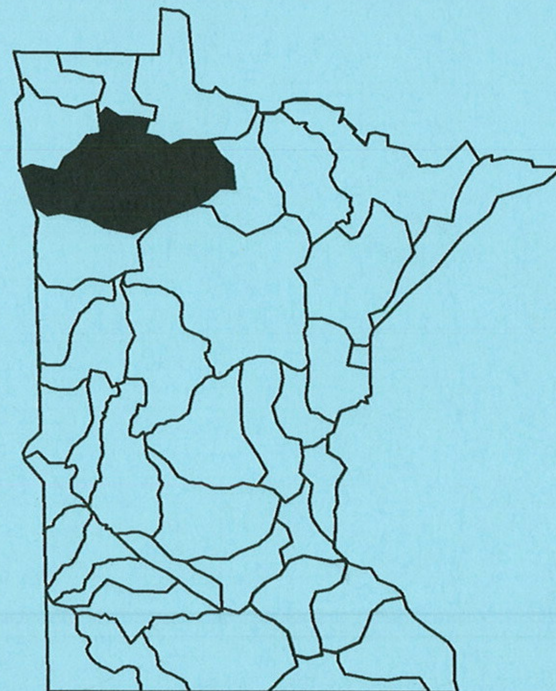
RED LAKE RIVER WATERSHED

Recommendations for Streamflow and Habitat Protection



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Report to the
Legislative Commission on
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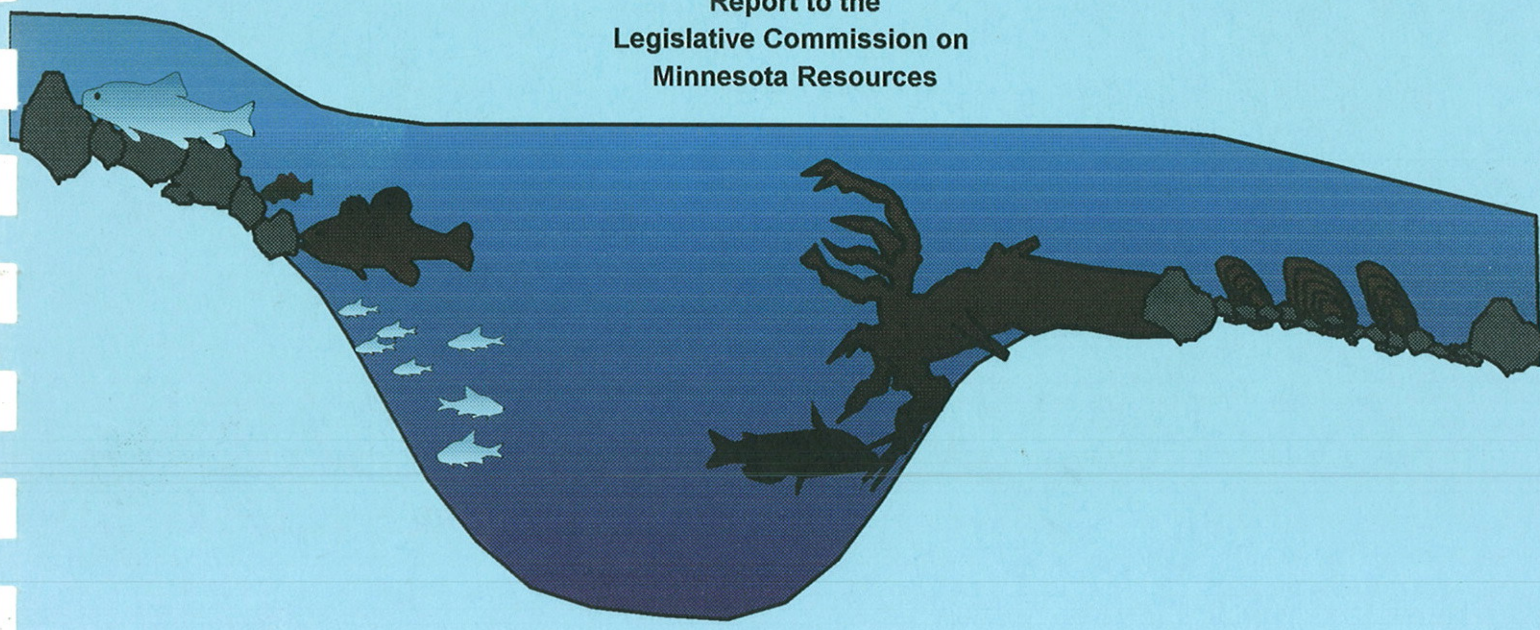

Red Lake River Watershed: Recommendations for Streamflow and Habitat Protection

Report to the
Legislative Commision on Minnesota Resources

by

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FORWARD

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 stream flows, 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 stream flows 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 their 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; Standford 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 stream flow 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, stream flow 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 stream flow and habitat protection are being developed for each of Minnesota's 39 major watersheds. This report presents recommendations for the Red Lake River 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 DESCRIPTION

2.1 Watershed Characteristics

The Red Lake River Watershed unit is located in northwestern Minnesota (Figure 1) in parts of seven counties: Red Lake, Koochiching, Beltrami, Clearwater, Marshall, Pennington, and Polk (Hydrologic Atlas of Minnesota 1959). With an area of 5,988 square miles, it is one of the largest of the 39 major watersheds within Minnesota. With a total length of 196 river miles, the main stem of the Red Lake River originates in Lower Red Lake, flowing west about 70 miles to Thief River Falls were it is joined by the Thief River. The Lost, Hill, and Poplar rivers empty into the Clearwater River which joins the Red Lake River at Red Lake Falls. From Red Lake Falls, the Red Lake River flows to its junction with the Red River of the North near East Grand Forks.

The glacial geology of the region determined the character of the rivers within the watershed. From headwaters to mouth, the Red Lake River and many of its tributaries flow across the bed of Glacial Lake Agassiz (Waters 1977). West of the Red Lakes, the Red Lake River flows through part of the Big Bog, an area of peat lands and wooded islands. The Clearwater River and many of its tributaries originate in the moranic region south of the Red Lakes. Two major beach ridges, formed by wave action of the glacial lake, are present within the watershed. The Herman Beach reflects Lake Agassiz at its greatest extent in Minnesota 12,000 years ago. Campbell Beach, formed over 2,000 years of wave action, is the most massive and visible of the beach ridges within Minnesota. As rivers within the watershed flow across the beach ridges, they scour through the accumulated debris creating high gradient reaches within the relatively flat lake plain. Figures 2a and 2b illustrate the sinuosity and gradient of the Red Lake and Clearwater Rivers as they flow through the watershed. The rivers are relatively high gradient in the moranic regions (Clearwater River headwaters) and beach ridges, and low gradient as they flow through the lake plain.

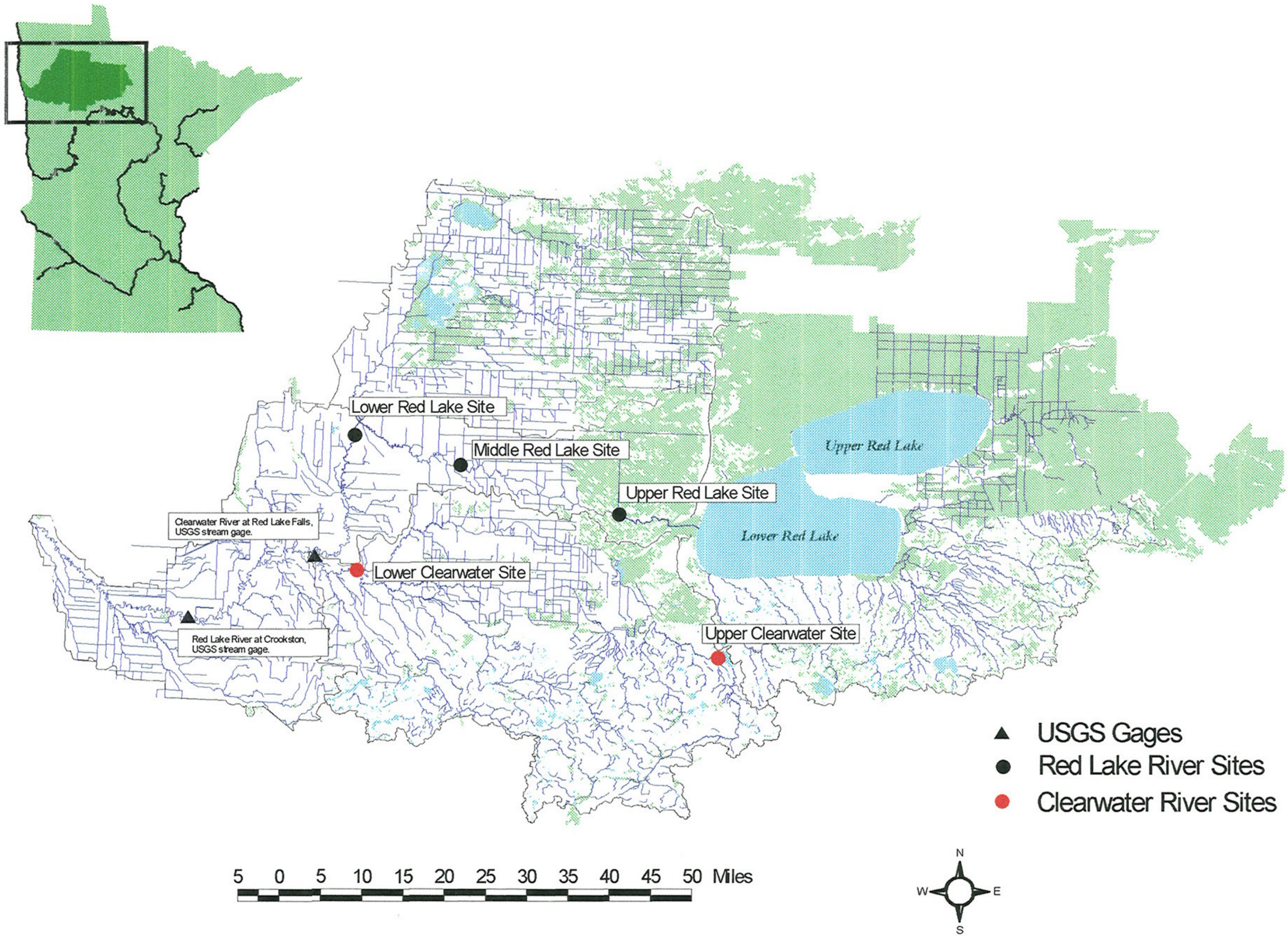

Figure 1. Map of the Red Lake Watershed showing study sites and USGS gages used in this study. Surface waters are blue and wetland are green.

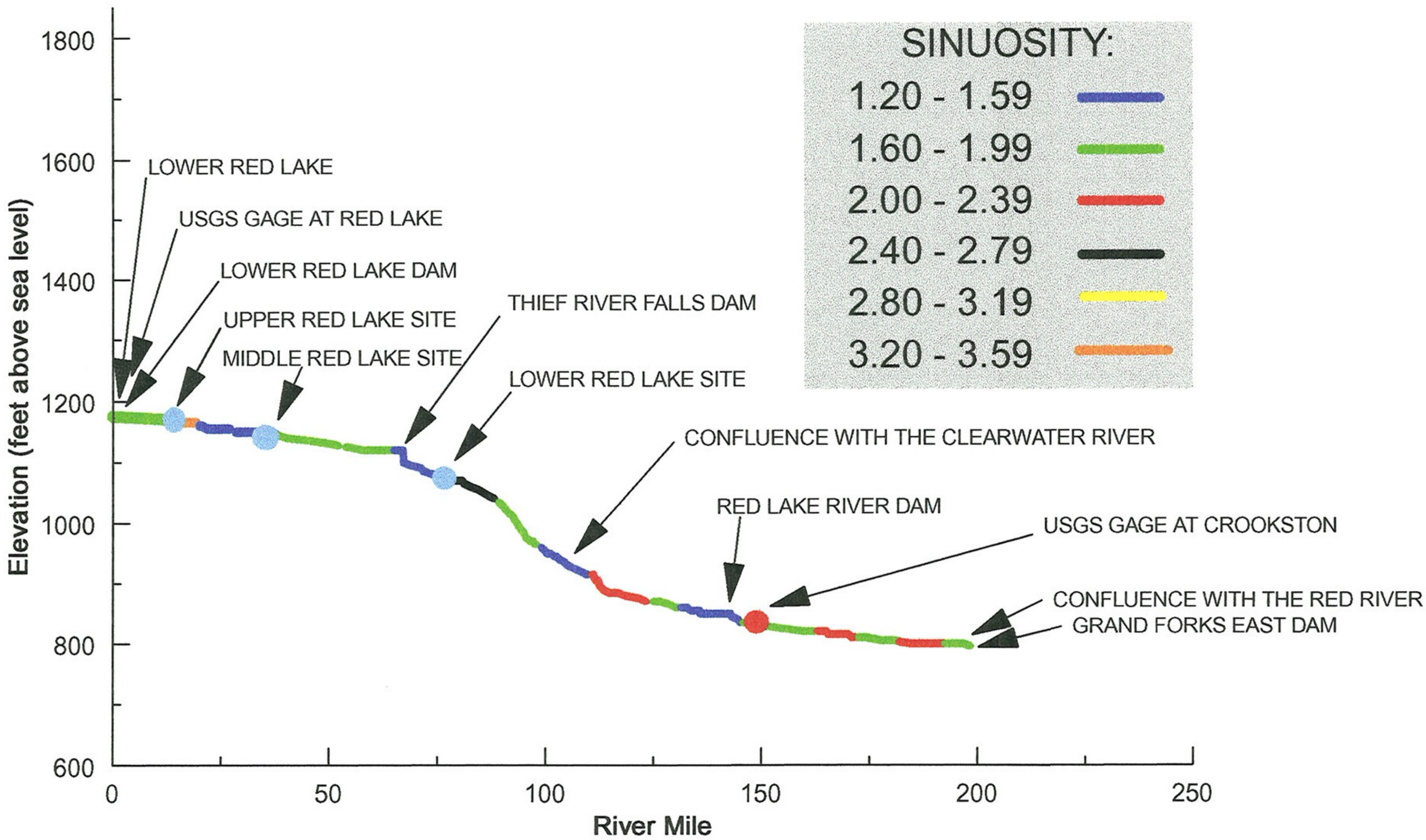

FIGURE 2a.--Elevation and sinuosity of the Red Lake River from its headwaters to its confluence with the Red River.

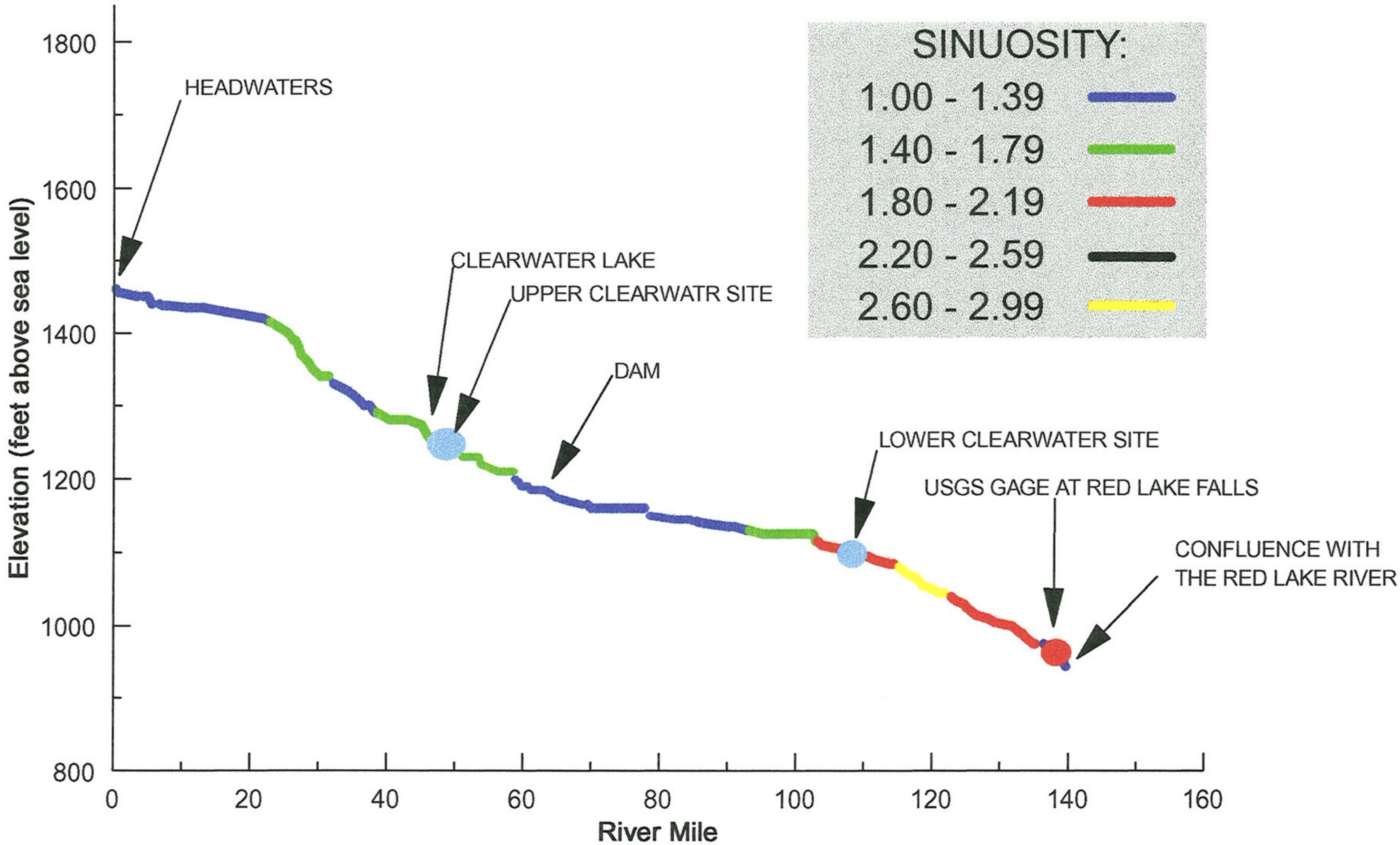

FIGURE 2b.--Elevation and sinuosity of the Clearwater River from its headwaters to its confluence with the Red Lake River.

2.2 Hydrology

The Red Lake River has a mean annual discharge of 1127 cfs at the USGS stream gage at Crookston, MN (gage number 05079000)(Figure 1). The mean of mean daily flows and the mean annual discharge over the period of hydrologic record for the gage are presented in Figure 3. The river drains 5270 square miles of its watershed at the Crookston gage, including the Clearwater and Thief Rivers, and many smaller tributaries (Mitton et al. 1996). The largest instantaneous peak flow was 28400 cfs on the 12th of April in 1969, and the lowest instantaneous flow was 0 cfs caused by operation of an upstream powerplant in July of 1960 (Appendix A). Runoff for the watershed at the gage is 0.21 cfs per square mile. Runoff throughout Minnesota ranges from .035 cfs per square mile for the Lac Qui Parle River to 1.07 cfs per square mile for the Knife River near Two Harbors, with a mean of .382.

The Clearwater River has a mean annual discharge of 318 cfs at the USGS stream gage at Red Lake Falls, MN gage (gage number 05078500)(Mitton et al. 1996)(Figure 1). The mean of mean daily flows and the mean annual discharge over the period of hydrologic record for the gage are presented in Figure 4. The drainage area at the gage is 1,370 square miles. The instantaneous peak discharge of record was 10300 cfs, on 25 April 1979 (Appendix A).

2.3 Resource Values

Recreation plays an important role in the economy of the watershed, and much of this recreation is associated with rivers and streams. Recreational activities include fishing, hunting, trapping, camping, canoeing, picnicking, bird watching, hiking, etc. In addition to fishing, canoeing and tubing are also popular on the Red Lake River. There are three canoeing and tubing outfitters in Red Lake Falls, as well as 7 boat landings and 7 carry-in canoe accesses along the length of the river. Located just downstream from Huot, MN, Old Crossing Treaty State Historical Wayside Park was once an important crossing of the Red River Oxcart Trail, where in 1868 the Ojibwa Indians ceded nearly 10 million acres of Red River Valley land for white settlement.

Many species of macroinvertebrates, reptiles, amphibians, birds, and mammals, and at least 48 species of fish (Goldstein 1995) and 12 species of mussels (MNDNR unpub. data)(Tables 1, and 2) depend on rivers in this watershed to meet daily requirements such as food, and reproduction. The Red Lake River and its tributaries also provide important spawning habitat for fishes inhabiting the

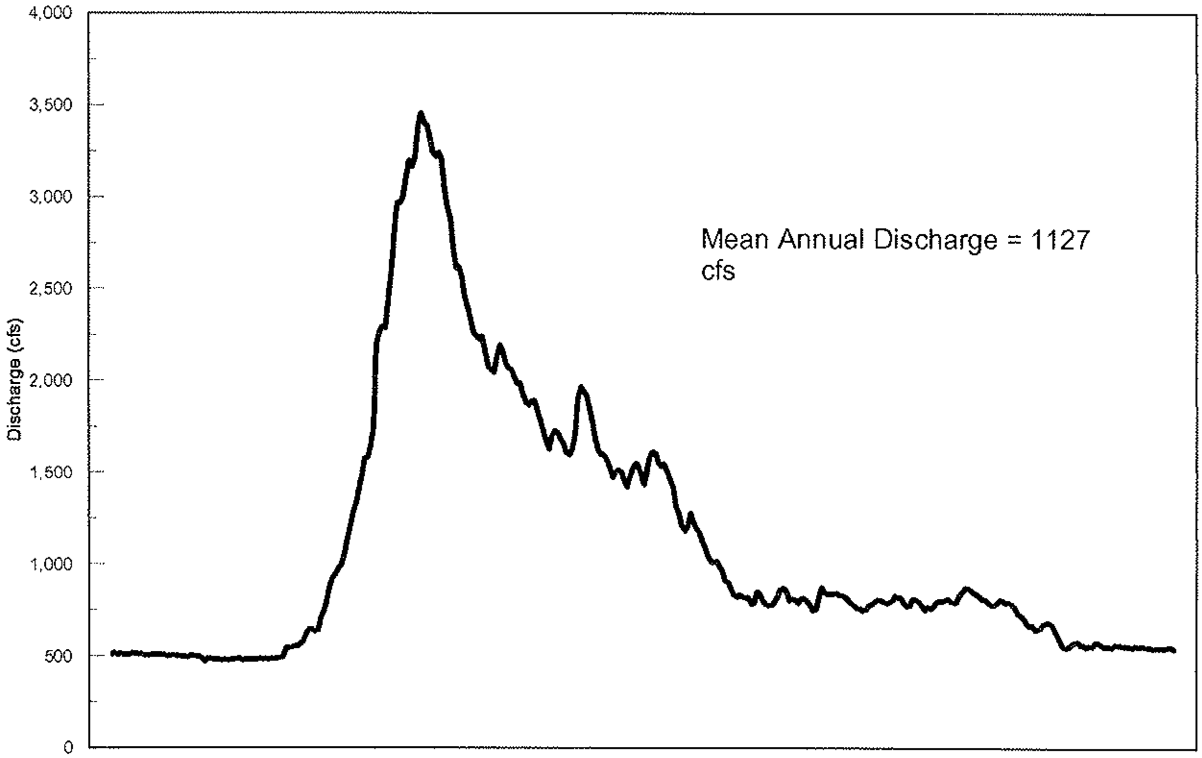

Figure 3. Hydrograph for the Red Lake River at Crookston, MN, based on mean daily discharge from 1901 to 1995.

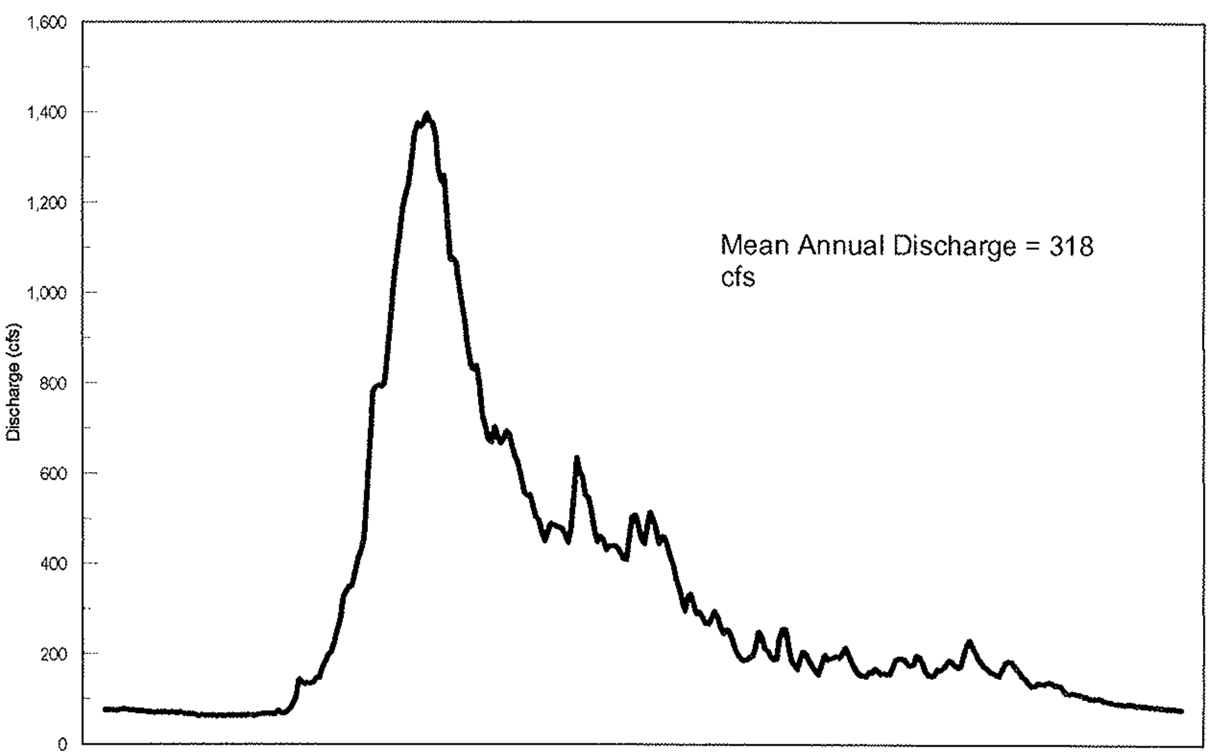

Figure 4. Hydrograph for the Clearwater River at Red Lake Falls, MN, based on mean daily discharge from 1909 to 1995.

Red River of the North, a river which lacks high gradient spawning habitat needed by walleye and many other species. Excellent spawning riffles occur in the reaches of the Red Lake River where it passes through the beach ridges of Glacial Lake Agassiz. After the spawning season has ended, the Red Lake River provides rearing habitat for the fry and fingerlings.

Table 1. Fish species present in the Red Lake River Watershed (Goldstein 1995) and their habitat guilds by life stage, where YOY=young-of-year, split into fry and fing(erling) for smallmouth bass; SP=shallow pool; MP=medium pool; DP=deep pool; SR=slow riffle; FR=fast riffle; and RW=raceway. Distribution of species within the watershed is noted behind each common name, where RLR = Red Lake River; CR = Clearwater River; and TR = Thief River.

Common Name and Distribution Within Watershed	Scientific Name	YOY Fry, Fing	**Habitat** Juvenile	**Guilds** Adult	Spawnin g
Chestnut lamprey[RLR]	*Icthyomyzon castaneus*			RW	
Mooneye[RLR]	*Hiodon tergisus*				
Central mudminnow[RLR, TR]	*Umbra limi*			SP	
Northern pike[RLR, CR, TR]	*Esox lucius*	SP		DP	
Silver chub[RLR]	*Macrhybopsis storeriana*				
Hornyhead chub[RLR, CR]	*Nocomis biguttatus*	SP	MP	RW	SP
Golden shiner[RLR]	*Notemigonus crysoleucas*	SP		MP	
Emerald shiner[RLR]	*Notropis atherinoides*	SP		SR	
Common shiner[RLR, CR, TR]	*Luxilus cornutus*	SP	DP	MP	RW
Bigmouth shiner[RLR, CR, TR]	*Notropis dorsalis*	SP		SR	
Blackchin shiner[RLR]	*Notropis heterodon*			SP	
Spottail shiner[RLR]	*Notropis hudsonius*	SP		MP	SP
Rosyface shiner[RLR, CR]	*Notropis rubellus*			RW	
Sand shiner[RLR, CR]	*Notropis stramineus*	SP		SP	SR
Weed shiner[RLR]	*Notropis texanus*				
Northern red belly dace[RLR, TR]	*Phoxinus eos*			SP	
Finescale dace[RLR, TR]	*Phoxinus neogaeus*				
Bluntnose minnow[RLR]	*Pimephales notatus*	SP		SP	SP
Fathead minnow[RLR, CR, TR]	*Pimephales promelas*	SP		SP	SP
Blacknose dace[RLR, CR]	*Rhinichthys atratulus*	SP		SR	FR
Longnose dace[RLR, CR]	*Rhinichthys cataractae*	SP		FR	SR
Pearl dace[RLR, TR]	*Margariscus margarita*				
Quillback carpsucker[RLR, TR]	*Carpiodes cyprinus*	SP	MP	MP	SP
Longnose sucker[CR]	*Catostomus catostomus*				
White sucker[RLR, CR, TR]	*Catostomus commersoni*	SR	SR	DP	RW
Silver redhorse[RLR, CR]	*Moxostoma anisurum*	SP	DP	RW	FR
Golden redhose[RLR, CR]	*Moxostoma erhyrurum*	SP	MP	DP	SR
Shorthead redhorse[RLR, CR]	*Moxostoma macrolepidotum*	SR	RW	RW	FR
Black bullhead[RLR]	*Ameiurus melas*	MP	MP	MP	
Brown bullhead[RLR]	*Ameiurus nebulosus*				
Channel catfish[RLR]	*Ictalurus punctatus*	SR	MP	MP	
Tadpole madtom[RLR, CR]	*Noturus gyrinus*	SP		SR	FR
Trout-perch[RLR]	*Percopsis omiscomaycus*			DP	
Burbot[RLR]	*Lota lota*		SP		
Brook stickleback[RLR, CR, TR]	*Culea inconstans*	SP		SP	
Rock bass[RLR, CR]	*Ambloplites rupestris*	MP	MP	SP	SP
Smallmouth bass[CR]	*Micropterus dolomieui*		RW	RW	MP
Largemouth bass[RLR]	*Micropterus salmoides*	DP	MP	SP	
Black crappie[RLR]	*Pomoxis nigromaculatus*	SP	MP	DP	
Iowa darter[TR]	*Etheostoma exile*	SP		DP	
Johnny darter[RLR, CR, TR]	*Etheostoma nigrum*	SP		SP	SR
Yellow perch[RLR]	*Perca flavescens*	SP	DP	DP	
Logperch[RLR]	*Percina caprodes*	SR		FR	RW
Blackside darter[RLR, CR, TR]	*Percina maculata*	SP		SP	RW
River darter[RLR]	*Percina shumardi*				
Sauger[RLR]	*Stizostedion canadense*			SR	
Walleye[RLR, CR]	*Stizostedion vitreum*	MP	MP	DP	RW
Freshwater drum[RLR]	*Aplodinotus grunniens*	MP	DP	RW	

Table 2. Unionid mussel species present in the Red Lake River Watershed and their habitat guilds (MNDNR unpub. data).

Common Name	Scientific Name	Habitat Guild
mapleleaf	*Quadrula quadrula*	MP
threeridge	*Amblema plicata*	RW
Wabash pigtoe	*Fusconaia flava*	RW
giant floater	*Anodonta grandis*	RW
cylindrical papershell	*Anodontoides ferussacianus*	MP
squawfoot	*Strophitus undulatus*	RW
white heelsplitter	*Lasmigona complanata*	MP
mucket	*Actinonaias carinata*	RW
fragile papershell	*Leptodea fragilis*	
black sandshell	*Ligumia recta*	RW
fat mucket	*Lampsilis siliquiodea*	RW
pocketbook	*Lampsilis ovata ventricosa*	RW

A Stream Management Plan for the Red Lake River states that angling, especially for catfish, has been popular for many years (MNDNR unpub. data 1993). Local reports indicate that smallmouth bass fishing has become very popular since initial stockings in 1985. There is increasing special interest (Smallmouth Bass Alliance) support and pressure for experimental angling regulations on smallmouth bass in many Minnesota waters, including the Red Lake River. Area Fisheries Supervisors have indicated management interest for numerous species in the watershed including: walleye, northern pike, smallmouth bass, channel catfish, and lake sturgeon. Lake sturgeon are currently considered to be at best very rare in the entire Red River of the North Basin, including rivers within the Red Lake River Watershed, but there are plans to reintroduce it in the Red Lake River below Thief River Falls in the near future.

3.0 METHODS

3.1 Site Selection

Five study sites were selected, 3 on the Red Lake River (referred to as the lower, middle, and upper sites), and 2 on the Clearwater River (referred to as the lower and upper sites). The lower Red Lake River site is in Pennington County, about 2.1 miles downstream from the confluence of the Red Lake and Thief Rivers. The site is bordered on the west by a park near the City of Thief River Falls, and on the east by privately owned land. The middle Red Lake River site is about 7 miles downstream from High Landing, MN, and .75 miles south of the junction of State Highway 6 and County Road 6 in Pennington County. The upper Red Lake River site is in Clearwater County, on Red Lake Tribal land approximately 11 miles downstream of Lower Red Lake, and just downstream from a small dam which controls the elevation of the river as it flows through a large marsh complex.

The lower Clearwater River site is 5 miles east of Red Lake Falls, .75 miles south of County, State Aid Highway 4, in Red Lake County. The upper Clearwater River site is .2 miles downstream of Clearwater Lake west of County, State Aid Highway 4 in Clearwater County. All study sites were selected based on several criteria, including a) gradient and ecological context, b) habitat diversity, c) resource values, d) channel stability, and e) presence of hydraulic controls

Both Clearwater sites and the lower Red Lake site represent relatively high gradient reaches (Figure 2a and 2b). High gradient stream reaches generally have diverse habitat conditions and are ecologically important. Selecting sites with diverse habitat allows for habitat analysis of the diverse aquatic community in the watershed. Higher gradient reaches are often composed of riffle habitat, a habitat type generally absent from low gradient reaches. Riffles are biologically important and productive habitats: they typically support the highest densities and diversity of fishes and invertebrates in warmwater streams (Hynes 1970; Lobb and Orth 1991; Aadland 1993). Riffles provide important spawning habitats for a large proportion of the fishes in the watershed, including many species of game fish, darters, and suckers. Because high gradient reaches are limited along the Red River of the North, large numbers of fish migrate up rivers in the Red Lake watershed from the Red River to spawn.

High gradient reaches are more sensitive to changes in flow than are low gradient reaches: as flow increases, riffle habitat shifts to raceway habitat, and as flow decreases, riffles become shallow pool habitat or dewatered. Habitat types found in low gradient reaches, such as pools, tend to change less dramatically in response to moderate changes in flow (pools remain pools as flow changes).

Consequently, flows which protect instream habitat of high gradient reaches should also protect habitat found in lower gradient reaches throughout the watershed. The opposite is not true, i.e., flows which protect instream habitat of low gradient reaches probably would not protect habitat of high gradient reaches.

High gradient, diverse stream reaches generally have higher resource values than less diverse reaches and are therefore critical to protect. Large, low gradient streams with quality fisheries such as the Red River of the North, often depend on higher gradient tributaries for reproduction of many of their fish species. Much of the high gradient habitat in the Red River Basin has been lost through impoundment by construction of over 500 dams. Gradient, habitat diversity, quality of the fishery, and recreational use are all related. High gradient reaches are therefore preferable when selecting study sites because they 1) have diverse habitat, 2) are flow sensitive, 3) have high resource values, and 4) serve important ecological roles in maintaining healthy river communities, and 5) are rare due to dam construction.

Sites were also selected based on the presence of stable channels and hydraulic controls. Selecting sites with stable channels is important because channel stability is an assumption of the hydraulic models. Sites with hydraulic controls are needed to help calibrate the hydraulic models.

3.2 Transect Selection

Transects locations were selected to describe the hydraulic and microhabitat conditions of each site, and were positioned perpendicular to streamflow. Eleven transects were established at the lower Red Lake site, three at the middle site, and four at the upper site. Fifteen transects were established at the lower Clearwater River site, and 17 at the upper site. Transect descriptions are summarized in Appendices B1 - B3, C1 and C2.

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 (high, medium, and low) 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 using 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.

Data sets for the lower Red Lake site were collected in August 1992, April 1994, and October 1991; at 475, 337, 61 cfs respectively. Data sets for the middle Red Lake site were collected in August 1992, June 1992, and October 1991; at 282, 86, and 61 cfs. Data sets for the upper Red Lake site were collected by the Corps of Engineers in August 1994, July 1994, and June 1994; at 656, 425, and 184 cfs.

Data sets for the lower Clearwater River site were collected in August 1991, and June 1991; at 140, and 50 cfs respectively. Data sets for the Upper Clearwater site were collected in July 1992, July 1993, and September 1991; at 100, 60, and 40 cfs.

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 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.

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 or at regular intervals across the transect. Channel cross sections for the each site are presented in Appendices D1- D5. Thalweg and measured water surface elevations are presented in Appendix E1 - E5.

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 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. 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. Water depth was measured to the nearest 0.1 ft with a top setting wading rod. Measured velocities are graphed in Appendix D.

Substrate and cover were described according to criteria (Aadland 1993) in Table 3. The area of each cell 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 indicate the extent of the river, between transects, described by each transect.

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 (Appendix F1 - F5). Photographs were taken of each transect at each flow.

3.4 Computer Modeling

The PHABSIM was used for hydraulic and habitat modeling. Field data were collected such that any model or combination of models could be used as needed. Models were developed separately for each site. Thirty flows were simulated at all sites, except the middle Red Lake site, for which 16 flows were simulated. Simulated flows ranged from 32 to 1100 cfs for the lower Red Lake site, 30 to 700 for the middle Red Lake site, 74 to 1640 for the upper Red Lake site, 20 to 350 cfs for the lower Clearwater site, and 10 to 250 at the upper Clearwater site. 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.

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 23 sampling sites since 1987, representing over 80,000 observations (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).

Twenty six representative target species-life stages, known to occur in the Red Lake River watershed, were selected from six habitat-preference guilds for habitat modeling in three seasons (Tables 4 - 8). 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 at each site. 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. The three seasons were early spring (April 17 to May 29), late spring (May 29 - June 30), and summer/fall/winter (July 1 - April 15). Protected flow recommendations were developed for each of these seasons. The habitat suitability criteria for the guild representatives modeled for the Red Lake River watershed are provided in Appendix G.

Table 4. Species-life stages modeled for the lower Red Lake River site.

	April 17 to May 29	3 May 30 to June 0	July 1 to April 16
Deep Pool		Walleye - Adult Northern Pike - Adult	Walleye - Adult Northern Pike - Adult
Medium Pool	Fluted Shell Mussel	Fluted Shell Mussel Walleye - Juvenile Channel Catfish - Juvenile Channel Catfish - Adult Smallmouth Bass - Spawning	Fluted Shell Mussel Walleye - Juvenile Channel Catfish - Juvenile Channel Catfish - Adult
Shallow Pool		Gen. Larval Fish Smallmouth Bass - Fry Horny Head Chub - Spawning Sand Shiner - Adult	Gen. Larval Fish Sand Shiner - Adult Smallmouth Bass - Fingerling
Raceway	Fat Mucket Mussel Wabash Pigtoe Mussel Lake Sturgeon - Spawning Walleye - Spawning	Fat Mucket Mussel Wabash Pigtoe Mussel Golden Redhorse Adult Smallmouth Bass - Juvenlie Horny Head Chub - Adult	Fat Mucket Mussel Wabash Pigtoe Mussel Smallmouth Bass - Adult Smallmouth Bass - Juvenlie Horny Head Chub - Adult Golden Redhorse Adult
Fast Riffle		Logperch - Adult Longnose Dace - Adult	Logperch - Adult Longnose Dace - Adult
Slow Riffle		Channel Catfish - Young	Channel Catfish - Young

Table 5. Species-life stages modeled for the middle Red Lake River site.

	April 17 to May 29	May 30 to June 30	July 1 to April 16
Deep Pool	Northern Pike - Adult	Northern Pike - Adult	Northern Pike - Adult
Medium Pool	Fluted Shell Mussel	Fluted Shell Mussel	Fluted Shell Mussel
Shallow Pool		Gen. Larval Fish	Gen. Larval Fish
Raceway	Fat Mucket Mussel Wabash Pigtoe Mussel Horny Head Chub - Adult Golden Redhorse Adult Walleye - Spawning	Fat Mucket Mussel Wabash Pigtoe Mussel	Fat Mucket Mussel Wabash Pigtoe Mussel
Fast Riffle		Logperch - Adult	Logperch - Adult
Slow Riffle			

Table 6. Species-life stages modeled for the upper Red Lake River site.

	April 17 to May 29	May 30 to June 30	July 1 to April 16
Deep Pool		Walleye - Adult Northern Pike - Adult	Walleye - Adult Northern Pike - Adult
Medium Pool	Fluted Shell Mussel	Fluted Shell Mussel Smallmouth Bass - Spawning	Fluted Shell Mussel
Shallow Pool		Smallmouth Bass - Fry Sand Shiner - Adult Horny Head Chub - Spawning	Sand Shiner - Adult
Raceway	Fat Mucket Mussel Wabash Pigtoe Mussel	Fat Mucket Mussel Wabash Pigtoe Mussel Golden Redhorse Adult	Fat Mucket Mussel Wabash Pigtoe Mussel Golden Redhorse Adult
Fast Riffle	Walleye - Spawning	Logperch - Adult	Logperch - Adult
Slow Riffle		Horny Head Chub - Adult	Horny Head Chub - Adult
Special	Northern Pike - Spawning (from NERC)		

Table 7. Species-life stages modeled for the lower Clearwater River site.

	April 17 to May 29	May 30 to June 30	July 1 to April 16
Deep Pool		Walleye - Adult Northern Pike - Adult	Walleye - Adult Northern Pike - Adult
Medium Pool	Fluted Shell Mussel	Fluted Shell Mussel Walleye - Juvenile Channel Catfish - Adult Channel Catfish - Juvenile Smallmouth Bass - Spawning	Fluted Shell Mussel Walleye - Juvenile Channel Catfish - Adult Channel Catfish - Juvenile
Shallow Pool		Gen. Larval Fish Smallmouth Bass - Fry Horny Head Chub - Spawning Sand Shiner - Adult	Gen. Larval Fish Sand Shiner - Adult Smallmouth Bass - Fingerling
Raceway	Fat Mucket Mussel Wabash Pigtoe Mussel Walleye - Spawning	Fat Mucket Mussel Wabash Pigtoe Mussel Golden Redhorse Adult Smallmouth Bass - Juvenlie Horny Head Chub - Adult	Fat Mucket Mussel Wabash Pigtoe Mussel Smallmouth Bass - Adult Smallmouth Bass - Juvenlie Horny Head Chub - Adult Golden Redhorse Adult
Fast Riffle		Logperch - Adult Longnose Dace - Adult	Logperch - Adult Longnose Dace - Adult
Slow Riffle		Channel Catfish - Young	Channel Catfish - Young

Table 8. Species-life stages modeled for the upper Clearwater River site.

	April 17 to May 29	May 30 to June 30	July 1 to April 16
Deep Pool		Walleye - Adult Northern Pike - Adult	Walleye - Adult Northern Pike - Adult
Medium Pool	Fluted Shell Mussel	Fluted Shell Mussel Walleye - Juvenile Smallmouth Bass - Spawning	Fluted Shell Mussel Walleye - Juvenile
Shallow Pool		Gen. Larval Fish Smallmouth Bass - Fry Horny Head Chub - Spawning Sand Shiner - Adult	Gen. Larval Fish Sand Shiner - Adult Smallmouth Bass - Fingerling
Raceway	Fat Mucket Mussel Wabash Pigtoe Mussel Walleye - Spawning	Fat Mucket Mussel Wabash Pigtoe Mussel Smallmouth Bass - Juvenlie Horny Head Chub - Adult	Fat Mucket Mussel Wabash Pigtoe Mussel Smallmouth Bass - Adult Smallmouth Bass - Juvenlie Horny Head Chub - Adult
Fast Riffle		Logperch - Adult Longnose Dace - Adult	Logperch - Adult Longnose Dace - Adult
Slow Riffle	Blacknose Dace -Adult	Blacknose Dace -Adult	Blacknose Dace -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 selected guild representatives at each simulated flow. WUA was calculated as:

$$WUA = \sum_{i=1} S_i A_i$$

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 either bimodal, zero, or unchanging across the range of simulated flows. To illustrate this point using figure 5, 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 CBFs 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

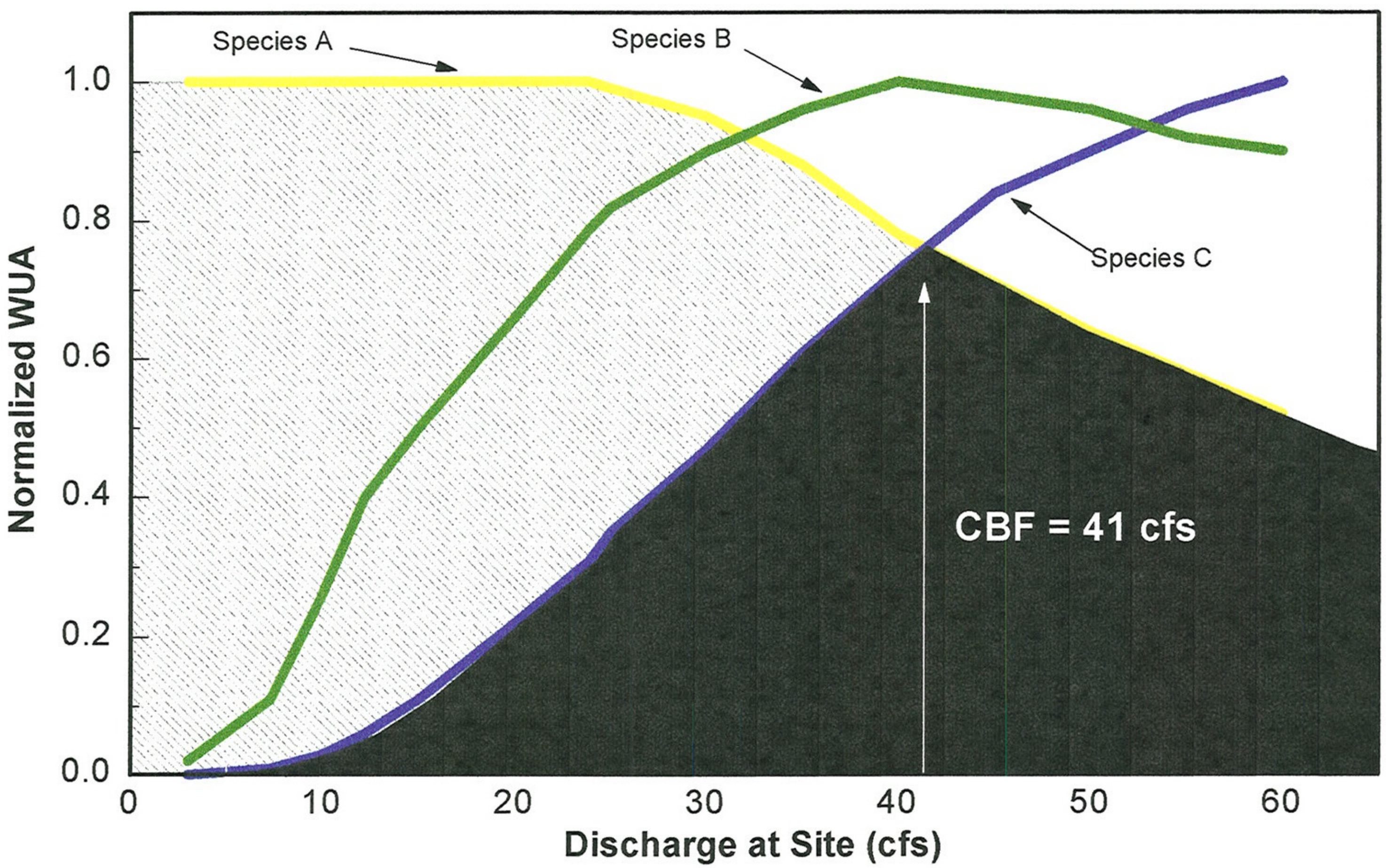

FIGURE 5. Graphical procedure for identifying the community-based flow (CBF): generally the highest point of the black area to the right of and below all WUA lines.

Figure Legend

Table of codes for all species life stages modeled and their legends for the graphs in this section.

BNDA	BLACKNOSE DACE - ADULT		LKSS	LAKE STURGEON SPAWNERS	
CCFA	CHANNEL CATFISH - ADULT		LNDA	LONGNOSE DACE ADULT	
CCFJ	CHANNEL CATFISH - JUVENILE		NOPA	NORTHERN PIKE - ADULT	
CCFY	CHANNEL CATFISH - YOY		PTO	WABASH PIGTOE MUSSEL	
FROG	LEOPARD FROG		SDSA	SAND SHINER - ADULT	
FTM	FAT MUCKET MUSSEL		SMBA	SMALLMOUTH BASS - ADULT	
FTS	FLUTED SHELL - MUSSEL		SMBFi	SMALLMOUTH BASS - FINGERLING	
GLRA	GOLDEN REDHORSE ADULT		SMBFr	SMALLMOUTH BASS - FRY	
HHCA	HORNYHEAD CHUB ADULT		SMBJ	SMALLMOUTH BASS - JUVENILE	
HHCS	HORNYHEAD CHUB - SPAWNING		SMBS	SMALLMOUTH BASS - SPAWNING	
LARVA	ALL LARVAL FISH COMBINED		WAEA	WALLEYE - ADULT	
LGPA	LOGPERCH ADULT		WAEJ	WALLEYE - JUVENILE	
			WAES	WALLEYE - SPAWNING	

southwestern Minnesota streams yielded similar results.

The drainage area at USGS gages was 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.

CBFs from the Red Lake River sites are applied at the USGS stream gage at Crookston, MN (USGS gage number 05059000) (Figure 1), and the CBF from the Clearwater River sites were applied to the USGS stream gage at Red Lake Falls, MN (USGS gage number 05078500).

The drainage areas (in square miles) for each site are: 3513, 2333, and 2029 for the lower, middle, and upper Red Lake sites; and 1198 and 167 for the lower and upper Clearwater sites. Drainage areas for the Crookston and Red Lake Falls gages are 5280 and 1370 square miles. CBFs from the lower Red Lake site were adjusted by a factor of 1.503 (5280/3513) to determine the corresponding CBF at the Crookston gage. Recommendations from the lower Clearwater site were adjusted by a factor of 1.144 (1370/1198), to determine the corresponding CBF at the Red Lake Falls 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 will 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 6 - 20). 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., sand shiner adult, shallow pool guild) 2) WUA increased as flow increased, peaking at a high flow (e.g., walleye spawning, raceway guild), and 3) WUA peaked at an intermediate flow and decreased as flow either increase or decreased (e.g., blacknose dace adult, slow riffle guild). Non-normalized WUA versus discharge relations are provided in appendix H.

The diversity of available habitat types was also related to discharge (Figures 21 - 25). Both Clearwater, and the lower Red Lake River sites had diverse habitat at moderate flows. For those three sites, the amount of riffle and raceway habitat increases with flow, and the amount of shallow pool habitat decreases with flow. However, for the upper Red Lake site, the relationship for riffles and pool is reversed from what would be expected; the amount of riffle habitat decreases with flow, while the amount of pool habitat increases.

4.2 Community-Based Flow

The CBFs for the early spring (April 17 to May 29), late spring (May 30 to June 30), and summer/fall/winter seasons were : 1) 450, 220, and 275 cfs for the lower Red Lake site, where the drivers were walleye spawners and fluted shell mussels, pigtoe mussels and smallmouth bass spawners, and pigtoe mussels and channel catfish, 2) 200, 200, and 200 cfs for the middle Red Lake site where the drivers were fluted shell mussels and walleye spawners, fluted shell mussels and larval fish, and fluted shell mussels and larval fish, 3) 250, 320, and 425 cfs for the upper Red Lake site, where the drivers were fluted shell mussels and walleye spawners, northern pike adults and hornyhead chub spawners, and northern pike adults and fluted shell mussels, 4) 250, 145, and 145 cfs for the lower Clearwater site, where the drivers were fluted shell mussels and walleye spawners, channel catfish adults and longnose dace adults, and channel catfish adults and longnose dace adults, 5) 140, 90, and 90 cfs for the upper Clearwater River site, where the drivers were pigtoe mussels and blacknose dace, pigtoe mussels and sand shinner adults, and pigtoe mussels and sand shinner adults.

4.3 Relating the CBFs to Stream Gages

Of the 5 sites, the lower Clearwater and the lower Red Lake sites were used to determine the final CBF for each river, which were then adjusted by drainage area to USGS stream gages for

Figure Legend

Table of codes for all species life stages modeled and their legends for the graphs in this section.

BNDA	BLACKNOSE DACE - ADULT		LKSS	LAKE STURGEON SPAWNERS	
CCFA	CHANNEL CATFISH - ADULT		LNDA	LONGNOSE DACE ADULT	
CCFJ	CHANNEL CATFISH - JUVENILE		NOPA	NORTHERN PIKE - ADULT	
CCFY	CHANNEL CATFISH - YOY		PTO	WABASH PIGTOE MUSSEL	
FROG	LEOPARD FROG		SDSA	SAND SHINER - ADULT	
FTM	FAT MUCKET MUSSEL		SMBA	SMALLMOUTH BASS - ADULT	
FTS	FLUTED SHELL - MUSSEL		SMBFi	SMALLMOUTH BASS - FINGERLING	
GLRA	GOLDEN REDHORSE ADULT		SMBFr	SMALLMOUTH BASS - FRY	
HHCA	HORNYHEAD CHUB ADULT		SMBJ	SMALLMOUTH BASS - JUVENILE	
HHCS	HORNYHEAD CHUB - SPAWNING		SMBS	SMALLMOUTH BASS - SPAWNING	
LARVA	ALL LARVAL FISH COMBINED		WAEA	WALLEYE - ADULT	
LGPA	LOGPERCH ADULT		WAEJ	WALLEYE - JUVENILE	
			WAES	WALLEYE - SPAWNING	

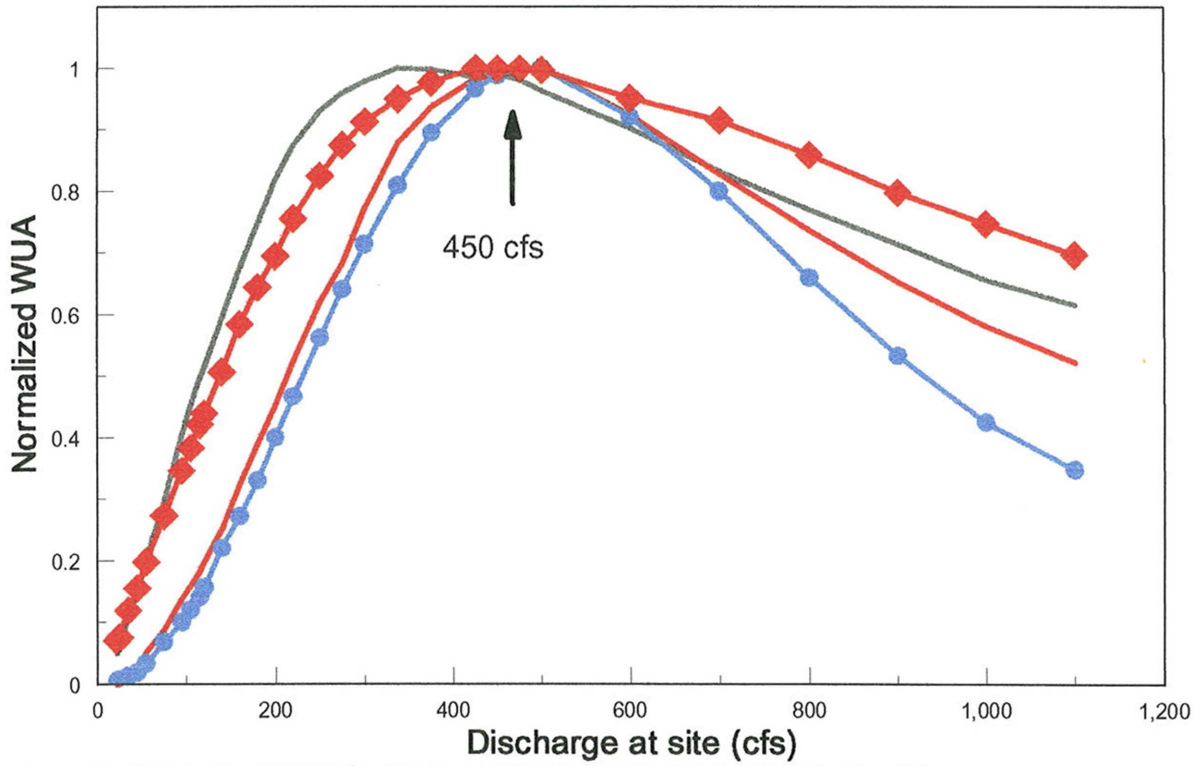

Figure 6. Normalized WUA for the lower Red Lake site for April 17 to May 29, where drivers are walleye spawners and fluted shell mussels.

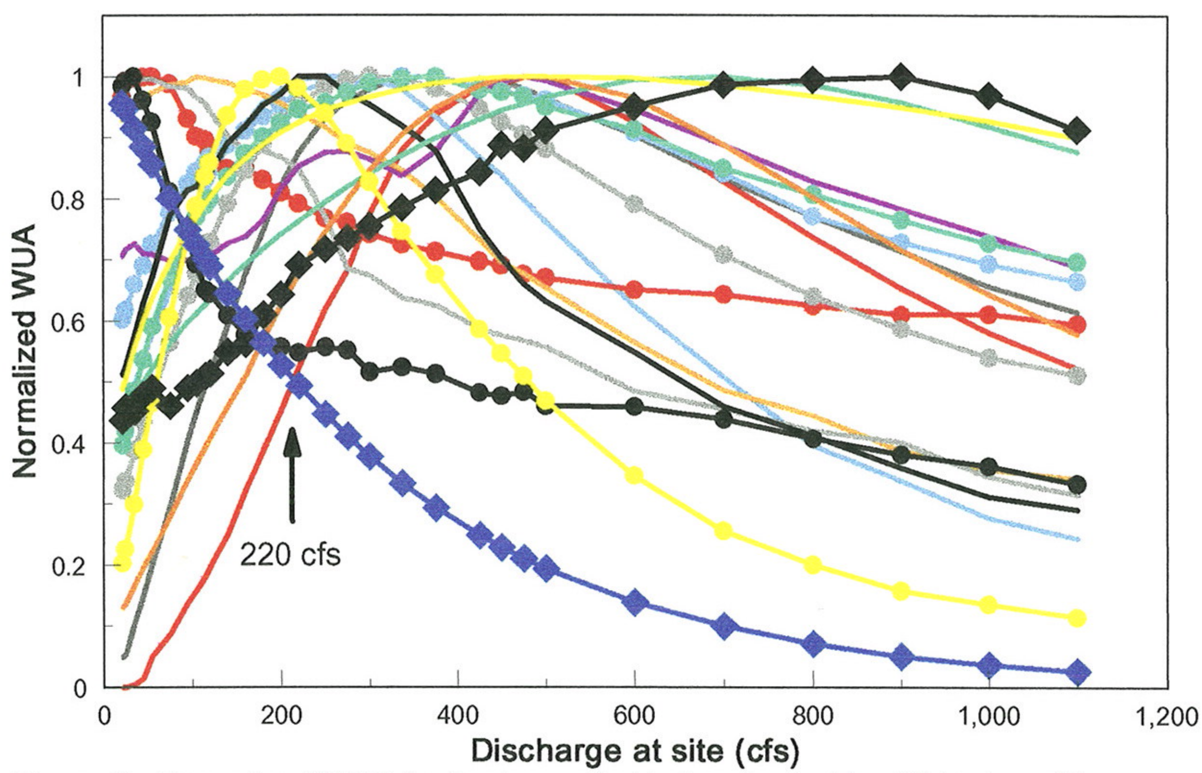

Figure 7. Normalized WUA for the lower Red Lake site for May 30 to June 30, where drivers are pigtoe mussels and smallmouth bass spawners.

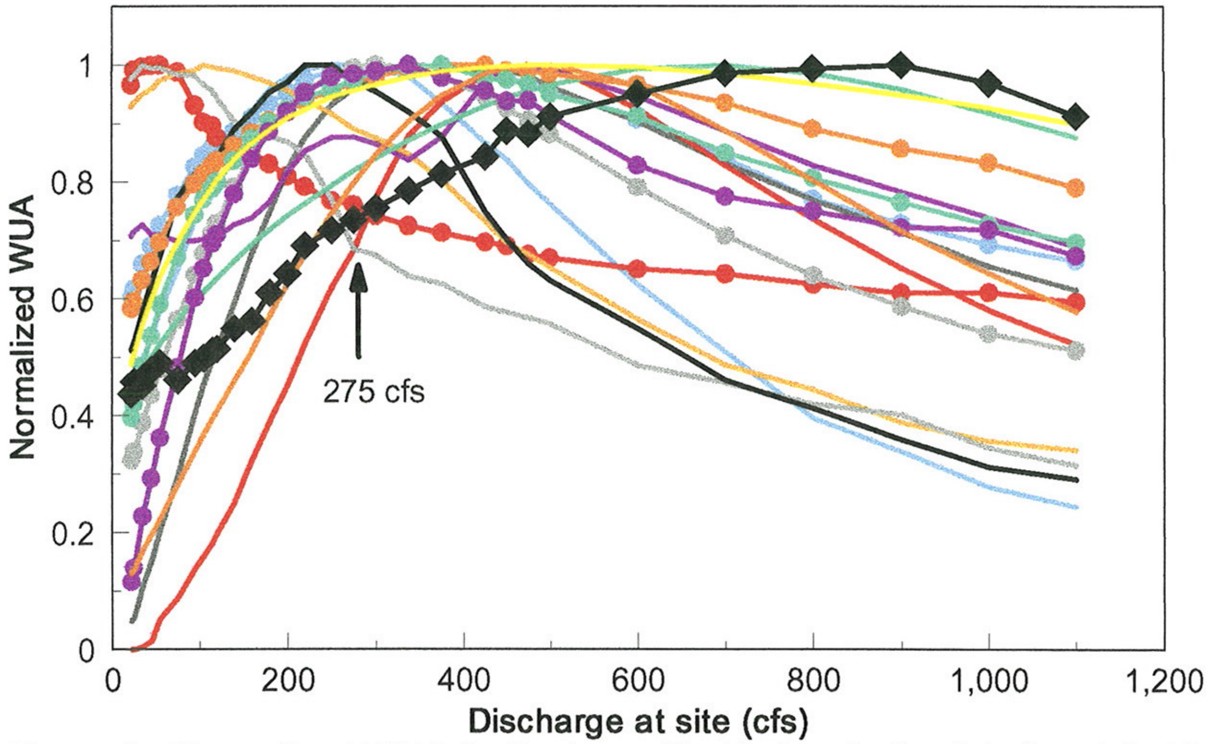

Figure 8. Normalized WUA for the lower Red Lake site for July 1 to July 16, where drivers are pigtoe mussels and channel catfish adults.

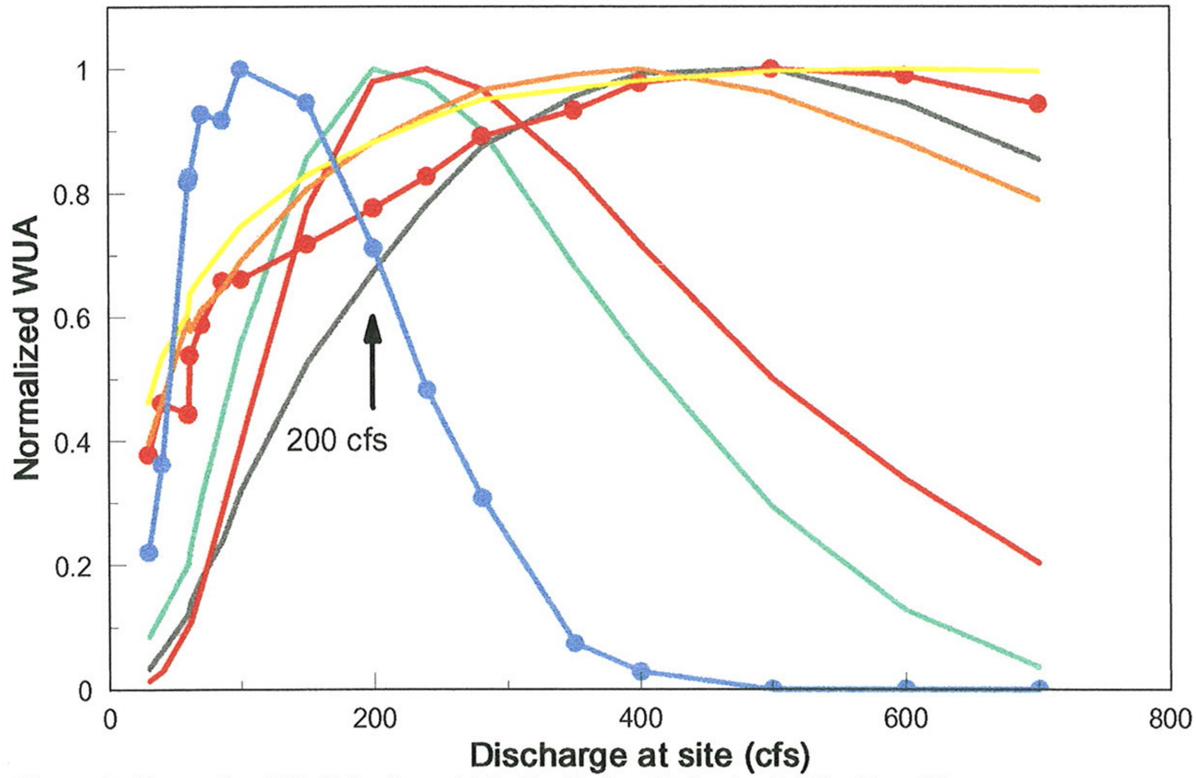

Figure 9. Normalized WUA for the middle Red Lake site for April 17 to May 29,, where drivers are fluted shell mussels and walleye spawners.

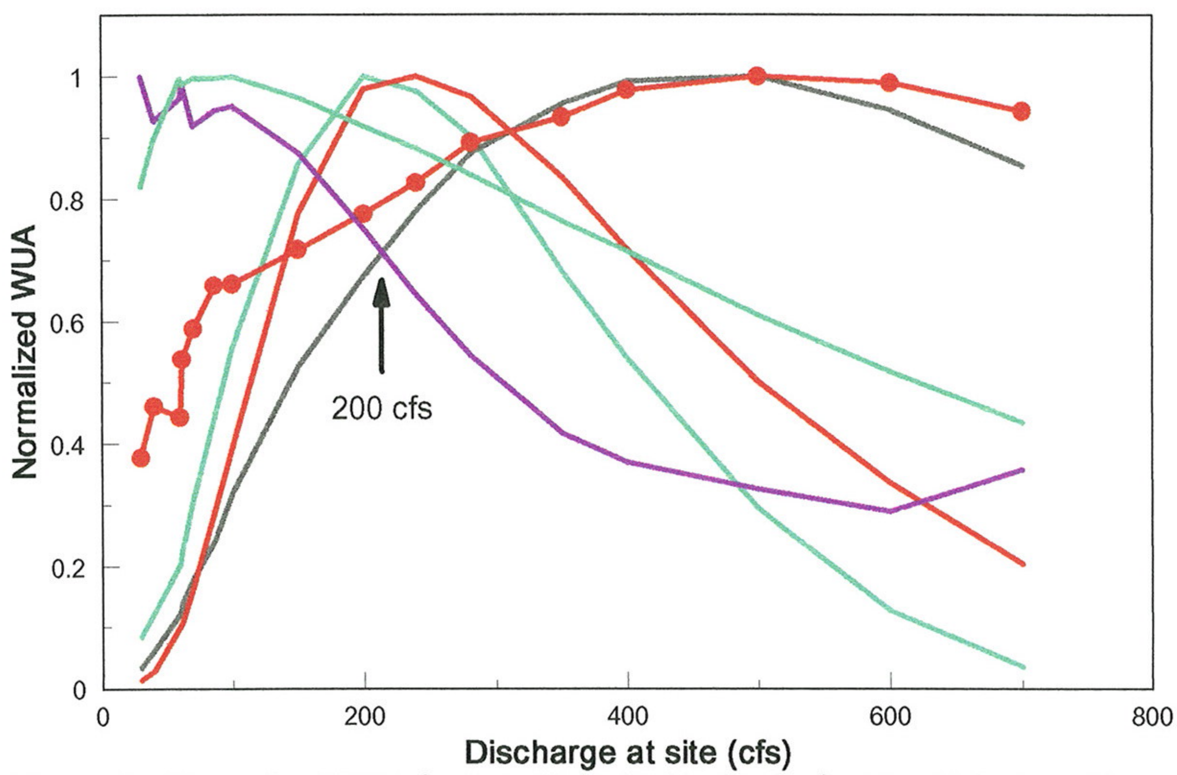

Figure 10. Normalized WUA for the middle Red Lake site for May 30 to June 30, where drivers are fluted shell mussels and larval fish.

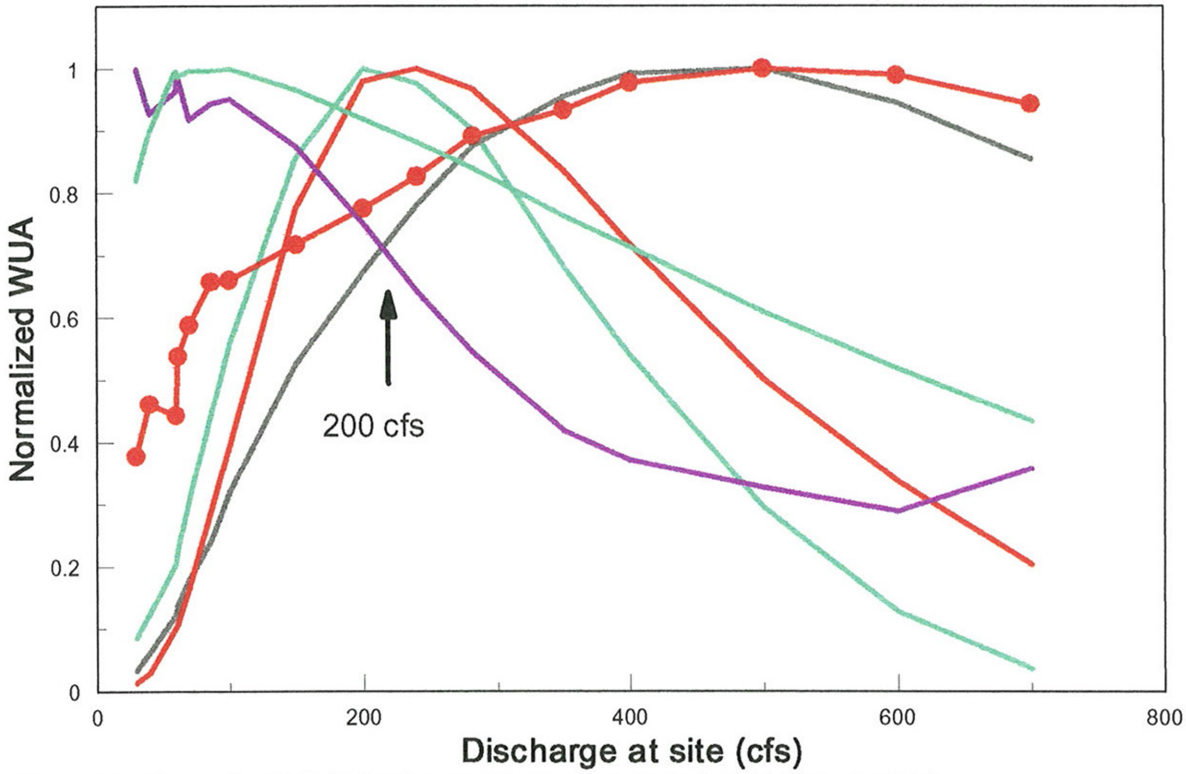

Figure 11. Normalized WUA for the middle Red Lake site for July 1 to April 16, where drivers are fluted shell mussels and larval fish.

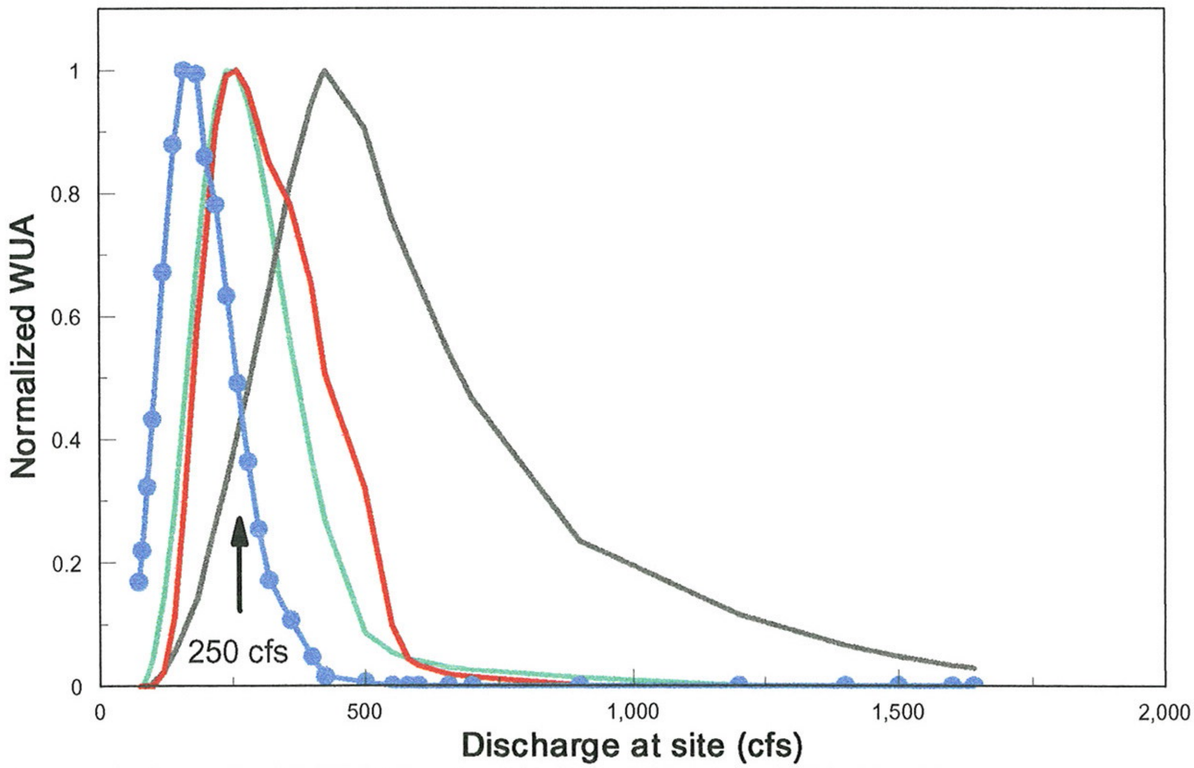

Figure 12. Normalized WUA for the upper Red Lake site for April 17 to May 29,, where drivers are fluted shell mussels and walleye spawners.

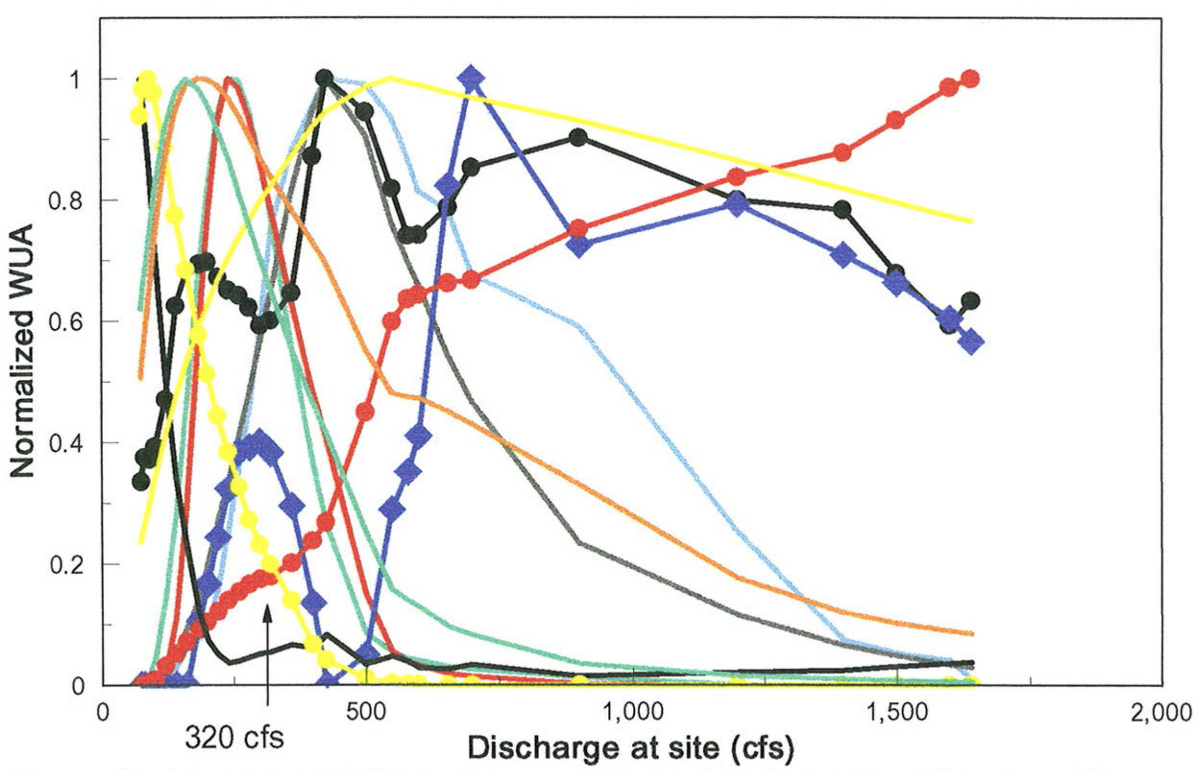

Figure 13. Normalized WUA for the upper Red Lake site for May 30 to June 30, where drivers are northern pike adults and hornyhead chub spawners.

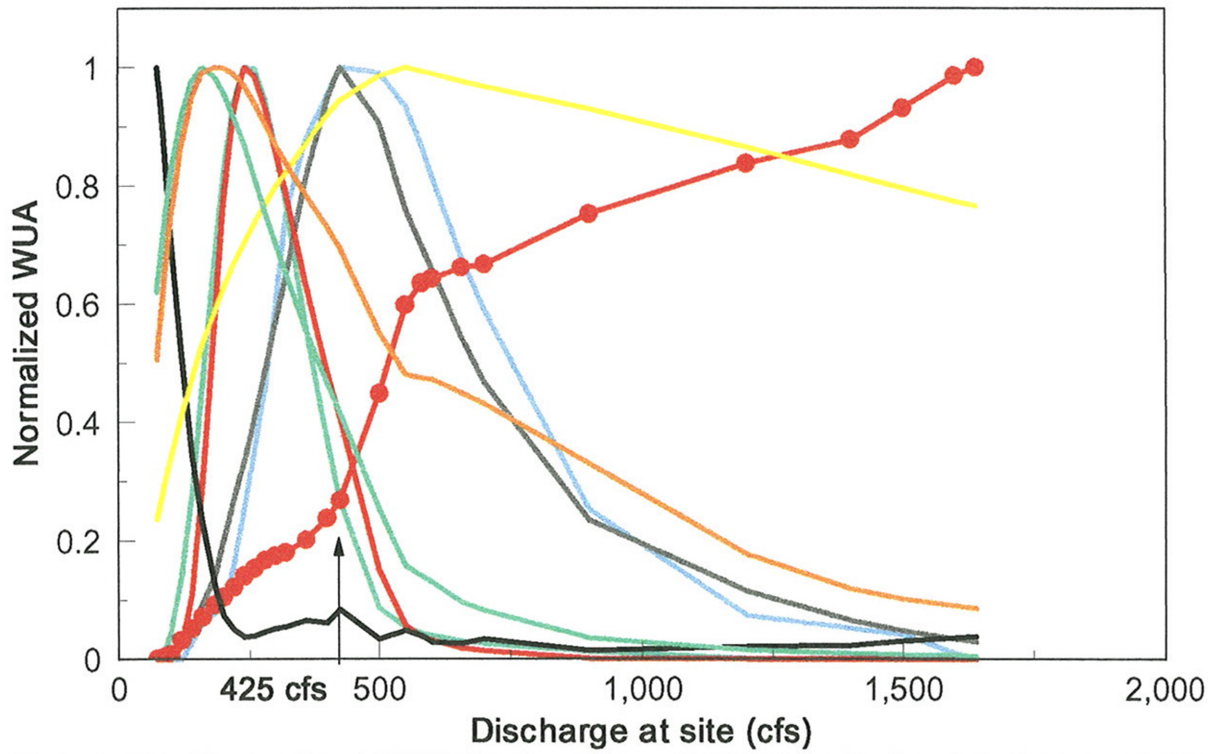

Figure 14. Normalized WUA for the upper Red Lake site for July 1 to April 16, 31, where drivers are northern pike adults and fluted shell mussels.

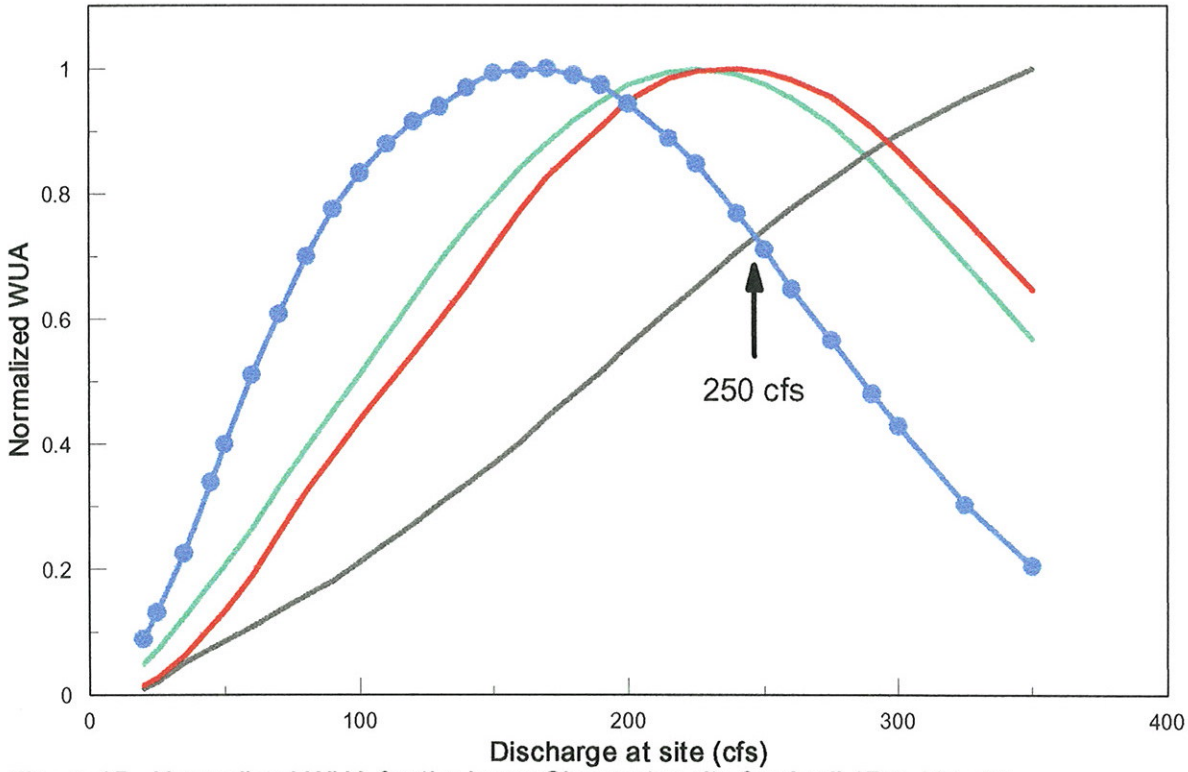

Figure 15. Normalized WUA for the lower Clearwater site for April 17 to May 29 where drivers are fluted shell mussels and walleye spawners.

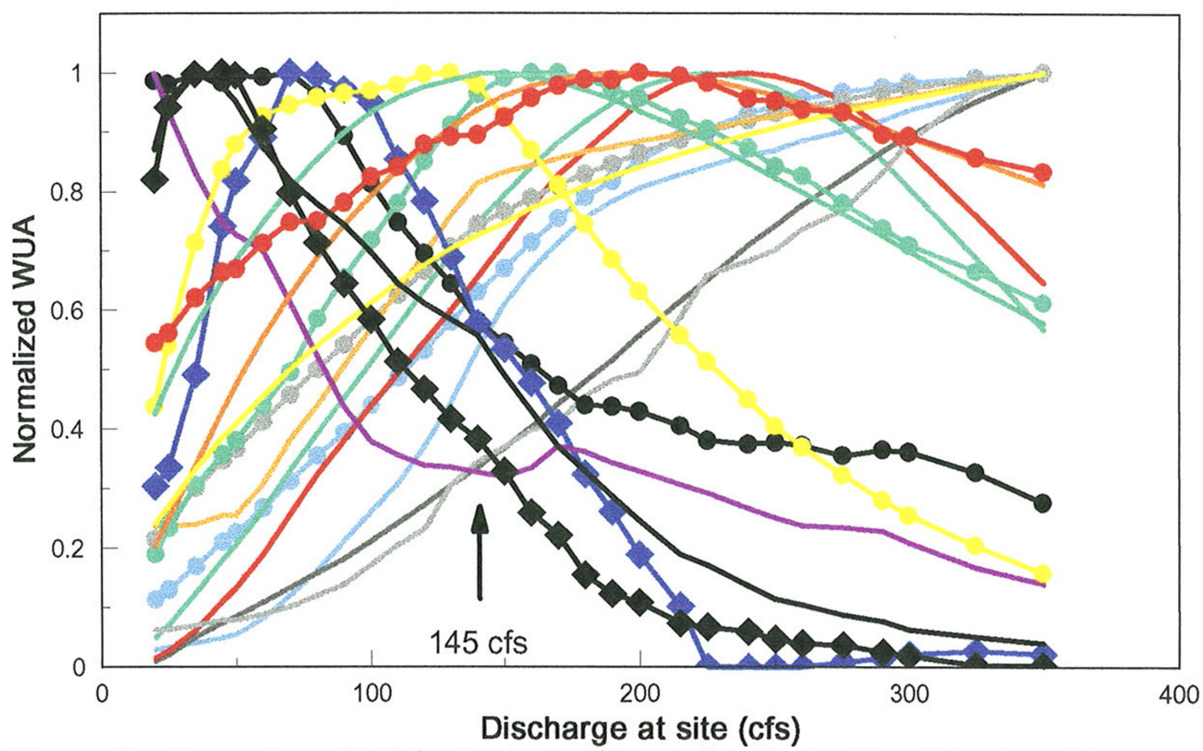

Figure 16. Normalized WUA for the lower Clearwater site for May 30 to June 30, where drivers are channel catfish adults and longnose dace adults.

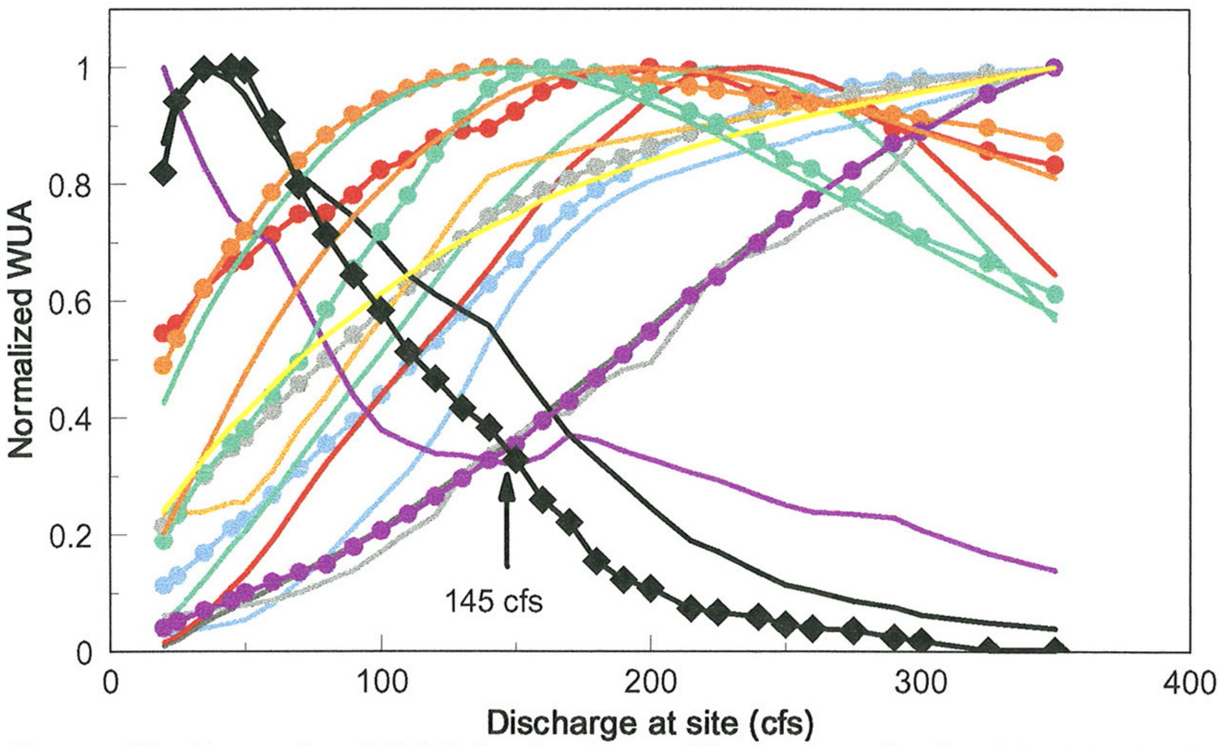

Figure 17. Normalized WUA for the lower Clearwater site for July 1 to April 16 where drivers are channel catfish adults and longnose dace adults.

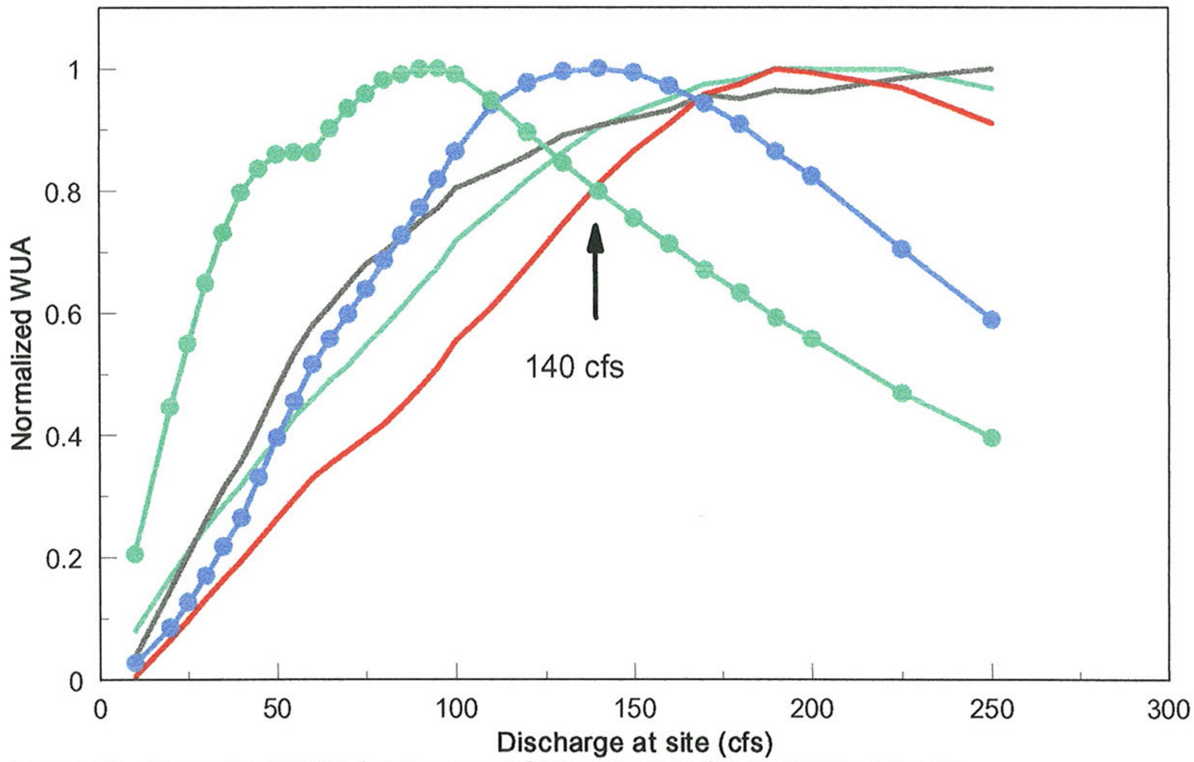

Figure 18. Normalized WUA for the upper Clearwater site for April 17 to May 29 where drivers are pigtoe mussels and blacknose dace.

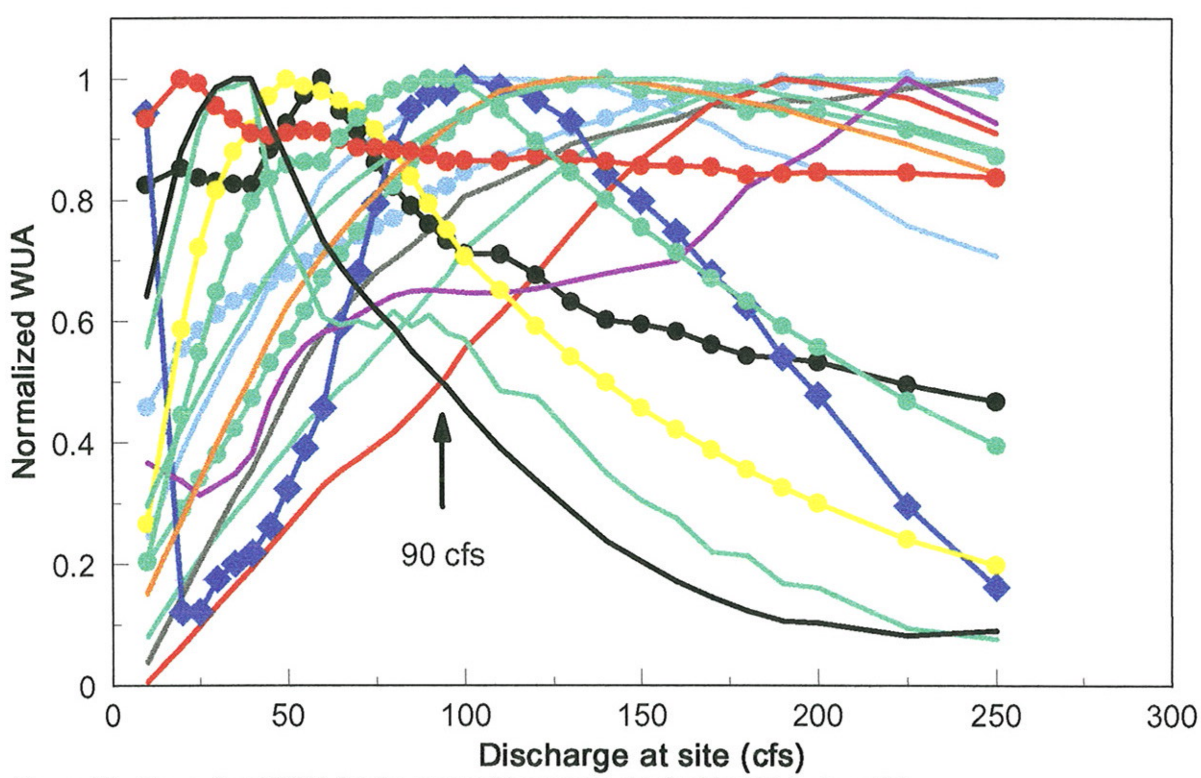

Figure 19. Normalized WUA for the upper Clearwater site for May 30 to June 30, where drivers are pigtoe mussels and sand shinner adults.

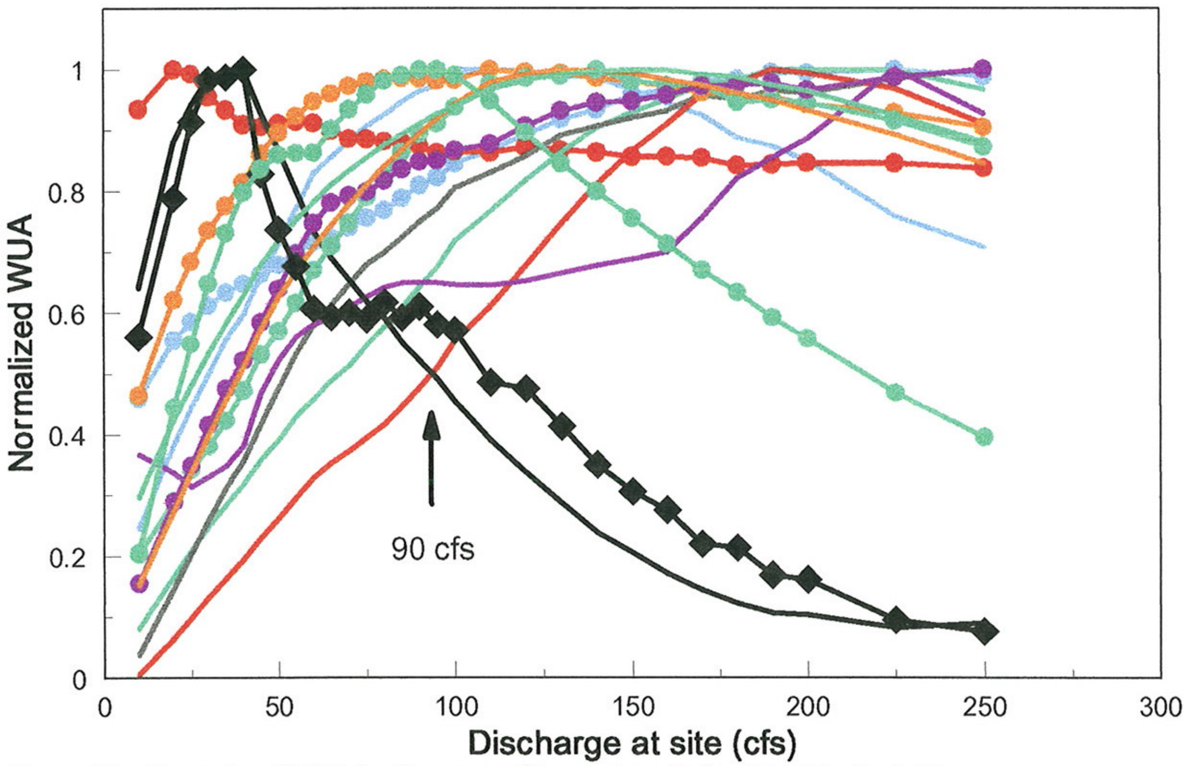

Figure 20. Normalized WUA for the upper Clearwater site for July 1 to April 16 where the drivers are pigtoe mussels and sand shinner adults.

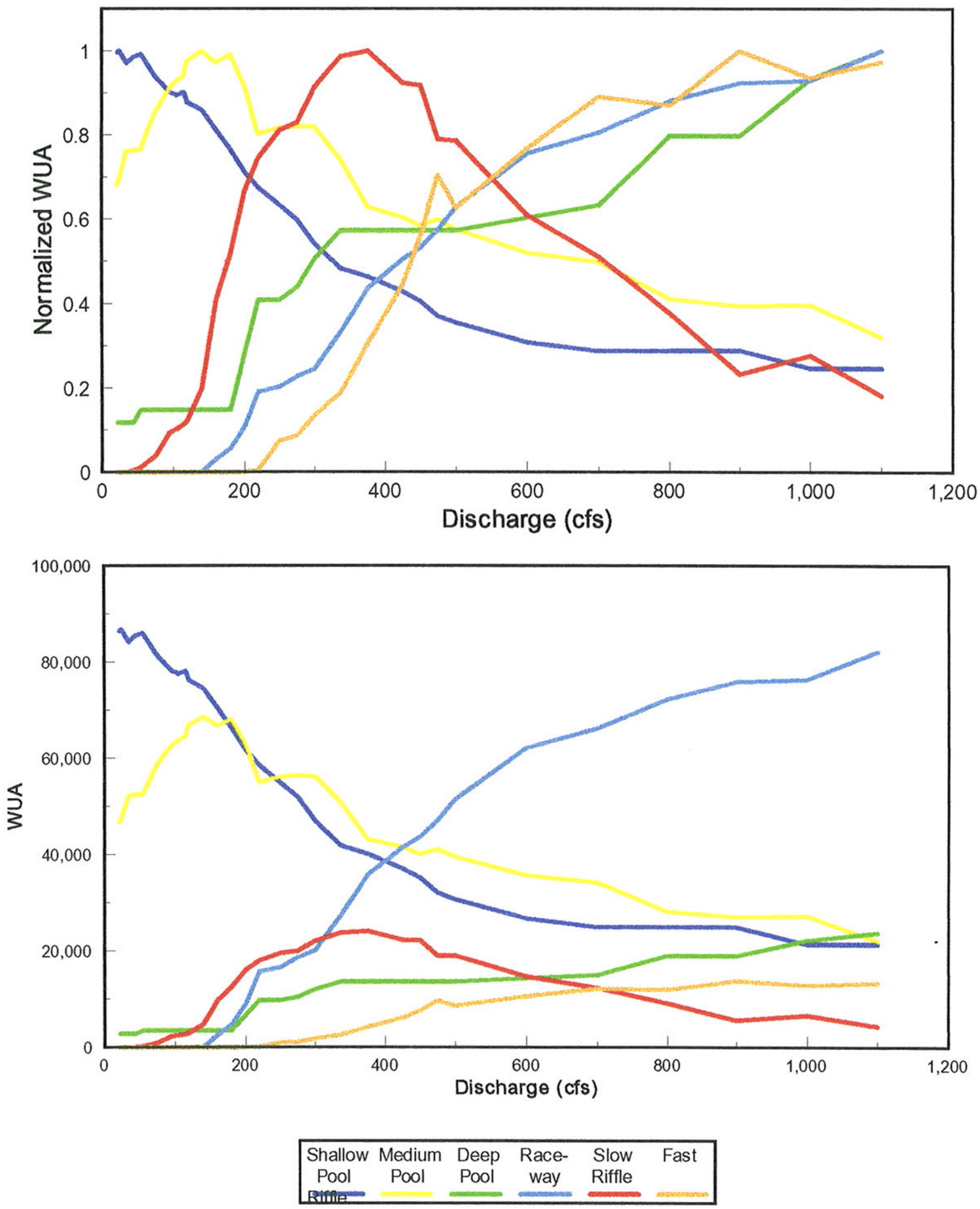

Figure 21. Normalized and non-normalized WUA for habitat types for the lower Red Lake River site.

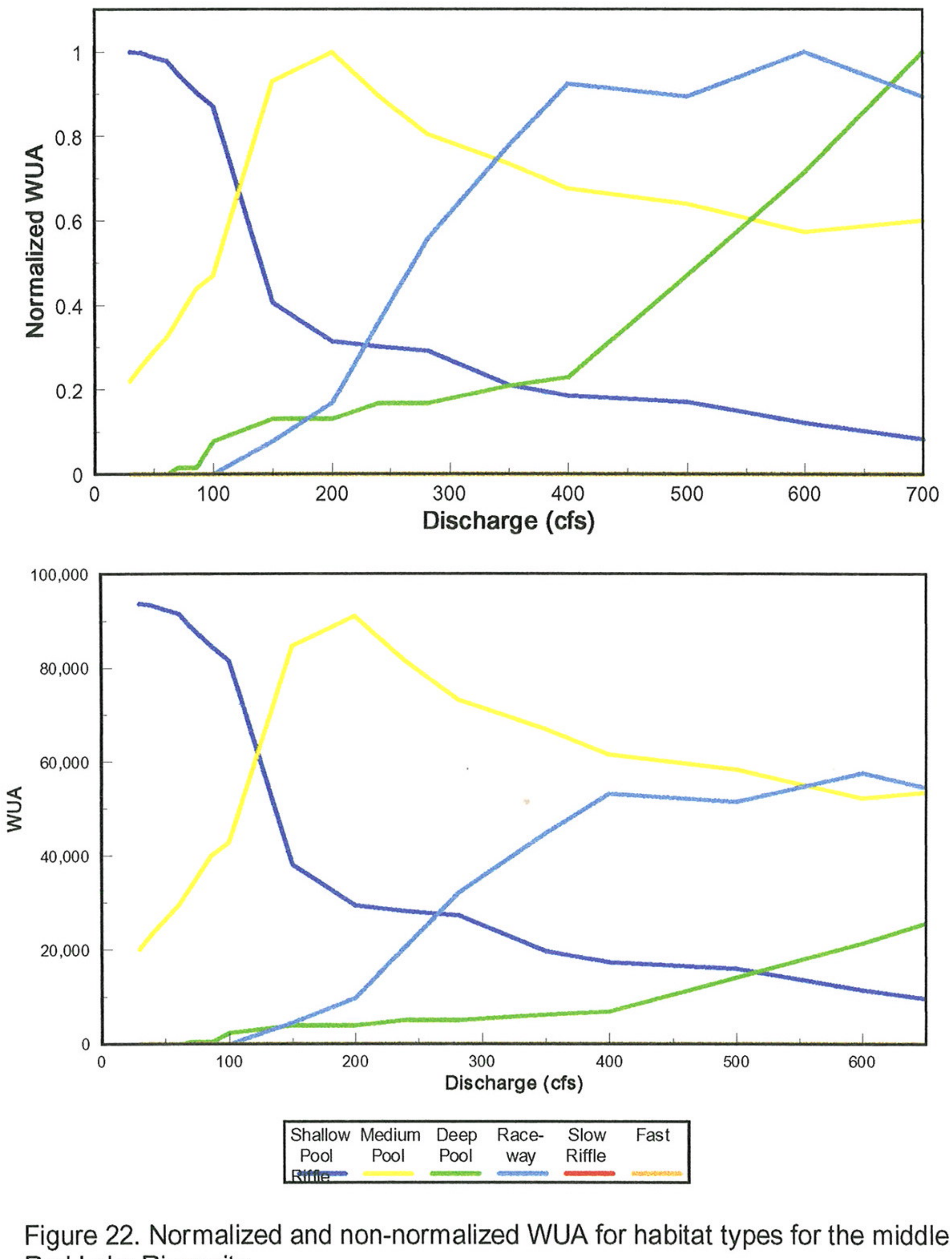

Figure 22. Normalized and non-normalized WUA for habitat types for the middle Red Lake River site.

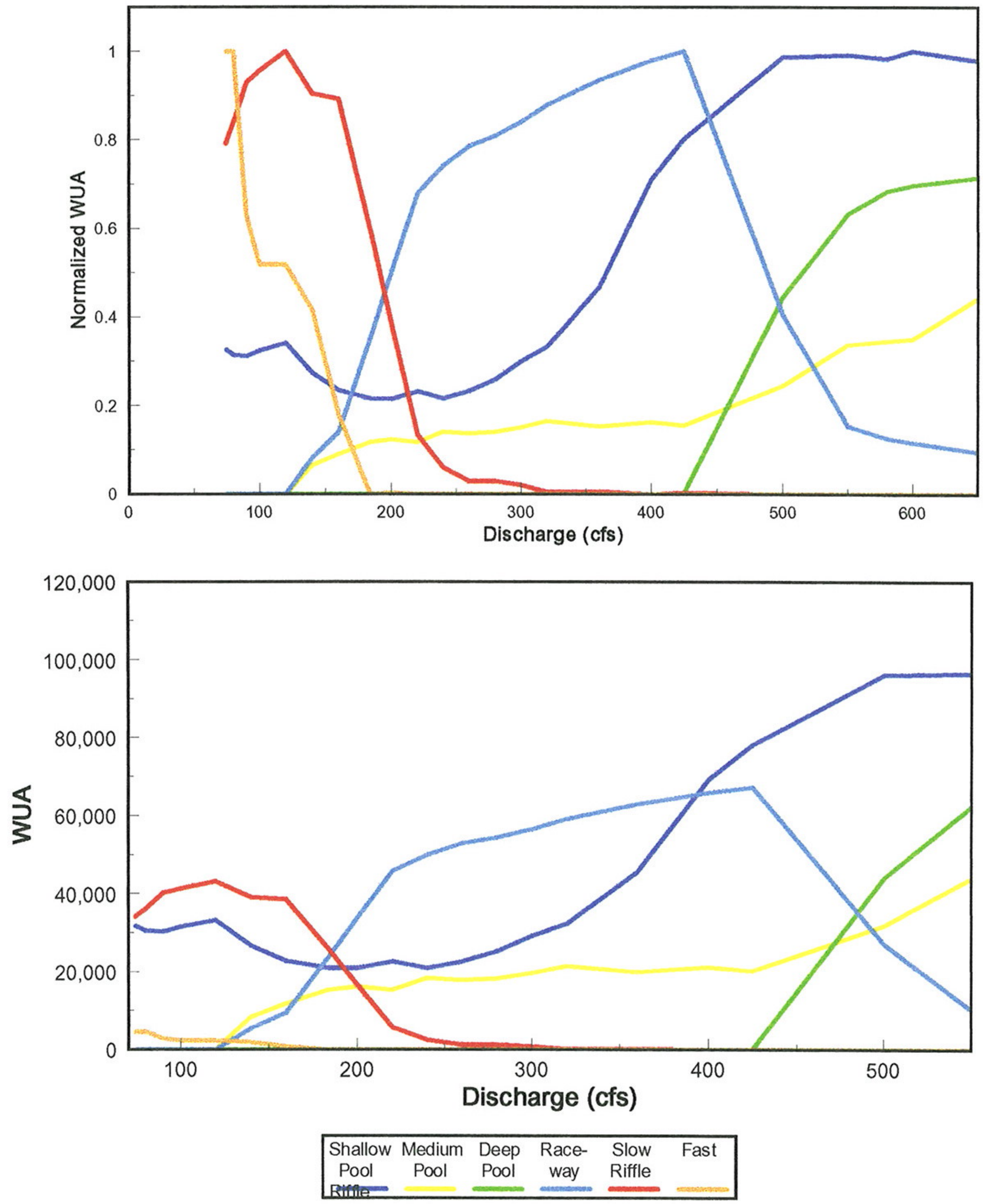

Figure 23. Normalized and non-normalized WUA for habitat types for the upper Red Lake River site.

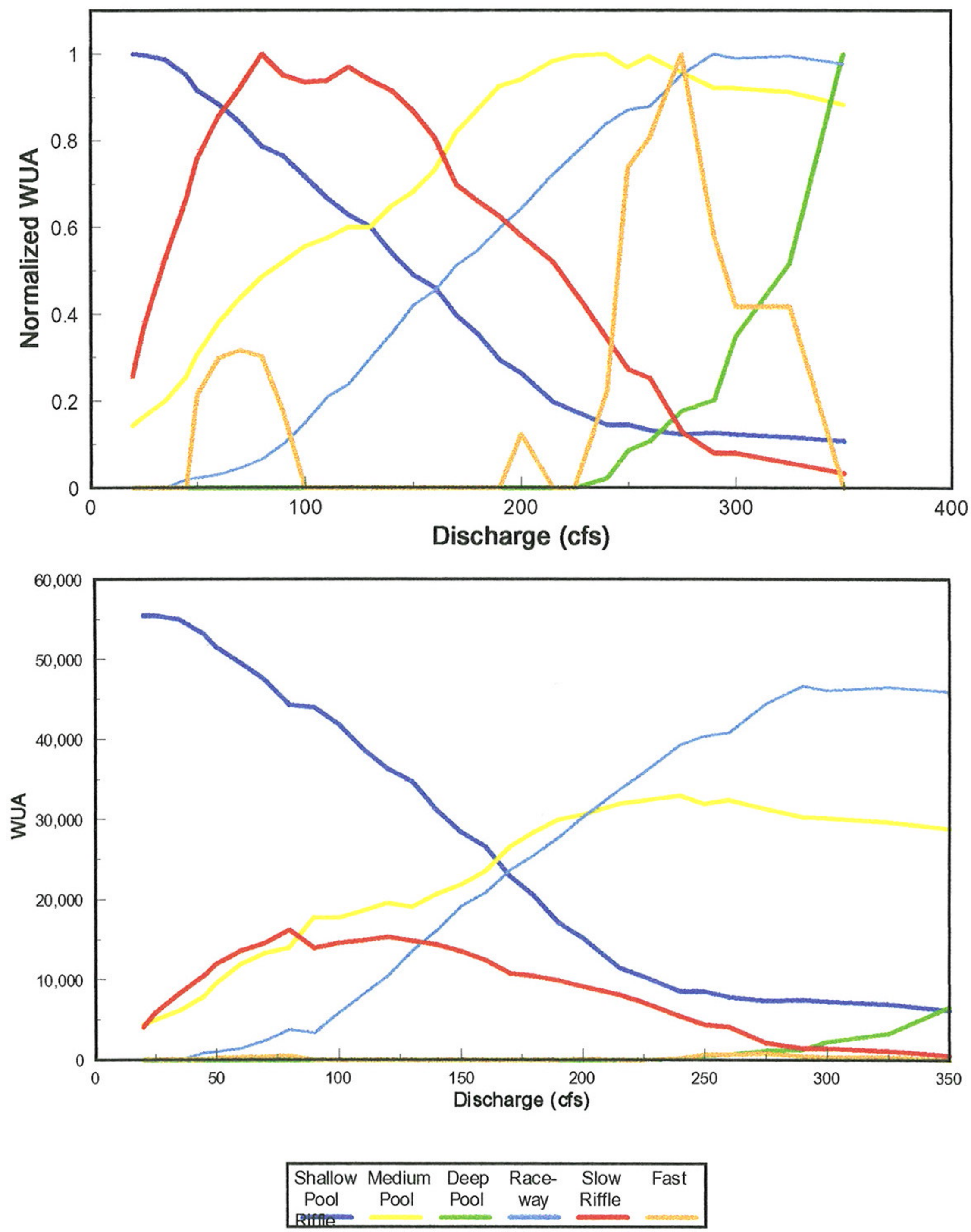

Figure 24. Normalized and non-normalized WUA for habitat types for the lower Clearwater site.

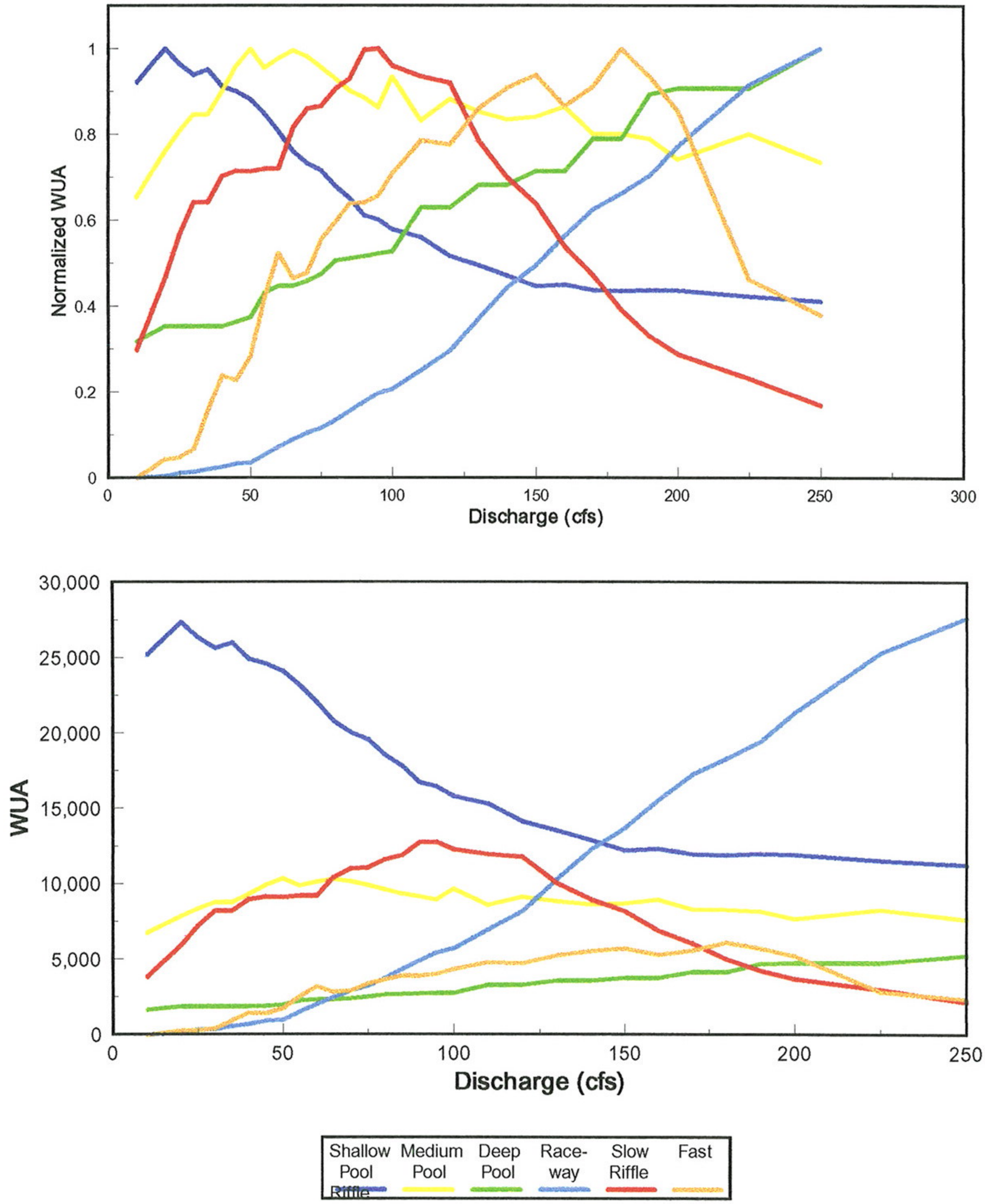

Figure 25. Normalized and non-normalized WUA for habitat types for the upper Clearwater site.

application. These 2 sites were chosen for 2 reasons. First, both of these lower sites have diverse habitat available for the aquatic community of the rivers. Because our methodology seeks to provide a diversity of habitats by protecting stream flows that ensure this diversity, it is essential that sites used to make recommendations have diverse habitats available. The upper and middle Red Lake sites do not have diverse habitats available, and therefore were not used to establish protected flow recommendations. The upper Clearwater site, which has diverse habitat representative of the upper Clearwater River, could be used for implementing protected flows should gages closer to the site become available. Secondly, the two lower sites are closest to the USGS stream gages that were used to establish the brackets for implementing protected flows (section 4.3). The two gages, Clearwater River at Red Lake Falls (USGS gage 05078500) and Red Lake River at Crookston (USGS gage 05082500), have extended periods of record, are currently active, and provide a good picture of the watershed's streamflow conditions because they are located on the most downstream portion of the rivers.

The CBFs for each season at the lower Red Lake River site were multiplied by 1.50 (the ratio of the drainage area of the Crookston gage to the drainage area of the lower Red Lake study site) to determine the corresponding CBFs at the Crookston gage, and by 1.14 (the ratio of the drainage area of the Red Lake Falls gage to the drainage area of the lower Clearwater study site) to determine the corresponding CBFs at the Red Lake Falls gage (Table 9). This simply means that when the discharge at the lower Red Lake study site is 450 cfs for instance, the discharge at the Crookston gage is 676 cfs. These relations were established so that bracketed protected flow recommendations could be implemented at the gages.

Note that if strictly applied, the May 30 to June 30 CBF at the Crookston gage would have been 331 cfs rather than 413 (Table 9). The higher value results in a more naturally shaped hydrograph, provides a somewhat higher level of protection, and simplifies the final recommendation and its application. Because the CBFs for the May 30 to June 30 season and the July 1 to April 16 season were the same, they were combined into one season for establishing protected flow brackets. The two resulting seasons are April 17 to May 29 and May 30 to April 16.

Table 9. CBFs from the lower Red Lake and lower Clearwater River sites related to USGS stream gages.

Season	CBF (cfs) at Lower Red Lake Study Site	CBF (cfs) related to USGS Stream Gage at Crookston	CBF (cfs) at Lower Clearwater River Study Site	CBF (cfs) related to USGS Stream Gage at Red Lake Falls
April 17 to May 29	450	676	250	286
May 30 to June 30	220	413 (331[1])	145	166
July 1 to April 16	275	413	145	166

[1] July 1 to April 16 CBF is used, rather than May 30 to June 30 CBF.

4.4 Bracket Approach for Implementing Protected Flows

The seasonal brackets used for determining when appropriations would be limited or suspended upstream from the Crookston and Red Lake Falls gages are presented in tables 10 and 11. The breaks between brackets for the April 17 to May 29 season at the Crookston gage were 338 and 1014 cfs (or 50% and 150% of 676 cfs, the CBF for this season at the Crookston gage). When flows at the Crookston gage are above 1014 cfs, appropriators upstream from the gage would be allowed to take their full permitted amount of water. When flows at the gage are between 338 and 1014 cfs, total appropriations upstream from the gage would be limited to 135 cfs (which is 20% of the CBF). Within this bracket, the 20% cap translates into allowing total combined appropriations that range from 13% to 40% of the available flow (135 cfs is 13% of 1014 cfs and 40% of 338 cfs). When the flow at the gage drops below 338 cfs, all appropriations upstream from the gage would be suspended. This same approach was used for determining when appropriations would be limited or suspended upstream from the Crookston gage for the May 30 to April 16 season (Table 10) and when appropriations would be limited or suspended upstream from the Red Lake Falls gage during the seasons in Table 11. Seasonal protected flow brackets for both gages are shown in relation to their respective annual hydrographs in Figures 26 and 27.

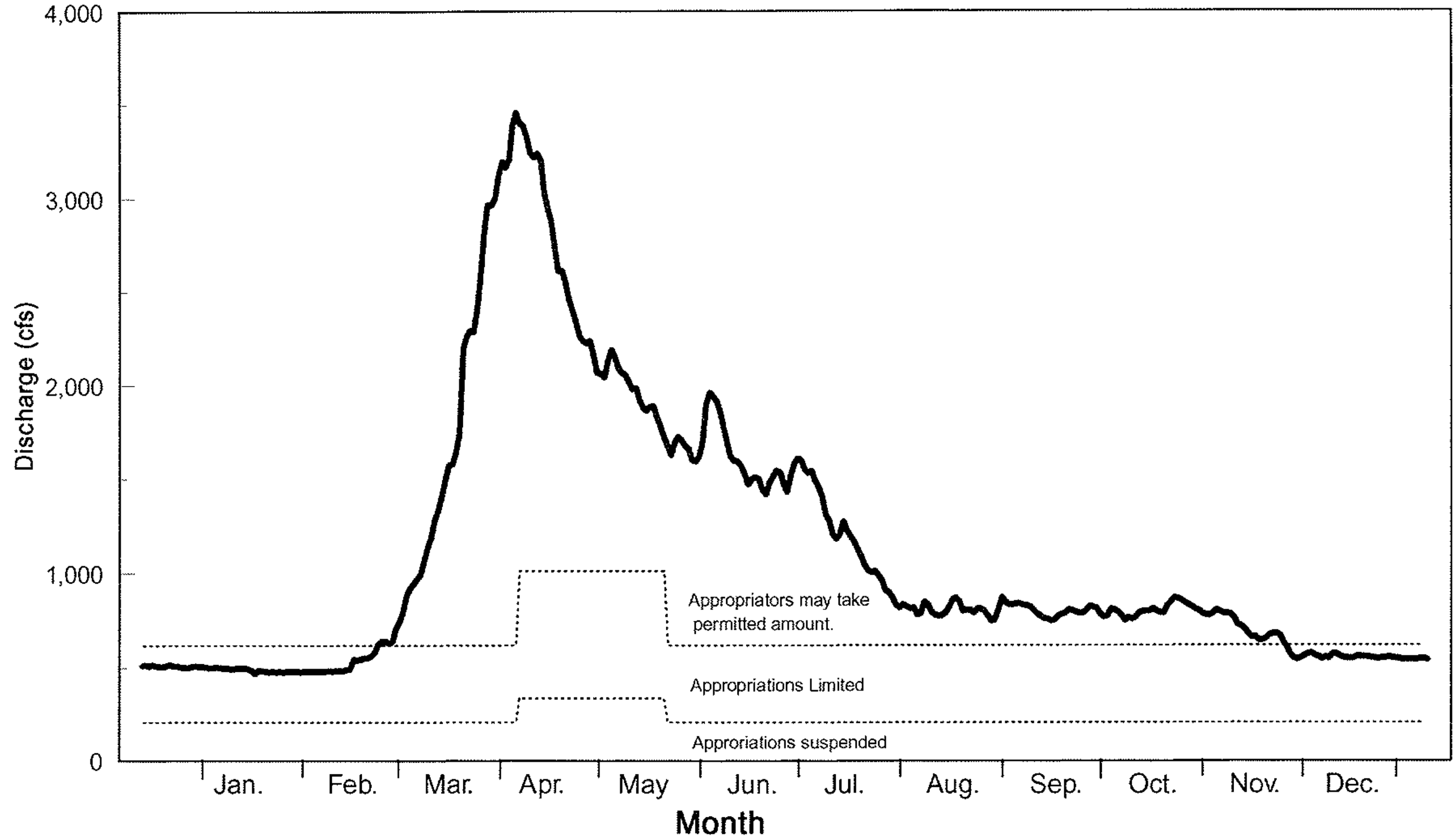

Figure 26. Hydrograph for the Red Lake River at Crookston,MN, with bracketed recommendations. When flows are above the top bracket, appropriators may take their total permitted amount. When flows are within the bracket, appropriators may take a combined total of 135 cfs between April 17 and May 29, or 82 cfs between May 30 and April 16. When flows are less than the lower bracket, appriations will be suspended.

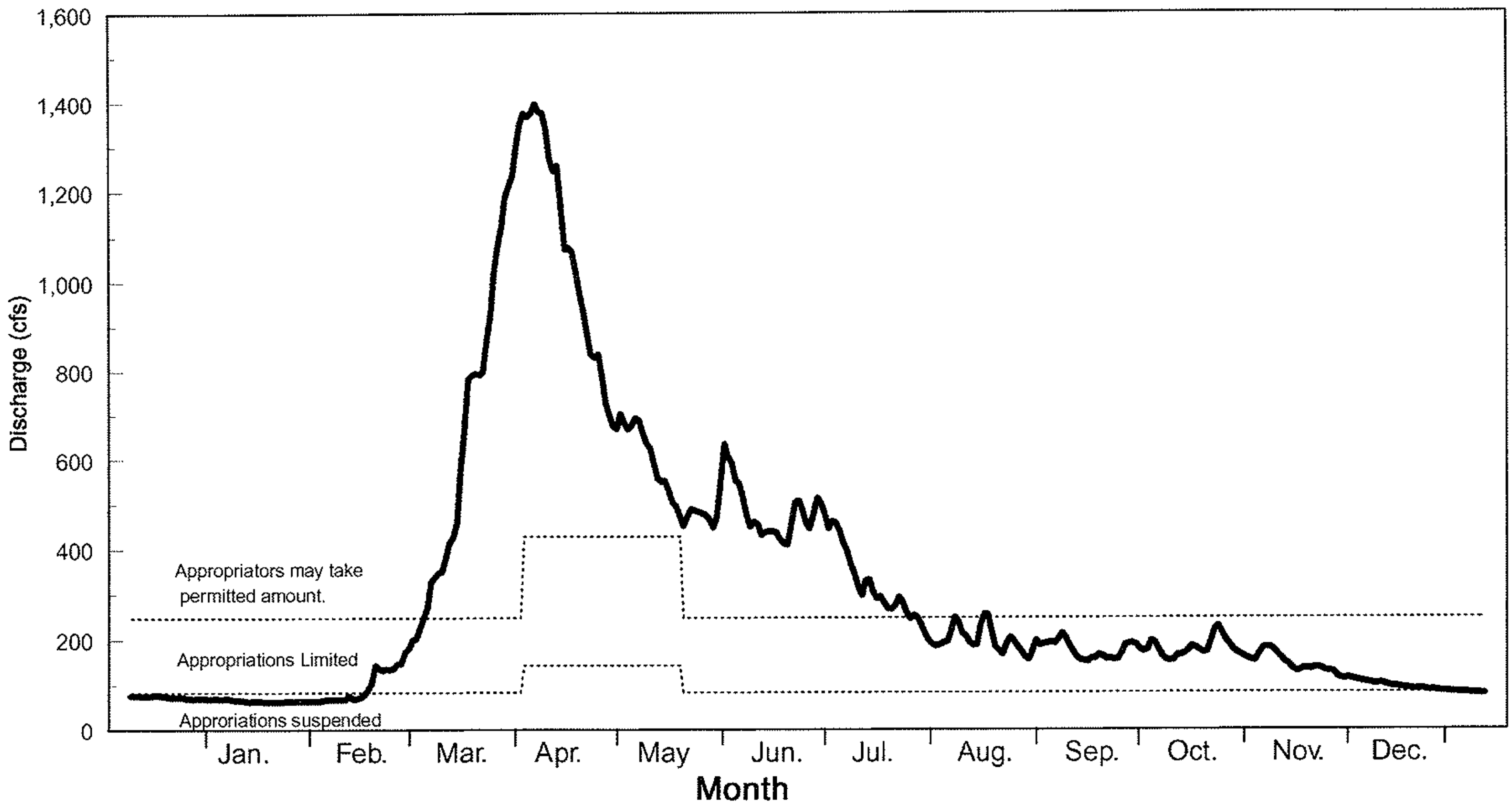

Figure 27. Hydrograph for the Clearwater River at Red Lake Falls, MN, with bracketed recommendations. When flows are above the top bracket, appropriators may take their total permitted amount. When flows are within the bracket, appropriators may take a combined total of 57 cfs between April 17 and May 29, or 33 cfs between May 30 and April 16. When flows are less than the lower bracket, appriations will be suspended.

Table 10. Recommendations for streamflow protection and allowable appropriation for the Red Lake River applied at the USGS stream gage at Crookston MN (gage number 05079000).

Season	CBF at Crookston gage	If flow at Crookston gage is...	then the action is...
April 17 to May 29	676 cfs	> 1014 cfs	appropriators may take their total permitted amount
		338 to 1014 cfs	appropriators may take a combined total of 135 cfs or the total permitted amount, whichever is less
		< 338 cfs	suspend all appropriations
May 30 to April 16	413 cfs	> 620 cfs	appropriators may take their total permitted amount
		206 to 619 cfs	appropriators may take a combined total of 82 cfs or the total permitted amount, whichever is less
		< 207 cfs	suspend all appropriations

Table 11. Recommendations for streamflow protection and allowable appropriation for the Clearwater River applied at the USGS stream gage at Red Lake Falls, MN (gage number 05078500).

Season	CBF at Red Lake Falls gage	If flow at Red Lake Falls gage is...	then the action is...
April 17 to May 29	286 cfs	> 429 cfs	appropriators may take their total permitted amount
		143 to 429 cfs	appropriators may take a combined total of 57 cfs or the total permitted amount, whichever is less
		< 143 cfs	suspend all appropriations
May 30 to April 16	166 cfs	> 249 cfs	appropriators may take their total permitted amount
		83 to 249 cfs	appropriators may take a combined total of 33 cfs or the total permitted amount, whichever is less
		< 83 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 velocites, 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 stream flows 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 will be limited or suspended. 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. When considering the impact of appropriation in the watershed on streamflow, groundwater appropriations should be assumed to affect surfacewaters, and thus streamflow. Some water appropriators use groundwater, although use of groundwater in the Red River Basin has been limited (USCOE and MNDNR 1996), and long term trends in water level changes (groundwater) are not apparent for the glacial drift aquifers for the past 20 to 30 years. Groundwater withdrawals can significantly alter local groundwater levels (USCOE and MNDNR 1996), and many of the bedrock and glacial-drift aquifers are hydraulically connected to streams in the region (Stoner et al. 1993). On a basin-wide scale, streams tend to receive ground water from the glacial-drift aquifer system in the upland moraine areas. Even after surface water appropriations have been suspended to maintain protected flows in a watershed, groundwater withdrawals may continue to deplete stream flows (Olson et al. 1989). Delin (1991) reported that groundwater discharge to streams has decreased by 39% in the Rochester, MN area due to historical groundwater pumping. 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 stream flow. Any groundwater permit determined to potentially impact stream flow should be considered as a surface water appropriation.

The middle bracket, when the discharge is between 50% and 150% 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 Approach Compared to Tennant Method

The Tennant Method is another tool used to recommend instream flows. The method involves recommending flows based on the mean annual flow of a river, and subjectively, the effect the recommended flow will have on a rivers condition (Tennant 1975 and 1976). Table 12 shows the various categories of flows, for October to March and April to September. The categories range from severe degradation flows which are 10% of the mean annual flow, to flushing or maximum flows which are 200% of the mean annual flow. If the Tennant Method were used to recommend a protected flow for the Red Lake and Clearwater Rivers using the "Good" range for base flow regimes, recommended flows for April 17 to May 29, and May 30 to April 16 would be 450 and 225 cfs for the Red Lake River, and 127 and 63 cfs for the Clearwater River. Recommendations based on the Tennant method and those based on the Bracket system and IFIM methodology are shown in Tables 13 and 14. Flows recommended using the Tennant method are not based on the biological requirements of a rivers' aquatic communities, and therefore may not fully address their needs, while still allowing some appropriation.

Table 12. Tennant's recommended base flow regimes (from Tennant, 1976). Flows are calculated as a percentage of the mean annual flow.

	Base flow Regimes	
Description of flow	**October to March**	**April to 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	10% to 0	10% to 0

Table 13. Lower bracket recommendations for the Red Lake River at Crookston compared to recommendations based on "Good" base flow regimes from the Tennant Method.

Season from Bracket Recommendation	Lower Bracket Recommendation	Tennant Method Recommendation
April 17 to May 29	338 cfs	450 cfs
May 30 to April 16	207 cfs	May 30 to April 1 - 450 cfs October 1 to March 31 - 225 cfs

Table 14. Lower bracket recommendations for the Clearwater River at Red Lake Falls compared to recommendations based on "Good" base flow regimes from the Tennant Method.

Season from Bracket Recommendation	Lower Bracket Recommendation	Tennant Method Recommendation
April 17 to May 29	143 cfs	127 cfs
May 30 to April 16	83 cfs	May 30 to April 1 - 127 cfs October 1 to March 31 - 63 cfs

5.1.2 Frequency of Appropriation Suspension under Bracket System

Based on an analysis of historic flow data for the Red Lake River at Crookston, MN, from 1901 to 1996, flows were in the unrestricted range of the brackets (i.e., greater than 150% of the CBF) 65% of the time between April 17 and May 29, and 50% of the time between May 30 and April 16 (Table 15.). Based on a similar analysis for the Clearwater River at Red Lake Falls, MN, from 1909 to 1980, flows were in the unrestricted range of the brackets 57% of the time between April 17 and May 29, and 19% of the time between May 30 to April 16 (Table 16.). Data from after 1980 were not used for the Clearwater River because there was a significant amount of appropriation during that period which would complicate the analysis. Because appropriations artificially reduce streamflows, including years with significant appropriations would increase the percent of days in the limited or suspended range of the bracket recommendations.

Appropriation would be least often limited or suspended in April for both rivers, and most often in January and February (Tables 17 and 18). For the Red Lake River, flows were in the unrestricted range 75% of the time for April; percentages for the other months ranged from 34 to 73%. Flows were in the suspended range 34% of the time in January, 41% of the time in February, and ranged from 11 to 30% in the remaining months. For the Clearwater River, flows were in the unrestricted range 69% of the time in April; percentages for the other months ranged from 0 to 51%. Flows were in the suspended range 78% of the time in January, 81% of the time in February, and ranged from 8 to 61% in the remaining months.

Under our recommendations, appropriations would be limited or suspended most often when flows are low, during late summer and winter, and least often when flows are higher during spring. The amount of appropriation from rivers within each watershed will effect how often flows fall into the limited or suspended range, as will climatic conditions and antecedent moisture conditions. It may be necessary for appropriators to coordinate the withdrawal of water from the rivers to prevent reducing streamflow to limited or suspended ranges. This is especially true of rivers, such as the Clearwater, that have significant appropriations.

Table 15. Percent of days from 1901 to 1996 within each level of the bracketed recommendations for the Red Lake River at Crookston, MN, using USGS stream gage 05079000. Percentages are based on analysis of historic flow records applied to the bracketed recommendations.

Season	CBF at Crookston gage	If flow at Crookston gage is...	then the action is...	Percent of days within each level
April 17 to May 29	676 cfs	> 1014 cfs	appropriators may take their total permitted amount	65%
		338 to 1014 cfs	appropriators may take a combined total of 135 cfs or the total permitted amount, whichever is less	20%
		< 338 cfs	suspend all appropriations	15%
May 30 to April 16	413 cfs	> 620 cfs	appropriators may take their total permitted amount	50%
		206 to 619 cfs	appropriators may take a combined total of 82 cfs or the total permitted amount, whichever is less	25%
		< 207 cfs	suspend all appropriations	25%

Table 16. Percent of days from 1909 to 1980 within each level of the bracket recommendations for the Clearwater River at Red Lake Falls, MN, using USGS stream gage 05078500. Percentages are based on analysis of historic flow records applied to the bracketed recommendations.

Season	CBF at Red Lake Falls gage	If flow at Red Lake Falls gage is...	then the action is...	Percent of days within each level
April 17 to May 29	286 cfs	> 429 cfs	appropriators may take their total permitted amount	57%
		143 to 429 cfs	appropriators may take a combined total of 57 cfs or the total permitted amount, whichever is less	34%
		< 143 cfs	suspend all appropriations	9%
May 30 to April 16	166 cfs	> 249 cfs	appropriators may take their total permitted amount	19%
		83 to 249 cfs	appropriators may take a combined total of 33 cfs or the total permitted amount, whichever is less	34%
		< 83 cfs	suspend all appropriations	47%

Table 17. Percent of days from 1901 to 1996 within each level of the bracketed recommendation for each month for the Red Lake River at Crookston, MN, using USGS stream gage 05079000. Percentages are based on analysis of historic flow records applied to the bracketed recommendations.

	Bracket level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percent of days for each month	take permitted amounts	34	37	47	75	62	73	63	48	51	50	45	39
	limited	32	22	29	13	23	14	21	27	23	27	27	31
	suspended	34	41	25	11	14	14	16	24	26	24	28	30

Table 18. Percent of days from 1909 to 1980 within each level of the bracketed recommendation for each month for the Clearwater River at Red Lake Falls, MN, using USGS stream gage 05078500. Percentages are based on analysis of historic flow records applied to the bracketed recommendations.

	Bracket level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percent of days for each month	take permitted amounts	0	0	12	69	51	52	34	14	16	19	11	4
	limited	22	19	26	24	39	33	37	40	43	39	46	36
	suspended	78	81	61	8	10	15	29	46	42	41	43	61

5.1.3 Existing Appropriations

5.1.3.1 Appropriations from Rivers and Ditches

The most direct effect of appropriation on streamflow is from the withdrawal of water from rivers and ditches. Appropriations of this type have the potential to reduce streamflow in the Red Lake River watershed by 283 cfs (Table 19). Appropriations for wild rice irrigation alone, have the potential to reduce streamflow by 204 cfs. This is a significant amount of water. The annual 80% exceedence for the Red Lake River at Crookston is 212 cfs. This means that the total appropriation from river and ditches in the watershed exceeds available streamflow 20% of the time.

Although they should be considered exempt from streamflow protection recommendations, municipal waterworks do have the potential to effect riverine habitat by reducing streamflow. Municipal waterworks are currently permitted to withdraw 35.7 cfs from the Red Lake River. There are currently no municipal surfacewater appropriations from the Clearwater River.

Table 19. Summary of appropriations from rivers or ditches for the Red Lake, and Clearwater River Watershed. Information was provided by DOW staff and summarized by the author. n/l = none listed

Description of Use	Watershed	Total Appropriation in Millions of Gallons per year	Pump Rate in Gallons per minute	Pump Rate in Cubic Feet per second	Number of permits
Municipal Waterworks	Red Lake	4,740.0	16,003.0	35.7	3
	Clearwater	n/l	n/l	n/l	n/l
Agricultural Processing (food and livestock)	Red Lake	1,313.0	2,101.0	4.7	2.0
	Clearwater	n/l	n/l	n/l	n/l
Temporary for Construction (non-dewatering)	Red Lake	3.3	302.0	0.7	2
	Clearwater	n/l	n/l	n/l	n/l
Golf Course (non-crop irrigation)	Red Lake	34.4	1,201.0	2.7	1
	Clearwater	n/l	n/l	n/l	n/l
Nursery (non-crop irrigation)	Red Lake	9.6	151.0	0.3	1
	Clearwater	n/l	n/l	n/l	n/l
Major Crop Irrigation	Red Lake	503.7	15,305.0	34.1	23
	Clearwater	10.0	351.0	0.8	2
Wild Rice Irrigation	Red Lake	2,894.5	65,820.0	146.7	36
	Clearwater	11,870.3	25,801.0	57.5	25
Totals		21,378.8	127,035.0	283.2	

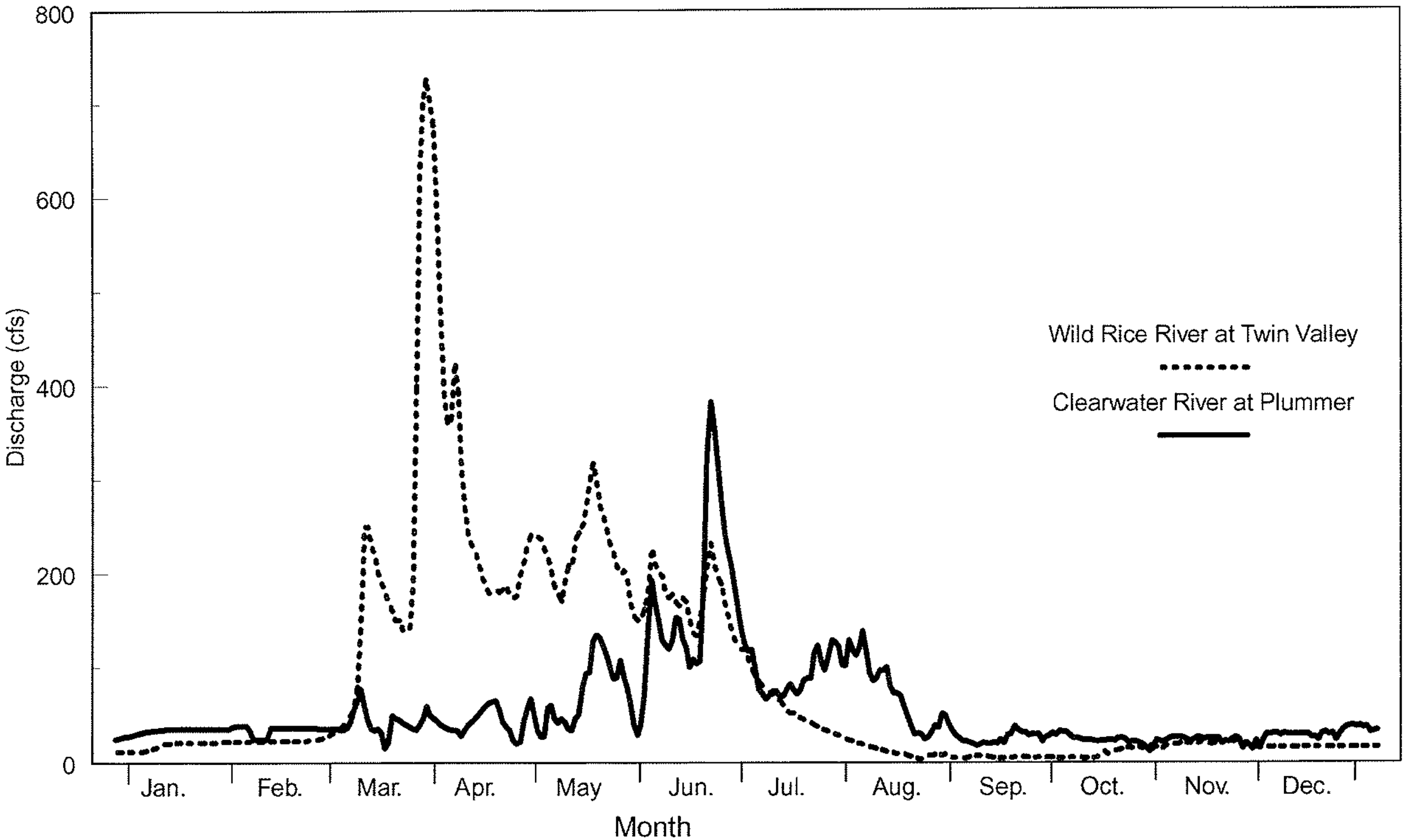

Figure 28. Hydrographs of mean daily discharge for 1990. Hydrographs show transposition of normal high and low flows on the Clearwater River as a result of water appropriation for wild rice production.

5.1.3.2 Total Appropriations

This study does not address the link between surface waters and groundwater. Although there is reason to believe that groundwater and surfacewaters are linked, we cannot confirm that withdrawal of groundwater will directly impact streamflow in the watershed. The extent of any link between groundwater withdrawals and reduction of streamflow should be studied, given the significant present appropriations in the watershed. If groundwater appropriation is found to reduce streamflows, we recommend that permitted appropriations be treated as if they were surfacewater. If we assume that groundwater appropriations directly reduce streamflows, there could be an additional 53.8 cfs reduction in streamflow for the watershed, bringing the total potential reduction in streamflow to 337 cfs (Table 20).

Table 20. Summary of all appropriations for the Red Lake River watershed (Red Lake, Thief, and Clearwater Rivers combined), Red Lake River including the Thief River, and Clearwater River. Appropriations listed include groundwater, and surfacewater appropriations for each watershed. Information was provided by DOW staff and summarized by the author. n/l = none listed

Description of Use	Watershed	Total Appropriation in Millions of Gallons per year	Pump Rate in Gallons per minute	Pump Rate in Cubic Feet per second	Number of Permits
Municipal Waterworks	Red Lake	5,319.5	20,055.0	44.7	12
	Clearwater	282.6	2,135.0	4.8	8
Private Waterworks (small housing units, etc.)	Red Lake	2.0	50.0	0.1	1
	Clearwater	8.0	170.0	0.4	2
Agricultural Processing (food and livestock)	Red Lake	1,320.6	2,155.0	4.8	3
	Clearwater	n/l	n/l	n/l	n/l
Sand and Gravel Washing	Red Lake	340.0	2,500.0	5.6	1
	Clearwater	19.0	n/l	n/l	1
Temporary for Construction (non-dewatering)	Red Lake	1.3	300.0	0.7	2
	Clearwater	n/l	n/l	n/l	n/l
Temporary for Pipeline and Tank Testing	Red Lake	n/l	n/l	n/l	n/l
	Clearwater	20.0	1500	3.3	1
Pollution Confinement	Red Lake	5.3	10.0	< 0.1	1
	Clearwater	3.0	5.0	< 0.1	1
Aquaculture (hatcheries, fisheries)	Red Lake	n/l	n/l	n/l	n/l
	Clearwater	20	400	0.9	1
Snow Making	Red Lake	2.9	100.0	0.2	1
	Clearwater	n/l	n/l	n/l	n/l
Pipeline and tank Testing	Red Lake	n/l	n/l	n/l	n/l
	Clearwater	26.2	2,700.0	6.0	2
Golf Course (non-crop irrigation)	Red Lake	33.4	1,200.1	2.7	12
	Clearwater	14.4	550.0	1.2	
Nursery (non-crop irrigation)	Red Lake	20.2	550.0	1.2	3
	Clearwater	n/l	n/l	n/l	n/l
Major Crop Irrigation	Red Lake	759.4	19,985.0	44.5	29
	Clearwater	289.5	4,310.0	9.6	6
Wild Rice Irrigation	Red Lake	2,908.5	65,800.0	146.6	37
	Clearwater	11,895.0	26,791.0	59.7	28
Totals		23,291.1	151,266.0	337.0	143

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. It should be emphasized, however, that high flows are extremely important for maintaining the integrity of stream habitats and their biotic communities, and that it is possible to impact these flows. Of particular importance are bankfull flows and flows needed for maintaining the connection between a river's channel and its floodplain. In the Red Lake River watershed, appropriators could potentially withdraw 283 cfs of water from rivers and ditches (Section 5.1.2). That level of appropriation could impact important high flows. Using the methodology outlined in this report, we cannot address flows greater than those recommended to protect the instream habitat needs of aquatic communities. However, the effect of appropriation and other practices on the flows discussed in the following sections, should be determined, and recommendations should be made to protect or restore those flows.

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. 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.

As discussed in Section 5.1.3.1, the total appropriation from rivers and ditches for wild rice irrigation in the Clearwater River watershed is 11, 870.3 million gallons per year, with a combined pumping capacity of 57.5 cfs (Table 19). The result of these appropriations and subsequent late summer releases is the transposition of the normal high and low flows (Figure 28). A comparison of daily discharges from 1990 for the Clearwater and Wild Rice Rivers, which have similar drainage area and watershed characteristics, show the hydrologic effects of removing water from the river in the spring followed by late summer releases. The normal "flood-pulse" is absent on the Clearwater, while late summer flows are elevated when compared to the Wild Rice River. This transposition could lead to a decrease in biomass of riverine plants and animals keyed to take advantage of the natural "flood-pulse".

5.3 Existing Flow Protection

The MNDNR was directed in 1977 to set protected stream flows 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. For example, fish kills occurred on two rivers in August 1978, even though flows were above the protected flow (MNDNR DOW Water Appropriations Manual 1986). 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 Clearwater River has a protected flow of 36 cfs at the Red Lake Falls gage (36 cfs was the annual Q90 at the gage at the time when the protected flow was established, the current annual Q90 at Red Lake Falls is 37 cfs), which translates to 31.5 cfs at the lower Clearwater River site. There is no current flow protection for the Red Lake River. The 36 cfs protected flow for the Clearwater provides very little protection for the aquatic community and very little habitat diversity (Figure 24). Habitat diversity, is an important factor governing the diversity of fishes and invertebrates found in warmwater streams (Ward 1976; Gorman and Karr 1978; Schlosser 1982a).

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. The percentages of wetlands that have been drained in Red Lake, Koochiching, Beltrami, Clearwater, Marshall, Pennington, and Polk counties are 91.8%, 2.0%, 5.9%, 22.4 %, 80.8%, 92.0%, and 95.5% (Anderson and Craig 1984). Most of these wetlands were drained via the construction of ditches for the purpose of converting land to row crop agriculture. The flat glacial lake plain of the Red River Valley is probably the most intensively ditched and drained area in the world. Ditching is extensive throughout the Red Lake watershed. These ditches empty into all of the major rivers and their tributaries in the watershed. In addition to this created drainage, many miles of naturally meandering stream channels have been converted to ditches, i.e., have been channelized (see next section on channelization). Based on data from USGS maps (1:100,000 scale), there are approximately 806 mile of ditches and channelized stream reaches in the Red Lake watershed and 434 miles in the Clearwater River watershed. This does not include all of the private ditches. The numerous straight lines on Figure 1 indicate ditches and channelized stream reaches.

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 state. 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).

As part of the USCOE Red Lake and Clearwater Rivers Project (USCOE 1975), the Red Lake River was channelized between river miles 154.3 and 178.5, also in a 3.2 mile reach below the outlet structure of Red Lake Dam at Lower Red Lake, as well as above river mile 162.6 at the River Valley Bridge. The Clearwater River was also modified to accommodate 10-year frequency flows (channelized) between river miles 31.8 and 79.1. Streamflow capacities of the "improved" reaches of the Red Lake River varies from 1000 to 1520 cfs. Streamflow capacities of the "improved" reaches of the Clearwater River varies from 850 to 1510 cfs. These actions have certainly degraded the quality of habitat and decreased the biological productivity of these rivers and streams.

Both the upper and middle Red Lake River study sites where in channelized portions of the river. The channelization directly effected the habitat at those sites, which is evident in the non-normalized WUA output for those sites (Figure 22 and 23). For the upper site, the relationship for riffles and pools is reversed from what would be expected, and there is little diversity of habitats at either site. The two Clearwater, and the lower Red Lake sites were not channelized, had diverse habitat at moderate flows, and the relationship between habitat and flow was consistent with those we have observed at other IFIM study sites throughout the state. The biological productivity of the channelized portions of the Red Lake and Clearwater rivers is most likely reduced as was observed at the Whitewater River in Winona County, MN. Fish biomass was 280 times higher in an unchannelized reach as compared to a channelized reach (MNDNR, unpublished data). The diversity of habitats was much greater in the unchannelized reach.

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. The Red Lake River, where it flows across the flat, lake plain of Glacial Lake Agassiz is turbid, and carries a heavy silt load. 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.

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 throughout 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).

There are at least 7 dams on major rivers in the watershed (USCOE 1996). The most significant of those, are dams which act as a barrier to the upstream migration of fishes. The two dams on the lower Red Lake River, one in East Grand Forks, and the other in Crookston, effectively block the migration of fishes from the Red River of the North into the Red Lake River's watershed and all of its tributaries, except during periods of extensive flooding. Because the Red River of the North lacks the high gradient habitats needed by many aquatic species, dams such as the two on the lower Red Lake River, effect not only the Red Lake River, but also the Red River of the North. Two dams associated with the U.S. Corp of Engineers Red Lake and Clearwater Rivers Projects, block the movement of fishes between the Red Lake River and Upper and Lower Red Lakes. In addition to acting as a migration barrier, the U. S. Corp of Engineers operates the dam between Lower Red Lake and the Red Lake River as part of a multiple-purpose project which includes flood control, water supply, and fishery enhancment as primary goals. The project's operation induces drastic changes in the flow regime of the Red Lake River. The hydropower dam on the Red Lake River in Thief River Falls also blocks the movement of fishes. As a group, the dams act to divide the watershed into isolated segments which may not have the diverse habitats necessary to sustain many riverine species, such as: lake sturgeon, channel catfish, or smallmouth bass.

Hydropower facilities are of special concern because they not only act as a barrier to sediment and fish, but because they can induce changes in streamflow as part of their operation. The hydropower facility in Thief River Falls, is owned and operated by the City of Thief River Falls, MN. The city has indicated that they will operate the hydropower facility in run of the river mode. Run of river operation is defined as instantaneous inflows to the reservoir being equal to instantaneous outflows from the dam, in other words, no peaking or storage of water in the reservoir to drive the generating turbines. From an ecological perspective and its impact to streamflow, run of river operation is the best possible mode of operation for hydropower facilities because it does not alter the flow regime of the river. Compared to other hydropower facilities in the state, the Thief River Falls hydro is small, with only 0.55 megawatt generating capacity. Generating capacities range from an 88.6 megawatt capacity for the St. Louis River Project, with its complex of 4 dams and 5 reservoirs, to only 0.1 megawatt for the Lanesboro Project on the South Branch of the Root River. While the facility is small in comparison to others in the state, there are still ecological concerns related to the facility.

6.0 RESTORATION OPPORTUNITIES

There are many opportunities to protect and restore the ecological integrity of the rivers and streams of the Red Lake River watershed. Restoration efforts should focus on protecting stream flows, restoring migratory pathways of fishes blocked by dams, 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 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.

Efforts should be made to remove dams that do not serve a useful function, or, for dams which cannot be removed, modifying the dams to allow fish passage over or around dams which cannot be removed. This would help restore the migratory pathways used by fishes throughout the Red River of the North Basin, by allowing fishes inhabiting the lower reaches of the Red Lake River and fishes in the Red River of the North access to the high quality, high gradient, and ecological important habitat located upstream. Restoring migratory pathways is particularly important in light of recent increased interest in lake sturgeon. Records summarized by the Bell Museum indicate that lake sturgeon did inhabit the Red Lake River basin (Eddy et al, 1972). Radio tagging studies completed by the MNDNR and the Ontario Ministry of Natural Resources indicate that sturgeon often make extensive migrations (over 100 miles) to preferred spawning habitats (Mike Larson, personal communication). These long migrations would be hindered or prevented by many of the dams in the Red Lake River watershed. Recently, lake sturgeon have been re-introduced into the Red River of the North Basin. During the fall of 1997, lake sturgeon collected from the Rainy River in Minnesota were placed in the Otter Tail River near Fergus Falls, MN, and there are plans to re-introduce sturgeon in the Red Lake River below Thief River Falls. Removing dams, or establishing fishways around barriers would help to ensure that once re-introduced, lake sturgeon and other migratory fishes such as channel catfish or smallmouth bass would have access to high gradient areas throughout the basin.

Restoration efforts should also focus on restoring stream channel morphology and stability. To achieve long-term stream stability and function, stream protection and 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 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 Red Lake 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. 1992; 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.

Effort to stabilize stream banks need to be made throughout the watershed. Bank erosion is 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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Appendices

Appendix A1. Hydrologic statistics for the period of record for USGS stream gage number 05079000 at Crookston, MN. Monthly statistics are based on mean daily values within a month in cubic feet per second (cfs). Annual statistics are based on all mean daily values in cubic feet per second (cfs).

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Minimum	8	7	11	15	31	18	9	5	3	4	4	4	3
Maximum	2,970	3,020	10,700	27,100	26,700	16,300	13,400	9,240	5,310	6,050	6,650	3,310	27,100
Median	450	440	600	1,900	1,320	1,190	921	596	642	620	499	480	675
Mean	524	501	993	2,983	2,085	1,637	1,291	817	812	822	677	576	1,144
10% exceedance	1,050	1,020	2,480	6,862	4,563	3,437	2,810	1,830	1,670	1,863	1,480	1,130	2,570
90% exceedance	73	72	120	364	291	213	132	72	75	103	101	77	112

Appendix A2. Hydrologic statistics for the period of record for USGS stream gage number 05078500 at Red Lake Falls, MN. Monthly statistics are based on mean daily values within a month in cubic feet per second (cfs). Annual statistics are based on all mean daily values in cubic feet per second (cfs).

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Minimum	5.5	4.6	2.2	7.0	18.0	11.0	0.5	0.1	0.1	2.4	5.2	3.7	0.1
Maximum	405	545	5210	10000	9060	8300	5210	6720	2970	3010	3320	404	10000
Median	65	60	80	632	400	245	173	102	105	102	97	80	109
Mean	73.9	69.4	242.4	1155	686.3	477.4	372.8	205.2	181.0	189.5	140.2	90.8	324.8
10% exceedance	115	115	630.5	2740	1480	1040	921	436	438	426.1	267.0	154.4	789.0
90% exceedance	32	30	33	120	118	64	45	33	30	36	40	37	37

Appendix B1. Transect descriptions and proximity to adjacent transect(s) at the lower Red Lake River Site.

Transect Number	Transect Description	Dist. to next transect on left bank (ft.)	Dist. to next transect on right bank (ft.)	Approx. Average Thalway Distance (ft.)	Cumulative thalweg distance (ft.)
1	Hydraulic Control	61	124.2	123.4	0
2	Riffle/raceway	203.6	194.0	211.4	123.4
3	Shallow Pool	0	380.3	483.0	334.8
4	Pool	311.4	104.4	213.3	817.8
5	Hydraulic Control	54.2	39.9	53.0	1031.1
6	Riffle	30.5	26.5	31.6	1084.1
7	Control/Riffle	23.6	78.5	169.5	1115.7
8	Riffle/backwater	137.5	95.8	158.3	1285.2
9	Pool	162.6	138.8	168.7	1443.5
10	Hydraulic Control	191.7	124.6	34.2	1612.2
11	Hydraulic Control	n/a	n/a	n/a	1646.4

Appendix B2. Transect descriptions and proximity to adjacent transect(s) at the middle Red Lake River Site.

Transect Number	**Transect Description**	**Dist. to next transect on left bank (ft.)**	**Dist. to next transect on right bank (ft.)**	**Approx. Average Thalway Distance (ft.)**	**Cumulative thalweg distance (ft.)**
1	Hydraulic Control	574.0	583.0	578.5	0
2	Pool	232.0	296.0	264.0	578.5
3	Pool	n/a	n/a	n/a	842.5

Appendix B3. Transect descriptions and proximity to adjacent transect(s) at the upper Red Lake River Site.

Transect Number	**Transect Description**	**Dist. to next transect on left bank (ft.)**	**Dist. to next transect on right bank (ft.)**	**Approx. Average Thalway Distance (ft.)**	**Cumulative thalweg distance (ft.)**
1	Raceway	n/a[1]	n/a[1]	54	0
2	Raceway	n/a[1]	n/a[1]	71	54
3	Raceway	n/a[1]	n/a[1]	25	125
4	Raceway	n/a[1]	n/a[1]	n/a	150

n/a[1] = Site was essentially straight, and channelized so distance was about equal along each shoreline.

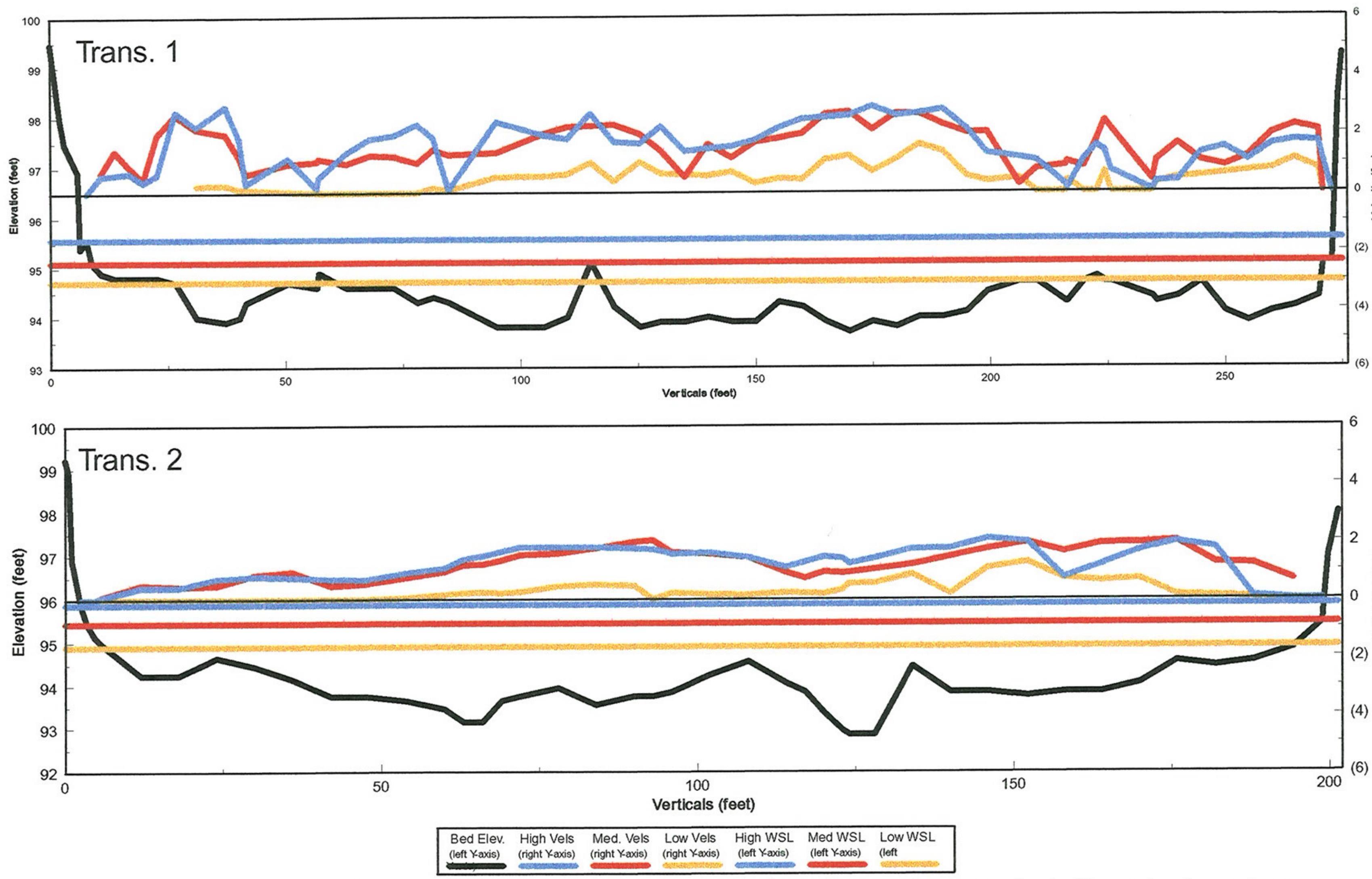
Appendix C1. Transect descriptions and proximity to adjacent transect(s) at the lower Clearwater River site.

Transect Number	Transect Description	Dist. to next transect on left bank (ft.)	Dist. to next transect on right bank (ft.)	Approx. Average Thalway Distance (ft.)	Cumulative thalweg distance (ft.)
1	Hydraulic Control	201.	24.1	23.4	0
2	Riffle, pool transition	55.9	63.5	62.5	23.4
3	Pool	81.7	130.9	113.6	85.9
4	Riffle, Pool transition	24.7	27.9	27.0	199.5
5	Riffle	28.6	27.15	28.7	226.5
6	Riffle	33.1	30	31.9	255.2
7	Pool, Riffle transition	13.8	22.1	20.1	287.1
8	Pool	24.1	39.7	33.0	307.2
9	Pool, Riffle transition	17.3	30.75	31.8	340.2
10	Riffle	17.3	15.7	19.2	372.0
11	Riffle, Pool transition	74.3	92	84.8	391.2
12	Raceway	88.5	100.3	96.9	476.0
13	Pool	50.9	79.8	67.8	572.9
14	Hydraulic Control	33.8	32.5	33.4	640.7

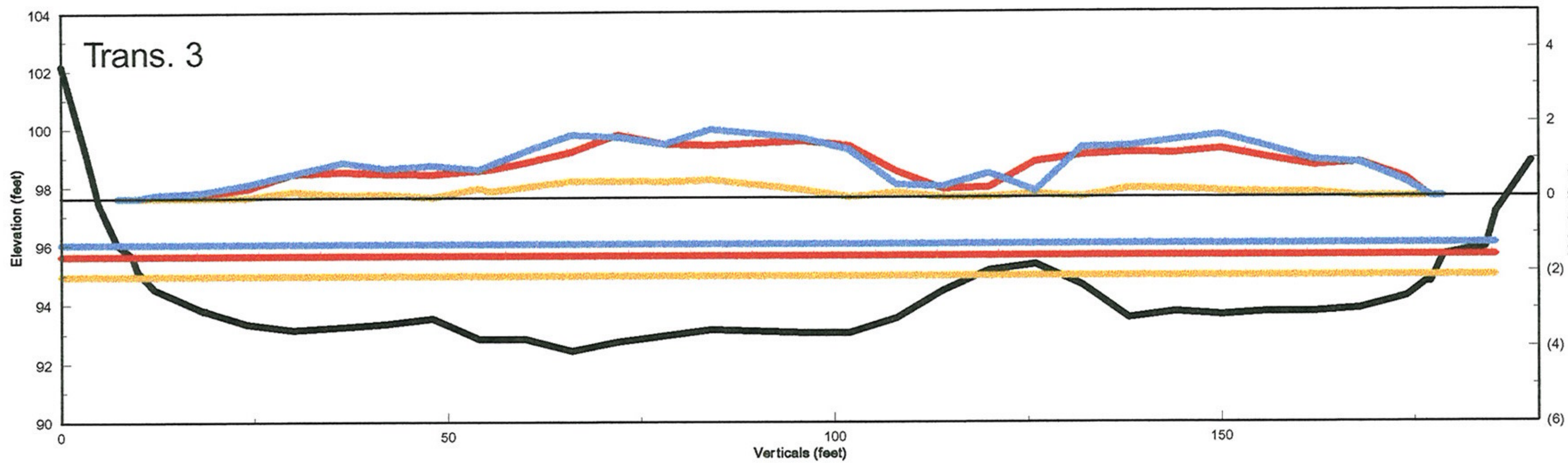
Transect Number	Transect Description	Dist. to next transect on left bank (ft.)	Dist. to next transect on right bank (ft.)	Approx. Average Thalway Distance (ft.)	Cumulative thalweg distance (ft.)
15	Hydraulic Control	n/a	n/a	n/a	674.14

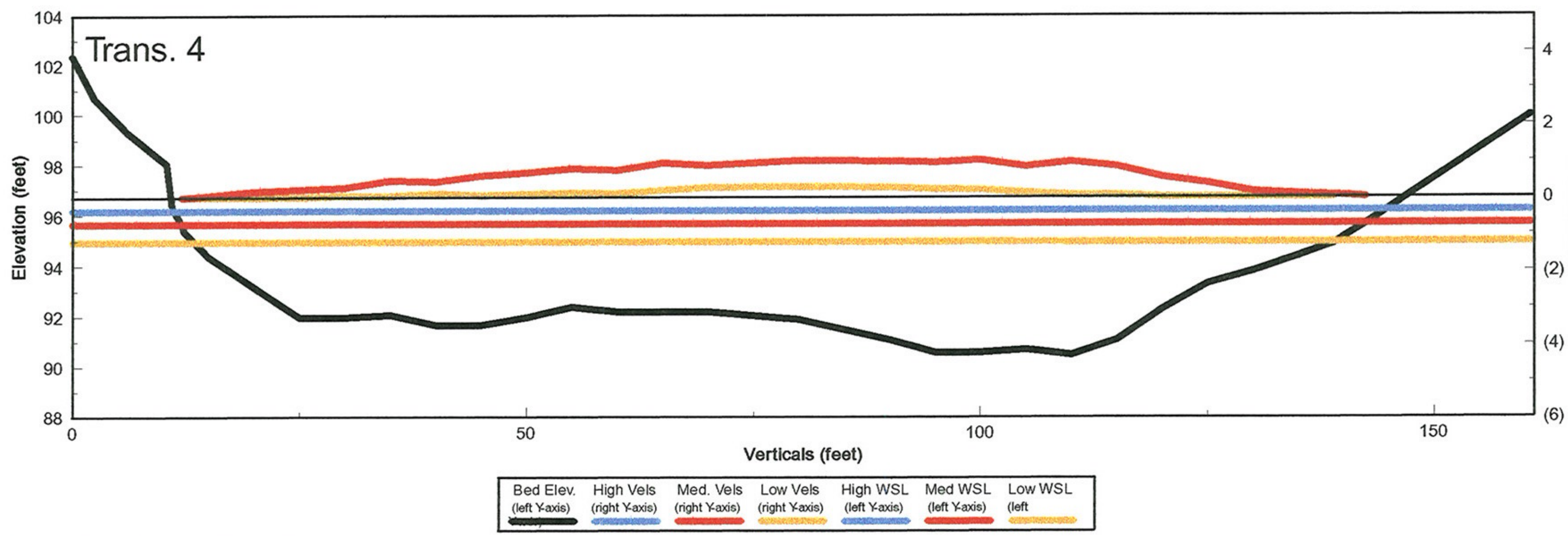
Appendix C2. Transect descriptions and proximity to adjacent transect(s) at the upper Clearwater River site.

Transect Number	**Transect Description**	**Dist. to next transect on left bank (ft.)**	**Dist. to next transect on right bank (ft.)**	**Approx. Average Thalway Distance (ft.)**	**Cumulative thalweg distance (ft.)**
1	Hydraulic Control	52.8	99.8	82.2	0.0
2	Raceway	29.75	70.6	56.1	82.2
3	Pool	20.9	27.8	27.9	138.3
4	Raceway	28.6	62.2	52.0	166.2
5	Pool	35.0	45.4	43.9	218.2
6	Riffle	56.5	105.2	84.3	262.1
7	Raceway	38.2	50.5	48.2	346.4
8	Riffle	38.7	32.3	37.4	394.6
9	Riffle	62.0	57.2	65.8	432.0
10	Riffle	59.0	99.1	73.8	497.8
11	Raceway	28.8	72.9	53.6	571.6
12	Pool	26.4	52.0	43.0	625.2
13	Riffle	16.7	19.0	20.1	668.2
14	Hydraulic Control	29.9	38.8	43.3	688.3
15	Riffle	47.6	54.8	51.4	731.6
16	Riffle	24.9	21.0	26.6	783.0
17	Hydraulic Control	n/a	n/a	n/a	809.6



Appendix D1. Cross sections at the lower Red Lake site's transects showing bed elevations, and measured velocities and water surface elevations (WSL).





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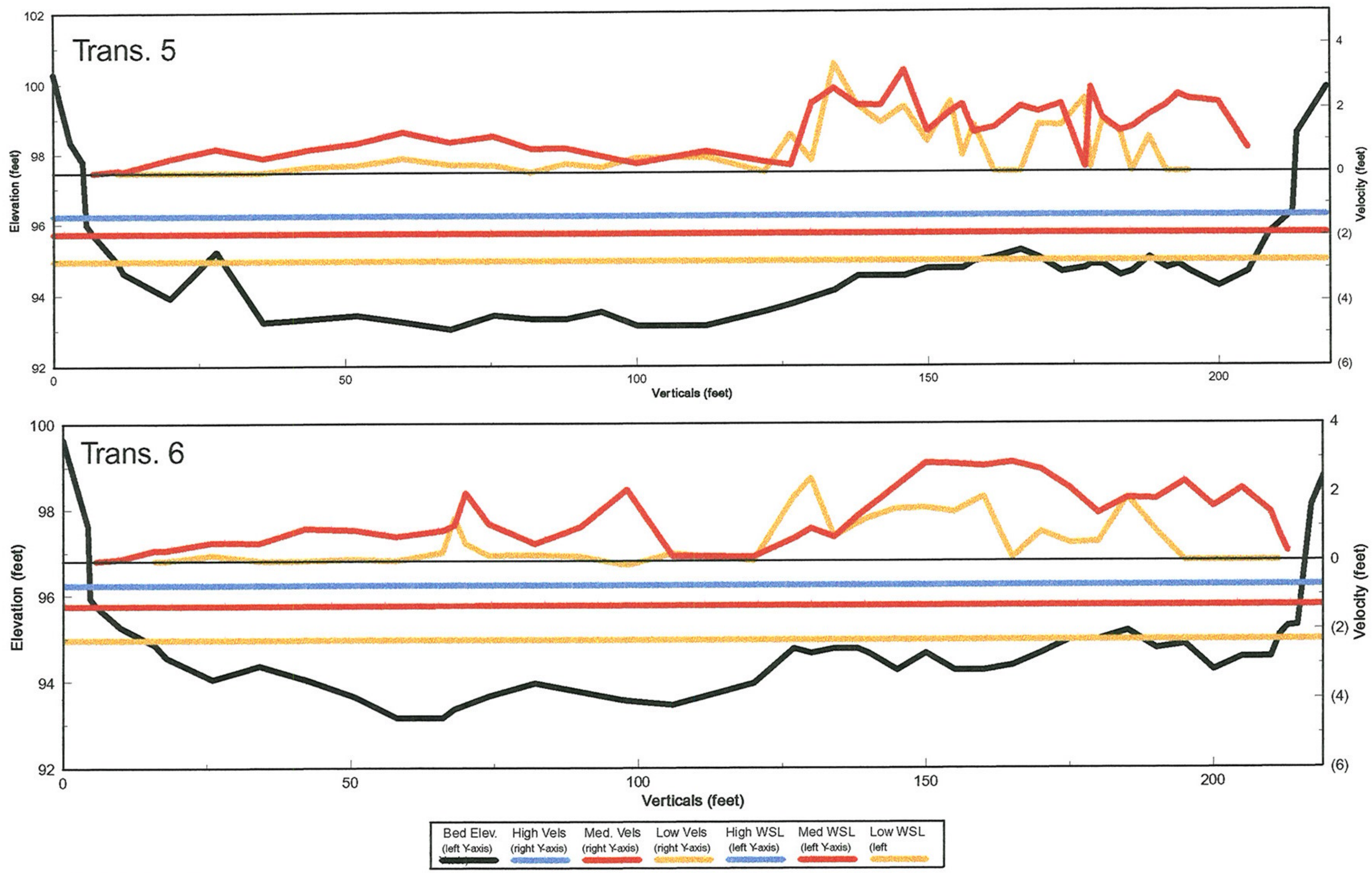
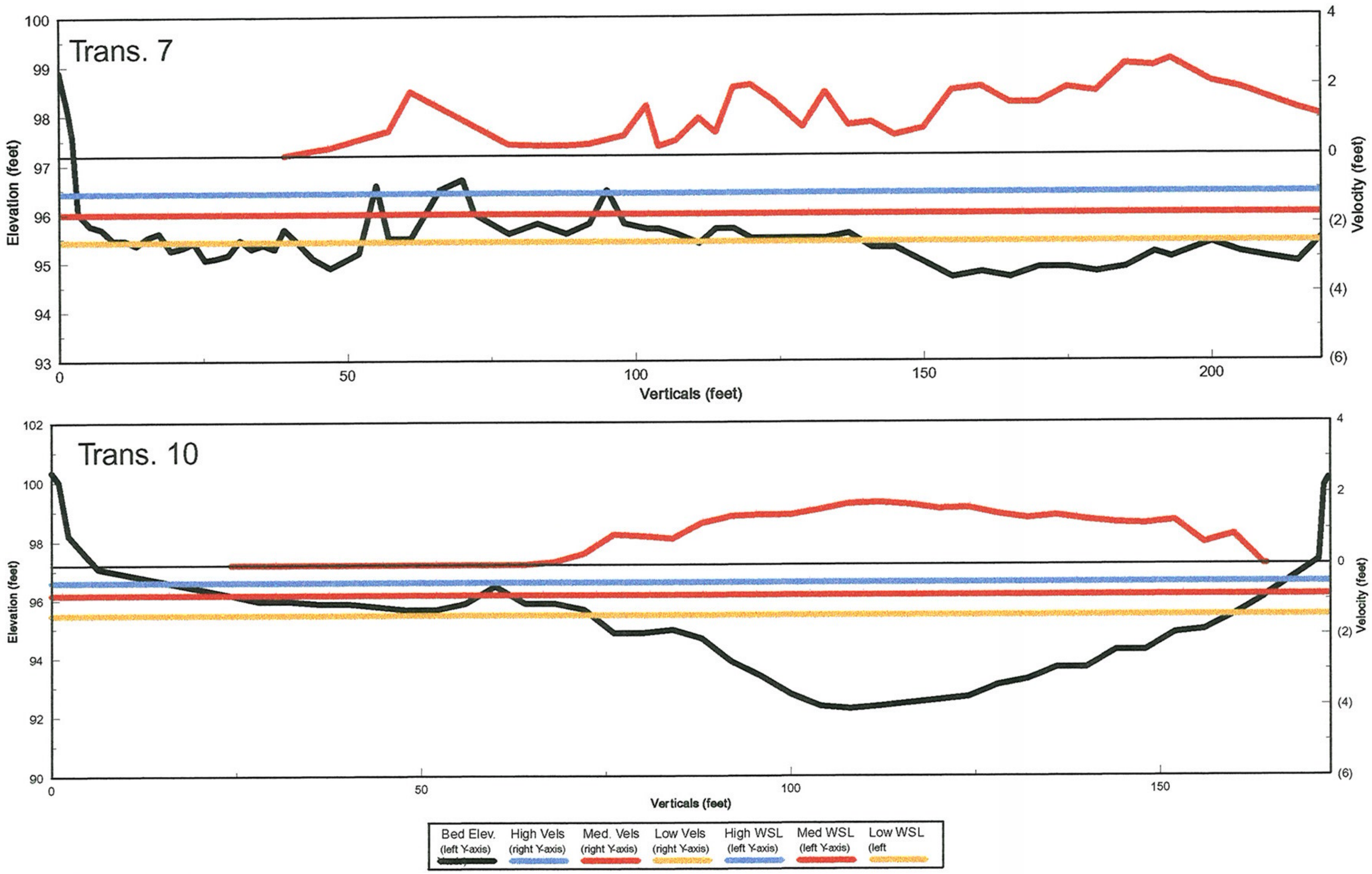
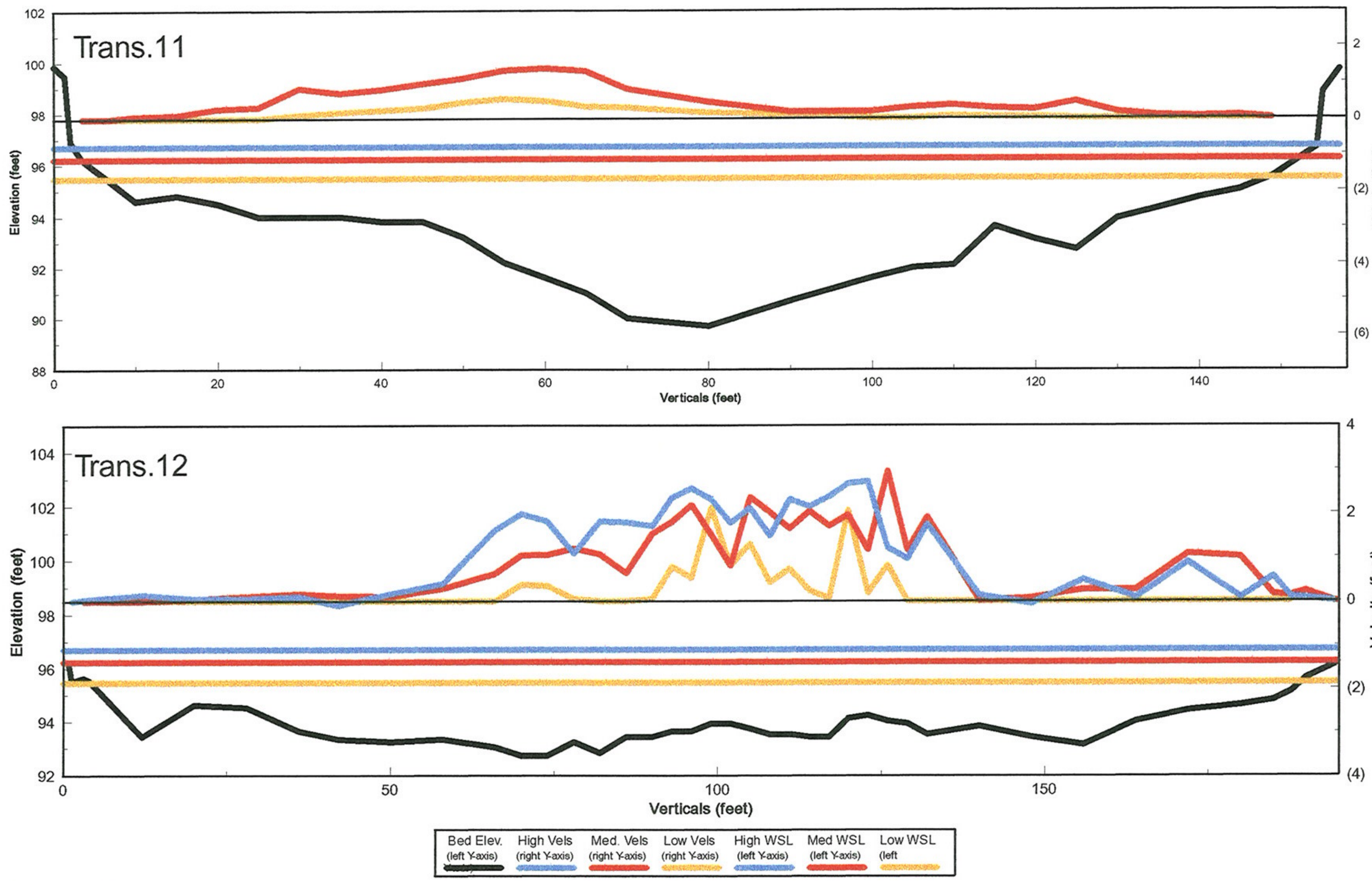


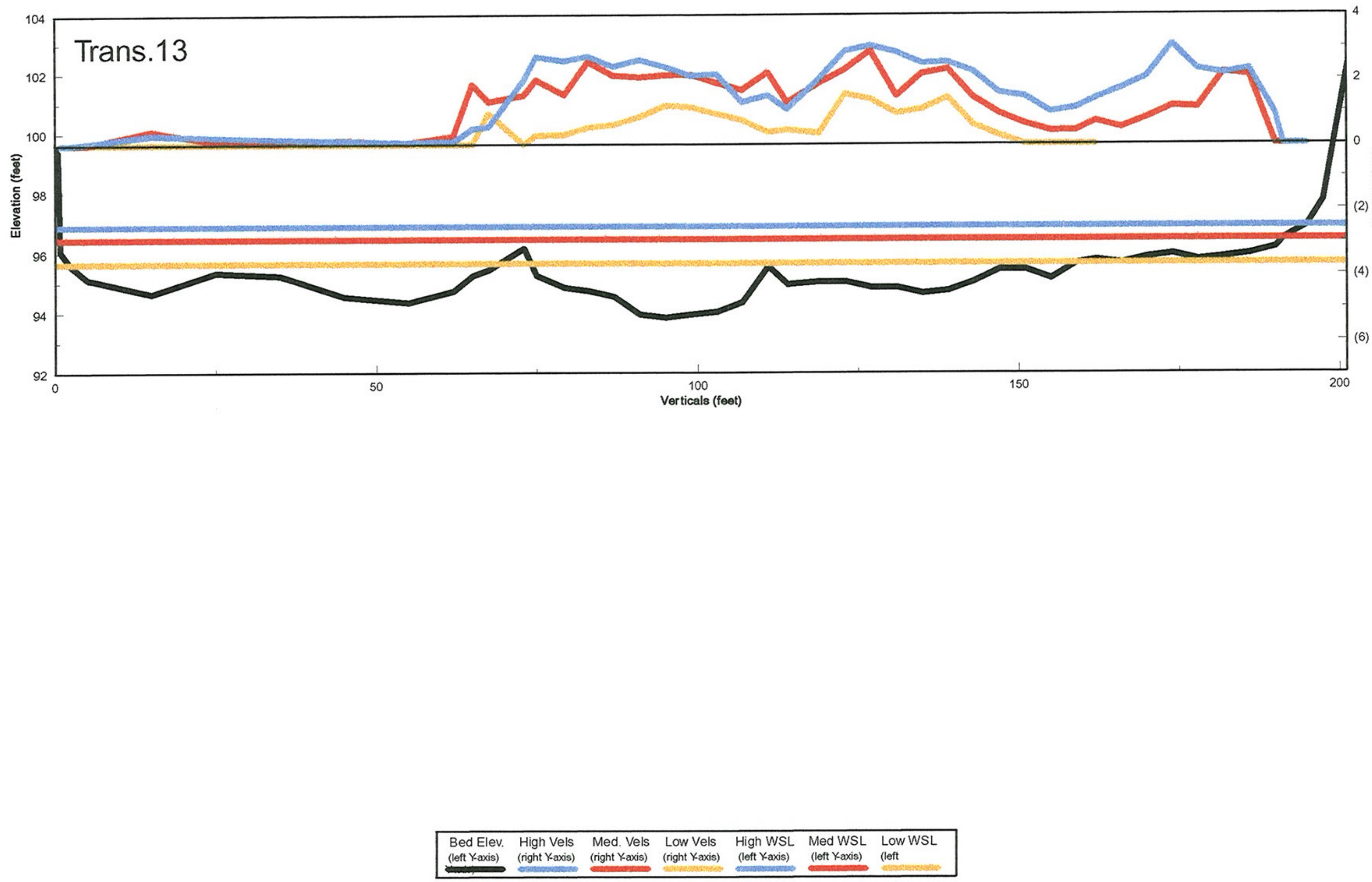
Appendix D1. (continued)



Appendix D1. (continued)



Appendix D1. (continued)



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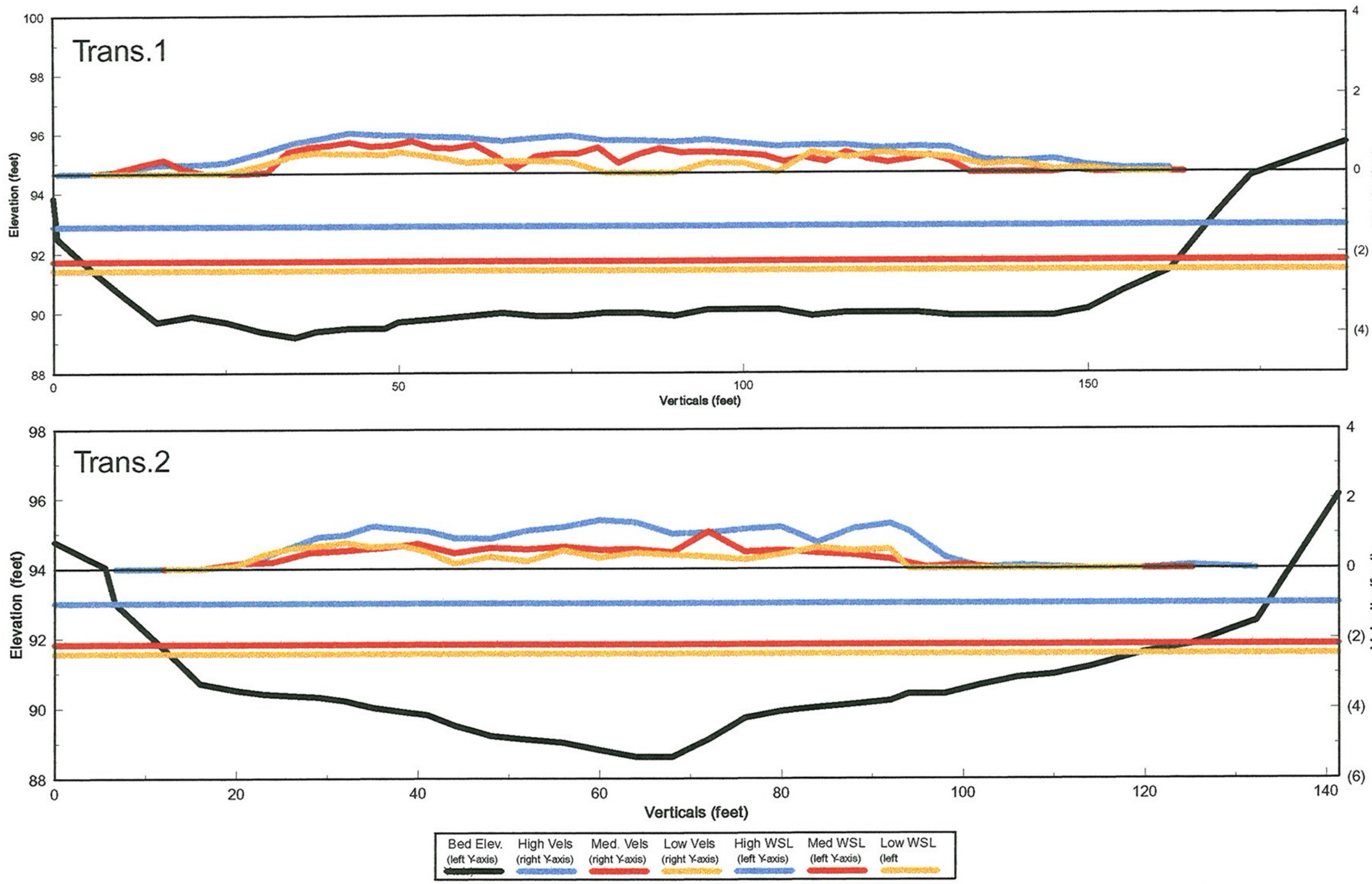
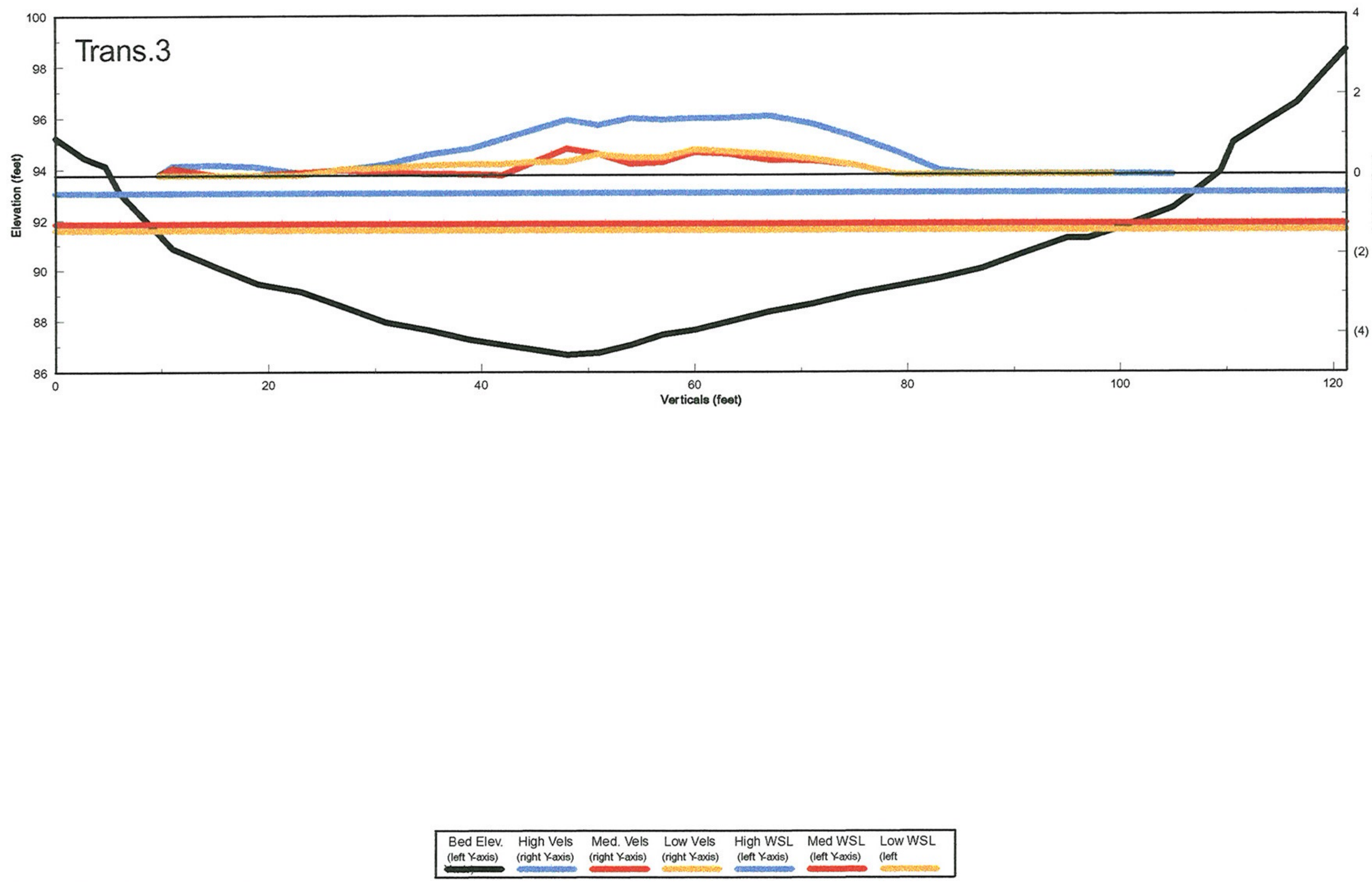
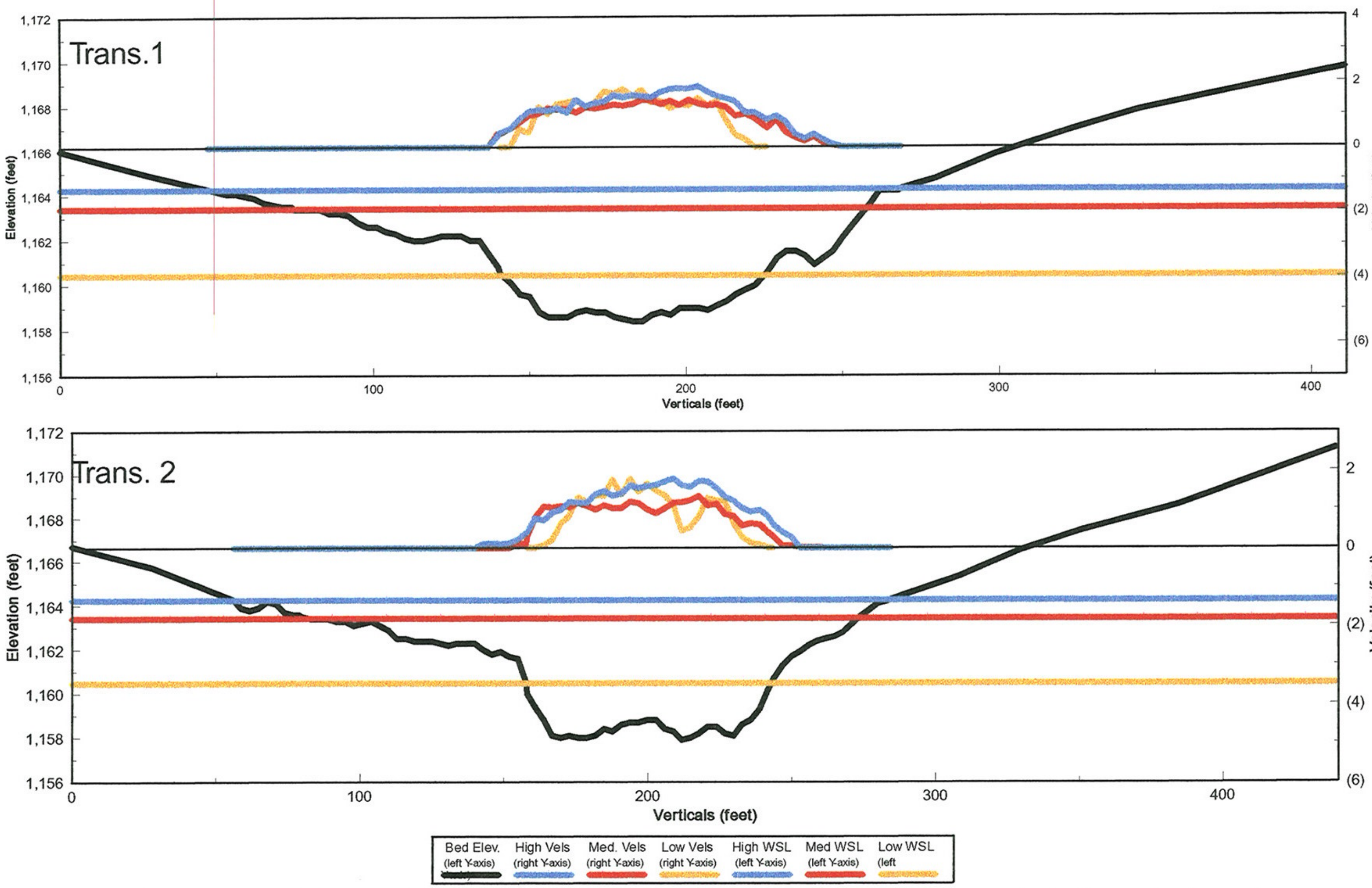


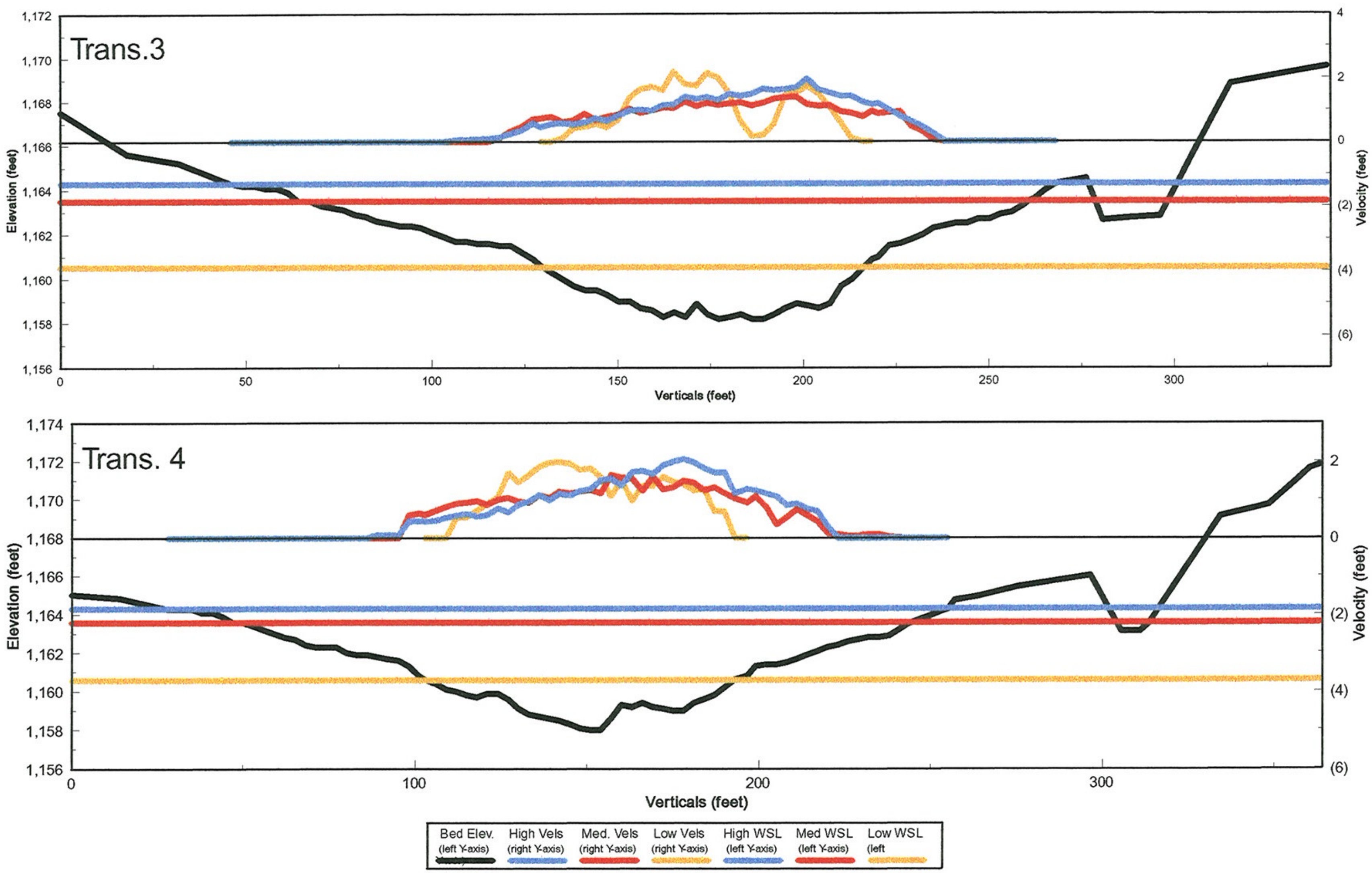
Appendix D2. Cross sections at the middle Red Lake site's transects showing bed elevations, and measured velocities and water surface elevations (WSL).



Appendix D2. (continued)



Appendix D3. Cross sections at the upper Red Lake site's transects showing bed elevations, and measured velocities and water surface elevations (WSL).



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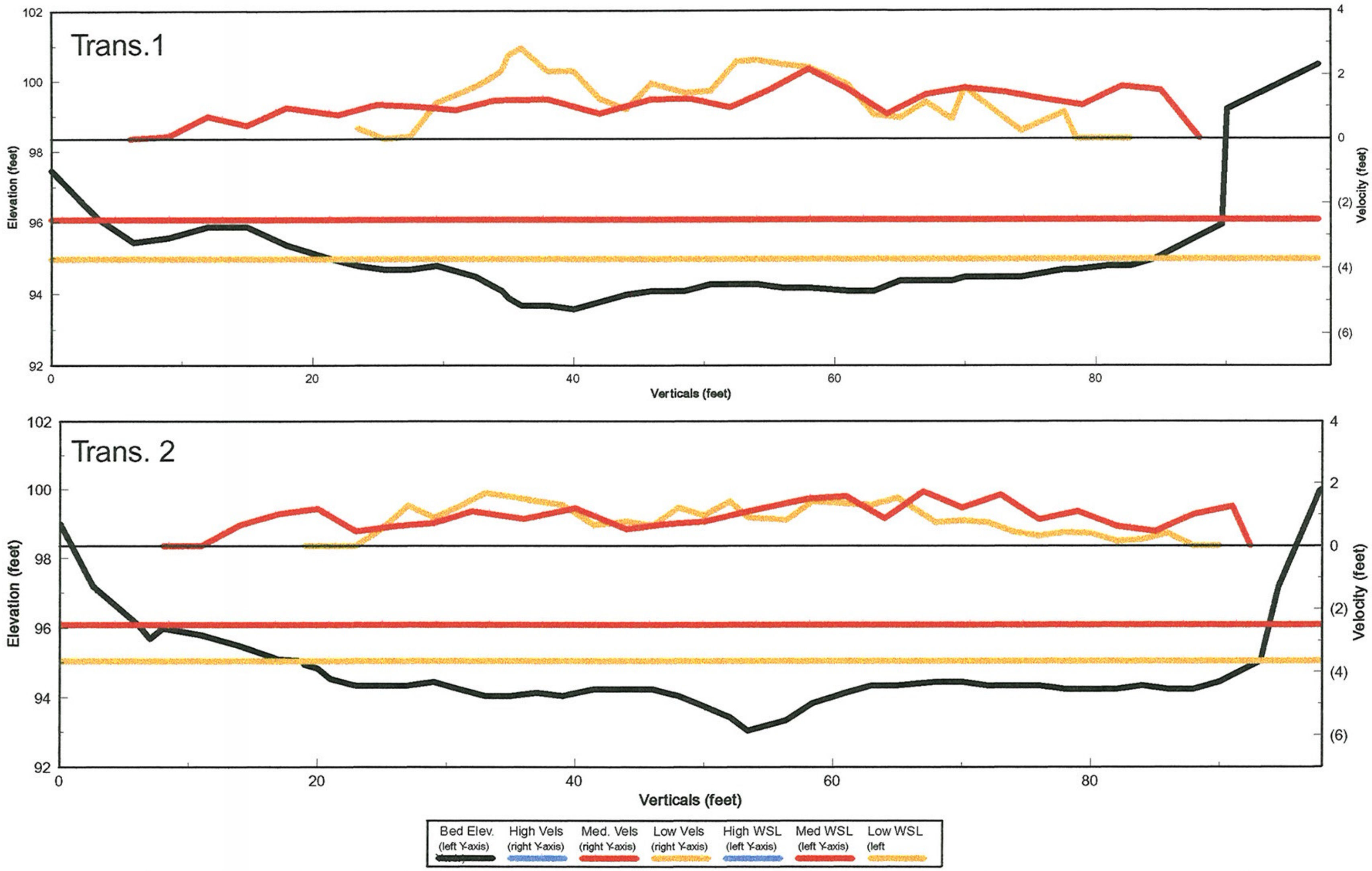
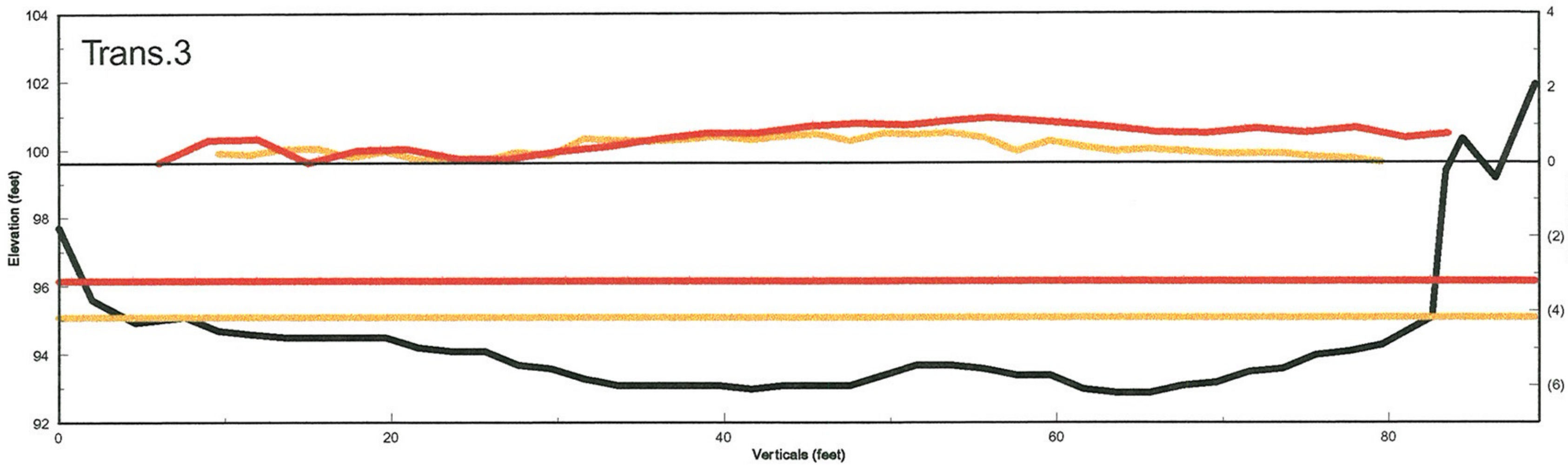
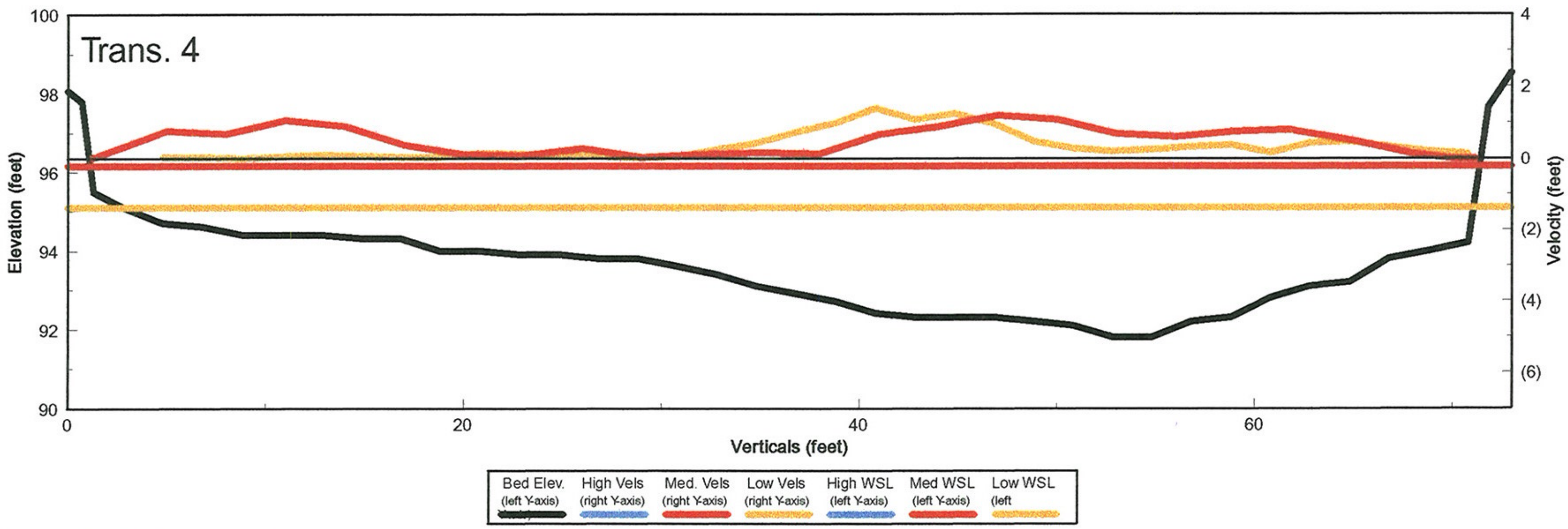


Appendix D4. Cross sections at the lower Clearwater site's transects showing bed elevations, and measured velocities and water surface elevations (WSL).





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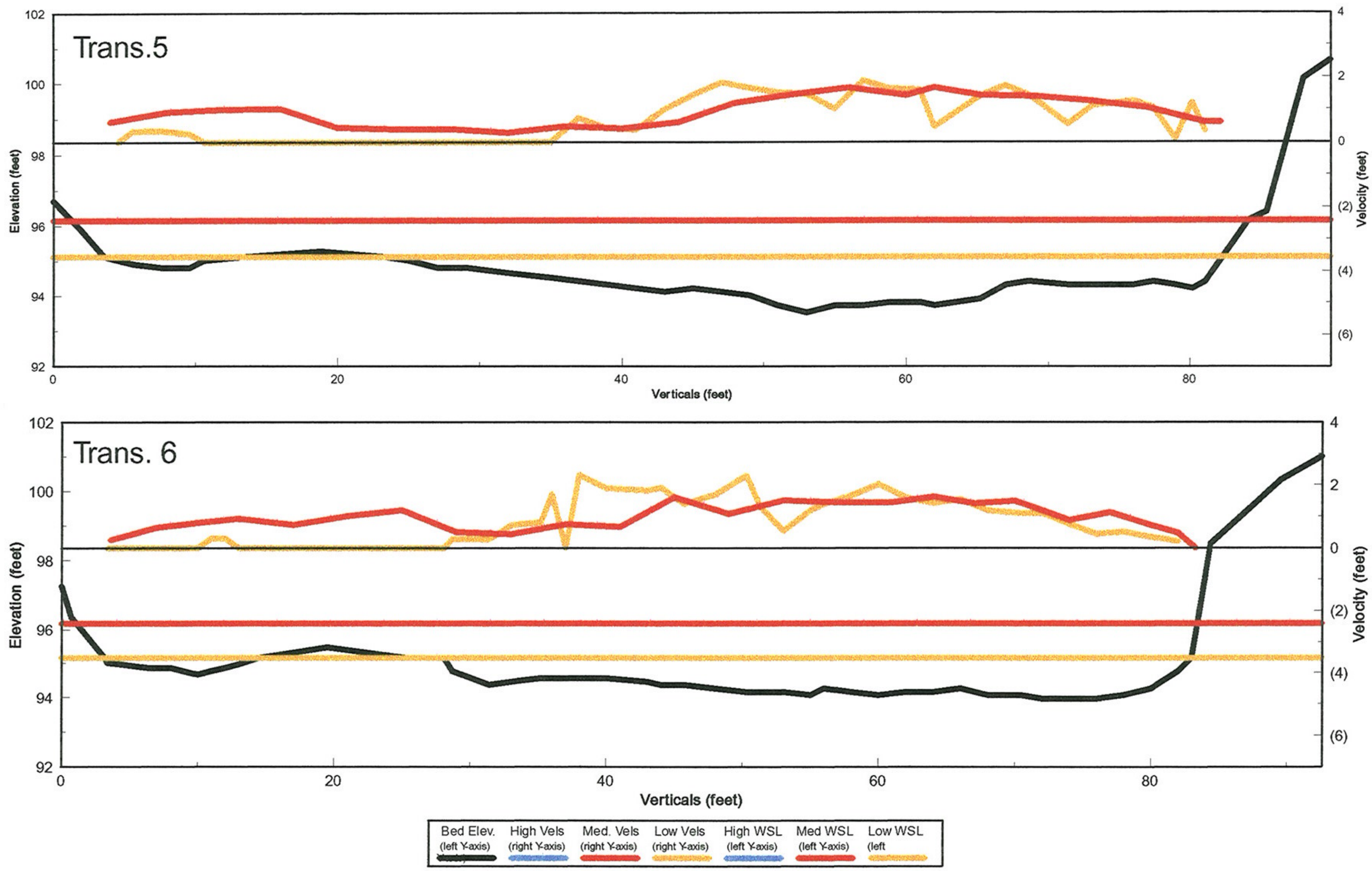

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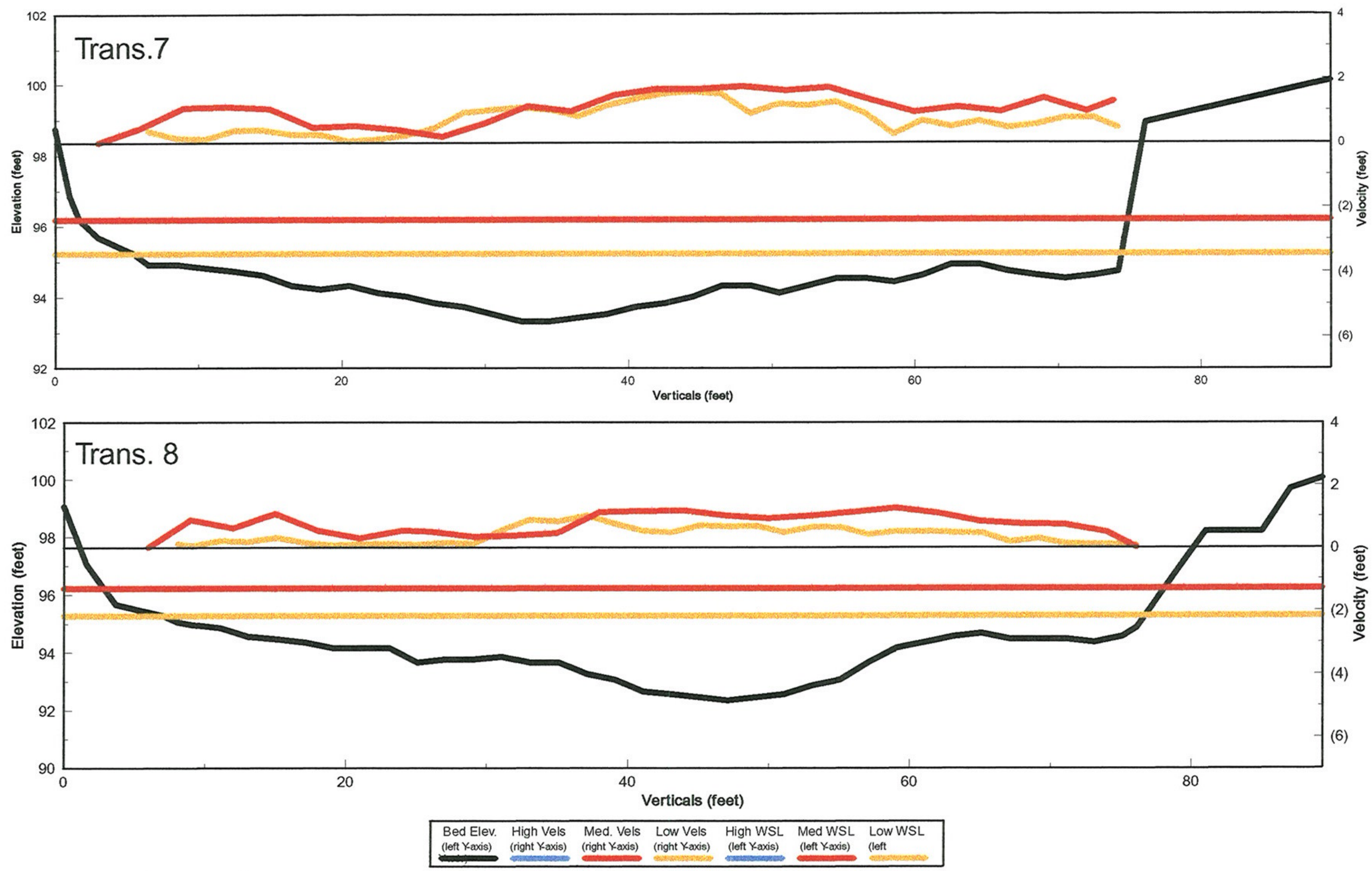

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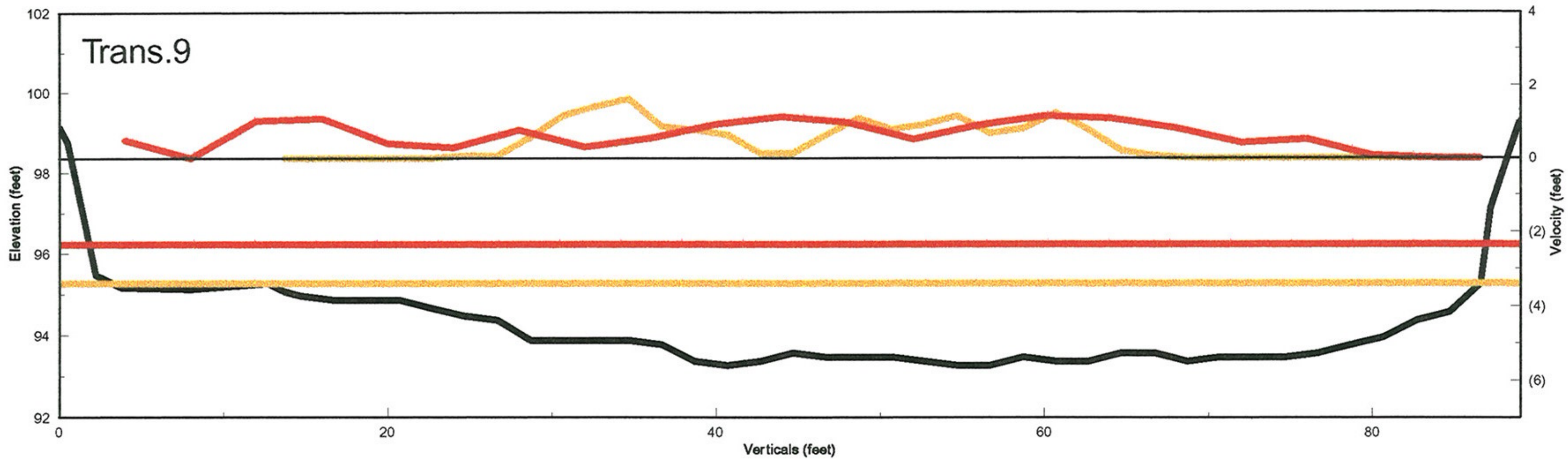

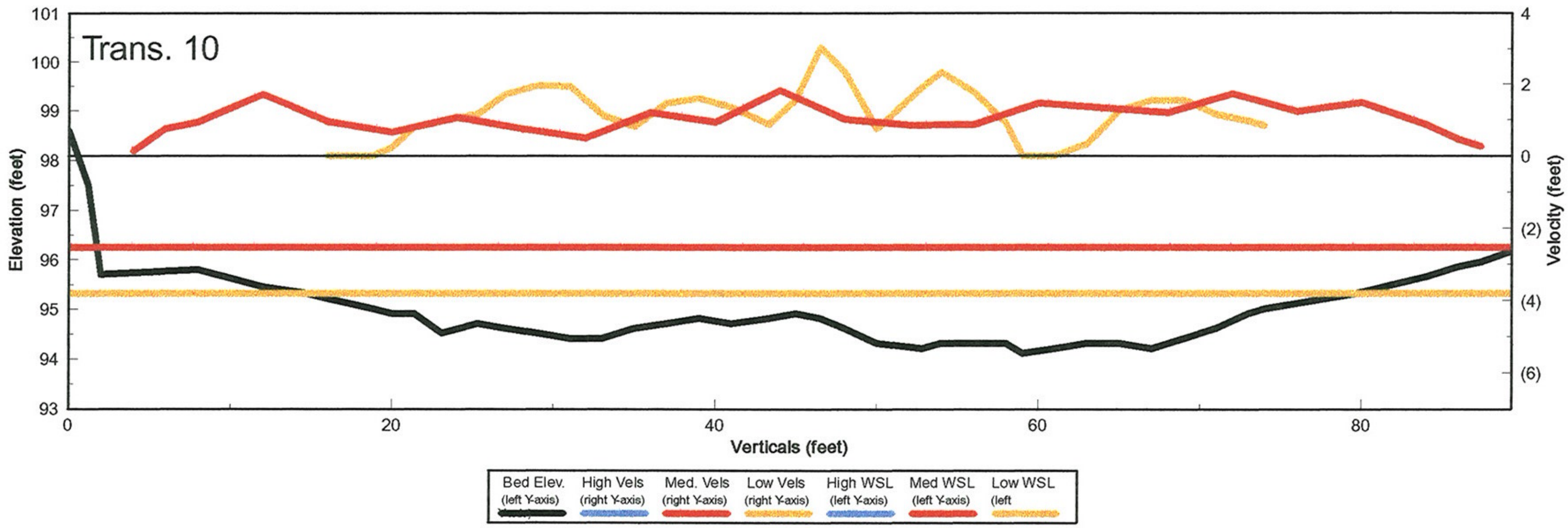

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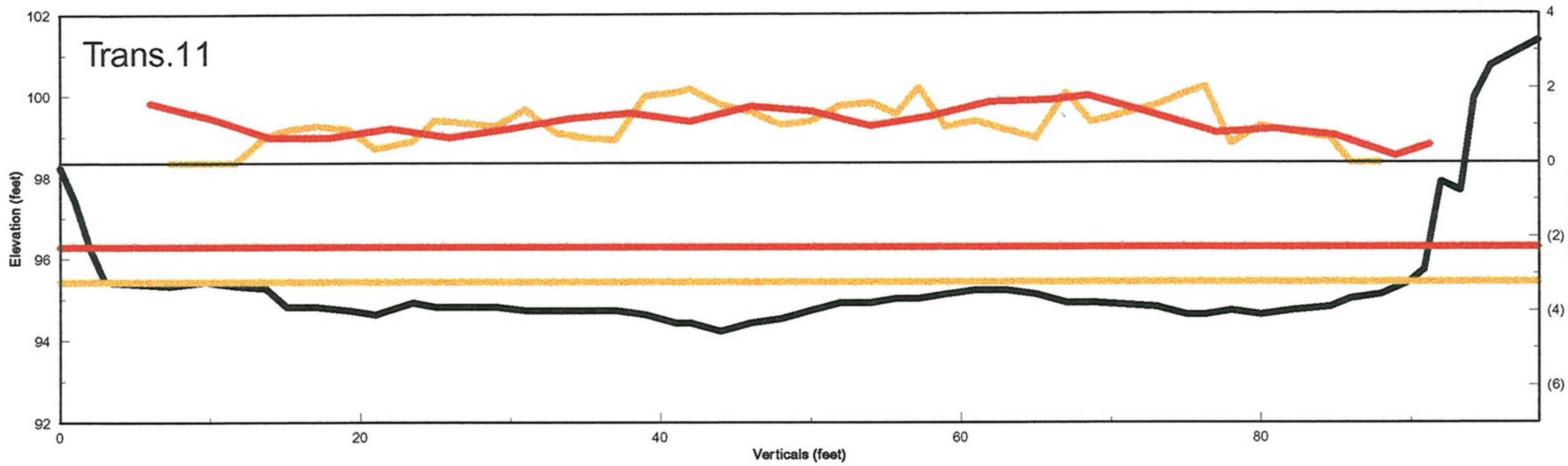

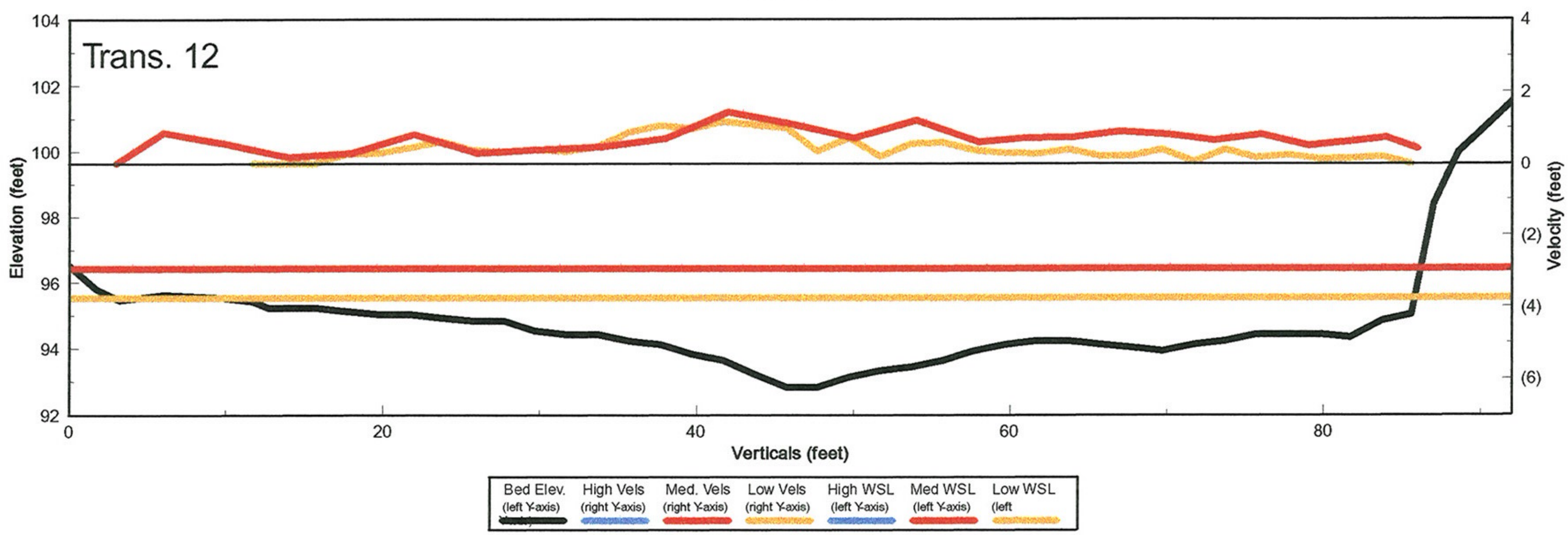

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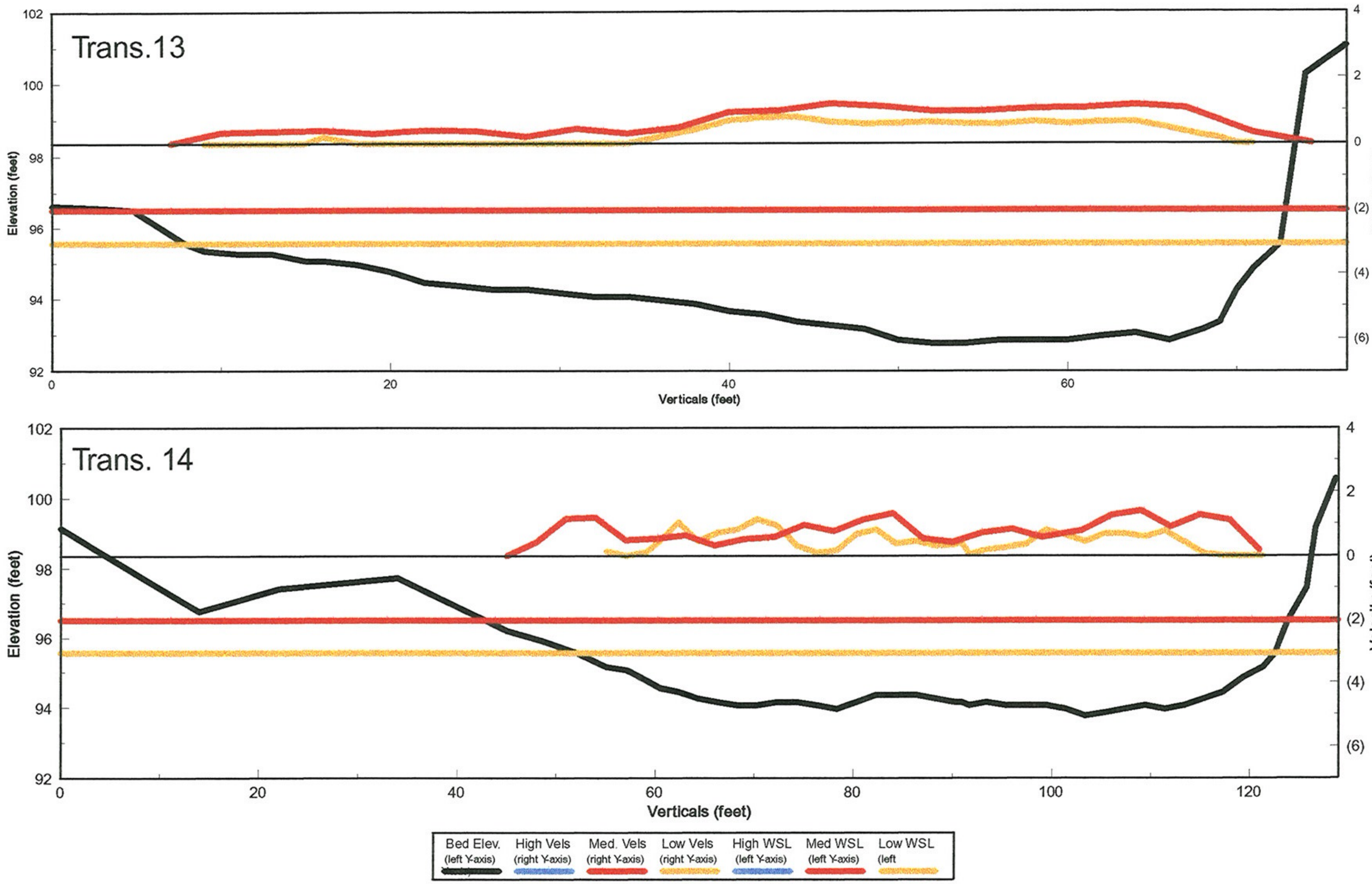
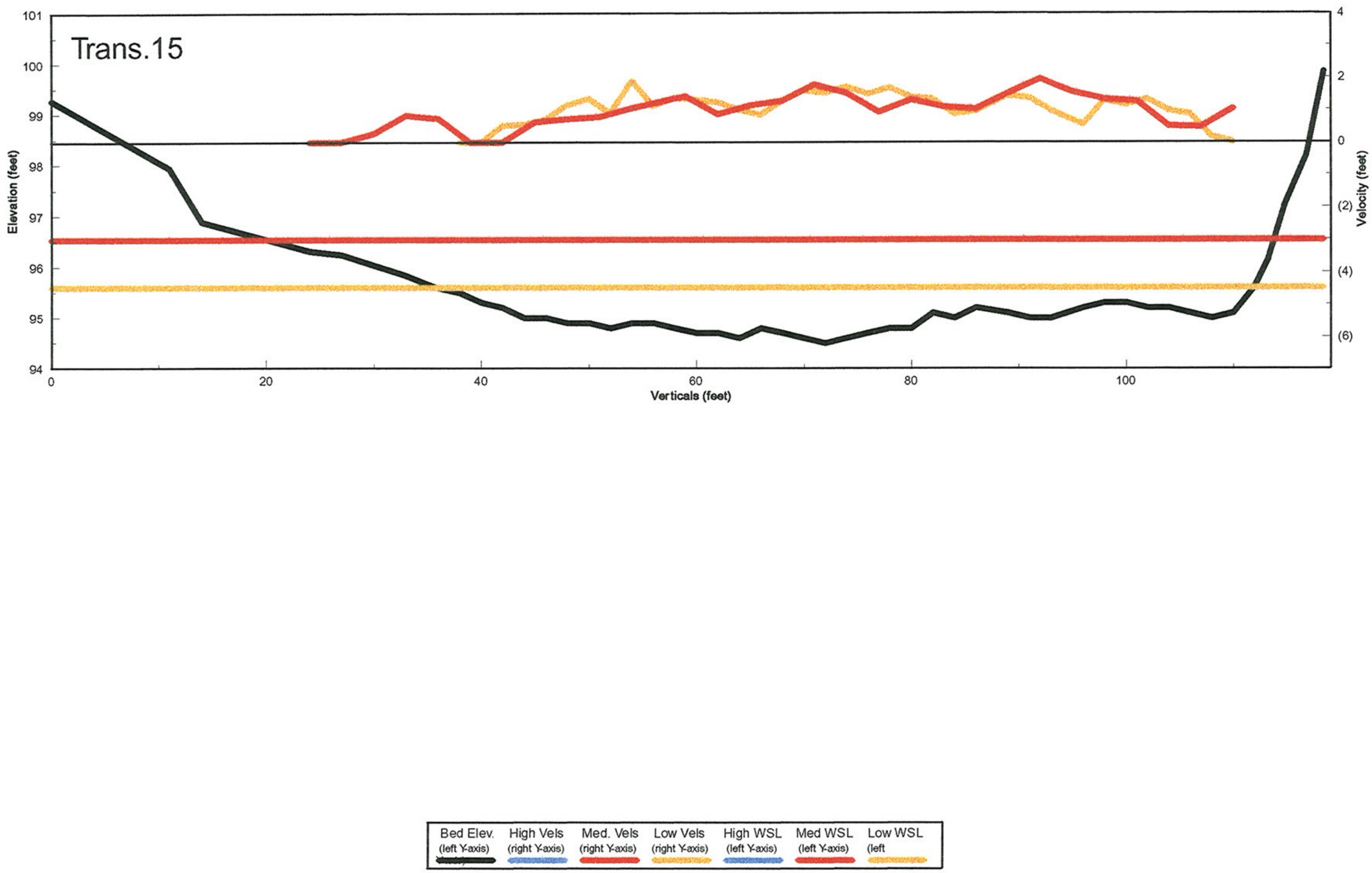


Appendix D4. Cross sections at the Lower Red Lake site's transects showing bed elevations, and measured velocities and water surface elevations (WSL).



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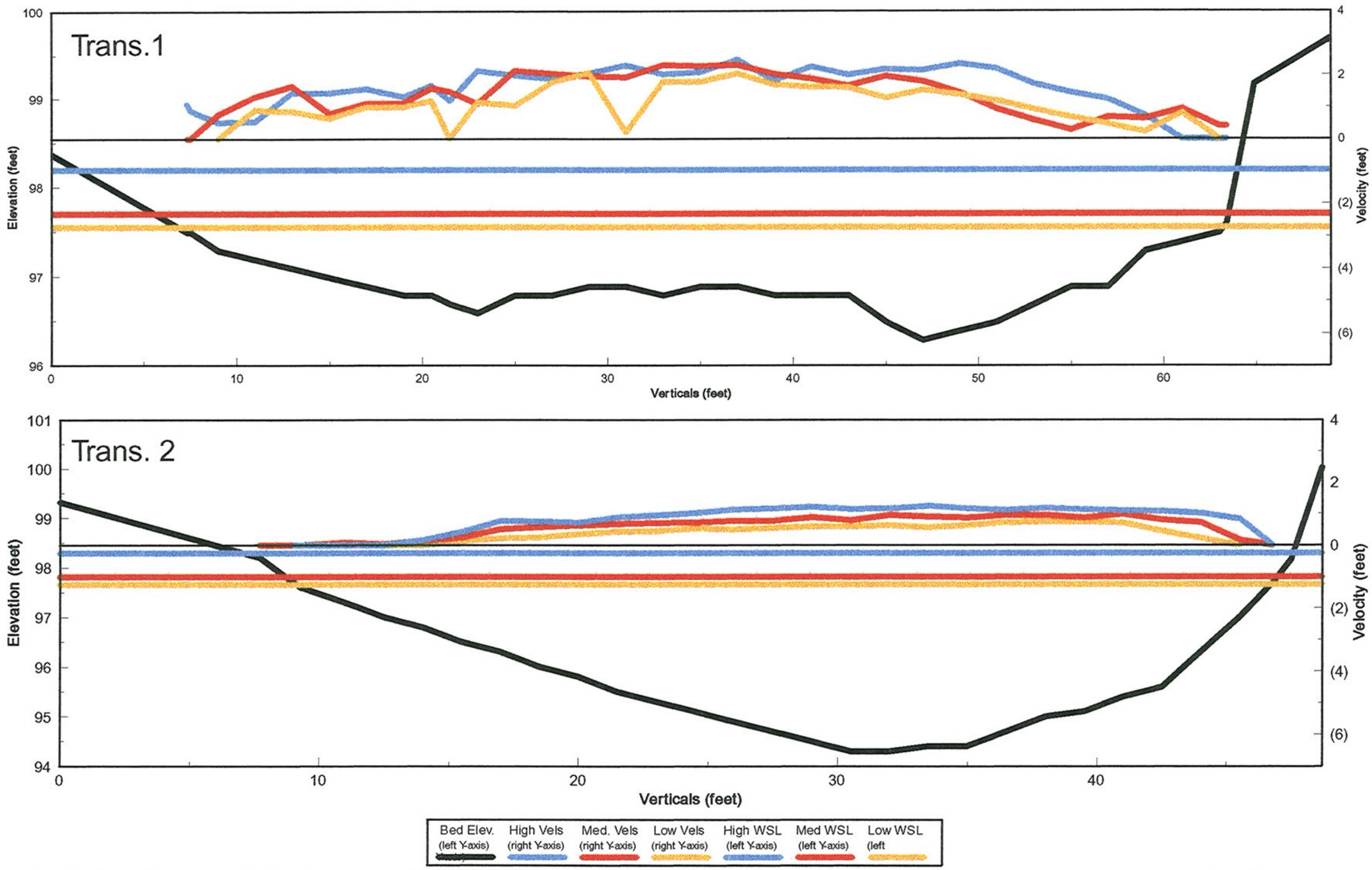
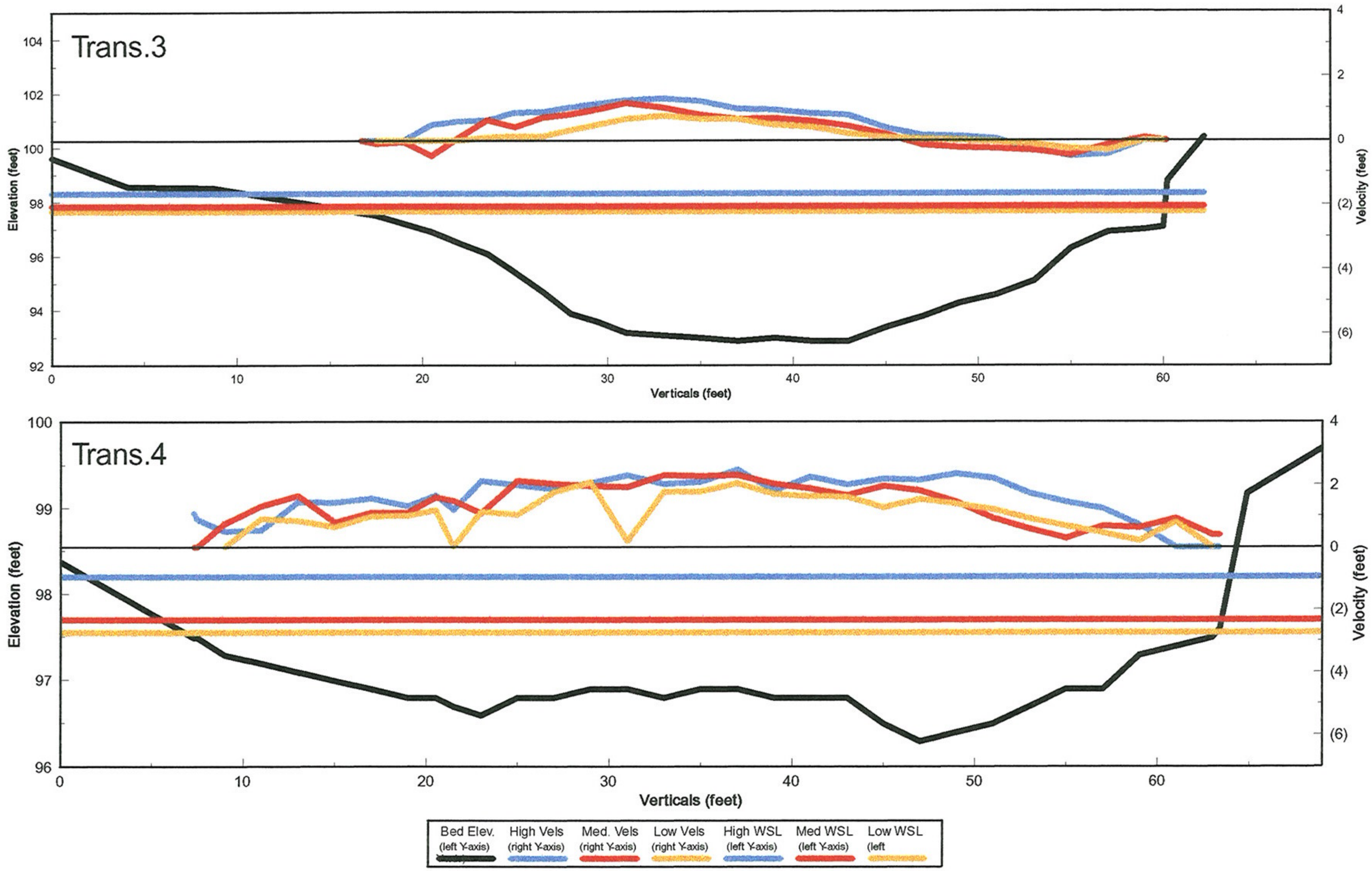


Appendix D5. Cross sections at the upper Clearwater site's transects showing bed elevations, and measured velocities and water surface elevations (WSL).



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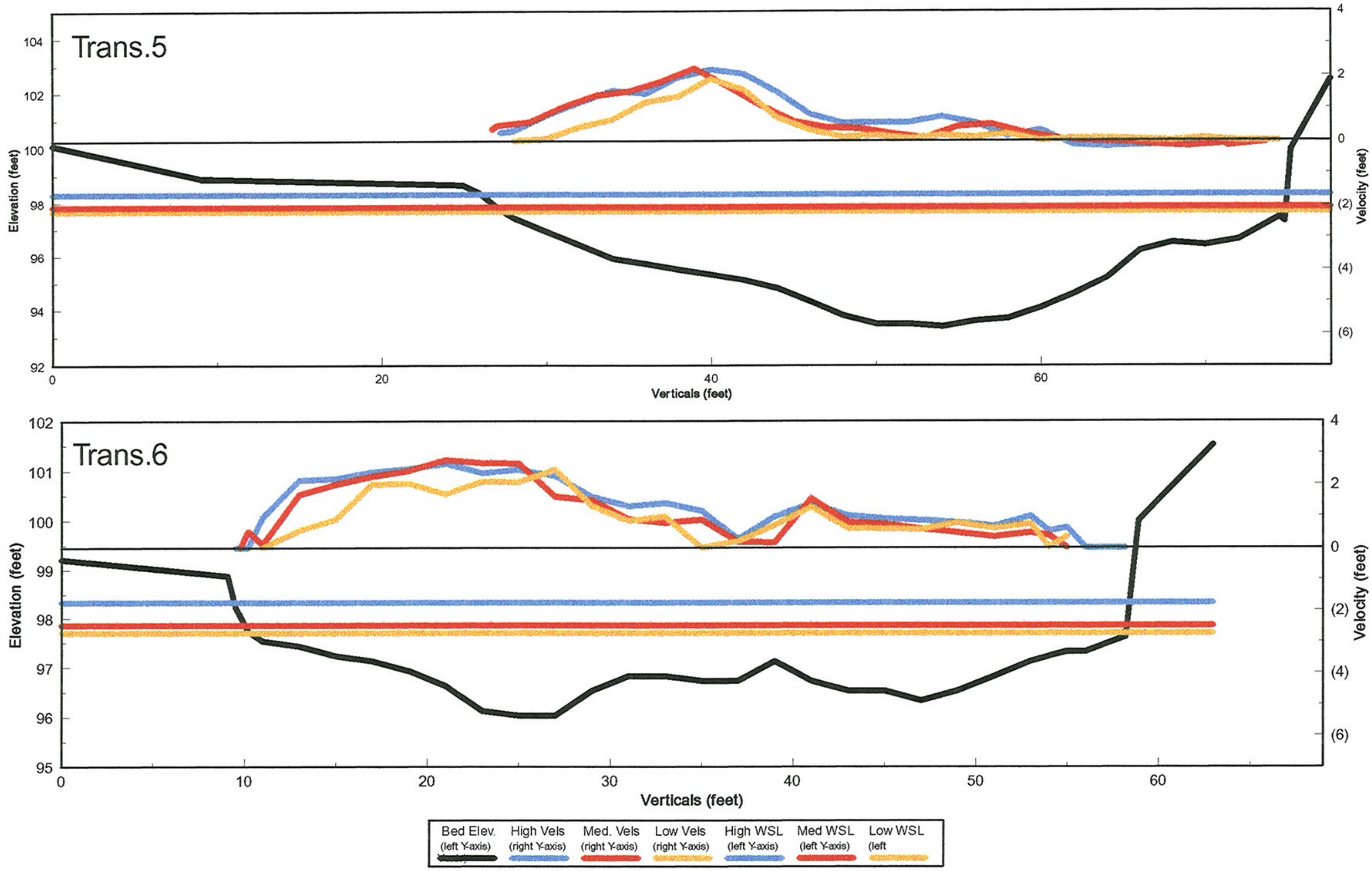

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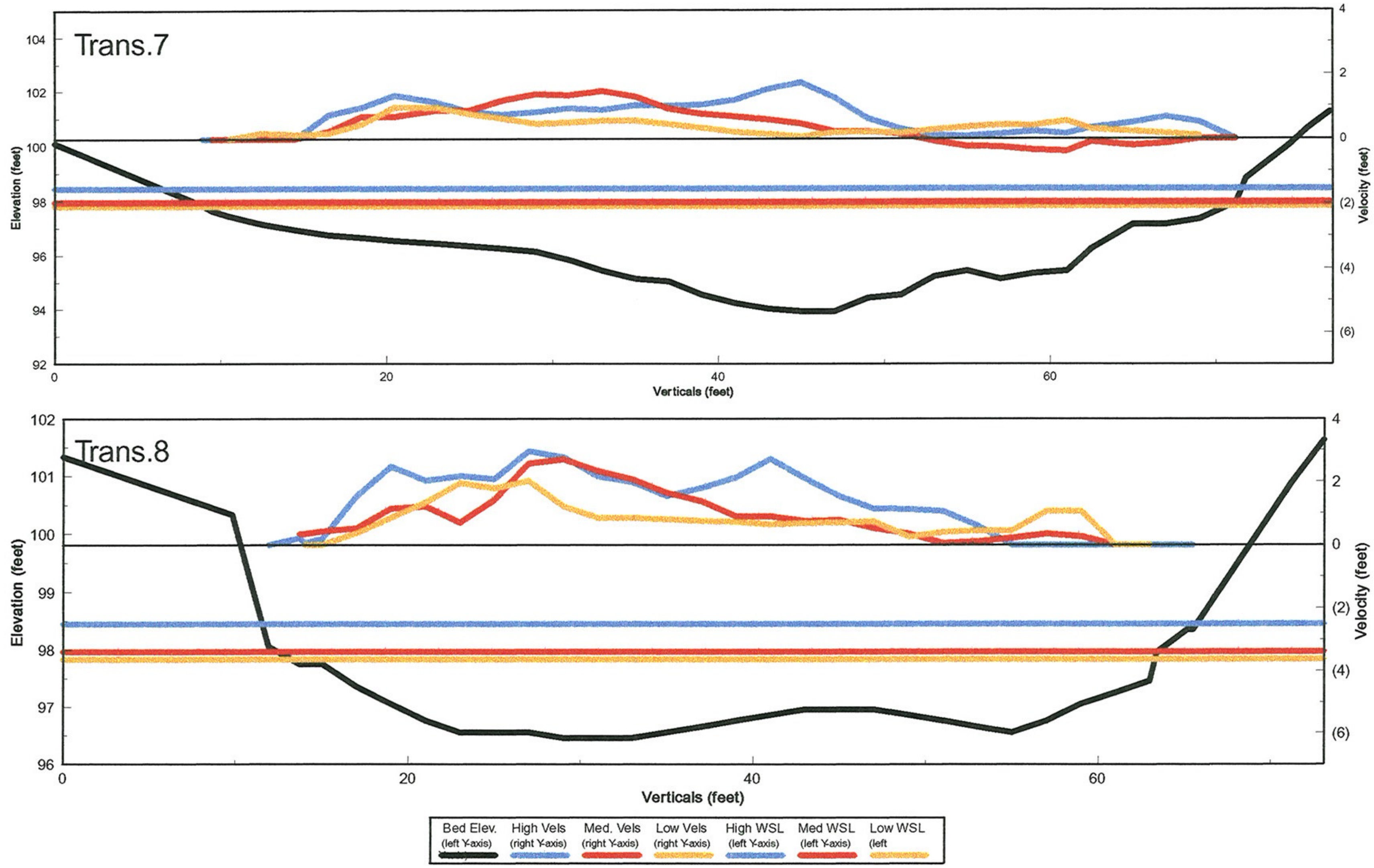

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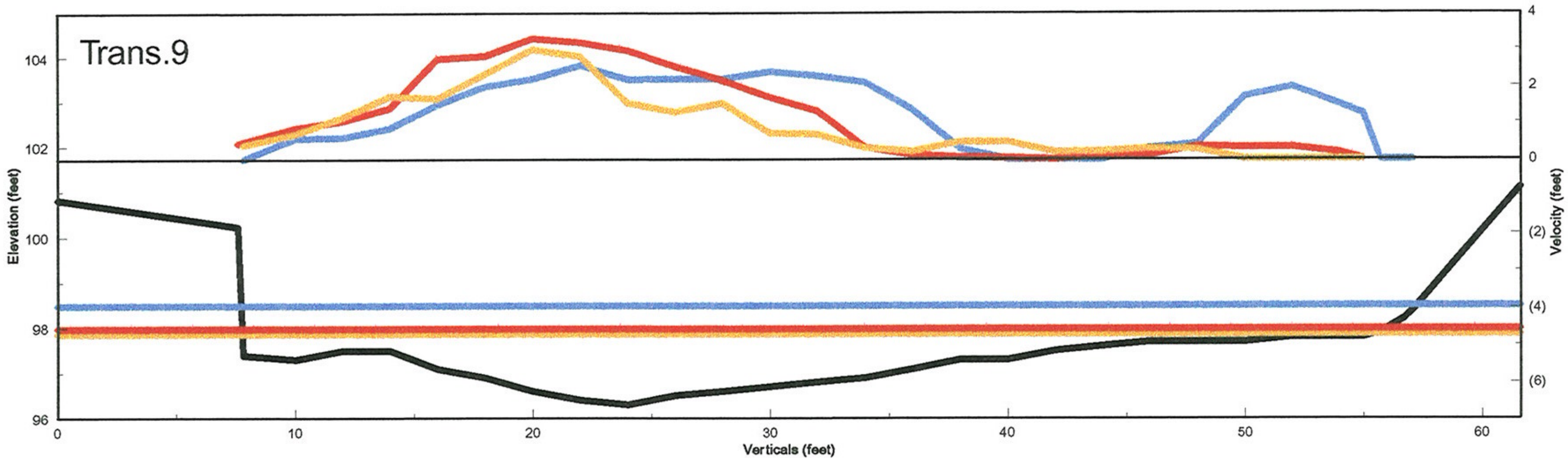

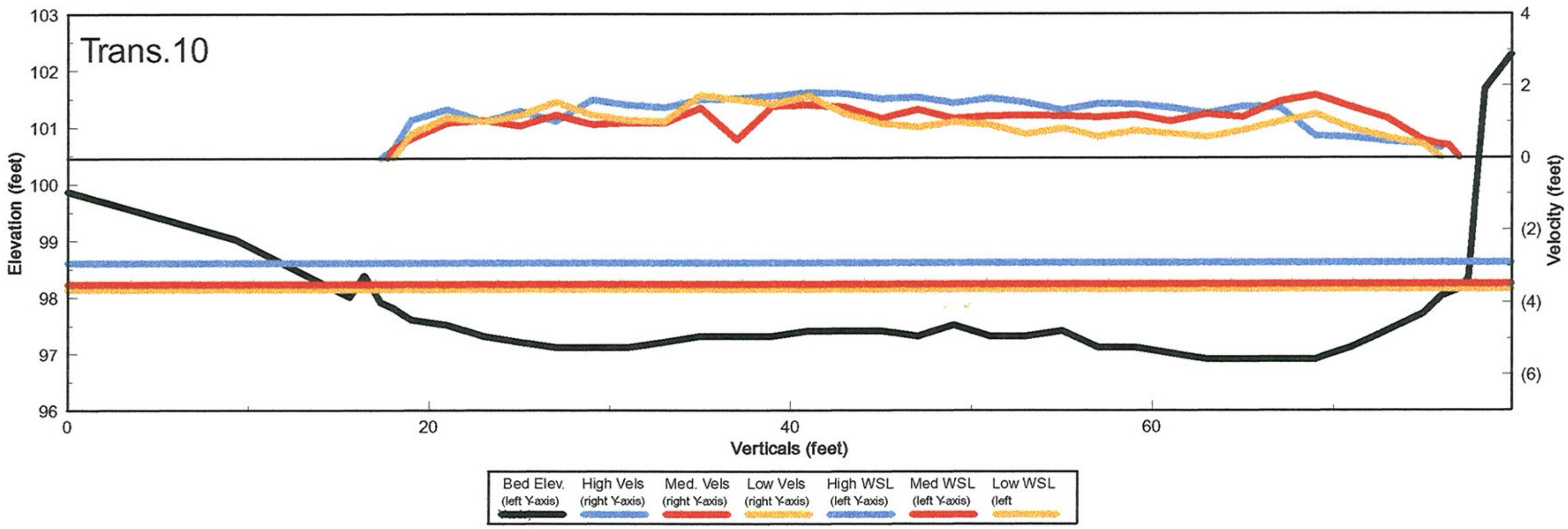

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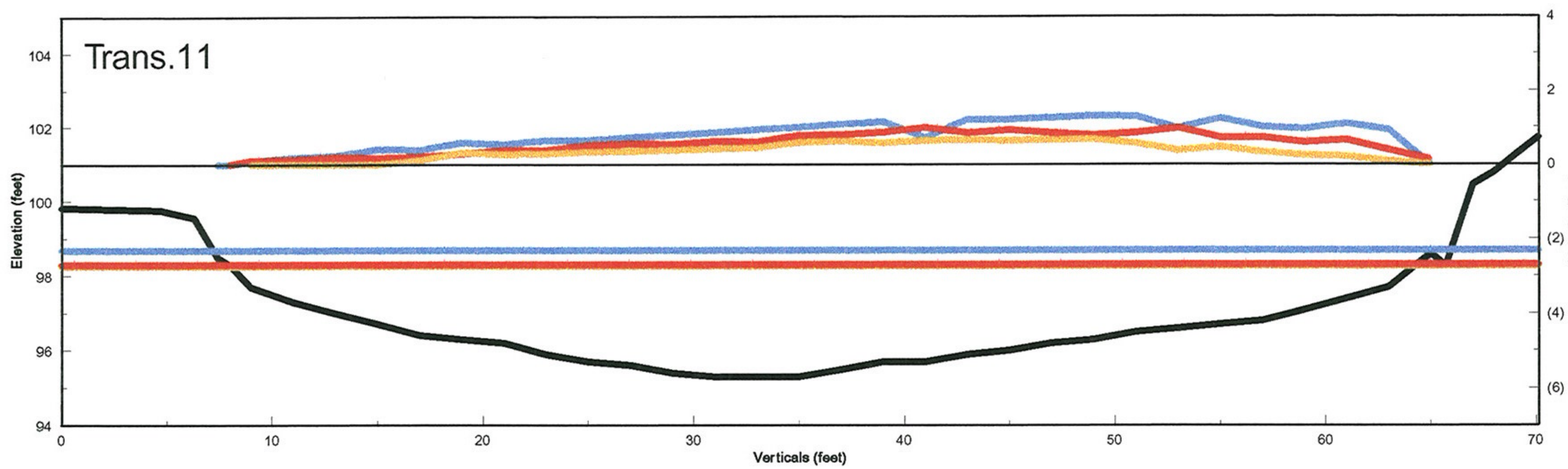

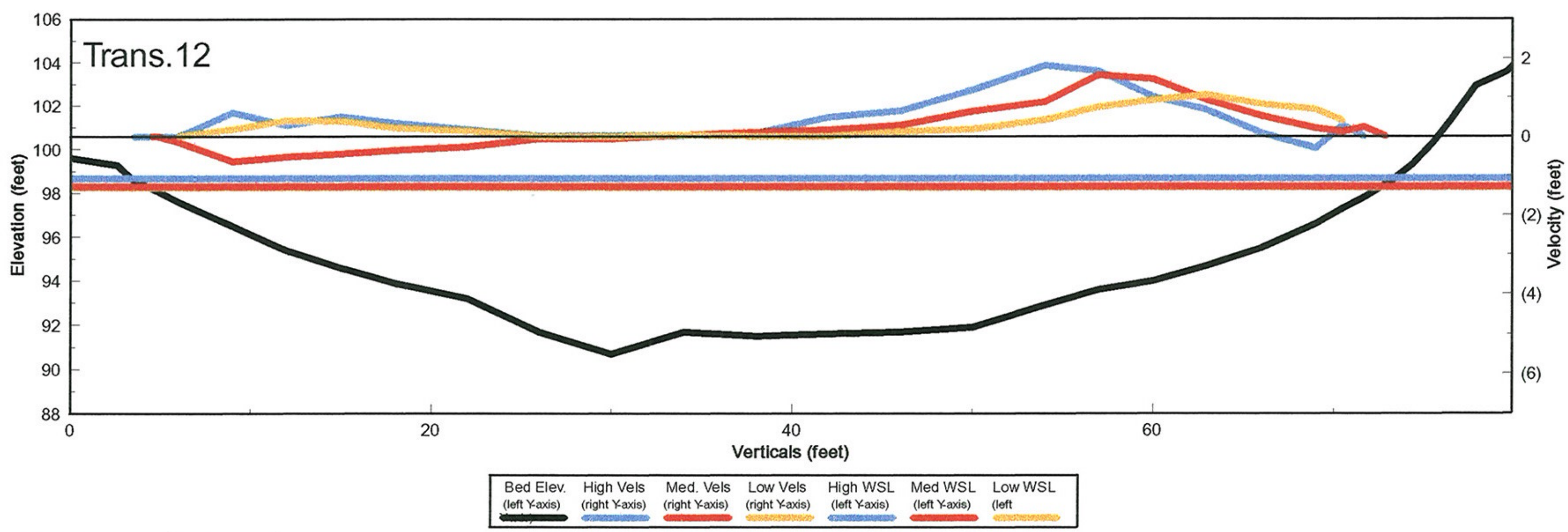

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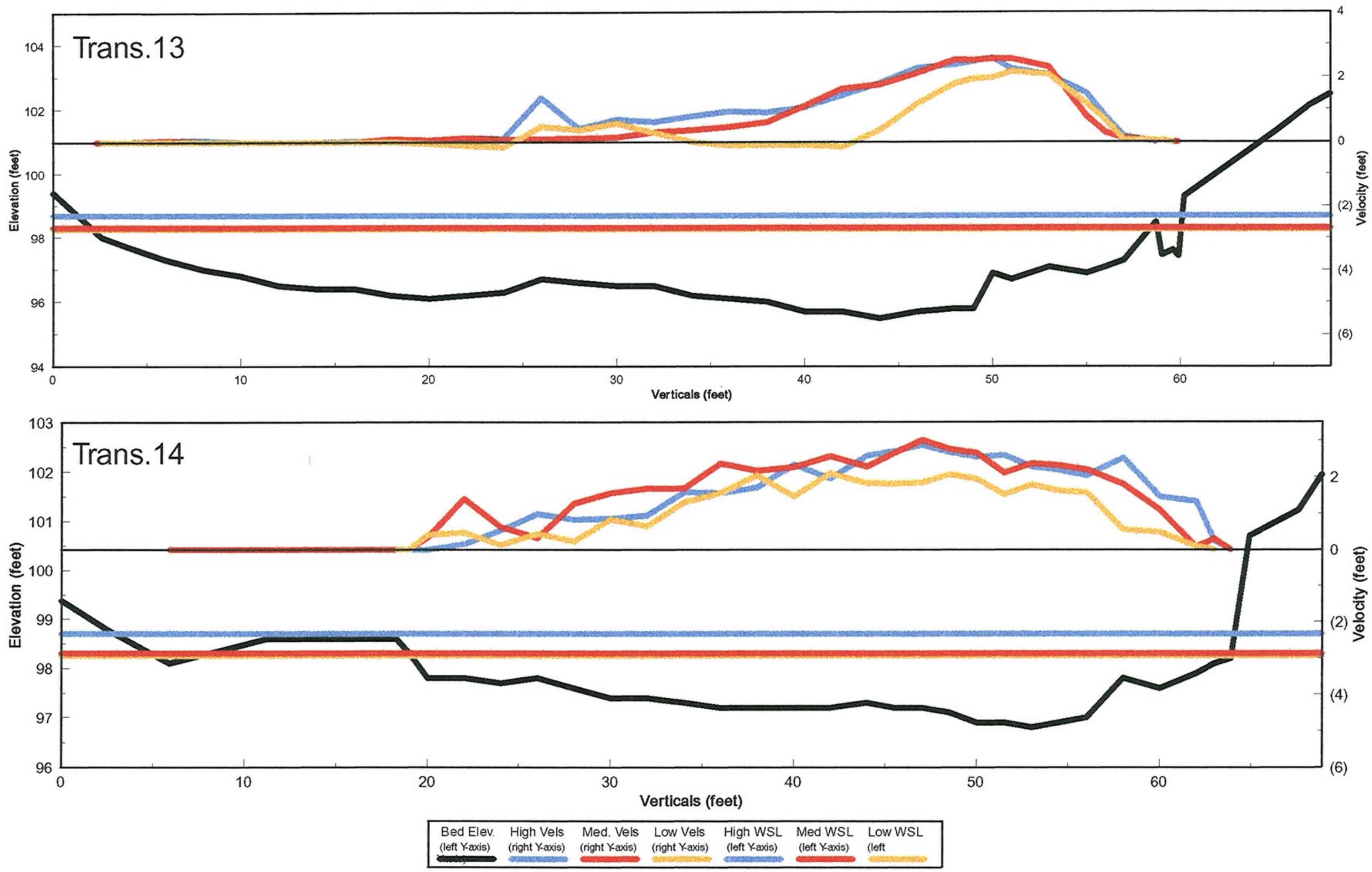

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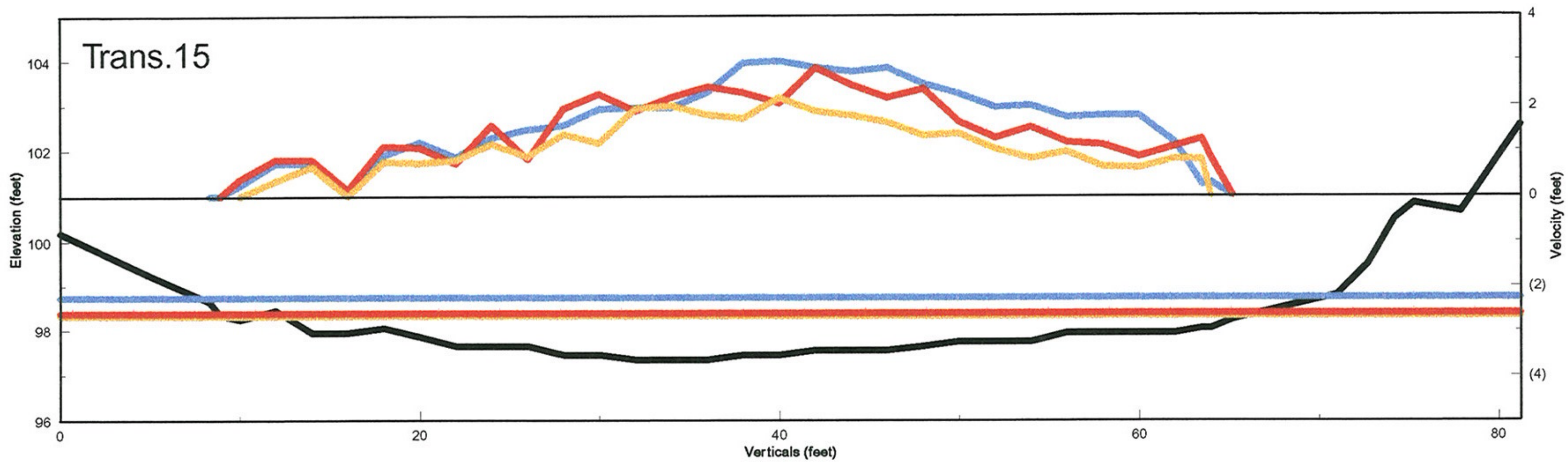

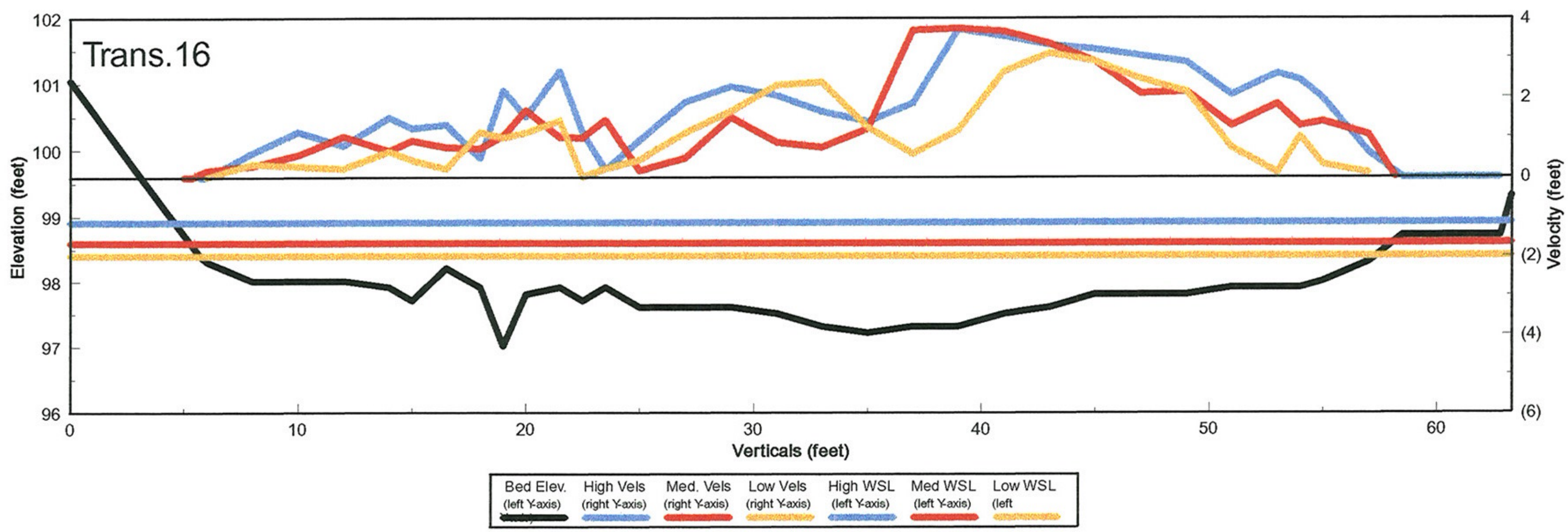

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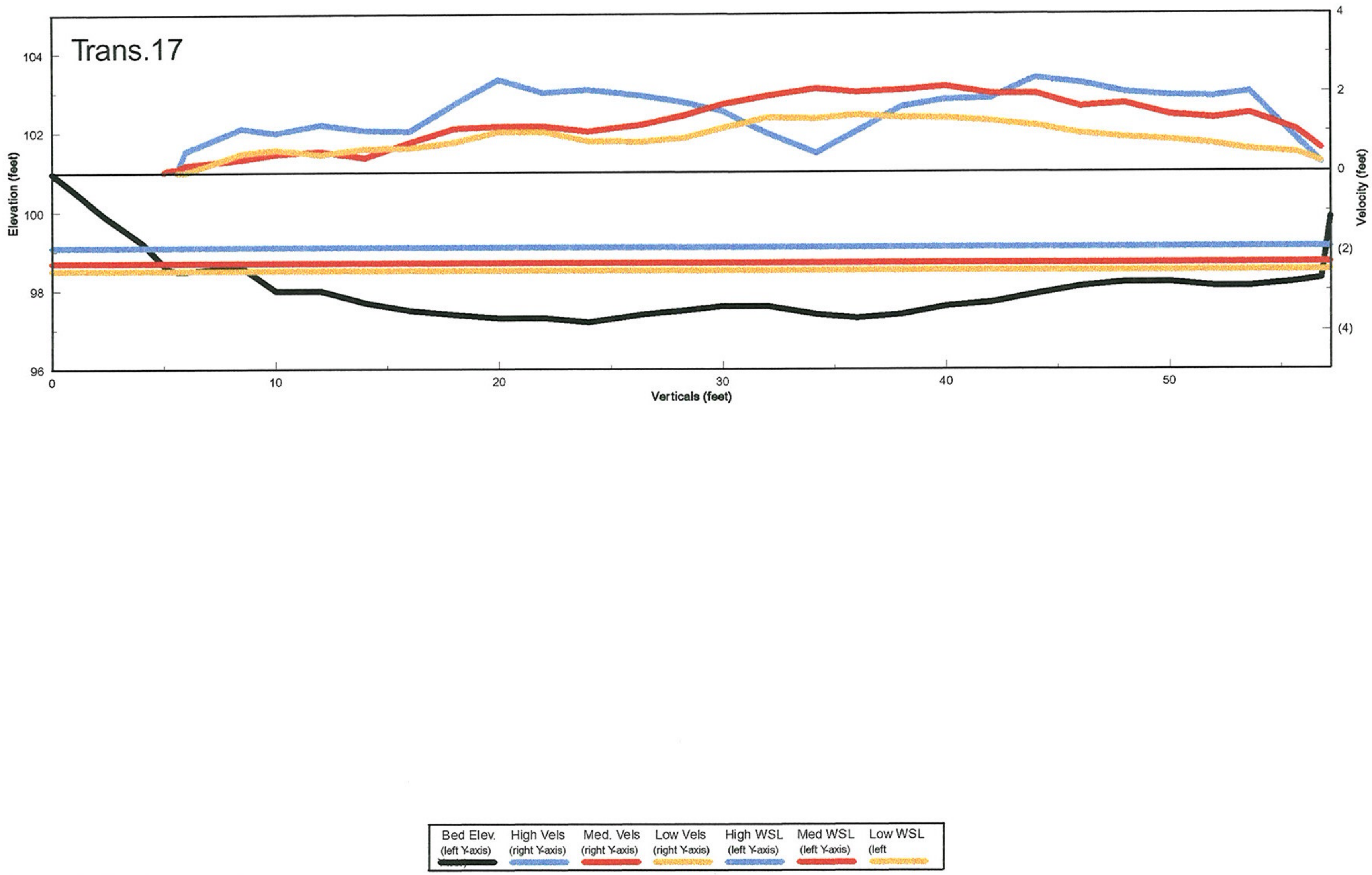
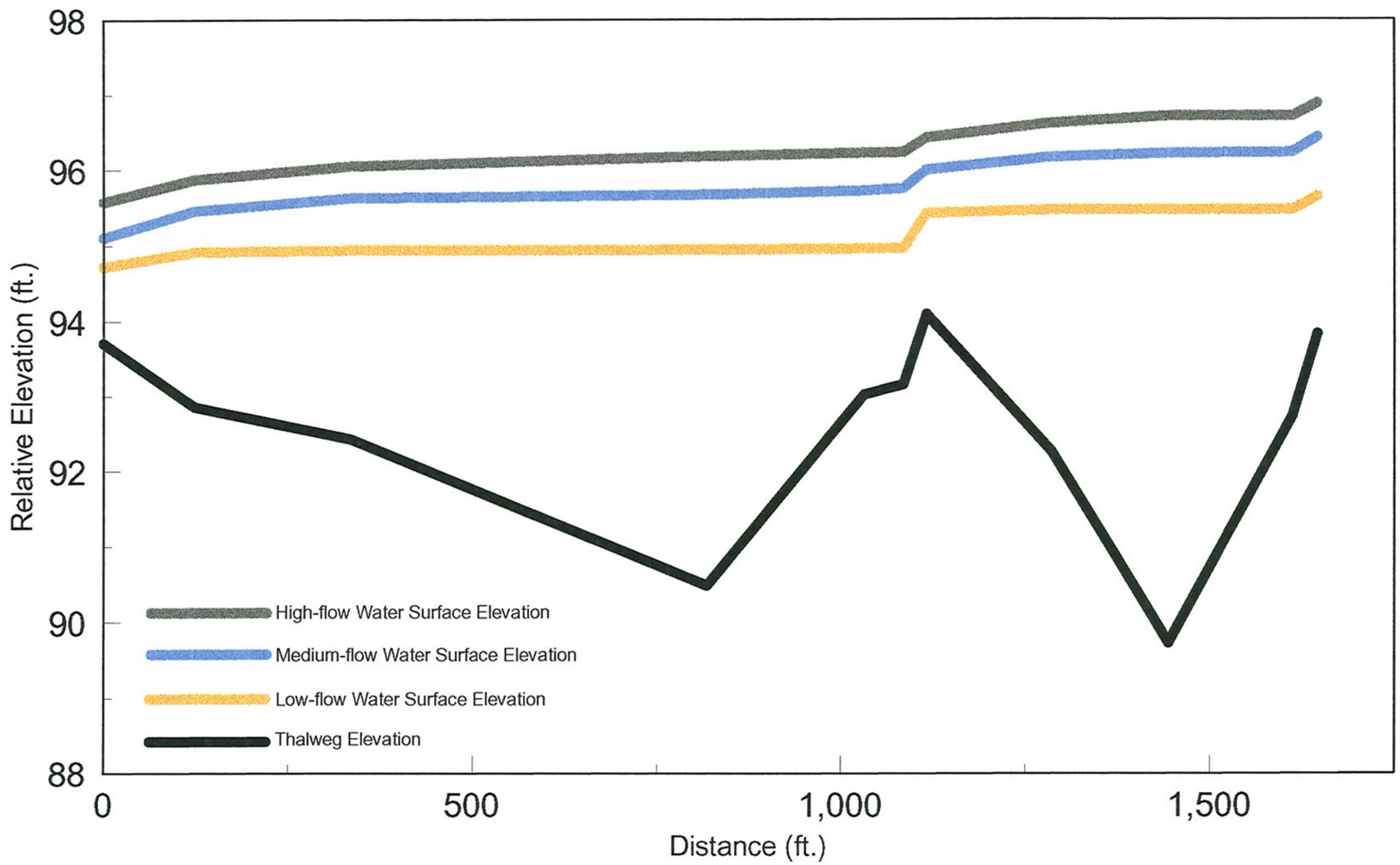
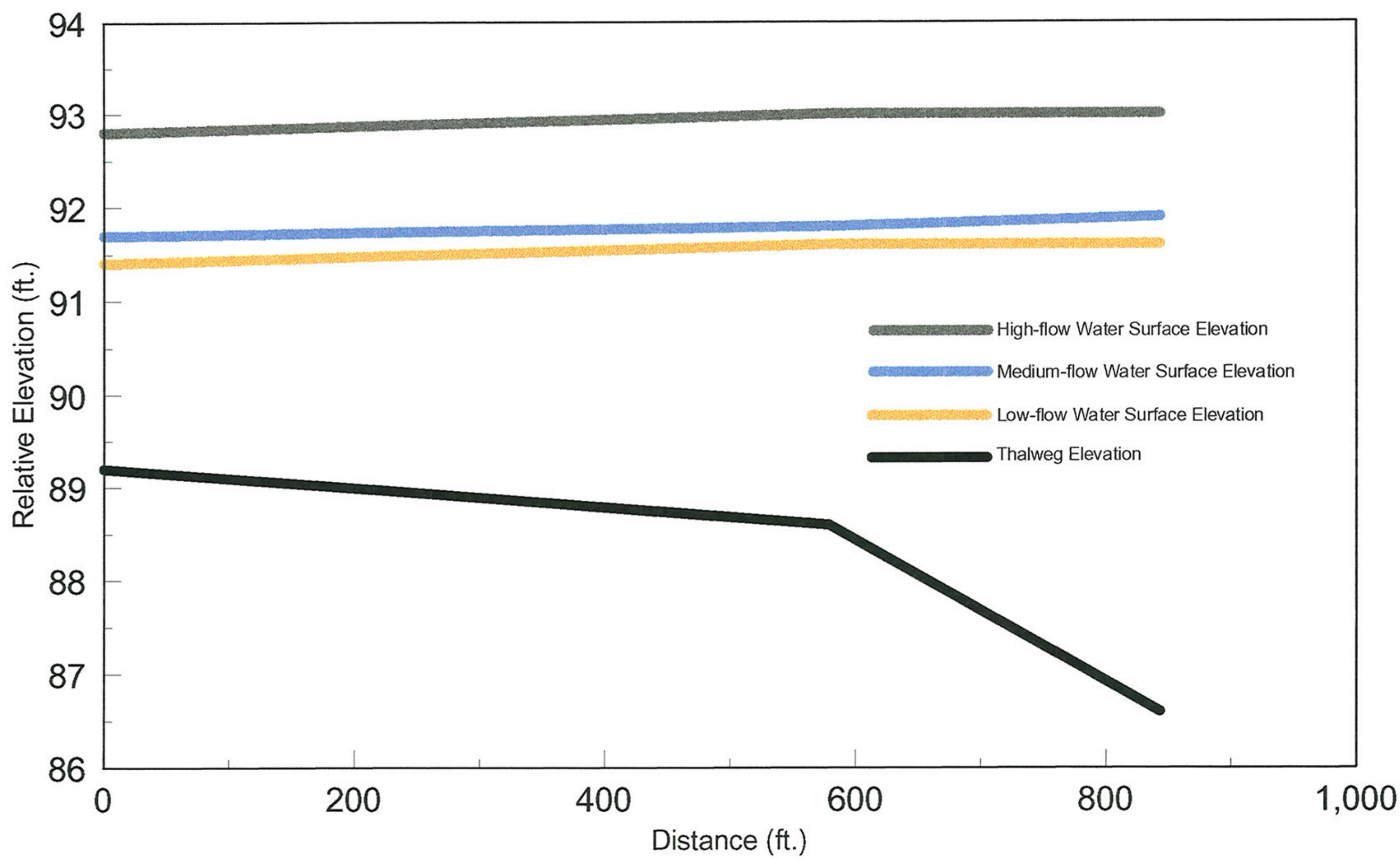


Appendix D5. (continued)

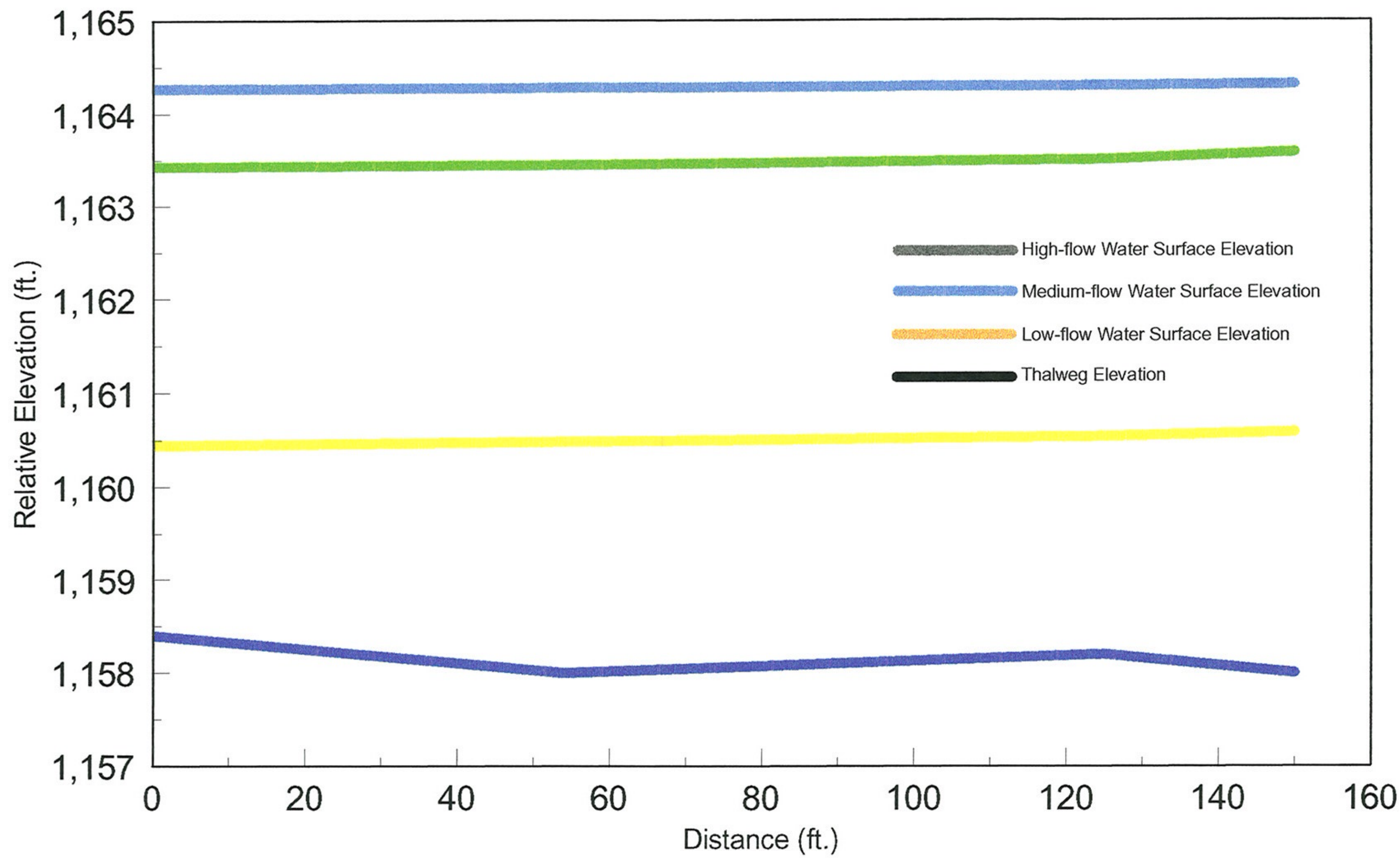
Appendix E1. Longitudinal profile of thalweg and measured water surface elevations at the lower Red Lake site.



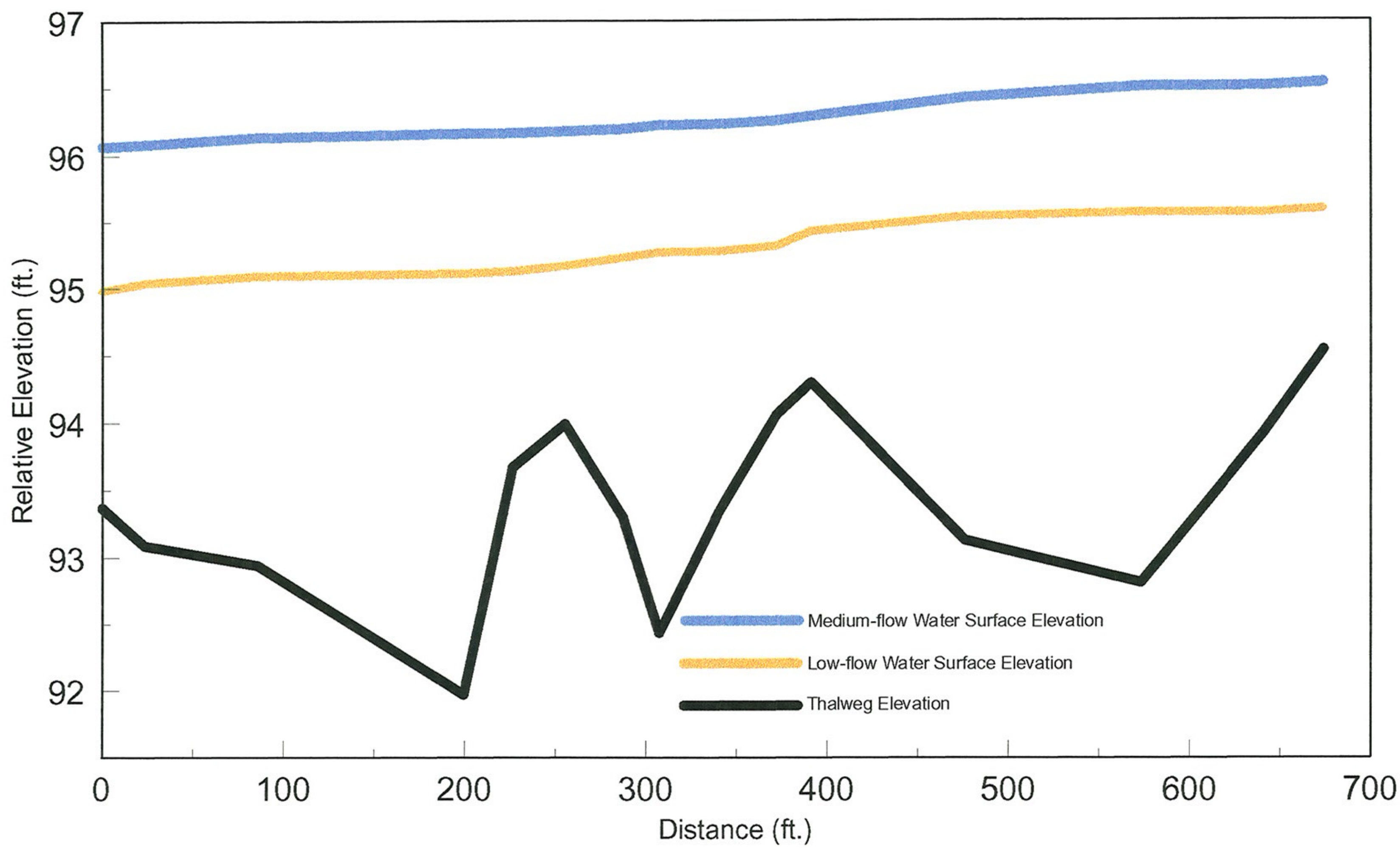
Appendix E2. Longitudinal profile of thalweg and measured water surface elevations at the middle Red Lake site.



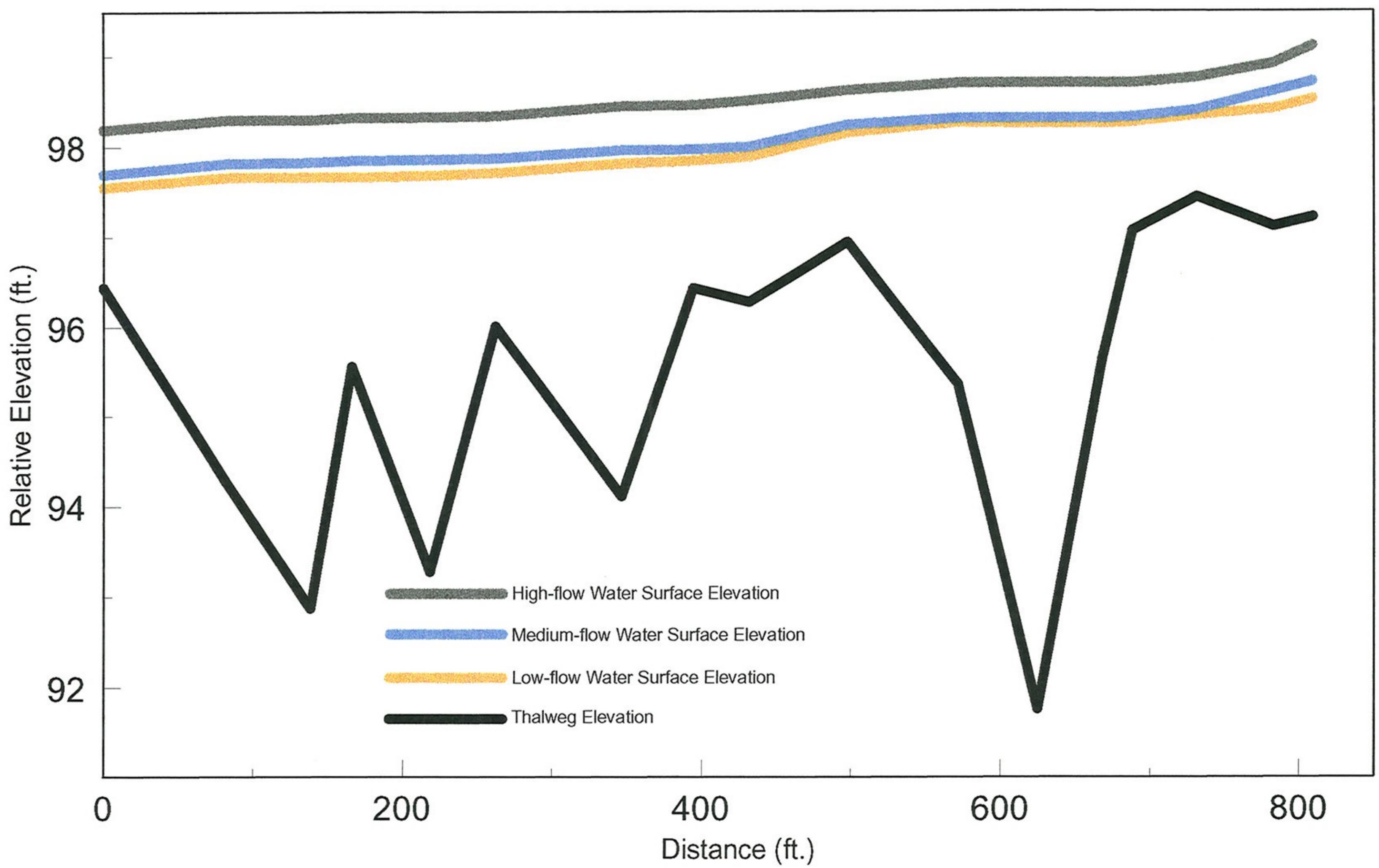
Appendix E3. Longitudinal profile of thalweg and measured water surface elevations at the upper Red Lake site.



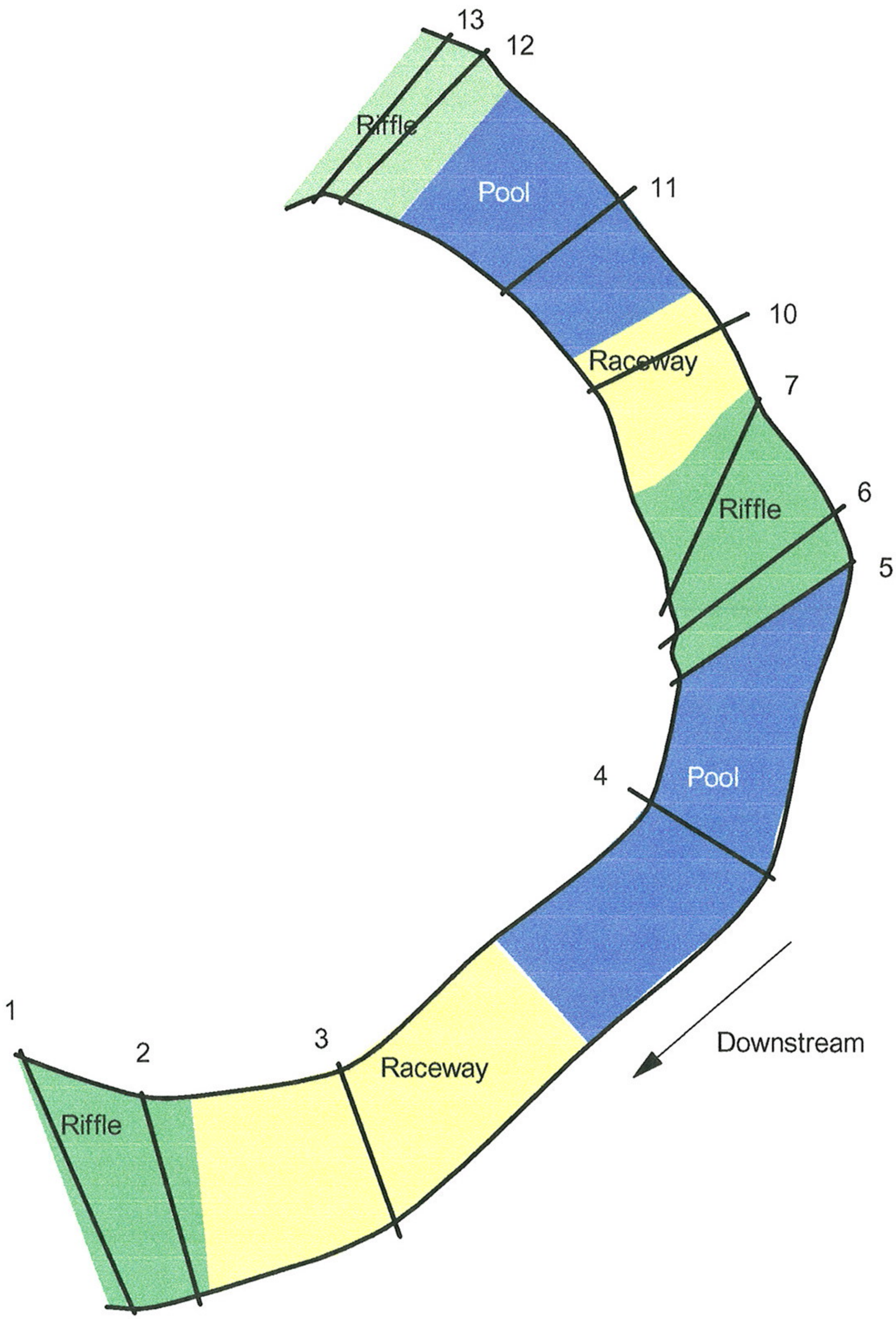
Appendix E4. Longitudinal profile of thalweg and measured water surface elevations at the lower Clearwater site.



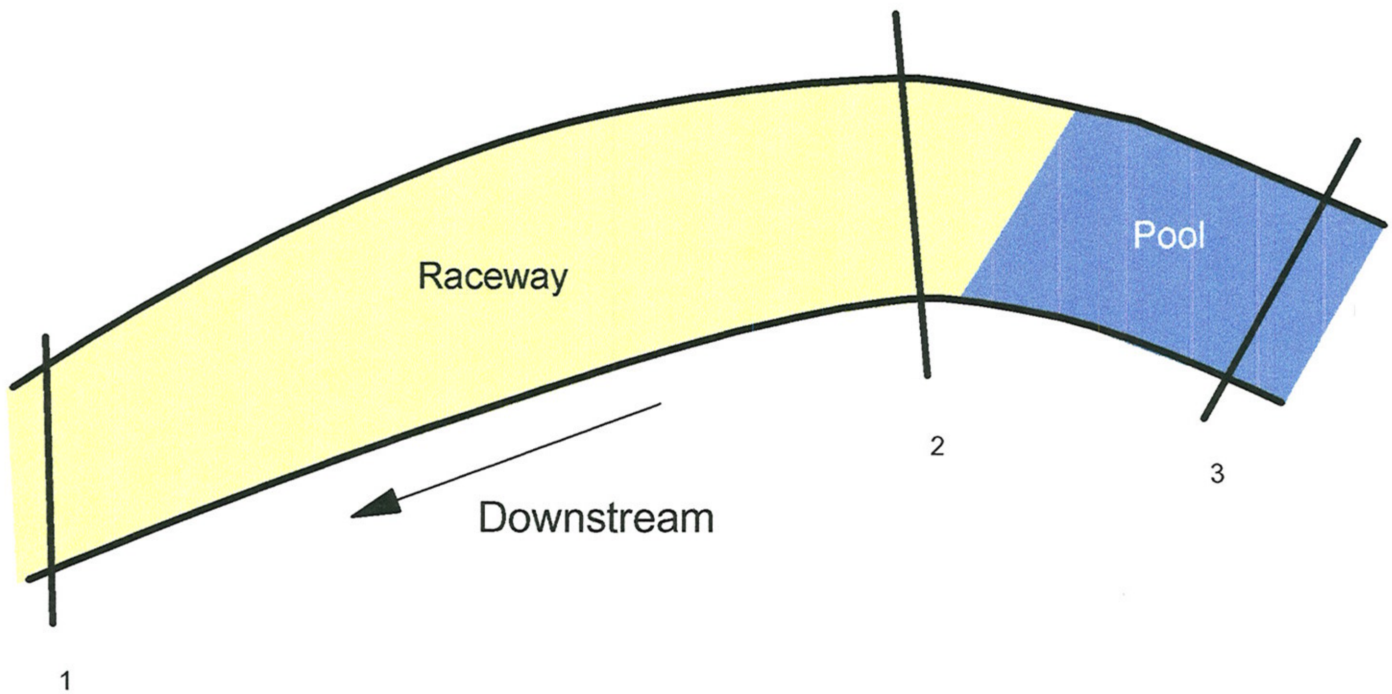
Appendix E5. Longitudinal profile of thalweg and measured water surface elevations at the upper Clearwater site.



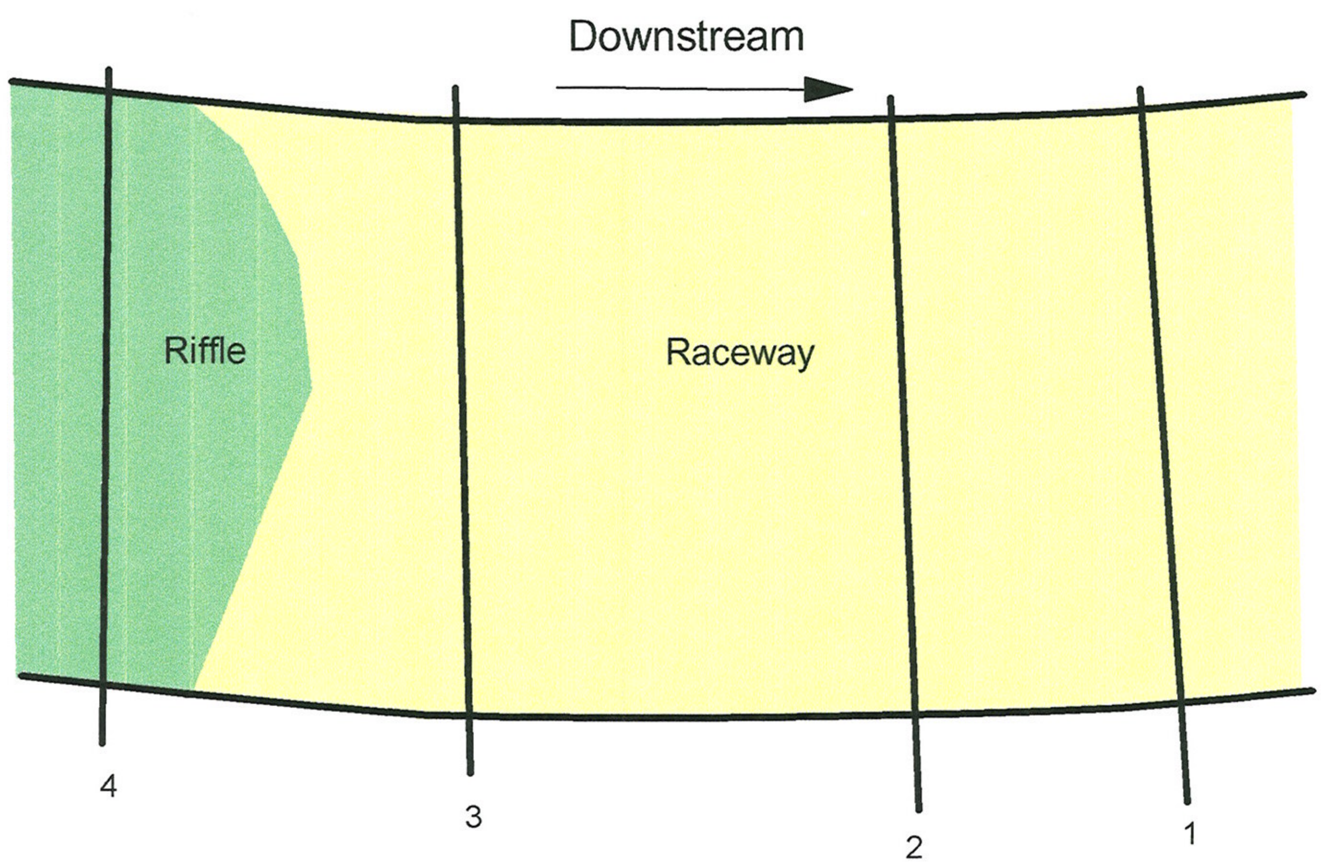
Appendix F1. Map of lower Red Lake River study site showing transects and general habitat types.



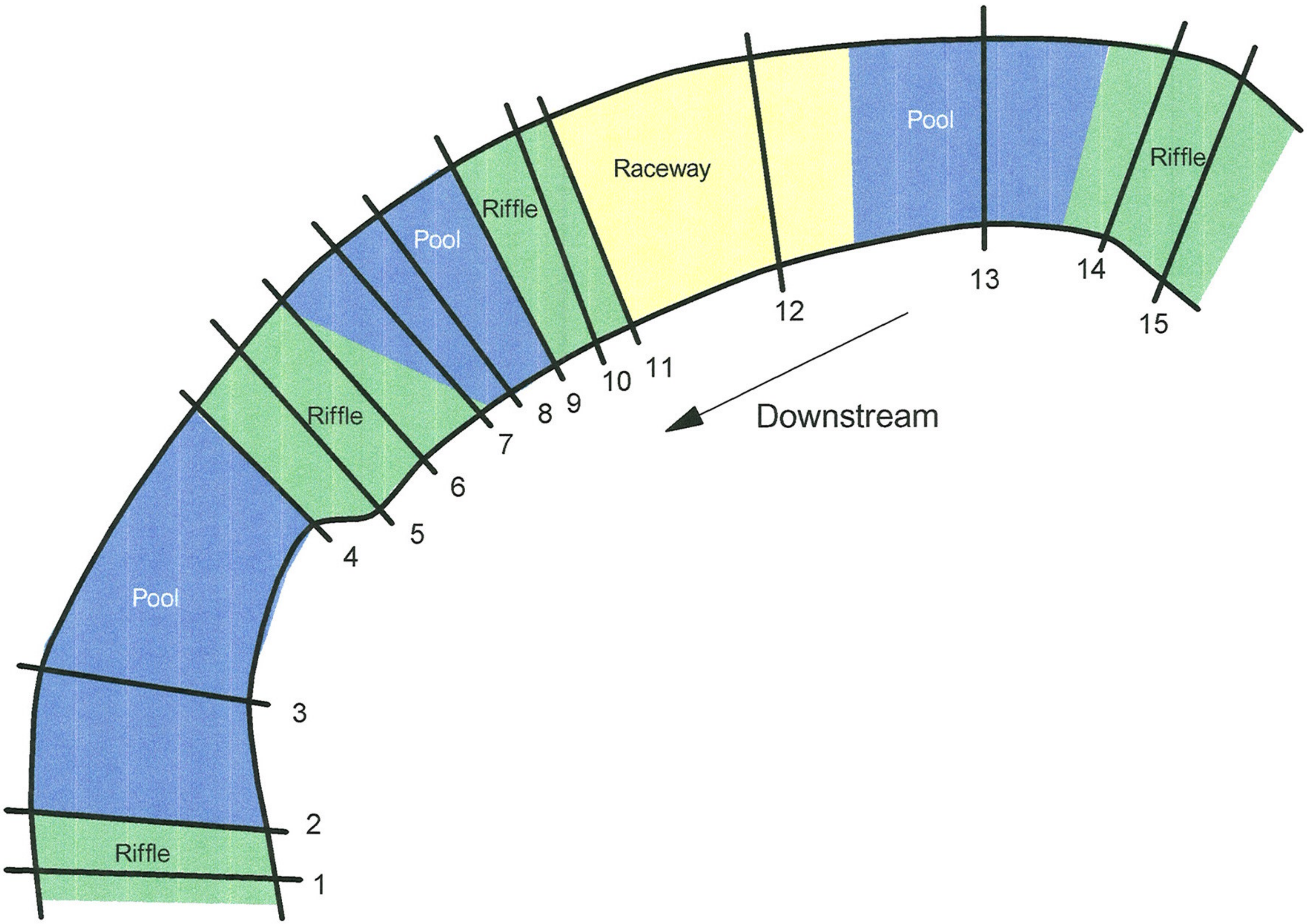
Appendix F2. Map for the middle Red Lake River study site showing transects and general habitat types.



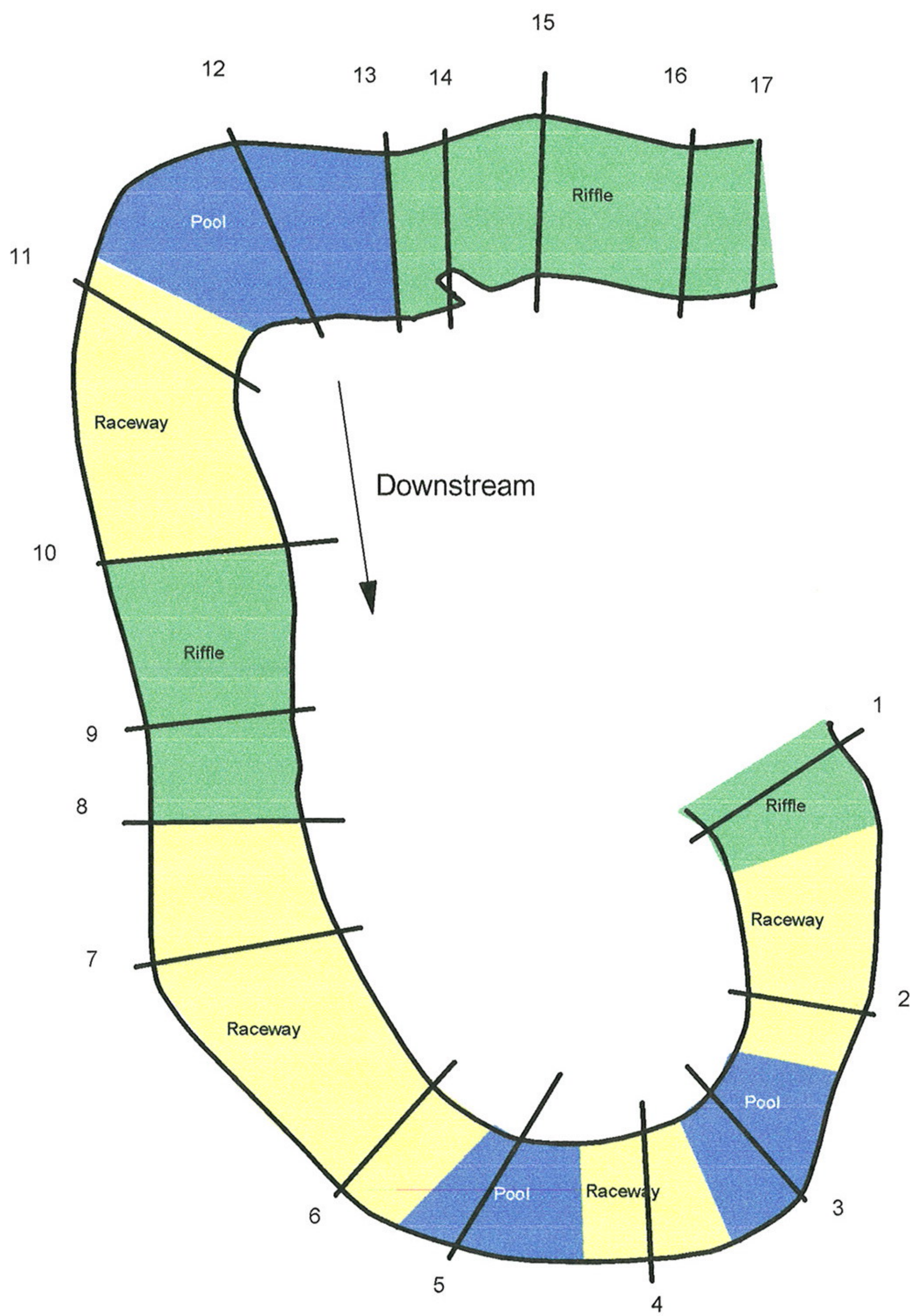
Appendix F3. Map for the upper Red Lake River study site showing transects and general habitat types.



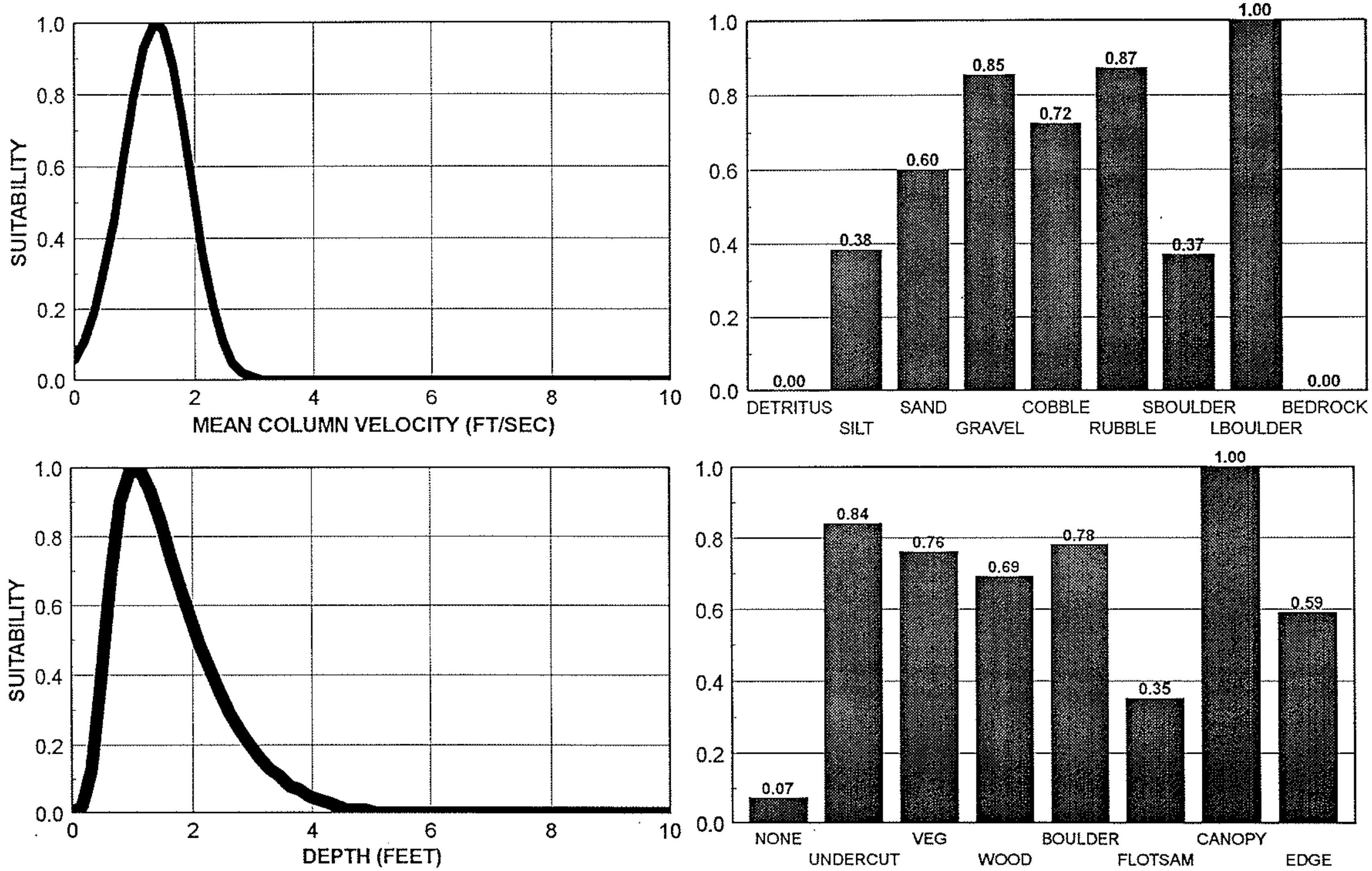
Appendix F4. Map of lower Clearwater River study site showing transects and general habitat types.



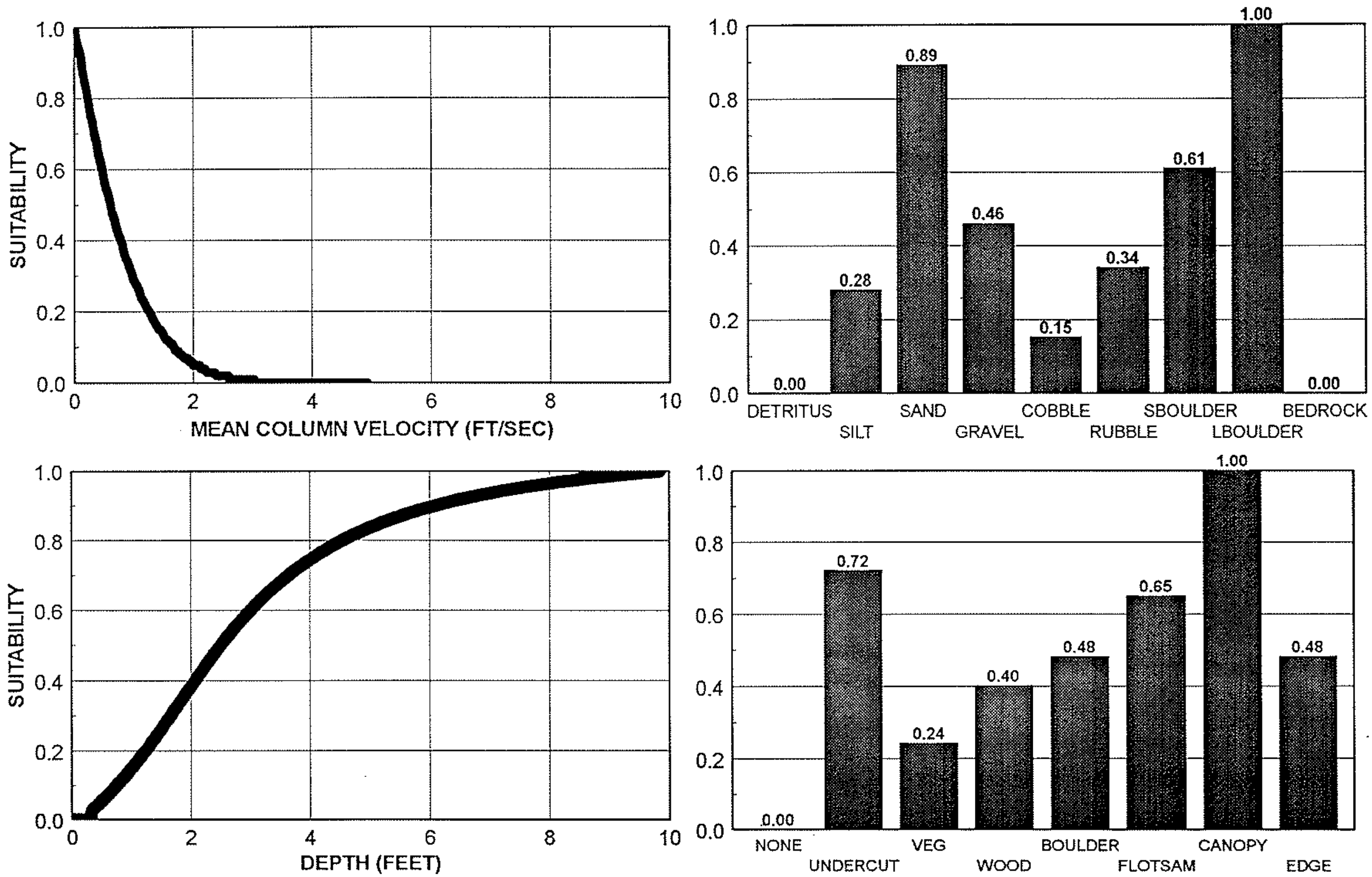
Appendix F5. Map of upper Clearwater River study site showing transects and general habitat types.



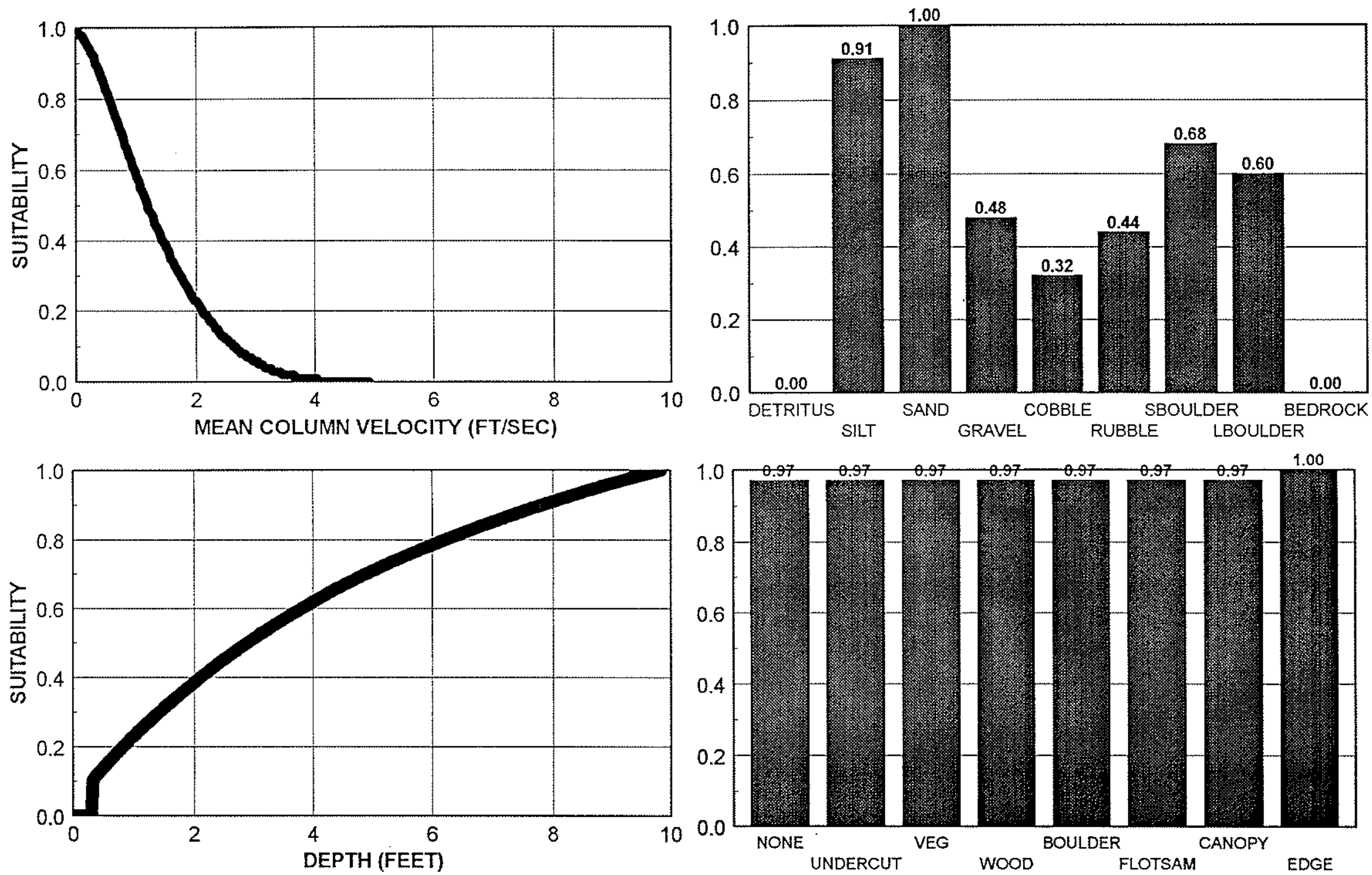
BLACKNOSE DACE ADULT



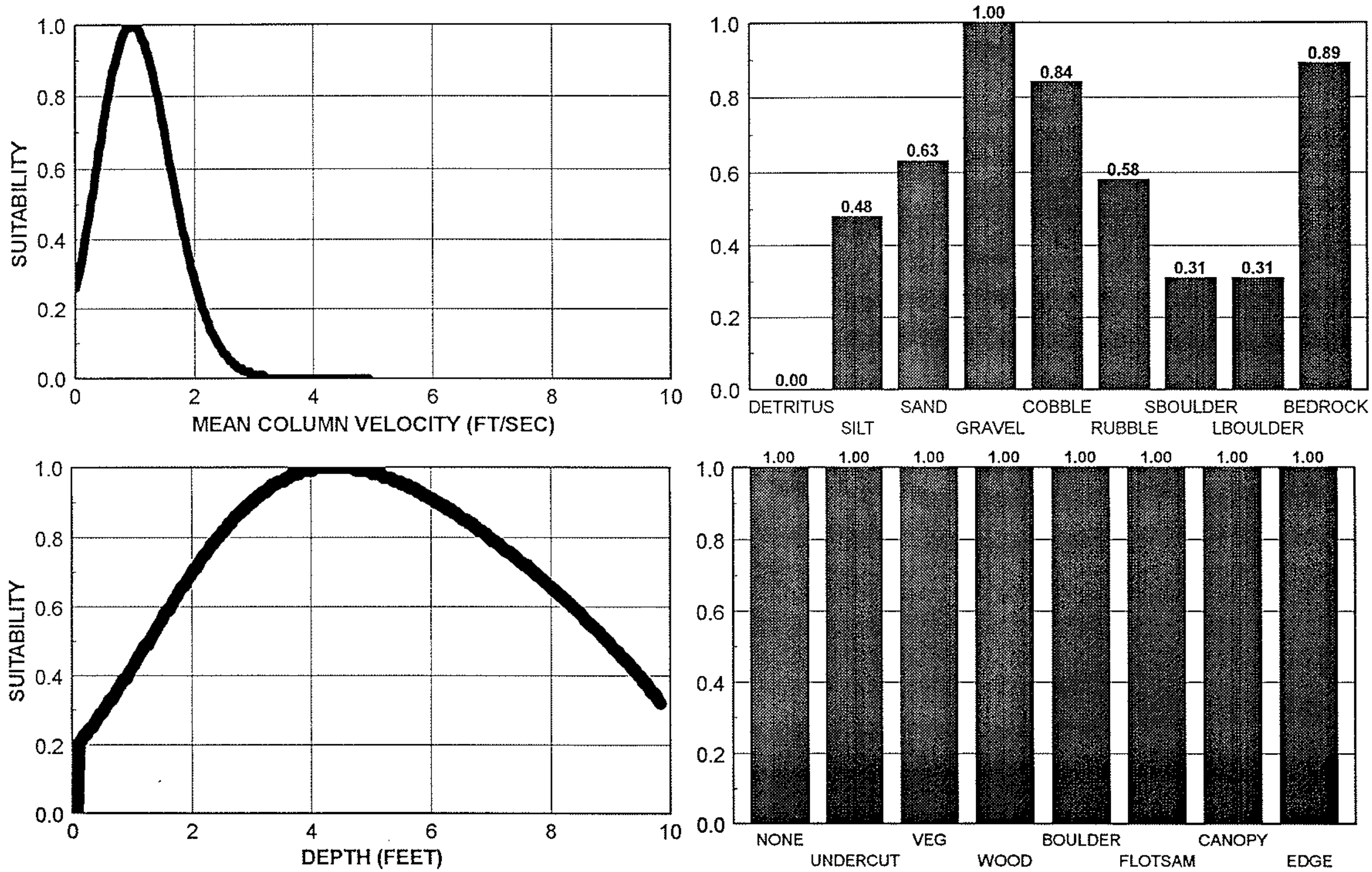
CHANNEL CATFISH ADULT



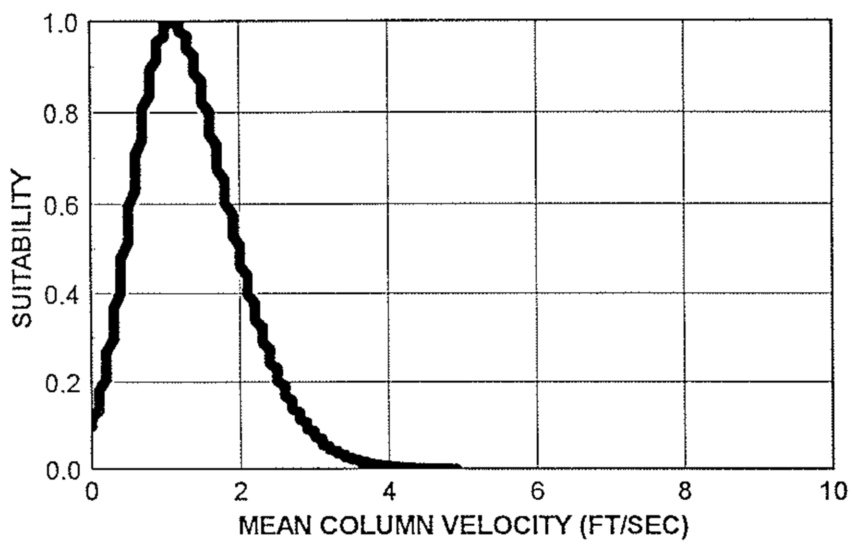
CHANNEL CATFISH JUVENILE

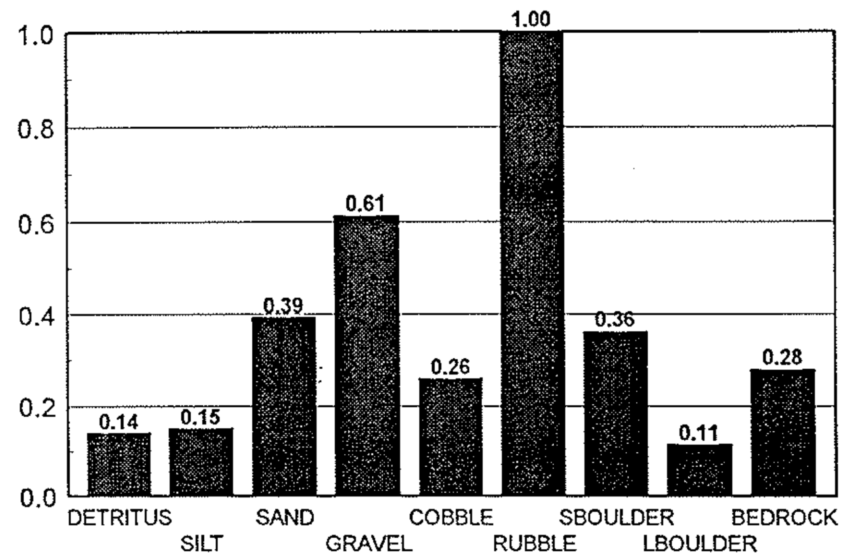


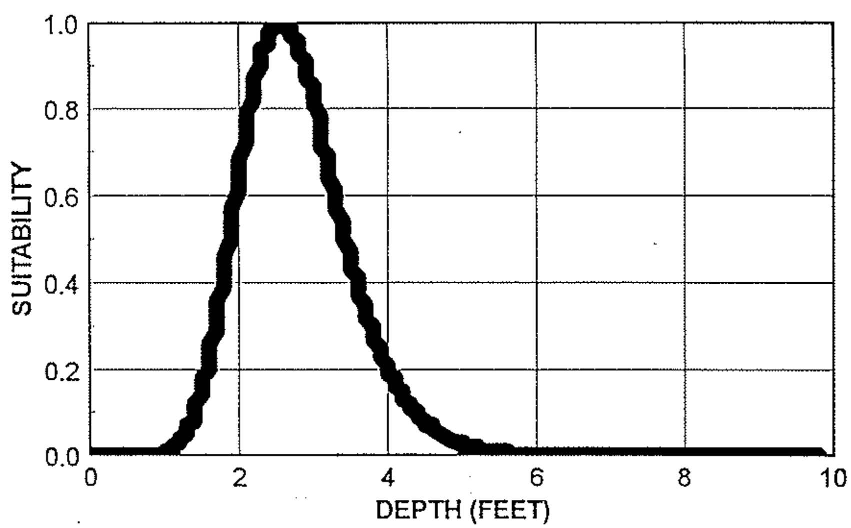
CHANNEL CATFISH YOY



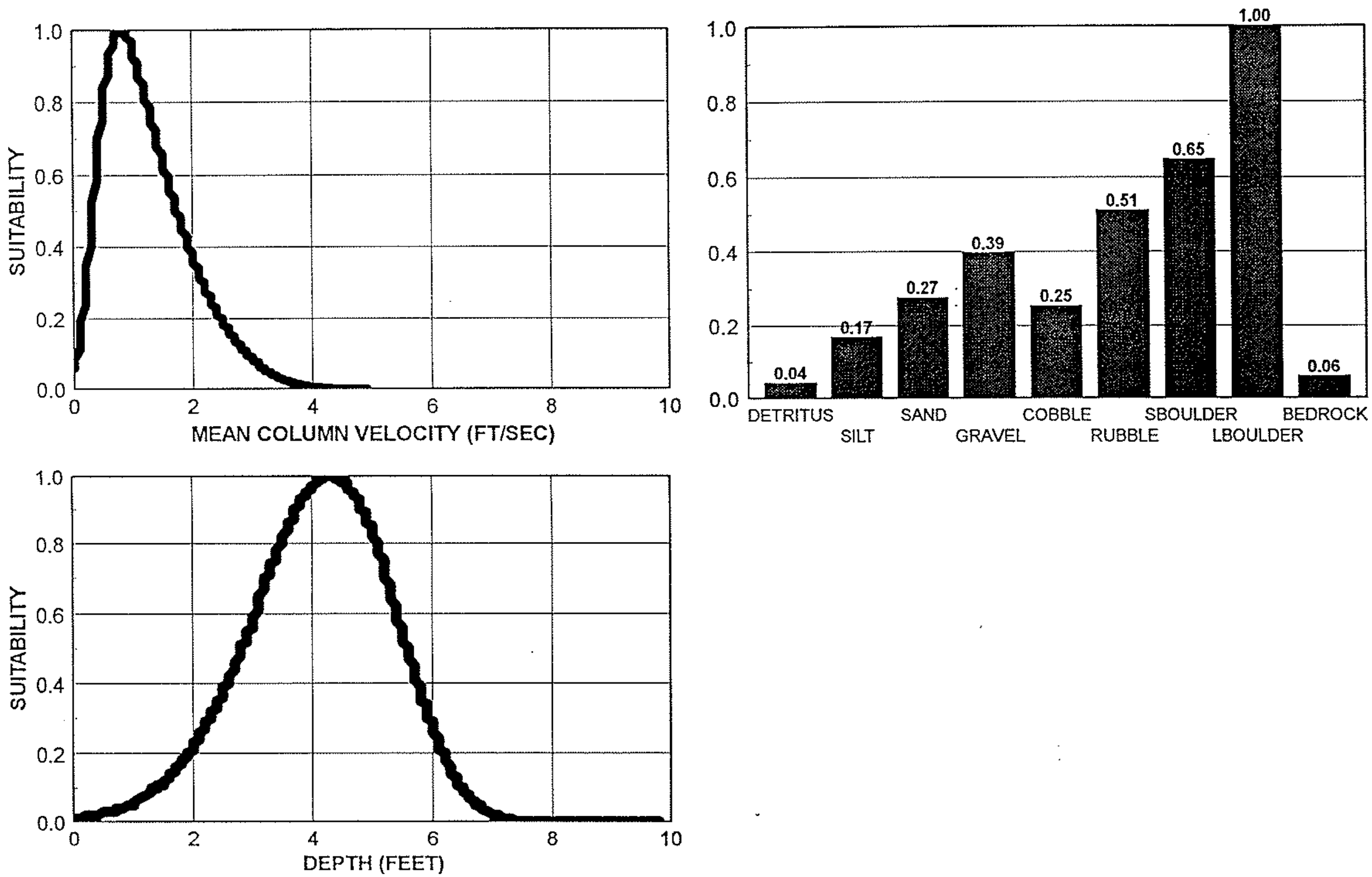
FAT MUCKET


SUITABILITY
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
MEAN COLUMN VELOCITY (FT/SEC)

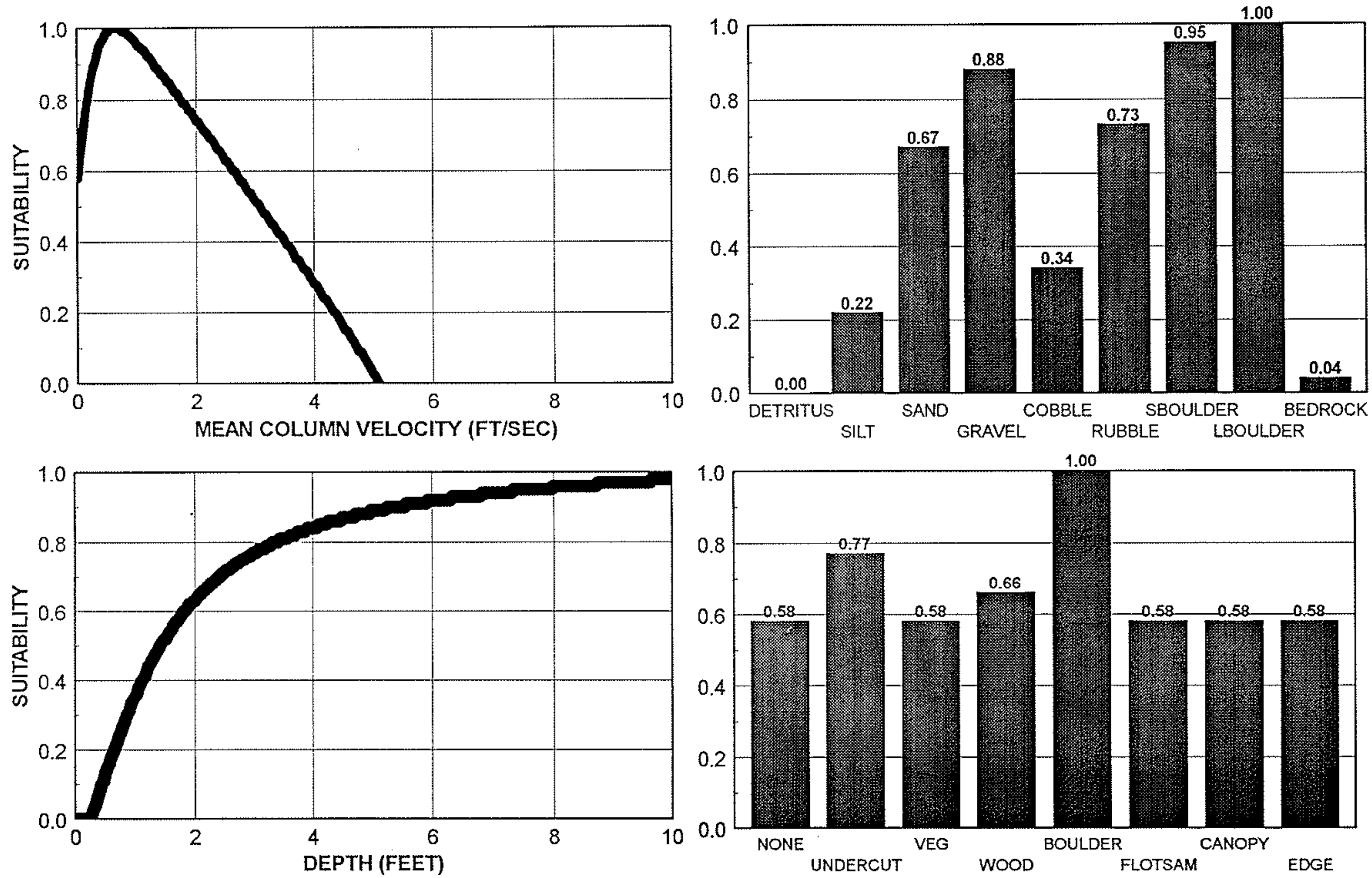

1.0
0.8
0.6
0.4
0.2
0.0
0.14
0.15
0.39
0.61
0.26
1.00
0.36
0.11
0.28
DETRITUS
SILT
SAND
GRAVEL
COBBLE
RUBBLE
SBOULDER
LBOULDER
BEDROCK


SUITABILITY
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
DEPTH (FEET)

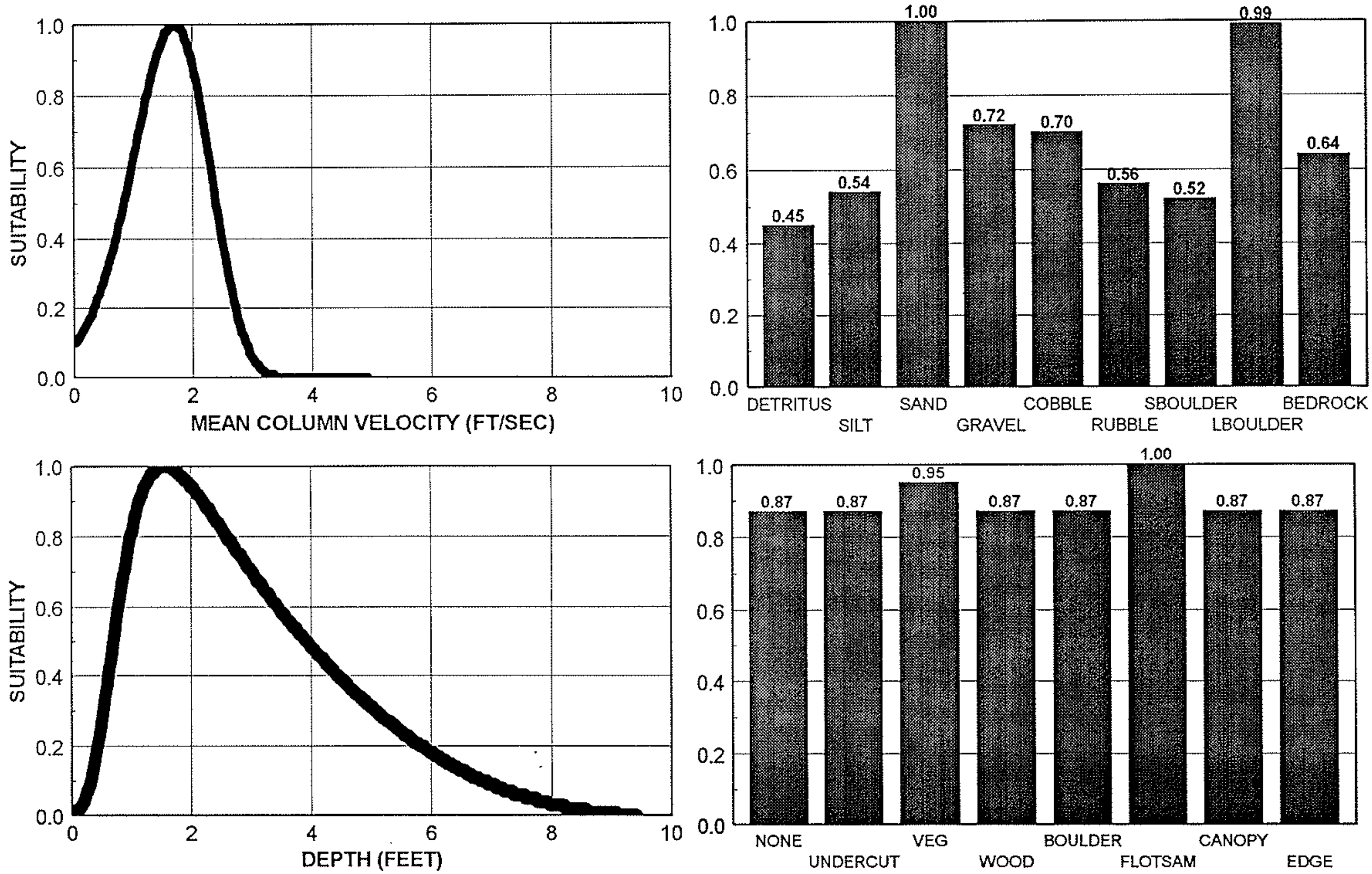
FLUTED SHELL



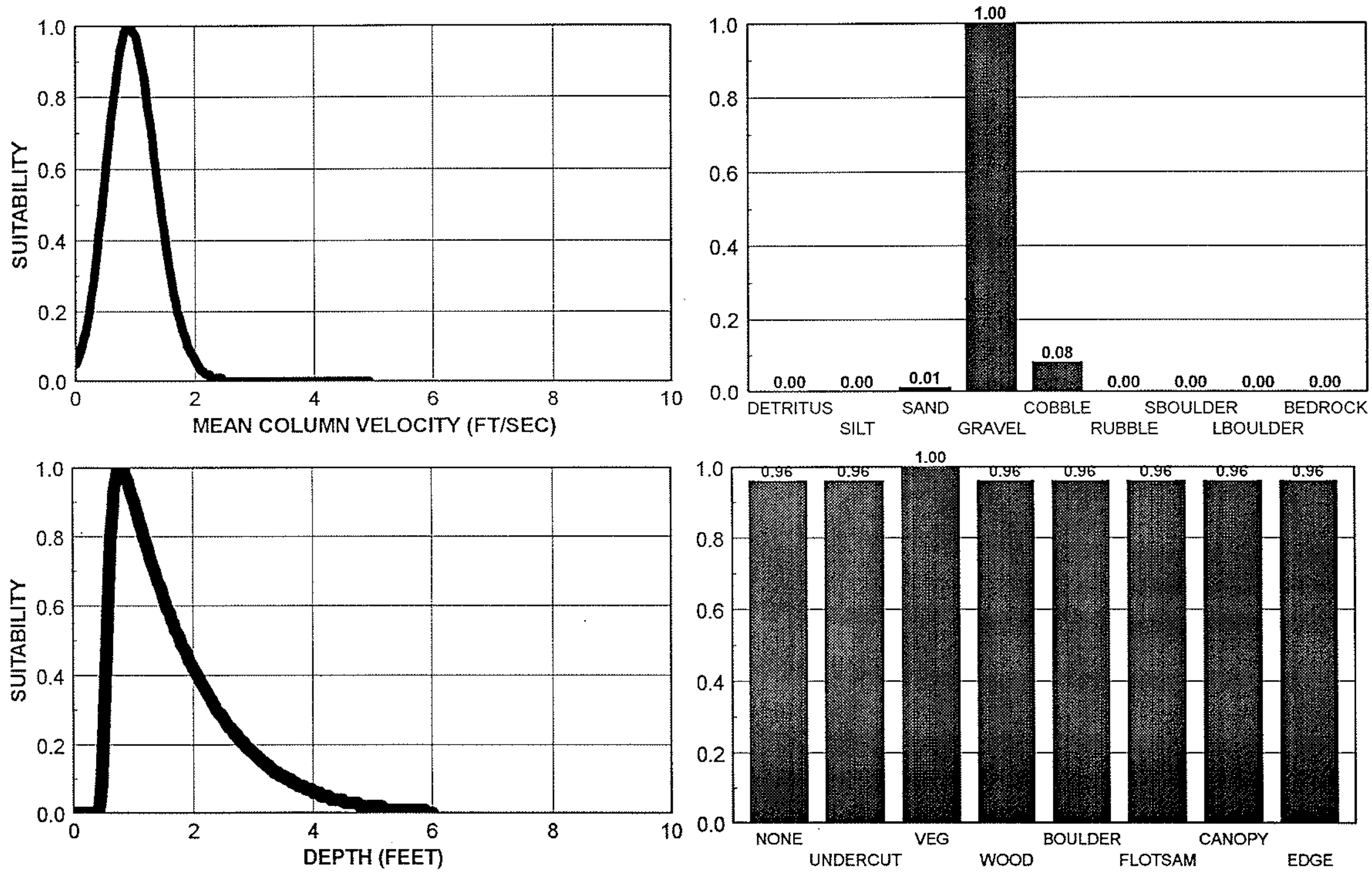
GOLDEN REDHORSE ADULT



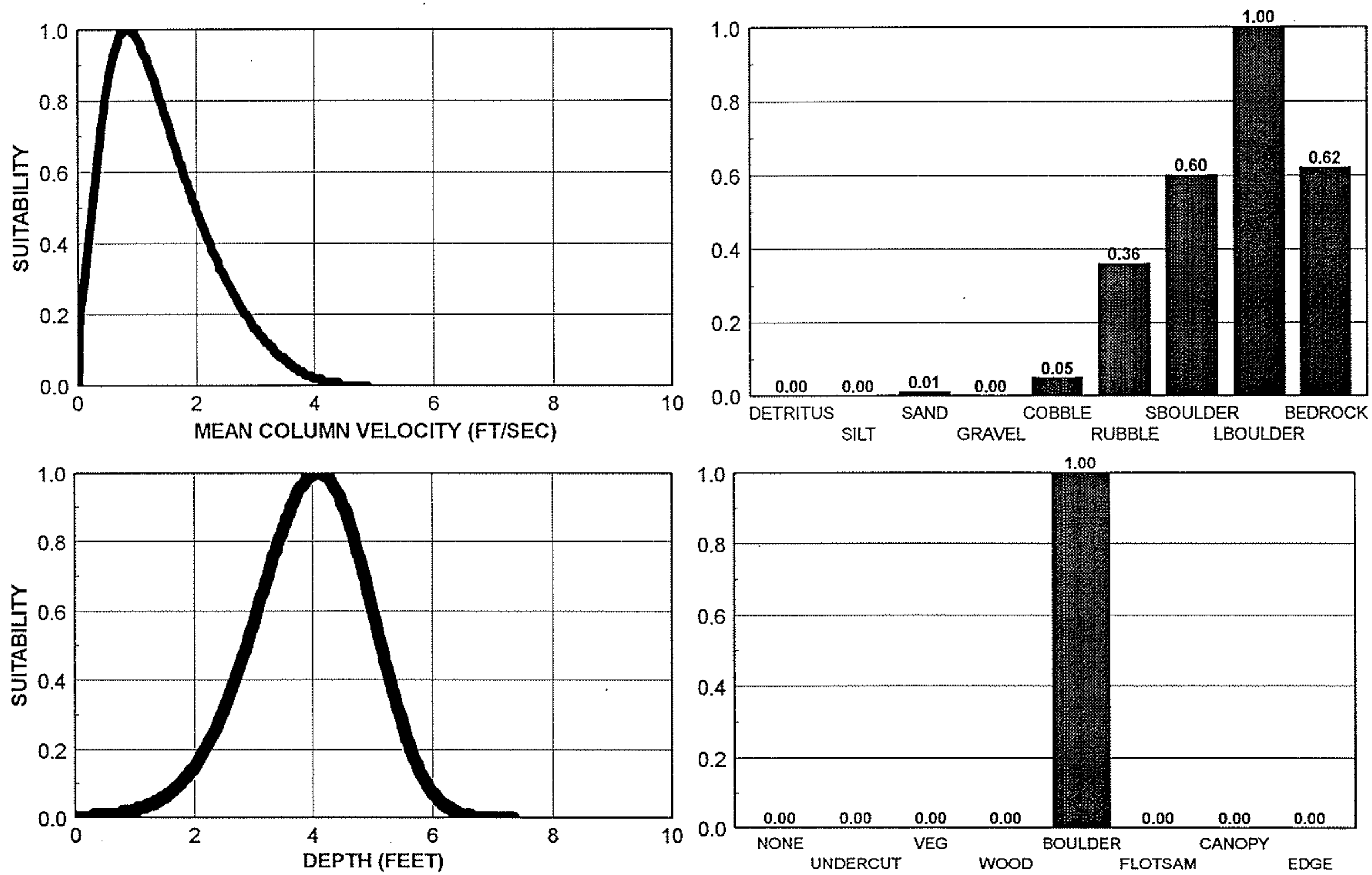
HORNYHEAD CHUB ADULT



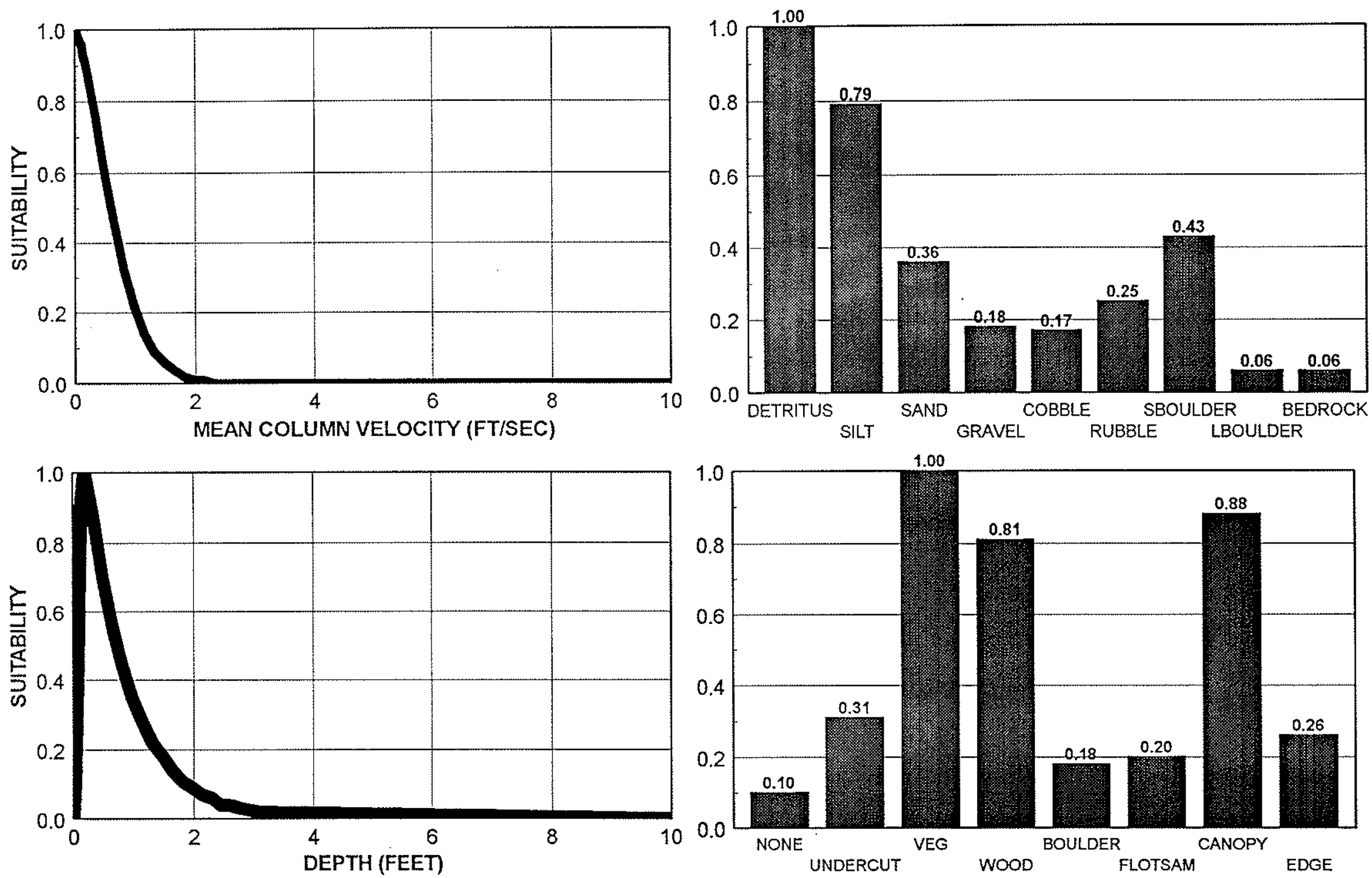
HORNYHEAD CHUB SPAWNING



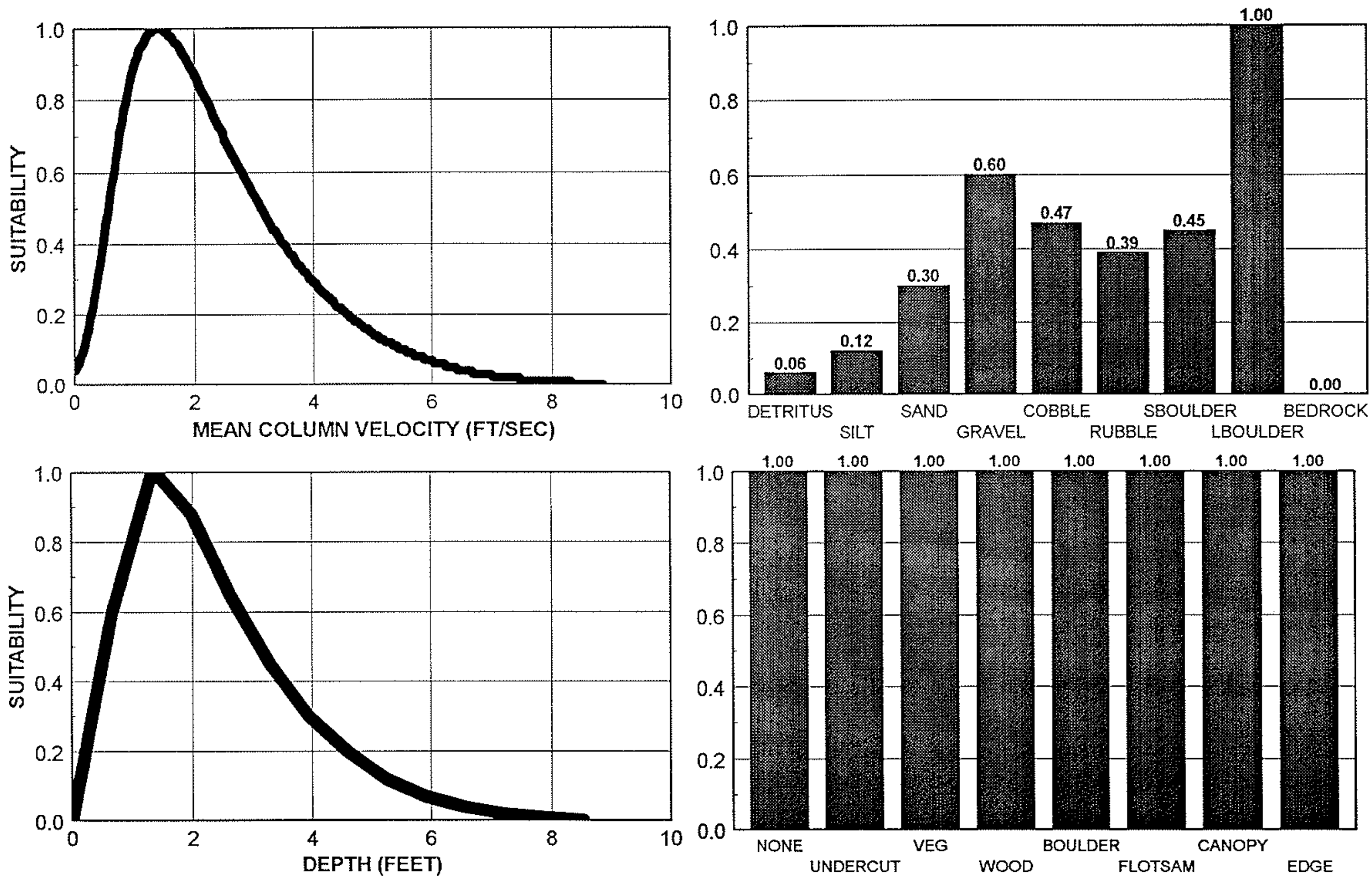
LAKE STURGEON SPAWNING



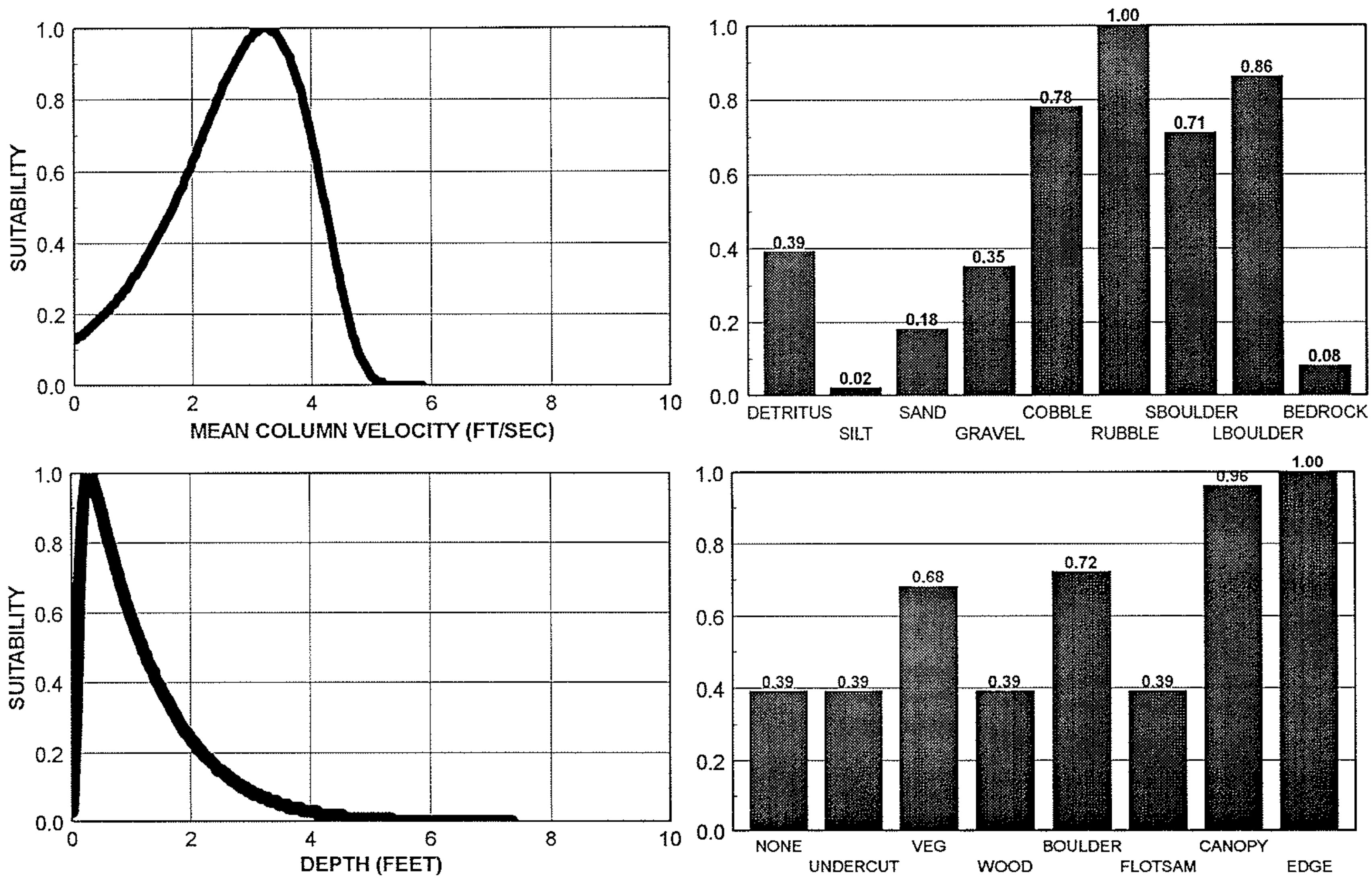
LARVA - GENERAL



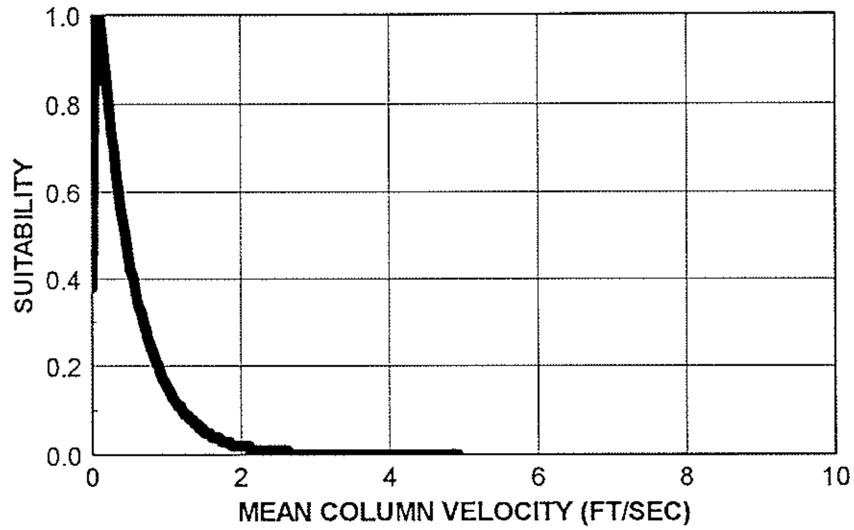
LOGPERCH ADULT

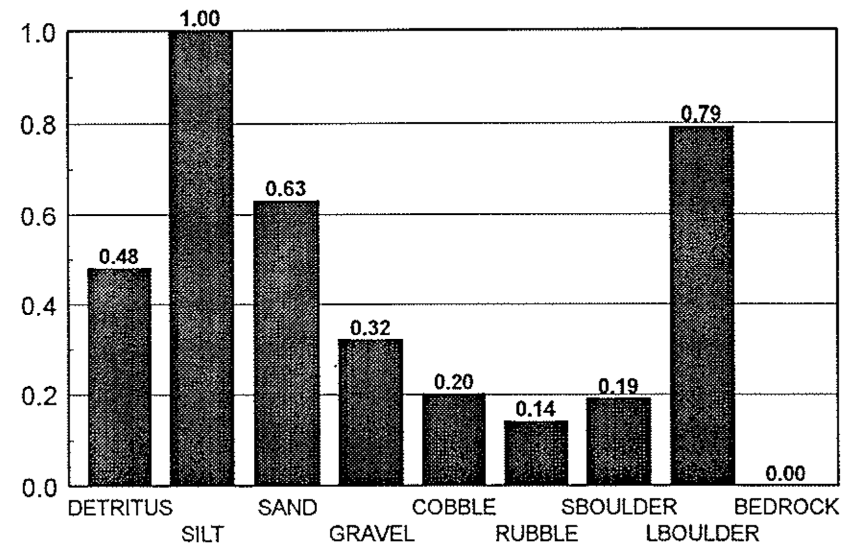


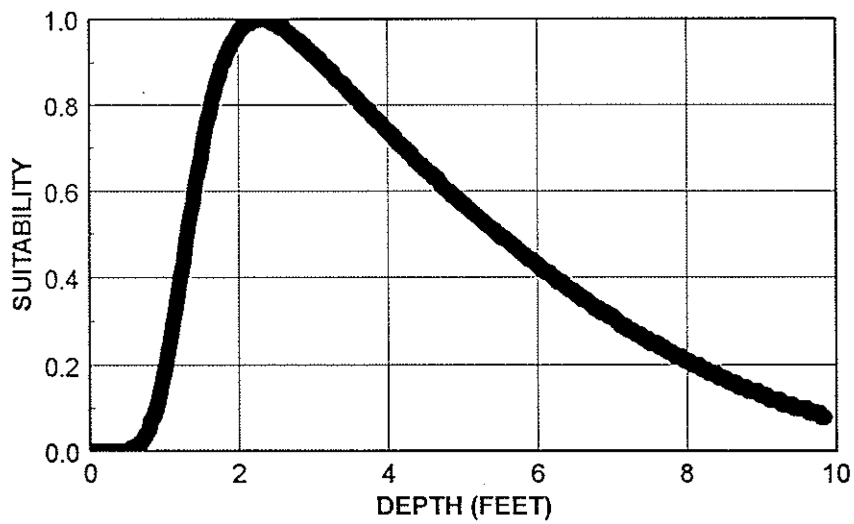
LONGNOSE DACE ADULT

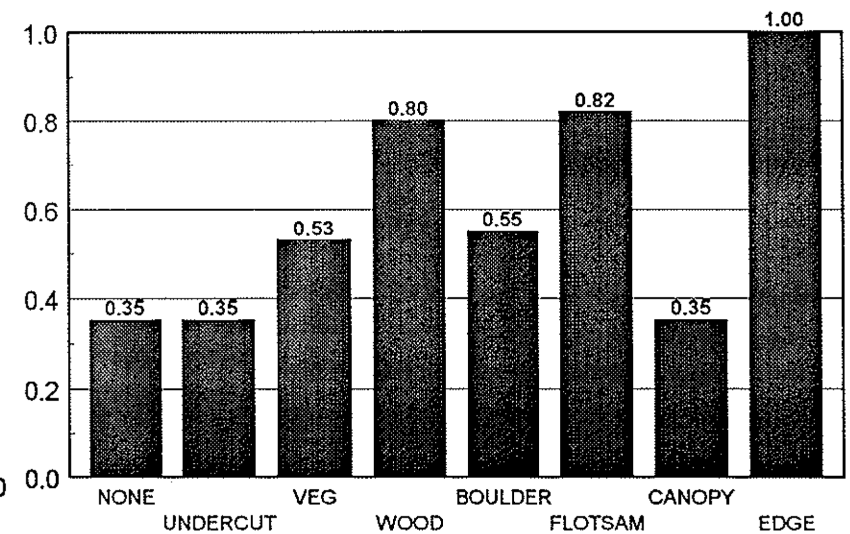


NORTHERN PIKE ADULT

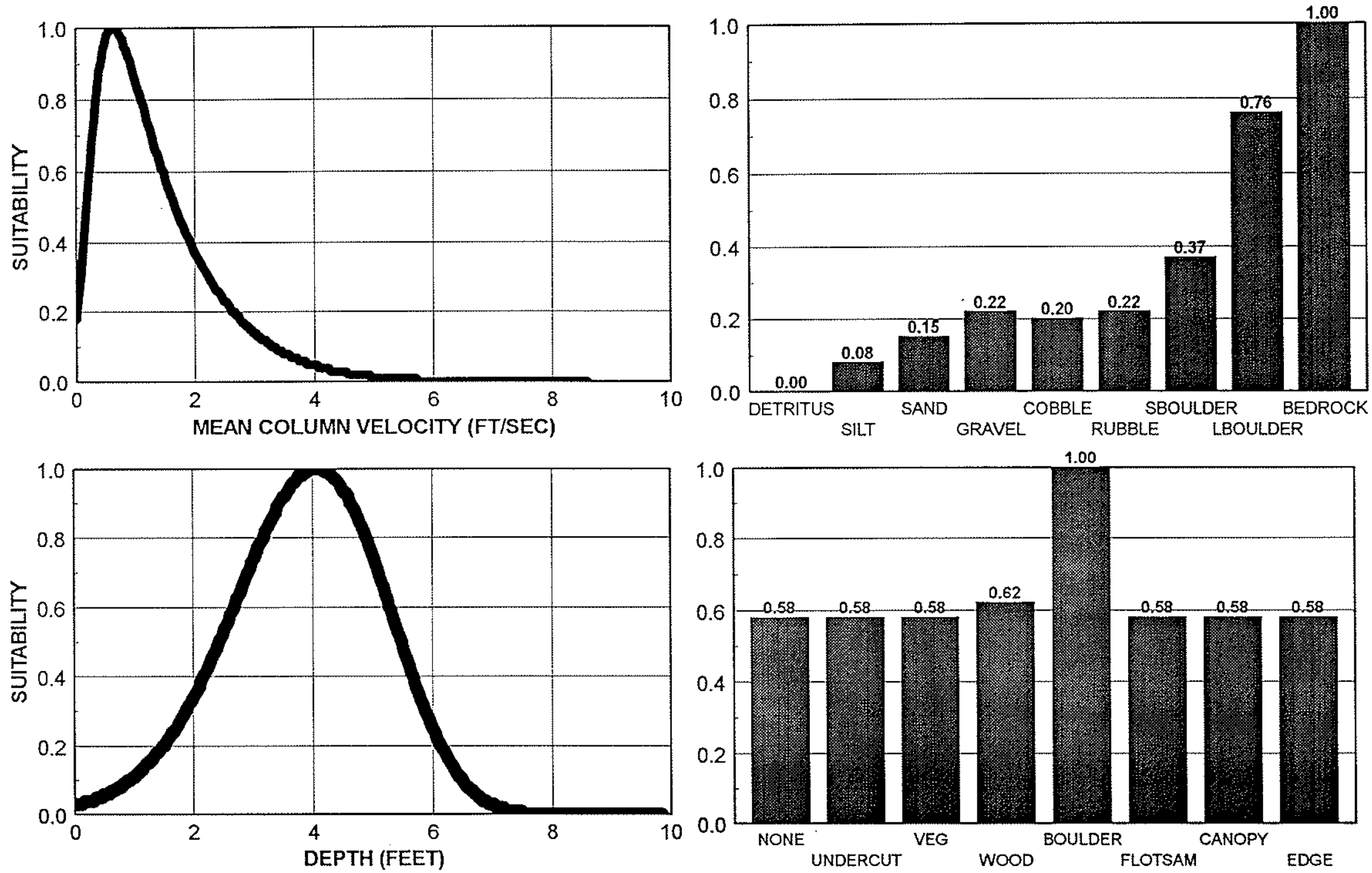




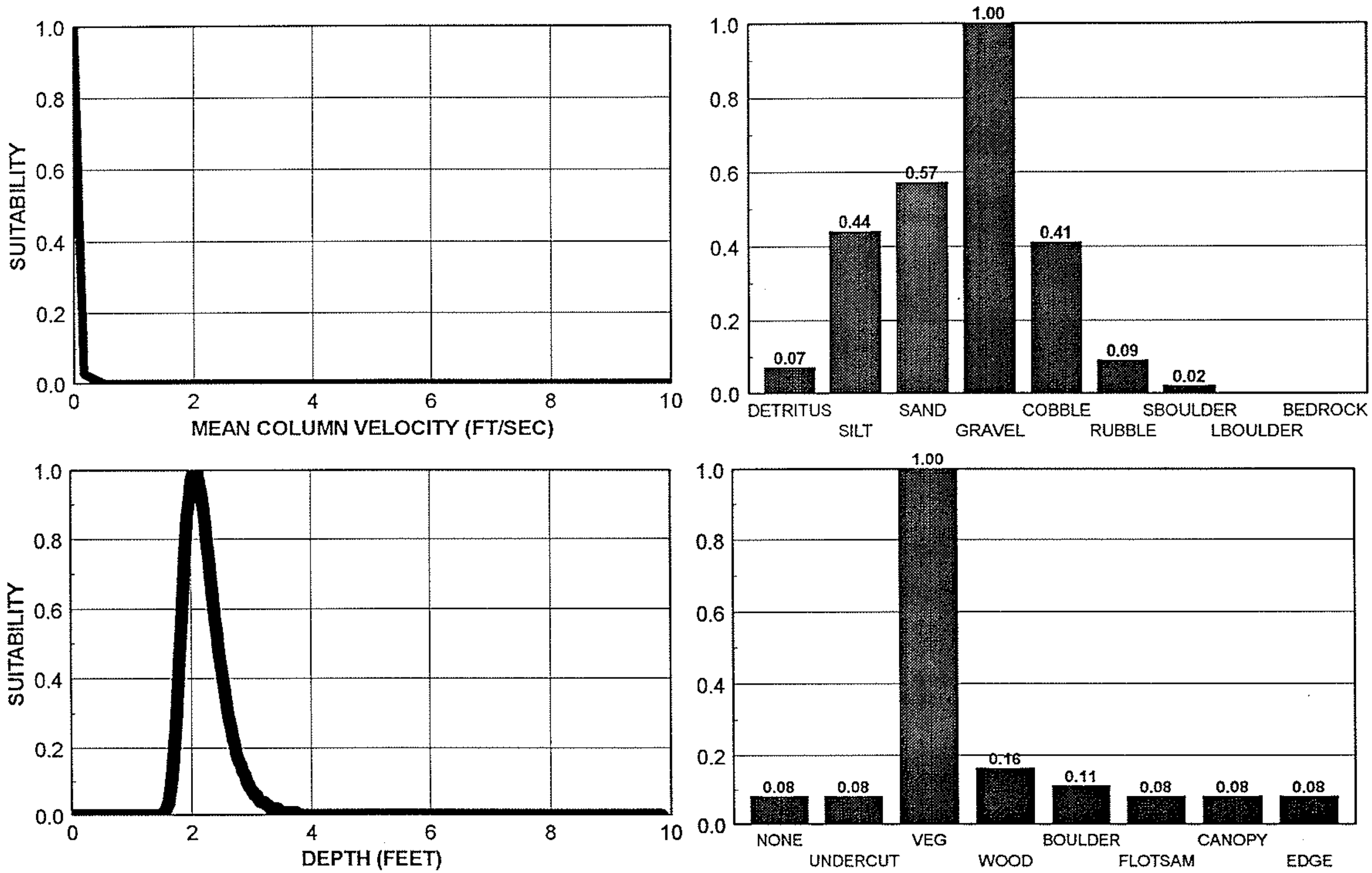




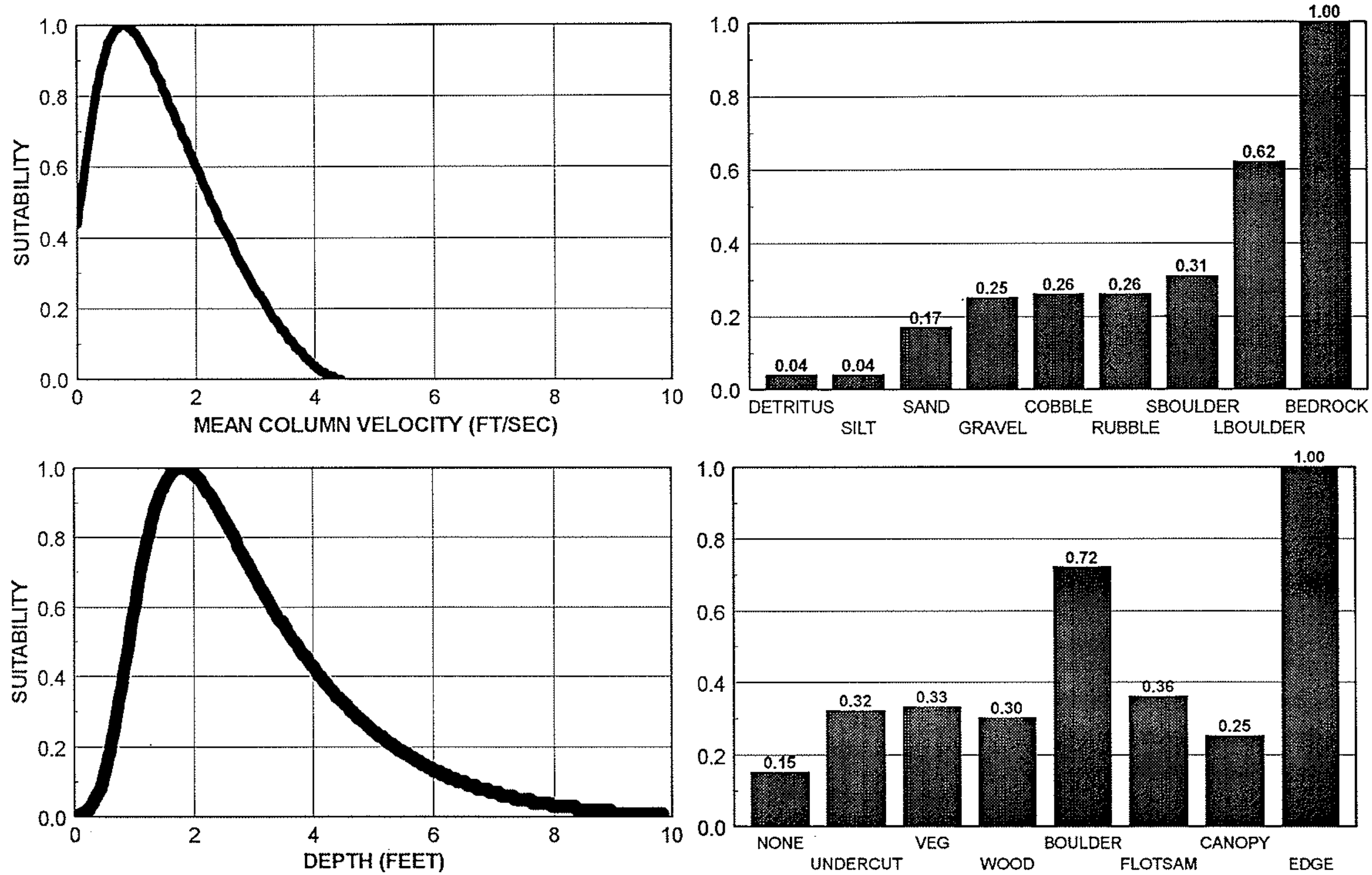
SMALLMOUTH BASS ADULT



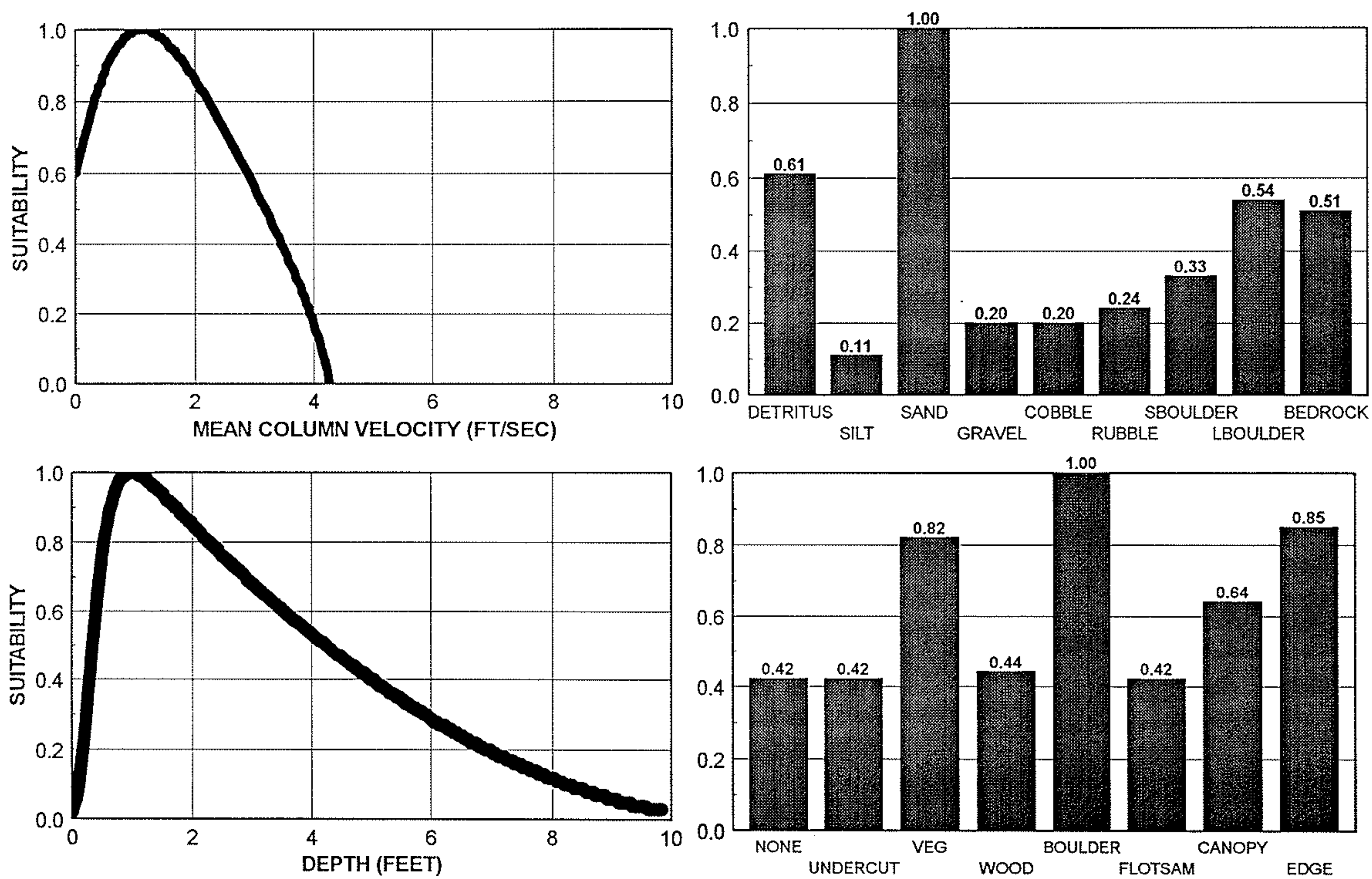
SMALLMOUTH BASS SPAWNING



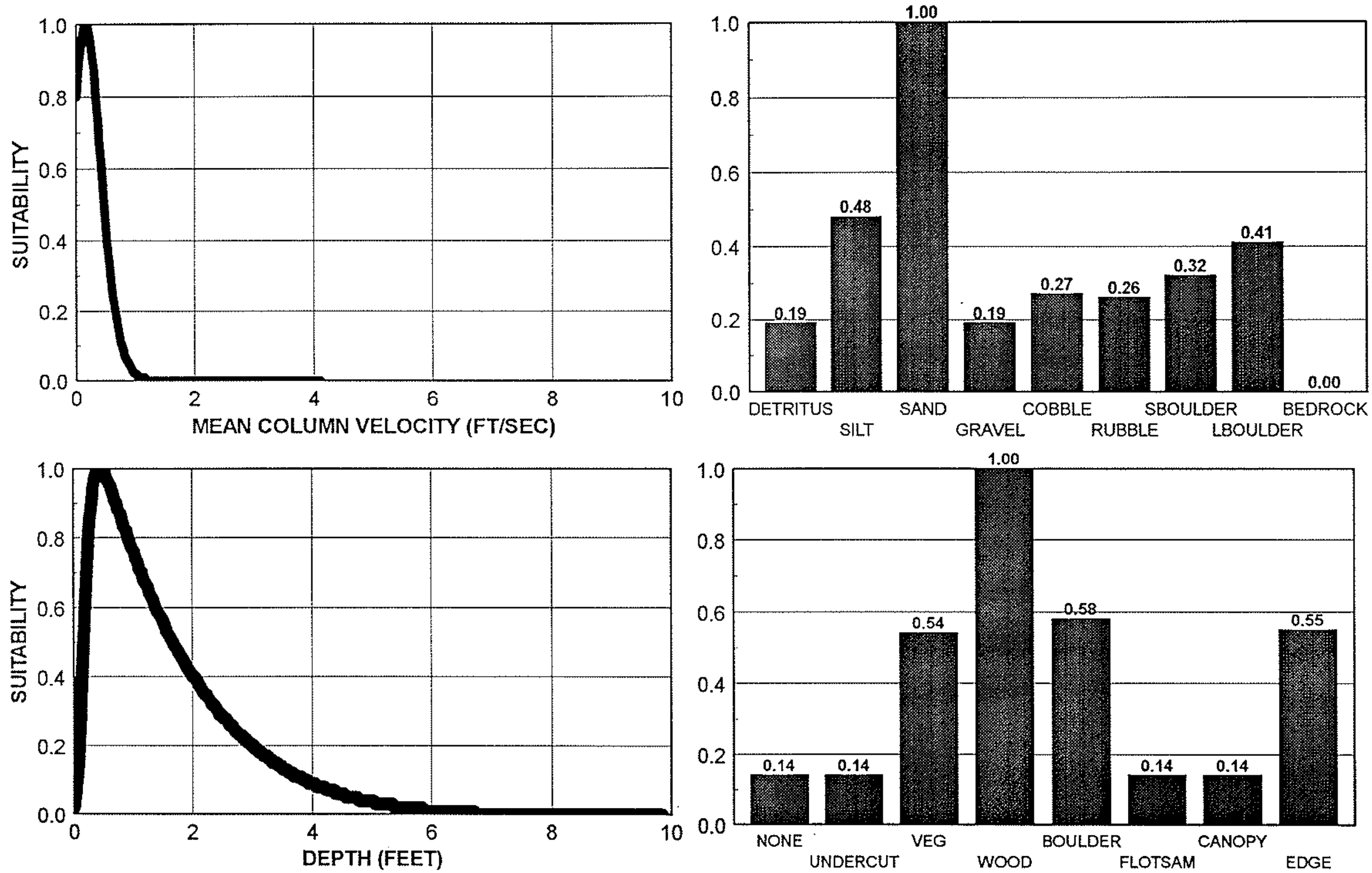
SMALLMOUTH BASS JUVENILE



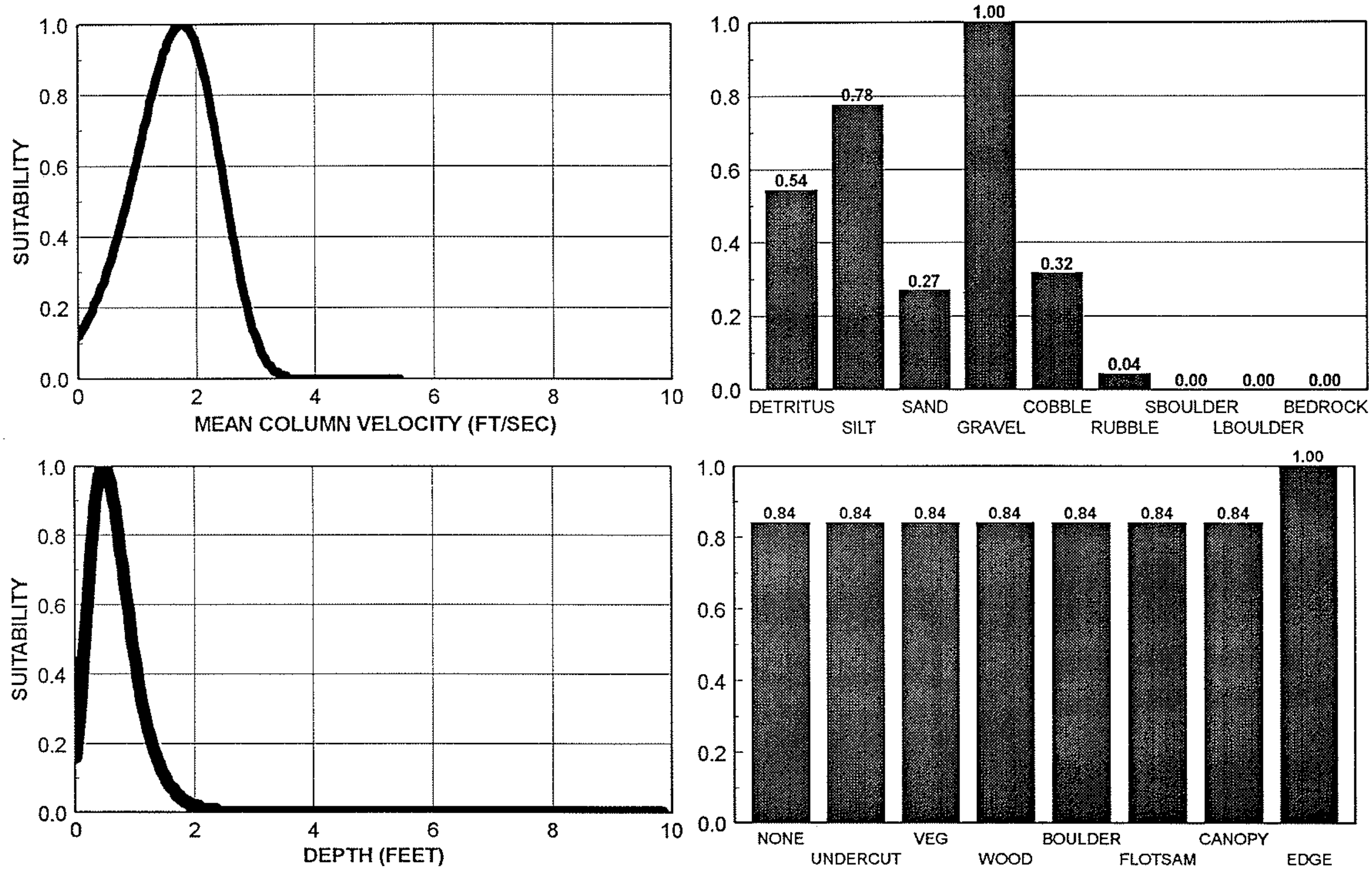
SMALLMOUTH BASS FINGERLING



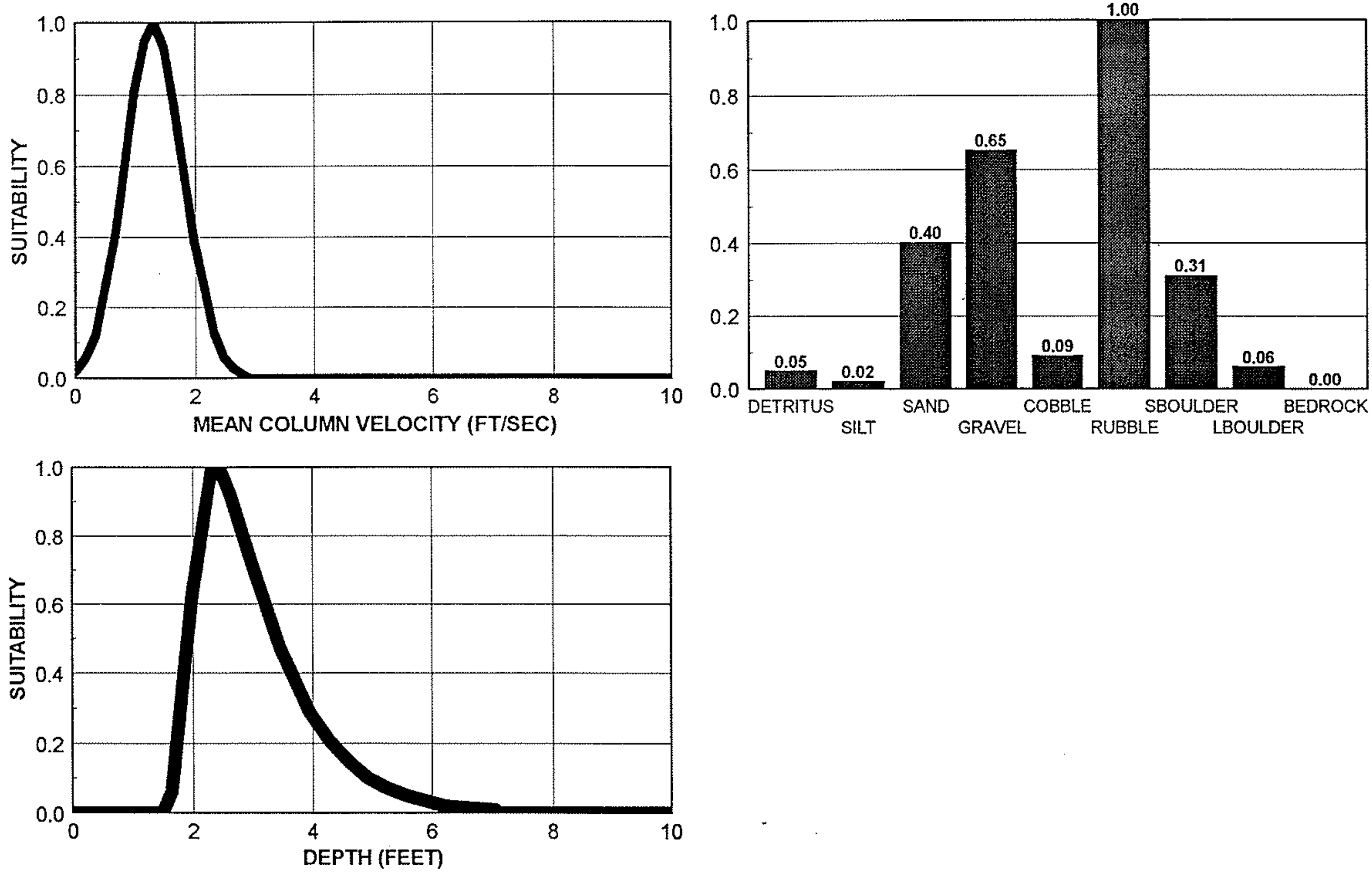
SMALLMOUTH BASS FRY



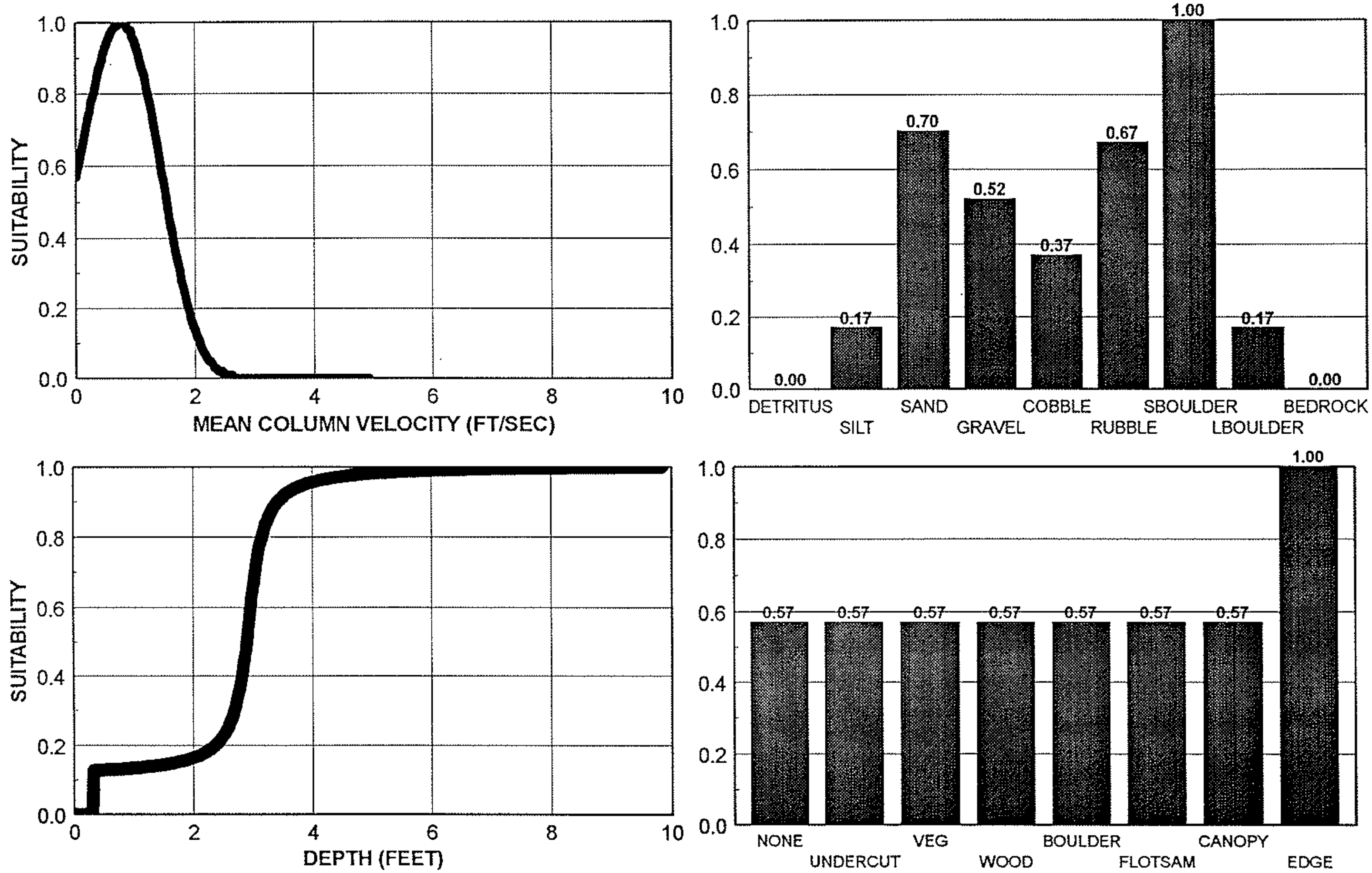
SAND SHINER ADULT



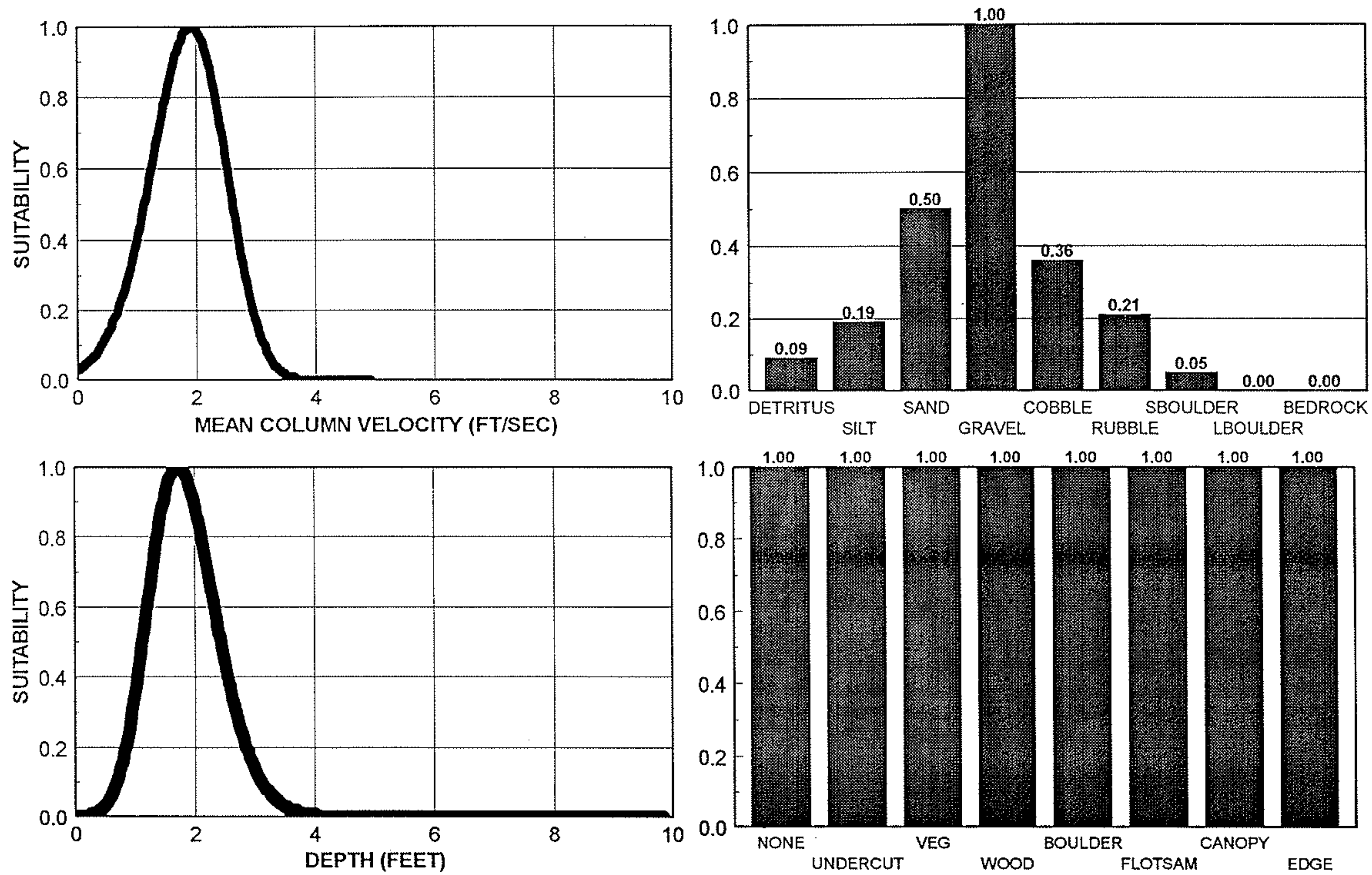
WABASH PIGTOE



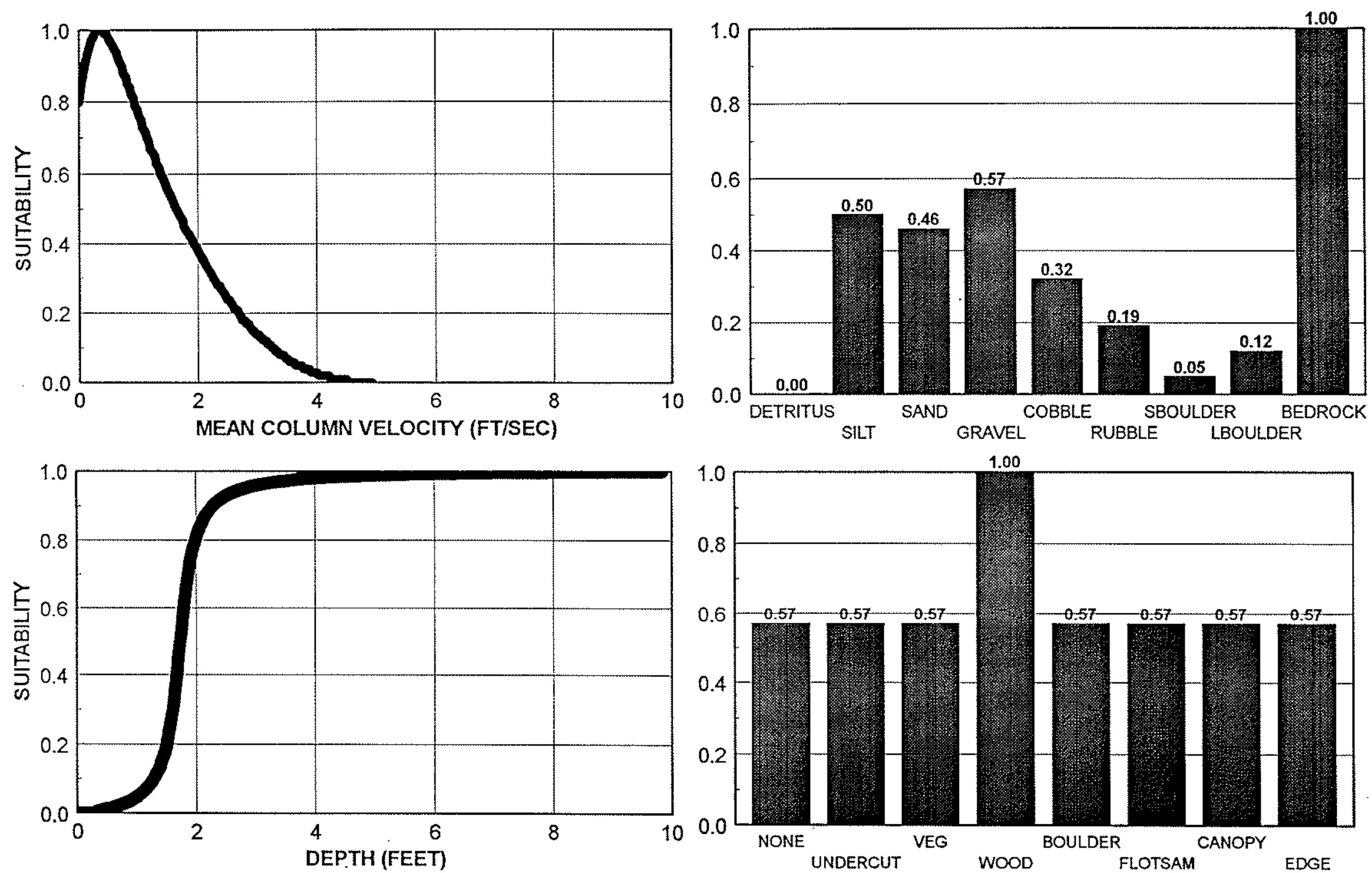
WALLEYE ADULT



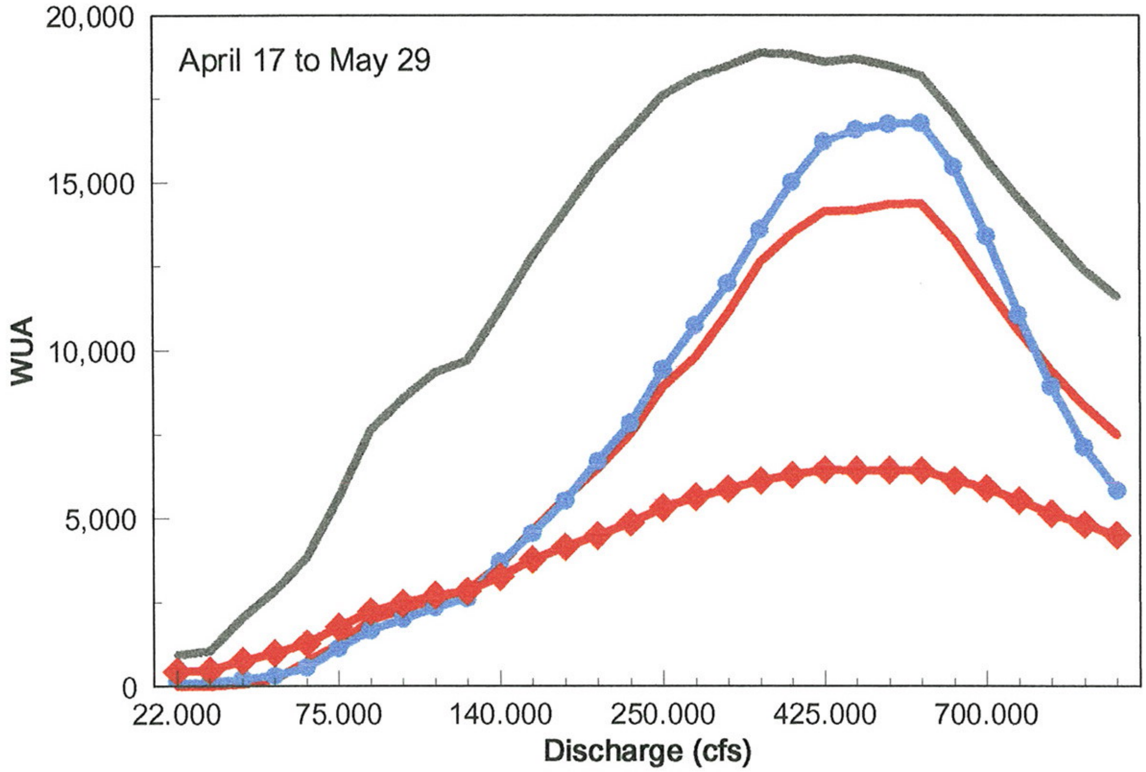
WALLEYE SPAWNING

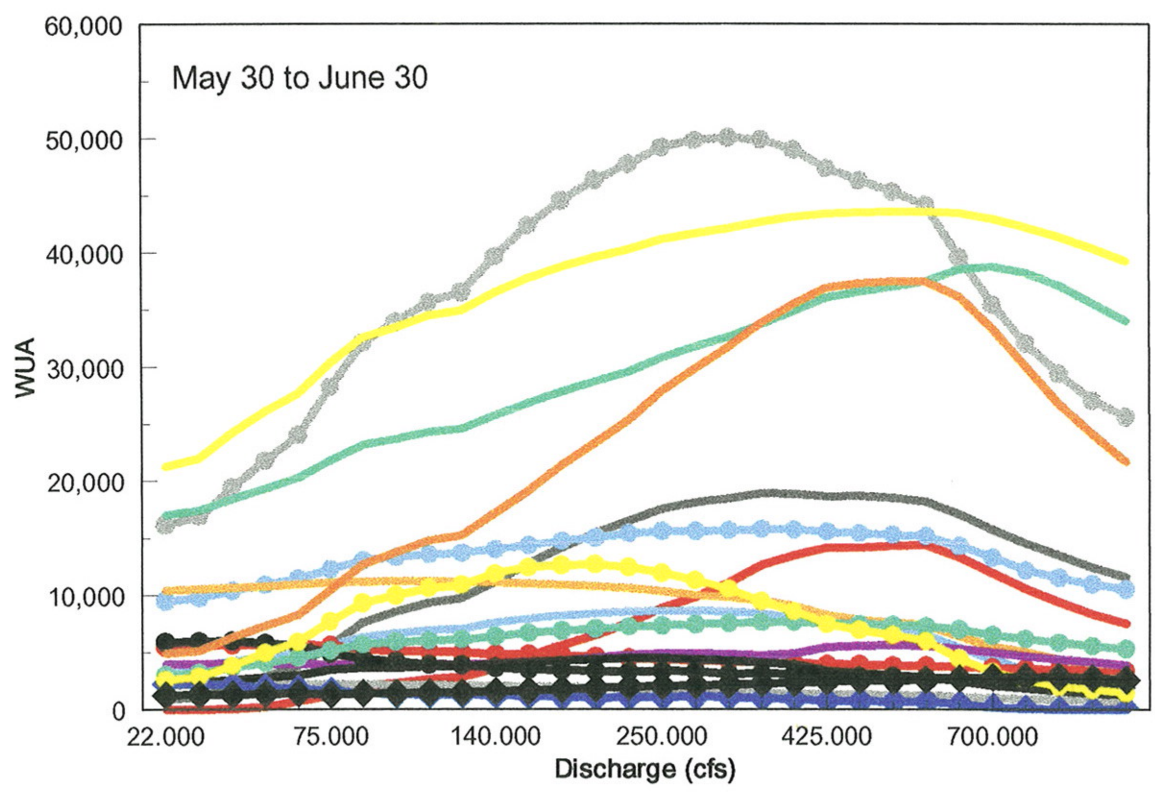


WALLEYE JUVENILE

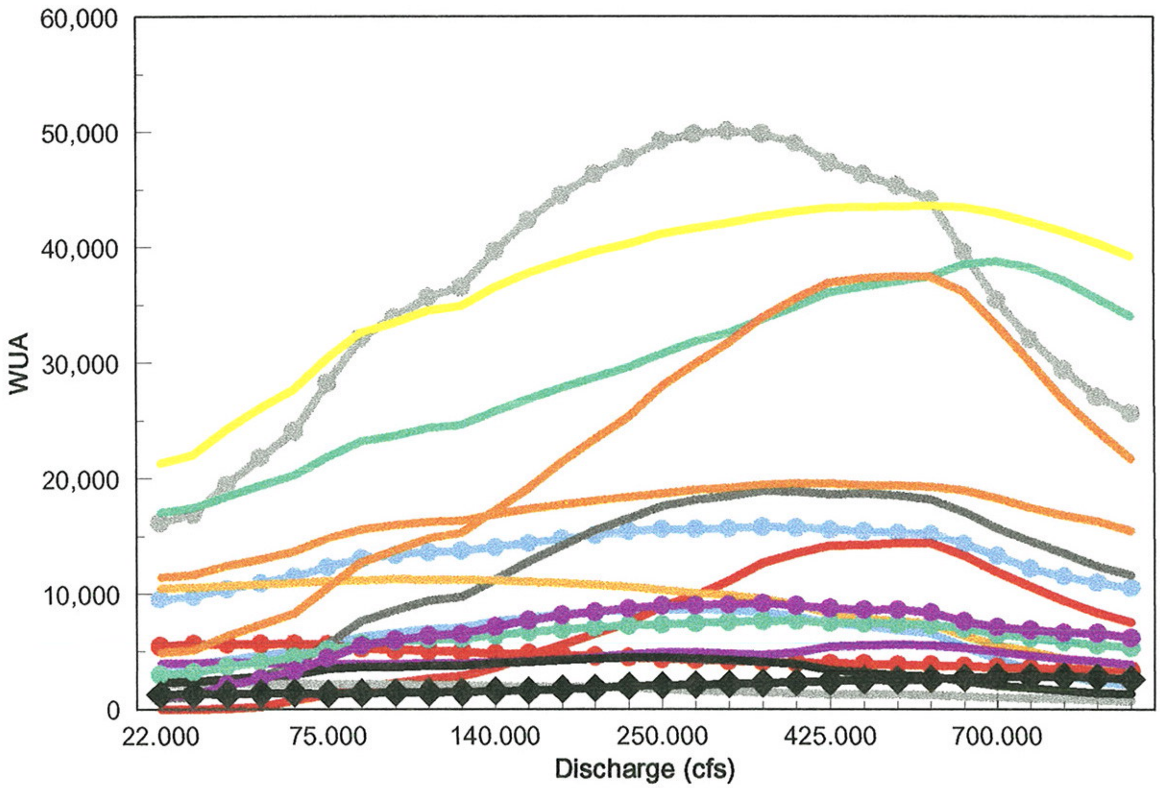


Appendix H1. Non-normalized weighted usable area as a function of discharge for April 17 to May 29, and May 30 to June 30 for the lower Red Lake site.

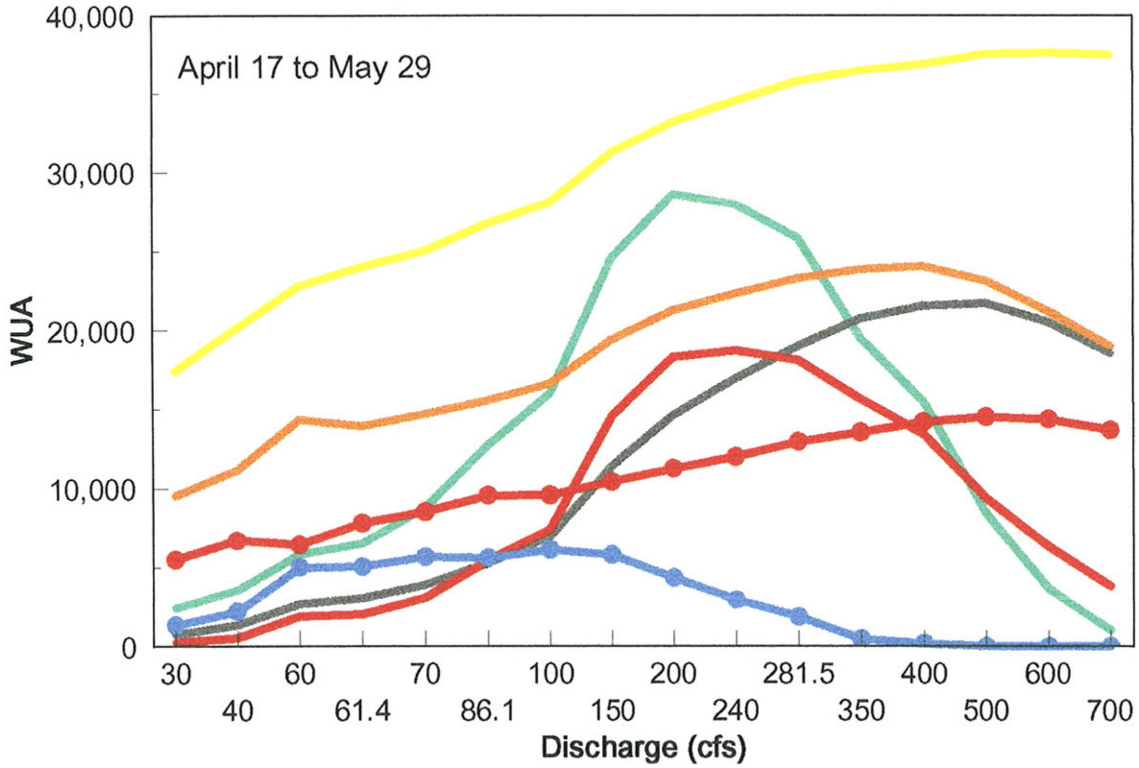


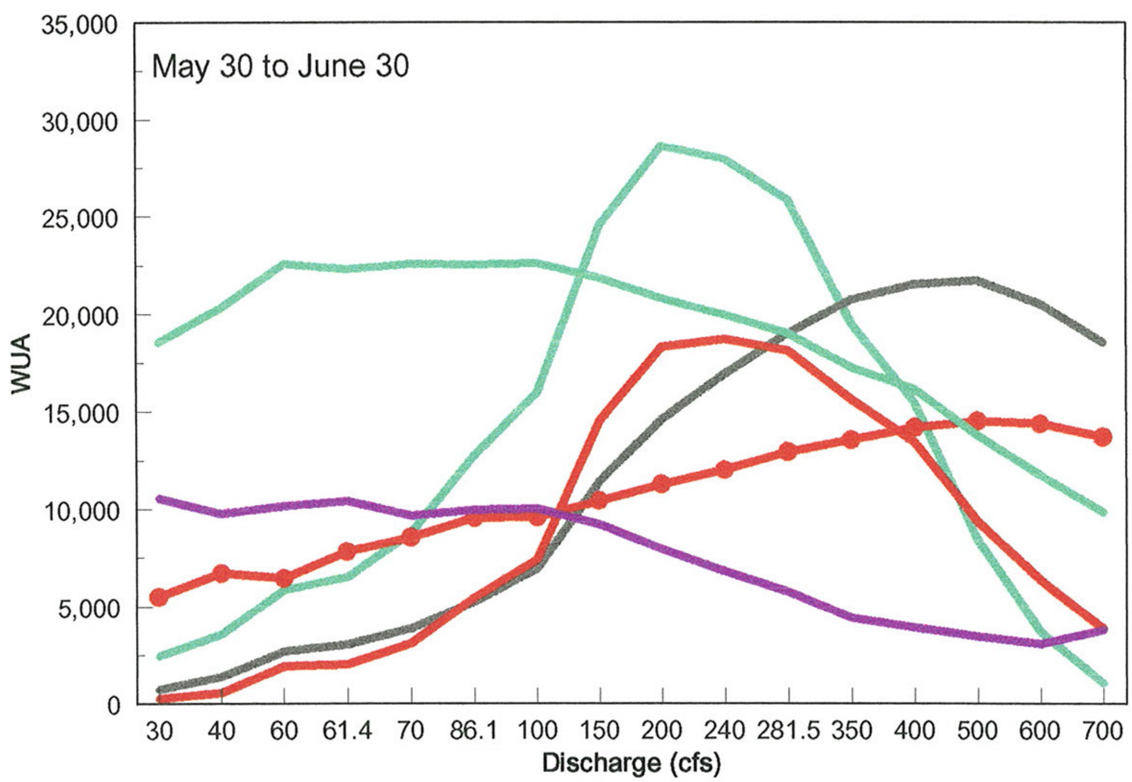


Appendix H2. Non-normalized weighted usable area as a function of discharge for July 1 to April 16 for the lower Red Lake site.

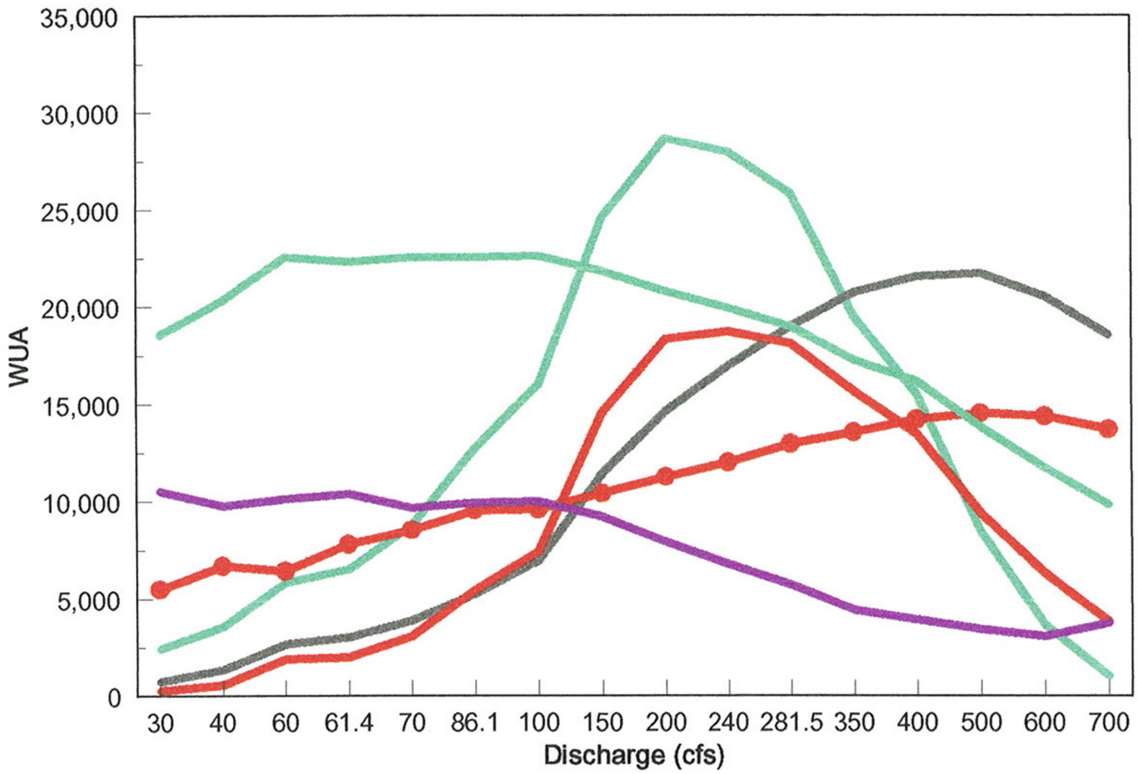


Appendix H3. Non-normalized weighted usable area as a function of discharge for April 17 to May 29, and May 30 to June 30 for the middle Red Lake site.

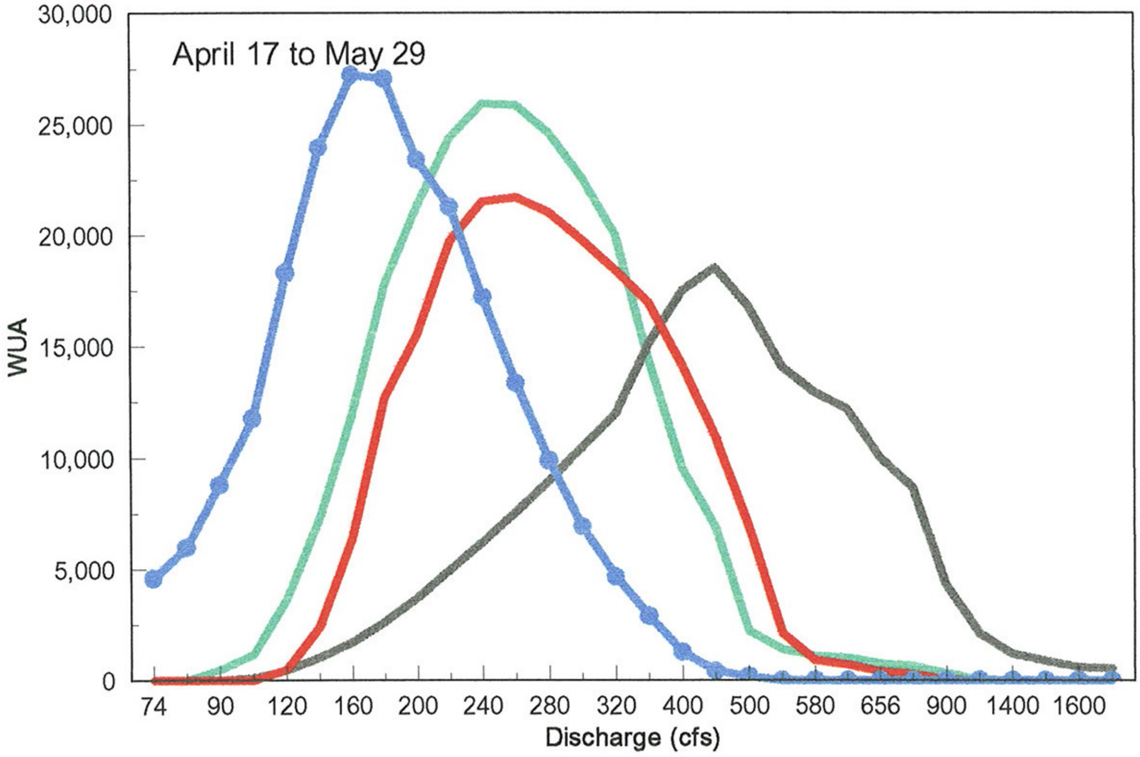


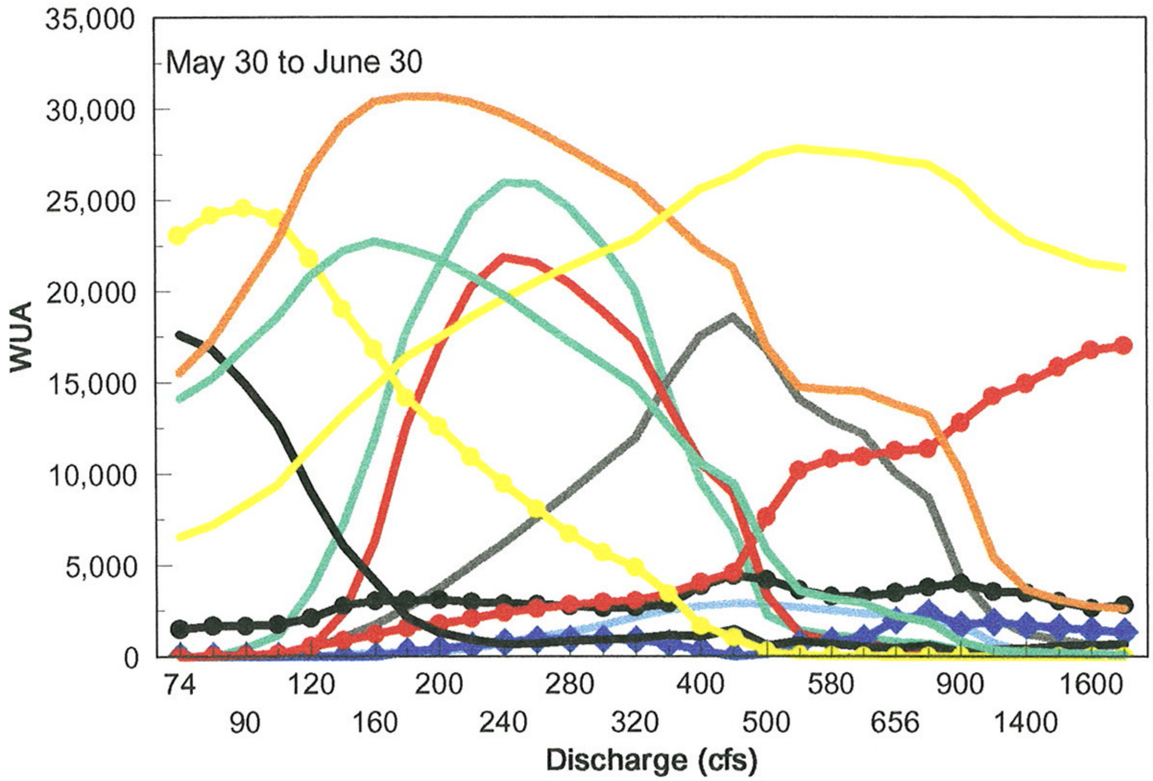


Appendix H4. Non-normalized weighted usable area as a function of discharge for July 1 to April 16 for the middle Red Lake site.

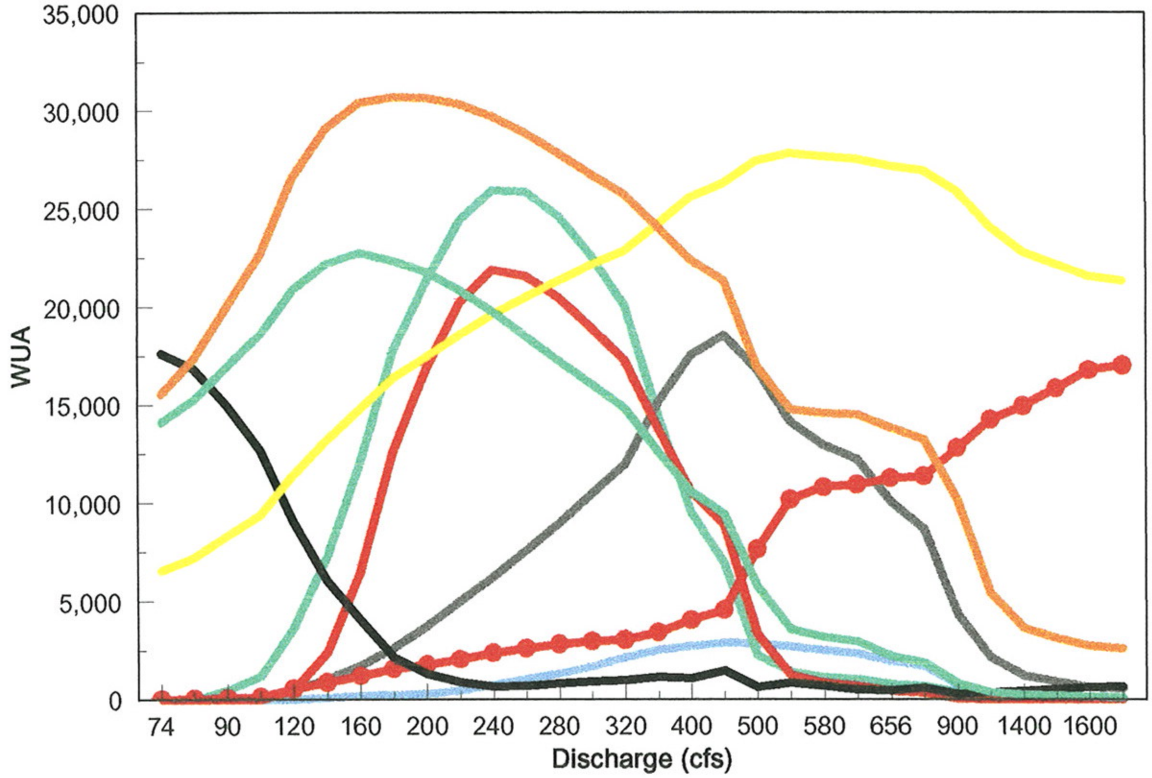


Appendix H5. Non-normalized weighted usable area as a function of discharge for April 17 to May 29, and May 30 to June 30 for the upper Red Lake site.

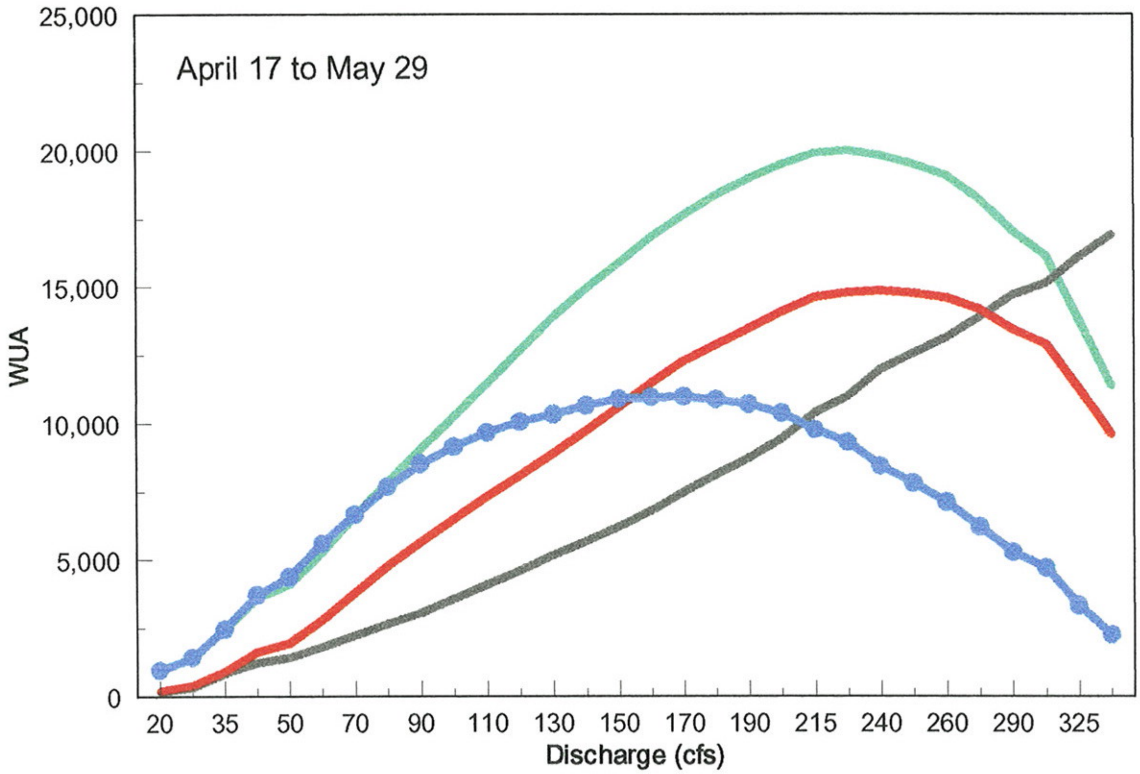


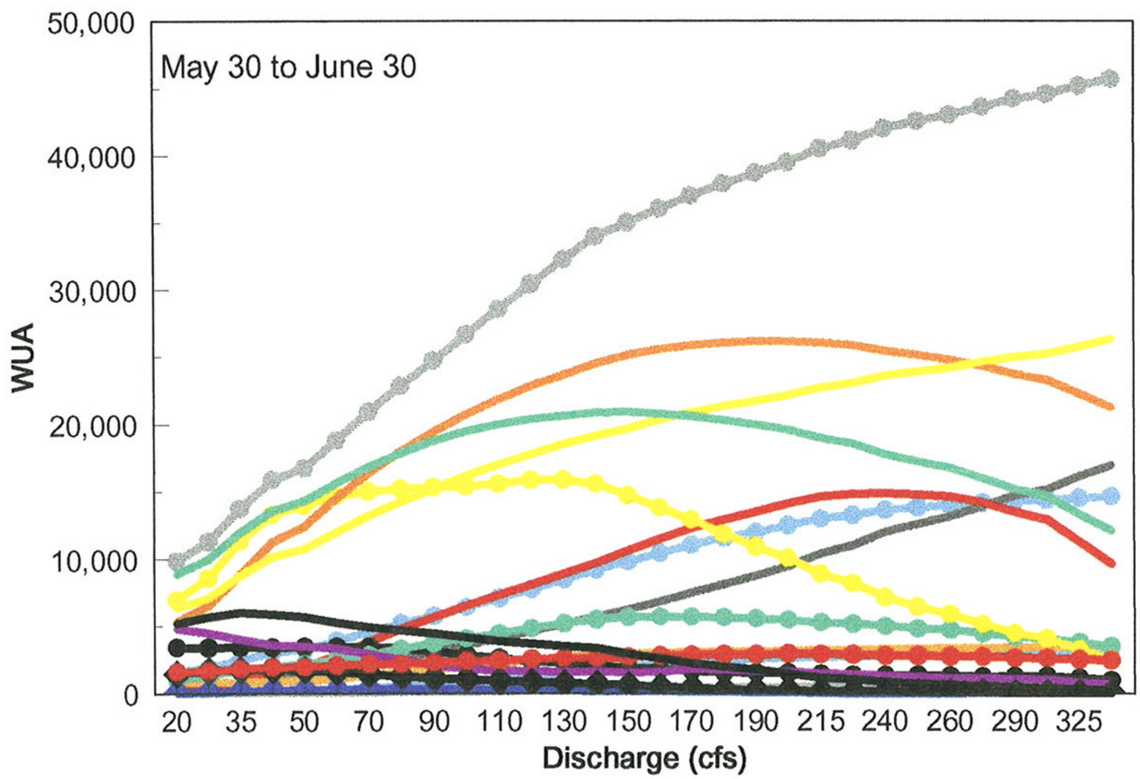


Appendix H6. Non-normalized weighted usable area as a function of discharge for July 1 to April 16 for the upper Red Lake site.

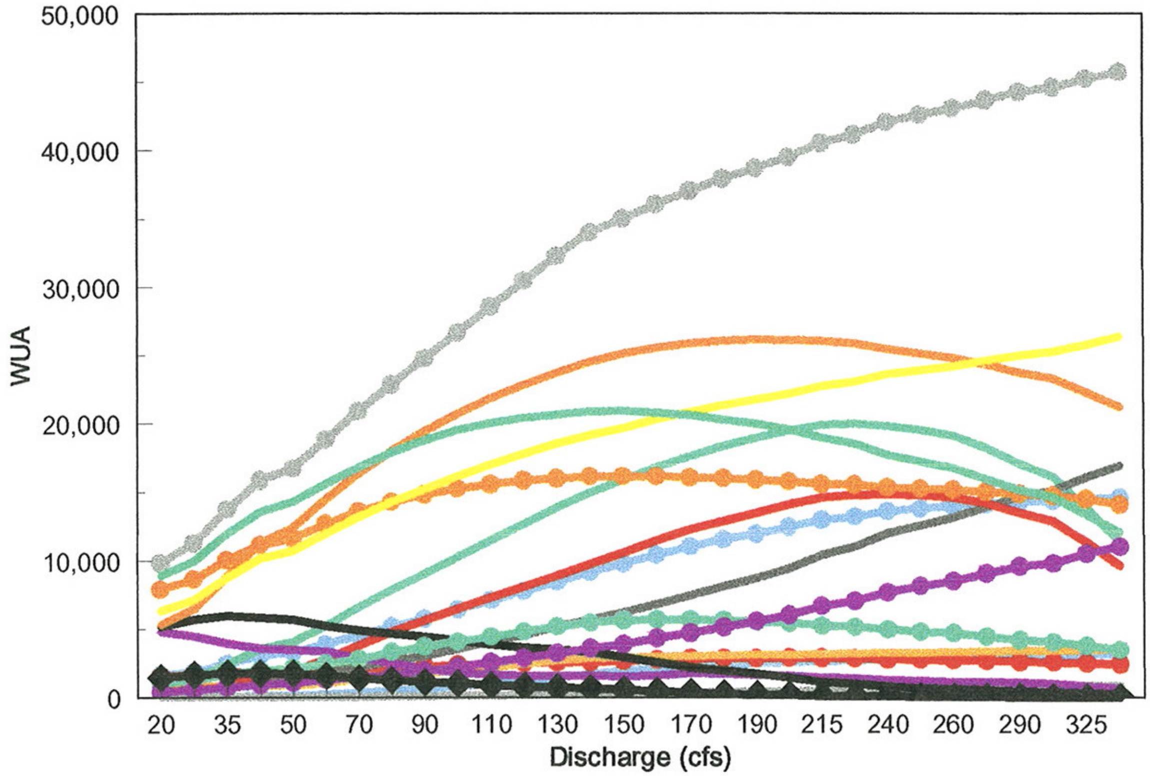


Appendix H7. Non-normalized weighted usable area as a function of discharge for April 17 to May 29, and May 30 to June 30 for the lower Clearwater site.

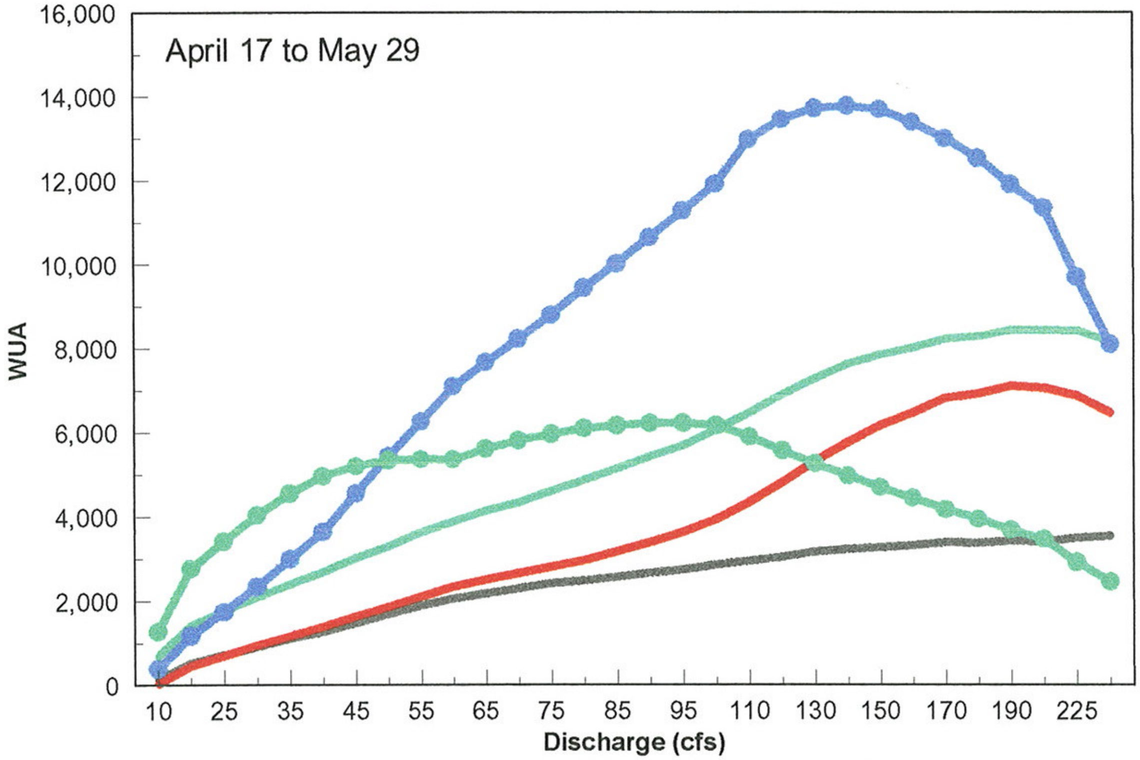


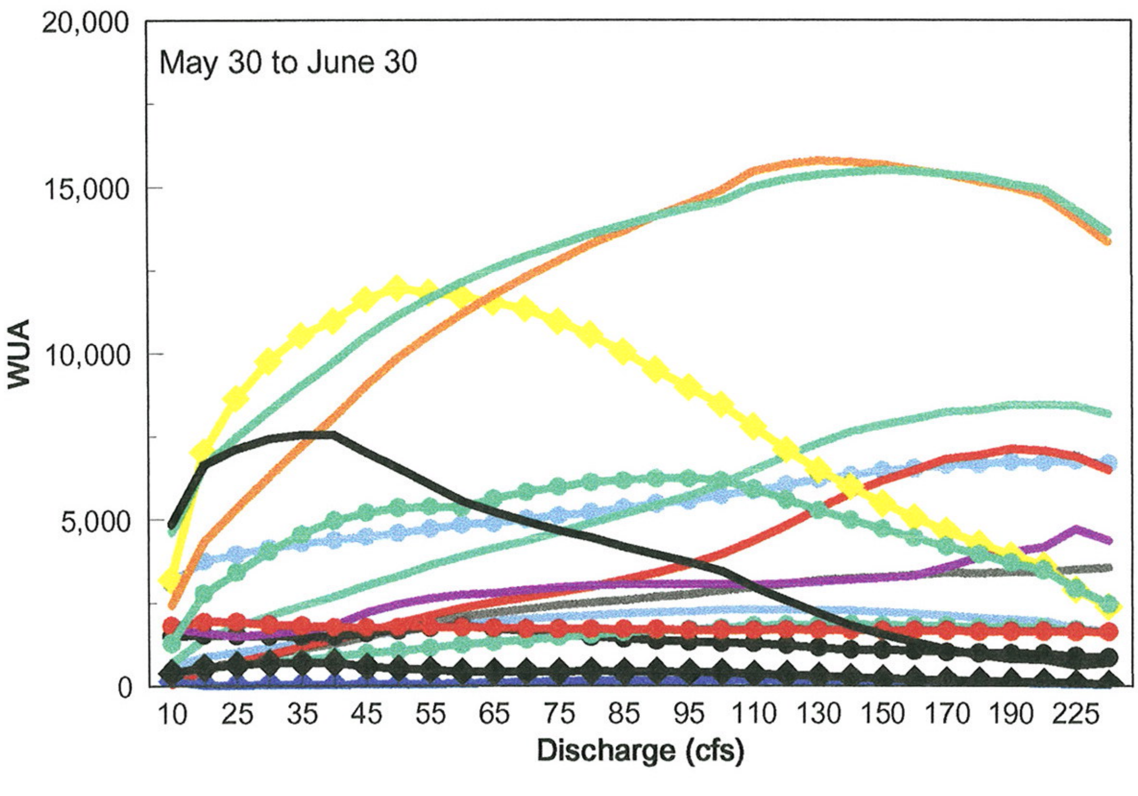


Appendix H8. Non-normalized weighted usable area as a function of discharge for July 1 to April 16 for the lower Clearwater site.



Appendix H9. Non-normalized weighted usable area as a function of discharge for April 17 to May 29, and May 30 to June 30 for the upper Clearwater site.





Appendix H10. Non-normalized weighted usable area as a function of discharge for July 1 to April 16 for the upper Clearwater site.