EVALUATION OF POTENTIAL BARRIERS TO FISH MOVEMENT ABOVE AND BELOW SAN ACACIA DIVERSION DAM

Project Completion Report
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by

Thomas A. Wesche
HabiTech, Inc.
Laramie, WY

and

Sterling Grogan
Middle Rio Grande Conservancy District
Albuquerque, NM

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EXECUTIVE SUMMARY

Upstream movement is likely an important phase of the Rio Grande silvery minnow (*Hybognathus amarus*) life cycle. The U. S. Fish and Wildlife Service, in its' March 17, 2003 Biological Opinion, ordered that fish passage for the minnow be provided around San Acacia diversion dam by 2008. In light of this mandate and the large capital expenditure required, the San Acacia Fish Passage Workgroup, at the request of the Middle Rio Grande Conservancy District, felt it judicious to conduct an appraisal study to first determine if the minnow would be able to move upstream in the degraded middle Rio Grande channel to use such a passage facility, and if successful in passing, would they be able to move further upstream. This study addresses these information needs.

Aerial reconnaissance followed by ground-truthing and field investigations were conducted from June 2002 to January 2003 to identify, describe and evaluate potential physical barriers to silvery minnow upstream movement within the Rio Grande from San Marcial upstream to Isleta, a study area of about 110 river miles. The "physical barriers" to be evaluated included man-made structures across the channel (other than the major diversion dams), hydraulic features such as steep, turbulent, high velocity chutes, and locations with dramatic changes in bed relief. Once identified, field data were collected and habitat modeling conducted to evaluate the suitability of these potential barriers for minnow passage.

Four potential passage barriers were identified, all being steep, turbulent, high velocity chutes located at and immediately downstream of the Rio Salado confluence with the Rio Grande, just upstream from San Acacia dam. Conditions here are poorly suited for silvery minnow passage due to excessive water velocities and the length of the chutes through which the fish must pass. At flows above 250 cfs, there is a high probability this river section is a passage bottleneck for upstream movement. Recommendations are made for a fish movement study to be conducted in the vicinity of the Rio Salado confluence. Should the movement study confirm our physical-based findings reported here, restoration planning and implementation to improve passage at this location should be initiated.

TABLE OF CONTENTS

List of Tables

List of Figures

INTRODUCTION

Upstream movement is likely an important phase of the Rio Grande silvery minnow (*Hybognathus amarus)* (RGSM) life cycle. The short-lived species (1 to 2 years) is a pelagic spawner whose reproductive strategy involves the release of semi-buoyant eggs which drift downstream for 24 to 48 hours prior to hatching (Platania, 1995). If younger fish ready to recruit into the adult spawning population are not able to re-locate upstream, a down-river shift in species distribution may occur. Recent fish collections indicate an uneven distribution of RGSM within the middle Rio Grande (MRG), with increasing numbers in a downstream direction (U. S. Fish and Wildlife Service, 1999). Such a trend supports the upstream movement hypothesis and the need for fish passage capability.

Until recently, little has been known about the swimming performance and movement behavior of RGSM. Historically, concentrations of minnow have been occasionally found downstream of diversion dams in late summer and fall suggesting that upstream re-colonization may occur at that time, although such schooling may have been to avoid unfavorable conditions downstream (Koster, 1957; Bestgen and Platania, 1991). Results from recent laboratory studies suggest the species is a fairly capable and motivated swimmer with the ability to successfully move upstream through passageways of moderate velocity, turbulence and length (Bestgen et al, 2003). These researchers conclude that if a structure is engineered around the physiological and behavioral constraints of the species, and if environmental conditions at the time of passage are favorable, a fishway structure may enhance passage capability of a portion of the RGSM population.

Critical habitat for the federally-endangered RGSM comprises 157 river miles of the MRG from Cochiti Dam downstream to about San Marcial, just above Elephant Butte Reservoir (U. S. Fish and Wildlife Service, 2003). Three low-head diversion weirs (Angostura, Isleta, and San Acacia), in addition to Cochiti Dam itself, currently span the river within this section and have been identified as likely barriers to upstream movement by RGSM (U. S. Fish and Wildlife Service, 1999). Recent Biological Opinions of the U. S. Fish and Wildlife Service (2001; 2003) (USFWS) require the Bureau of Reclamation (BOR) and other parties to the consultation to develop a plan for evaluating a full suite of fish passage alternatives at the San Acacia dam, the most downstream of the three, and complete passage for RGSM at the structure by 2008. The San Acacia Fish Passage Workgroup (Workgroup), formed following the August 2, 2000 Agreed Order, has taken the lead in addressing this issue and initiated several research studies involving fish passage matters, including the project reported here.

As presently mandated by the USFWS, a large capital Program expenditure will be necessary to assure fish passage at San Acacia dam by 2008. Prior to such an investment however, the Workgroup, at the request of the Middle Rio Grande Conservancy District (MRGCD), felt it judicious to conduct an appraisal study to answer two important questions:

1. Will fish be able to move upstream from below to access a passageway installed at San

Acacia dam?

2. How far upstream will fish be able to move once they successfully pass through the San Acacia structure?

These questions were raised due to the highly altered condition of the MRG channel from San Marcial upstream through the San Acacia reach to Isleta. Channel modification and bank stabilization for a variety of land and water uses have discouraged lateral channel migration leading to reductions in active channel width, secondary channels and backwaters while increasing water velocity, substrate size, and localized bed slopes (USFWS, 1999). Such channel and habitat changes are contrary to the described preferences of the RGSM (Dudley and Platania, 1997) and heighten the probability that physical barriers (other than the major diversion weirs) may exist which hamper or prevent upstream fish movement. In this context, "physical barriers" refer not only to man-made structures within or across the channel, but also to hydraulic conditions such as excessive water velocities, shallow water depths, areas of high turbulence, and locations having dramatic changes in bed relief. If one, or a combination of these barriers is present over part or all of the water year, RGSM could be prevented from reaching a passageway installed at San Acacia from downstream, or they may be unable to move upstream from the structure to more desirable habitat.

Based upon this background and justification, the primary objectives of this study are to:

1. Identify and describe potential physical barriers to RGSM upstream movement from San Marcial upstream through San Acacia to just below the Isleta diversion weir over a range of stream flow conditions;

2. Evaluate identified barriers and prioritize them applying the RGSM swimming and passage capability criteria developed by the recently completed companion study of Bestgen et al, 2003;

3. Recommend locations identified as high-probability physical passage barriers as candidates for habitat restoration and any additional passage studies that may be needed.

A secondary objective of the study has been to inventory potential physical barriers to fish movement within the drainage system of the Middle Rio Grande Conservancy District's (MRGCD) Socorro Division.

METHODS

Study Area

Our primary study area extended from River Mile (RM) 169.3 at Isleta diversion dam downstream to about RM 60 at the headwaters of Elephant Butte Reservoir (Figure 1). No on-the-ground field work was conducted on Isleta Pueblo lands. To meet our secondary objective, surveys were conducted on the Riverside, Polvadera, and Louis Lopez drains within MRGCD's Socorro Division.

Review of Existing Data

Prior to the initiation of field work, existing river cross-section information available from the BOR AGG-DEG and RANGELINE databases were reviewed. This screening was conducted to identify possible channel locations where, due to channel narrowing and other management actions, the likelihood of fish passage was suspect and further aerial and ground investigation might be warranted. Also, the October 1997 BOR aerial photograph series for the study area was inspected to identify river crossing locations for bridges, pipelines, and other structures which might create hydraulic conditions detrimental to fish passage. Discussions were also initiated with the Principal Investigators of the study entitled, "Swimming performance of Rio Grande silvery minnow" to determine the status of their research and key findings (Bestgen et al, 2003).

Field Investigations

Aerial Reconnaissance

Three aerial reconnaissance flights of the entire study area were made to identify and locate potential fish passage barriers. Flights occurred on June 21, September 7 and December 5, 2002 using a Maule MXT-7-180 fixed-wing aircraft designed for low level, low speed ground observation. Each flight was about 4 hours in duration. A Sony Mavica 156 megabyte digital still camera (20X precision lens, 2.1 mega-pixel resolution) was used to photograph each identified potential barrier, with locations marked on appropriate maps to allow re-location for ground-truthing and field data collection.

Field Data Collection

Ground-truthing and field data collection were conducted after each aerial reconnaissance flight on the following dates: June 20-24, September 7, 8 and 17, October 7-9, and December 5-9, 2002, and January 20-25, 2003. Field surveys of the Socorro Division drains were conducted during the January 2003 sampling period.

Four potential hydraulic barrier sites were identified and field-measured within the main channel of the primary study area, while two additional sites were established in a secondary channel adjacent to the four main channel sites. At each site, field data were collected following the protocols established for the Physical Habitat Simulation (PHABSIM) system of the Instream Flow Incremental Method (IFIM) by the USFWS (Bovee and Milhous, 1978; Trihey and Wegner, 1981; Bovee, 1988). A bench mark was established for each site and one to three surveyed cross-sections (transects) were installed. The number of transects per site was based upon hydraulic diversity, length of the potential barrier, and ability to safely wade. Bed elevation, water depth, water velocity, and bed material particle size were measured at 20 to 30 locations (or "verticals") along each transect to describe the hydraulic characteristics of the site. Where sufficient water depth allowed, velocity was measured within 0.05 ft of the channel bottom (V_b), also referred to as "nose velocity", at 0.6 of depth from the surface of the water column ($V_{.6}$), or "mean velocity", and near the water surface at 0.2 of depth ($V_{.2}$), using a Marsh-McBirney Model 2000 Portable Flow Meter and a top-setting depth rod. Substrate at each vertical was classified into one of the following categories: sod/organics; silt/clay; sand (0.04 - 0.24 in); fine gravel (0.24 - 0.99 in); coarse gravel (1.00 - 2.99 in); cobble (3.0 - 11.99 in); boulder (>12 in); bedrock; aquatic vegetation. In shallow water, substrate particle diameter was measured along the intermediate axis, while in deeper, heavy flow, an ocular or tactile categorization was necessary. Water surface elevation at each transect and hydraulic control within a site was measured relative to the installed bench mark using a TOPCON AT-G6 Auto level and survey rod. Total site length and the length of channel represented by each transect was measured with a 200ft tape. Color photographs were taken of each site.

The survey of potential passage barriers in the Socorro Division drains was conducted by motor vehicle and foot travel. Each road crossing was also inspected. Where possible fish passage problems were observed, field measurements to describe site characteristics were taken following the guidance of Powers and Orsborn (1985). Color photographs were also taken to document site conditions.

Data Analysis

Analysis of field data collected at the six sites sampled within the primary study area was undertaken using RHABSIM (Riverine Habitat Simulation) version 2.0, a recent improvement of the PHABSIM software developed by T. R. Payne and Associates (1998). RHABSIM, like PHABSIM, is a series of computer programs that link stream channel hydraulics over a range of flow conditions with physical habitat utilization by aquatic organisms, usually fish. The simulation sequence is a multi-step process that incorporates physical data from specific transects with biologically-based data on habitat suitability to develop habitat (expressed as weighted usable area, WUA) versus discharge (Q) relationships for each site.

The hydraulic algorithms of RHABSIM were calibrated to field data, and predictions made of mean water velocity and depth at unmeasured discharges over a stable range of substrates. Hydraulic decks were calibrated according to the guidelines of Milhous et al (1984) and T. R. Payne and Associates (1998). The recommended prediction limits of 0.4 to 2.5 times the field measured flow were followed. The predicted channel hydraulics were then coupled with RGSM swimming capability criteria developed from Bestgen et al (2003) to produce WUA-Q relations and surface area maps depicting passage suitability at each site over a range of flows.

Passage suitability criteria for RGSM in terms of water velocity, water depth and substrate are absent from the published literature. Therefore, we linked the laboratory-based swimming ability data developed by Bestgen et al (2003) with a measure of species passage performance to develop passage suitability relations for use within RHABSIM. We selected the minnow's success rate in traversing a 60ft long hydraulic flume under varying mean water velocity conditions as our measure of passage performance (see Figure 16 from Bestgen et al, 2003, presented in Appendix A). For selected water velocity values (8, 23, 38, and 53 cm/s; or, 0.25, 0.75, 1.25, and 1.75 ft/s), the three corresponding "percent finished" values were averaged and expressed as "suitability" on a decimal scale of 0.0 to 1.0. A suitability of 1.0 was assigned to 0.0 ft/s and a suitability of 0.0 was assigned to 3.28 ft/s based upon the recommendation by Bestgen et al (2003) that maximum velocities encountered by RGSM for even very short periods of time should not exceed 100 cm/s (3.28 ft/s). Substrate criteria were defined based on the conclusion reached by Bestgen et al (2003) that coarser particles aided RGSM upstream passage by providing low velocity resting areas. Accordingly, finer grain sizes (silt, sand, fine gravel) that would afford little protection for RGSM were assigned a suitability of 0.5, and larger particles (cobble and boulder) were assigned a suitability of 1.0. Coarse gravel (1 to 3 in. diameter) was assigned an intermediate value of 0.75. Water depth criteria were based on the minimum depth felt necessary to keep adult RGSM wetted and gain the necessary propulsion for upstream movement. All depths greater than or equal to 0.2 ft were assigned a suitability of 1.0, while lesser depths were assigned a value of 0.0. The passage suitability curves developed and applied for RGSM are presented in Appendix A.

Stream flow records for the two U. S. Geological Survey (USGS) gage stations nearest the study sites, Rio Grande Floodway near Bernardo (USGS#08332010) and Rio Grande Floodway at San Acacia (USGS# 08354900), were obtained for the periods-of-record from the New Mexico USGS website.

RESULTS

Middle Rio Grande Study Area

Four potential fish passage barrier sites were identified within the MRG study area, all situated at or immediately downstream of the Rio Salado confluence (Figure 2). This 1.2 mile section of river just above San Acacia diversion dam is highly dynamic and unstable due to the Rio Salado's large sediment contribution and highly variable flow regime. The four steep, turbulent chutes identified and sampled were located at RM 118.6 (Site #1), RM 118.4 (Site #2), RM 118.3 (Site #3), and RM 117.4 (Site #4) (Figures 3 to 6). The most downstream site (#4) is 1.2 miles upstream of San Acacia dam.

Hydraulic characteristics of the four main channel study sites varied considerably (Table 1). Stream flow at the time of field measurement ranged from 137 to 542 cubic feet per second (cfs), while wetted channel width varied from 26 to 108 ft. Mean transect water depth ranged from 0.71 to 1.89 ft and site lengths extended from 89 to 159 ft. All sites were characterized by a relatively steep gradient (for the MRG) of 0.30 to 0.69 % and were predominated by coarse substrates of cobble and gravel. Transect mean velocities ranged from 1.86 to 4.34 ft/s, while nose velocities averaged 0.76 to 2.12 ft/s. The flow condition at each transect was turbulent, but sub-critical, at the time of field measurement, with Froude numbers ranging up to 0.7 at Site #4. The Froude number expresses the ratio of kinetic energy (velocity) to gravitational energy (depth) at a specific stream location, with values greater than 1.0 representing "super-critical" flow conditions (Gordon et al, 1992).

RGSM passage suitability varied by site and by flow (Table 2; Figures 7 to 14). Overall, passage conditions at Site #4 (the most downstream site) were the least favorable at all modeled flows, with usable habitat for RGSM passage ranging from about 9.0% of the total site area at 250 cfs to 0.6% of the total site area at 850 cfs (Figure 13). "Usable" is here defined as that area within the site having a passage suitability greater than 0.0 (on a scale of 0.0 to 1.0, with 1.0 being optimum passage conditions). At the 250 cfs flow level, the highest cell suitability was in the 0.2 - 0.39 range, with passage through the majority of the transect having suitability less than 0.2. At 850 cfs, over 99% of the transect width at Site #4 had a passage suitability of 0.0. While water depth and substrate were adequate for RGSM over the range of flows modeled, mean water velocity was the hydraulic parameter responsible for the unsuitable passage conditions encountered (Figure 14). Although nose velocity cannot be modeled by the RHABSIM hydraulic program, the field measured values (average nose velocity of 2.12 ft/s, range of 0.93 to 3.62 ft/s) at 542 cfs suggest that passage suitability deep in the water column near the substrate is also problematic. Given the 118 ft length of this steep, high velocity, turbulent chute, it is quite probable that Site #4 represents a substantial upstream passage barrier for silvery minnow over a wide range of stream flow conditions.

To further evaluate this opinion regarding Site #4, we compared the observed hydraulic conditions with the RGSM swimming distance relationships presented in Figure 20 of Bestgen et al, 2003 (see Appendix A). Based upon a chute length of 118 ft (36 m), the maximum passage velocities for all fish sizes considered are 1.51 to 1.64 ft/s (46 to 50 cm/s). The mean cross-section velocity at Site #4 at 542 cfs was 4.24 ft/s (Table 1), while the mean water column velocity at 28 of the 29 measured verticals along this cross-section exceeded the recommended maximums. Furthermore, 26 of the 29 measured nose velocities along the cross-section also exceeded the recommended maximum velocity. These findings also suggest that conditions such as those found at Site #4 may be problematic for RGSM upstream passage.

RGSM passage conditions at the three other main channel sites were more suitable than at Site #4, but still marginal. At Site #2, usable habitat for the three modeled flows (75, 180 and 350 cfs) ranged from 11.5 to 15.3% of the total site area, while at Site #3 usable passage area accounted for 10.7 to 19.4% of the total area over the modeled flow range of 72 to 400 cfs (Table 2; Figures 9 and 11). Passage conditions were most suitable at Site #1, the uppermost of the four sites. Here, usable habitat for the three modeled flows (55, 137 and 300 cfs) ranged from 18.4 to 30.4% of the total site area (Table 2; Figure 7). As at Site #4, mean water velocity was the dominant hydraulic parameter controlling passage suitability at these three sites (Figures 8,10, and 12).

The MRG channel immediately below the Rio Salado confluence is braided, with Sites 2, 3, and 4 located in the main channel on river left (looking downstream) (Figure 2). The secondary channel on river right is approximately 4000 ft in length and departs the main channel just upstream of Site #2, re-entering just downstream of Site #4 (Figure 15). The possibility exists that under certain flow conditions, RGSM might be able to bypass the three steep, turbulent, high velocity chutes in the main channel by moving upstream through this secondary channel, leaving only Site #1 at the Rio Salado confluence to negotiate. To explore this passage option, two study sites were installed across shallow riffles in the secondary channel, near the mouth (SC#1) and near the upper end (SC#2) (Figure 16). Hydraulic characteristics of these sites are summarized in Table 1.

Passage suitability for RGSM at the two secondary channel sites was similar to that encountered at main channel sites. At SC#1, usable habitat over the range of modeled flows (3, 7, and 16 cfs) varied from 16.8 to 26.2% of the total site area (Table 2; Figure 17), while at SC#2, usable passage area was from 15.4 to 18.8% of the total area over a flow range of 3 to 18 cfs (Table 2; Figure 19). However, mean water velocity was not as dominant in controlling passage suitability as it was at the main channel sites (Figures 18 and 20). Both shallow water depths and fine-grained substrates contributed to unsuitable passage conditions within the secondary channel.

RGSM passage upstream through the secondary channel appears possible at times under certain flow conditions. However, our field observations and measurements indicate that flow into this channel fluctuates widely and is regulated by highly variable upstream hydraulic control conditions. For example, on June 23, 2002, 137 cfs was measured in the MRG at main channel Site#1 (Table 1), with a substantial portion of this flow entering the secondary channel downstream. However, a headcut about 3.0 ft in height at the inlet to the secondary channel blocked upstream passage into the main channel. By October 7, the headcut had disappeared, but with 180 cfs in the main channel, there was no flow entering the secondary channel (Figure 15). By December 7, with well over 200 cfs in the main channel, we measured 31.4 cfs in the secondary channel with adequate passage conditions observed. However, by January 24, 2003, when 542 cfs was measured at main channel site #4 (Table 1), only about 7 cfs was present in the secondary and passage was marginal. Such variability results from the dynamic sediment loading received from the Rio Salado and the MRG's main channel capability to differentially transport this material. The possibility also exists that at times, river stage in this area is controlled by backwater conditions at San Acacia diversion dam. Given such instability, it is impossible, based upon our present understanding of the situation, to predict passage suitability through the secondary channel at particular times based upon MRG flow conditions alone.

<u>Socorro Division Drains</u>

Two likely barriers to fish passage were identified by our survey of the Socorro Division drain system (Figure 21). Both barriers were the result of poor fish entrance conditions on the downstream ends of culverts characterized by excessive water velocities and dramatic localized changes in water surface elevation. Fish exit conditions at the upstream ends of these culverts were marginal for passage.

The passage barrier identified on the Riverside Drain is located at the Highway 380 road crossing just east of San Antonio, NM. This round corrogated steel culvert is 120 ft in length and 4 ft in diameter. Flow through the culvert on January 21, 2003 was measured at 28.9 cfs and can be described as a "torrent" at the downstream end. The mean velocity of the flow exiting the culvert was 8.6 ft/s while the nose velocity was 8.2 ft/s. There is a 1.2 ft elevation differential between the culvert floor and the downstream receiving pool. Based upon what is currently known regarding

RGSM swimming capabilities (Bestgen et al, 2003), there is little doubt this culvert is a passage barrier.

The passage barrier identified on the Polvadera Drain is located at the railroad crossing north of Lemitar, NM near RM 109 on the MRG. This oval corrogated steel culvert is 55 ft long, 8 ft high and 7 ft wide. Flow through the culvert was measured at 1.0 cfs on January 22, 2003, with mean water velocities at the downstream end up to 3.10 ft/s and water depths of 0.2 ft or less. There is a 1.2 ft elevation differential between the culvert floor and the downstream receiving pool. As with the Riverside Drain at Highway 380 culvert, there is little doubt this culvert is a fish passage barrier.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Our knowledge of RGSM swimming capabilities has expanded substantially over the past year (Bestgen et al, 2003). While questions remain about the movement behavior of the species regarding timing, duration, and motivation, we can at least now begin to develop and evaluate engineering-based fishway design alternatives for passage around major diversion facilities and quantitatively assess the MRG and its environs for other potential passage barriers. Our study has addressed this latter need by identifying, surveying and evaluating such potential barriers.

There is a high probability that the MRG at and immediately below the confluence of the Rio Salado is a bottleneck for RGSM upstream passage for at least portions of the water year. Our analysis determined that hydraulic conditions for passage are most unsuitable at Site #4, located just 1.2 miles upstream of the San Acacia diversion dam. If RGSM can pass this steep, turbulent, high velocity chute, they should then be able to successfully move upstream through the other sites identified as potential passage barriers. At modeled flows of 250 cfs or more, usable passage habitat ranged from less than 10% to almost zero within Site #4. Conditions such as these are likely a serious impediment to RGSM upstream movement through this 118 ft long section.

Flow duration analysis of the Bernardo and San Acacia gage records provides an approximation of the percent time passage may be impeded at Site #4. Based on the 1958 to 2001 period for the Bernardo gage and the 1959 to 2001 period for the San Acacia gage, flow exceeded 250 cfs 53 and 47% of the time, respectively. Using a more recent period-of-record (1980 to 2001), which better reflects more current river conditions, passage would have been possible on only 10% of the days based on the Bernardo gage record and 17% of the days based on the San Acacia gage. While these flow records are likely affected by problems of poor gage site control and are not as site-specific as we would like, they do suggest that passage may be problematic over an extended period of time given current channel conditions near the Rio Salado confluence.

Of course, physically-based analyses such as these are underlain by several assumptions. Key among these are that 1) RGSM swimming capabilities in the wild are similar to those in the laboratory; 2) the passage suitability indices applied accurately reflect the true capabilities of the species; 3) water temperature and other water quality parameters in the wild at the time of passage are at or near the optimums determined in the laboratory; 4) hydraulic model predictions of water velocity and depth at unmeasured stream flows are accurate; 5) substrate remains stable over the range of modeled stream flows; 6) passage suitability of stream flows outside the limits of accurate model prediction are similar to those within the modeled range; and 7) the stream flow records for the Bernardo and San Acacia gage stations accurately reflect the flow régime through the study sites.

Despite these assumptions, we feel our analysis presents sufficiently strong evidence to conclude that the section of the MRG at and immediately below the Rio Salado confluence represents a high risk area as an RGSM passage bottleneck. Given its location just upstream of the San Acacia diversion dam and the likelihood of large capital expenditures by 2008 to provide fish passage around this structure, further study of this area is warranted to first better refine passage limitations and second, if necessary, explore restoration options. There is little sense in building a passageway at San Acacia if fish can only move a mile further upstream for much of the year.

No fisheries information presently exists to suggest, or verify, that RGSM can move upstream through the potential passage bottleneck identified near the Rio Salado confluence. Monitoring data collected downstream (RM 116.8) and upstream (RM 127.0) of this area indicate RGSM numbers are consistently low and relatively stable, both spatially and temporally (Dudley and Platania, 2002), and provide no compelling evidence of fish movement in either direction. Based upon this lack of information, we recommend a movement study using marked RGSM be conducted in this area following procedures such as those applied by Platania et al (2003) below San Acacia dam. The two permanent fish monitoring stations described above, as well as several temporary sampling stations located in the immediate vicinity of the Rio Salado confluence, could be used to assess movement of RGSM upstream from the San Acacia dam pool over a range of hydrologic, hydraulic, and geomorphic conditions. Should fish movement results confirm our physical-based conclusions, restoration planning to explore the feasibility of various management options such as channel widening, channel stabilization, and resting area development should be conducted as part of the San Acacia dam passage effort.

Fish passage problems were observed at only two of the numerous culvert crossings investigated along the Socorro Division drain system. Other types of barriers such as permanent beaver dams and steep, turbulent, high velocity chutes were not found. If passage within the drains were to become an issue at some future time, the observed problems could be corrected by culvert re-sloping, the addition of downstream backwater controls, or both. A culvert analysis and design program such as FishXing (USDA Forest Service, 1999) could be used to guide the restoration.

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Table 1. Hydraulic characteristics of the middle Rio Grande study sites at the field measured flow.

Site	Transect	Date Sampled	Flow (cfs)	Wetted Width (ft)	Mean Depth (ft)	Mean Velocity (ft/sec)	Average Nose Velocity (ft/s)	Substrate		Site Length (ft)	Water Surface Slope (%)
								Dominant (%)	Sub-dominant (%)		
#1	1	6/23/02	137.2	60.0	1.23	1.86	0.76	Cobble (59)	C. Gravel (23)	159	0.34
	2	-	-	73.5	0.90	2.07	1.00	Cobble (48)	Boulder (20)	-	-
	3	-	-	102.6	0.71	1.88	0.90	Cobble (54)	Sand (25)	-	-
#2	1	10/09/02	180.4	25.7	1.89	3.71	1.27	C. Gravel (58)	Cobble (26)	94	0.51
	2	-	-	31.8	1.65	3.44	0.84	C. Gravel (53)	Sand (42)	-	-
	3	-	-	26.8	1.55	4.34	1.13	C. Gravel (61)	Cobble (17)	-	-
#3	1	10/07/02	179.9	47.2	1.21	3.15	0.93	C. Gravel (35)	F. Gravel (35)	89	0.30
	2	-	-	44.3	1.63	2.49	0.96	C. Gravel (50)	Sand (38)	-	-
	3	-	-	35.0	1.78	2.89	1.05	C. Gravel (47)	F. Gravel (32)	-	-
#4	1	1/24/03	542.0	107.5	1.19	4.24	2.12	Cobble (90)	C. Gravel (6)	118	0.69
[1]SC#1	1	1/24/03	7.1	22.0	0.32	1.01	-	Sand (83)	Silt (17)	186	0.21
[1]SC #2	1	1/24/03	7.9	13.8	0.31	1.85	1.09	C. Gravel (73)	Cobble (20)	104	0.38

[1]SC = Secondary Channel

Table 2. Predicted hydraulic and passage characteristics of the middle Rio Grande study sites at the three flow levels modeled with RHABSIM.

Site	Flow (cfs)	Wetted Width (ft)	Mean Depth (ft)	Mean Velocity (ft/sec)	Total Wetted Area (ft^2)	Passable Area (ft^2)	Passable Area (%)
1	55 137 300	69.8 80.7 86.6	0.58 0.96 1.4	1.1 1.6 2.2	11100 12839 13768	3378 3680 2531	30.4 28.7 18.4
2	75 180 350	24.3 30.0 32.6	1.2 1.8 2.6	2.3 2.8 3.3	2284 2824 3069	344 325 471	15.1 11.5 15.3
3	72 180 400	37.9 42.4 46.5	0.93 1.5 2.4	1.8 2.4 3.1	3376 3772 4140	655 463 444	19.4 12.3 10.7
4	250 542 850	103.0 107.5 109.4	0.77 1.2 1.6	2.9 4.2 4.7	12158 12681 12907	1092 221 79	9.0 1.7 0.6
SC#1	3 7 16	20.0 22.0 25.3	0.2 0.3 0.5	0.6 0.9 1.1	3727 4084 4700	626 1068 1027	16.8 26.2 21.8
SC#2	3 8 18	10.8 13.8 16.8	0.2 0.3 0.4	1.2 1.4 1.8	1120 1435 1751	188 269 272	16.8 18.8 15.5

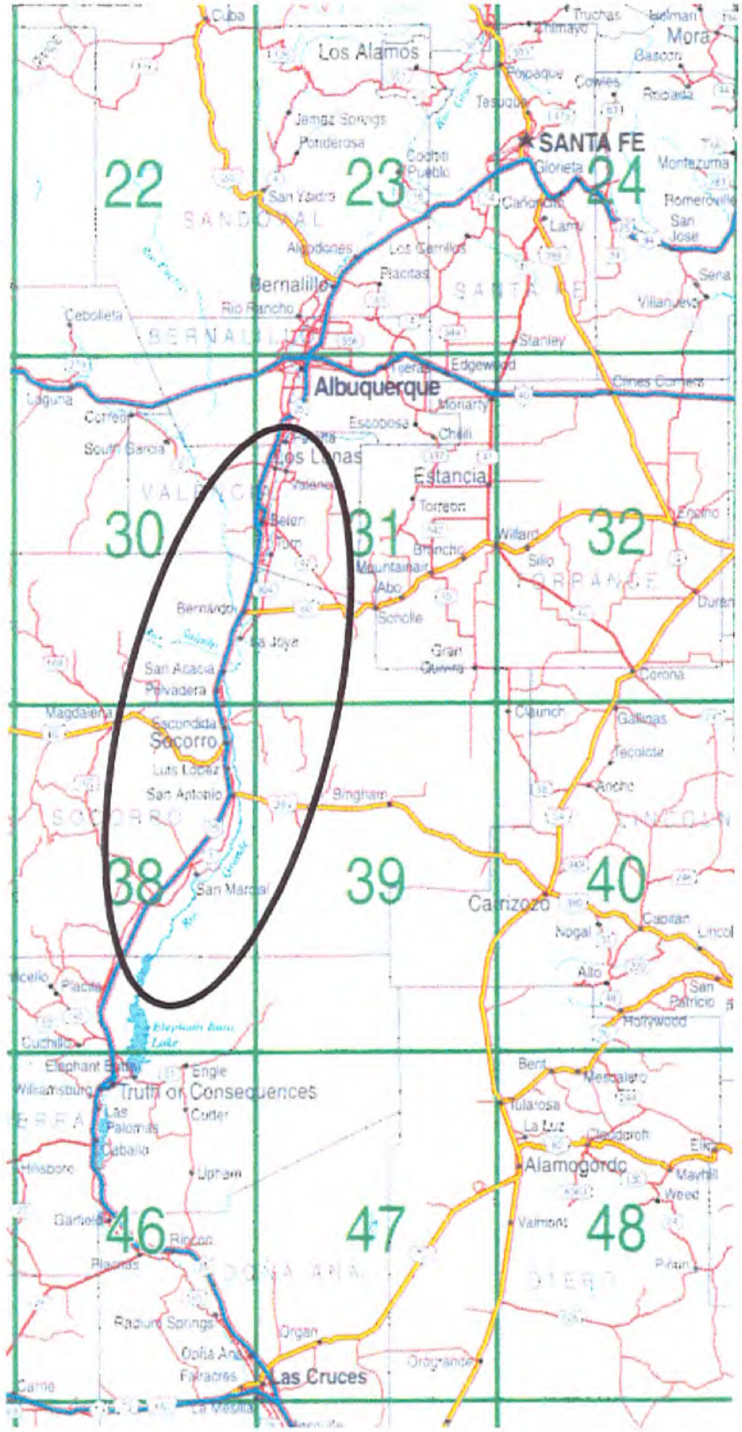
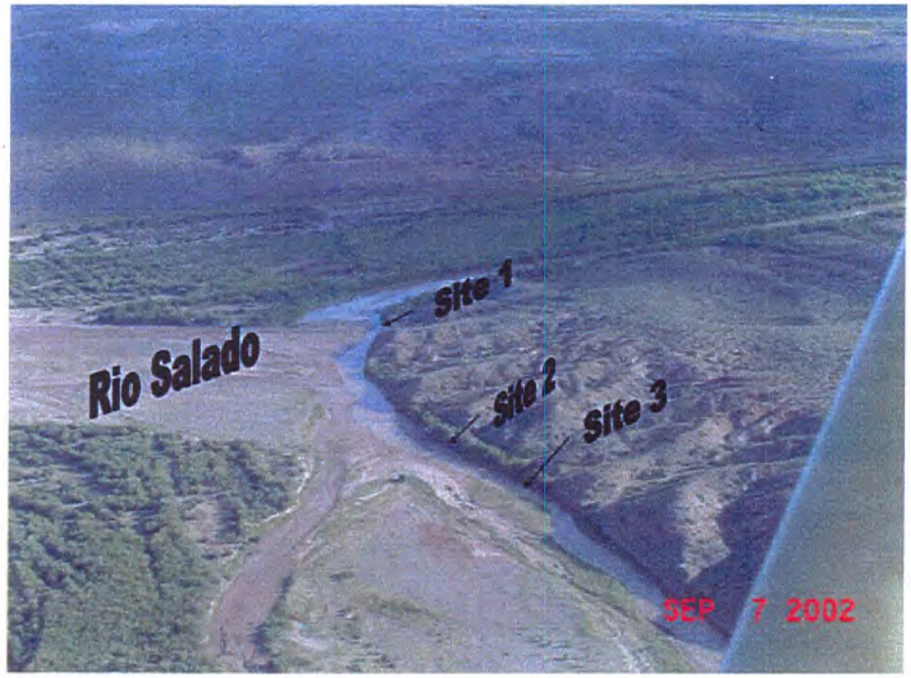


Figure 1. Location of middle Rio Grande study site.



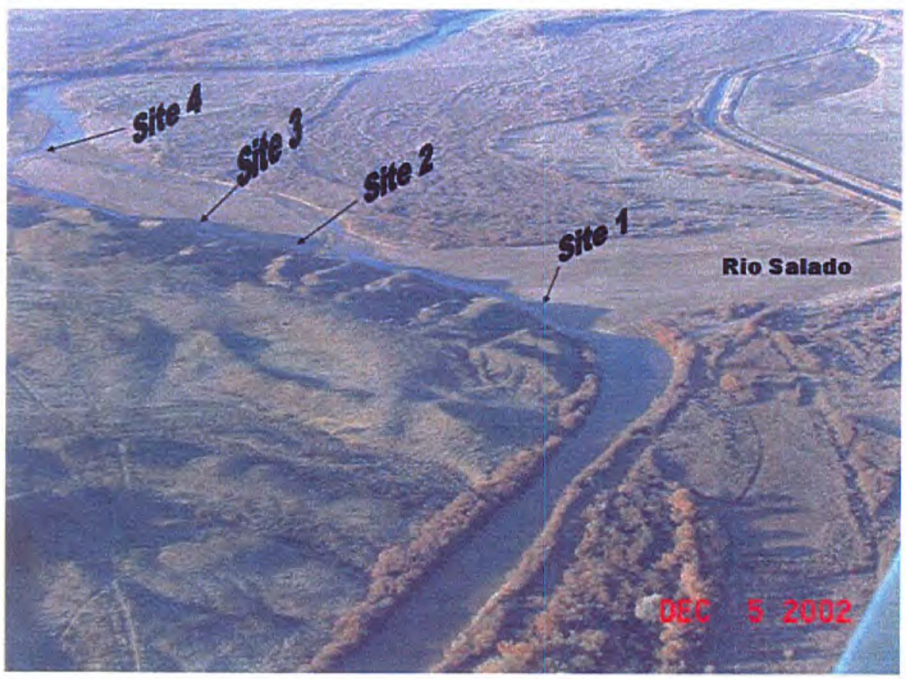


Figure 2. Aerial views of potential fish passage barrier sites on the middle Rio Grande at confluence of Rio Salado. Upper: View of sites 1, 2 and 3 on September 7, 2002. Lower: View of sites 1, 2, 3 and 4 on December 5, 2002.

Figure 3. Middle Rio Grande Study Site #1, June 2002.

Figure 4. Middle Rio Grande Study Site #2, June 23, 2003.

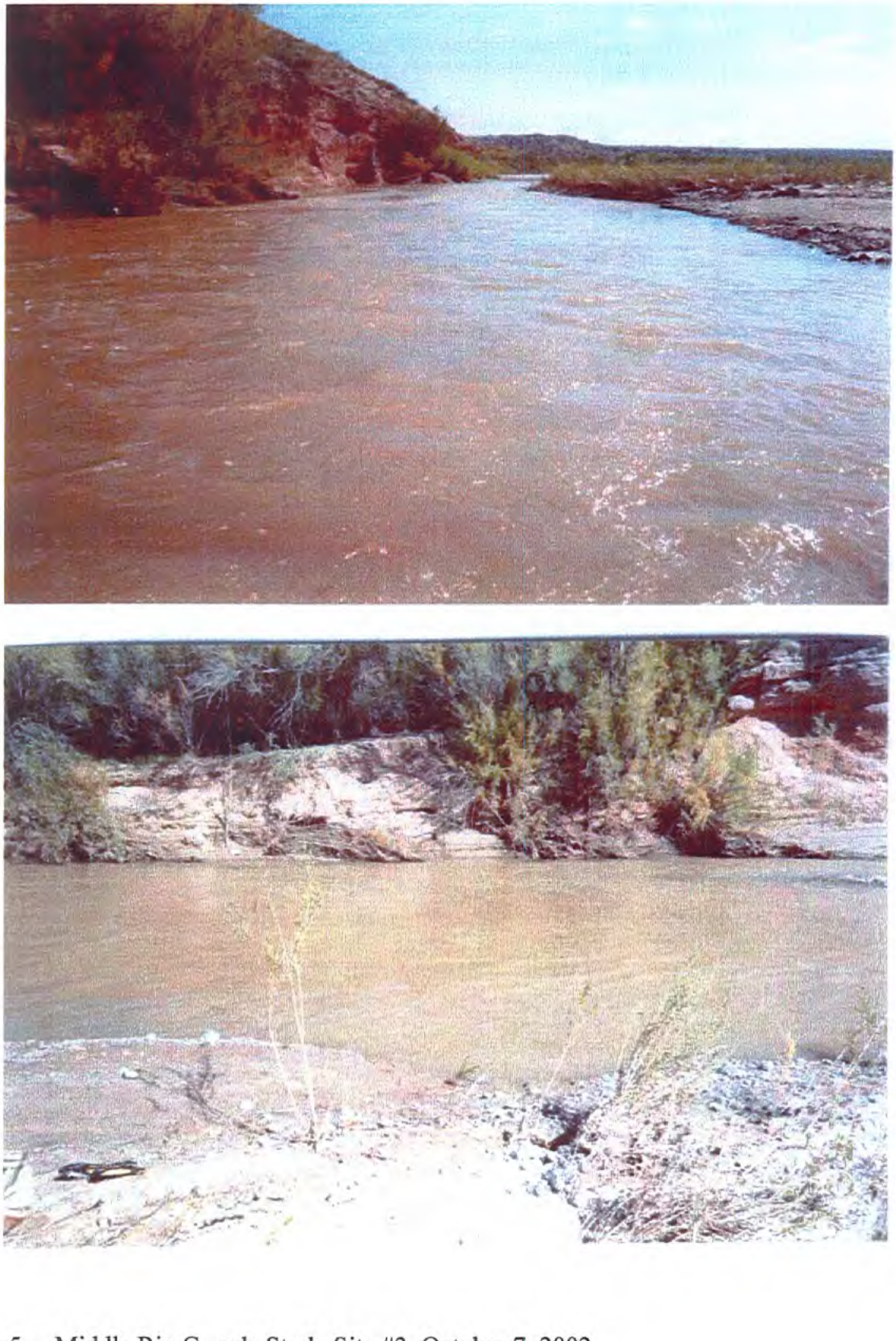


Figure 5. Middle Rio Grande Study Site #3, October 7, 2002.

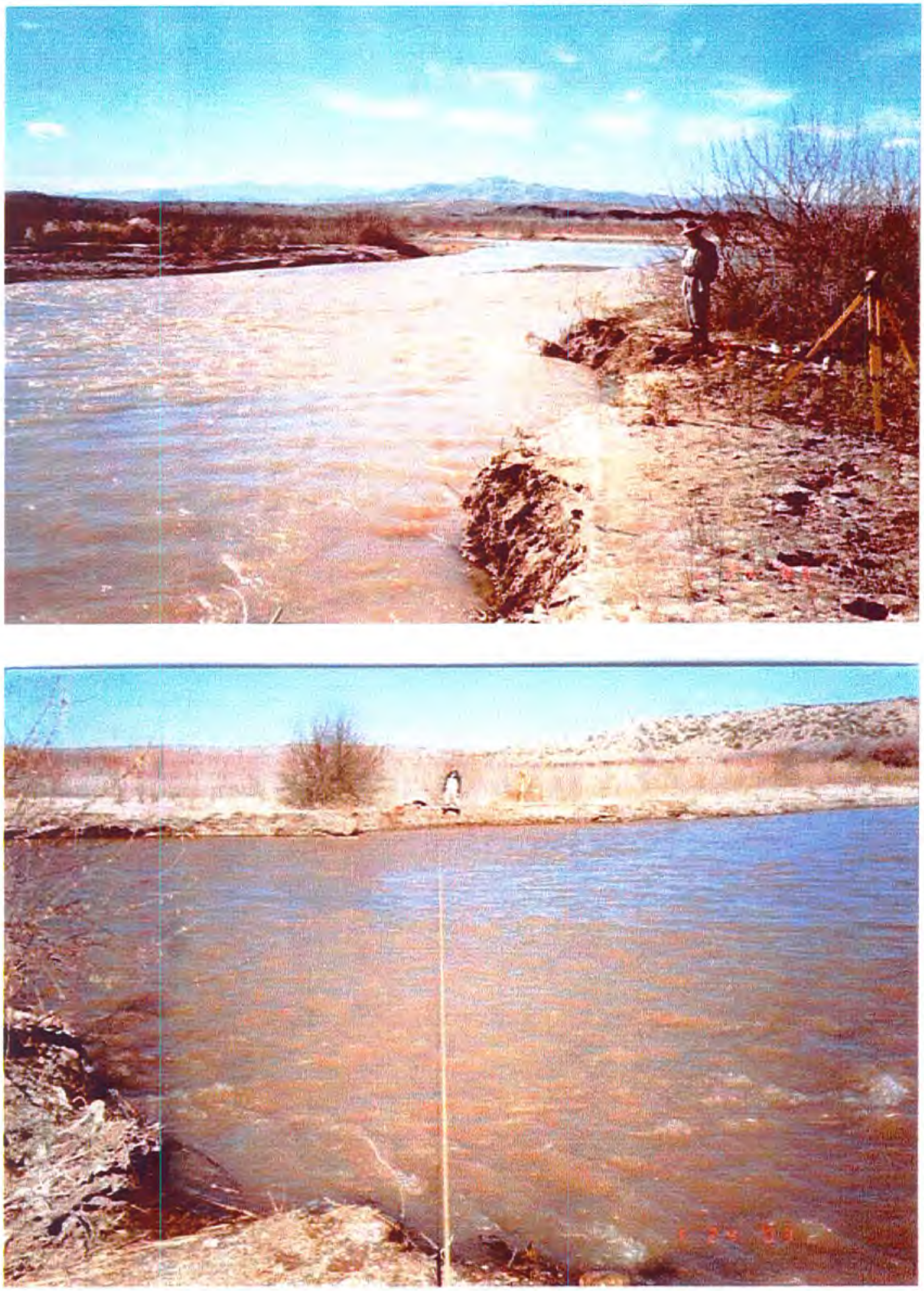


Figure 6. Middle Rio Grande Study Site #4, January 24, 2003.

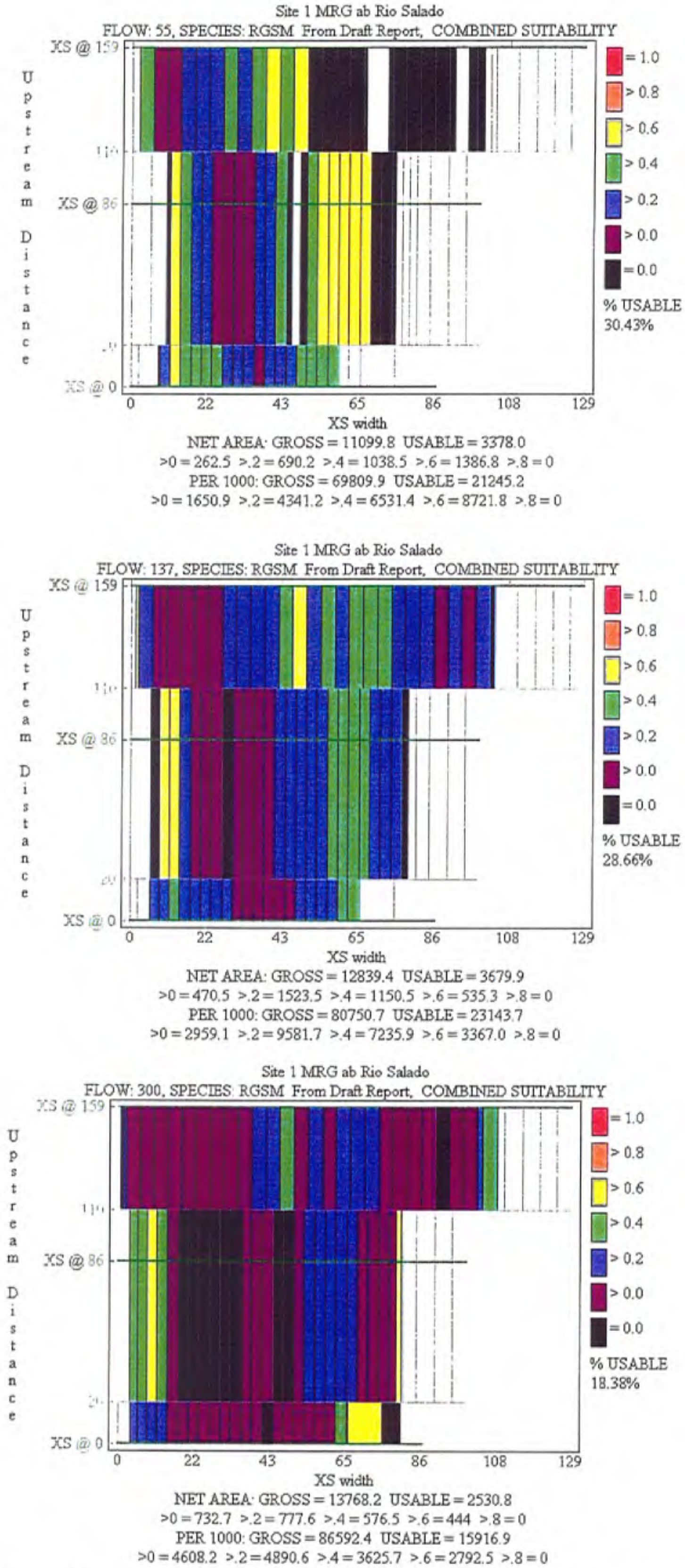


Figure 7. Combined passage suitability for Rio Grande silvery minnow at MRG Study Site #1 for three stream flow levels (55, 137 and 300 cfs).

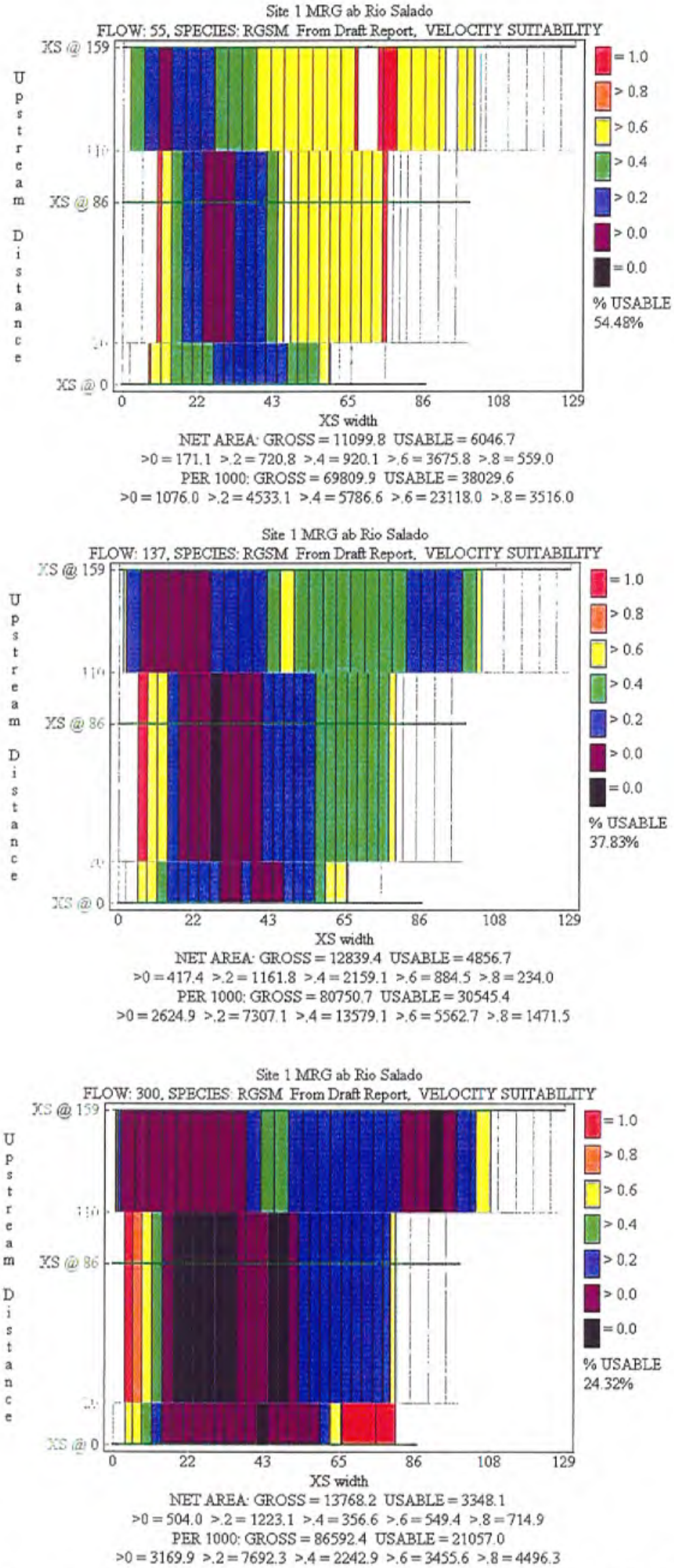


Figure 8. Passage suitability based upon mean water velocity for Rio Grande silvery minnow at MRG Study Site #1 for three stream flow levels (55, 137 and 300 cfs).

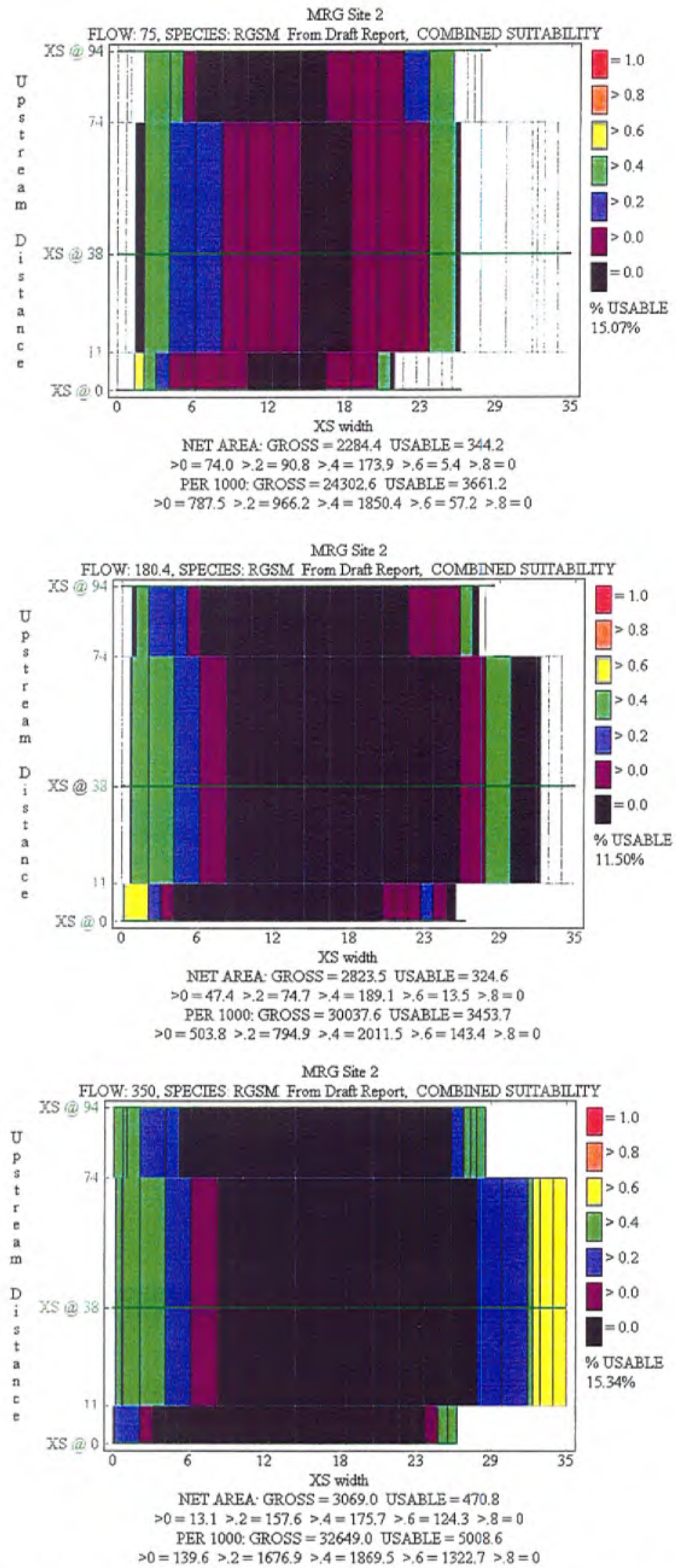


Figure 9. Combined passage suitability for Rio Grande silvery minnow at MRG Study Site #2 for three stream flow levels (75, 180 and 350 cfs).

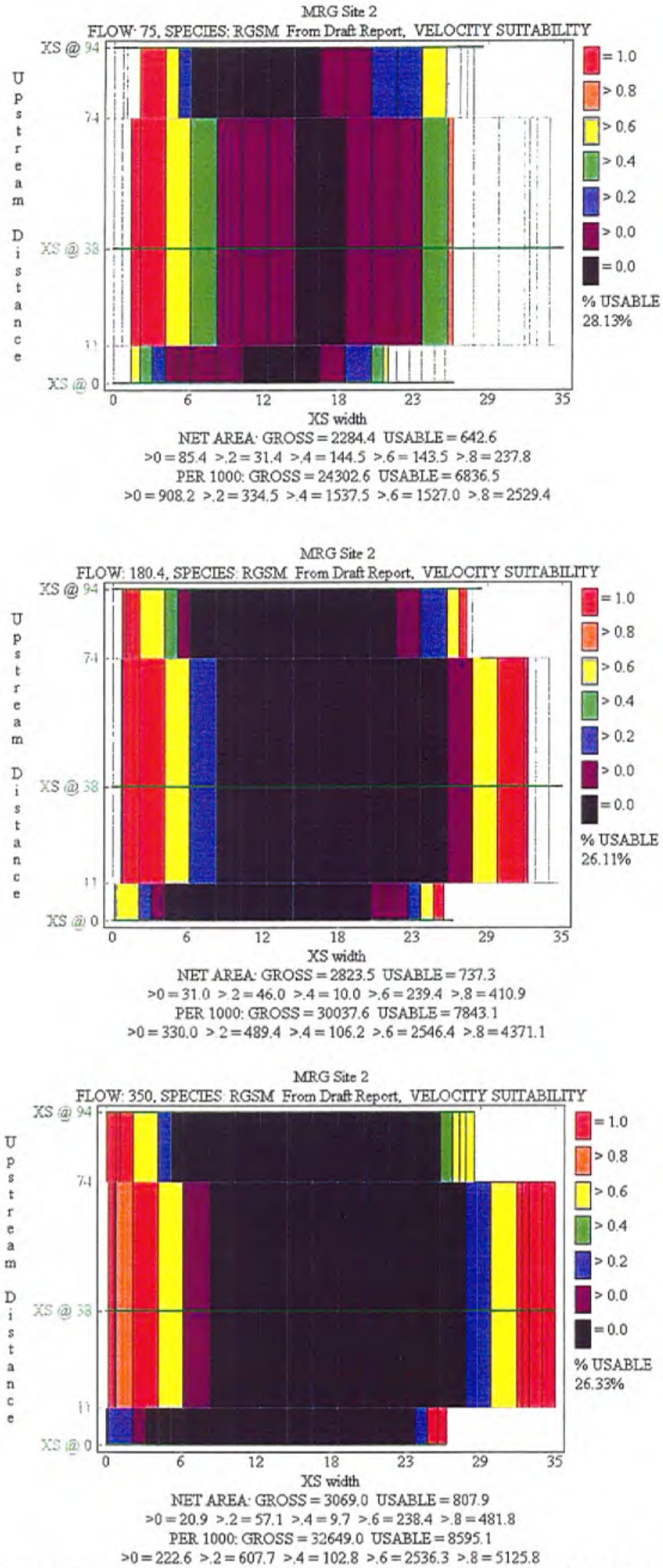


Figure 10. Passage suitability based upon mean water velocity for Rio Grande silvery minnow at MRG Study Site #2 for three stream flow levels (75, 180 and 350 cfs).

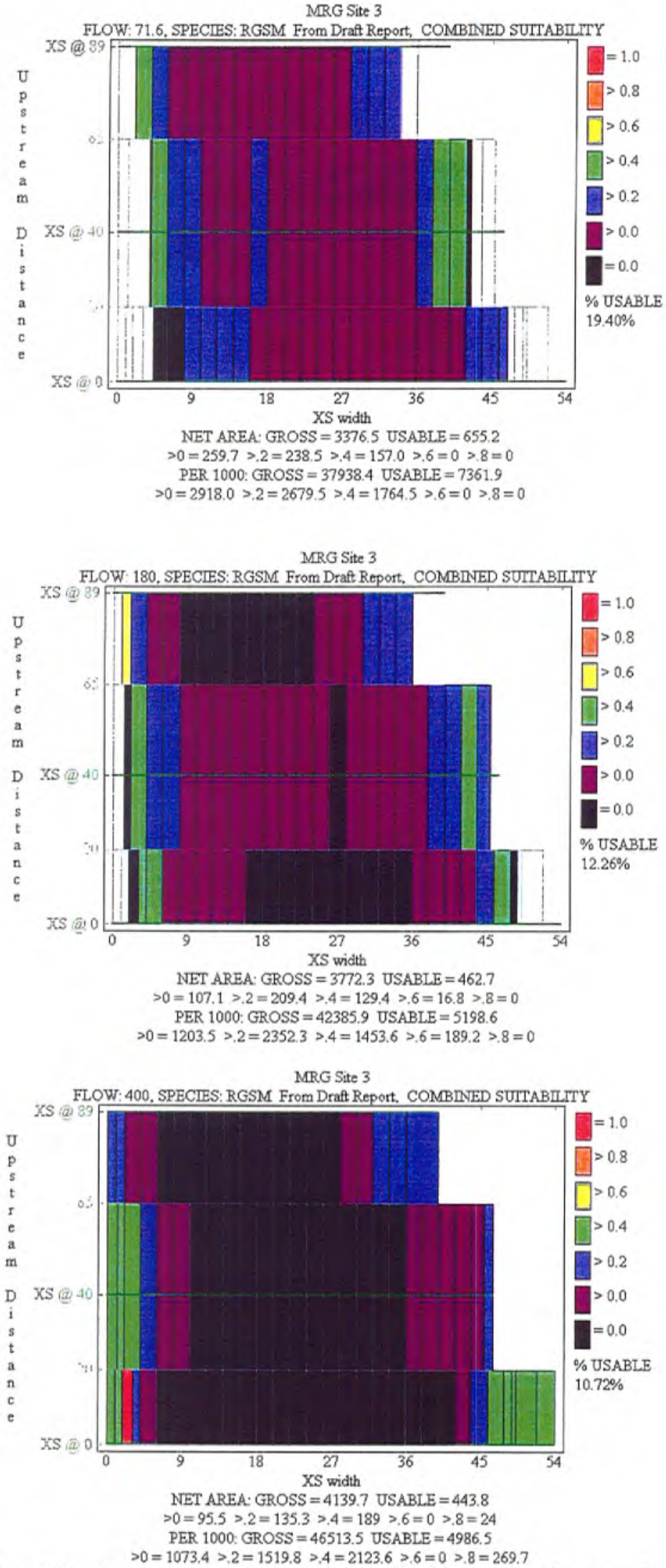


Figure 11. Combined passage suitability for Rio Grande silvery minnow at MRG Study Site #3 for three stream flow levels (72, 180 and 400 cfs).

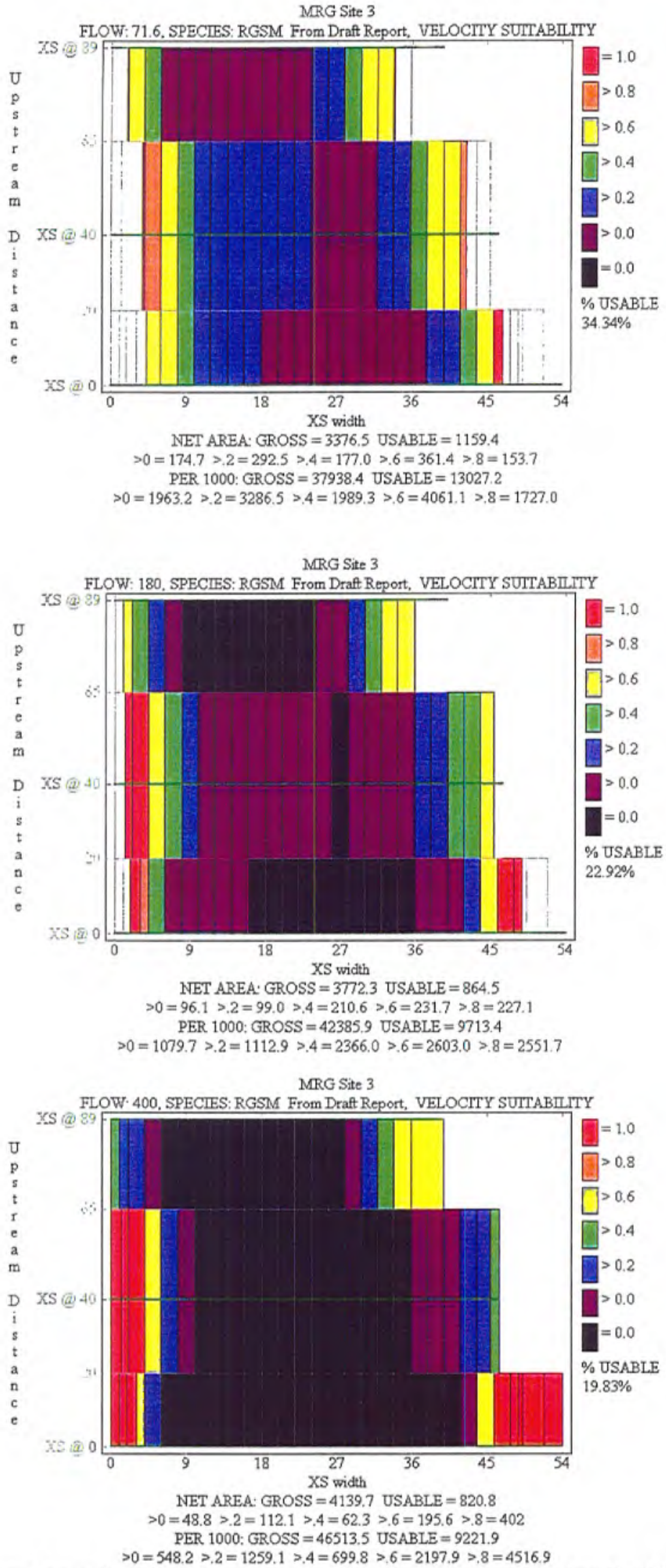


Figure 12. Passage suitability based upon mean water velocity for Rio Grande silvery minnow at MRG Study Site #3 for three stream flow levels (72, 180 and 400 cfs).

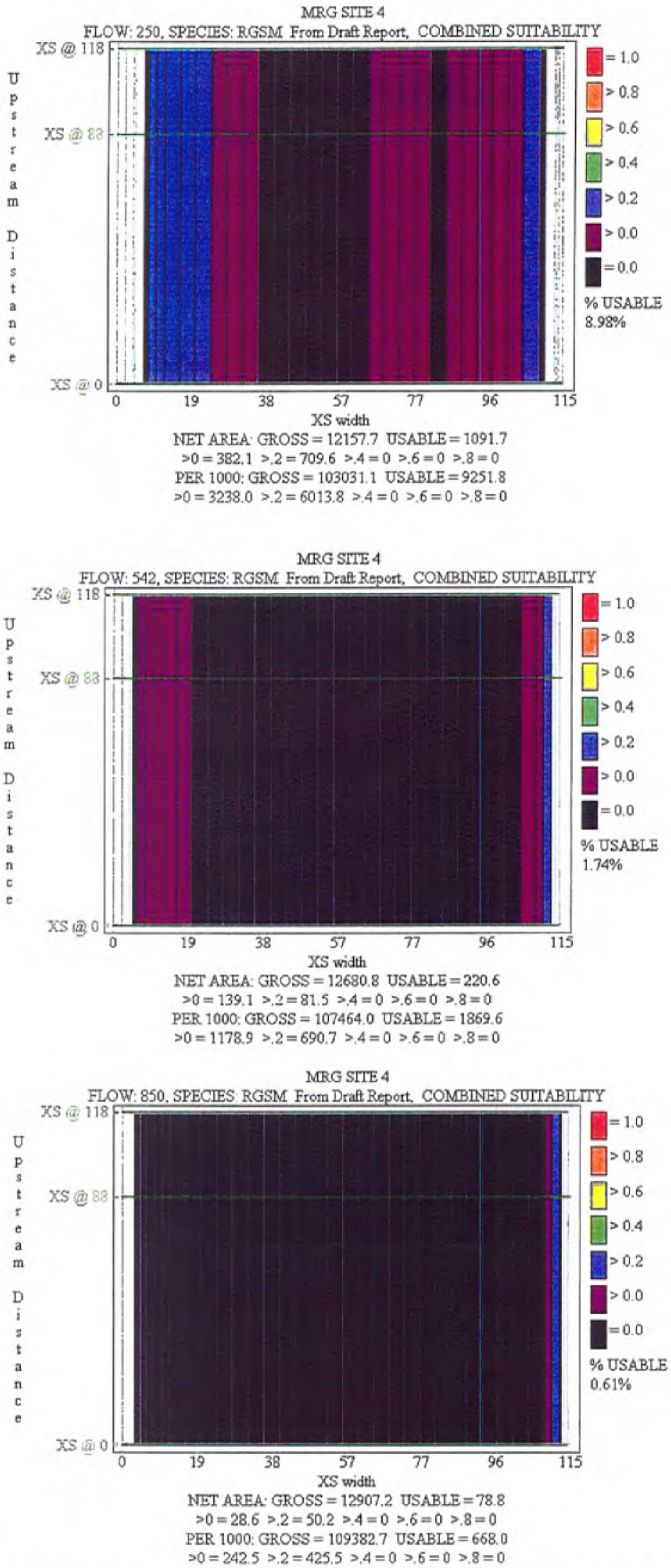


Figure 13. Combined passage suitability for Rio Grande silvery minnow at MRG Study Site #4 for three stream flow levels (250, 542 and 850 cfs).

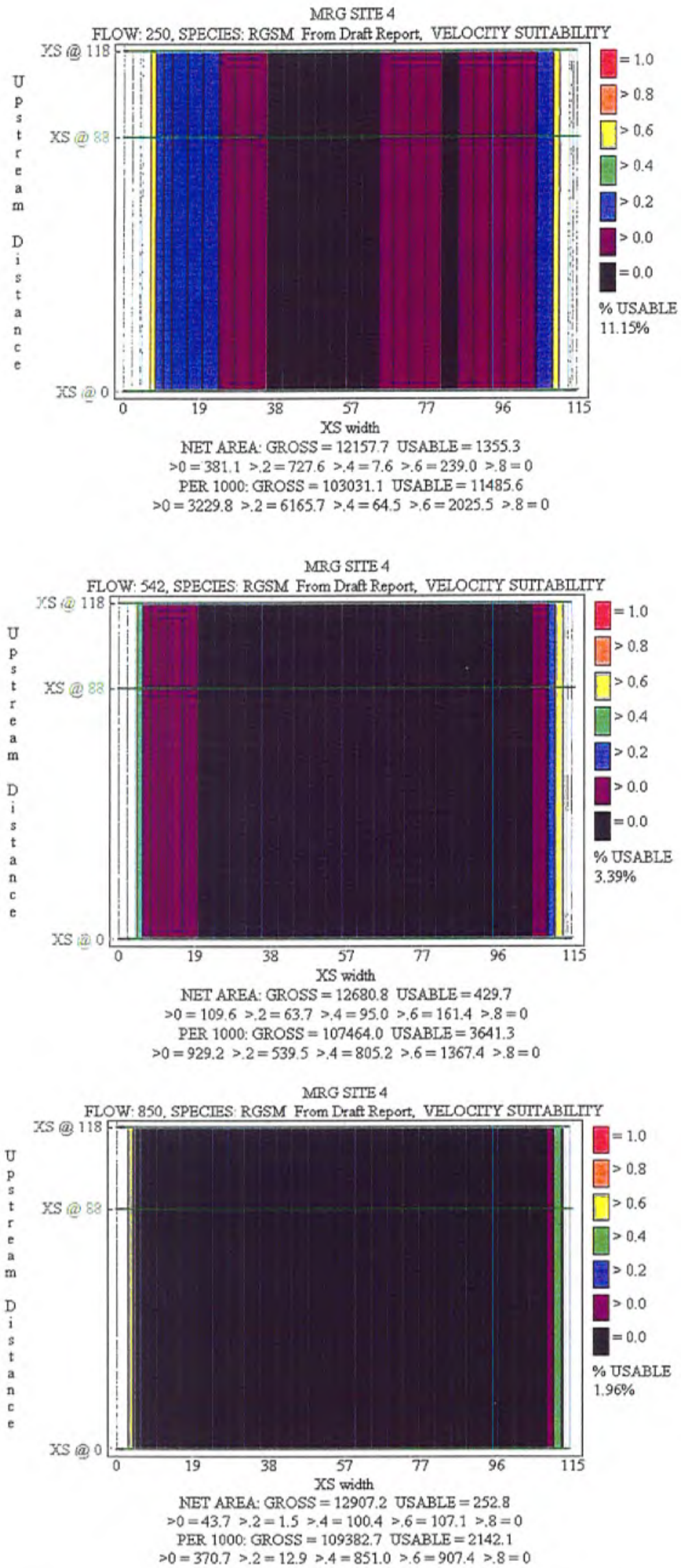


Figure 14. Passage suitability based upon mean water velocity for Rio Grande silvery minnow at MRG Study Site #4 for three stream flow levels (250, 542 and 850 cfs).

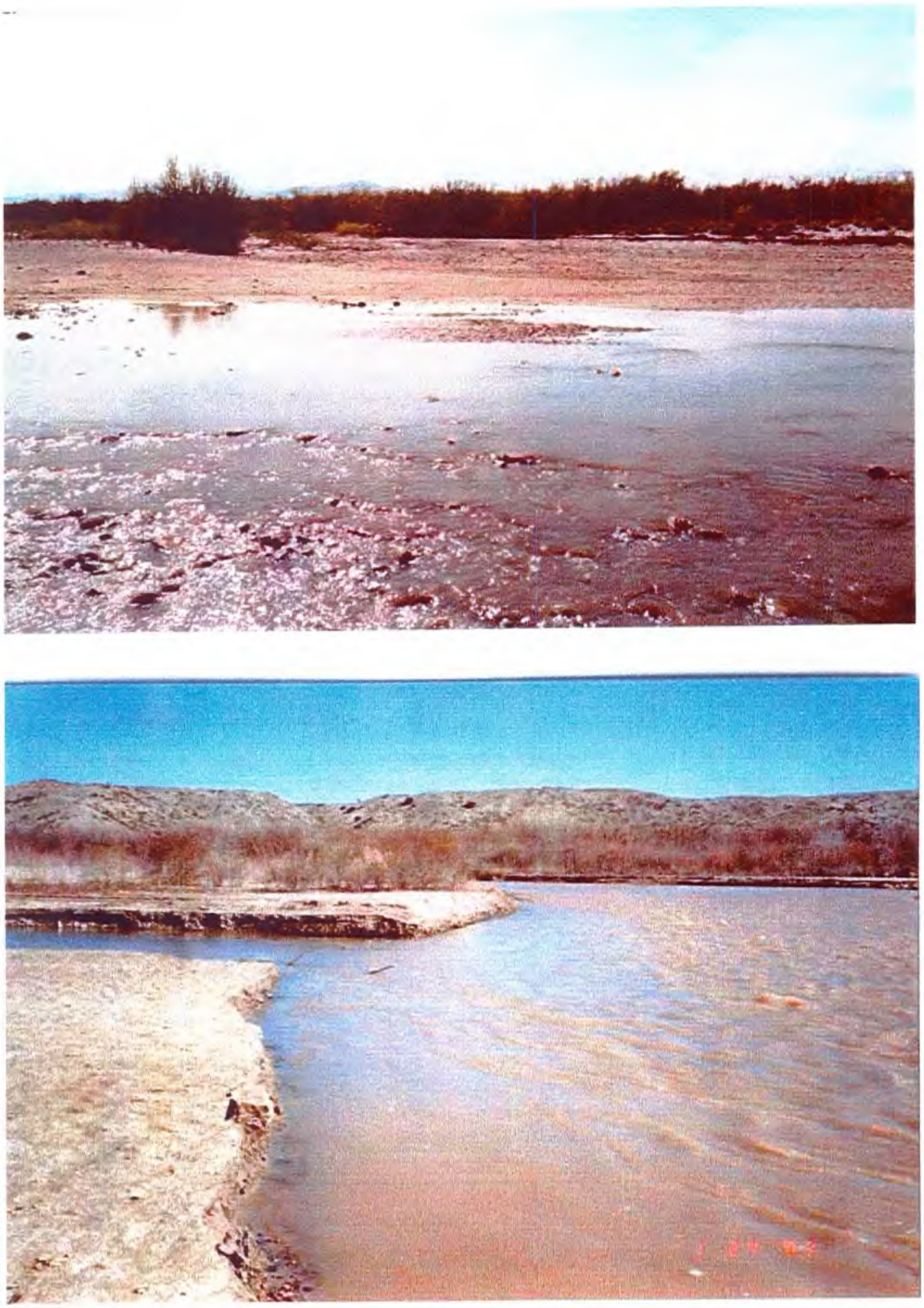


Figure 15. Middle Rio Grande at Rio Salado confluence. Upper: Dry secondary channel entrance, October 2002. Lower: confluence of secondary and main channels at Study Site #4, January 24, 2003.

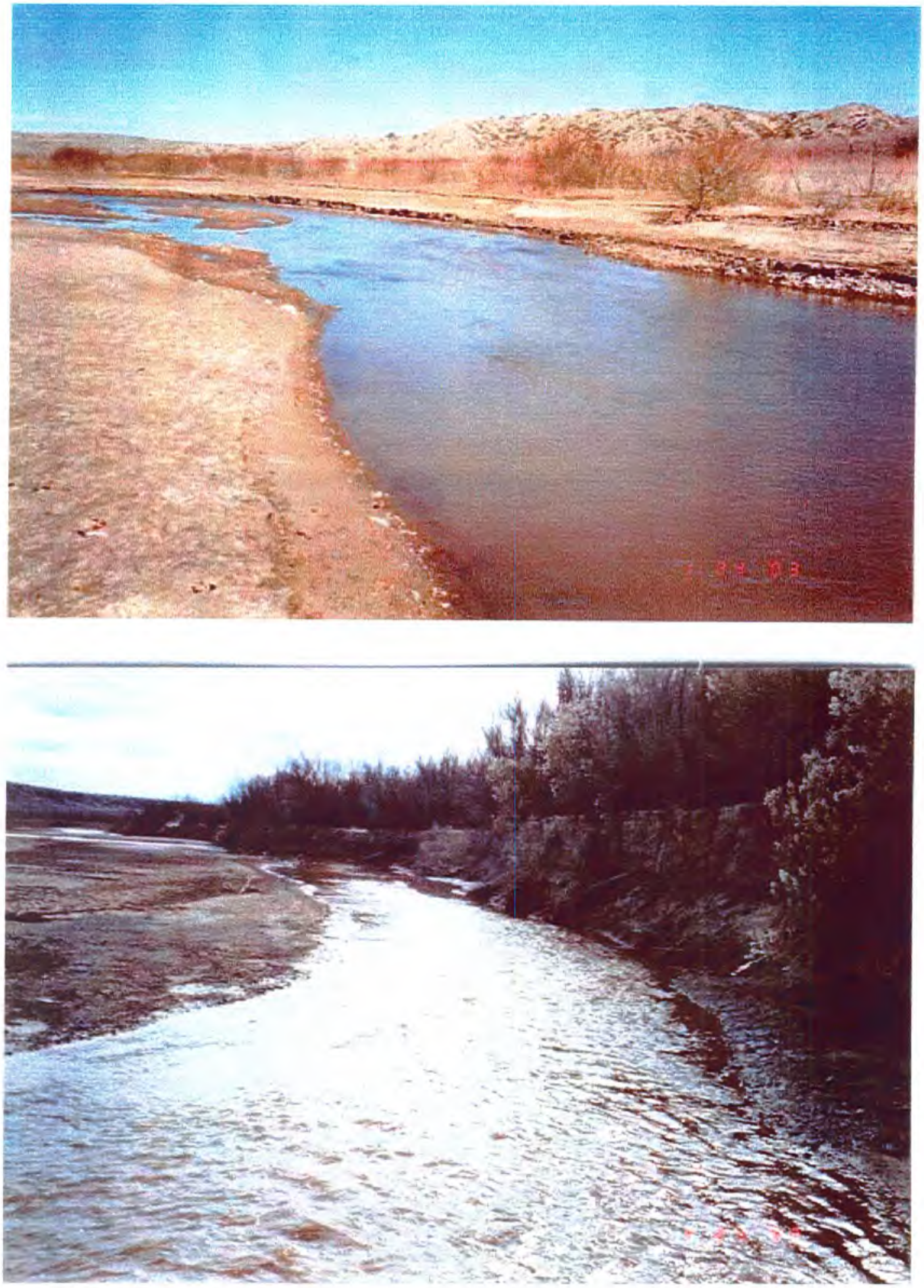


Figure 16. Middle Rio Grande Secondary Channel Study Sites #1 (upper) and #2 (lower), January 24, 2003.

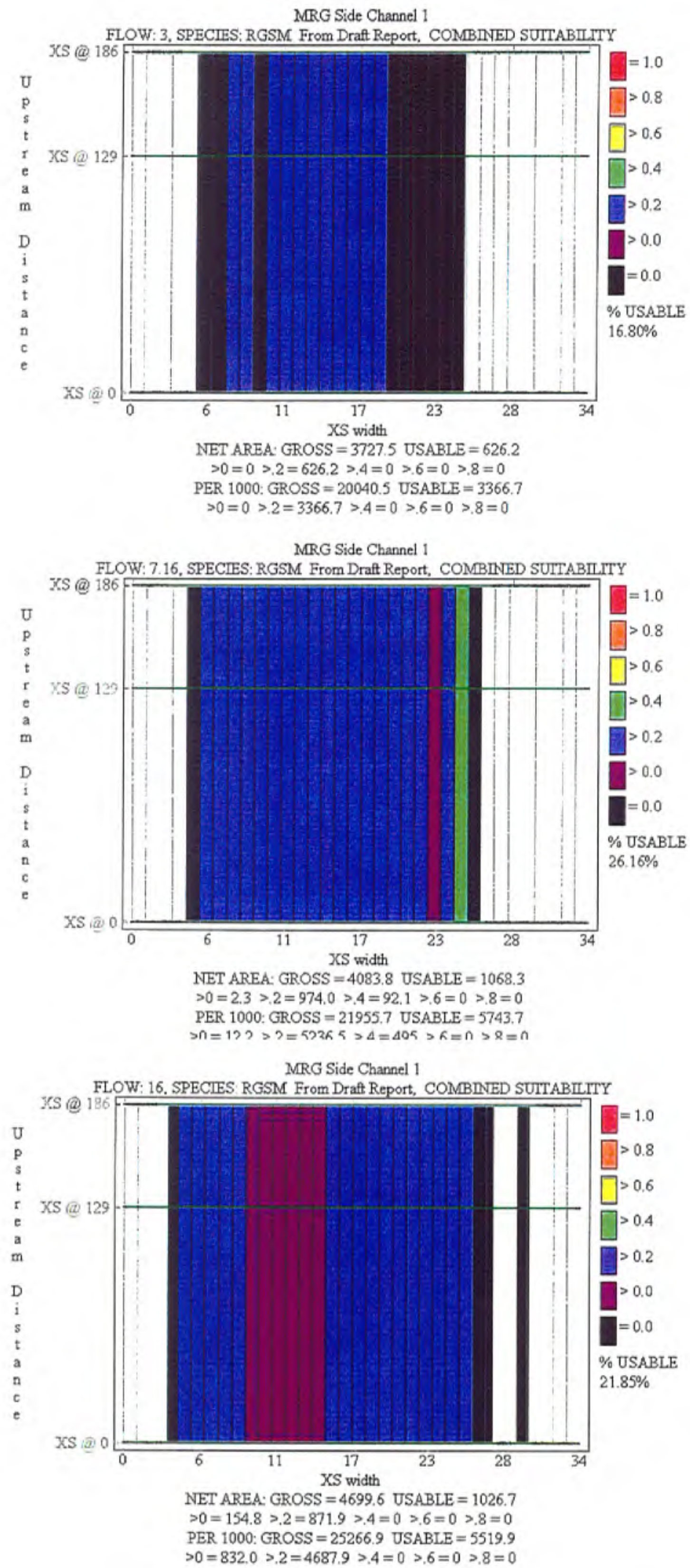


Figure 17. Combined passage suitability of Rio Grande silvery minnow at MRG Secondary Channel Study Site #1 for three stream flow levels (3, 7 and 16 cfs).

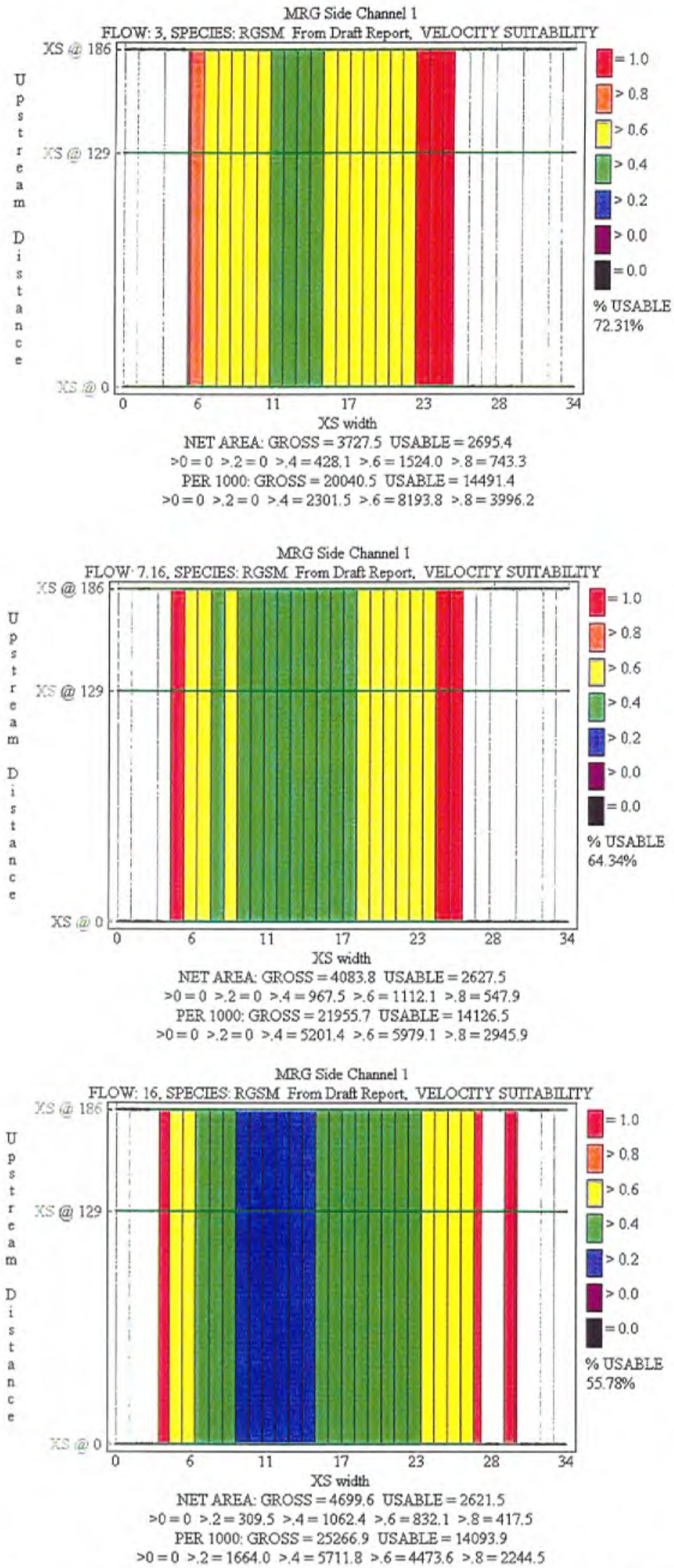


Figure 18. Passage suitability based upon mean water velocity for Rio Grande silvery minnow at MRG Secondary Channel Study Site #1 for three stream flow levels (3, 7 and 16 cfs).

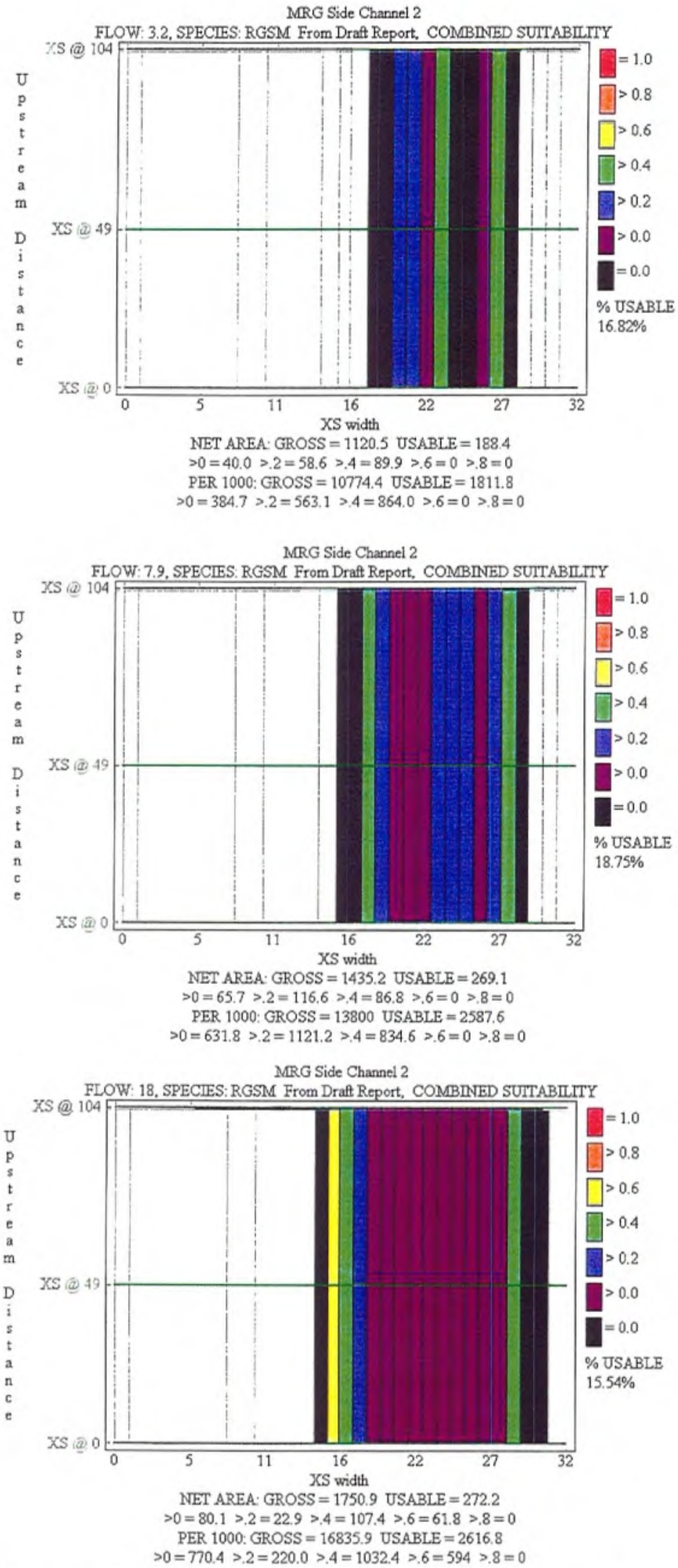


Figure 19. Combined passage suitability for Rio Grande silvery minnow at MRG Secondary Channel Study Site #2 for three stream flow levels (3, 8 and 18 cfs).

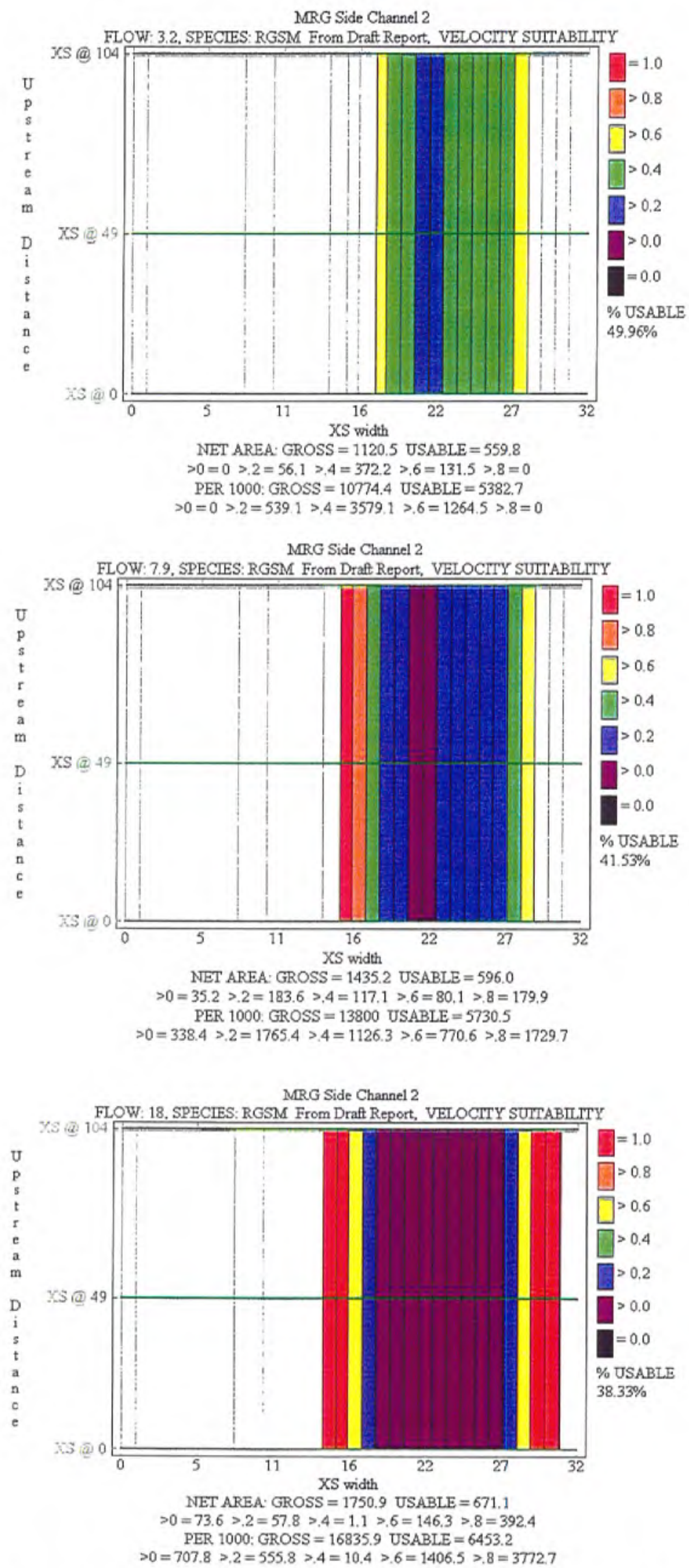


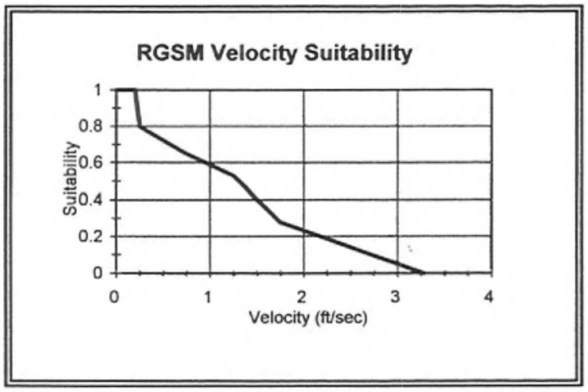
Figure 20. Passage suitability based upon mean water velocity for Rio Grande silvery minnow at MRG Secondary Channel Study Site #2 for three stream flow levels (3, 8 and 18 cfs).

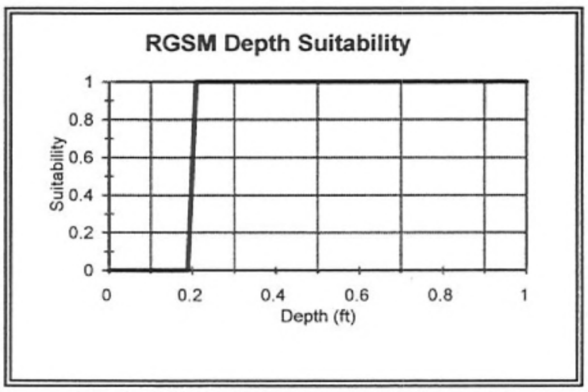
Figure 21. Fish passage barriers at culverts on Riverside Drain (upper) and Polvadera Drain (lower), January 2003.

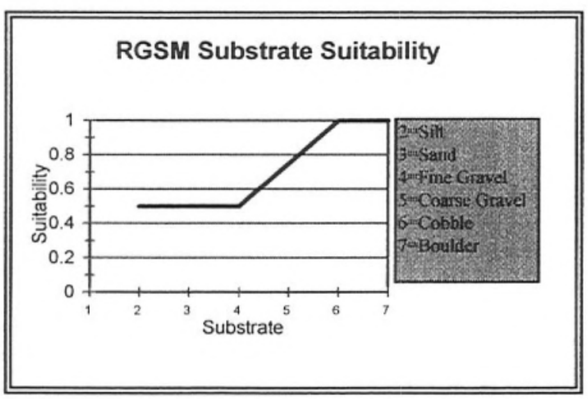
APPENDIX A

Rio Grande Silvery Minnow
Passage Suitability Curves For
Mean Water Velocity, Water Depth and Substrate

Curves developed from laboratory results by Bestgen et al (2003)


RGSM Velocity Suitability
Suitability
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
Velocity (ft/sec)


RGSM Depth Suitability
Suitability
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Depth (ft)


RGSM Substrate Suitability
Suitability
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
Substrate
2=Silt
3=Sand
4=Fine Gravel
5=Coarse Gravel
6=Cobble
7=Boulder

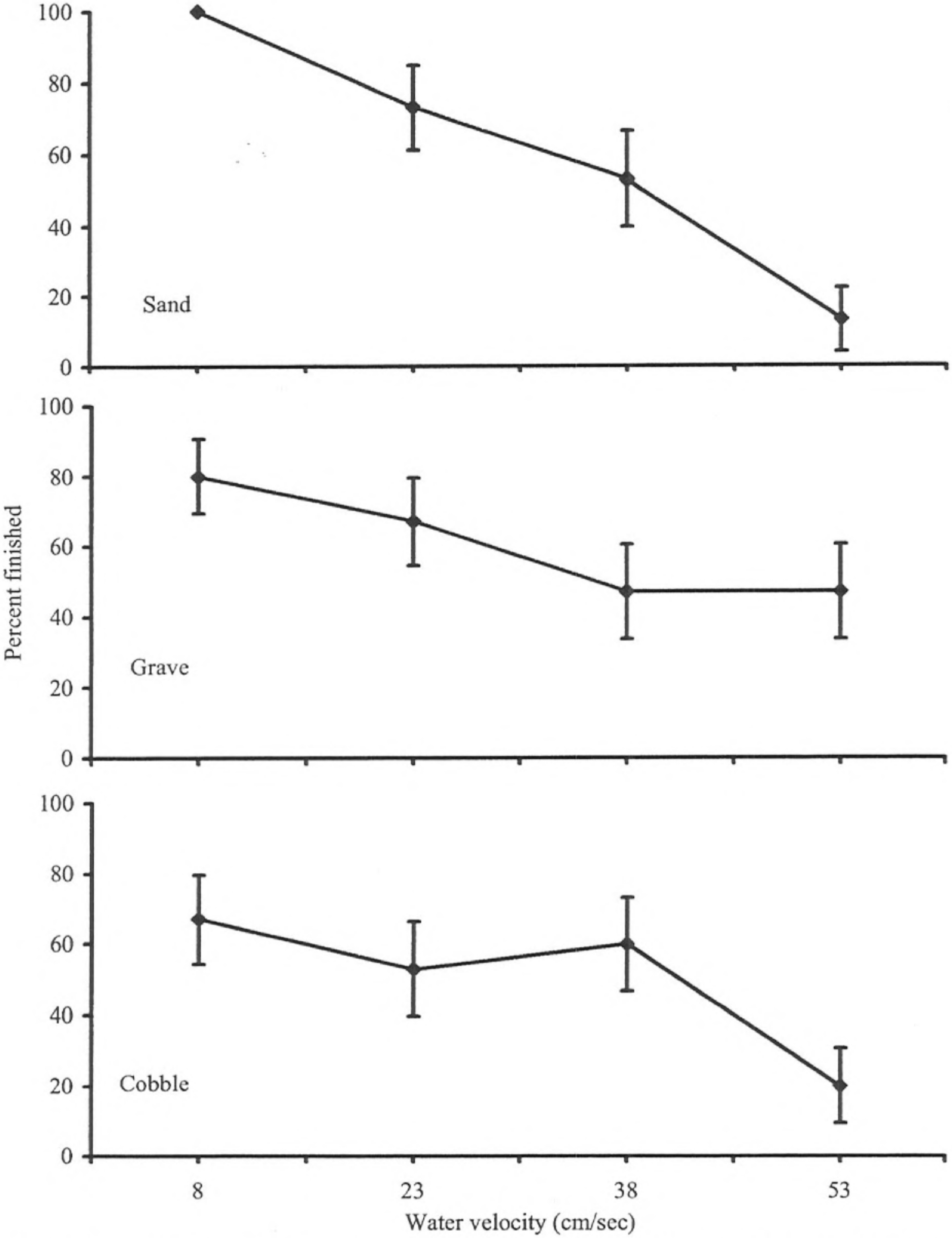


Figure 16. Proportion of Rio Grande silvery minnow that successfully swam the entire length of the experimental flume as a function of water velocity over sand, gravel, and cobble bed particles. Regression coefficients and model fits for relationships fitted are presented in Table 5. Vertical bars represent ± 1 SE.

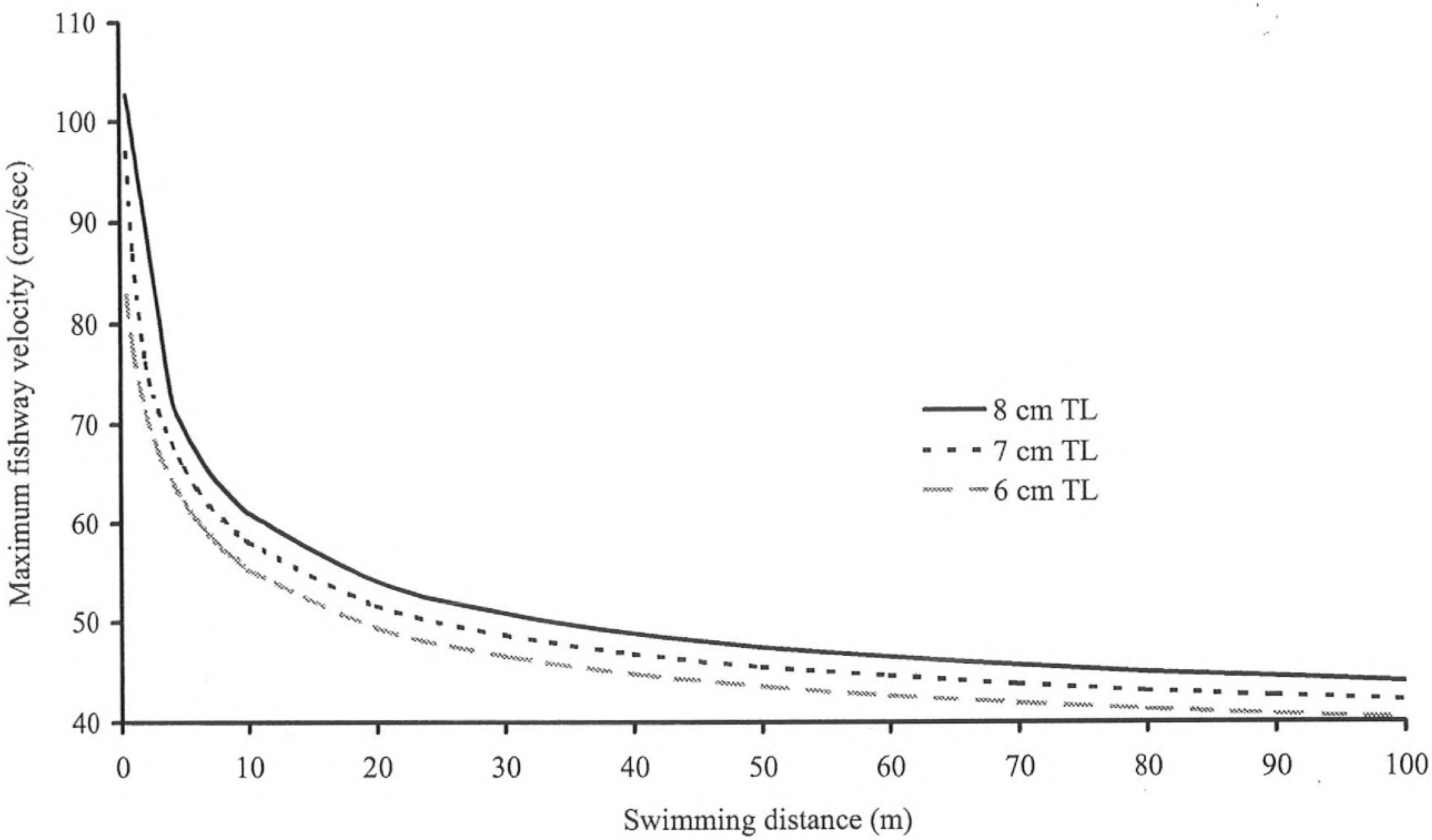


Figure 20. Relationship depicting maximum fishway flow velocity that would allow 6, 7, and 8 cm TL Rio Grande silvery minnow to pass a distance of 0.5 - 100 m. Relationships were derived by solving equation 2 at a variety of passage distances, assuming a temperature of 19 C, plotting the maximum for each distance and joining the points.