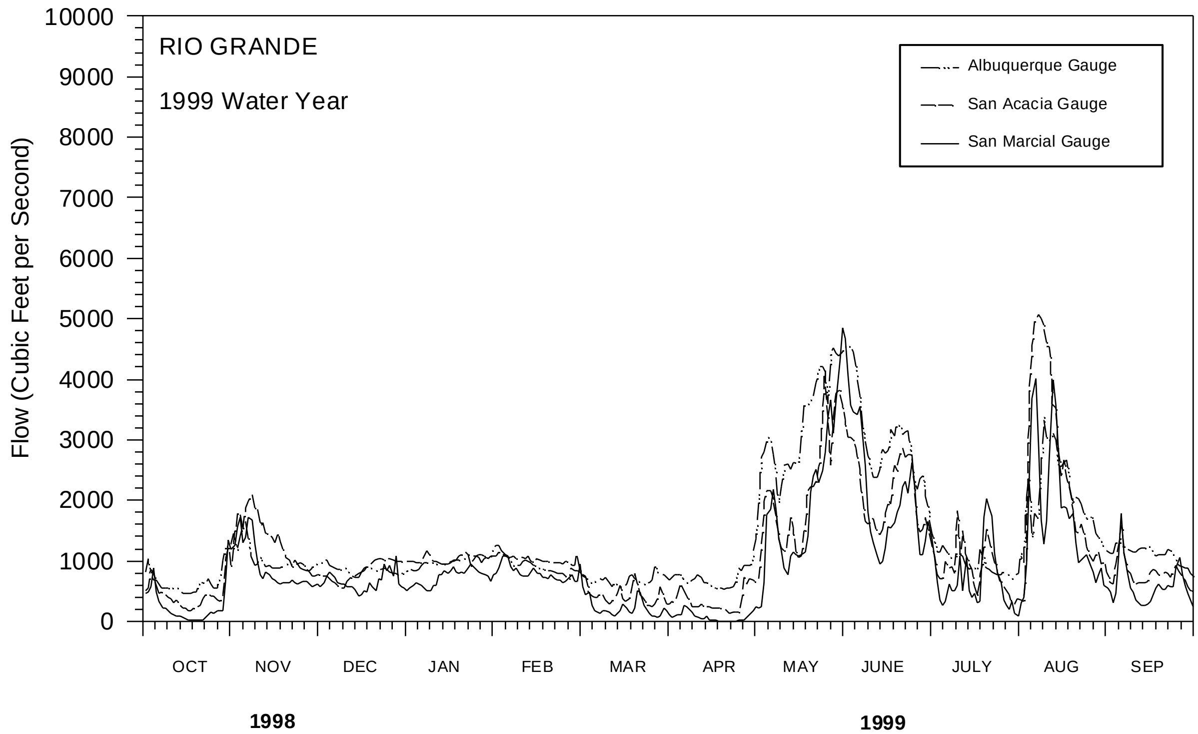
SPATIAL SPAWNING PERIODICITY OF RIO GRANDE SILVERY MINNOW DURING 1999

__**Final Report**__



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EXECUTIVE SUMMARY

The historical Middle Rio Grande fish fauna was reflective of a Great Plains river. At least five cyprinid species that can be characterized as Great Plains river fishes formerly occurred throughout the Middle Rio Grande. Spawning by members of this reproductive guild is associated with high-flow events such as spring runoff or summer rainstorms. Upon release, eggs are about 1.6 mm in diameter but quickly swell (ca. 3.0 mm) and remain suspended in the water column during development. The last remaining member of this reproductive guild in the Rio Grande, NM is the federally endangered Rio Grande silvery minnow (*Hybognathus amarus*). Population monitoring studies have shown an annual decline in the number and catch rate of Rio Grande silvery minnow since 1996. Currently over 90% of the catch of Rio Grande silvery minnow is in the San Acacia Reach of the Middle Rio Grande.

Sampling for this study began on 29 March 1999 and concluded with collections made on 2 July 1999. Each of the nine collection localities were sampled every weekday during this period (n=96 dates). The 96 days between 29 March 1999 and 2 July 1999 on which collection efforts for Rio Grande silvery minnow eggs occurred resulted in sampling of over 300 acre-feet of water (369,933 m^3 ; 13,062,333 ft^3) and a cumulative total of 24,786 silvery minnow eggs from the nine stations. There was a general downstream longitudinal increase in the number and catch rate of Rio Grande silvery minnow eggs. The two sites in the Angostura Reach yielded the fewest eggs (n=4) while the five sites in the San Acacia Reach produced 97% of the total egg catch (n=24,152). Maximum catch rates were recorded between 19-21 May 1999 at four sites and between 11-14 May at three sites. The principal spawn of Rio Grande silvery minnow at the Los Lunas, Bernardo, and San Acacia sites, as determined by egg catch rate, occurred in mid-May in response to the ca. 600 cfs increase in flow (Albuquerque Gauge) between 16 - 17 May 1999. Mean daily water temperature at Albuquerque during this period was 17^{o}C. As spring discharge continued to rise towards its maximum level for the year, Rio Grande silvery minnow continued to spawn at all sites, although at reduced levels, through late May.

Spawning periodicity investigations on species of the semibuoyant egg reproductive guild have consistently demonstrated that the majority of the reproductive effort occurs during a single short duration event. It is not unusual for >99% of all eggs collected in such studies to be taken during a one or two day period. Low levels or “background” spawning may continue for several weeks but the number of eggs produced is insignificant compared to the primary event. This investigation provides support for the hypothesis that the current distribution of Rio Grande silvery minnow is largely the result of downstream displacement of propagules.

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INTRODUCTION

The reach of the Rio Grande between Cochiti Dam and Elephant Butte Reservoir, known as the Middle Rio Grande, has been greatly modified over the past 50 years (Lagasse, 1985). Historically, this section of the river gradually meandered through a wide floodplain in a vegetated valley. Extensive braiding of the river as it flowed over the shifting sand substrate was common and flow was generally perennial except during times of severe or extended drought (Scurlock, 1998). The Middle Rio Grande was relatively shallow throughout most of the year because of regionally low precipitation levels (Gold and Dennis, 1985) but was subjected to periods of high flow. Flow was generally greatest during the annual spring snow melt runoff (April-June), however intense localized summer rainstorms (monsoonal events) often caused severe flooding and were important in maintaining perennial flow. Historically, the Middle Rio Grande possessed all of the characteristics distinctive of a Great Plains aquatic ecosystem.

The historical Middle Rio Grande fish fauna was also reflective of a Great Plains river. At least five cyprinid species that can be characterized as Great Plains river fishes formerly occurred in the Middle Rio Grande (Platania and Altenbach, 1998). Of the aforementioned species, speckled chub, *Macrhybopsis aestivalis*, Rio Grande shiner, *Notropis jemezanus*, and Rio Grande bluntnose shiner, *Notropis simus simus*, have been extirpated from the Middle Rio Grande. A fourth species, phantom shiner , *Notropis orca*, is extinct (Bestgen and Platania, 1990). Rio Grande silvery minnow, *Hybognathus amarus*, is the only extant member of the Great Plains River cyprinid fish fauna fish (Bestgen and Platania, 1991; Platania, 1991).

This group of cyprinids shared several life-history characteristics. All were small (generally < 100 mm TL), short-lived (2-5 years), fishes that occupied mainstem habitats. Four of the species are characterized as omnivorous while Rio Grande silvery minnow is herbivorous and feeds on epipsammonic algae. In addition to these shared traits, all five species were members of a reproductive guild of fishes characterized by pelagic spawning and production of semibuoyant eggs.

Spawning by members of this reproductive guild is associated with high-flow events such as spring runoff or summer rainstorms. Upon release, eggs are about 1.6 mm in diameter but quickly swell (ca. 3.0 mm) and remain suspended in the water column during development. Egg hatching time is temperature dependent but usually occurs in 24-48 hours. Recently hatched larval fish remain a component of the drift until development of the gas bladder. This physiological development corresponds with a shift in swimming behavior as larvae actively seek low-velocity habitats.

The 3-5 days necessary for propagules to attain the developmental stage that allows them to control their horizontal movements allows time for considerable downstream dispersal of eggs and larvae in the Middle Rio Grande. As has been well documented for other aquatic organisms, it is necessary for at least some portion of the drifting propagules to settle out into appropriate low-velocity habitats or move upstream to maintain viable populations (Speirs and Gurney, 2001). Historically, there were no permanent barriers to upstream dispersal of fishes in the Middle Rio Grande. There are currently three instream diversion structures between Cochiti Dam and Elephant Butte Reservoir that are barriers to upstream movement of fishes and fragment the once continuous range of the only remaining member of this reproductive guild.

Population monitoring studies of Rio Grande silvery minnow have shown an annual decline in the number and catch rate of this species since 1996 (Dudley and Platania, 1999, 2000, 2001). Currently over 90% of the catch of Rio Grande silvery is in the San Acacia Reach of the Middle Rio Grande (Dudley and Platania, 2001). Multi-agency efforts in areas of habitat improvement, research, and propagation are underway in an attempt to increase population size and distribution with the ultimate goal being recovery of this species.

This study was designed to acquire spatial information on the timing, duration, and magnitude of spawning by Rio Grande silvery minnow. These data are a will provide a more complete understanding of the biology and ecology of Rio Grande silvery minnow and are an important component of efforts to recover populations of this endangered fish (U.S. Department of the Interior, 1994; U.S. Fish and Wildlife Service, 1999).

STUDY AREA

Collection sites were selected so as to maximize the potential number of eggs collected per river reach. Nine sample locations were selected in the 218 km (135 mile) reach of the Rio Grande between Bernalillo and San Marcial Railroad Bridge Crossing (Figure 1; Table 1). Two sites were chosen in both the Angostura and Isleta Reaches while the remaining five sites were located in the San Acacia Reach. An attempt was made to locate sites near the upper and lower portions of each reach

The Angostura Reach is about 65 km (40 miles) long extending from Angostura Diversion Dam to Isleta Diversion Dam. The uppermost sampling location in this reach, at Bernalillo, was 9.5 km (5.9 miles) downstream of Angostura Diversion Dam. This locality was selected to ascertain the level of reproduction in Rio Grande silvery minnow in the Cochiti Reach and the upper portion of the Angostura Reach. The lowermost site in the Angostura Reach was 33.3 miles (53.7 km) downstream of Angostura Diversion Dam and 8.2 km (5.1 miles) upstream of Isleta. This site was deemed necessary to determine the reproductive effort of Rio Grande silvery minnow in the Albuquerque Reach.

As in the Angostura Reach, only two sampling locations were selected in the 85.7 km (53.1 mile) long Isleta Reach. A lack of access on Isleta Pueblo precluded sampling at the uppermost location (Isleta Diversion Dam) of this reach. Instead, the most upstream Isleta Reach site was 12.7 km (7.9 miles) downstream of the dam in the city of Los Lunas. The downstream-most collecting locality in this reach was 49.7 km (30.8 miles) south of Los Lunas at Bernardo which is 23.2 km (14.4 miles) upstream of San Acacia Diversion Dam.

The San Acacia Reach of the Middle Rio Grande is the longest of the three reaches extending about 96.7 km (60 miles) from the apron of San Acacia Diversion Dam (SADD) to the head of Elephant Butte Reservoir. The five sample locations in this reach were distributed along 74.4 km (46.1 miles) of the Rio Grande between San Acacia Diversion Dam and San Marcial Railroad Bridge Crossing. The presence of over 90% of the remaining population of Rio Grande silvery minnow in this reach of river necessitated a more extensive series of collection localities than in the two upstream river reaches.

The most upstream sampling location in the San Acacia Reach was about 2.4 km (1.5 miles) downstream of the San Acacia Diversion Dam. The Socorro Site, the next site downstream, was 24.5 km (15.2 miles) south of San Acacia and was selected to acquire information on the reproductive effort of Rio Grande silvery minnow in the upper portion of the San Acacia Reach. Conversely, the San Antonio Site (44.5 km [27.6 miles] from SADD) encompassed the upper half of the San Acacia Reach. The reach between San Antonio and Bosque del Apache was the shortest of this study (8.0 miles) but was necessary because it represented a river reach that dried frequently over the last five years. Finally, the downstream-most site (San Marcial) was selected to discern differences in reproductive effort in the upper and lower portions of the San Acacia Reach.

METHODS

Sampling for this study began on 29 March 1999 and concluded with collections made on 2 July 1999. Each of the nine collection localities were sampled every weekday during this period

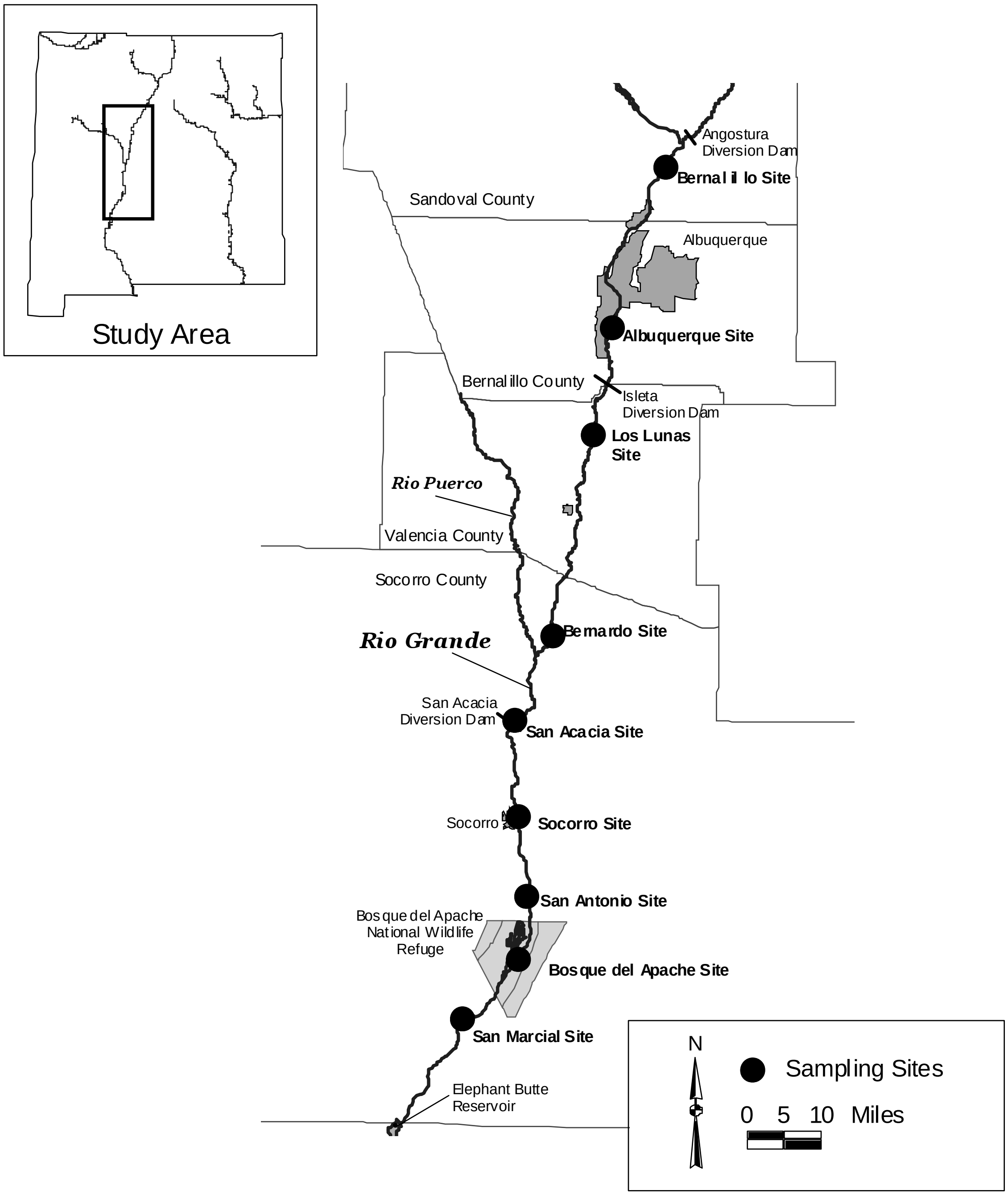

Figure 1. Map of the Middle Rio Grande, NM study area and sampling sites.

Table 1. Collection localities for 1999 Rio Grande silvery minnow spawning periodicity study.

Site #	Site Locality
	ANGOSTURA REACH SITES
1	**Bernalillo Site** New Mexico, Sandoval County, Rio Grande, at NM State Highway 44 bridge crossing, Bernalillo. River Mile 203.8 BERNALILLO QUADRANGLE UTM Easting: 358543 UTM Northing: 3909722 Zone: 13
2	**Albuquerque Site** New Mexico, Bernalillo County, Rio Grande, about 1.9 miles downstream from Rio Bravo Boulevard bridge crossing (NM State Highway 500), Albuquerque. River Mile 176.4 ALBUQUERQUE WEST QUADRANGLE UTM Easting: 347077 UTM Northing: 3875351 Zone: 13
	ISLETA REACH SITES
3	**Los Lunas Site** New Mexico, Valencia County, Rio Grande at Los Lunas bridge crossing (NM State Highway 49), Los Lunas. River Mile 161.4 LOS LUNAS QUADRANGLE UTM Easting: 342898 UTM Northing: 3852531 Zone: 13
4	**Bernardo Site** New Mexico, Socorro County, Rio Grande, ca. 3.5 miles downstream of US Highway 60 bridge crossing, Bernardo. River Mile 127.0 ABEYTAS QUADRANGLE UTM Easting: 331094 UTM Northing: 3805229 Zone: 13
	SAN ACACIA REACH SITES
5	**San Acacia Site** New Mexico, Socorro County, Rio Grande, ca. 1.5 miles downstream of San Acacia Diversion Dam, San Acacia. River Mile 114.6 LEMITAR QUADRANGLE UTM Easting: 325263 UTM Northing: 3790442 Zone: 13

Table 1. Collection localities for 1999 Rio Grande silvery minnow spawning periodicity study. (continued)

Site #	Site Locality
	SAN ACACIA REACH SITES (continued)
6	**Socorro Site** New Mexico, Socorro County, Rio Grande, east of Socorro, 0.5 miles upstream of the Socorro Low Flow Conveyance Channel bridge; east and upstream of Socorro Wastewater Treatment Plant, Socorro. River Mile 99.5 LOMA DE LAS CANAS QUADRANGLE UTM Easting: 327097 UTM Northing: 3771043 Zone: 13
7	**San Antonio Site** New Mexico, Socorro County, Rio Grande, at US Highway 380 bridge crossing, San Antonio. River Mile 87.1 SAN ANTONIO QUADRANGLE UTM Easting: 328914 UTM Northing: 3754471 Zone: 13
8	**Bosque del Apache Site** New Mexico, Socorro County, Rio Grande, directly east of Bosque del Apache National Wildlife Refuge Headquarters. River Mile 79.1 SAN ANTONIO, SE QUADRANGLE UTM Easting: 327055 UTM Northing: 3740839 Zone: 13
9	**San Marcial Site** New Mexico, Socorro County, Rio Grande, at San Marcial Railroad bridge crossing, San Marcial. River Mile 68.6 SAN MARCIAL QUADRANGLE UTM Easting: 315284 UTM Northing: 3728347 Zone: 13

(n=96 dates). Collecting activities did not occur during weekends. The most efficient means of sampling was to cluster sites in groups of three (Bernalillo, Albuquerque, and Los Lunas; Bernardo, San Acacia, and Socorro; San Antonio, Bosque del Apache, and San Marcial) thereby requiring only three individuals to acquire spawning periodicity information daily at each of the nine sites. Individuals would spend five-days working the same series of three sites and switch to the next downstream series of three sites the following week. The individual who had completed five-days of work at the lowest three sites would sample the upper three sites the following week.

Moore Egg Collectors (MEC) were used, following the protocol described in Altenbach et al., (2000), to collect drifting Rio Grande silvery minnow eggs. Two MEC's were operated in close proximity to each other at each site for two hours per day between 0700h and 1800 h. An attempt was made to vary the sampling time (early, middle, or late in the day) at an individual site throughout the week. Mechanical flow-meters were attached to each of the MEC's and volume of water filtered was determined. Eggs collected during the sampling period were retained in a plastic bag containing river water and a tag inscribed with unique alpha-numeric code. At the end of the two-hour sampling period, the eggs and tag were transferred to a jar containing a 5% solution of buffered formalin so that eggs could be enumerated under laboratory conditions. Daily site specific collection data from the two MEC's were combined to yield one catch rate per site per day. Catch rate data are presented as the number of Rio Grande silvery minnow eggs collected per 100 m^3 of water sampled.

Water temperature logging devices were deployed at each of the nine sampling sites and programmed to record temperatures hourly. High flows dislodged or buried the temperature loggers at the Los Lunas, Socorro, and Bosque del Apache sites and were never relocated. The data logger at the Bernardo Site malfunctioned failing to yield any data. Water temperature information at the Albuquerque Site are available until about 15 May 1999 at which time high flow and shifting substrate buried the temperature logger under over 1 m of sand-silt precluding its ability to provide accurate surface water temperature data.

Hourly water temperature data were recorded between 29 March and 2 July 1999 at the Bernalillo, San Acacia, San Antonio, and San Marcial sites. Water temperature data loggers were retrieved on in July 1999 and information downloaded. Hourly water temperature data are presented in Appendix I.

Mean daily discharge data were obtained from U.S. Geological Survey river gauges at Albuquerque (# 08330000; Figure 2), Bernardo (# 08332010; Figure 3), San Acacia (# 08354800; Figure 4), and San Marcial (# 08358400; Figure 5) and are presented in cubic feet per second (cfs). An attempt was made, when comparing egg catch rate and daily discharge, to use flow data from the gauge in closest proximity to the respective sampling site. Albuquerque gauge information were used for the Bernalillo, Albuquerque, and Los Lunas sites and Bernardo gauge data were used for the Bernardo Site. In the San Acacia Reach, the San Acacia gauge information were used for all except the Bosque del Apache and San Marcial sites. San Marcial gauge data were used the aforementioned two downstream most sites.

A spawning event, as used in this report, was a temporally discrete episode delineated by the absence of spawning for several consecutive dates both preceding and succeeding the event in question. The numerous spawns by Rio Grande silvery minnow during May 1999 were relatively contiguous and no attempt was made to separate or catagorize them as individual events. Conversely, there was a marked period devoid of spawning prior to and after the June 1999 (=second) spawning event.

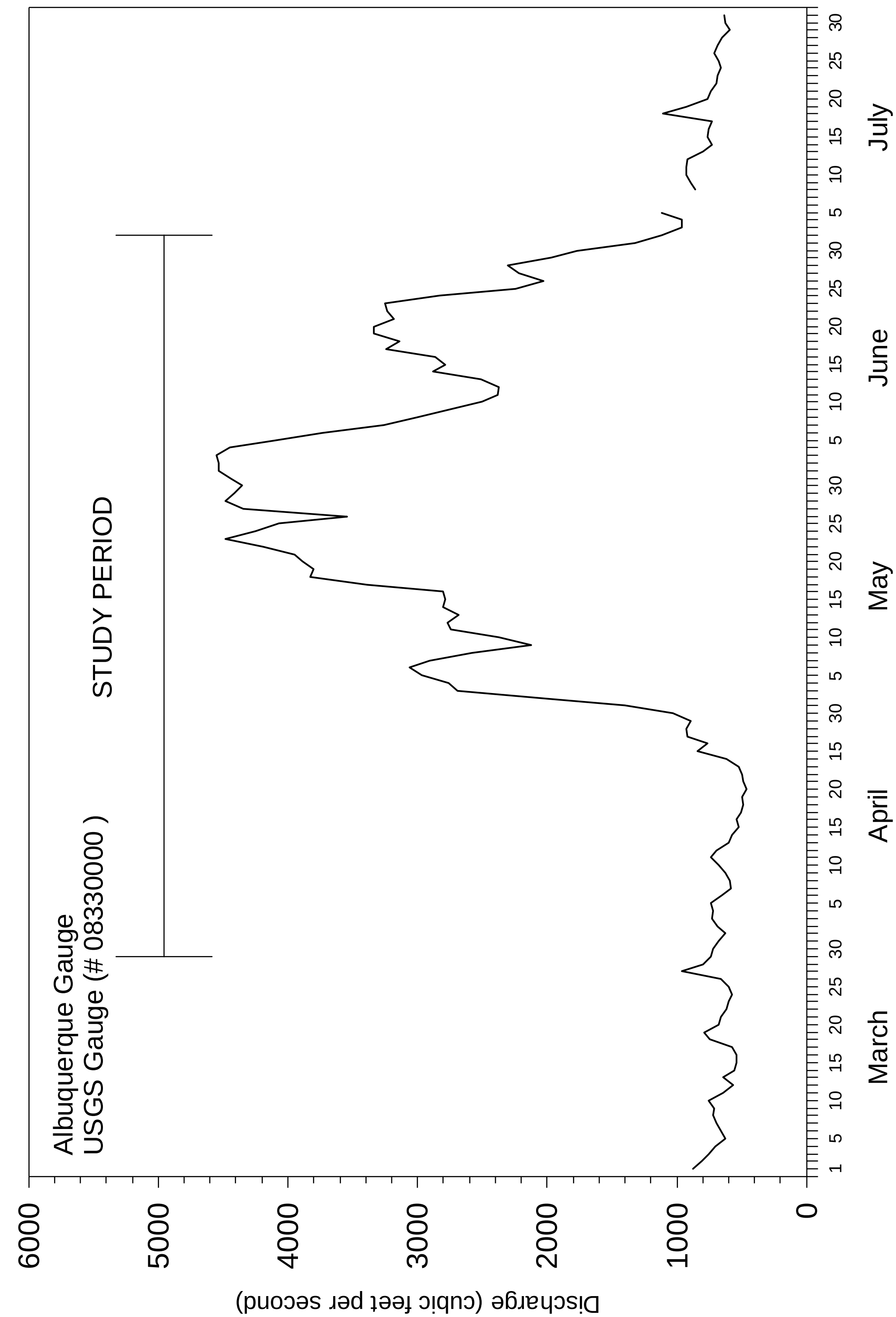

Figure 2. Hydrograph of the Rio Grande, NM at Albuquerque before, during, and after the 1999 study period.

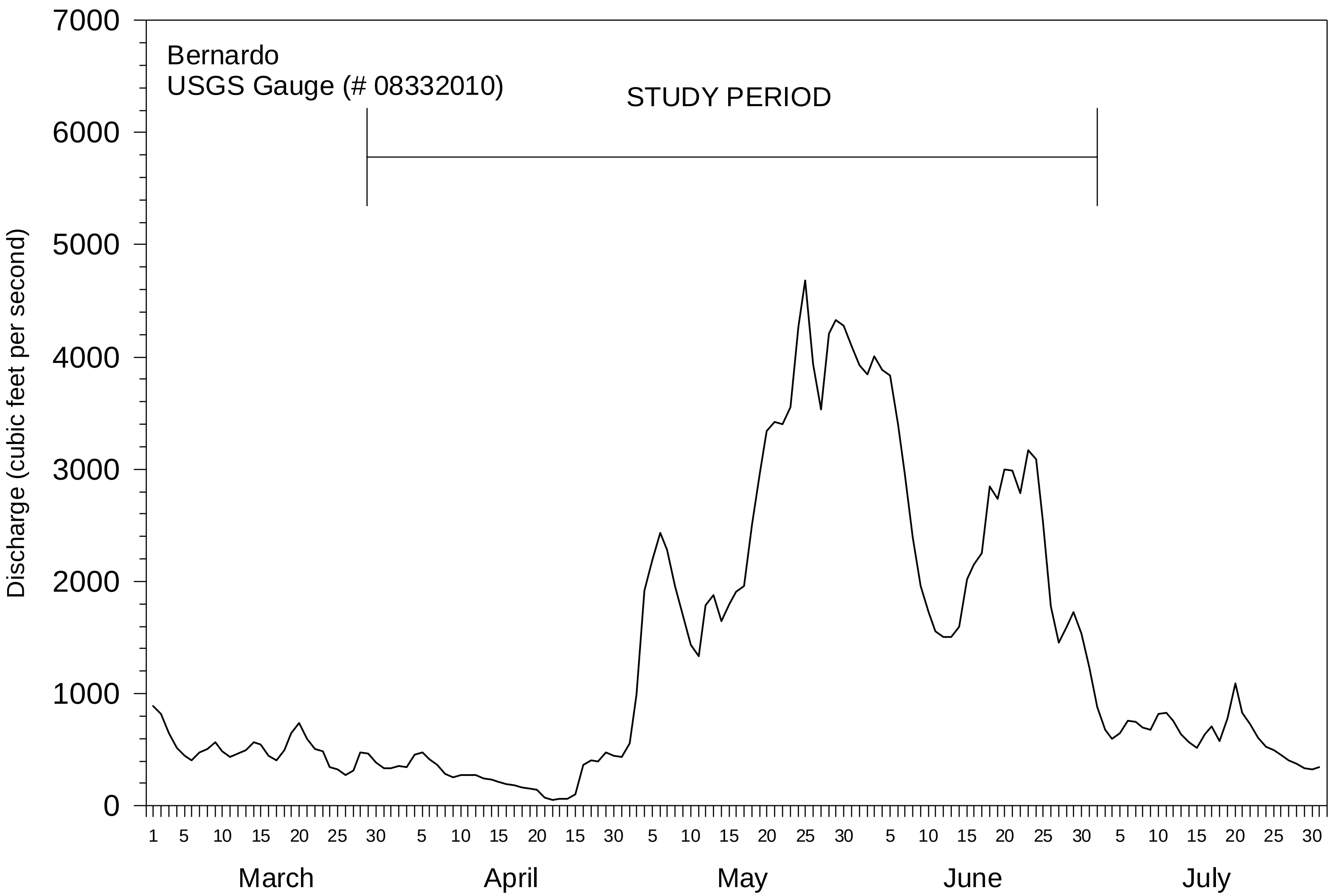

Figure 3. Hydrograph of the Rio Grande, NM at Bernardo before, during, and after the 1999 study period.

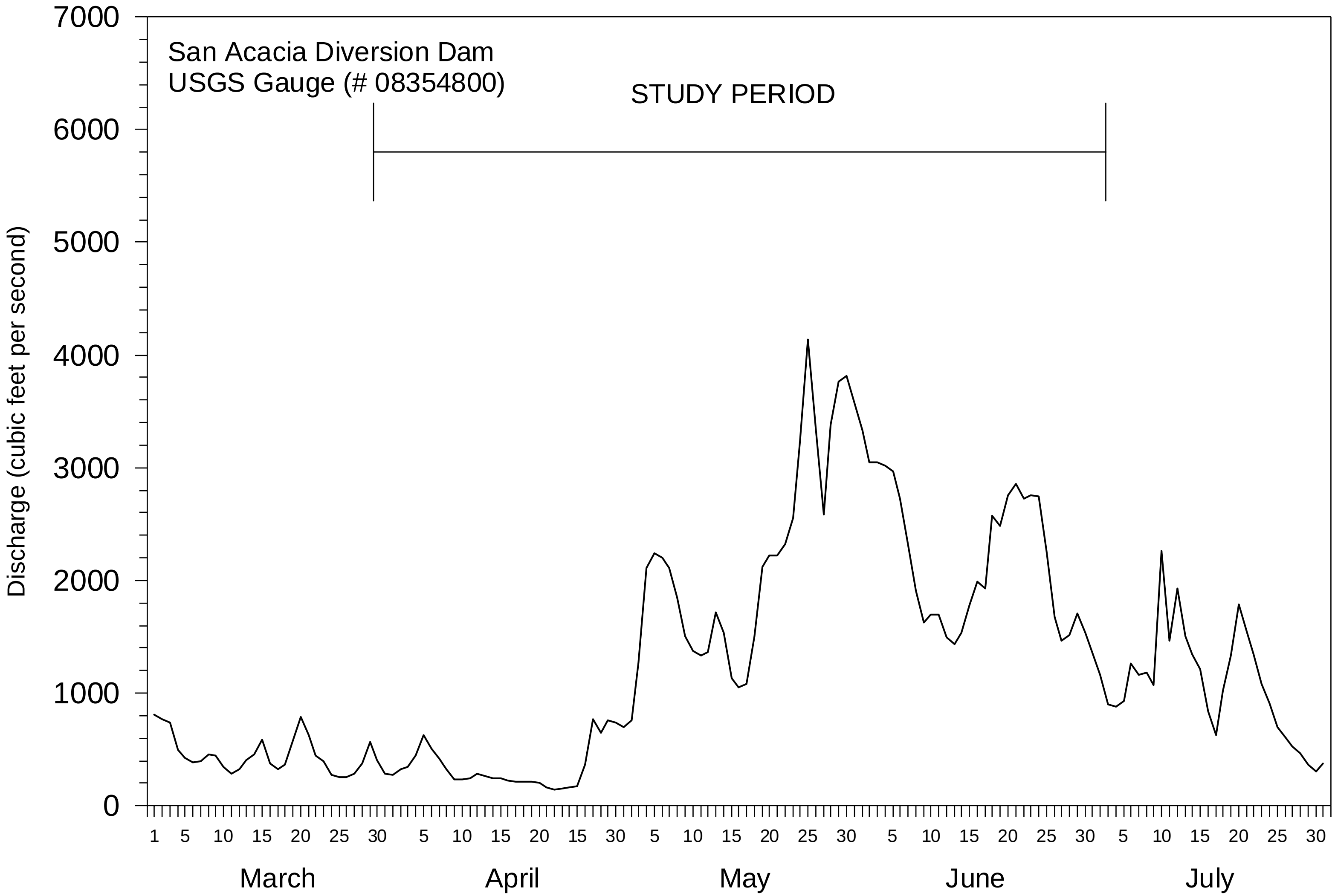

Figure 4. Hydrograph of the Rio Grande, NM at San Acacia Diversion Dam before, during, and after the 1999 study period.

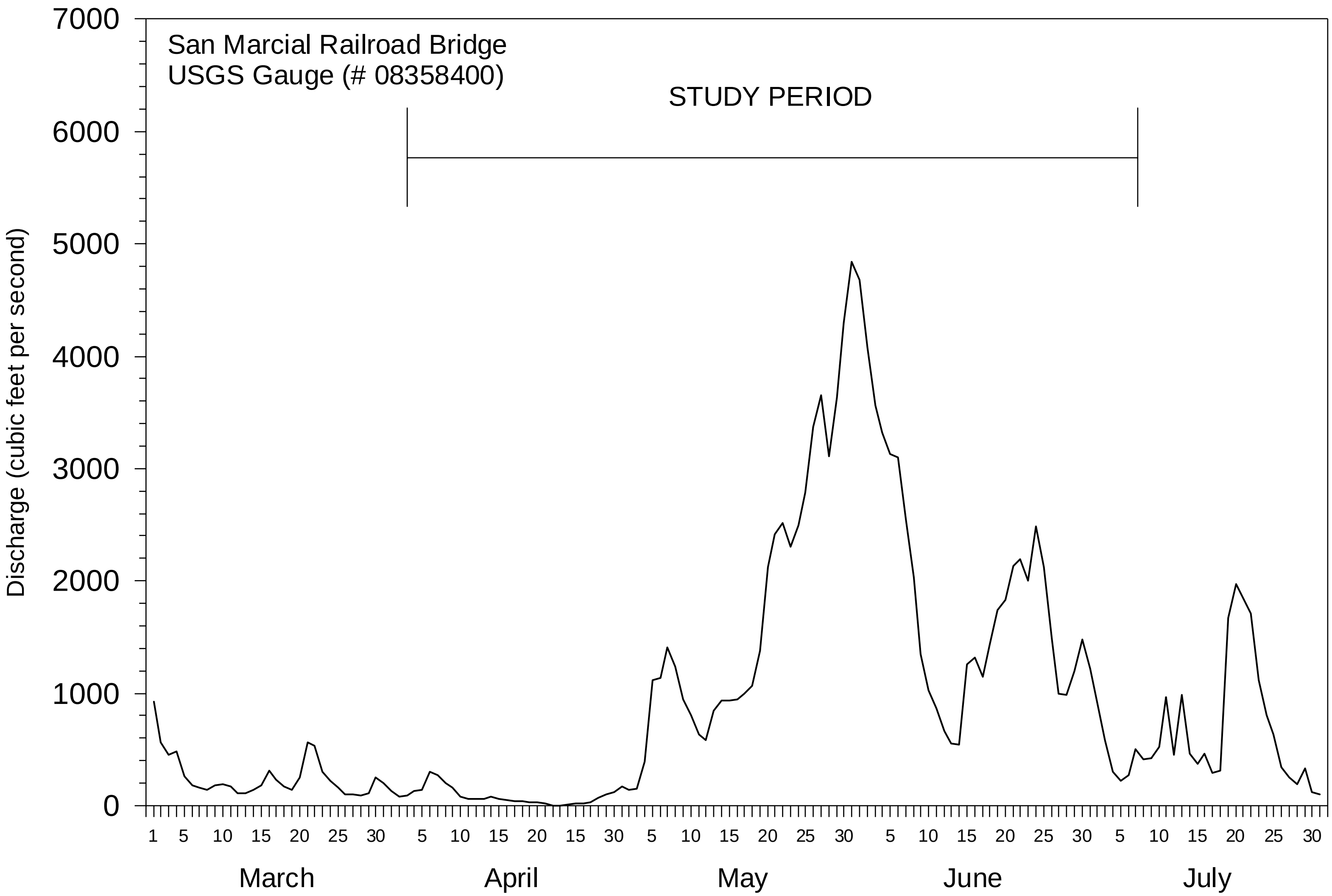

Figure 5. Hydrograph of the Rio Grande, NM at San Marcial Railroad Bridge before, during, and after the 1999 study period.

RESULTS

Rio Grande Silvery Minnow Egg Collection - Overview

The 96 days between 29 March 1999 and 2 July 1999 on which collection efforts for Rio Grande silvery minnow eggs occurred resulted in sampling of over 300 acre-feet of water (369,933 m^3 ; 13,062,333 ft^3) and a cumulative total of 24,786 silvery minnow eggs from the nine stations. The first egg was collected on 31 March 1999 at San Marcial (n=6) while the last eggs were taken on 25 June 1999 at San Antonio (n=2). The number of eggs per collecting locality varied from 0 at Bernalillo to 9,495 at Bosque del Apache National Wildlife Refuge (Table 2).

There was a general downstream longitudinal increase in the number and catch rate of Rio Grande silvery minnow eggs (Figures 6 and 7). Exceptions to this trend were at the San Acacia and San Marcial sites, both of which yielded fewer eggs than the next upstream site, respectively. The frequency of dates on which Rio Grande silvery minnow eggs were collected also followed an increasing downstream progression, except at San Marcial.

In addition to a downstream increase in the number of Rio Grande silvery minnow eggs collected per site, the same longitudinal pattern applied to the three river reaches. The two sites in the Angostura Reach yielded the fewest eggs (n=4) while the five sites in the San Acacia Reach produced 97% of the total egg catch (n=24,152). Likewise, cumulative egg catch rate by reach resulted in the Angostura Reach being the lowest, the Isleta Reach being second, and the San Acacia Reach producing the highest catch rate.

The tenure of Rio Grande silvery minnow spawning season and peak spawning event was relatively similar between sites. Earliest spawning was recorded at the three most downstream localities while the latest initiation of reproduction was recorded at the two most upstream sites (that produced eggs). Maximum catch rates were recorded between 19-21 May 1999 at four sites and between 11-14 May at three sites. In general, maximum catch rates at downstream preceded those of upstream sampling localities. (The Albuquerque Site was excluded from the previous comparison as it only yielded four eggs).

Rio Grande Silvery Minnow Egg Collection - Site Specific

The two collection sites in the Albuquerque Reach produced the fewest Rio Grande silvery minnow eggs. The absence of eggs at Bernalillo was mirrored by a dearth of eggs (n=4) at Albuquerque. Rio Grande silvery minnow eggs at Albuquerque were taken on two occasions (18 and 26 May 1999) with two eggs collected on each date. In contrast to the number of eggs collected, the sampling effort at these two upstream-most sites were some of the highest expended during the investigation. The greatest volume of water sampled was at Bernalillo (55,887 m^3; 1,973,369 ft^3) while the third highest amount of water sampled was at the Albuquerque Site (43,783 m^3; 1,545,964 ft^3).

The two sampling localities in the Isleta Reach collectively accounted for 2.5% (n=630) of the total egg catch by number. Los Lunas, the most upstream site in this reach and the locality with the second greatest volume of water sampled, yielded Rio Grande silvery minnow eggs on six separate occasions. As at Albuquerque, all eggs at Los Lunas were taken between 18 - 26 May 1999. The number of eggs collected gradually increased from 18 May (n=2) until culminating on 21 May (n=33).

There was a large increase in the number of eggs taken at the Bernardo Site, as compared with the three upstream collecting localities. The majority of eggs (88.8%; n=507) were taken during 10 sampling dates between 13 - 28 May 1999. The maximum number of eggs collected at Bernardo during a single sampling event was 271 (19 May 1999) which translated to a catch rate of 98.57 eggs per 100 m^3 of water sampled. A second Rio Grande silvery minnow spawning event was recorded at Bernardo when eggs were collected (n=64) on the first three and final of seven sampling

Table 2. Egg collection duration and CPUE from all sampling sites in the Middle Rio Grande, NM during 1999.

Site Name	River Mile	# of eggs	# of days eggs collected	Date of first capture	Date of last capture	Date of maximum CPUE	Maximum CPUE value
Bernalillo	203.8	0	0	-	-	-	-
Albuquerque	176.4	4	2	18 May	26 May	26 May	0.58
Los Lunas	161.4	6	59	18 May	26 May	21 May	4.79
Bernardo	130.6	571	14	13 May	24 Jun	19 May	98.57
San Acacia	114.6	358	15	11 May	24 Jun	19 May	37.36
Socorro	99.5	2,566	22	5 May	23 Jun	14 May	188.58
San Antonio	87.1	7,446	24	28 Apr	25 Jun	20 May	666.12
Bosque del Apache	79.1	9,495	28	28 Apr	22 Jun	14 May	650.30
San Marcial	68.6	4,287	24	31 Mar	22 Jun	11 May	154.07
Total		24,786					

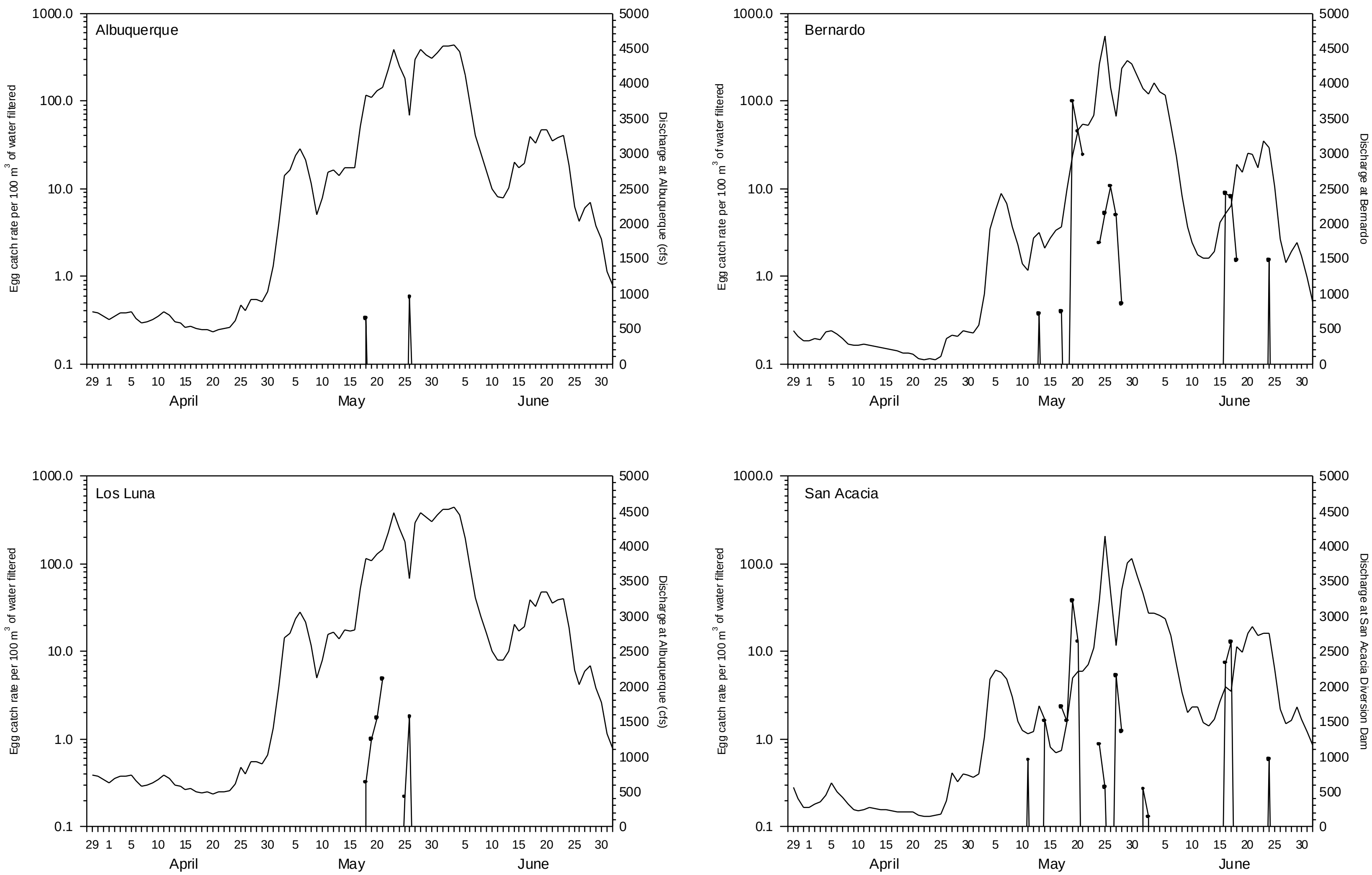

Figure 6. Rio Grande silvery minnow egg CPUE compared with mean daily discharge for the 1999 study period at Albuquerque, Los Lunas, Bernardo, and San Acacia sampling localities. Note that the catch rate (Y) axis is logarithmic.

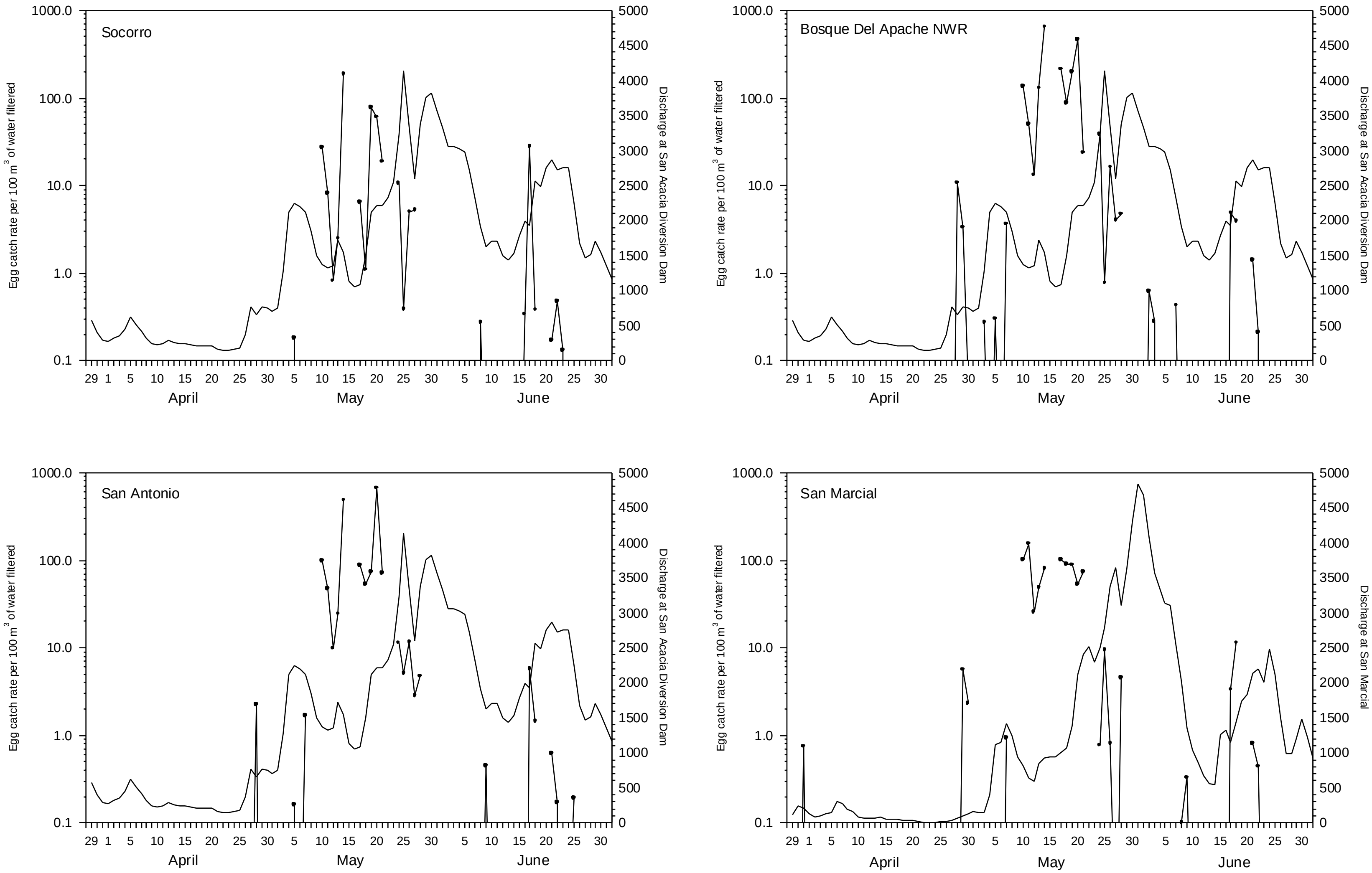

Figure 7. Rio Grande silvery minnow egg CPUE compared with mean daily discharge for the 1999 study period at Socorro, San Antonio Bosque del Apache NWR, and San Marcial sampling localities. Note that the catch rate (Y) axis is logarithmic.

dates between 16 - 24 June 1999. Maximum catch rate during this second spawning event was <0.1 (8.87 eggs per 100 m^3 of water sampled) of the maximum recorded during the primary spawn.

The San Acacia Site was the most upstream collection locality in the San Acacia Reach and recorded both the lowest number of eggs (n=358) and cumulative catch rate (0.02 eggs per 100 m^3 of water sampled) for this reach. Egg collection information at this site was more similar to that of the next upstream locality (Bernardo) than of those downstream (Socorro, San Antonio, etc.). The number of dates on which eggs were collected (n=15), the first (11 May 1999) and last date of egg collection (24 June 1999), and the date of maximum catch rate at San Acacia (19 May 1999) were all nearly the same as recorded at Bernardo. However, the cumulative catch rate at San Acacia was less than half that at Bernardo (0.06 eggs per 100 m^3 of water sampled). Eggs collected at San Acacia comprised about 1.5% of the total for this reach.

There was a marked increase in the number of Rio Grande silvery minnow eggs collected at Socorro as compared to San Acacia. The 2,566 eggs taken over 22 sampling dates were 10.6% of the San Acacia Reach catch. Eggs were collected on 14 consecutive sampling dates between 10 - 27 May 1999 with the maximum catch rate (188.58 eggs per 100 m^3 of water sampled) for this site occurring on 14 May 1999. As observed at the upstream two sampling sites, a second spawning event was recorded at Socorro between 16 - 24 June 1999. The maximum catch rate during this period (28.00 eggs per 100 m^3 of water sampled) occurred on 17 June 1999 both at Socorro and San Acacia. Rio Grande silvery minnow eggs were not collected at Socorro following this event.

The highest Rio Grande silvery minnow egg catch rate (666.12 eggs per 100 m^3 of water sampled) and the second greatest number of eggs (n=7,446) collected during this study were recorded at the San Antonio Site. Silvery minnow eggs were collected every sampling date (n=16) between 7 May and 28 May. During 10 -14 May, collection rate varied between 9.86 and 482.90 eggs per 100 m^3 of water sampled while the following week (17 -21 May) egg catch rate was never <53.34 (eggs per 100 m^3 of water sampled). Catch rate on 14 May (482.90 eggs per 100 m^3 of water sampled) was the second highest at this site and the only other catch rate to exceed 100 (eggs per 100 m^3 of water sampled). Between 31 May - 16 June 1999, there was only one date on which eggs were collected. However, on 17 June 1999 a second spawning event, persisting over four consecutive sampling dates, was initiated. As at the two collection sites immediately upstream, the maximum catch rate during the second spawning event occurred on 17 June 1999.

Bosque del Apache yielded the largest number (n=9,495) of Rio Grande silvery minnow eggs during this study accounting for 38.3% of the total egg catch and 39.3% of the San Acacia Reach egg collection. The number of dates on which eggs were collected (n=28) and overall catch rate at Bosque del Apache (0.80 eggs per 100 m^3 of water sampled) was the highest of any of the sampling sites. Rio Grande silvery minnow egg catch rates were >130 eggs per 100 m^3 of water sampled on six of the 16 consecutive sampling dates between 7 - 28 May 1999. The 14 May 1999 catch rate of 650.30 eggs per 100 m^3 of water sampled was the second highest during this study and mirrored the high catch rate at the San Antonio Site on the same date. Likewise, the second highest catch rate at Bosque del Apache (20 May 1999; 461.09 eggs per 100 m^3 of water sampled) corresponded well with that recorded immediately upstream (San Antonio) on 20 May 1999. Finally, the second spawning event noted at all sites upstream to (and including) Bernardo, was also recorded at Bosque del Apache. Spawning was initiated and peaked on 17 June 1999 and persisted over four consecutive sampling dates. No eggs were collected at this site following the second spawning event.

Far fewer eggs were collected at the most downstream site (San Marcial) than at either of the two collecting localities immediately upstream. Likewise, both maximum and overall San Marcial egg catch rates were markedly less than either Bosque del Apache or San Antonio. In contrast, the San Marcial Site produced the earliest record of spawning by Rio Grande silvery minnow (31 March 1999) and catch rate at San Marcial peaked three days earlier (11 May 1999) than any other site.

There were 20 sampling dates between the collection of the first (n=6) and second (n=47; 29 April 1999) samples of Rio Grande silvery minnow eggs at the San Marcial Site.

Rio Grande silvery minnow eggs were collected at San Marcial on 15 of 16 days between 7 - 28 May 1999 with catch rates on nine of those days exceeding 50 eggs per 100 m^3 of water sampled. The second spawning event noted at upstream localities was also recorded at San Marical on four consecutive dates between 17 - 22 June 1999. However, maximum catch rate at San Marcial during the second spawning event occured one-day after (18 June 1999) that observed immediately upstream. No eggs were collected at San Marical after the second spawning event.

Comparison between Discharge and Spawning Events

The spring release pattern on the Rio Grande (based on the Albuquerque Gauge) can be characterized generally as a gradual increase in discharge that began in late April and continued until early June. The gradual post-peak decline in discharge that began on 4 June was interrupted in mid-June (13 June) by another period of increased flow. This resulted in a broad mid-June peak (=second peak) although of lesser magnitude and duration than had occurred a few weeks earlier. On 24 June 1999, discharge in the Rio Grande began a gradual decline towards summer base-flow conditions. Daily fluctuations in flow throughout this period (April-June) accentuated the hydrograph with flow spikes and declines of varying but generally minor magnitude. This same general pattern of discharge was noted at the three gauges downstream of Albuquerque (Bernardo, San Acacia, San Marcial). The principal between gauge differences in flow was the progressive downstream delay in arrival and reduction in magnitude of specific events.

The principal spawn of Rio Grande silvery minnow at the Los Lunas, Bernardo, and San Acacia sites, as determined by egg catch rate, occurred in mid-May in response to the ca. 600 cfs increase in flow (Albuquerque Gauge) between 16 - 17 May 1999. Mean daily water temperature at Albuquerque during this period was 17^{o}C. Maximum Rio Grande silvery minnow egg catch rates were achieved on 19 May at Bernardo and San Acacia and 21 May at Los Lunas. Spawning at the four most downstream sites appeared to have been initiated by the more than tripling of discharge between 1 - 6 May 1999 (701 cfs to 2,200 cfs; San Acacia Gauge). Mean daily water temperatures at San Acacia were between 12.8^{o}C and 15.0^{o}C. Discharge at San Acacia declined gradually between 6 - 11 May before rising sharply (260 cfs) on 13 May. This flow increase might have been responsible for increased catch rates as maximum (or near maximum) catch rate at three of these four sites was achieved 13 - 14 May. In addition to increased flow, water temperature also increased during this period. Mean daily water temperatures in the San Acacia Reach were between 18.5^{o}C and 19.6^{o}C with maximum daily temperature >21^{o}C. As at the three upstream sites, the increase in discharge that was initiated on 16 May appears to have elicited a relatively large spawn by Rio Grande silvery minnow. May 20th was the date of maximum egg capture at San Antonio and second highest catch rate at Socorro and Bosque del Apache.

As spring discharge continued to rise towards its maximum level for the year, Rio Grande silvery minnow continued to spawn at all sites, although at reduced levels, through late May. By 1 June, there was little difference (<1^{o}C) in mean daily water temperatures between San Acacia, San Antonio, or San Marcial (Figure 8). There was a general lack of spawning by Rio Grande silvery minnow between 31 May and 16 June. However, the increase in discharge that was initiated on 15 June 1999 was followed by a corresponding second spawning event at all sites from Bernardo downstream. The magnitude of the 16 - 22 June 1999 Rio Grande silvery minnow spawn was considerably less than that recorded in May 1999. From 9 June 1999 until the end of this study, mean daily water temperature in the San Acacia Reach was never <20^{o}C and maximum daily water temperature was >30^{o}C on only three dates.

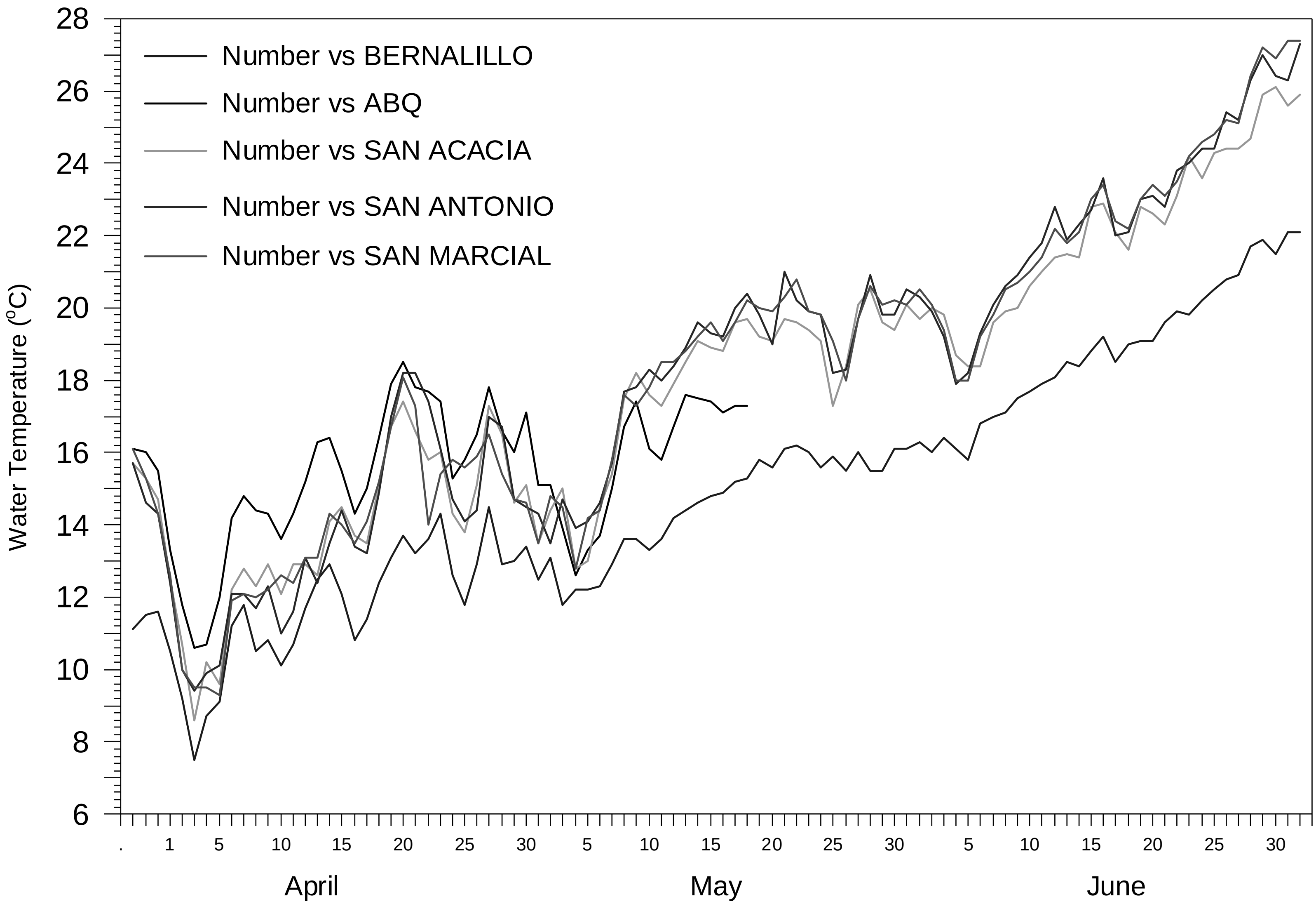

Figure 8. Mean daily water temperatures of the Rio Grande, NM at five sampling sites during the 1999 study period.

DISCUSSION

The 1999 Rio Grande silvery minnow spawning periodicity study provided the most extensive understanding of the longitudinal pattern of reproduction by this species to date and established a baseline dataset. This study confirmed the hypothesis that Rio Grande silvery minnow spawning is initiated by increases in discharge, typically the result of spring runoff. While there were two discrete spawning events identified during this study, Rio Grande silvery minnow continued to spawn at low levels over several weeks. However, the importance of those reproductive efforts to the overall population is likely minimal. Spawning periodicity investigations on species of the semibuoyant egg reproductive guild have consistently demonstrated that the majority of the reproductive effort occurs during a single short duration event. It is not unusual for >99% of all eggs collected in such studies to be taken during a one or two day period. Low levels or "background" spawning may continue for several weeks but the number of eggs produced is insignificant compared to the primary event. That maximum catch rates at most of the Rio Grande sites occurred within a short time-frame suggests that Rio Grande silvery minnow undertake a relatively synchronized spawn following the aforementioned practice.

The longitudinal pattern of increasing number of Rio Grande silvery minnow eggs provides additional support for the results of at least two concurrent areas of silvery minnow research. The lack of eggs at Bernalillo and near absence of eggs at Albuquerque are indicative of the relative rarity of this species in the Cochiti and Angostura reaches, respectively. The scarceness of Rio Grande silvery minnow in the Cochiti Reach was been demonstrated by several fish surveys in that reach (Platania and Bestgen, 1988; Platania, 1993; Platania, 1994). Likewise, Rio Grande silvery minnow population monitoring efforts during 1997 and 1999 (Dudley and Platania 1999, 2000) documented the decline of this species in the Angostura Reach of the Middle Rio Grande. This same monitoring effort has also demonstrated that the relative abundance of this species is greatest in the San Acacia Reach while the Isleta Reach contains the second largest number of Rio Grande silvery minnow. This is the same pattern as was demonstrated by the number of eggs collected during this study. It should not be surprising that the downstream increase in the number of Rio Grande silvery minnow eggs per river reach would mirror the results of the population monitoring.

This investigation also provided support for the hypothesis that the current distribution of Rio Grande silvery minnow is largely the result of downstream displacement of propagules. The three diversion structures in the Middle Rio Grande (Angostura, Isleta, and San Acacia) allow for downstream transport of fish and their reproductive products but are impenetrable barriers to upstream dispersal. Although there are no direct data available that document the fate of eggs transported over a diversion structure, cursory laboratory observation suggest that the eggs are relatively durable and able to tolerate turbulent water conditions. The increasing downstream abundance (by river reach) of Rio Grande silvery minnow provides indirect evidence that some considerable portion of eggs transported over diversions survive. In addition, this reach-specific pattern of increasing abundance highlights the necessity of river reconnectivity for this and other species of this reproductive guild.

The limited site specific daily duration of sampling produced a relatively small depiction of the actual daily Rio Grande silvery minnow reproductive effort. Likewise, the absence of sampling on weekends leaves voids in the continuity of the data. We believe that increased duration of daily sampling or addition of weekend sampling might have resulted in changes in the data regarding magnitude of spawning but generally would not have affected the fundamental patterns observed. A primary reason for this assumption is that spawning by this species (not individuals) is not a short-duration event. As demonstrated by this study, spawning continues for several days (potentially weeks) resulting in an accumulation of reproductive products in the river. The additive process of egg accrual allows for reliable extrapolation of short-duration sampling data to characterize the reproductive effort.

Conversely, discrete data collected during the sampling event such as maximum daily catch rate must be viewed in the context in which they were obtained. While daily catch rates are likely relatively indicative of the mean catch rate for that date, it is unlikely that, on any given date, the two-hour sampling period was representative of the maximum reproductive effort during the study. Our observation of spawning by guild members revealed gradual increases in catch rate culminating in a relatively short-duration (2-4 hours) maximum rate which was followed by a gradual decline to a base level reproductive effort. We believe that the catch-rates on dates of high or relatively high reproduction actually underestimate both the mean catch rate for that date and maximum site specific catch rate.

The two exceptions to the downstream increase in number of eggs collected were San Acacia and San Marcial. The difference in the number of eggs collected at San Acacia as compared to the next upstream site (Bernardo) was relatively small (n=213). The close proximity of the San Acacia Site to the diversion dam probably provides a cogent explanation for this difference. This site was closer than any other site to a diversion structure and allowed for sampling of only 2.4 km (1.5 miles) of uninterrupted river. An additional factor was that the small number of eggs from the Isleta Reach and relatively wide and meandering river channel between Bernardo and San Acacia would have served to diffuse the number of eggs transported between the two sites. Potentially the most important explanation for the lack of eggs at the San Acacia Site was the large body of standing water pooled immediately upstream of San Acacia Diversion Dam. The specific gravity of Rio Grande silvery minnow (all guild members) eggs is slightly greater than that of water (Dudley and Platania, 1999). The importance of this fact is that it means semibuoyant eggs require flow to remain in suspension in the water column. The diminished water velocity in this section of the river would have provided the opportunity for Rio Grande silvery minnow eggs to fall out of suspension and remain in the water ponded behind the diversion dam.

At Bosque del Apache, the site immediately upstream of San Marcial (16.9 km;10.5 miles), over twice as many Rio Grande silvery minnow eggs were collected (n=9,495) as compare to San Marcial (n=4,287). There were no similar circumstances encountered, such as at San Acacia (diversion dam, pooled water), in the vicinity of San Marcial that would have affected the number of eggs at this site. It was likely the death of numerous gravid adult Rio Grande silvery minnow in late-April 1999 that resulted in the downstream reduction of eggs at San Marcial. Between 22 -28 April 1999 large portions of the Rio Grande between the north boundary of Bosque del Apache National Wildlife Refuge and its confluence with Elephant Butte Reservoir dried. There were some scattered isolated pools throughout this reach but most were devoid of fish. It is noteworthy that this drying event does not appear in the San Marcial gauging station report (USGS, 2000). Instead, the USGS incorrectly reports mean daily flows at that gauge during this period (22 - 28 April 1999) between 3.6 and 65 cfs. The river became reconnected and continuous from San Marcial upstream at 10:35 hr on 28 April 1999.

The loss of these fish would certainly have affected the results at the San Marcial and Bosque del Apache sites. Approximately 8 km (5 miles) of the Bosque del Apache portion of the river dried while fish were basically eliminated from the entire 24.8 km (15.4 miles) San Marcial study reach. It is impossible determine the magnitude of the affect of this drying event on results from the Bosque del Apache Site especially given the large number of eggs collected at that location. Conversely, it appears that the affects of the river drying event on the number of eggs and catch rates at San Marcial can not be overstated.

Future efforts to monitor the spawning periodicity of Rio Grande silvery minnow should be concentrated in the lowermost portions of the San Acacia Reach. Sample sites in that location should yield the maximum catch rates and maximum number of eggs during a given duration. If drying occurs prior to spawning, strong consideration should be given to the relocation of the study site to a point upstream of or near the upstream end of the reach that had dried. Until the long-term population monitoring data indicate a substantial increase in the number of Rio Grande silvery minnow in the Angostura and Isleta reaches, little information should be expect to be gained by undertaking egg sampling in either of these reaches.

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Appendix 1.

DATE	Bernalillo Daily Mean	Bernalillo Daily Min	Bernalillo Daily Max	DATE	Bernalillo Daily Mean	Bernalillo Daily Min	Bernalillo Daily Max
29-Mar-99	11.13	9.32	12.58	16-May-99	14.85	12.42	17.29
30-Mar-99	11.54	10.41	12.73	17-May-99	15.18	12.89	17.77
31-Mar-99	11.64	10.26	13.19	18-May-99	15.30	13.04	17.45
01-Apr-99	10.55	9.48	11.34	19-May-99	15.81	13.66	18.25
02-Apr-99	9.21	7.47	10.72	20-May-99	15.59	13.19	18.09
03-Apr-99	7.51	6.54	8.39	21-May-99	16.13	13.66	18.57
04-Apr-99	8.69	7.78	9.32	22-May-99	16.25	14.28	18.25
05-Apr-99	9.06	6.85	11.19	23-May-99	15.96	14.75	17.13
06-Apr-99	11.15	9.32	13.04	24-May-99	15.59	14.59	16.66
07-Apr-99	11.79	10.57	13.51	25-May-99	15.94	14.43	17.45
08-Apr-99	10.52	8.86	11.96	26-May-99	15.53	13.81	17.45
09-Apr-99	10.84	9.48	12.42	27-May-99	15.96	14.12	18.09
10-Apr-99	10.14	8.24	11.81	28-May-99	15.53	13.81	17.61
11-Apr-99	10.73	8.71	12.42	29-May-99	15.53	13.81	17.45
12-Apr-99	11.73	9.79	13.51	30-May-99	16.06	13.97	18.25
13-Apr-99	12.55	11.49	13.97	31-May-99	16.15	14.28	18.41
14-Apr-99	12.88	11.34	14.75	01-Jun-99	16.31	14.28	18.74
15-Apr-99	12.08	11.03	13.35	02-Jun-99	16.05	14.28	17.93
16-Apr-99	10.80	9.17	12.58	03-Jun-99	16.37	14.12	18.90
17-Apr-99	11.42	8.71	13.81	04-Jun-99	16.06	13.97	18.25
18-Apr-99	12.36	11.19	13.66	05-Jun-99	15.77	13.66	17.77
19-Apr-99	13.07	11.03	15.07	06-Jun-99	16.75	14.28	19.39
20-Apr-99	13.66	12.11	15.39	07-Jun-99	16.99	14.12	19.72
21-Apr-99	13.21	12.42	13.97	08-Jun-99	17.14	14.59	19.39
22-Apr-99	13.58	11.34	15.71	09-Jun-99	17.51	14.75	20.04
23-Apr-99	14.30	13.04	15.86	10-Jun-99	17.71	14.91	20.20
24-Apr-99	12.64	11.49	14.75	11-Jun-99	17.87	14.91	20.52
25-Apr-99	11.82	10.57	12.73	12-Jun-99	18.08	15.54	20.52
26-Apr-99	12.90	10.88	14.43	13-Jun-99	18.45	16.02	20.69
27-Apr-99	14.49	12.11	16.18	14-Jun-99	18.39	16.02	20.69
28-Apr-99	12.92	12.11	15.86	15-Jun-99	18.75	16.49	20.85
29-Apr-99	12.98	10.88	14.75	16-Jun-99	19.17	16.97	21.52
30-Apr-99	13.42	10.88	14.75	17-Jun-99	18.46	16.81	19.88
01-May-99	12.53	11.03	14.12	18-Jun-99	19.01	16.66	21.52
02-May-99	13.10	10.57	15.54	19-Jun-99	19.11	17.29	21.02
03-May-99	11.75	11.03	12.73	20-Jun-99	19.08	16.97	21.02
04-May-99	12.24	10.57	13.97	21-Jun-99	19.64	17.77	21.35
05-May-99	12.17	10.26	14.12	22-Jun-99	19.86	17.77	22.18
06-May-99	12.33	9.94	14.59	23-Jun-99	19.75	17.13	22.35
07-May-99	12.87	9.94	15.39	24-Jun-99	20.20	17.29	23.02
08-May-99	13.61	10.57	16.18	25-Jun-99	20.54	18.09	22.68
09-May-99	13.64	11.19	15.71	26-Jun-99	20.79	18.41	22.85
10-May-99	13.26	10.10	15.71	27-Jun-99	20.94	18.41	22.85
11-May-99	13.60	11.81	15.39	28-Jun-99	21.66	18.90	24.22
12-May-99	14.22	11.34	16.97	29-Jun-99	21.91	19.56	23.87
13-May-99	14.43	11.65	16.81	30-Jun-99	21.54	18.57	23.70
14-May-99	14.62	12.11	16.97	01-Jul-99	22.07	19.23	24.22
15-May-99	14.80	12.27	17.29	02-Jul-99	22.05	20.20	23.18

Appendix 1.

DATE	Albuquerque Daily Mean	Albuquerque Daily Min	Albuquerque Daily Max
29-Mar-99	16.06	12.07	19.94
30-Mar-99	16.04	13.16	19.14
31-Mar-99	15.55	12.38	18.82
1-Apr-99	13.25	10.69	15.17
2-Apr-99	11.77	10.23	13.46
3-Apr-99	10.58	6.84	14.08
4-Apr-99	10.74	8.54	12.69
5-Apr-99	12.00	6.38	16.74
6-Apr-99	14.23	9.31	18.82
7-Apr-99	14.77	11.14	19.31
8-Apr-99	14.37	9.00	18.82
9-Apr-99	14.28	10.69	17.86
10-Apr-99	13.55	8.84	18.01
11-Apr-99	14.28	10.23	18.33
12-Apr-99	15.24	11.14	19.47
13-Apr-99	16.28	12.54	20.10
14-Apr-99	16.42	12.69	20.10
15-Apr-99	15.50	11.30	20.10
16-Apr-99	14.32	10.07	18.66
17-Apr-99	15.04	9.61	20.10
18-Apr-99	16.41	12.07	20.42
19-Apr-99	17.92	12.85	22.91
20-Apr-99	18.49	14.08	22.91
21-Apr-99	17.84	15.17	20.42
22-Apr-99	17.72	13.77	21.75
23-Apr-99	17.36	13.92	21.75
24-Apr-99	15.30	11.76	18.66
25-Apr-99	15.82	12.69	18.82
26-Apr-99	16.46	12.38	20.26
27-Apr-99	17.82	13.77	20.92
28-Apr-99	16.59	15.17	18.66
29-Apr-99	16.02	12.54	19.47
30-Apr-99	17.07	13.77	20.42
1-May-99	15.13	12.85	16.90
2-May-99	15.14	11.61	18.17
3-May-99	13.94	12.38	15.79
4-May-99	12.56	10.53	13.77
5-May-99	13.31	11.30	15.17
6-May-99	13.70	11.14	15.95
7-May-99	15.04	11.92	17.69
8-May-99	16.67	13.16	19.94
9-May-99	17.39	14.86	20.10
10-May-99	16.14	13.00	18.82
11-May-99	15.81	13.77	17.53
12-May-99	16.66	13.62	19.47
13-May-99	17.55	15.01	19.94
14-May-99	17.51	14.86	20.10
15-May-99	17.41	14.86	20.10

DATE	Albuquerque Daily Mean	Albuquerque Daily Min	Albuquerque Daily Max
16-May-99	17.14	14.54	19.62
17-May-99	17.32	14.86	19.47
18-May-99	17.33	15.48	18.66
19-May-99	—	—	—
20-May-99	—	—	—
21-May-99	—	—	—
22-May-99	—	—	—
23-May-99	—	—	—
24-May-99	—	—	—
25-May-99	—	—	—
26-May-99	—	—	—
27-May-99	—	—	—
28-May-99	—	—	—
29-May-99	—	—	—
30-May-99	—	—	—
31-May-99	—	—	—
1-Jun-99	—	—	—
2-Jun-99	—	—	—
3-Jun-99	—	—	—
4-Jun-99	—	—	—
5-Jun-99	—	—	—
6-Jun-99	—	—	—
7-Jun-99	—	—	—
8-Jun-99	—	—	—
9-Jun-99	—	—	—
10-Jun-99	—	—	—
11-Jun-99	—	—	—
12-Jun-99	—	—	—
13-Jun-99	—	—	—
14-Jun-99	—	—	—
15-Jun-99	—	—	—
16-Jun-99	—	—	—
17-Jun-99	—	—	—
18-Jun-99	—	—	—
19-Jun-99	—	—	—
20-Jun-99	—	—	—
21-Jun-99	—	—	—
22-Jun-99	—	—	—
23-Jun-99	—	—	—
24-Jun-99	—	—	—
25-Jun-99	—	—	—
26-Jun-99	—	—	—
27-Jun-99	—	—	—
28-Jun-99	—	—	—
29-Jun-99	—	—	—
30-Jun-99	—	—	—
1-Jul-99	—	—	—
2-Jul-99	—	—	—

Appendix 1.

DATE	San Acacia Daily Mean	San Acacia Daily Min	San Acacia Daily Max	DATE	San Acacia Daily Mean	San Acacia Daily Min	San Acacia Daily Max
29-Mar-99	15.69	14.09	17.09	16-May-99	18.81	17.73	19.99
30-Mar-99	15.26	14.09	16.14	17-May-99	19.61	18.22	21.97
31-Mar-99	14.70	13.33	15.67	18-May-99	19.70	17.89	20.80
1-Apr-99	12.49	11.47	14.56	19-May-99	19.18	18.06	20.31
2-Apr-99	10.66	10.08	11.78	20-May-99	19.12	17.41	21.63
3-Apr-99	8.64	7.14	9.77	21-May-99	19.71	18.54	20.64
4-Apr-99	10.17	8.99	11.62	22-May-99	19.57	18.38	20.31
5-Apr-99	9.63	6.99	12.40	23-May-99	19.43	18.70	20.64
6-Apr-99	12.25	10.39	14.09	24-May-99	19.11	18.22	19.83
7-Apr-99	12.79	11.78	13.79	25-May-99	17.33	15.98	18.54
8-Apr-99	12.29	9.92	14.56	26-May-99	18.43	16.77	19.83
9-Apr-99	12.93	11.62	13.94	27-May-99	20.13	18.06	22.30
10-Apr-99	12.10	9.61	13.94	28-May-99	20.51	19.67	21.30
11-Apr-99	12.89	11.47	13.63	29-May-99	19.56	18.70	20.64
12-Apr-99	12.91	10.54	14.72	30-May-99	19.42	18.06	20.80
13-Apr-99	12.57	11.62	13.33	31-May-99	20.13	19.67	20.97
14-Apr-99	14.08	11.47	15.98	1-Jun-99	19.71	19.02	20.47
15-Apr-99	14.46	12.24	15.98	2-Jun-99	20.03	19.83	20.15
16-Apr-99	13.70	11.78	15.03	3-Jun-99	19.80	19.34	19.99
17-Apr-99	13.45	10.69	15.35	4-Jun-99	18.66	17.41	19.99
18-Apr-99	15.11	12.40	16.93	5-Jun-99	18.40	16.62	19.51
19-Apr-99	16.73	13.63	18.86	6-Jun-99	18.40	17.09	19.34
20-Apr-99	17.42	15.19	19.02	7-Jun-99	19.57	19.34	19.99
21-Apr-99	16.65	14.56	18.86	8-Jun-99	19.90	19.67	20.31
22-Apr-99	15.82	12.56	19.02	9-Jun-99	19.99	19.51	20.47
23-Apr-99	16.01	14.25	17.73	10-Jun-99	20.58	20.47	20.97
24-Apr-99	14.27	13.02	15.35	11-Jun-99	21.01	20.64	21.63
25-Apr-99	13.83	12.87	14.88	12-Jun-99	21.38	21.13	21.63
26-Apr-99	15.12	12.40	17.73	13-Jun-99	21.50	21.30	21.63
27-Apr-99	17.26	15.03	19.67	14-Jun-99	21.40	20.64	22.96
28-Apr-99	16.52	14.72	18.86	15-Jun-99	22.77	20.80	24.85
29-Apr-99	14.61	12.71	16.30	16-Jun-99	22.92	21.47	24.51
30-Apr-99	15.07	13.63	16.46	17-Jun-99	22.08	21.30	23.30
1-May-99	13.51	12.71	14.72	18-Jun-99	21.63	20.15	23.64
2-May-99	14.38	11.62	17.25	19-Jun-99	22.76	21.30	23.98
3-May-99	14.98	14.25	16.14	20-Jun-99	22.64	21.97	23.81
4-May-99	12.85	11.31	13.79	21-Jun-99	22.32	21.47	23.30
5-May-99	13.02	11.78	14.72	22-Jun-99	23.13	22.30	24.51
6-May-99	14.45	11.78	16.46	23-Jun-99	24.18	23.13	25.37
7-May-99	15.43	12.71	17.89	24-Jun-99	23.62	23.13	24.51
8-May-99	17.47	14.88	19.99	25-Jun-99	24.25	23.64	24.85
9-May-99	18.23	16.62	19.67	26-Jun-99	24.40	24.16	24.68
10-May-99	17.56	15.83	18.38	27-Jun-99	24.43	24.16	25.37
11-May-99	17.32	16.14	18.54	28-Jun-99	24.71	24.16	26.42
12-May-99	17.86	16.30	20.47	29-Jun-99	25.92	25.37	26.59
13-May-99	18.53	17.73	19.83	30-Jun-99	26.07	25.37	26.77
14-May-99	19.11	17.25	21.13	1-Jul-99	25.56	24.33	26.59
15-May-99	18.87	17.09	20.64	2-Jul-99	25.89	25.54	26.77

Appendix 1.

DATE	San Antonio Daily Mean	San Antonio Daily Min	San Antonio Daily Max
29-Mar-99	15.70	11.47	19.84
30-Mar-99	14.63	11.94	17.90
31-Mar-99	14.26	9.92	19.03
1-Apr-99	12.42	9.31	16.62
2-Apr-99	9.96	7.46	12.56
3-Apr-99	9.40	5.13	13.49
4-Apr-99	9.88	7.77	12.56
5-Apr-99	10.07	4.82	15.21
6-Apr-99	12.10	7.92	16.62
7-Apr-99	12.14	9.46	16.31
8-Apr-99	11.67	6.37	17.26
9-Apr-99	12.33	7.92	17.74
10-Apr-99	10.98	4.50	17.58
11-Apr-99	11.65	7.15	16.62
12-Apr-99	13.12	8.07	18.54
13-Apr-99	12.38	8.99	16.62
14-Apr-99	13.49	8.53	19.68
15-Apr-99	14.40	8.23	21.31
16-Apr-99	13.41	8.84	19.52
17-Apr-99	13.17	6.84	19.36
18-Apr-99	14.93	8.69	21.64
19-Apr-99	17.02	9.92	24.52
20-Apr-99	18.16	12.25	24.34
21-Apr-99	18.20	14.42	23.14
22-Apr-99	17.37	12.56	22.98
23-Apr-99	16.05	11.32	21.81
24-Apr-99	14.67	12.87	16.62
25-Apr-99	14.14	11.94	16.15
26-Apr-99	14.38	10.39	18.38
27-Apr-99	16.98	13.34	20.48
28-Apr-99	16.67	15.84	18.71
29-Apr-99	14.73	14.26	15.68
30-Apr-99	14.51	14.26	14.89
1-May-99	14.35	14.11	14.73
2-May-99	13.49	13.18	14.11
3-May-99	14.65	14.26	14.89
4-May-99	13.94	13.34	14.57
5-May-99	14.11	13.03	14.73
6-May-99	14.55	12.56	16.94
7-May-99	15.72	12.41	19.19
8-May-99	17.66	13.95	21.31
9-May-99	17.80	14.89	20.65
10-May-99	18.33	16.47	20.98
11-May-99	18.00	15.21	20.65
12-May-99	18.45	14.57	21.98
13-May-99	18.89	15.84	21.31
14-May-99	19.62	16.62	22.48
15-May-99	19.29	17.26	21.48
16-May-99	19.18	17.42	21.31
17-May-99	19.96	16.31	23.14
18-May-99	20.36	17.58	22.81
19-May-99	19.82	18.06	21.64
20-May-99	19.01	17.74	20.81
21-May-99	21.02	19.68	22.81
22-May-99	20.25	18.22	22.48
23-May-99	19.92	18.54	20.98
24-May-99	19.81	18.54	21.64
25-May-99	18.20	17.10	19.52
26-May-99	18.31	16.31	20.00
27-May-99	19.71	17.58	21.81
28-May-99	20.88	19.36	22.48
29-May-99	19.77	18.38	21.81
30-May-99	19.79	17.90	21.98
31-May-99	20.47	19.03	22.31
01-Jun-99	20.28	18.22	22.64
02-Jun-99	19.86	18.87	21.48
03-Jun-99	19.24	17.74	21.48
04-Jun-99	17.92	16.62	19.52
05-Jun-99	18.16	15.84	20.65
06-Jun-99	19.31	16.62	22.31
07-Jun-99	20.07	17.42	22.81
08-Jun-99	20.59	18.38	23.48
09-Jun-99	20.91	17.90	24.00
10-Jun-99	21.43	18.38	24.69
11-Jun-99	21.75	18.38	25.21
12-Jun-99	22.81	19.03	26.78
13-Jun-99	21.91	19.84	24.52
14-Jun-99	22.33	18.87	25.90
15-Jun-99	22.72	19.68	26.25
16-Jun-99	23.62	20.81	27.13
17-Jun-99	22.02	20.65	23.66
18-Jun-99	22.05	19.52	24.86
19-Jun-99	23.00	20.65	25.56
20-Jun-99	23.09	20.98	25.73
21-Jun-99	22.77	21.14	25.03
22-Jun-99	23.78	20.98	26.78
23-Jun-99	23.97	21.64	26.96
24-Jun-99	24.35	22.14	26.96
25-Jun-99	24.37	22.81	26.08
26-Jun-99	25.37	23.14	27.49
27-Jun-99	25.20	22.64	27.49
28-Jun-99	26.27	23.32	29.68
29-Jun-99	27.05	24.00	30.61
30-Jun-99	26.41	23.14	29.31
01-Jul-99	26.29	23.14	29.13
02-Jul-99	27.26	24.52	30.61

Appendix 1.

DATE	San Marcial Daily Mean	San Marcial Daily Min	San Marcial Daily Max	DATE	San Marcial Daily Mean	San Marcial Daily Min	San Marcial Daily Max
29-Mar-99	16.10	12.09	20.33	16-May-99	19.07	16.63	22.15
30-Mar-99	15.26	12.87	17.91	17-May-99	19.63	16.47	23.15
31-Mar-99	14.34	11.78	17.42	18-May-99	20.20	17.58	22.65
1-Apr-99	12.57	9.45	16.16	19-May-99	20.04	18.07	22.32
2-Apr-99	10.01	6.83	12.40	20-May-99	19.93	16.94	23.15
3-Apr-99	9.55	4.81	14.26	21-May-99	20.25	17.58	22.98
4-Apr-99	9.52	6.37	11.78	22-May-99	20.83	18.55	23.32
5-Apr-99	9.35	4.03	14.26	23-May-99	19.86	18.55	21.65
6-Apr-99	11.90	8.38	14.57	24-May-99	19.81	18.07	22.15
7-Apr-99	12.14	9.76	14.88	25-May-99	19.15	17.42	21.65
8-Apr-99	11.99	8.38	15.52	26-May-99	17.97	15.84	20.17
9-Apr-99	12.23	9.30	15.68	27-May-99	19.66	17.42	22.15
10-Apr-99	12.62	7.45	18.23	28-May-99	20.64	19.04	22.65
11-Apr-99	12.41	8.22	17.26	29-May-99	20.12	18.39	22.15
12-Apr-99	13.10	8.07	18.55	30-May-99	20.21	18.23	22.32
13-Apr-99	13.14	9.92	17.26	31-May-99	20.06	18.55	21.48
14-Apr-99	14.27	9.61	19.84	1-Jun-99	20.46	18.39	22.98
15-Apr-99	14.02	8.22	20.17	2-Jun-99	20.07	18.71	21.48
16-Apr-99	13.51	7.76	19.84	3-Jun-99	19.40	17.91	21.32
17-Apr-99	14.07	8.22	20.33	4-Jun-99	17.96	16.31	19.68
18-Apr-99	15.17	8.68	21.82	5-Jun-99	17.95	15.52	20.66
19-Apr-99	16.68	9.61	24.01	6-Jun-99	19.19	16.31	22.15
20-Apr-99	18.07	11.78	26.09	7-Jun-99	19.82	16.94	22.65
21-Apr-99	17.32	13.79	24.01	8-Jun-99	20.47	17.91	23.15
22-Apr-99	14.03	10.86	16.63	9-Jun-99	20.71	17.74	24.01
23-Apr-99	15.43	14.10	16.47	10-Jun-99	21.03	18.07	24.18
24-Apr-99	15.79	15.21	16.47	11-Jun-99	21.43	18.39	24.88
25-Apr-99	15.61	14.73	16.47	12-Jun-99	22.22	19.04	25.74
26-Apr-99	15.86	14.57	17.26	13-Jun-99	21.77	20.01	23.66
27-Apr-99	16.55	15.04	17.91	14-Jun-99	22.06	19.36	25.22
28-Apr-99	15.43	13.48	16.47	15-Jun-99	23.02	20.82	25.05
29-Apr-99	14.71	11.47	18.07	16-Jun-99	23.43	20.82	26.27
30-Apr-99	14.58	11.63	17.26	17-Jun-99	22.39	21.15	23.83
1-May-99	13.52	11.32	14.57	18-Jun-99	22.24	19.84	25.39
2-May-99	14.82	11.01	18.07	19-Jun-99	23.02	21.15	25.05
3-May-99	14.50	12.71	16.16	20-Jun-99	23.36	21.15	25.74
4-May-99	12.80	9.76	15.99	21-Jun-99	23.12	20.98	25.39
5-May-99	14.16	12.40	16.78	22-Jun-99	23.51	20.66	26.62
6-May-99	14.43	10.70	18.55	23-Jun-99	24.18	21.82	26.62
7-May-99	15.84	11.78	20.17	24-Jun-99	24.59	22.15	27.33
8-May-99	17.60	13.94	21.48	25-Jun-99	24.77	22.48	27.33
9-May-99	17.27	15.04	19.84	26-Jun-99	25.24	22.98	27.69
10-May-99	17.83	14.10	21.15	27-Jun-99	25.11	22.98	27.33
11-May-99	18.52	16.31	20.98	28-Jun-99	26.40	23.49	29.52
12-May-99	18.53	15.52	21.82	29-Jun-99	27.22	24.18	30.26
13-May-99	18.83	16.31	21.48	30-Jun-99	26.94	24.01	29.89
14-May-99	19.21	16.47	22.15	1-Jul-99	27.36	24.18	30.63
15-May-99	19.57	17.42	22.15	2-Jul-99	27.37	25.05	29.33