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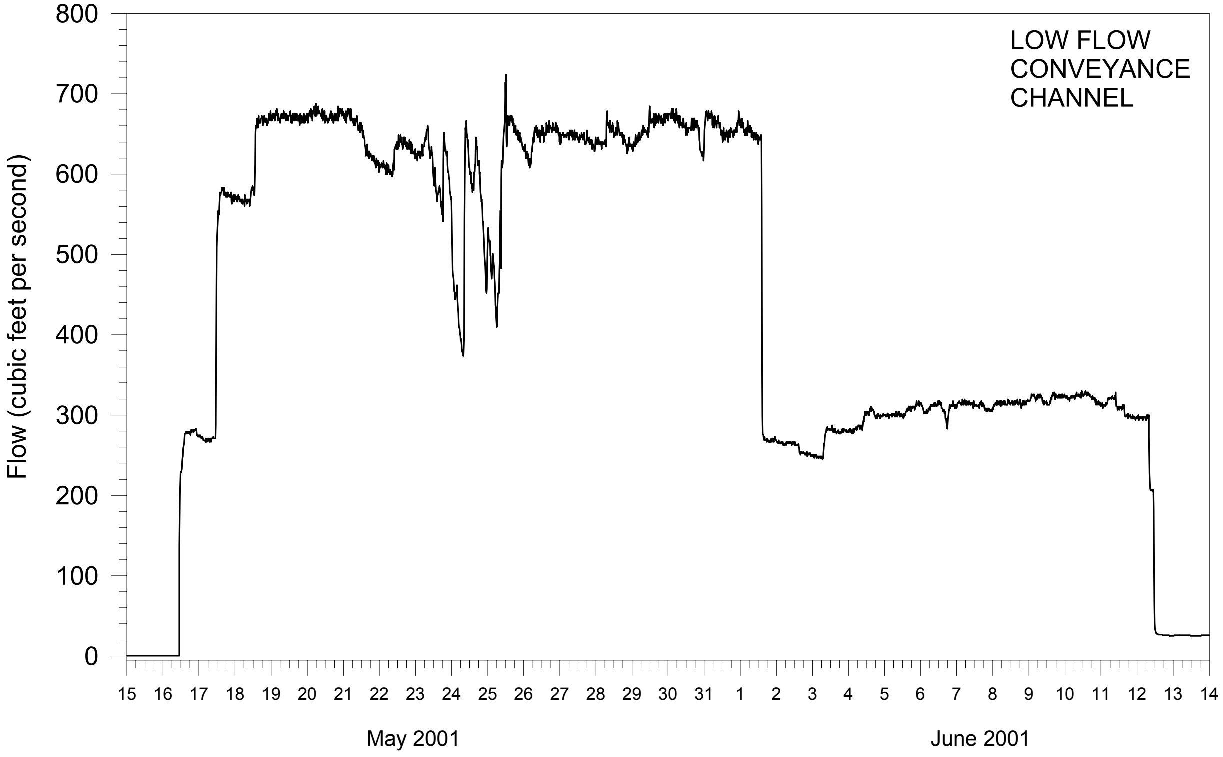
Final Report



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INTRODUCTION

The Middle Rio Grande (Velarde, NM to Elephant Butte Reservoir) is a highly regulated system designed to efficiently transport water to downstream users. The Rio Grande within this region is fragmented by two reservoirs (Cochiti and Elephant Butte) and three diversion dams (Angostura, Isleta, and San Acacia). There are also about 834 miles (1,342 km) of irrigation channels and 386 miles (621 km) of interior and riverside drains that form a matrix across the Middle Rio Grande Valley. This large-scale flood irrigation network (operated by the Middle Rio Grande Conservancy District, MRGCD) diverts and transports large quantities of water.

The Low Flow Conveyance Channel (LFCC), a man-made structure, was designed with the intent of efficiently transporting Rio Grande water during periods of low flow from San Acacia Diversion Dam to Elephant Butte Reservoir. Water was to be artificially diverted into the LFCC where it would travel parallel to and on the west side of the Rio Grande. This hydrologic project was completed in 1959 with a maximum capacity of about 2,000 cfs. Operation of the LFCC was ceased in April 1981 following problems with siltation within the channel near the headwaters of Elephant Butte Reservoir. Operations were resumed for a 15 month period between 1983-1985. Only several brief periods of experimental operations have been conducted in the 1990s. An outfall was constructed in 1997 for the purpose of returning seepage water from the LFCC to the Rio Grande at a point about 9 miles (14.5 km) downstream of San Acacia Diversion Dam. However, no water from the LFCC returns to the Rio Grande downstream of the outfall. Flow in the lower reaches of the LFCC, near San Marcial, NM, averages 200-300 cfs because of irrigation returns and notable groundwater seepage (i.e., LFCC is below elevation of bed of Rio Grande).

The LFCC is one of two anthropogenic waterways carrying flow in this region of the Middle Rio Grande Valley's cross section. The other is the Socorro Main Canal North (operated by MRGCD) which carries water for irrigation and is normally operated from about March 1 to October 31. Flow in this irrigation network varies seasonally and between years but is generally between 100-300 cfs during its operation. Canals operated by the MRGCD from San Acacia Diversion Dam to Elephant Butte Reservoir return no water to the Rio Grande; all diverted irrigation water returns to the LFCC.

Preliminary surveys of the MRGCD irrigation system revealed that nonnative taxa dominated the total catch and were often able to successfully recruit within these areas (Lang and Altenbach, 1994). Native fishes were occasionally collected in irrigation ditches but their presence was temporary. Also, Rio Grande silvery minnow *Hybognathus amarus* eggs and larvae were entrained into the MRGCD system. The highly fragmented nature of this irrigation network (e.g., multiple instream weirs and turn-out gates) combined with regular dewatering and homogenous instream habitats produced an unstable aquatic system that was not conducive for the survival of most native Rio Grande fishes.

Studies on the potential impacts of LFCC operations on the Rio Grande fish community, with emphasis on Rio Grande silvery minnow, were conducted in 1997 (Smith, 1998) and 1998 (Smith, 1999). The results of these studies indicated that the number of Rio Grande silvery minnow present in the LFCC increased following its operation, and was likely caused by the entrainment of drifting eggs and larvae. During 600 cfs flow events in the LFCC, the number of Rio Grande silvery minnow eggs entrained was estimated to be minimal. No tests were conducted to determine the rates of entrainment during lower flow events in the LFCC.

The Moore Egg Collector (MEC; Altenbach et al., 2000) provides an efficient mechanism for quantifying the catch rate and magnitude of entrainment of Rio Grande silvery minnow eggs in the LFCC. However, determining the rate (velocity) and magnitude (transport efficiency) of eggs and larvae in the LFCC requires the release of a known number of particles whose physical properties are similar to those of passively drifting Rio Grande silvery minnow propagules. Recapture of those particles at downstream sites provide data necessary to model the aforementioned vectors.

Passively drifting particles were developed by researchers at the University of New Mexico to examine the downstream displacement of passively drifting eggs of several Rio Grande basin cyprinids (Dudley and Platania, 1999). Field trials indicate that these approximately neutrally buoyant particles also closely mimic the downstream transport of drifting fish larvae that are passively transported with the current (Dudley and Platania, 2000). The ability to quantify the downstream displacement of drifting eggs and larval fishes between study sites and at various flows provides a methodology to determine potential impacts of the operation of the LFCC.

The first objective of this project was to determine the magnitude of entrainment of Rio Grande silvery minnow eggs into the LFCC. An additional goal was to acquire, through a field study, the rate and magnitude of downstream displacement of passively drifting particles in the LFCC. This approach and data set will ultimately provide resource managers a tool necessary to make more informed decisions as to whether the LFCC should be operated. These objectives addressed goal 1.5.3 (The extent of entrainment should be investigated and quantified under a range of flows) as defined in the Rio Grande silvery minnow recovery plan (U. S. Fish and Wildlife Service, 1999).

STUDY AREA

The headwaters of the Rio Grande are located in the San Juan Mountains of southern Colorado. The Rio Grande flows about 750 km through New Mexico. Snowmelt from southern Colorado and northern New Mexico provides the majority of water for the Rio Grande, but transmontane diversions from the San Juan River drainage (Colorado River basin) supplement flow. The highest flow in the Rio Grande generally occurs during spring snowmelt, while the lowest flow usually occurs in late summer and autumn. Low flow later in the year is due, in part, to the large diversions of water out of the river and into irrigation canals. Precipitation in the region is low and averages <25 cm/year (Gold and Denis, 1985).

Flow in the Rio Grande is regulated by five mainstem reservoirs on the rios Chama and Grande and numerous smaller irrigation diversion dams throughout the drainage. The complex system of ditches, drains, and conveyance channels provide water for extensive irrigated agriculture in the Rio Grande Valley. Cochiti Reservoir, located 76 km above Albuquerque and operational since 1973, is the primary flood control reservoir on the mainstem of the Middle Rio Grande.

The section of river from San Acacia, NM to Elephant Butte Reservoir (Figure 1) was wide and meandering with a predominantly sand substrata, high suspended silt load, and a broad variety of mesohabitats. The mainstem channel was generally wide (100-300 m), <1 m deep, and had a current velocity of <1 m/s. A wide variety of fish species, including many endemic taxa and the majority of Rio Grande silvery minnow, are present within this reach of the Rio Grande (Dudley and Platania, 2001).

In contrast, the LFCC is a narrow drainage ditch with steep banks armoured with rip-rap and lacking all characteristics of an aquatic ecosystem with the exception of the presence of water. The width of the LFCC is uniform (ca. 20 m) and flows increase progressively downstream as groundwater influx and irrigation returns increase. The ichthyofaunal community of the LFCC is numerically dominated by nonnative taxa.

During operation of the LFCC during the 1960s and 1970s, all flow was diverted out of the river during winter and dry seasons resulting in repeated and extensive river drying. The average number of days per year with no flow at the USGS San Marcial Gauge (#08358400) was 36 from 1985-1995. From 1960-1973, that value was 276 and represented the effects of fully operating the LFCC.

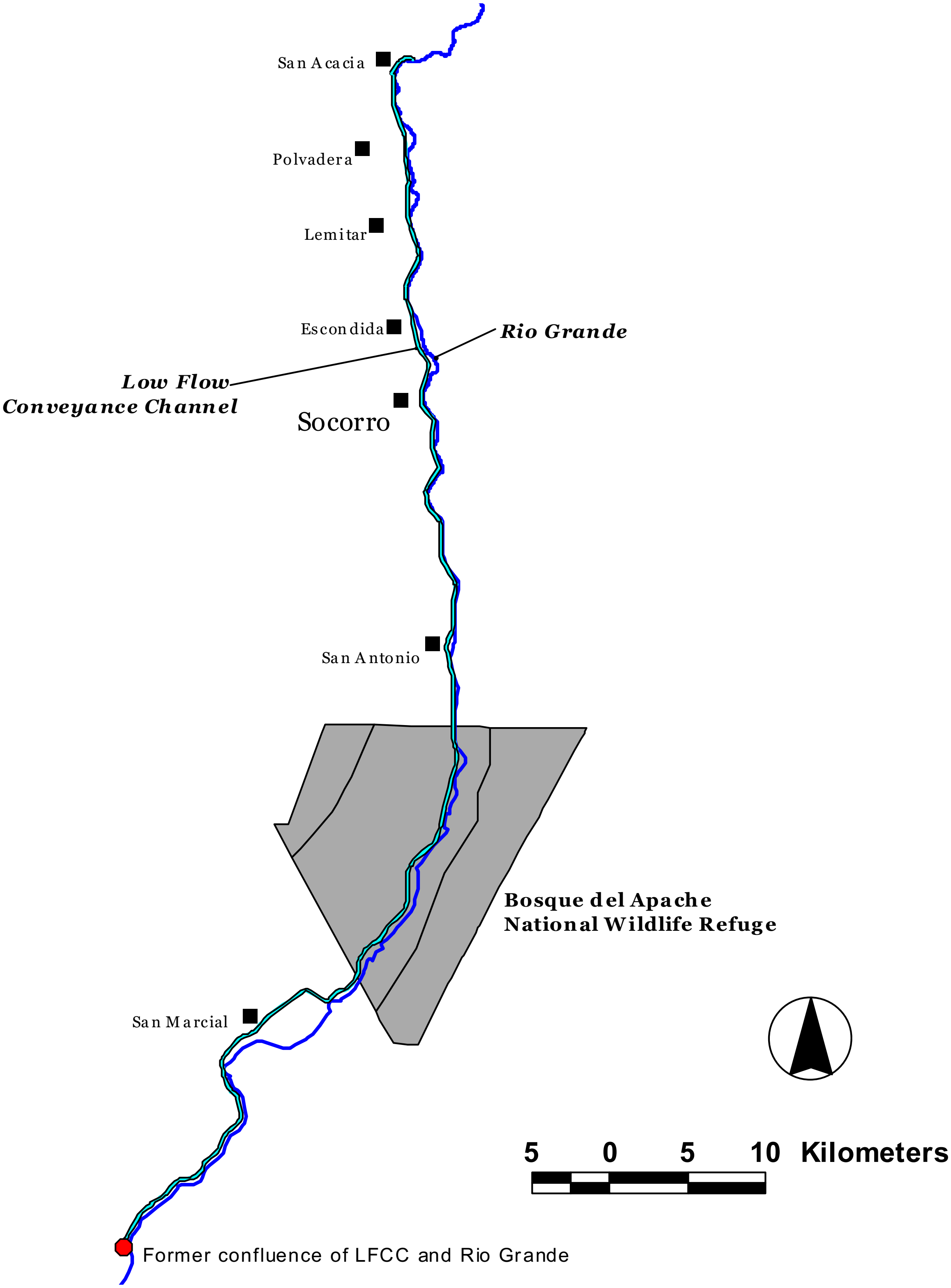

Figure 1. Map of the Middle Rio Grande showing location of Low Flow Conveyance Channel.

There were three sampling sites for collection of Rio Grande silvery minnow eggs (Figure 2). The first site was in the Rio Grande about 1 km upstream of San Acacia Diversion Dam on Sevilleta National Wildlife Refuge (SEV). This site was established to determine the relative number of Rio Grande silvery minnow eggs susceptible to entrainment in the LFCC. The next two collection sites for Rio Grande silvery minnow eggs were in the LFCC (Sites UPP and MID) and are described below.

Passively drifting particles were released at a point where water that is diverted from the Rio Grande emerges from an underground culvert (CUL). Flow in the immediate vicinity of the release point was highly turbulent as it passes through the narrow culvert opening (under great force) and into the LFCC. Water velocities in this area, and for several kilometers downstream, were relatively high (at 600 cfs) possibly because of the absence of weirs.

The upper collection site (UPP) was 6.1 km downstream of the release point of passively drifting particles. The LFCC, in this reach, was relatively deep, water velocity remained high and substrate was a mixture of boulder rip-rap and sand. This site was used for both Rio Grande silvery minnow egg monitoring and collection of passively drifting particles.

The middle sampling site (MID) was 4.2 km downstream of the previous site. Water velocity was notably reduced at this locality because of the presence of several nearby weirs. These structures resulted in the creation of elongated pool-run habitats. The in-channel elevation of water in the LFCC at the site was notably higher than at the previous site. The MID site was the only other locality that was used for both Rio Grande silvery minnow egg monitoring and collection of passively drifting particles.

The downstream-most site (LOW) was 5.2 km below the MID site and was used only for the collection of passively drifting particles. This sampling locality was located immediately upstream of the confluence of the LFCC with the Rio Grande. A large bend in the LFCC, as it redirected flow to the Rio Grande, resulted in a large eddy pool, relatively reduced instream water velocities, and a sand and silt substrata.

METHODS

Sampling for Rio Grande silvery minnow eggs occurred between 21 May and 12 June 2001 at intervals that averaged about three times per week. An MEC was used following the protocol described in (Altenbach et al., 2000) to determine the catch rate and magnitude of entrainment of Rio Grande silvery minnow eggs in the LFCC. All sites were visited on the same day but at different times (sequentially). Because of the limited time spent at each of the three egg sampling localities, two MEC's were operated in an effort to increase the volume of water sampled per unit of time. Mechanical flow-meters were attached to each of the MEC's so that volume of water filtered could be calculated and catch rate per unit of water determined

The sequence of site visitation was UPP, MID, and SEV. The Rio Grande site (SEV) was sampled for the shortest duration (about two hours per day sampled) while the upstream most LFCC site (UPP) was sampled for the longest daily duration (between 3 - 4 hours). The length of sampling time at the middle LFCC site (MID) was intermediate between the two upstream sites at about three hours per visit.

Data regarding entrainment of Rio Grande silvery minnow eggs into the LFCC were also obtained during the passively drifting particle portion of this study program. The primary differences in collecting protocol between the two studies were the continuous sampling (recorded in 15-minute intervals) and overall greater daily duration of the passively drifting particle research. Finally, the SEV site was not included in the sampling scheme for this latter portion of the study program.

We obtained estimates of the downstream transport rates of reproductive products (eggs and larvae) by releasing and tracking the movements of passively drifting particles (Dudley and Platania, 1999). These particles (modified nylon 12 polyamide) were originally developed to mimic the physical

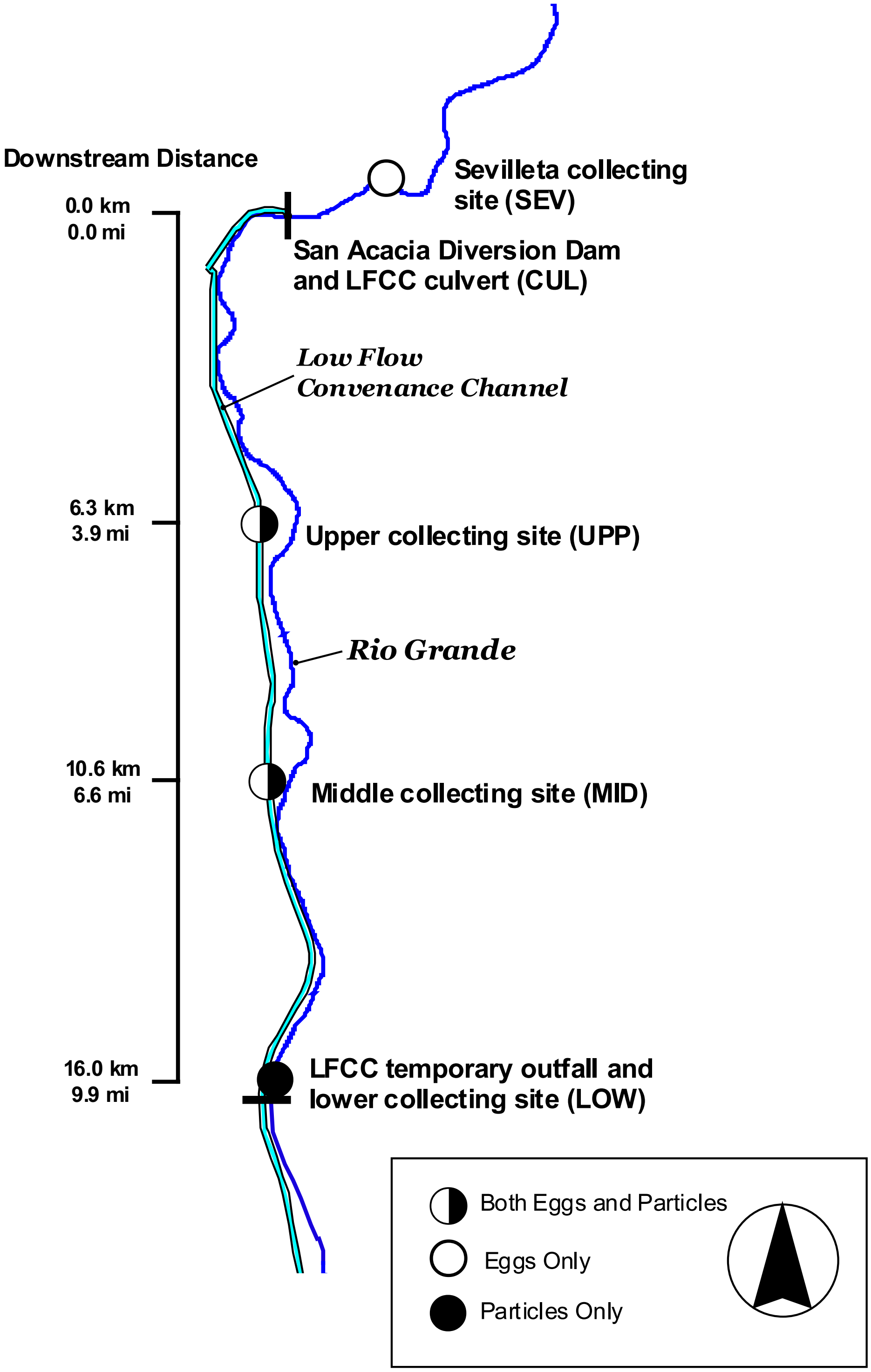

Figure 2. Map of the upper portion of Low Flow Conveyance Channel.

properties of semibuoyant fish eggs from the reproductive guild of Rio Grande basin cyprinid taxa (Platania and Altenbach, 1998). The specific gravity (SG) of these semibuoyant fish eggs (SG=1.006) is essentially the same as distilled water (SG=1.000) meaning that they were approximately neutrally buoyant. Passively drifting particles (=beads) closely mimicked (SG=1.005) the properties of semibuoyant fish eggs. In aquaria, semibuoyant fish eggs and passively drifting particles remained in suspension even at the lowest flows generated (<1 cm/s).

Laboratory and field experiments indicate that passively drifting particles are also effective for estimating the downstream transport of drifting fish larvae. Although drifting larval fish have some control over their vertical movement (i.e., swimming up in areas of low or no water velocity), they are unable to move horizontally until the development of the swim bladder at least 3 - 4 days after hatching (Platania and Altenbach, 1998). Larval fish remain a part of the drift during this 3 - 4 day period and possibly after depending on stream flows and available habitats. Observations in aquaria demonstrate that larval fish are passively moved by even the lowest currents generated (e.g., <1 cm/s).

Recent field studies in the San Juan river (Dudley and Platania, 2000) demonstrated that the downstream displacement and dispersal of larval Colorado pikeminnow *Ptychocheilus lucius* and passively drifting particles nearly matched. Over short distances (<30 km), larval fish and particles arrived within 15 min of each other at downstream sampling stations. The transport rates of larval Colorado pikeminnow (3.6 km/h) and passively drifting particles (3.5 km/h) were also quite similar over long distances (250.5 km).

Passively drifting particles were collected with Moore Egg Collectors (Altenbach et al., 2000). Sampling was continuous after particles first arrived at a collecting station. Each collection consisted of 15 minutes of continuous sampling. The catch-per-unit-effort (CPUE) of passively drifting particles was calculated for each 15 minute interval as the total number of beads collected · volume of water sampled^{-1} · 100 (i.e., N [beads] · m^{3} water^{-1} · 100). The "first arrival" rate of travel was the longitudinal river distance travelled divided by the time required for the first particle to arrive at the collecting locality (km · h^{-1}). This value is indicative of the maximum rate of downstream transport. The "50% arrival" rate of travel was also the longitudinal distance travelled by passively drifting particles but was divided by the time necessary for 50% of particles to arrive at the collecting locality (km · h^{-1}). This latter value was an estimate of the median transport rate.

Mean individual passively drifting particle mass, based on 91 samples comprising 148,319 counted particles, was 0.01795 g ± 0.0001 g. For each study release, the total mass of passively drifting particles released was determined to the nearest 0.0001 g and divided by the mean individual mass to provide an estimate of the total number of particles released. Estimates of the total number of particles released are provided to the nearest hundred.

The first release of passively drifting particles occurred on 1 June 2001 at 0751 h. Mean daily discharge at the U. S. Geological Survey (USGS) Rio Grande Conveyance Channel at San Acacia, NM (#08354800) ranged from 530 cfs to 674 cfs from 18 May to 31 May 2001 (Figure 3). Instream debris levels were extremely heavy soon after operations commensed and remained high for a period of about one week. Discharge on 1 June 2001 averaged 499 cfs but ranged between 227-670 cfs. Flows were maintained above between 637-670 cfs until 1400 h at which point they were rapidly dropped to <300 cfs within 1 hour. Purple passively drifting particles were released from IFL and then collected at UPP, MID, and LOW. Instream debris levels were moderate but did not prevent efficient sampling. Extended sampling was precluded by the premature reduction of flow that occurred on 1 June 2001.

The second release of passively drifting particles occurred on 8 June 2001 at 0740 h. Mean daily discharge measured at the U. S. Geological Survey (USGS) Rio Grande Conveyance Channel at San Acacia, NM (#08354800) ranged from 260 cfs to 322 cfs from 2 June to 11 June 2001. Instream debris levels remained moderate during this portion of LFCC experimental operations. Flows averaged 315 cfs and ranged between 309-319 cfs on 8 June 2001.

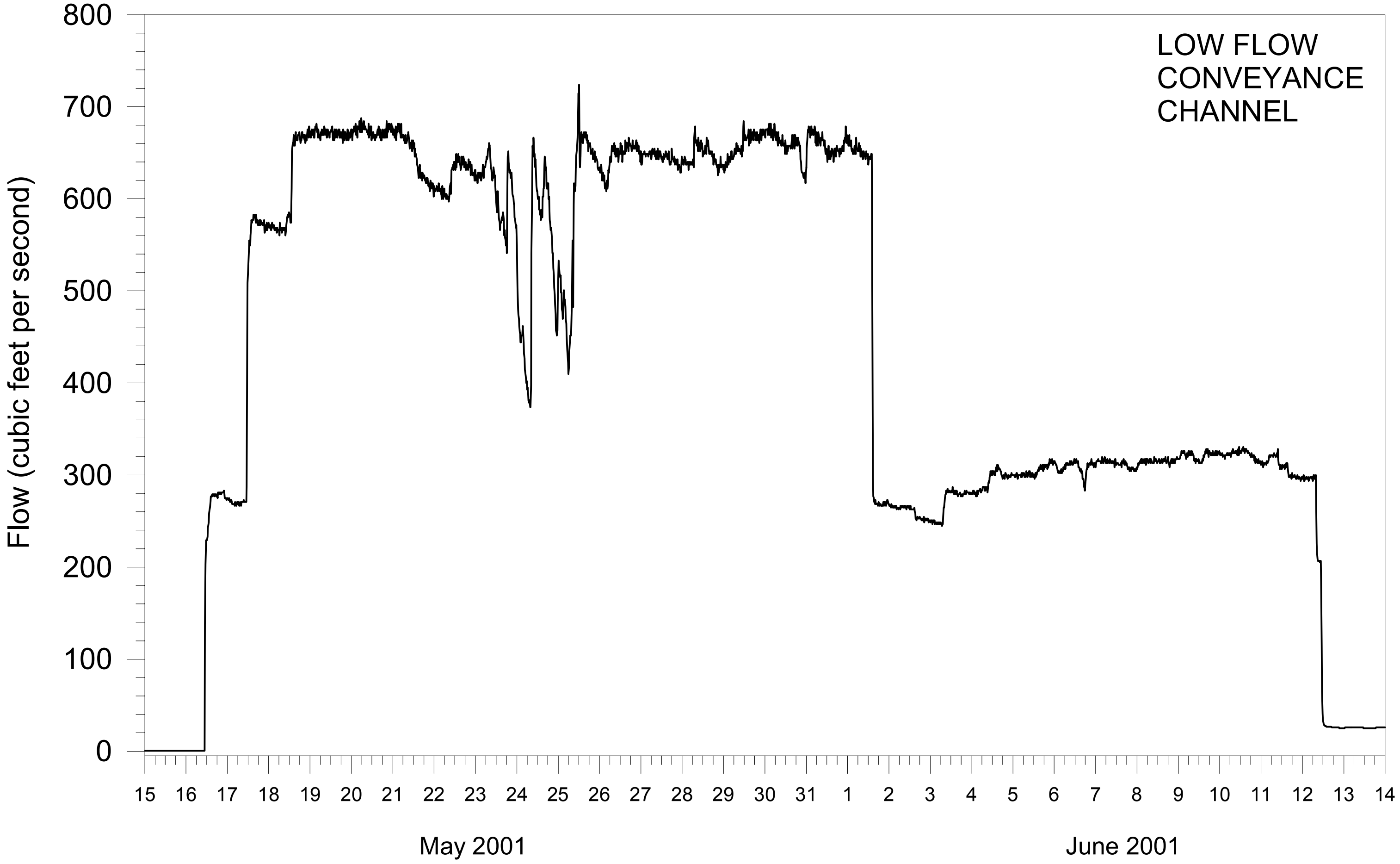

Figure 3. Hydrograph of the Low Flow Conveyance Channel during the period of experimental operations in 2001.

RESULTS

Rio Grande Silvery Minnow Egg Entrainment

Experimental operation of the LFCC began on 16 May 2001 with 21 May 2001 being the first sample date. The 35,600 ft^3 of water filtered during the Rio Grande silvery minnow egg entrainment study (21 May - 12 June 2001) yielded a total of two silvery minnow eggs. Both eggs were collected on 25 May 2001 with one taken at the UPP site and the second from the MID site. The test flow in the LFCC during 25 May 2001 was 600 cfs. No Rio Grande silvery minnow eggs were taken at the SEV site during this study. All fish collected in the MEC's were examined (and released) but none were Rio Grande silvery minnow.

First Constant LFCC Release (600 cfs)

Passively drifting particles were transported long distances in short periods of time during the first constant LFCC release of 600 cfs (Figure 4). Orange passively drifting particles released from IFL first arrived at UPP in 1.4 h, MID in 2.8 h, and LOW in 4.5 h (Table 1). The time for 50% of drifting particles to pass the collecting locality occurred shortly after (IFL to: UPP- 1.9 h, MID- 3.4 h, and LOW- 5.4 h) the arrival of the first particles. Following the initial rapid rise and fall in the catch rate of passively drifting particles, there was a slow and gradual decline in the number caught over the remainder of the sampling duration. The most rapid rise and fall in catch rates were observed at UPP and MID. At the downstream site (LOW), the shape of the particle catch rate plot was quite different than the plots for either UPP or MID. The maximum catch rate of passively drifting particles at LOW was $988.3/100m^3$ vs. $1,663.3/100m^3$ at MID and $1,703.3/100m^3$ at UPP. Also, the catch rate did not decline as quickly following its peak at LOW compared to MID or UPP. The temporal difference between first arrival and 50% arrival at LOW was 0.9 h but was notably lower at both UPP (0.5 h) and MID (0.6 h). The time for particle catch rates to drop below $70/100m^3$ was prolonged at LOW (2.6 h) compared to MID (1.9 h) or UPP (1.5 h). Catch rates at LOW remained moderate for several hours following arrival of the peak density of passively drifting particles. At the termination of the experiment, it was apparent that low numbers of particles remained in the LFCC and would be displaced at a low rate over a prolonged time period.

The 50% arrival rate of travel of particles varied only slightly between study sites (IFL to UPP- 3.3 km/h, IFL to MID- 3.1 km/h, and IFL to LOW- 3.0 km/h). Particles travelled slightly faster in the upper reach of the study area than in the lower reach (Table 2). The first arrival rate of travel of particles exhibited a similar pattern (IFL to UPP- 4.5 km/h, IFL to MID- 3.8 km/h, and IFL to LOW- 3.6 km/h).

The vast majority of particles that were released travelled quickly downstream and returned to the Rio Grande via the LFCC temporary outfall. Overall catch rates between UPP, MID, and LOW were similar over the sampling period and did not suggest that large numbers of particles were entrained between sampling localities. While the majority of particles passed these sites over a short duration, there were low numbers that did not travel with the group and took longer to be transported downstream. It is difficult to estimate how many particles would still be entrained in the LFCC over a 24 h period but was likely <5%.

Second Constant LFCC Release (300 cfs)

During the second constant LFCC release (300 cfs), purple passively drifting particles travelled downstream at a moderate rate and became widely dispersed (Figure 5). The reduced turbulence and water velocities in the LFCC during this release did not allow particles to become fully integrated into the water column until they had reached the downstream sampling site. Also, placement of the MID site just upstream of a weir resulted in notably reduced water velocities and increased pooling during the 300 cfs flow event. Thus, the catch rate data for UPP and MID are not

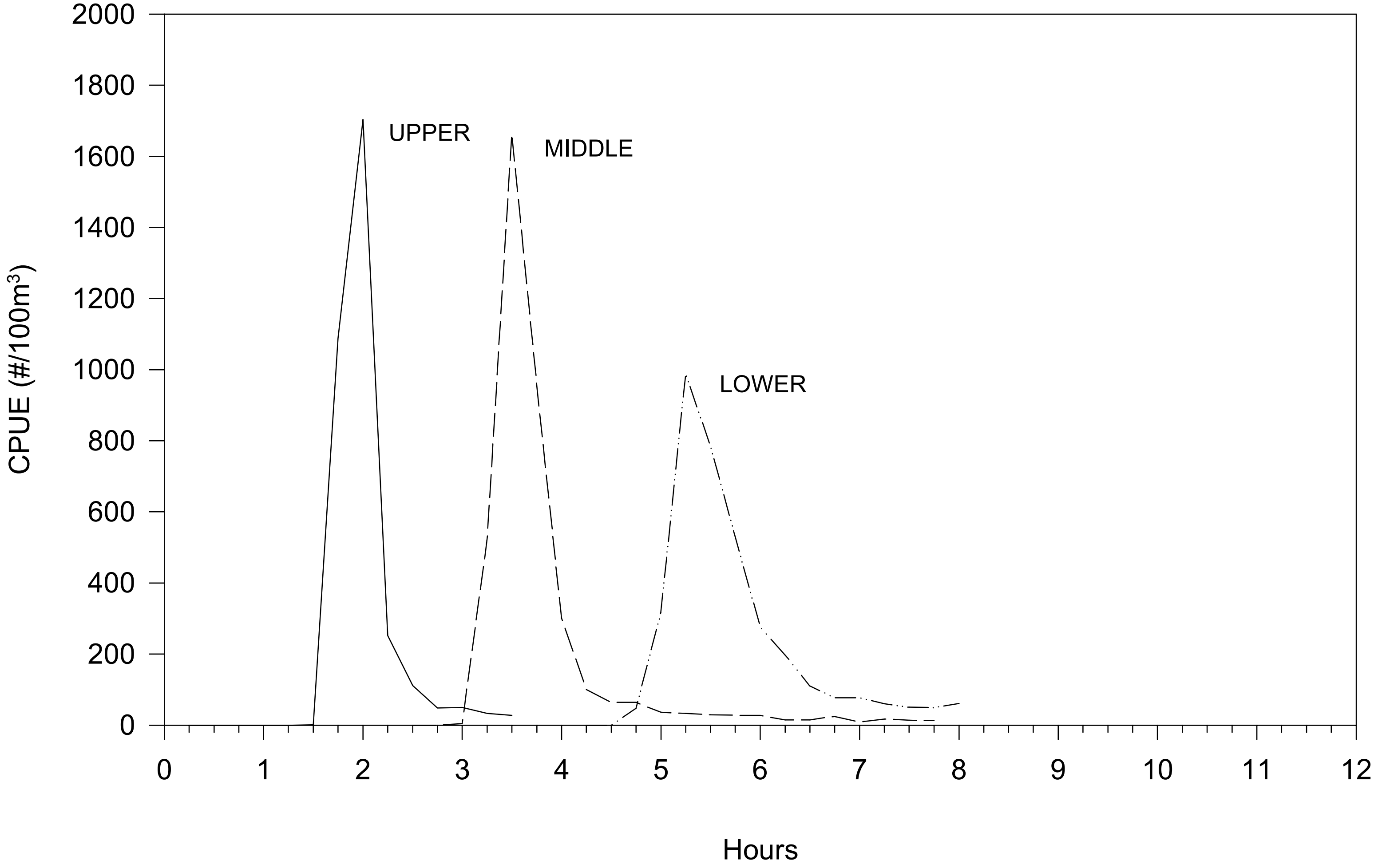

Figure 4. Travel time and dispersion of passively drifting particles released from the inflow of the Low Flow Conveyance Channel (600 cfs).

Table 1. Time for first and 50% arrival of passively drifting particles during Release 1 (600 cfs) and Release 2 (300 cfs).

REACH	CODE	DISTANCE [1]	RELEASE 1 Egg Color and Number First Arrival (h) 50% Arrival (h)	RELEASE 2 Egg Color and Number First Arrival (h) 50% Arrival (h)
SITE				
LFCC CULVERT	CUL	0	ORANGE 660,900	PURPLE 670,300
UPPER REACH OF LFCC	UPP	6.3	1.4 1.9	1.5 3.0
MIDDLE REACH OF LFCC	MID	10.6	2.8 3.4	3.1 4.6
LOWER REACH OF LFCC	LOW	16.0	4.5 5.4	4.7 7.3

[1] indicates distance (in km) from Low Flow Conveyance Channel culvert (upstream release site)

Table 2. Travel time for first and 50% arrival of passively drifting particles during Release 1 (600 cfs) and Release 2 (300 cfs).

REACH	CODE	DISTANCE [1]	RELEASE 1 Egg Color and Number First Arrival (km/h) 50% Arrival (km/h)	RELEASE 2 Egg Color and Number First Arrival (km/h) 50% Arrival km/(h)
SITE				
LFCC CULVERT	CUL	0	ORANGE 660,900	PURPLE 670,300
UPPER REACH OF LFCC	UPP	6.3	4.5 3.3	4.2 2.1
MIDDLE REACH OF LFCC	MID	10.6	3.8 3.1	3.4 2.3
LOWER REACH OF LFCC	LOW	16.0	3.6 3.0	3.4 2.2

[1] indicates distance (in km) from Low Flow Conveyance Channel culvert (upstream release site)

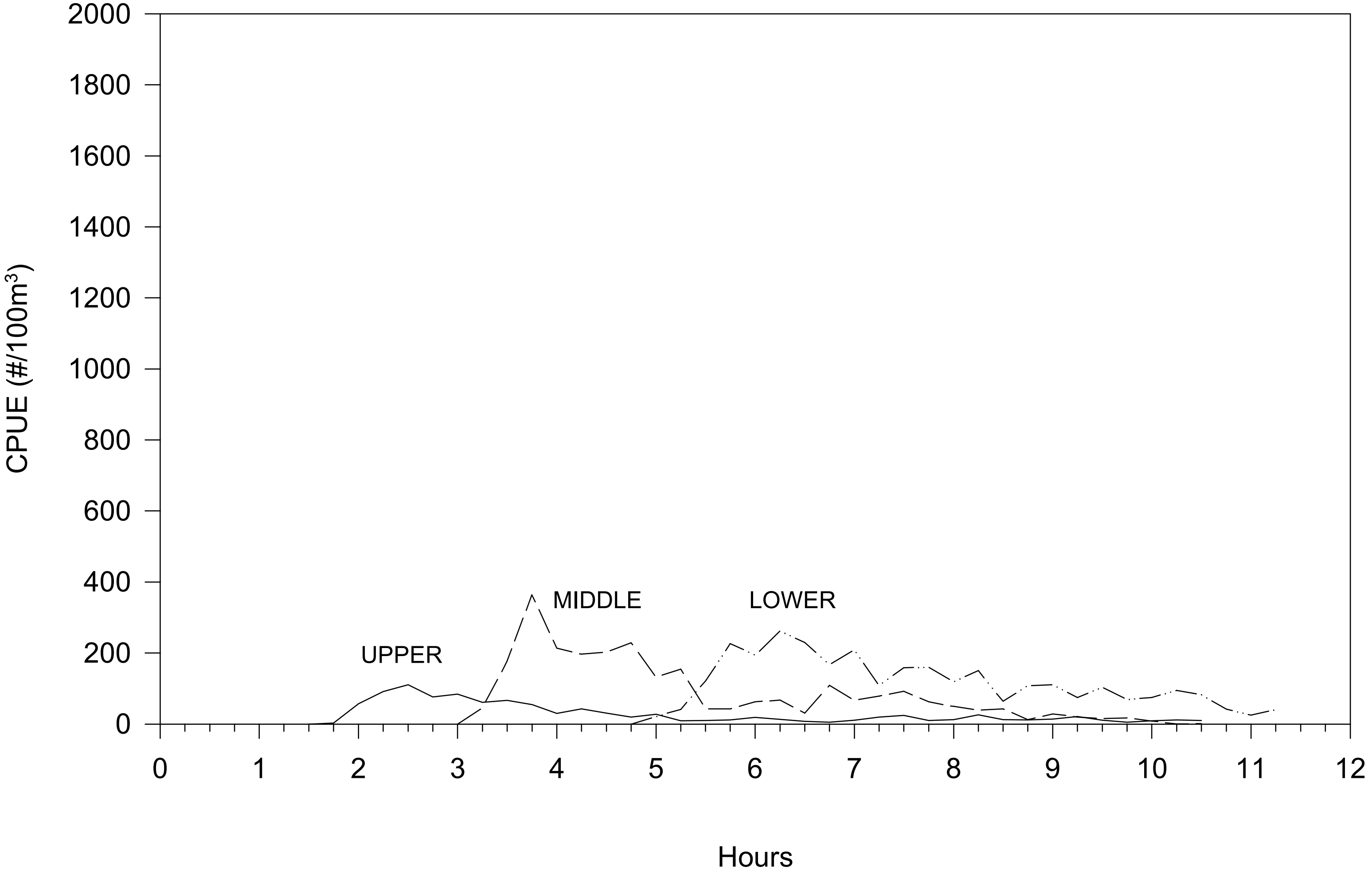

Figure 5. Travel time and dispersion of passively drifting particles released from the inflow of the Low Flow Conveyance Channel (300 cfs).

comparable (i.e., more particles collected at MID than UPP). In the future, preparatory steps can be undertaken to eliminate the problem encountered at low flows by relocating the MID site downstream of the weir and/or by aggitating passively drifting particles underwater prior to their release. The travel time information for UPP and MID are included in this report as this information is independent of catch rate. Particles first arrived at the first downstream collecting locality (UPP) in 1.5 h. This was only slightly longer to the IFP-UPP travel time recorded during the first constant LFCC release (1.4 h). Purple particles were collected at MID within 3.1 h of their release from IFP. Their arrival at LOW in 4.7 h was somewhat slower than the time it took orange particles to arrive there during the first constant LFCC release (4.5 h). The peak catch rate of particles was greatly reduced at LOW during the second constant LFCC release (262.1/100m^3) compared with the first constanct LFCC release (988.3/100m^3). It took a longer period of time to reach the peak catch rate and densities of particles collected declined very gradually.

The time for more than 50% of particles released during the second constant LFCC release to pass UPP was 3.3 h. A total of 1.8 h had elapsed from the first arrival until the majority of collected purple particles had passed UPP. At the MID collecting locality, the majority of drifting particles passed within 4.6 h from the time of release. The time for 50% of the particles to reach LOW (7.3 h) was nearly two hours longer than the travel time observed during the first constant LFCC release (5.4 h).

The 50% arrival travel rate for purple particles was notably slower (IFL to UPP- 2.1 km/h, IFL to MID- 2.3 km/h, and IFL to LOW- 2.2 km/h) than the rate orange particles travelled during the first release. The first arrival travel rate was also slower (IFL to UPP- 4.2 km/h, IFL to MID- 3.4 km/h, and IFL to LOW- 3.4 km/h) than the rate observed during the first constant LFCC release. Travel times between sites did not seem to differ with the exception of a faster first arrival travel rate between IFL and UPP. A similar pattern was observed during the first constant LFCC release.

Although particles travelled more slowly during the second release, many were displaced rather quickly (i.e., within 12 h) into the Rio Grande via the LFCC temporary outfall. The overall catch rate of particles at LOW was somewhat lower than what was observed during the first constant LFCC release. The primary difference was that during the second release particles were much more dispersed and arrived at a moderately steady rate over a longer period of time. There was also visual evidence that particles had become entrained at points along the LFCC throughout the study reach. Particles could be seen trapped in numerous small eddies along the shoreline created by rip-rap and instream debris. Small changes in local hydrologic conditions along the shoreline acted as sinks for dispersing particles as they were transported downstream. While many particles passed the sampling sites within a short period of time, there were low-moderate numbers that became entrained within the LFCC. A small number of orange particles were collected during the second constant LFCC release indicating long-term entrainment (i.e., 7 days).

DISCUSSION

The Middle Rio Grande Valley of New Mexico was being rapidly colonized by the later half of the 19th century. The increased presence of people who wanted to live and farm near the Rio Grande created an uneasy situation that was often marked with loss of life and property during floods. Extensive damage was reported throughout the early 1900s from flooding events that regularly inundated the Middle Rio Grande Valley. The natural conditions of the Rio Grande (i.e., floods and drought) were in conflict with anthropogenic habitability and agricultural productivity within the region.

The extensive flood irrigation system operated by the Middle Rio Grande Conservancy District diverted large quantities of water that was not returned to the Rio Grande. Flood irrigation is a highly inefficient agricultural technique (see Postel, 1999, 2001 for review) and often results in water shortages, salinization of soils, and drainage problems. Decreased agricultural productivity and the inability of the State of New Mexico to meet its downstream water delivery obligations (as mandated in the Rio Grande Compact of 1938) resulted in water shortages in Texas and the Republic of Mexico during the 1940s and 1950s.

The Low Flow Conveyance Channel was constructed to improve the efficiency of moving water and sediment through the Middle Rio Grande while minimizing water losses to evaporation and ground infiltration. The plan following the construction of the LFCC was to allow water to flow in the Rio Grande only when the combined capacities of the LFCC (about 2,000 cfs) and Socorro Main Canal North (about 200 cfs) were exceeded. During times of reduced flow, the Rio Grande would be purposefully dried for its entire length from San Acacia, NM to Elephant Butte Reservoir (a distance of about 100 km) and her waters would flow though the ditches of the MRGCD and LFCC. The profound negative environmental impacts of such a strategy will probably never be fully described as they largely occurred prior to recent systematic monitoring of the biota within this region.

The extirpation of several endemic fishes (speckled chub *Macrhybopsis aestivalis* and Rio Grande shiner *Notropis jemezanus*), the extinction of Rio Grande bluntnose shiner *Notropis simus simus* and phantom shiner *Notropis orca*, and the decline of Rio Grande silvery minnow can be partially attributed to anthropogenic river drying (Bestgen and Platania, 1990, 1991, Platania, 1991) caused by operation of upstream reservoirs, the LFCC, and the MRGCD irrigation network. Another reason for the loss or decline of these taxa was that their drifting eggs and larvae were displaced downstream of MRGCD diversion dams where they could not repopulate upstream reaches. Also, a potentially large number of drifting eggs and larvae were entrained into the LFCC and MRGCD waterways. The cumulative loss of a portion of the reproductive effort of these species over time because of entrainment or river drying ultimately led to their demise or decline.

The problem of entraining Rio Grande silvery minnow into the LFCC was largely eliminated following the end of regular operations of the LFCC in the 1980s. An outfall was constructed in 1997 that can return water from the LFCC to the Rio Grande at a point about 9 miles (14.5 km) downstream of San Acacia Diversion Dam. Several brief periods of experimental operations in 1997 and 1998 demonstrated that YOY Rio Grande silvery minnow were being entrained in the LFCC during its operation (Smith, 1998, 1999).

Operation of the LFCC in 2001 provided the opportunity to determine the magnitude of entrainment of Rio Grande silvery minnow eggs during short durations and to acquire information on rate and magnitude of downstream displacement of passively drifting particles in the LFCC. The dearth of entrainment of Rio Grande silvery minnow eggs in the LFCC during this study was indicative of the lack of propagules in the Rio Grande at the time of operation rather than the innocuous nature of the canal to drifting organisms. Spawning by Rio Grande silvery minnow, as indicated by 2001 egg collections at San Marcial, peaked in early May (8-10) and declined markedly by 22 May 2001. It is likely that there was a similar Rio Grande silvery minnow spawning sequence in the Isleta Reach. The 2001 spawning periodicity of Rio Grande silvery minnow in combination with the relatively small number of fish upstream of San Acacia Diversion are the key elements resulting in the extreme rarity of Rio Grande silvery minnow at our river sampling site and in the LFCC.

Data from this study indicated that the vast majority of passively drifting particles were transported through the LFCC in a short period of time. However, there were many particles that took an extended period of time to be transported through the LFCC. Based on the rate and magnitude of travel distribution curves, it appeared that low numbers of particles (i.e., <5%) would be entrained in the LFCC for >24 hours during both the 600 cfs and 300 cfs flow events.

The degree of entrainment of drifting organisms in any anthropogenic waterway is largely dependent on flow, channel width, and habitat complexity. The LFCC was a narrow, deep waterway that was generally free of debris. However, structure provided by rip-rap created limited small microhabitats where water velocities often approached 0 cm/s along the shoreline. These habitats often included instream debris that became impinged along the rip-rap water surface interface.

Limited numbers of passively drifting particles could be visually seen accumulating below the waters surface along the shoreline within these areas. Habitats with larger pieces of rip-rap and/or more instream debris appeared to retain higher numbers of particles.

At low flows (300 cfs) these habitats appeared to have more influence on the downstream displacement of particles than they did at higher flows (600 cfs). The reduced volume of water in the LFCC resulted in the collection of more instream debris along the rip-rap shoreline. The continuous source of this drifting instream debris was from water diverted from the Rio Grande into the LFCC. A much higher percentage of this debris was simply flushed through the LFCC during the 600 cfs flow event as compared to the 300 cfs flow event.

The LFCC within the study area contained several weirs that raised the water level and decreased water velocities on their upstream side and resulted in a run/riffle complex on their downstream side. Water velocities upstream of the weir were noticeably reduced during the 600 cfs and especially during the 300 cfs flow events during this study. Shoreline habitats appeared to retain more of the drifting particles in the vicinity immediately upstream of weirs.

The difference in travel rate of drifting particles was quite pronounced between the 600 cfs and 300 cfs flow events. The time for 50% of the particles to pass a particular collecting locality was longer during the 300 cfs event. A factor leading to the reduced travel time during the 300 cfs event was likely the increased suseptibility of particles to slow down or become retained within low velocity areas along the shoreline and in the vicinity immediately upstream of weirs.

The travel time for the arrival of the first particle at each of the collecting sites was only slightly longer during the 300 cfs flow event. This suggests that particles had the potential to travel at about the same maximum rate during the 300 cfs and 600 cfs flow events. The doubling of flow volume surprisingly did not notably alter the maximum rate of travel for drifting particles but did result in a more protracted collection of moderate densities of particles. Perhaps most importantly, the 300 cfs flow event produced more low water velocity habitats that appeared to notably slow or temporarily halt the progress of many passively drifting particles through the LFCC.

Studies on the downstream displacement of particles indicated that Rio Grande silvery minnow eggs and larvae would be entrained within the LFCC to some degree during both 300 cfs and 600 cfs flow events. The collection of particles seven days after their initial release and the prolonged capture of low densities of particles indicate that conditions within the LFCC result in the low-moderate retention of drifting eggs and larvae. Circumstantial evidence of entrainment in the LFCC was provided by Smith (1998, 1999) and in the MRGCD irrigation system by Lang and Altenbach (1994).

The level of entrainment of Rio Grande silvery eggs and larvae into the LFCC is dependent on both hydrological and biological factors. Lower flows appear to result in increased habitat heterogeneity, decreased instream water velocities, and higher levels of entrainment of eggs and larvae. Experimental operations during the spawning season results in a greatly increased probability of diverting drifting reproductive products into the LFCC. However, juvenile and adult Rio Grande silvery minnow may be entrained during these and other times of the year as well.

The potential for trapping all life stages (eggs through adults) of Rio Grande silvery minnow in the LFCC during experimental operations necessitates a re-evaluation of the utility of these exercises. Experimental operations of the LFCC for the purposes of studying sediment transport should be conducted during a time of the year when Rio Grande silvery minnow are not spawning and when YOY (young-of-year) are less active in the main channel. The months that would be most suitable would be January and February. Concentrating experiments within a short time interval would also alleviate the amount of entrainment that occurs.

The LFCC currently has an outfall that returns diverted water back into the Rio Grande at a point 16.0 km downstream of its inflow at San Acacia Diversion Dam. This outfall is necessary to prevent large-scale entrainment of Rio Grande silvery minnow into the LFCC. Any diversion of water into the LFCC should exit at the temporary outfall to prevent Rio Grande silvery minnow population fragmentation and the loss of individuals that become entrained.

Rio Grande silvery minnow are being entrained in the LFCC even with the present outfall. It is suggested that experimental operations in the LFCC be minimized throughout the year and be avoided during the spawning season of Rio Grande silvery minnow. As continued operation of the LFCC will contribute to the current issues that threaten the continued existence of the federally endangered Rio Grande silvery minnow, permanent closure of the LFCC should be considered.

RECOMMENDATIONS FOR IMPROVING SAMPLING PLATFORMS

Sampling for Rio Grande silvery minnow eggs and passively drifting particles at the UPP and MID sites was conducted on platforms constructed by personnel from the USBR-Socorro. These platforms were very well constructed and made sampling in the Low Flow Conveyance Channel far easier than it had ever been in the past. These structures also allowed researchers to access deep water portions of the channel that would have been inaccessible otherwise. There were some issues that made sampling difficult, however, and herein we present some recommendations for improving the sampling platforms.

Water levels at the UPP site platform were ideal for sampling during 300 cfs. During the 600 cfs flow event, water levels increased more than 50 cm and it would have been more effective if the platform was raised an additional 12 inches (31 cm) and extended to the bank. It is estimated that effective sampling at 1,200 cfs would involve raising the platform at least an additional 12 inches (31 cm), from the 600 cfs recommendation, but it is difficult to assess this figure as 1,200 cfs was not released during the study.

The MID site platform was adequate for the 300 cfs flow event, but was nearly impossible to use during the 600 cfs flow event because water levels rose nearly three feet (91 cm). It is recommended that this platform be two feet (61 cm) higher to sample effectively during 600 cfs flow events. Also, the top of the posts that anchored the platform were nearly underwater during the 600 cfs flow event. A 1,200 cfs flow event would likely completely submerge the posts making it impossible to sample the site. Additional posts and the sampling platform could be set farther up the bank at this site to allow access during high flow events.

The current platforms and the future platform (LOW site) would benefit from a design that would allow effective sampling during a variety of flows. The need for having platforms that extend to the bank at different heights to match flow conditions and also to have posts that extend well above (e.g., at least two feet [61 cm]) the surface of the water are two factors that would improve their current utility. Also, the UPP site performed much better than the MID site and this was primarily a factor of how much water levels rose during the 600 cfs flow event. The placement of the MID site just upstream of a weir resulted in pooling of water and a dramatic increase in water level. In, contrast the UPP site was located much farther away from the nearest weir and water levels rose less. It may be worthwhile to relocate the MID site several 100 meters downstream of that weir.

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