Santa Fe River Studies

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Stream Flow Losses

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This is one of a series of scientifically-based studies designed to provide the technical background information for decision makers and the community in evaluating management options for the Santa Fe River. The series covers the following topics: stream flow, storm flow, reservoir storage, ecosystem watershed yield analysis, stream flow losses, stream-aquifer interaction, and fate of reservoir releases. For more information on the series, please contact Claudia Borchert at 505-955-4203 or ciborchert@santafenm.gov

Santa Fe River Studies: Stream Flow Losses

The Santa Fe River flows west from the Sangre de Cristo Mountains and becomes ephemeral downstream of Nichols Reservoir, in large part because the river is stored and used for water supply. Periodic reservoir spills and storm flows provide intermittent flow in the river through the City of Santa Fe. Public concern for the riparian habitat along the Santa Fe River has generated interest in developing a living river through town. The adopted City's Long Range Water Supply Plan calls for 1,000 acre-feet (ac-ft) to be contributed to the river through town in normal and wet years. Review of stream flow data and seepage studies have helped to answer questions such as how far will this water travel downstream and what frequency should the water be released? This report analyzes previous work to provide a range of estimates on seepage losses.

Seepage studies and stream gage data were examined to assess the stream flow losses by reach on the Santa Fe River. Stream flow can increase or decrease for different reaches of the river if water is entering or leaving the stream. This dynamic changes from season to season or from day to day, depending on diversions from acequias, precipitation events, evapotransporation, and fluctuating groundwater levels. A seepage study on a stream determines the river sections where stream flow is greater downstream (gaining reach) and where stream flow is less downstream (losing reach). Seepage studies measure stream flow at different locations as instantaneously as possible, preferably not during a storm.

Seepage studies and stream gage data were examined to assess the stream flow losses by reach on the Santa Fe River. The stream reaches examined are losing reaches except during storm events. A total of eight seepage studies have been conducted on the Santa Fe River through town beginning in 1973 and are summarized in this report. Veenhuis (2008) describes these and additional seepage studies conducted downstream of the waste water treatment plant (WWTP). This study also examines stream gage records located on the Santa Fe River from Nichols Reservoir to Ricardo Road to assess losses along the Santa Fe River through town.

Seepage Studies

Each seepage study measured different sections of the Santa Fe River from below the reservoirs downstream to the Rio Grande. The results of the seepage studies, summarized in Table 1, are separated by three reaches for this discussion: 1) the 4.4-mile-long *up-town* reach from the *below Nichols Reservoir* gage (*below Nichols*) to the *above St. Francis Bridge* gage (*above St. Francis*), 2) the 1.6-mile-long *mid-town* reach from the *above St. Francis* gage to *Ricardo Road* gage (*Ricardo*) up-stream of Frenchy's Park, and 3) the 7.3-mile-long *west-side* reach from the *Ricardo* gage to the WWTP, above the outfall of treated effluent (Figure 1). Most of the mid-town reach seepage studies have extended to below the *Ricardo* gage approximately 0.7 to 0.9 miles downstream, near Camino Carlos Rael. The seepage studies measure all losses or gains. The studies do not differentiate the amount of water lost to recharge, evapotranspiration or acequia diversions; therefore, the term "seepage loss" is referring to all losses from the stream flow. The term "seepage rate" is the total loss for the reach divided by the length of the reach and is expressed as cubic-feet per second per mile (cfs/mile). The details of each measurement location are provided in Veenhuis (2008).

Table 1. Summary of seepage investigations on the Santa Fe River from Nichols Reservoir to the Waste Water Treatment Plan.

Source	Date of Study	River Mile Up-stream	River Mile Down-stream	Flow at Upstream point	Seepage rate	Comments
		mi	mi	cfs	cfs/mi	
Up-town Reach: Cerro Gordo to St. Francis Bridge						
USGS, 1981	6/24/1980	31.1	29.7	3.18	0.29	Made at end of spring runoff which began on May 7, diversions from acequias not measured
USGS, 1980	6/28/1979	33.4	29.7	24.8	1.22	Made at end of spring runoff which began on April, diversions from acequias not measured
USGS, 1980	7/5/1979	33.4	29.7	13	0.70	
Mid-town reach: St. Francis Bridge to Camino Carlos Rael						
DBS&A and WW, 2002	5/26/2001	29.9	27.6	3.5	0.42	No flow for a month before test
Lewis, 2001	9/23/1999	29.7	27.6	3	0.29	Average of later part of 7-day test. Water released for seepage study, intermittent small flows for months prior to test.
USGS 1981	6/24/1980	29.7	27.4	2.12	0.43	Made at end of spring runoff which began on May 7, diversions from acequias not measured
USGS, 1980	6/28/1979	29.7	27.4	20.3	0.74	Made at end of spring runoff which began on April, diversions from acequias not measured
USGS, 1980	7/5/1979	29.7	27.4	10.4	0.09	
USGS, 1975	6/18/1973	30.6	27.4	36.3	0.78	Made at end of spring runoff which began in late April, diversions from acequias not measured
USGS, 1975	7/3/1973	30.6	27.4	13	0.91	
	St. Francis Bridge to *Ricardo* Gage					
Veenhuis, 2008	4/10/2007	29.9	28.3	5.61	0.54	Continuous flows for months prior to test
Veenhuis, 2008	4/10/2007	29.9	28.3	5.45	0.48	
West-side Reach: *Ricardo* Gage to Santa Fe Relief Route						
Veenhuis, 2008	4/10/2007	28.3	21	4.74	0.13	Continuous flows for months prior to test
Veenhuis, 2008	4/10/2007	28.3	21	4.68	0.28	
USGS, 1981	6/24/1980	27.4	24.2	1.14	0.18	Made at end of spring runoff which began on May 7, diversions from acequias not measured
USGS, 1980	6/28/1979	27.4	24.2	18.6	0.78	Made at end of spring runoff which began on April, diversions from acequias not measured
USGS, 1980	7/5/1979	27.4	24.2	10.2	1.06	
USGS, 1975	6/18/1973	27.4	25.2	34.5	0.86	Made at end of spring runoff which began in late April, diversions from acequias not measured
USGS, 1975	7/3/1973	27.4	25.2	10.9	0.60	

River Mile (from confluence with Rio Grande)

Mile	Location
33.4	Cerro Gordo Road
30.6	Don Gasper St bridge
29.9	*Above St. Francis Bridge* Gage
29.7	St Francis Bridge
29.0	Alire St Bridge
28.3	*Ricardo Road* gage
27.6	Frenchy's Flume
27.4	Camino Carlos Rael
25.8	San Isidro Cemetery
25.2	Agua Fria
24.2	Race track crossing
21.0	Wastewater Treatment Plant

Figure 1. Santa Fe River stream gages and reach locations.

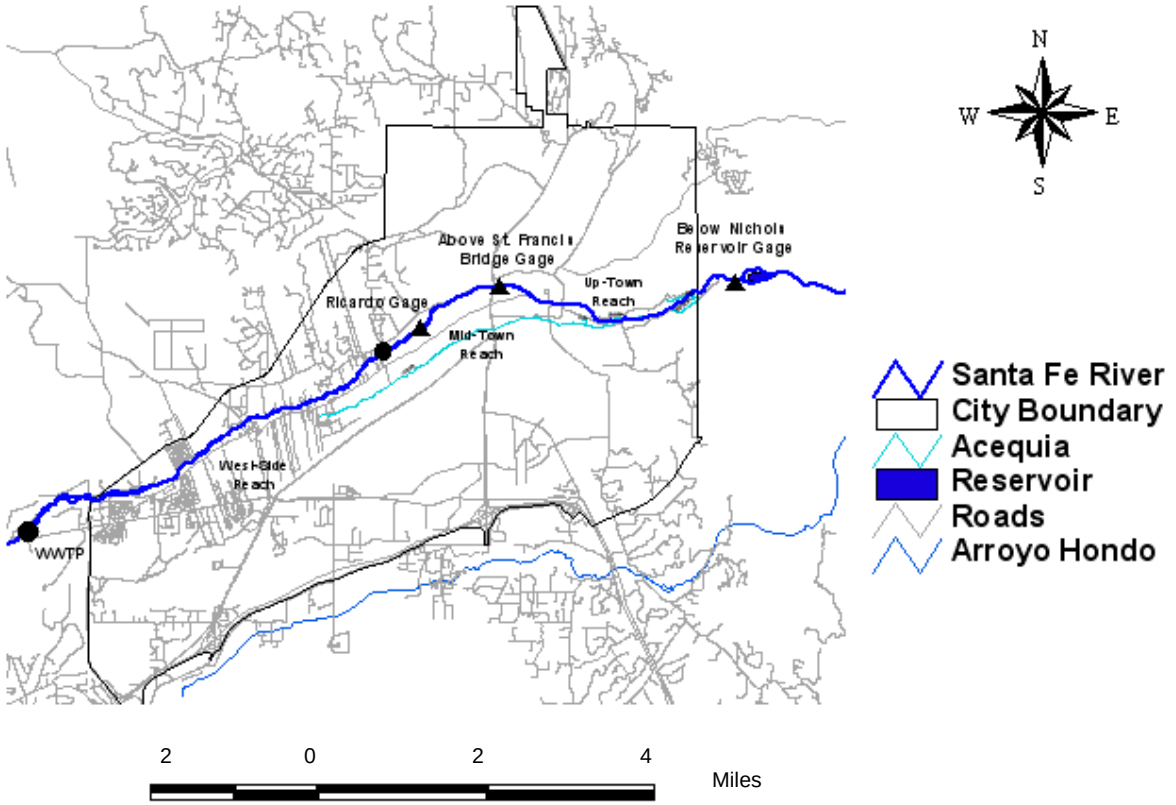
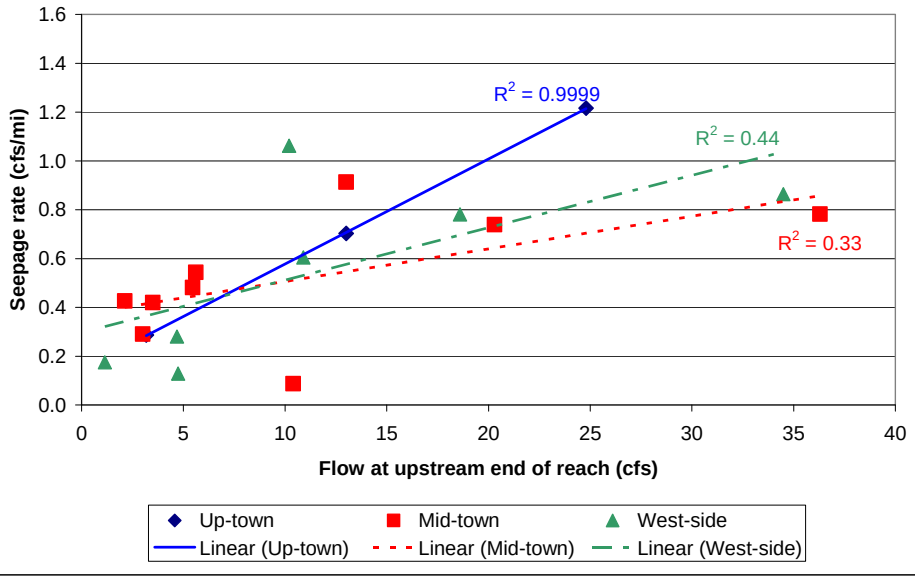


Figure 2 shows the correlation between seepage rates and flow rates for the seepage studies performed on the up-town, mid-town and west-side reaches. The linear correlation of the seepage studies for the up-town reach is higher, in part due to fewer studies to correlate. Additionally, the seepage studies done for the up-town reach were conducted during summer months when the acequias were diverting, which most likely accounts for the high rates of loss. The seepage data for the up-town reach

Figure 2. Seepage rates observed in the Santa Fe River from seepage investigations for three reaches from Nichols Reservoir to the Wastewater Treatment Plant.



can not be used to predict losses from seepage alone. However, the seepage data do reflect the actual losses of stream flow that occurs under current river operations. The mid-town and west-side reach seepage rates per flow rate at the upstream measurement have a poor correlation (r^2 =0.33 and 0.44, respectively). This is not necessarily due to variability in conditions of the river prior to each test, because even the correlation between only the UGSG tests which were done after the river had been flowing for at least a few weeks prior to the test, shows a poor correlation. The variability could be due to different rates of loss as the stream size changes and is in contact with different materials. For instance, the stream may reach rodent holes at one level that increases the loss rate. The stream may be in different locations with the channel bed that may have different hydraulic conductivities.

Up-town reach seepage investigations

The range of seepage rates measured in the three tests for the up-town reach is 0.29 to 1.22 cfs/mile (Table 1). The average seepage rate for the uptown reach is about 0.49 cfs/mile for the two lowest flow values which are less than 13 cfs. This may be an over-estimation of potential losses if the acequias were diverting during this time. However, a seepage study conducted at the end of September, 1999, when the acequias had closed their headgates for the study and thus were not diverting, shows a seepage rate of this magnitude. Lewis (2001) reported that 5 cfs was released from the reservoir for the study and about 3 cfs was measured at a flume just below St. Francis Bridge, which gives a seepage rate of about 0.4 cfs/mile. However, the actual amount released from Nichols Reservoir during this seepage study is uncertain. The *below Nichols* gage shows an average flow rate of 11 cfs during the September 1999 seepage study, which is much greater than the 5 cfs estimated by the City Water Treatment Plant personnel. If the gage data at the *below Nichols* gage is accurate, then the seepage rate for the up-town reach would be greater than 2 cfs/mile.

Mid-town reach seepage investigations

The seepage studies on the mid-town reach produced a wide range of seepage rates from a low of 0.09 cfs/mile to a high of 0.91 cfs/mile (Table 1). The average seepage rate from all seepage studies for the mid-town reach is about 0.52 cfs/mile. The average seepage rate from seepage studies conducted at flow rates less than 10 cfs is 0.43 cfs/mile; at rates above 10 cfs, the seepage rates averages 0.60 cfs/mi. At very low flow rates (less than 3 cfs) the channel may be very narrow and the seepage rate may not be as high. At higher rates of flow, the channel will spread out and result in a much higher rate of loss.

West-side reach seepage investigations

For the west-side reach, seepage rates range from 0.13 cfs/mile to 1.06 cfs/mile and average 0.56 cfs/mile (Table 1). Three seepage studies were conducted at flow rates below 10 cfs, two at 4.7 cfs and one of which was at 1.1 cfs for about half of the reach. For the two studies with flow rates at 4.7 cfs, the seepage rate averages 0.19 cfs/mile. For the seepage studies with flow rates above 10 cfs, the average seepage rate is 0.83 cfs/mile.

Stream Gage Analysis

To supplement the information available from seepage studies, stream gage data was also examined for the up-town and mid-town reaches to determine if stream losses could be calculated and compared to the seepage study estimates. Stream gage data with 15-minute records were available for January 2000 through September 2006 for the three gages (*below Nichols*, *above St. Francis* and *Ricardo* only). Days when the flow at the downstream gage was less than the upstream gage for an entire day (all 96 15-minute instantaneous readings) were used to calculate the seepage rates. This was done in order to eliminate days when runoff may have entered the river between the two gages, thus underestimating losses. The average flow rate at each gage was subtracted for those days when the loss occurred all day. If a loss did not occur

during one or more of the 96 instantaneous reading in a day, then the data for that day was not used. Although it is valid to compare stream flow between stream gages, the results need to be interpreted cautiously: 1) stream gage measurements of flow are usually less accurate than seepage studies conducted with flow meters, and 2) a small amount of runoff may have entered the stream even if the loss occurred all day, which would underestimate the losses.

Up-town Reach gage data

Figure 3 shows the flow at the *below Nichols* gage and seepage rates (Santa Fe River flows at *below Nichols* gage minus *above St. Francis* gage divided by 4.4 miles) for all days when the flow at the downstream gage is less than the upstream gage. A total of 1,070 days where loss occurred all day were available from 2000 to 2006 for the up-town reach (660 winter and 410 summer). The days for summer (April through September) and winter (Oct through April) are identified on Figure 3, and all of the winter seepage rates are lower than the summer seepage rates primarily due to acequia diversions and evapotranspiration. A line showing the seepage rate if all flows are lost to seepage is included on this graph. As shown on Figure 3, nearly all of the water in the river has been diverted by the acequias for flows up to 35 cfs. Winter seepage rates appear to reach a maximum of about 1.5 cfs/mile based on seepage rates observed in winter months when flow is about 30 cfs.

Figure 4 shows only the seepage rates at low flow rates, less than 2.5 cfs. Flow rates below about 2.5 cfs at the *below Nichols* gage do not appear to reach the *above St. Francis* gage, which results in a seepage rate of 0.56 cfs/mile for the 4.4 mile reach. In summer months, diversions from the acequias prohibit analysis of the seepage losses, thus, the 660 days available for winter months are the only measurements used in the analysis. Winter data has a large gap in the 2.5 to 10 cfs range of flow at the *below Nichols* gage. Figure 5 shows the correlation of the winter high flows for days when the loss occurs for the entire day. The seepage rate for flows above 10 cfs can be expressed by the equation: seepage rate for the upper reach = 0.0576 times the flow at the *below Nichols* gage minus 0.2716.

Figure 3. Comparison of winter and summer seepage rates along the up-town reach (2000-2006)

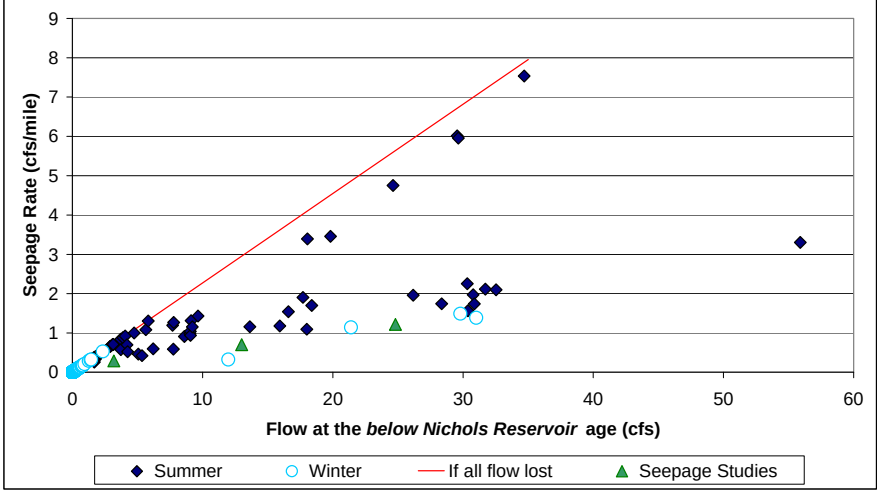
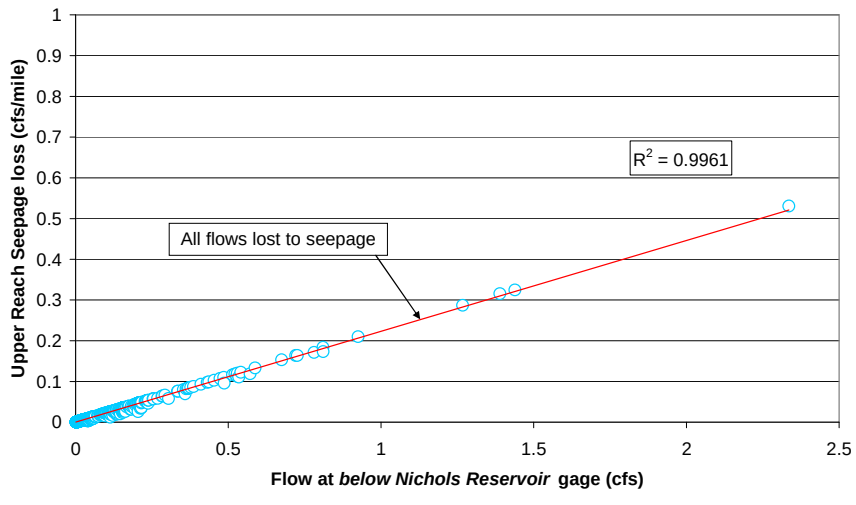
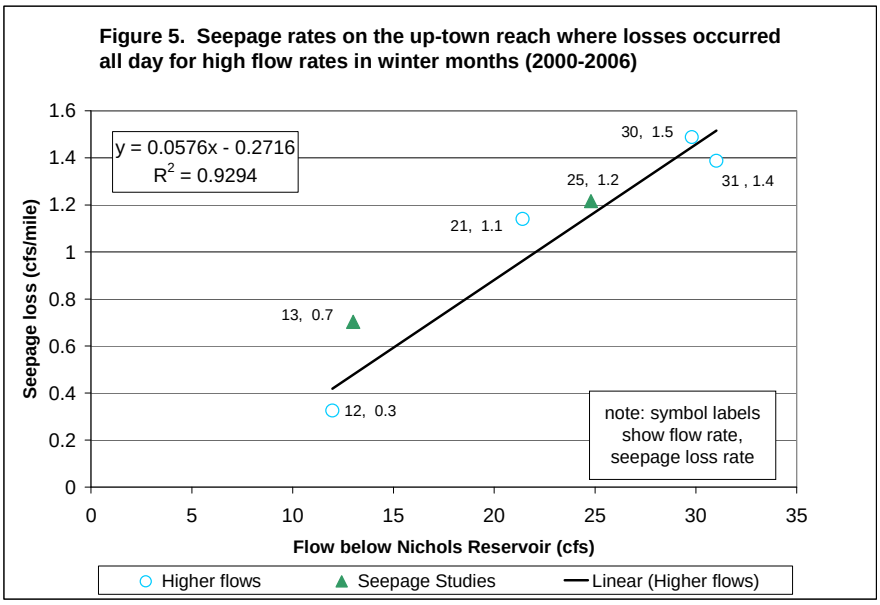


Figure 4. Winter seepage rates on the up-town reach where losses occurred all day for flow rates (2000-2006)





A flow of 2.8 cfs that does not reach the *Ricardo* gage results in a seepage rate of 1.8 cfs/mile, which is greater than the rates observed in the seepage studies. The seepage study conducted in 1999 (Lewis, 2001) measured a flow of approximately 3 cfs just below St. Francis bridge on the fourth day of a seven-day test and about 2.5 cfs at a location 0.7 miles downstream of the *Ricardo* gage, indicating a seepage rate of only 0.25 cfs/mile. However, seepage rates could be underestimated if other flow is entering downstream of the *above St. Francis* gage.

The seepage rates for flows between 3 and 10 cfs are poorly correlated as shown in Figure 8. The seepage rates range between 1.5 and 3.4 cfs/mile. Flows above 10 cfs and seepage rates for the mid-town reach are shown in Figure 9. While the stream gage data suggest an increasing seepage rate with increasing stream flow, the few seepage studies do not suggest this pattern. Seepage rates in the mid-town reach appear to be greater during summer months than winter, however, the measurement error in the gages may be too great to make conclusions about how much water is lost to

Mid-town Reach Gage Data

Figure 6 shows the Santa Fe River flow at the *above St. Francis* gage and the seepage rates estimated for the mid-town reach based on losses between gages. Also shown on this graph are the seepage estimates from seepage studies, all which are less than the seepage rates estimated from the gage data. This graph shows only data collected after 2003, when the structure at the *Ricardo* gage was installed to improve measurement of low flows. Gage data prior to the installation of this structure may overestimate stream losses, particularly at low flows when the stream could have by-passed the gage. A total of 215 loss days are available from the gage data for the mid-town reach, 125 for winter and 90 for summer. The apparent seepage losses from the gage data can be as high as 100 percent of the flow at *above St. Francis* gage, with flows less than 3 cfs as shown in Figures 6 and 7. Figure 7 shows the seepage rates for the low flows only, almost all of which fall on the line that represents no flow reaching the *Ricardo* gage.

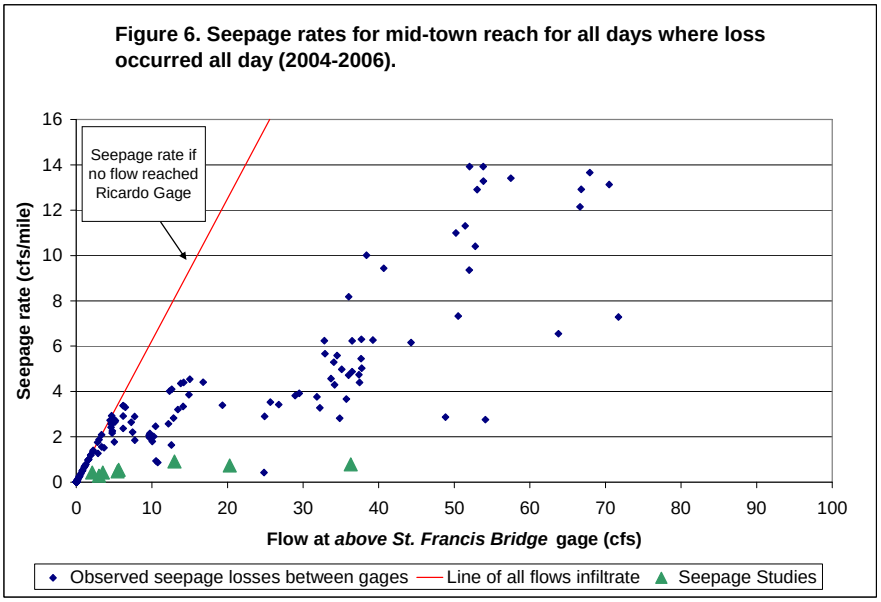


Figure 7. Seepage rates for winter low flows in the mid-town reach for all days where loss occurred all day (2004-2006)

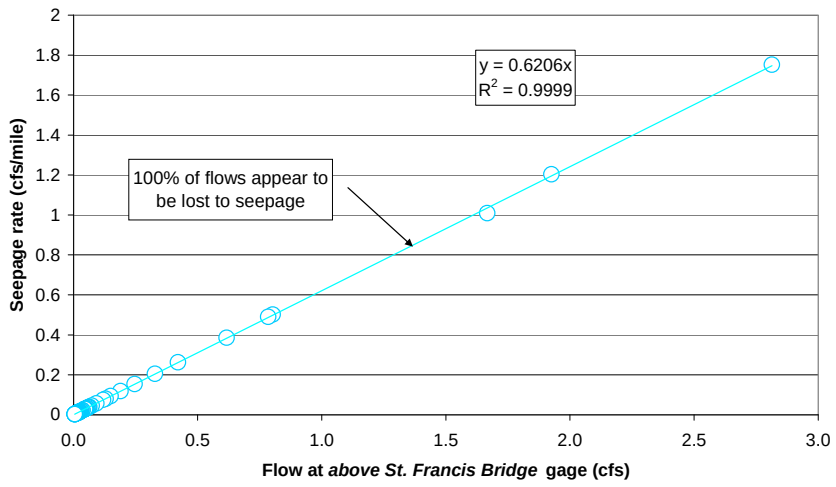
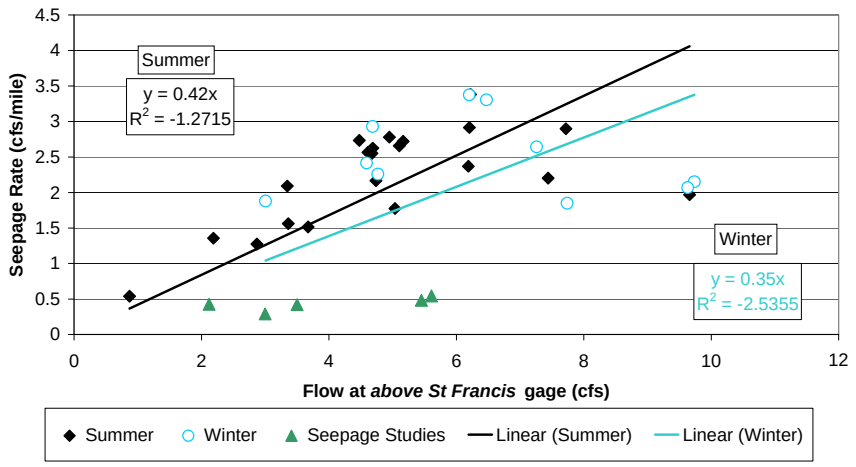


Figure 8. Comparison of winter and summer seepage rates along the mid-town reach for flows between 3 and 10 cfs for all days where loss occurred all day (2004-2006)



evapotranspiration. Seepage rates in the summer range from 0.4 to 20 cfs/mile for flow rates of 10 and 80 cfs, respectively.

West-side Reach Gage Data

No downstream gage is available for the west-side reach to analyze the losses from flows passing the *Ricardo* gage. A gage upstream of the confluence with effluent discharged from the WWTP and the Santa Fe River would be necessary to perform such an analysis.

Conclusions

Seepage studies and the analysis of stream gage data provide information regarding stream losses on the Santa Fe River between Nichols Reservoir and the WWTP. Table 2 summarizes the range of seepage rates observed at various flow rates for each reach based on seepage studies and gage data. Table 2 provides a "best estimate" of the seepage rates for each reach. The seepage rates are divided between three flow ranges for each of the reaches: less than 2.5 cfs, between 2.5 and 10 cfs and greater than 10 cfs. The 2.5 cfs threshold is based on the review of gage data at the upstream end of the up-town and mid-town reaches. For the uptown reach, a gap in gage data between 2.5 cfs and 10 cfs, where loss occurred all day in the winter, created a cut-off for analysis. Furthermore, flows below about 2.5 cfs in the up-town reach and 2.8 cfs in the mid-town reach did not appear to reach the downstream gage based on gage data, thus only flows above about 2.5 cfs could be used to estimate seepage rates.

For the up-town reach, the seepage rate is estimated to be 0.4 cfs/mile for flow rates below 10 cfs at the *below Nichols* gage. At flows below about 1.8 cfs (4.4 miles x .4 cfs/mile = 1.8 cfs), all water will infiltrate and no flow will reach the *above St. Francis* gage. For flows above 10 cfs, the seepage rate is defined by the linear relationship established by the analysis of gage data, which is also consistent with the seepage studies.

For the mid-town reach, the analysis of gage data is not consistent with seepage data. Gage data shows an increasing seepage rate as flow at the *above St. Francis* gage increases, whereas seepage data did not show a trend. The seepage investigations are considered to be more reliable estimates and thus, the average rates from seepage studies only for each flow

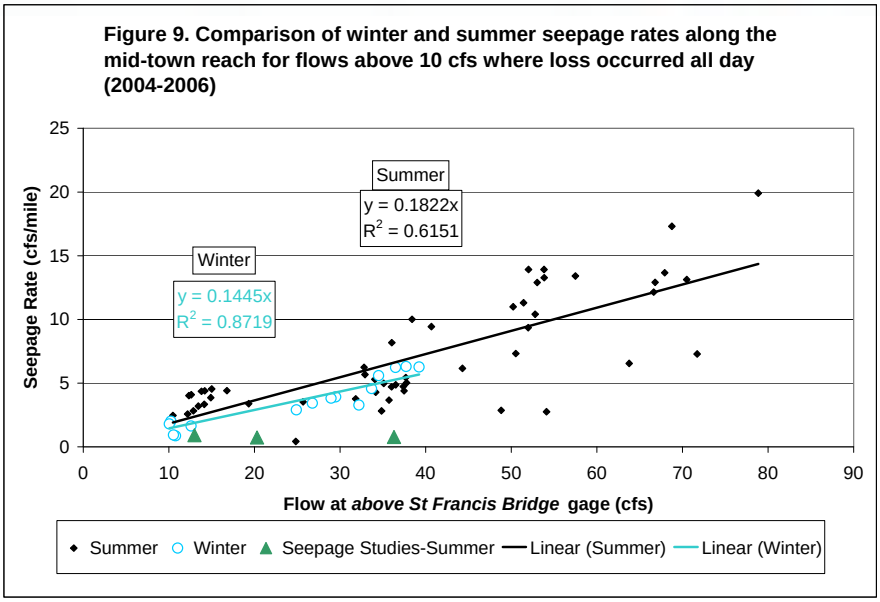


Figure 9. Comparison of winter and summer seepage rates along the mid-town reach for flows above 10 cfs where loss occurred all day (2004-2006)

range were used as the basis for the best estimate. For the mid-town reach the seepage rate is estimated to be 0.4 cfs/mile for flow rates below 10 cfs. At flows below about 0.6 cfs (1.6 miles x 0.4 cfs/mile = 0.6 cfs), all water will infiltrate and no flow will reach the *Ricardo* gage. For flows above 10 cfs, the seepage rate is 0.8 cfs based on the average of three seepage studies where the flow was above 10 cfs at the *above St. Francis* gage. Seepage rates could be much higher at higher flows if gage data are representative of the losses that have occurred.

The seepage rates for the west-side reach were all based on seepage studies because no downstream gage is available to evaluate losses downstream from the *Ricardo* gage. Seepage rates for the two seepage studies conducted at 4.7 cfs and one at 1.1 cfs were average to obtain the seepage rate of 0.2 cfs/mile for flow rates below 10 cfs at the *Ricardo* gage. Four seepage studies were averaged for flow rates above 10 cfs to obtain the seepage rate of 0.8 cfs/mile. A flat seepage rate is applied based on the poor correlation between flow at upstream end (*Ricardo* gage or Camino Carlos Rael) and the seepage rates, but conceptually the seepage rate should increase with increasing flow rate, particularly in the west-side reach where the area of the channel can be much greater than the upper reaches.

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Table 2. Summary of seepage rates for three reaches on the Santa Fe River.

Range of flows at upstream gage	Seepage Rates			Comments on Best Estimate of Seepage Rates
	Seepage Investigations	Analysis of Gage Data	Best Estimate of Seepage Rate	
	cfs/mi	cfs/mi	cfs/mi	
Up-town Reach (*below Nichols Reservoir* gage to *above St. Francis Bridge* gage				
up to 2.5 cfs	NA	0.5	0.4	Average of 1 seepage study and gage loss data at low flow rates during winter
2.5 to 10 cfs	0.3	NA	0.4	One seepage study at 3 cfs, no winter gage data available for the mid-range flow rates. Based best estimate on low flow loss rates.
> 10 cfs	0.7 to 1.2	0.3 to 1.4	= 0.0576 x -.2716	Based on linear relationship of seepage rates estimated from gage data, seepage studies agree with gage data
Mid-town reach (*above St Francis Bridge* gage to *Ricardo Road* gage)				
up to 2.5 cfs	0.4	1.8	0.4	Average of 3 seepage studies for low flow rates (between 2.1 and 3.5 cfs)
2.5 to 10 cfs	0.29 to 0.42	0.5 to 3.4	0.4	Average of 4 seepage studies for flows between 3 and 10 cfs
> 10 cfs	0.8	0.4 to 20 (Summer) 1 to 6. (Winter)	0.8	Based on average of 3 seepage studies, excluding one outlier
West-side reach (*Ricardo Road* gage to Waste Water Treatment Plant)				
up to 2.5 cfs	0.18	NA	0.20	Average of 3 seepage studies, including 2 at 4.7 cfs
2.5 to 10 cfs	0.14 to 0.32	NA	0.20	Average of 2 seepage studies at 4.7 cfs
> 10 cfs	0.6 to 1.1	NA	0.83	Average of 4 seepage studies above 10 cfs