Influence of Rio Grande reservoir water quality on agricultural and urban usage: Understanding options for maintaining sustainability within the river basin

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The function of this project was to determine the present status of the water quality within International Amistad Reservoir, particularly with emphasis toward upstream influence of agricultural activity on the reservoir, and the influence of water quality on downstream agricultural needs with regard to the water stored within the reservoir. This is a preliminary final report, as some of our laboratory analyses are still being performed, and the data analysis is also not complete. A number of concerns we were initially interested in (salinization and eutrophication of the reservoir), and became interested in (characteristics of the reservoir sediments), will all be dealt with here and in the final report. We also worked in concert with a research team from Lamar University led by Dr. Xing Fang. This collaboration focused on developing a CEQUAL-W2 model for the reservoir to model reservoir mixing, water quality, and the potential influence of climate change. This publication is appended to this report.

Study Site, Sampling, and Methods Three rivers of very different physical and chemical nature (the Rio Grande/Rio Bravo, Pecos, and Devils) flow into the large International Amistad Reservoir (Fig. 1), which represents a very valuable resource for downstream and local agricultural and domestic interests. In 2004 a great deal of the volume of the reservoir, which had decreased dramatically since 1994, has been recovered through high inflows. The wet spring of 2007 kept reservoir elevations high, though much water was released downstream, and the reservoir did not fill up to its listed conservation elevation.

International Amistad Reservoir is a critical surface water resource for the downstream inhabitants of the arid Rio Grande/Rio Bravo basin. In a review of certain water quality characteristics covering data up till 1989, Miyamoto et al. (1995) recognized trends of increasing salinity within the Rio Grande as a major threat to future water quality. The water volume of the reservoir began to decline dramatically in 1993, in what was to be the first year of a 10 year long drought. In May 2003 the reservoir volume had declined to $< 1,180 \times 10^6$ m^3, or 28% of the conservation volume. Drought conditions should accelerate trends of increasing salinity due both to a tendency for the inflowing rivers to be more saline under low flows, as well as increasing the importance of evaporation from the surface of the reservoir. This is apparently a false premise for this reservoir, because it is located within the Edwards-Trinity Aquifer of the Edwards Plateau, and as surface flows from the remotely fed Pecos and Rio Grande decrease, the diluting influence of local groundwater inflows into the tributaries and reservoir directly acts to dilute the salinity of the reservoir. Wet conditions in 2003 and 2004 have resulted in increase of volume back to $3,017 \times 10^6$ m^3 by October, 2004, and during our study the

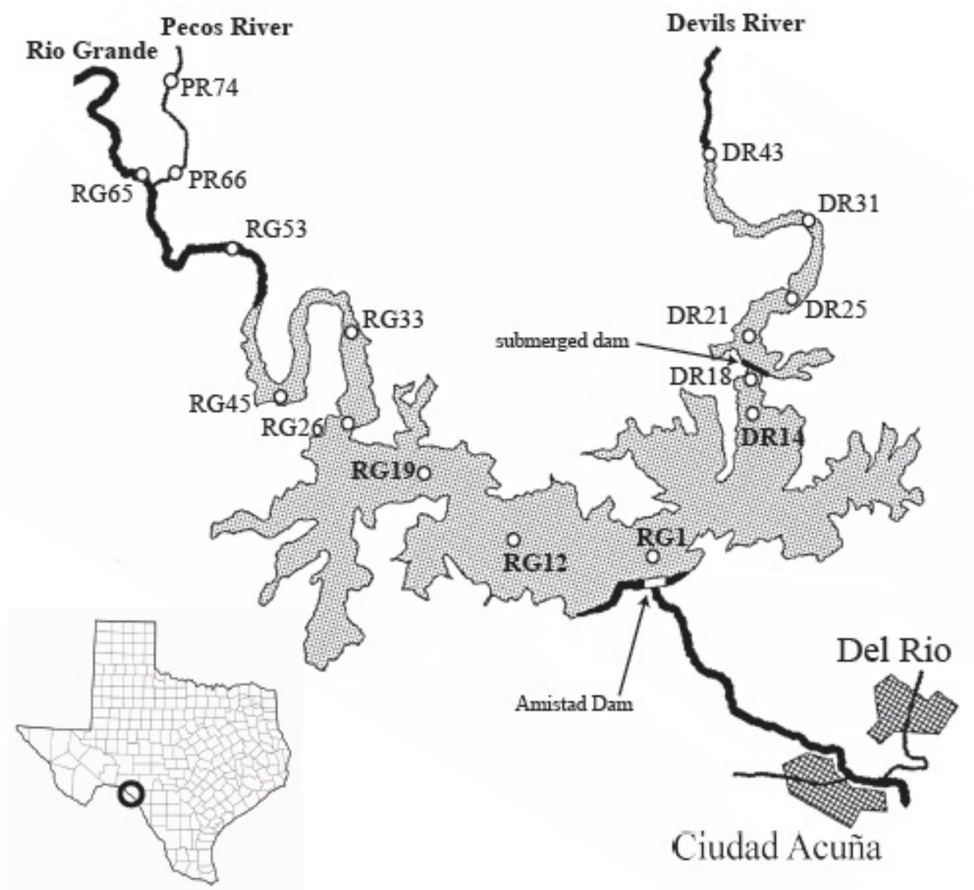

Figure 1. International Amistad Reservoir, located on the USA and Mexico border, just upstream from Del Rio, Texas. Sampling sites are marked with numbers corresponding to their distance upstream from the dam in river km. DR sites are up the Devils River arm, and RG sites are up the Rio Grande arm (and includes Pecos River [PR] sites). The RG1 site corresponds to Buoy 1, and is located at the confluence of the R. Grande and Devils R (is 1 km upstream from the dam). The sites are also described in Table 1.

volume was maximal in March, 2005. We started a sampling project on Amistad Reservoir in June 2004, and here we report preliminary results of the influence of this refilling of the reservoir on chemical and physical properties of the reservoir water.

We sampled sites along the two main arms (the Rio Grande and the Devils River) of Amistad Reservoir to determine longitudinal patterns of chemical, physical and biological characteristics of the water column (sites shown in Fig. 1 and described in Table 1).

At each station we carried out a vertical profile using a Hydrolab multiprobe Datasonde™, measuring temperature, pH, dissolved oxygen, specific conductance and turbidity at 1 m intervals (or 2 m within the mixed layer). We also collected a profile of both photosynthetically available radiation with a photometer and *in vivo* chlorophyll fluorescence with a field-deployable fluorometer, and measured Secchi disk water clarity. At each station we collected a surface whole water sample, and collected up to three additional samples at depth dependent on the water column structure as reflected by the multiprobe data. These water samples were placed on ice and processed usually with 8 h at local laboratory facilities near the Rough Canyon boat ramp. On the samples we measured alkalinity with a potentionmetric titration, turbidity, and processed and filtered samples for chlorophyll *a* and nutrient analysis, and froze samples when appropriate for later analysis in San Marcos (Wetzel and Likens, 2000). We sampled the reservoir four times during this study (15-17 June, 27-28 July, 24-25 August, and 27-28 September) during the 2004 growing season.

Inflowing Rivers- The three rivers flowing into the reservoir are quite different from each other in physical and chemical nature, as well as their total contribution to the volume of the reservoir (Table 2). Long-term records of flow, specific conductance, and turbidity were compiled for these three rivers from United States Geological Survey (USGS) Annual Water Years reports, with all the sites being located in near proximity to the reservoir. The flow data represent at least 37 y of daily flow records and the chemical and physical data represent a large number of samples over many years at all three sites. Median flows suggest that the Rio Grande will usually account for roughly 66% of the volume of the reservoir, with the Devils and Pecos rivers accounting for 19% and 13%, those these contributions may be easily changed over short term periods by high storm inflows.

The Pecos River is a relatively clear river with high concentrations of dissolved ions, as reflected by its high specific conductance. The ions include high concentrations of Na^+, Cl^-, SO_4^-, Ca^{+2}, and Mg^{+2} (USGS sources cited above), and reflect evaporite deposits in the Permian Reef Complex of the Guadalupe Mountain region of New Mexico and Texas (Holland, 1978), and saline irrigation return flow (Miyamoto et al., 1995). The Devils River, draining the southwestern portion of the Edwards Plateau, is clear and of much lower dissolved ion content, though the long-term USGS data and our data show that alkalinity (HCO_3^- and CO_3^{2-}) is higher than in the other two rivers, indicative of the influence of the upstream Edwards Plateau limestone. The Devils River is slightly more dilute than the rivers draining off the southern and eastern boundaries of the Edwards Plateau, but otherwise chemically similar (Groeger and Gustafson, 1994). The Rio Grande is a very turbid river with intermediate specific conductance. The Rio Grande upstream of Amistad Reservoir has been becoming more saline over the recent years (Miyamoto et al., 1995), which represents a major threat to the water quality of the lower Rio Grande system. The increasing trend in salinity would be exacerbated by the severe drought conditions by causing the Rio Grande and Pecos River to become more saline as flows decrease, and a further concentrating of ions would occur within the reservoir as evaporation becomes a larger fraction of the water budget. The high flows of the summer months in this current study indicate the Rio Grande and Pecos River being much more dilute than they have been historically (Table 2).

TABLE 2—Long-term characteristics of the rivers flowing into Amistad Reservoir. Long-term data was collected from the United States Geological Survey Water Data Reports (see text).

	Rio Grande	Pecos River	Devils River
Discharge (m^3 s^{-1})			
Long-term Mean	41.7	7.4	10.0
Long-term Median	23.5	4.6	6.7
Specific conductance (μS cm^{-1})			
Long-term Mean	1187	3293	385
Long-term Median	1155	3120	384
Turbidity (NTU)			
Long-term Mean	750	6.4	15.7
Long-term Median	90	1.5	1.4

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Mixing of the rivers within the reservoir—Another phenomenon obviously occurring is the intrusion of more saline water (> 750 μS cm^{-1}) up the Devils River arm. In June, we observed waters exceeding 900 μS cm^{-1} 14 km upstream of the dam. Because of the geological nature of the Devils River and the local springs, the specific conductance of this river would probably never much exceed 500 μS cm^{-1}, similar to other Edwards Plateau rivers (Groeger and Gustafson, 1994). The more saline, more dense (dependent on water temperature) water of the Rio Grande arm, therefore, commonly moves up the Devils River arm of the reservoir, with the most saline water tending to be deeper, but the surface waters are commonly influenced by this increased salinity at least 25 km upstream of the dam.

The Rio Grande and Pecos Rivers were relatively low in specific conductance (460 and 2070 $\mu S\ cm^{-1}$, respectively) in September due to high flows. In the upper Rio Grande arm of the reservoir (up to within roughly 20 river km of the dam) significant horizontal and vertical gradients of specific conductance were obvious (Fig. 1). In the water column closer to the dam, there was little variation in either dimension. In the water column closer to the dam there is a very significant influence of wind mixing which tends to mix the epilimnion quite strongly. Also, with significant water column cooling occurring during the late summer and early fall, the epilimnetic depth has increased by 7 to 10 m from July to September. This will further tend to homogenize the water column in this deep, unprotected area of the reservoir. One other factor that may be aiding the efficient mixing of the deep water column near the dam is that the water column may be much less stable than it would be during a more dry or typical year. Groeger and Tietjen (1998) found that the water column in Canyon Reservoir, a Texas reservoir at a similar latitude to Amistad, was much less stable in wetter years due to a loss of cold hypolimnetic water downstream as water is released from the dam. The gradients of specific conductance found up-reservoir in the Rio Grande arm are apparently maintained by the combination of much greater protection from the wind, and the plunging inflows of the colder, turbid storm flows that were common during the summer and fall of 2004.

Reservoir water chemistry—In a study classifying Texas reservoirs based on their water chemistry and ionic content, Amistad Reservoir was placed in the "western" group because of its relatively saline nature with a high specific conductance (Ground and Groeger, 1994). Past near-dam specific conductance values have been reported as 1040 $\mu S\ cm^{-1}$ (Miyamoto et al., 1995), and 1287 $\mu S\ cm^{-1}$ (Ground and Groeger, 1994), and were probably significantly higher in 2003 after the extended drought. On our four first sampling trips, specific conductance in the epilimnion at the dam was $< 900\ \mu S\ cm^{-1}$, and by September was $< 820\ \mu S\ cm^{-1}$. Thus, the high inflows of late 2003 and 2004 have caused a significant dilution of the water in Amistad Reservoir as it has refilled, and this should have very positive influence on downstream water quality for at least a few years.

Reservoir limnology. In Figure 2 and 3, we are looking at two different methods of studying water temperature at the near dam station. The reservoir predictably follows seasonal stratification and mixing pattern of a subtropical monomictic reservoir, and is very similar in temperature to Canyon Reservoir, located farther east on the Edwards Plateau (Groeger and Bass 2005). In each December the reservoir water column was mixing, with temperature and water chemistry uniform from top to bottom. While the temperatures remained largely isothermal in January and February of those years (winters of 2004-5, 2005-6, and 2006-7), the deep waters became much more saline, showing a significant underflow reaching the dam coming from the Pecos River salinity plume. This underflow displaces water upward and is the primary cause of more saline water flow way up the Devils River arm every winter. This is clearly seen in Fig. 4 when high salinities are seen every January after a homogeneous water column in December.