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Chapter 27

Spatial and Temporal Trends in Surface Water Quality in a Segment of the San Antonio River, Texas

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Abstract

Water quality as a function of land use was examined in the upper San Antonio River in the city of San Antonio, Texas. Five water sampling sites representative of different point and nonpoint pollution sources were spread over a distance of 3.2 km. Surface grab sampling was performed on a monthly basis between November 2004 and April 2005 excluding December. Water quality parameters that were evaluated include pH, dissolved oxygen, temperature, total dissolved solids (TDS), total nitrate–nitrogen, total orthophosphate, turbidity, alkalinity and hardness using standard analytical protocols. Results were statistically analyzed by MANOVA. Findings were compared to state (Texas Environmental Quality Commission) and/or federal (U.S. Environmental Protection Agency) limits to establish whether or not parameters were in compliance with those standards or guidelines. Of the routine water quality parameters examined, only turbidity and nitrate–nitrogen exceeded specific standards or guidelines in the segment of the San Antonio River that was sampled. Turbidity and nitrate–nitrogen also showed spatial and temporal trends, which were possibly, affected by land use and local precipitation patterns. Overall, this segment of the upper San Antonio River was considered to be relatively unpolluted and in most parts, unaffected by the land use.

27.1. Introduction

Uncontaminated water resources are declining in a global scale due to human overpopulation and a concomitant increase in the industry and agricultural activities. The pollution that enters the waterways can threaten the health of human drinking water and aquatic ecosystems.

Land use has a profound effect on water quality and surface water is particularly vulnerable to such pollution (Sekhar and Raj, 1995). Specifically, land use is known to affect the amount and quality of runoff during and following rainfall (Richards and Host, 1994). The U.S. Environmental Protection Agency (EPA) has identified some of the leading sources of pollution in rivers and streams of the United States as agriculture, urban runoff, storm sewers and municipal point sources (EPA, 2000).

The San Antonio River originates in central Texas and flows southeast for 346 km where it merges with the Guadalupe River before finally emptying into the Gulf of Mexico (Fig. 27.1a). Overall, the length of the San Antonio River is 362 km. The San Antonio River Basin consists of six major watersheds: Leon, Medio, Salado, Cibolo Creeks, and the Medina and San Antonio Rivers (Fig. 27.1a). Land use along the river is characterized by agriculture, ranching, industry, forestland and urban environments (San Antonio River Authority, 2003). Associated with the urban environment are numerous municipal discharge outflows as well as urban runoff.

The San Antonio River passes through five ecoregions that vary in terms of elevation, soil types and vegetation (SARA, 2003). For instance, in the area where sampling took place, elevation ranges from 200 to

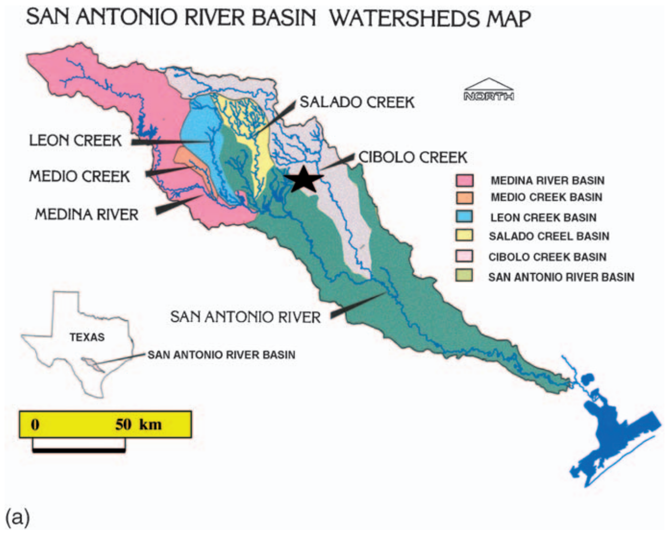

Figure 27.1a. Map shows the location of the San Antonio River Basin in Texas and that the San Antonio River flows to the Gulf of Mexico. (Map courtesy of the San Antonio River Authority). The star on the watershed map indicates the city of San Antonio.

670 m, the soil is generally shallow and underlain by limestone and the vegetation is predominantly oak and juniper woodlands. Meanwhile, the most downstream portion of the river is characterized by elevations of 2–45 m, soils are acidic sand to sandy loams with clay at the river bottom, and vegetation includes mesquite, acacia and tall grass prairies. There are four major aquifers beneath the San Antonio River: the Trinity, Carrizo, Edwards and Gulf Coast aquifers. In the study area, only the Trinity and Edwards aquifers are present (SARA, 2003). These aquifers are hydraulically interconnected and characterized by limestone and dolomite in the upper portions and sand in the lower portions (Boghici, 2004).

Although it is not a heavily polluted river (SARA, 2003), there are potential point sources of pollution (such as municipal effluent pipes) and nonpoint pollution sources (such as surface water runoff from golf courses, residential zones and urban roadways). Pollution from these sources may have negative effects on the freshwater ecosystem of the San Antonio River, which includes at least 73 species of fish (SARA, 2003).

Historically, nitrogen and phosphorous have been problem nutrients in almost all tributaries of the San Antonio River Basin (Ging, 1999; Bush et al., 2000; SARA, 2003). The San Antonio River Authority (SARA) speculated that wastewater discharge is a primary factor contributing to high amounts of these nutrients (SARA, 2003). The Lower San Antonio River can be expected to have high levels of nitrogen and phosphorous since it flows through the agricultural regions of Texas. Agricultural activities can have a major influence on nutrient input into rivers (Puckett, 1995). Meanwhile, the Upper San Antonio River passes adjacent to golf courses and residential zones, both of which may have fertilizer washed into the river during rain events. In high quantities, both of these nutrients can cause water systems to become eutrophic and can contribute to increase suspended sediments (Beránková and Ungerman, 1996; Drolc and Koncan, 1996). In a eutrophic system, excess nutrients promote algal blooms. When the algae die, bacteria decompose the organic matter via aerobic respiration, a process that depletes oxygen in the water system.

Periodic assessment of water quality in a river is essential to discover the appropriate water resource protection plan (Belic and Belic, 1996). The overall health of a waterway can be evaluated by routine chemical tests that include pH, dissolved oxygen (DO), temperature, conductivity (which can be used to calculate TDS), nitrate–nitrogen, phosphorous, turbidity, alkalinity and water hardness. The reported study constituted a six-month assessment program in a 3.2-km segment of the San Antonio River, which measured all these typical water quality parameters and compared the results to the standards established by the Texas Commission on Environmental Quality (TCEQ) and the EPA.

Selected sampling sites in this study were representative of various land uses that potentially contribute to water pollution along a small segment of the San Antonio River. High levels of pollutants originating from these points and nonpoint sources can degrade water quality and threaten the local habitat of fish and aquatic macroinvertebrates. The purpose of this study is to establish if the levels of pollutants in a short segment of the San Antonio River are compliant with state and federal standards and/or guidelines. Data will be useful in determining the water quality of the output from this segment and the effect of this output on the remaining portions of the river.

27.2. Sampling locations

Water samples were collected at a depth of less than 0.46 m one time a month from the upper San Antonio River at five different locations (Fig. 27.1b) five times during a six-month period (November 2004 to April 2005). Sites 1 (extreme upstream) and 5 (extreme downstream) were approximately 3.2 km apart. Site 1 was located within 5 m of the origin of the San Antonio River at a well, called the Blue Hole in the University of Incarnate Word campus. Situated 0.4 km downstream from Site 1, Site 2 was 15 m downstream from a pipe discharging water from the San Antonio Zoo. Located 0.4 km downstream from Site 2, Site 3 was next to a wastewater discharge pipe owned by the local municipal wastewater company (San Antonio Water System, SAWS). Approximately 0.8 km downstream from Site 3, Site 4 was located between a golf course on the one side of the river and a residential zone on the other side. Site 5 was 1.6 km downstream from Site 4 and occurred within an industrial zone of San Antonio immediately downstream from a discharge facility. In the confines of this study, Site 1 was most upstream while Site 5 was the most downstream. The location of this study was approximately 29.45° latitude north and 98.48° longitude west.

27.3. Methods and materials

The water parameters that were measured at each site included pH, dissolved oxygen (DO), temperature, conductivity (which was used to calculate TDS), nitrate–nitrogen, total orthophosphate, turbidity, total alkalinity and water hardness. Methods for collecting, storing and analyzing the samples followed standard EPA protocols (EPA, 1997). Surface grab samples from a depth of less than 0.46 m were collected at the midpoint of the portion of the stream width containing 50% of the total flow

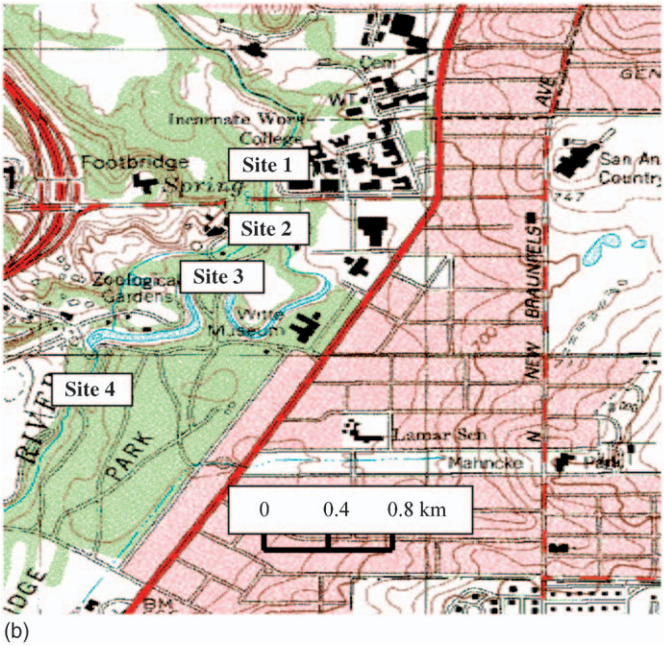

Figure 27.1b. Sampling sites in the San Antonio River. Site 1 is where the San Antonio River originates. Site 2 is in the vicinity of a discharge pipe from the Zoological Gardens. Site 3 is immediately downstream from a municipal discharge pipe. Site 4 is situated between a golf course on one side of the river and a residential zone on the other. Site 5 is not shown but is approximately 1.6 km downstream from Site 4 and is situated in a light industrial zone of the city of San Antonio. (This figures was taken from http://www.topozone.com.)

(EPA, 1997). Three replicate samples were collected in 125-ml Nalgene HDPE bottles. All samples was stored on ice in the field and immediately transferred to a refrigerator at 4°C upon return to the laboratory.

All instruments for measuring water parameters were calibrated. Dissolved oxygen and temperature were measured with a field meter (850081, SPER Scientific Ltd). The pH, electrical conductivity (EC) and nitrate–nitrogen were measured with an Oakton 510 series meter. Immediately upon return to the lab, pH was measured after a three-point calibration. Using EC, TDS was calculated with the equation

$$\mathrm{EC} * 0.564 = \mathrm{TDS}\ \ (\mathrm{mg\,l^{-1}})$$

expressed at 25°C, wherein 0.564 is a conversion factor for the chemical composition of dissolved solids (Boehnke and Delumyea, 2000). Nitrate–nitrogen levels were measured with an ion specific probe and calibration was performed with certified standard solutions ($1\,\mathrm{mg\,l^{-1}}$, $10\,\mathrm{mg\,l^{-1}}$ and $100\,\mathrm{mg\,l^{-1}}$).

Turbidity was measured using a turbidity meter (Cole Parmer Model #8391-40) following a two-point calibration with the certified standards 0.5 NTU and 10 NTU. Total orthophosphate levels were analyzed with the Molybdenum Blue Ascorbic Acid Method (Sparks, 1996) using a Cary 50 Bio UV-Visible Spectrophotometer with a wavelength set at 880 nm. A reagent solution was made by mixing 2.5 M sulfuric acid, 0.03 M ammonium molybdate, 0.004 M antimony potassium tartrate and 0.1 M ascorbic acid. Samples and standards were prepared using this reagent.

Water hardness was measured using the 0.01 M EDTA titration method in which samples were first treated with five drops of a certified standard pH 10 buffer solution and 50 mg Eriochrome black T. Total alkalinity was analyzed with a semi-automatic titrator (Titronic 96) using 0.02 N sulfuric acid. Phenolphthalein was not added to any sample since the pH never went over 8.3. Four drops of methyl orange were first added followed by a titrated amount of 0.02 N sulfuric acid until an approximate pH of 4.3 was achieved as noted by change in color from orange to pink (Sparks, 1996).

Measured water parameters were compared to federal (EPA) and state (TCEQ) maximum or minimum standards or informal guidelines in order to determine compliance. Specifically, criteria for federal standards originated from EPA (1986) while state criteria originated from Chapter 307 of the Texas Surface Water Quality Standards that are specifically designed for the upper San Antonio River (Texas Surface Water Quality Standards, 2000; SARA, 2003). For turbidity and total alkalinity, EPA (1986) served as the guideline since TCEQ does not specify a limit for these parameters.

27.4. Statistical analysis

MANOVA was used to determine the presence of significant spatial and temporal differences in the water quality data. The two factors of the model were site location (Sites 1–5) and the date of collection (November 2004 and January–April 2005). The interaction of these factors was included. Tukey's multiple comparison test was conducted to locate significant differences between the sites and dates of collection. Various regression analyses were also performed.

27.5. Results

The statistical interaction of the site and date of sampling was significant for pH ($p < 0.001$). Generally, pH tended to increase slightly downstream

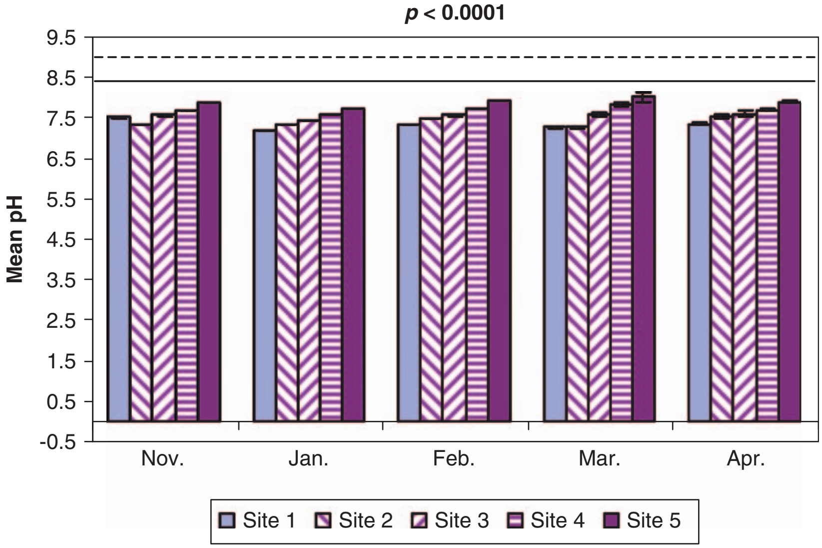

Figure 27.2. Comparisons of the mean (±SD) pH of each site from November 2004 through April 2005, exclusive of December, to the maximum federal and Texas state standards. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

from Site 1 to Site 5 (Fig. 27.2). However, the effect of this increase on organisms and water quality is not detrimental since the pH range at all sites for all collection dates ranged between 7.2 and 7.9. In fact, pH of upper San Antonio River complied with both state and federal maximum standards (Fig. 27.2) and is not judged to be problematic.

The statistical interaction of the site and date of sampling was significant for DO ($p < 0.001$). Generally, the DO data exhibited a tendency to increase slightly in a downstream manner (Fig. 27.3). The lowest DO levels were observed during the month of November 2004; however, this level ($5.4\,\mathrm{mg\,l^{-1}}$, Site 3) was in compliance with both state and federal minimum standards (Fig. 27.4). The highest DO measurement ($11.5\,\mathrm{mg\,l^{-1}}$, Site 2) was present during January 2005 when the water sampled had generally lower temperatures (Fig. 27.4). Since DO values ranged from 5.4 to $11.5\,\mathrm{mg\,l^{-1}}$, there were adequate amounts of oxygen for sustaining life.

The statistical interaction of site and date of sampling was significant for temperature ($p < 0.001$). An examination of the temperature at each site during each month of collection revealed that not only is the temperature range small (22.6–25.7°C); it also complies with both state and

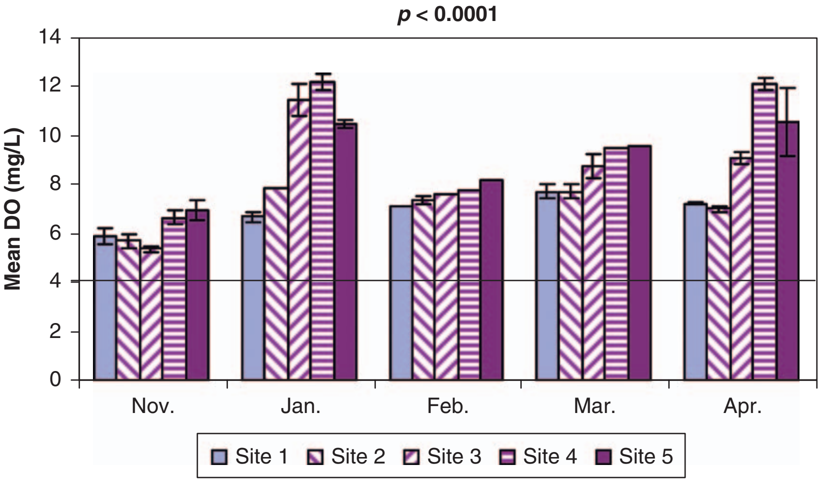

Figure 27.3. Comparisons of the mean (±SD) dissolved oxygen (DO) concentrations (mg l^{-1}) at each site from November 2004 through April 2005, exclusive of December, to the federal and Texas state minimum standards. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

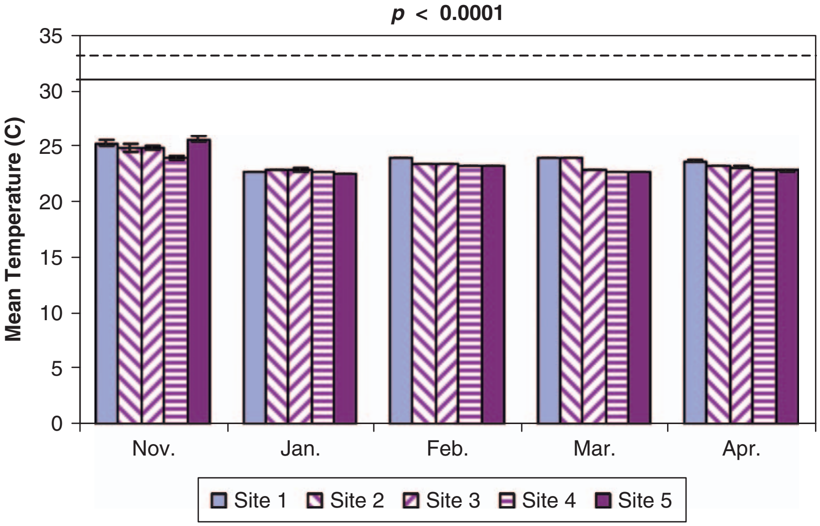

Figure 27.4. Comparisons of the mean (±SD) temperature at each site from November 2004 through April 2005, exclusive of December, to the federal (solid line) and Texas state (dashed line) maximum standards. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

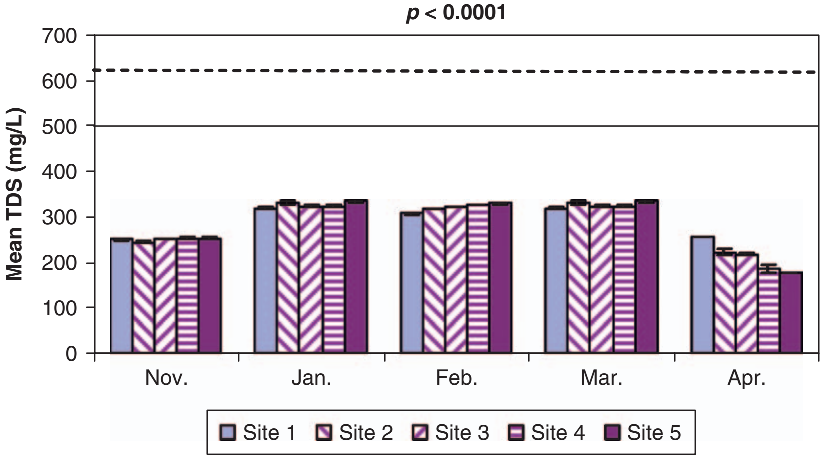

Figure 27.5. Comparisons of the mean (±SD) concentration of total dissolved solids (TDS) at each site from November 2004 through April 2005, exclusive of December, to the federal and the Texas state maximum standards. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

federal maximum standards (Fig. 27.4). Hence, water temperature was not considered a detriment to organisms or water quality for this portion of the San Antonio River.

Total dissolved solids complied with both federal and state maximum limits (Fig. 27.5). Highest TDS values occurred from January to March 2005 while the lowest level of TDS was present at Site 5 during April 2005. In addition, during April, TDS concentrations decreased slightly in a downstream manner. Generally, TDS levels were almost two times lower than the federal limit and 1.5 times lower than the state limit. Based on these low-TDS values, this parameter was deemed not one of concern for this segment of the San Antonio River.

The state and federal maximum standards for nitrate–nitrogen were exceeded for all dates and sites of sampling, excluding Site 1 during the month of March (Fig. 27.6). During November 2004, nitrate levels at all sites were higher than those during any other month of sampling. Also during the November sampling, there appeared to be a trend in which nitrates were decreasing in a downstream manner from 33 mg nitrate per liter at Site 1 to 19 mg nitrate per liter at Site 5. This decrease suggests dilution of nitrates in this segment of the river. Regression analysis revealed a weak inverse relationship between nitrate and DO ($R^2 = 0.55$, $p < 0.0001$).

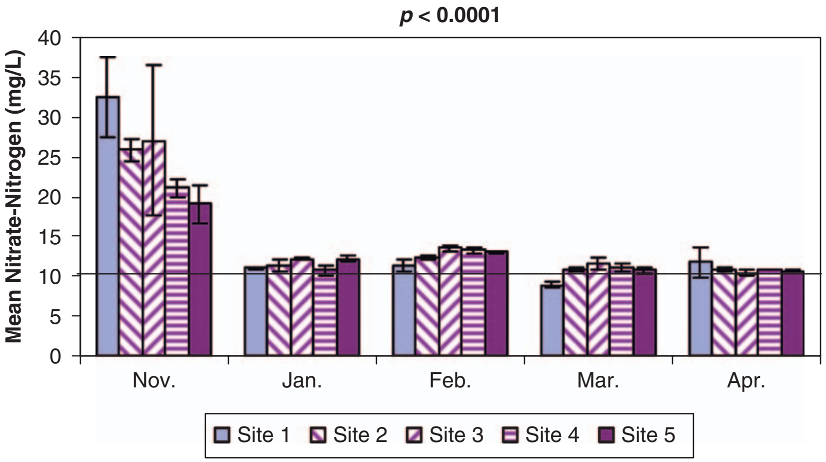

Figure 27.6. Comparisons of the mean (±SD) nitrate–nitrogen concentration (mg l^{-1}) at each site from November 2004 through April 2005, exclusive of December, to the federal and the Texas state maximum standards. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

Total orthophosphate levels in this portion of the San Antonio River ranged from 0.0004 to 0.08 mg l^{-1}. The statistical interaction of site and date of sampling was not significant for orthophosphate, nor was site of sampling, when considered individually. The only significant factor was the date of sampling ($p < 0.0001$). Total orthophosphate concentration was high during November, but still was beneath the federal maximum standard (Fig. 27.7). Despite past studies, which have indicated that phosphorous can be a nuisance nutrient in the San Antonio River (SARA, 2003), it was not judged to be problematic for this segment of the San Antonio River during the study period. Generally, the observed dissolved oxygen concentrations further support the lack of negative effects resulting from phosphorous – a known eutrophic agent.

Turbidity exceeded EPA guidelines at all dates and sites of sampling (Fig. 27.8). Spatially, turbidity tended to increase downstream. Consequently, Site 5 had the highest levels of turbidity at all sampling times. Temporally, turbidity decreased from November 2004 to April 2005. Regression analysis revealed a weak inverse correlation between DO and turbidity ($R^2 = 0.38$, $p < 0.0001$).

There appears to be a sufficient buffering capacity of the water sampled at Sites 1 to 5 in the San Antonio River at all sampling dates. Alkalinity values were well above the federal minimum guideline (Fig. 27.9).

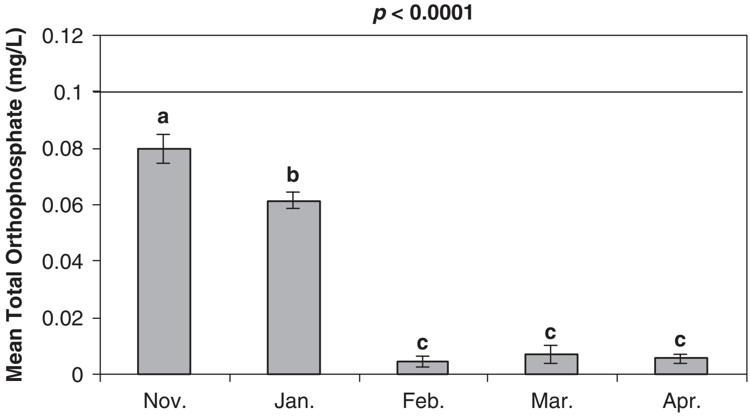

Figure 27.7. Comparisons of the mean (±SD) total orthophosphate concentrations (mg l^{-1}) from November 2004 through April 2005, exclusive of December, to the federal maximum standard. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling. Different letters indicate significant differences in means (Tukey's multiple comparison test, $p = 0.05$).

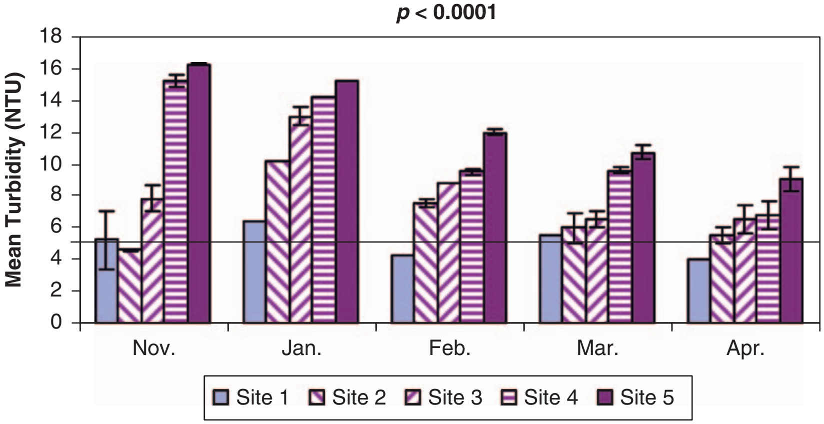

Figure 27.8. Comparisons of the mean (±SD) turbidity level (NTU) at each site from November 2004 through April 2005, exclusive of December, to the federal informal guideline. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

Alkalinity values above 20 mg $CaCO_3$ per liter are considered healthy and even 400 mg $CaCO_3$ per liter is not considered dangerous to humans (EPA, 1986). Calculations also suggest that bicarbonate was the predominant ion contributing to total alkalinity (data not shown).

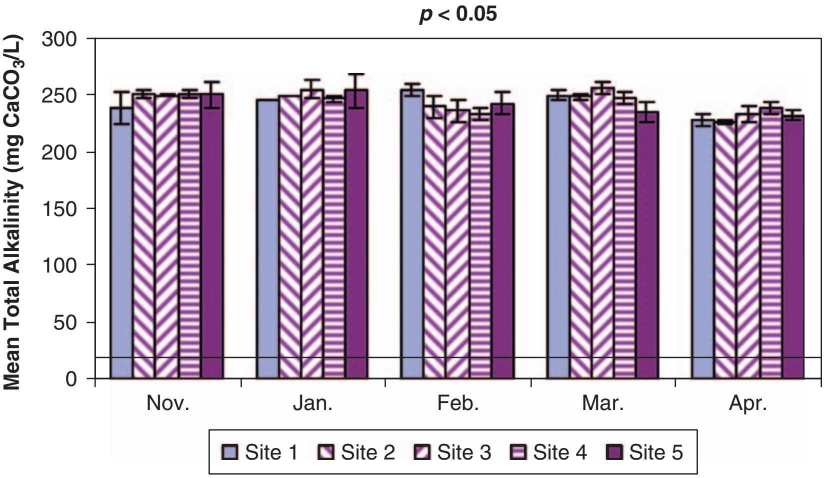

Figure 27.9. Comparisons of the mean (±SD) total alkalinity at each site from November 2004 through April 2005, exclusive of December, to the informal federal minimal guideline. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

Considering that part of the San Antonio River Basin overlies a limestone aquifer (Edwards Aquifer), water hardness values for the sites sampled were lower than expected, ranging from 36 to 52 mg $CaCO_3$ per liter (Fig. 27.10). Water in upper San Antonio River is considered "soft" since the $CaCO_3$ concentration is $<75\,\mathrm{mg\,l^{-1}}$ (EPA, 1986).

27.6. Discussion

The majority of the water parameters that were measured complied with state and federal standards and is of no concern for deterioration of water quality. Specifically, these parameters were pH, DO, temperature, TDS, orthophosphate, alkalinity, and hardness. The parameters of potential concern were turbidity and nitrate–nitrogen, both of which exceeded specific state and/or federal limits. Since water quality can change drastically within a short-period time, all of these results should be viewed as short-term findings. For instance, high rainfall can dilute nutrient levels, increase nutrient levels by causing runoff and/or increase turbidity. To ensure consistent compliance and healthy water quality, routine water quality monitoring should be ongoing over a prolonged period. As part of Texas Clean Rivers Program, the San Antonio River Authority oversees the monitoring of water quality in the San Antonio River by measuring parameters bimonthly (SARA, 2003).

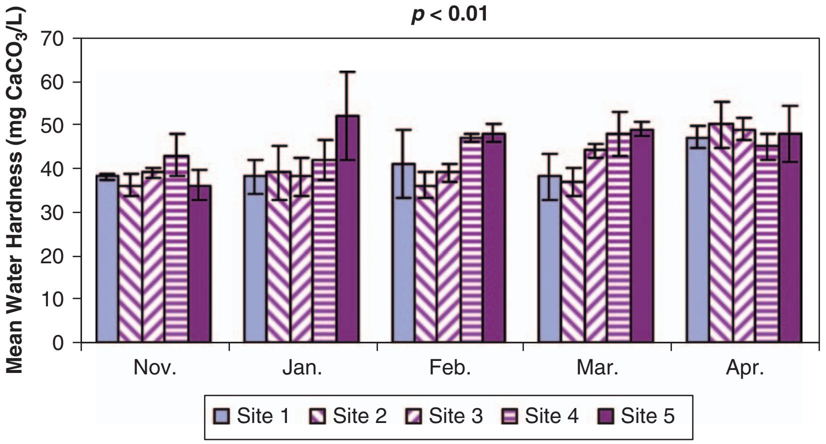

Figure 27.10. Comparisons of the mean (±SD) water hardness levels (mg $CaCO_3$ per liter) at each site from November 2004 through April 2005, exclusive of December. No federal or state standards are established. Refer to Fig. 27.1b for Site descriptions. The *p*-value indicates the interaction across sites and dates of sampling.

The overall healthy condition of this segment of the San Antonio River suggests that upstream portions of the river were not overtly polluted during the duration of the study or that if they were polluted; the pollutants were diluted before reaching this segment of the river. Land use along the upper parts of the river includes ranching, occasional landfills and municipal discharge facilities associated with the San Antonio River Basin (SARA, 2003). Likewise, for most months of sampling results suggest that water quality downstream from the study area would not dramatically degrade by inflow from this segment. An exception to this finding was noticeable during November 2004 when nitrate levels were 1.9–3.3 times greater than the state and federal standards for nitrate–nitrogen (Fig. 27.6). These findings for nitrate are ecologically significant in light of the lower San Antonio River already possessing relatively high-nitrate levels due to being predominantly agricultural land use (SARA, 2003).

Distinct spatial and temporal patterns exist for nitrate–nitrogen in the sampled segment of the river. During November 2004, when rainfall was highest (Fig. 27.11), nitrates decreased in a downstream manner. This pattern suggests a diluting of this nutrient in the study segment. There is also a possible seasonal variation for nitrate. However, our sampling only reflects five months of data and determining such a trend accurately would require additional months of data over the course of at least one year. Nitrate levels were higher during November as compared to the January through April sampling times. Brooker and Johnson (1984)

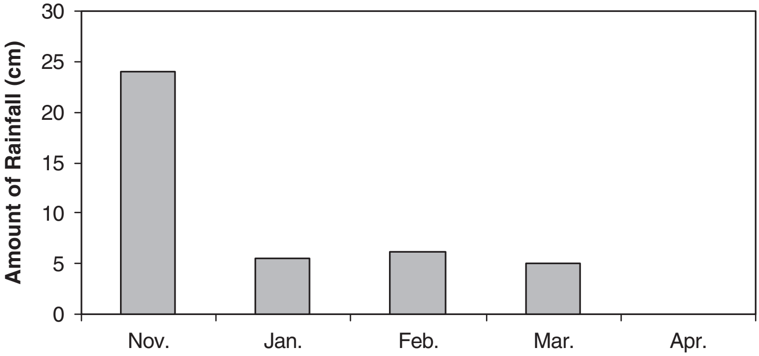

Figure 27.11. Recorded monthly rainfall (cm) for the San Antonio area during the sampling period. (Data are from the National Weather Service, 2005)

noted changes in the concentrations of nutrients in rivers as a function of sampling time and related the variabilities to seasons and climate.

Rainfall recorded in the San Antonio area during the duration of the study was highest in November compared to January through April (Fig. 27.11). Runoff-containing nitrates may have contributed to the concentrations measured. Upstream sources that may have contained nitrate include a golf course and an outdoor public sport fields in the Olmos Park area. During this period of high rain, fertilizer for maintaining these grounds may have been carried into Olmos Creek, which drains into the San Antonio River upstream from Sites 2 to 5. Studies in the United States have found that nitrate levels in creeks increased while passing through golf courses (Mallin and Wheeler, 2000) and that nutrient concentrations of golf course waterways were higher than those in reference locations (Lewis et al., 2002). In the suburban area upstream from the collection sites, residential and public lawns that are maintained with fertilizer could have contributed to elevated nitrate levels. Urban sprawl can increase dissolved solutes such as nitrates in a river and this increase is proportional to the quantity of the developed land area in suburban portions of the watershed (Interlandi and Crockett, 2003).

The San Antonio River Basin is known to have nitrate–nitrogen problems and wastewater has been implicated as a main source (SARA, 2003). In this study, Sites 2 and 3 were close pipes releasing water with high amounts of nitrates. Site 2 was located in the vicinity of an effluent pipe from the San Antonio Zoological Society. Animal feedlots are analogous to nonpoint pollution sources, which have animal wastes; some animal feedlots are known to have contributed high-nitrate levels to nearby waterways (Fryar et al., 2000; Harter et al., 2002). In addition, widespread-ranching activities that occur in the San Antonio River Basin upstream from the sampling sites could contribute to the presence of animal wastes in the river (SARA, 2003). Site 3 was located close to a pipe releasing recycled water by the municipal wastewater treatment organization. A recent study on water quality in the Central Texas region indicated that discharge from the same municipal wastewater treatment plant had the greatest effect on nutrient concentrations compared to any other identifiable source (Ging, 1999). The effluent pipe at Site 3 was removed sometime following the November sampling. This pipe was not present during the January-to-April sampling dates, when nitrate levels were lower at Site 3 as well as the sites downstream from it.

There has been a noticeable trend of increasing nitrate fluxes into waterways of the United States (Bollinger et al., 2000). This trend is a concern because high-nitrate levels can contribute to eutrophication, which is a serious problem in many rivers, and has severe detrimental effects on riverine ecosystems (Dijk et al., 1994). Although this trend appears to exist in the portion of the San Antonio River that was examined, the degree of noncompliance varies for each site and time of sampling. Our nitrate–nitrogen findings are consistent with the San Antonio River Basin Report (SARA, 2003) which also identifies nitrate–nitrogen as a problem associated with both point and nonpoint sources. Nevertheless, the dissolved oxygen concentrations that were measured comply with state and federal limits and are values that support life. Prior to the construction of an upgraded municipal wastewater treatment station (1980s) for the city of San Antonio, nitrate–nitrogen levels in the San Antonio River were higher than current levels (SARA, 2003).

Temporal and spatial trends exist for turbidity in the upper San Antonio River Basin. Generally, turbidity decreased from November 2004 to April 2005. The high amount of precipitation during November (Fig. 27.11) probably caused the high values that were measured during this month. Meanwhile, the lowest amount of rainfall occurred during April, when turbidity values were also the lowest. Spatially, turbidity increased downstream; this trend may be related to water flow at the time of sampling (EPA, 1997). Higher flow rate may cause sediments to be suspended over a longer distance.

The urban location of all sampling sites may have been a factor contributing to high turbidity. Benaabidate (2004) indicated that sites located close to urbanized and industrialized areas tend to contain high turbidity. Surface water bodies, such as rivers passing through cities, are considered to be vulnerable to transient pollution events arising from accidents and contaminated runoff events (Beck, 2005).

Turbidity interferes with recreational swimming because submerged hazards cannot be seen (EPA, 1986). Turbid water affects fish by reducing their growth rate and resistance to disease, preventing the development of fish eggs and larvae, altering migration and reducing food availability (EPA, 1986; Anderson, 2003; Richardson, 2003). If the suspended matter is organic, photosynthesis and the concentration of dissolved oxygen will be reduced and algal growth may ensue (EPA, 1986). Siltation from urban runoff is another nonpoint pollution source that is capable of altering aquatic habitat, suffocating fish eggs and benthic organisms and interfering with both drinking water treatment and recreational use of a river (EPA, 1997).

Speculation on the sources of turbidity is ambiguous in this segment of the San Antonio River. Siltation, urban runoff, wastewater discharge, eroding stream banks, fertilizer from golf course or residential zones, and animal wastes from the San Antonio Zoo discharge are potential sources. The temporal pattern for turbidity (Fig. 27.8) closely followed the rainfall pattern during the study period (Fig. 27.11). High rainfall close to the date of sampling in November possibly contributed to the relatively high-turbidity values in the downstream sites.

27.7. Conclusions

In the segment of the San Antonio River that was sampled, the majority of the routine water quality parameters were at levels lower than that would be considered detrimental to the health of the waterway. Such parameters include pH, DO, temperature, TDS, orthophosphate, alkalinity and hardness. Only turbidity and nitrate–nitrogen values exceeded specific limits established by state and/or federal agencies. In addition, both these water quality parameters revealed spatial and temporal trends. High turbidity can have negative effects on fish, macroinvertebrates, and plants and poses a recreational hazard to swimmers, whereas nitrate–nitrogen can cause eutrophication, which degrades the quality of water in an ecosystem. Results from this study indicate that the upper San Antonio River Basin can be considered relatively unpolluted and in most parts, unaffected by the land use. Future studies regarding the effects of seasonal variation on water quality of the San Antonio River are necessary.

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REFERENCES

Anderson, B.S., 2003. Ecotoxicologic impacts of agricultural drain water in the Salinas River, California, USA. Environ. Toxicol. Chem. 22, 2375–2384.

Beck, M.B., 2005. Vulnerability of water quality in intensively developing urban watersheds. Environ. Modell. Softw. 20, 381–400.

Belic, S.S., Belic, A.V., 1996. Water quality changes in a small plain agricultural catchment area. Water Sci. Technol. 33, 205–210.

Benaabidate, L., 2004. Assessment of water quality and toxicity of polluted Rivers Fez and Sebou in the region of Fez (Morocco). Environ. Pollut. 131, 163–172.

Beránková, D., Ungerman, J., 1996. Nonpoint sources of pollution in the Morava River basin. Water Sci. Technol. 33, 127–135.

Boehnke, D.N., Delumyea, R.D., 2000. Laboratory Experiments in Environmental Chemistry. Prentice Hall, New Jersey, pp. 81–89.

Boghici, R., 2004. Hydrogeology of Edwards–Trinity Aquifer of Texas and Coahuila in the border region. Texas Water Development Board. Texas Documents: W600.7 R299 NO.360, pp. 91–114. Accessed October 9, 2005, at http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R360AEPC/Ch04.pdf

Bollinger, J.E., Steinburg, L., Englande, A.J., Crews, J.P., Hughes, J.M., Velasco, C., Watanabe, K.H., Swalm, C.M., Mendler, J.M., White, L.E., George, W.J., 2000. Nutrient load characterization from integrated source data for the lower Mississippi River. J. Am. Water Resour. Assoc. 36, 1375–1390.

Brooker, M.P., Johnson, P.C., 1984. The behavior of phosphate, nitrate chloride and hardness in twelve welsh rivers. Water Res. 18, 1155–1164.

Bush, P.W., Ardis, A.F., Lynne, F., Ging, P.B., Hornig, C.E., Jennifer, L.R., 2000. Water quality in south-central Texas, 1996–98. U.S. Geological Survey Circular 1212, p. 32.

Dijk, G.M., Liere, L., Admiraal, W., Bannink, B.A., Cappon, J.J., 1994. Present state of the water quality of European rivers and implications for management. Sci. Total Environ. 145, 187–195.

Drolc, Á., Koncan, Ź., 1996. Water quality modeling of the river Sava, Slovenia. Water Resour 30, 2587–2592.

Environmental Protection Agency, 1986. Criteria for Water. EPA 440/5-86-001, retrieved on March 3, 2005, at http://www.epa.gov/waterscience/criteria/wqcriteria.html

Environmental Protection Agency, 1997. Volunteer Stream Monitoring: A Methods Manual. EPA 841-B-97-003, retrieved on November 20, 2004, at http://www.epa.gov/volunteer/stream/stream.pdf

Environmental Protection Agency, 2000. Water Quality and River Flow Interim Environmental Objectives: Water Objectives. NSW Environment Protection Authority, Sydney, retrieved on March 23, 2005, at http://www.epa.nsw.gov.au/ieo

Fryar, A.E., Stephen, A.M., Mullican, W.F. III, Katherine, D.R., Bennett, P.C., 2000. Nitrate reduction during ground-water recharge, Southern High Plains, Texas. J. Contam. Hydrol. 40, 335–363.

Ging, P.B., 1999. Water quality assessment of south central Texas—Descriptions and comparisons of nutrients, pesticides, and volatile organic compounds at three intensive fixed sites, 1996–98. U.S. Geological Survey Water Resources Investigations Report 99-4155, p. 24.

Harter, T., Davis, H., Mathews, M.C., Meyer, R.D., 2002. Shallow groundwater quality on dairy farms with irrigated forage crops. J. Contam. Hydrol. 55, 287–315.

Interlandi, S.J., Crockett, C.S., 2003. Recent water quality trends in the Schuylkill river, Pennsylvania, USA: A preliminary assessment of the relative influences of climate, river discharge and suburb development. Water Res. 37, 1737–1748.

Lewis, M.A., Boustany, R.G., Dantin, D.D., Quarles, R.L., Moore, J.C., Stanley, R.S., 2002. Effect of a coastal golf complex on water quality, periphyton and seagrass. Ecotox. Environ. Safe. 53, 154–162.

Mallin, M., Wheeler, T., 2000. Nutrient and fecal coliform discharge from coastal North Carolina golf courses. J. Environ. Qual. 29, 979–986.

National Weather Service, 2005. National Weather Service Forecast Office: Climate Information, retrieved on June 05, 2005, at http://www.srh.noaa.gov/ewx/html/climate.htm

Puckett, L.J., 1995. Identifying the major sources of nutrient water pollution. Environ. Sci. Technol. 29, 408–414.

Richards, C., Host, G., 1994. Examining land-use influences on stream habitats and macroinvertebrates: A GIS approach. Water Resour. 30, 729–738.

Richardson, K., 2003. Anthropogenically- induced changes in the environment: Effect on fisheries. In: Sinclair, M., Valdimarsson, G. (Eds.), Responsible Fisheries in the Marine Ecosystem. CAB International, Wallingford, England, pp. 275–289.

Sekhar, M.C., Raj, P.A., 1995. Landuse-water quality modeling: A case study. Water Sci. Technol. 31, 383–386.

Sparks, D.L., 1996. Methods of soil analysis: Chemical methods. Soil Sci. Soc. Am. Book Series (Part 3). Soil Sci. Soc. Am., Inc, Medison, WI.

San Antonio River Authority, 2003. Basin Summary Report for the San Antonio River Basin. Texas Commission on Environmental Quality. Retrieved from the worldwide web on June 5, 2005, at http://www.sara-tx.org/site/water_quality/water_qual_mon/clean_rivers/assessment_report.html

Texas Surface Water Quality Standards, 2000. Texas Natural Resource Conservation Commission, Chapter 307, retrieved on January 23, 2005, at http://www.tnrcc.state.tx.us/oprd/rules/pdflib/307%60.pdf