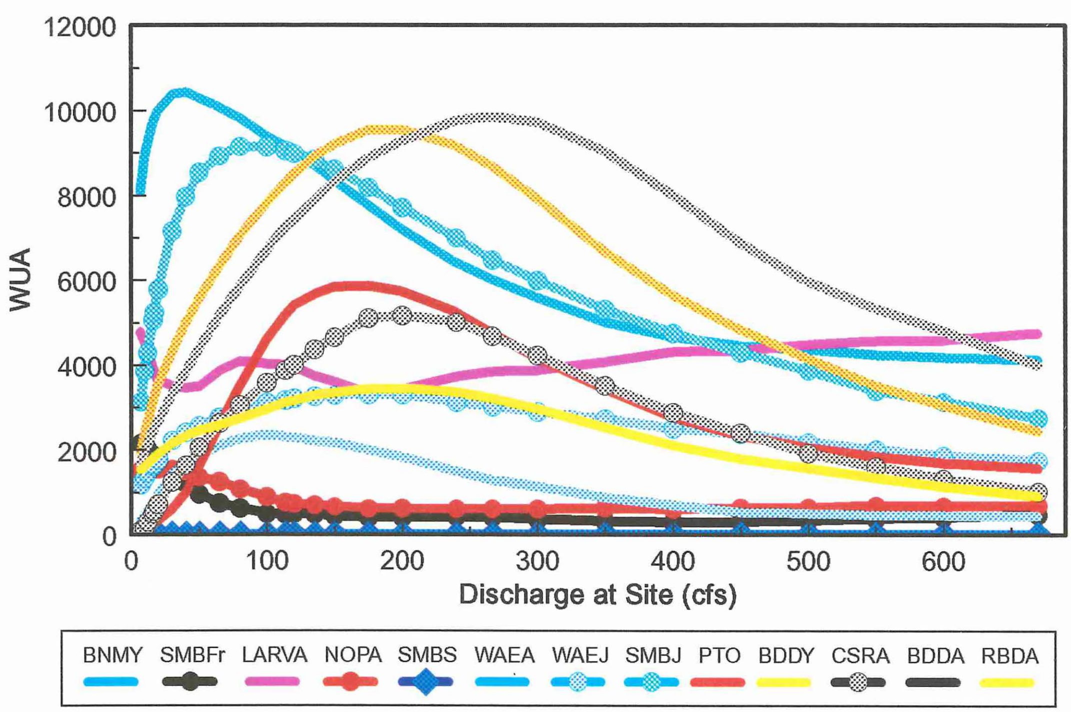


Appendix F1 (cont.). Non-normalized weighted usable area as a function of discharge for 5 November - 31 March at the upper Yellow Medicine River site.

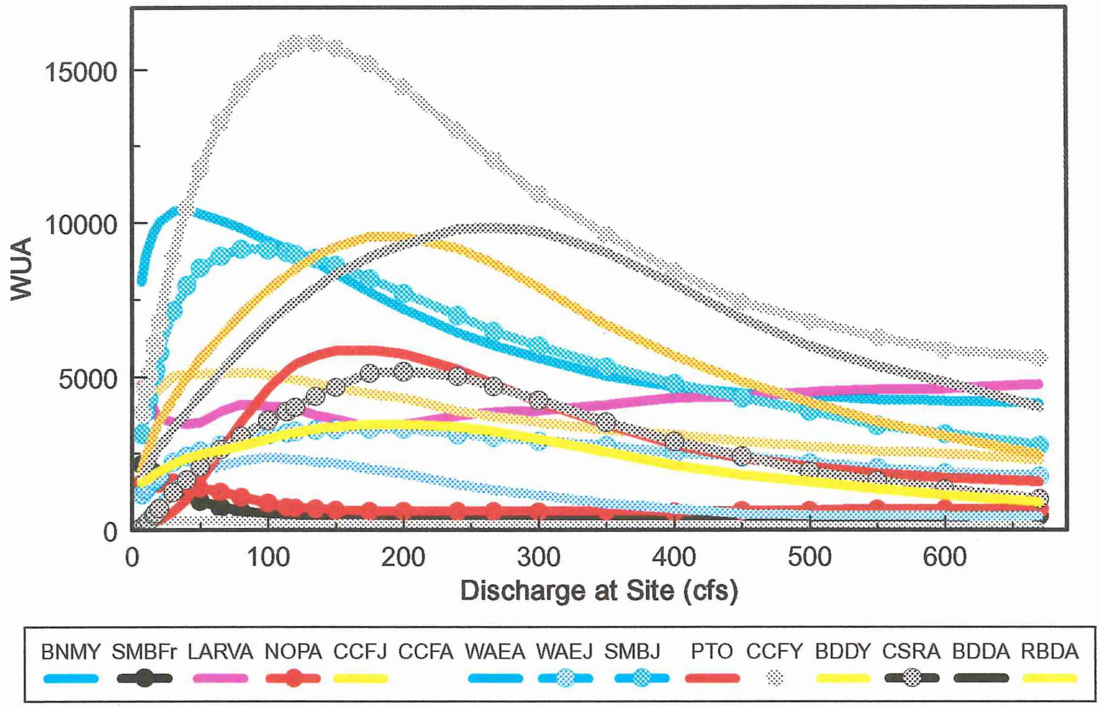


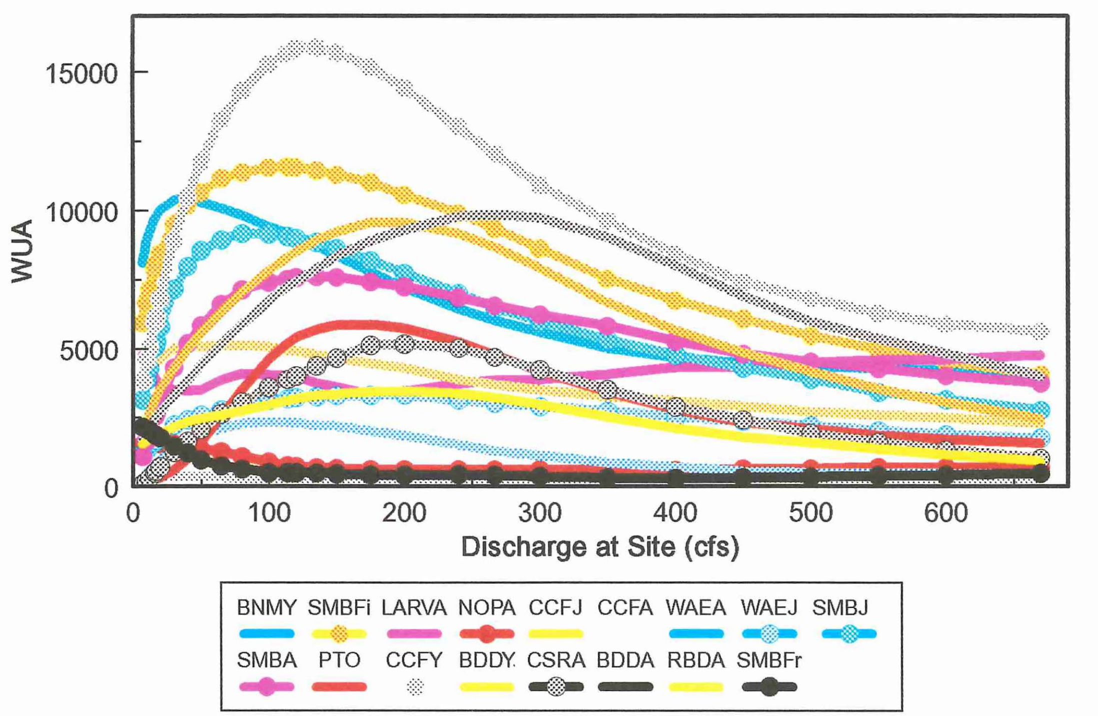
Appendix F2. Non-normalized weighted usable area as a function of discharge for 1 April - 15 May (top) and 16 May - 30 June (bottom) at the lower Yellow Medicine River site.



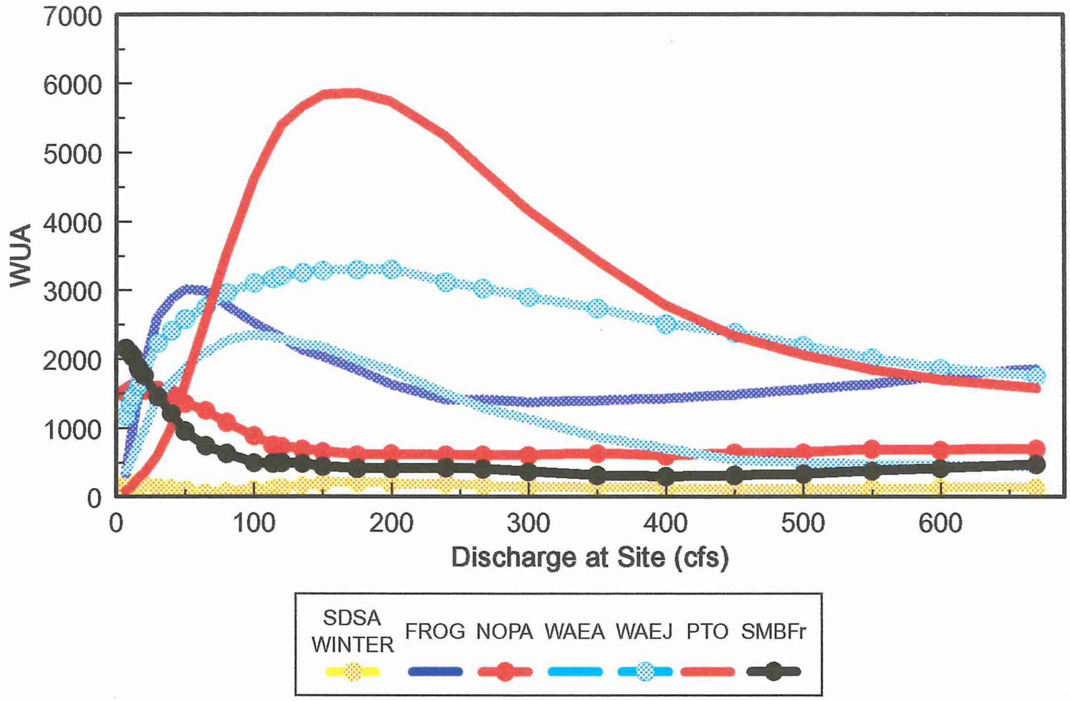


Appendix F2 (cont.). Non-normalized weighted usable area as a function of discharge for 1 July - 31 July (top) and 1 August - 4 November (bottom) at the lower Yellow Medicine River site.





Appendix F2 (cont.). Non-normalized weighted usable area as a function of discharge for 5 November - 31 March at the lower Yellow Medicine River site.



Appendix G. Percent of time each month that appropriations would be allowed based on historical flows and recommended flows.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
% of time flow equals or exceeds 29 cfs	10	15	55	---------	66	60	47	25	15	14	22	22
% of time flow equals or exceeds 98 cfs	---------	---------	---------	59	45	---------	---------	---------	---------	---------	---------	---------