2. Historical Changes in Stream Discharge and Loss

2.1 Introduction

Initially, the Roger Rd WRF provided effluent to agriculture, so from 1955 to 1970 virtually all effluent was used in agriculture rather than discharged to the LSCR (HLA, 1986). In 1971, records show that about 29,000 ac-ft of effluent was discharged from the Roger Rd WRF, and this accounted for a little more than half of the flow at the USGS gauge at Cortaro Rd that year (HLA, 1986). However, USGS data indicate that flows were not perennial at Cortaro until 1973. In 1977, the Ina Rd WRF opened and began discharging to the LSCR (HLA, 1986), so that in 1978, discharge from the Roger Rd WRF declined to about 27,000 ac-ft/yr, while the Ina Rd WRF added about 10,000 ac-ft/yr, resulting in a net increase in discharge to the LSCR from the WRFs.

In 1985, the State of Arizona classified the LSCR from the Roger Rd WRF to Baumgartner Rd in Pinal County, as an Effluent Dominated Water (EDW) because the State had determined that over 75% of the flow in this reach in a typical year was treated wastewater. While data exist on flow measurement and discharge, continuous datasets on flow and effluent discharge are available on data collected since about 1990, so most of the discussion in this chapter will focus on flows since 1990.
Losses and infiltration are also of particular interest because groundwater overdraft has been a significant concern in Arizona. The Arizona Groundwater Management Act of 1980 (State of Arizona, 1980) was established in 1980 to manage water supply for the future. The Act focuses on water management activities, such as establishing limits of groundwater withdrawals, and promoting conservation by mandating a balance between recharge and withdrawal. The Act established Active Management Areas (AMAs) where groundwater overdraft is severe. There are five AMAs in the state of Arizona. Each AMA has a statutory management goal.

In the Tucson AMA, the primary management goal is 'safe yield', which means to attain a long-term balance between the annual amount of groundwater withdrawn and the annual amount of natural and artificial recharge. Most of the aquifer recharge in the Tucson AMA occurs along major stream channels, like the Santa Cruz River, by infiltration through the channel beds and percolation through highly permeable alluvium (Galyean, 1996). Effluent discharged to the LSCR nearly doubled between 1971 (~29,000 ac-ft/yr, HLA, 1986) and 2004 (57,464 ac-ft/yr; per RWRD) as demand for the effluent from local farmers ceased and most effluent was discharged to the LSCR. Utilization of effluent is an important component of water resource plans, so infiltration of effluent has been of considerable interest in the Tucson AMA.

Pima County Regional Flood Control District (RFCD) is involved in several recharge projects, primarily intended to evaluate groundwater quality and riparian habitat viability. The following are examples of the pilot recharge projects.

The Lower Santa Cruz Replenishment Project was completed in 1998 by the RFCD in partnership with the Central Arizona Water Conservation District. The project was constructed in conjunction with a flood control levee along the LSCR to protect the Town of Marana from flooding and to provide for underground storage of Central Arizona Project water.

The Lower Santa Cruz River Managed Recharge Project is operated by the Cortaro-Marana Irrigation District. Effluent that is discharged from the Roger Rd. and Ina Rd is measured by the USGS gauges at Cortaro and Trico Roads, and the difference is used to estimate the volume of recharge with an assumption some of the difference is due to evapotranspiration. Phase 1 of the project calculates the recharge between Roger Rd and Ina Rd, and Phase 2 calculates the recharge between Ina Rd and Trico Rd. As a 'Managed Recharge Project', only 50% of the calculated recharge is credited to the owners of the effluent (Tucson Water, RWRD, Indian Water Rights [managed by the Bureau of Reclamation] and several smaller entities). The project began accruing credits in 2003 and has a maximum permit capacity of 43,000 AF annually. Since the inception of the Managed Recharge Project, recharge has never been more than 38,073 AF, and most years it.is about half of the permitted capacity.

The Marana High Plains Effluent Recharge Project (MHPERP) was developed in 2000 by RFCD in cooperation with the Bureau of Reclamation, Arizona Water Protection Fund, Cortaro-Marana Irrigation District, Pima County and the Town of Marana. This constructed effluent recharge project is located along the south bank of the LSCR. MHPERP was designed to investigate the feasibility of recharging treated effluent into the local groundwater aquifer, while simultaneously investigating wildlife habitat opportunities associated with recharge facilities. Overall objectives of the project include investigation of the feasibility of using treated effluent to enhance riparian habitat while recharging the aquifer. Sources of the effluent for the project are discharged from the Roger Rd. and Ina Rd. WRF. The effluent is conveyed downstream by the LSCR and is diverted to the recharge facilities by constructed ditches.

The purpose of this chapter is to describe changes in the discharge and infiltration in the LSCR that may affect the extent and availability of water for the wetlands in the LSCR.

2.2 Methods

The study used the data being collected by USGS at Cortaro Rd and Trico Rd, as well as recorded effluent discharge to evaluate historical discharge and infiltration rates. The data collected since 2003 with the establishment of the Lower Santa Cruz River Managed Recharge Project have also been used.

USGS flow data on the LSCR was selected to accompany the historical data of Roger Rd. WRF and Ina Rd. WRF. Two (2) USGS stream gauges (http://waterdata.usgs.gov/az/nwis/rt) and discharge data at two WRFs were analyzed to evaluate the historical conditions of the LSCR. Monthly discharge data was evaluated for each gauge for the following time periods:

- Cortaro Road: USGS 09486500 Santa Cruz River At Cortaro Rd, AZ
    - June 1990, October 1990 – December 2011
      (data available from 1939 to present with missing data from 1947 to 1950 and sporadic data from 1982 to 1990)
- Trico Road: USGS 09486520 Santa Cruz River at Trico Rd, Near Marana, AZ
    - October 1989 – September 2011
      (data available from 1989 to present)
- Roger Rd. WRF
    - 1989 – 2011
- Ina Rd. WRF
    - 1989 – 2011

Per the USGS National Water Information System disclaimer, annual and monthly stream gauge statistics utilized in the historical conditions report are based on approved daily-mean data and may not match those published by the USGS in official publications.

Flows at these gauges measure both stormflow and effluent inflow from the Roger Road and Ina Road WRFs. Effluent is reused on site, delivered to the City of Tucson's Reclaimed Water System, and discharged to groundwater. The rest of the effluent is released as surface water discharge under the authorization of Arizona Pollution Discharge Elimination System Permits (AZPDES). Fig. 2.1 shows the effluent production at the Ina Rd. and Roger Rd. WRFs and discharge to the LSCR in 2010. This chapter summarizes historical effluent generation and discharge to the LSCR and historical discharges at USGS gauge along the LSCR.

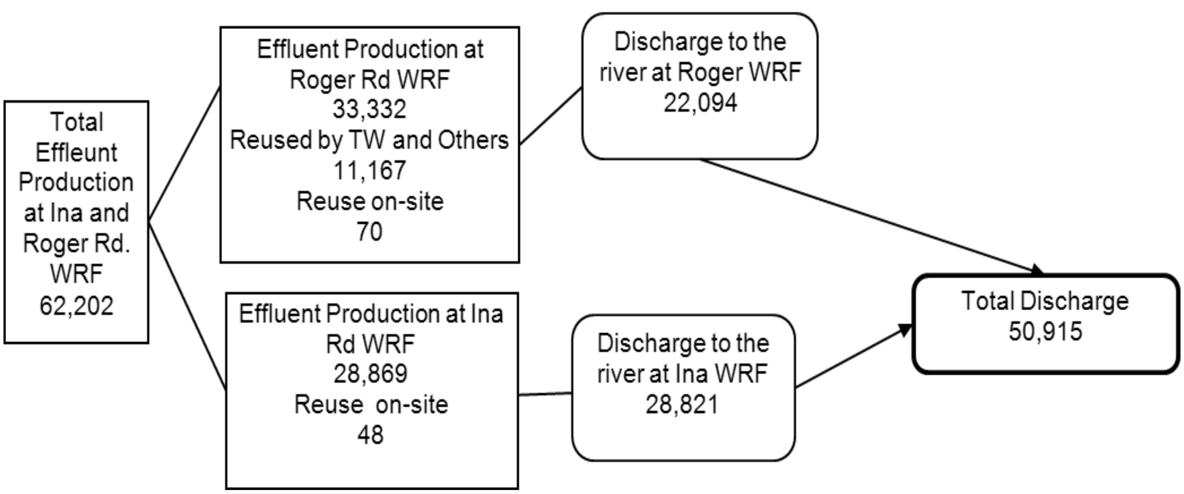


Fig. 2.1 Effluent Flow in 2010
Note: Unit: AFY, "TW" Tucson Water

More influent is delivered to Roger Rd. WRF, but discharge to the LSCR from Ina Rd. WRF has been greater in recent years, since effluent water is diverted to the reclaimed system at Roger Rd. WRF.

2.3 Results and Discussions

2.3.1 Annual Flows

Statistics and trends were evaluated for the annual flow in the LSCR. Fig.2.2 illustrates the mean annual discharge (Acre-Feet per Year, AFY) of the LSCR at Cortaro Rd and Trico Rd. Large flood events occurred in winter, 1993, and summer in 2006. The 1993 event produced the largest volume of flow, with a peak daily average of 25,000 cfs at the Santa Cruz at Cortaro. The large summer event in 2006 caused the flood of record on the Rillito and peaked at 40,900 cfs, with an average daily discharge of 11,700 cfs.. In all years, flows are greater at Cortaro Rd. than Trico Rd., indicating net losses due to infiltration and evapotranspiration between Cortaro Rd and Trico Rd.

The total effluent discharged from Roger Rd. and Ina Rd. WRFs annually is a significant portion of the annual discharge conveyed in the LSCR annually (Figs. 2.3 and 2.4). While stormwater flows depend on the weather and watershed conditions and vary from year to year, the effluent flows on the LSCR are entirely anthropgenic in origin and tend to be more stable (Fig. 2.3). Both total influent and total effluent increased during the period from 1989 to 2003, while they decreased during the period from 2003 to 2011 (Fig. 2.3).

On average, the annual flow at Cortaro Road and Trico Road are 1.21 and 0.65 of the total annual effluent discharge, respectively, indicating that most of the volume in the river is effluent - derived (Fig 2.4). However, large fractional annual discharges (LSCR discharge/total effluent discharge) indicate years with significant flows in the LSCR being contributed by storm generated flow (Fig. 2.4) with about 3.5 times more flow than effluent discharge in 1993 and about 2.0 times more flow than effluent discharge in 2006.

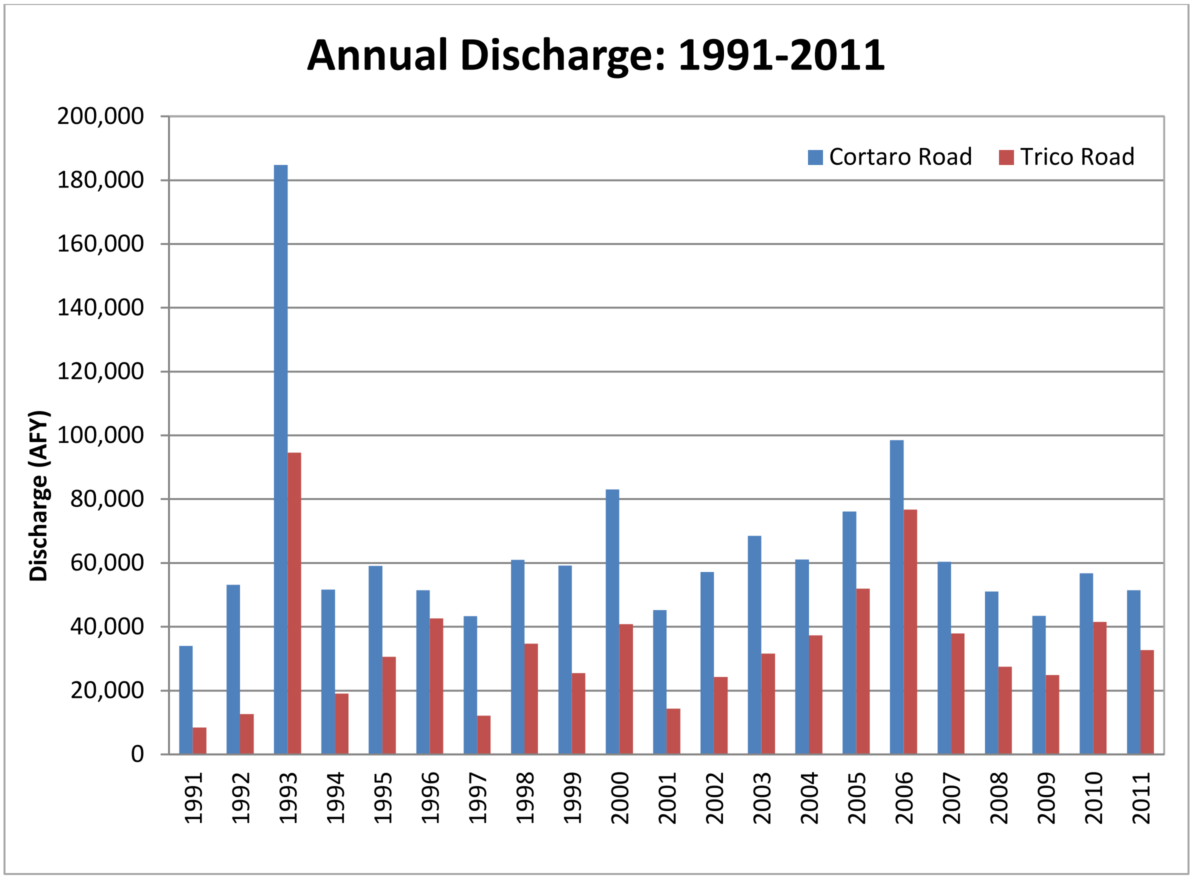


Fig. 2.2 Annual Discharge at Cortaro Rd. and Trico Rd. from 1991 to 2011

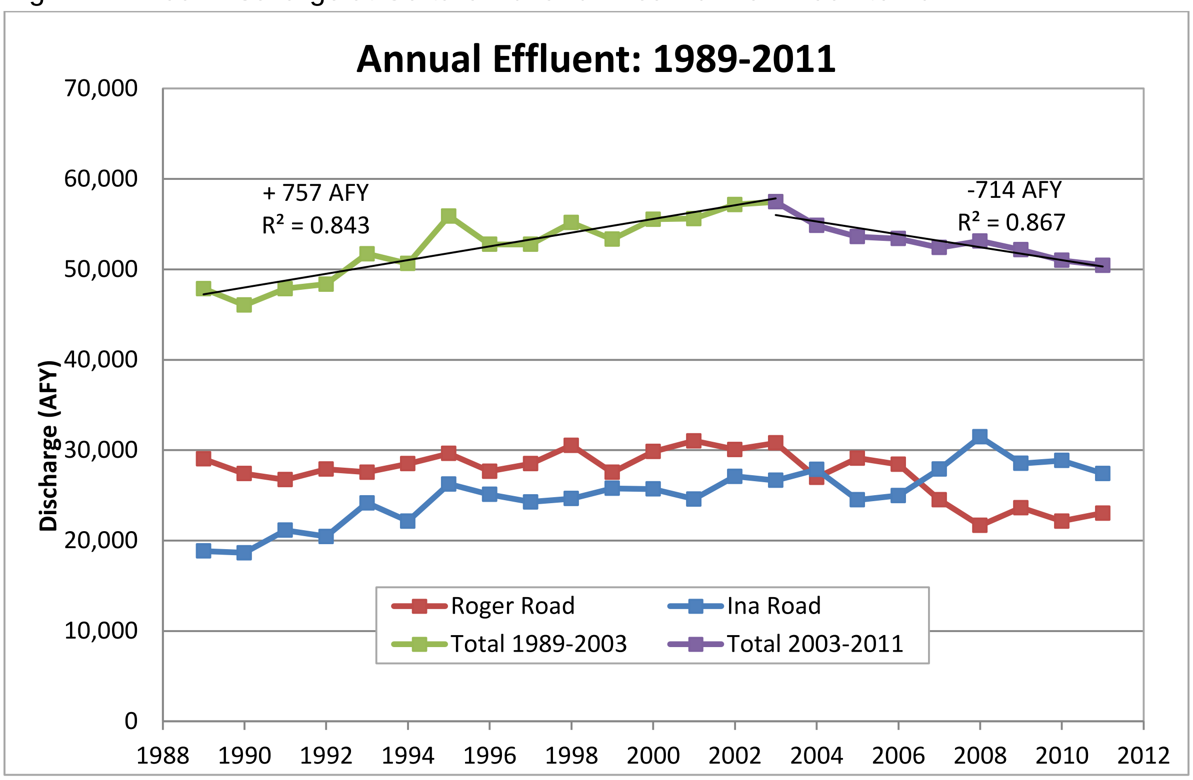


Fig. 2.3 Annual Effluent at Roger Rd. and Ina Rd. WRFs from 1989 to 2011

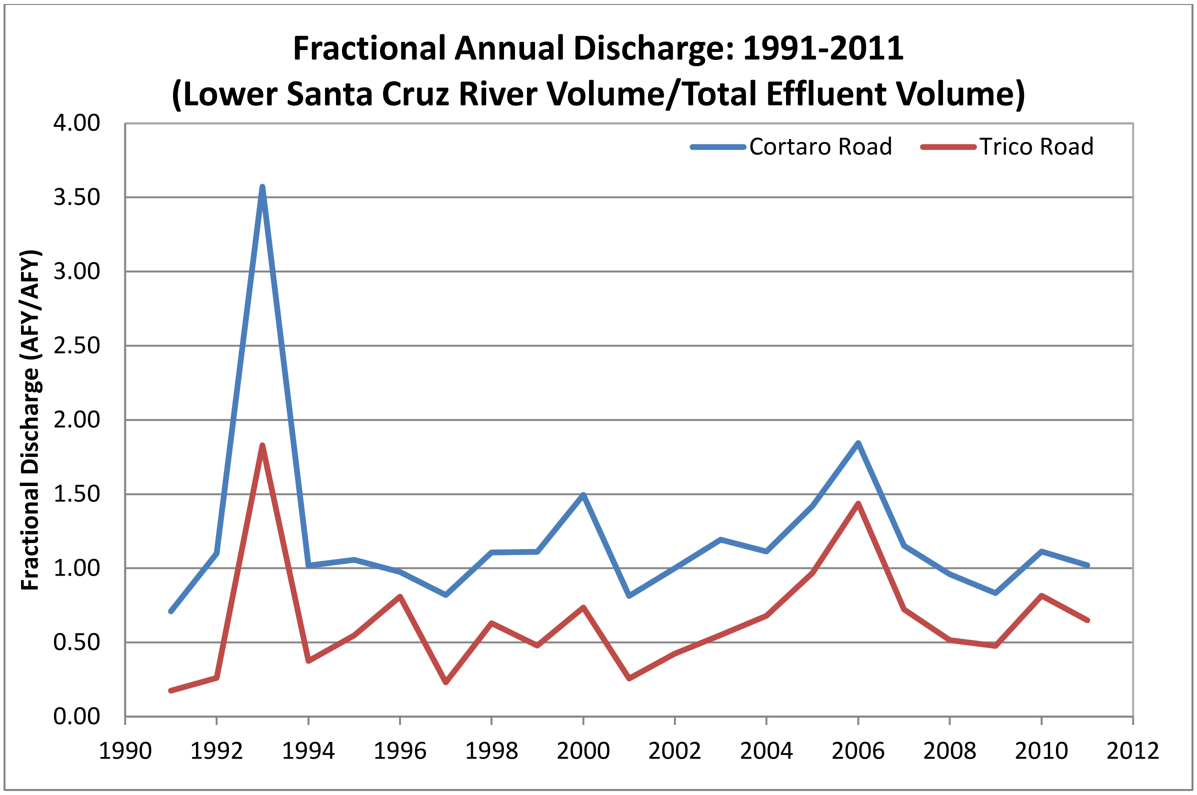
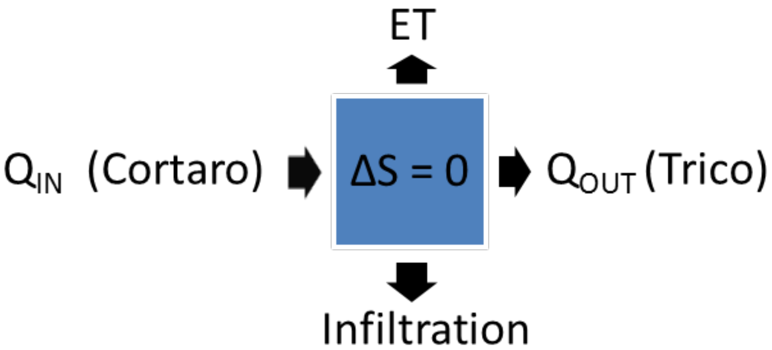


Fig. 2.4 Fractional Annual Discharge at Cortaro Rd. and Trico Rd. from 1991 to 2011

2.3.2 Annual Losses

Losses on the LSCR are determined from a simple mass balance conceptual model (Fig. 2.5). Assuming steady state conditions over long time periods, the change in storage (ΔS) is zero. Losses are derived as the difference between the upstream inflow discharge (Cortaro Rd) and the downstream outflow discharge (Trico Rd).



$$\Delta S = Q_{IN} - Q_{OUT} - ET - Infiltration$$
$$0 = Q_{IN} - Q_{OUT} - ET - Infiltration$$
$$Q_{IN} - Q_{OUT} = ET + Infiltration = Losses$$

Fig. 2.5 Mass Balance Conceptual Model

Losses in the water balance of a surface water riparian corridor like the LSCR consist of infiltration and evapotranspiration (ET). Fig. 2.6 illustrates the annual mean losses of the LSCR. Calendar Year 1993 is a year of note; the same year which experienced the greatest annual mean discharge also maintained the greatest losses. In addition, the last twelve (12) observed years, 2000-2012 have experienced a reduction in annual mean loss at an approximate rate of 2000 AFY.

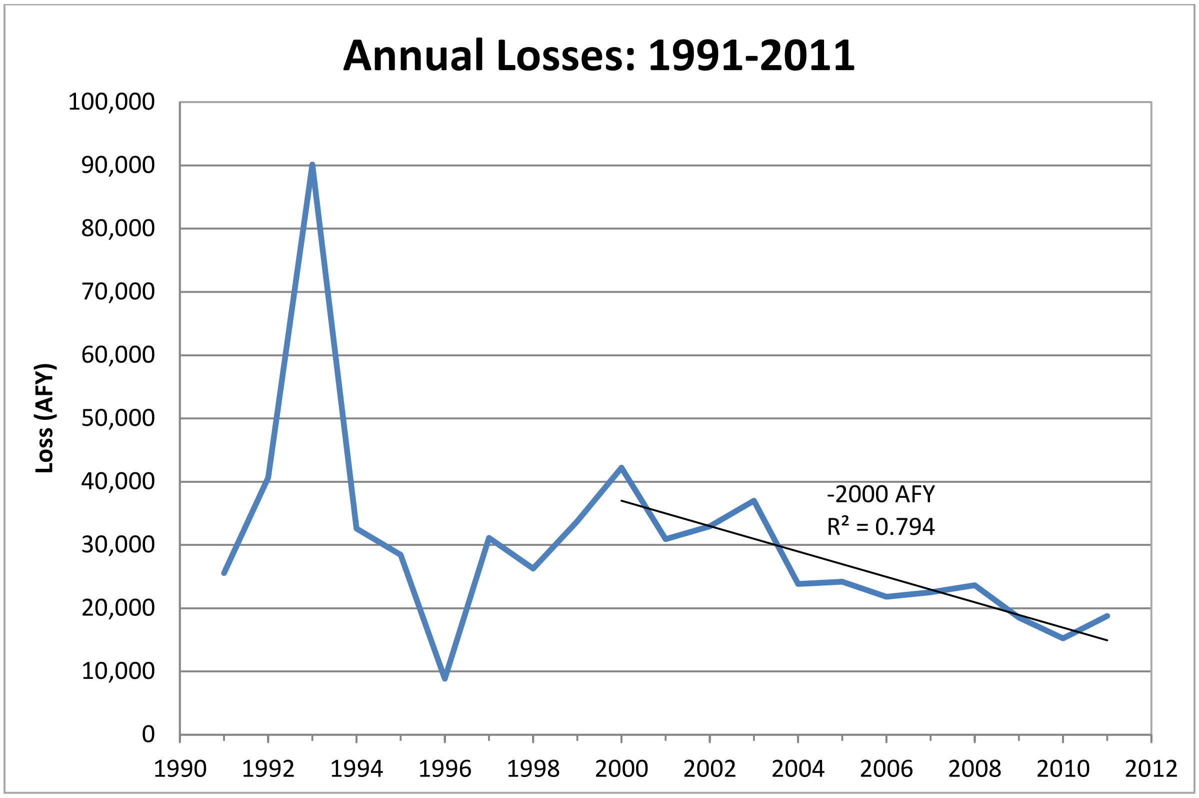


Fig. 2.6 Annual Losses, Cortaro Rd to Trico Rd. from 1991 to 2011

2.3.3 Monthly Discharge

Fig. 2.7 illustrates the monthly discharge (Acre-Ft per Month, AF-month) of the LSCR at Cortaro Rd and Trico Rd. Very low monthly discharge was observed at Trico Rd immediately following months when high discharge was observed at Cortaro Rd and Trico Rd. These results are discussed in more detail in Section 2.3.5.

Monthly flows have been perennial at Cortaro since 1973. The minimum monthly discharge at Cortaro Rd, 1370 AF-month, occurred during April 1991. In contrast, flow at Trico Rd has sometimes ceased for over a month. No monthly discharges (AF-month) at Trico Rd occurred during the following time periods: April 1991 – July 1991, February 1993 – July 1993, April 1995 – July 1995 (which was studied by Lacher, 1996), September 1995 – October 1995, and October 1996; mean monthly discharges less than 1.0 cfs occurred in September 1991 and

September 1993. These periods of flow generally occurred following major scouring periods, however there has not been a mean monthly flow < 1 cfs since 1996.

Fig. 2.8 illustrates the mean monthly discharge for Cortaro Rd and Trico Rd, sorted by month. January experienced the maximum monthly mean discharge during the observed time period, followed by July and August, all greater than 6,000 AF-month; May and June experienced the minimum monthly mean discharges, at approximately 3,000 AF-month.

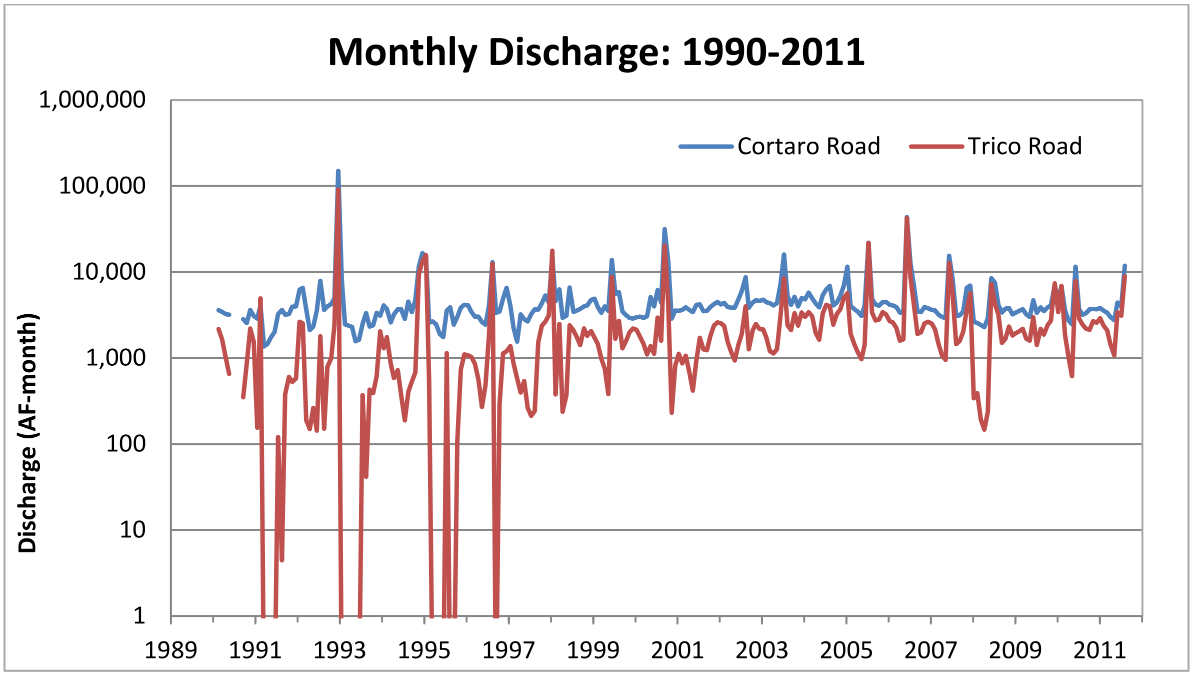


Fig. 2.7 Monthly Discharge at Cortaro Rd. and Trico Rd. from 1990 to 2011

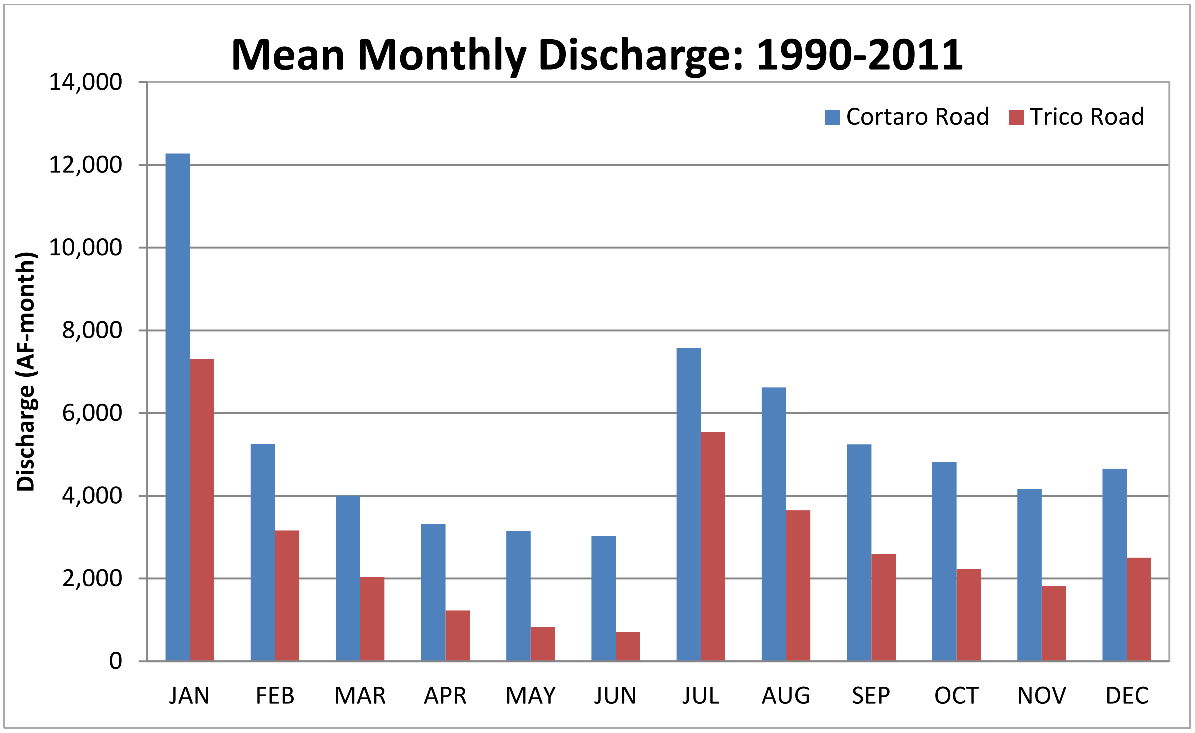


Fig. 2.8 Mean Monthly Discharge at Cortaro Rd. and Trico Rd. from 1990 to 2011

2.3.4 Monthly Losses

Monthly losses were calculated as the difference between the Cortaro Rd monthly mean discharge and the Trico Rd monthly mean discharge (Fig. 2.9). The average monthly mean loss is 2600 AF-month.

January 1993, the month that experienced the greatest monthly mean discharge at Cortaro Rd and Trico Rd experienced the greatest loss between the two stream gauge stations, 58,900 AF-month. Months that experienced negative losses (March 1991, February 1995, February 1998, January 2010, March 2010) suggest greater rainfall-runoff events occurring downstream of the Cortaro Rd stream gauge and upstream of the Trico Rd stream gauge.

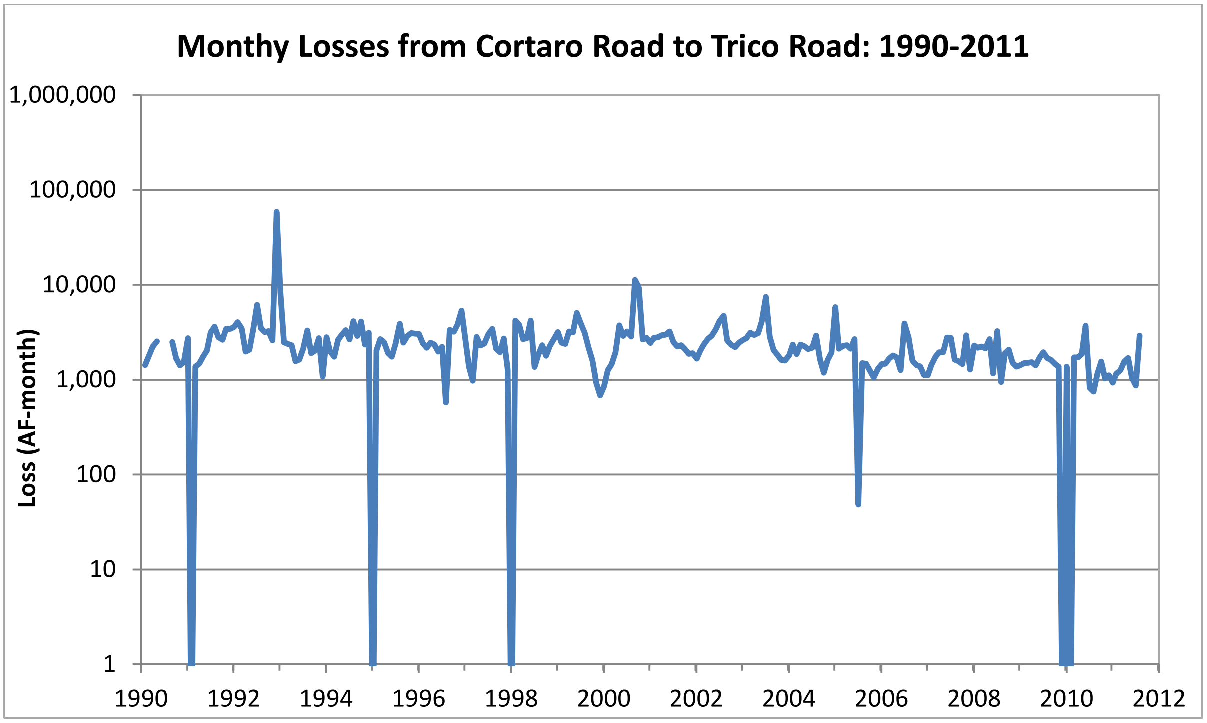


Fig. 2.9 Monthly Losses, Cortaro Rd. to Trico Rd. from 1990 to 2011

Table 2.1 provides a statistical analysis of the mean monthly losses. May is the least variable month and February is the most variable month for losses.

Table 2.1 Monthly Mean Losses: Sorted (1990-2011)

Mean Monthly Losses (AF-month)

	Mean	STD	Variance
JAN	4,600	12,500	148,500
FEB	2,200	2,100	4,300
MAR	1,900	1,100	1,200
APR	2,100	700	500
MAY	2,300	500	200
JUN	2,400	600	400
JUL	2,700	1,100	1,100
AUG	2,900	1,700	2,700
SEP	2,600	1,100	1,200
OCT	2,600	2,100	4,100
NOV	2,400	1,800	2,900
DEC	2,100	800	700

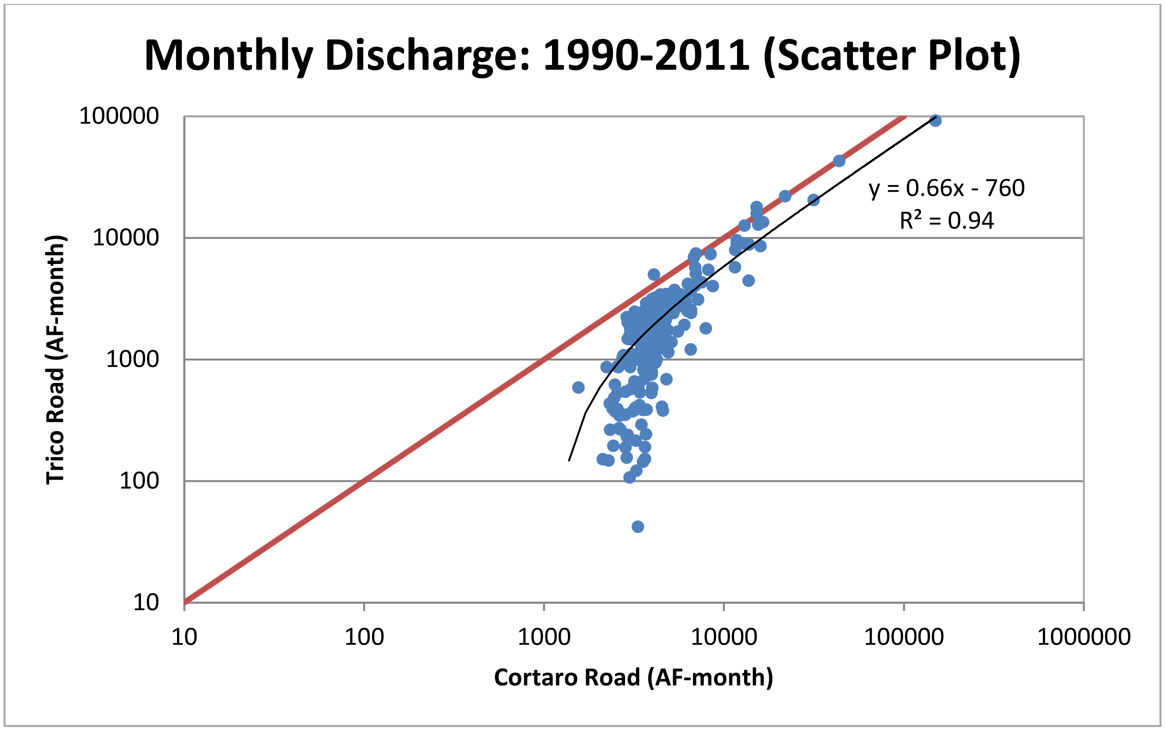


Fig. 2.10 Monthly Discharge: Cortaro Rd. vs. Trico Rd. from 1990 to 2011

Fig. 2.10 demonstrates the strong correlation between the monthly discharge at Cortaro Rd and Trico Rd. The linear regression indicates 66% of the flow conveyed at Cortaro Rd is conveyed at Trico Rd (explained by 94% of the variance).

2.3.5 Factors affecting Infiltration Losses

Studies have been conducted to quantify the amount of recharge from the effluent stream through the Lower Santa Cruz River bed to aquifer in the Tucson AMA. Lacher (1996) examined recharge characteristics of an effluent stream of the LSCR. Galyean (1996) studied the infiltration of effluent into the LSCR from WRFs in the early 1990s. More recently Case (2012) looked at the extent of the clogging layer in the LSCR, comparing it to infiltration in the San Pedro River (a control) and downstream of the Nogales International Treatment Plant, which discharges water with lower nutrients. She found that in the effluent streams, infiltration rates increase further from the treatment plant. She attributed the clogging in the LSCR to a combination of biotic (e.g. microbial or algal growth which would be affected by nutrients in the water) and abiotic processes, such as physiochemical effects, (which would also be impacted by water quality), and siltation in the interstitial spaces, (which would not be impacted by water quality). While she found the strongest correlation between percent fines and clogging, she concludes that higher quality effluent will result in reduced clogging.

These studies and the annual and monthly flow observations indicate that infiltration rates were higher in the early 1990s than present. Gaylean (1996) looked at infiltration rates of the effluent flows in the early 1990s and concluded that virtually no effluent reached the Pinal County line, and was instead lost to infiltration and evapotranspiration. His study indicated that 88.4-90.2% of the effluent discharged from Roger Rd and Ina Rd WRFs infiltrated the LSCR channel. He also observed that discharge of effluent downstream of the WRFs decreased sharply after storm flows, indicating that the disturbance of streambed by storm flows caused a considerable increase in infiltration rate. A summary of the annual discharges and flows are as follows:

Table 2.2 Annual Discharge, Infiltration and Percent Infiltration from 1991-1993

Water Year	Effluent Discharged (AF)	Infiltration (AF)	Percent Infiltrated
1991	46,600	41,890	90%
1992	49,380	43,640	88%
1993	50,620	45,670	90%

The data collected by USGS at Cortaro Road and Trico Road was used to determine infiltration rates from 2004 to 2011 in the LSCR for the managed recharge project, which also accounted for evapotranspiration. The results are summarized in Table 2.3.

Since the initiation of the Lower Santa Cruz Managed Recharge Project, the volumes of water infiltrated and the percent of the effluent discharged have both dropped considerably. While the volume of effluent discharged is slightly higher since the implementation of the managed recharge project, the volume actually infiltrated is only about half of the volumes observed by Gaylean in 1991-1993.

Table 2.3 Annual Discharge, Infiltration and Percent Infiltration from 2004-2011

Water Year	Effluent Discharged (ac-ft)	Recharge (ac-ft)	Percent Infiltrated
2004	55,903	21,960	39%
2005	53,287	21,620	41%
2006	53,102	22,370	42%
2007	52,390	28,701	55%
2008	53,523	38,073	71%
2009	52,404	28,773	55%
2010	51,632	25,436	49%
2011	49,500	22,268	45%

The findings of the past studies are summarized in the following sections.

a. Impacts of Clogging Layers

The formation of biological clogging layers (especially the black biological layer that forms below the surface in effluent-dependent streams known as Schmutzdecke) is well-documented in the Santa Cruz River. This has been associated with the nutrient-loading. Treese (2008) reported that localized clogging forms exist in the Santa Cruz River north of Nogales and that a clogging layer formed during pre-monsoon months and removed by a set of large flood flows during the monsoon season Furthermore, following the upgrades to the treatment plant in Nogales, the infiltration rates increased, presumably because the reduced nutrient loading resulted in a decline in the prevalence of this clogging.

While we can expect that decline in infiltration rate is related to the formation of a clogging layer, like Schmutzdecke (Treese et al, 2009), this decline in infiltration rate since the last major flow event has been observed in CAP water recharge project on the San Xavier District of the Tohono O'odham reservation and on the San Pedro River (Case, 2012), so it is not strictly a function of nutrient loads. However, Case found that in the effluent dependent Santa Cruz River there is a spatial component to the clogging, with higher infiltration rates further from the point of effluent discharge. Areas of lower infiltration had higher microbial counts and lower nitrates.

The USGS field notes from the Trico and Cortaro gauging stations describe a darkening of the soils in the channel at the soil/water interface, which indicates the development of an algal layer immediately at the surface. USGS staff who supervise the collection of the field data at these sites, say that he observes that the number of saltating grains of sand declines as this algal layer becomes more prevalent. This suggests that the biotic components that contribute to development of the clogging layer also contribute to sediment cohesion, which changes the sediment transport characteristics of the channel.

b. Impacts of Scouring Storm Events

Review of the historical data clearly indicates that approximately twice as much effluent infiltrated into the LSCR per year in the early 1990s than it has since the establishment of the Lower Santa Cruz River Managed Recharge Project (Phase 1 and Phase 2). While the water quality has become slightly more likely to disperse clays, thus reducing infiltration rates (, the more likely difference is that there were more scouring events in the early 1990s, and that infiltration rates decline following a scouring event. As such, the time since the last scouring event affects the amount of effluent infiltrated. Lacher (1996) studied the infiltration following a flow event in 1995. By calibrating the flow between two gaging stations using the Kineros 2 model, she was able to determine the effective hydraulic conductivity rate. She reported that vertical hydraulic conductivity of the effluent stream bed decreased exponentially following a summer storm, ranging from

37 mm/hr (1.5 in/hr) in late January to 11 mm/hr (0.43 in/hr) in early August. She pointed out that the decay of the hydraulic conductivity was caused by the development of microbial clogging layer. This modeling exercise with Kineros 2 was recreated using flow data from 2010, and the final infiltration rate was about half the rate observed by Lacher with a low of 6.4 mm/hr (0.25 in/hr) The results are described in Appendix D.

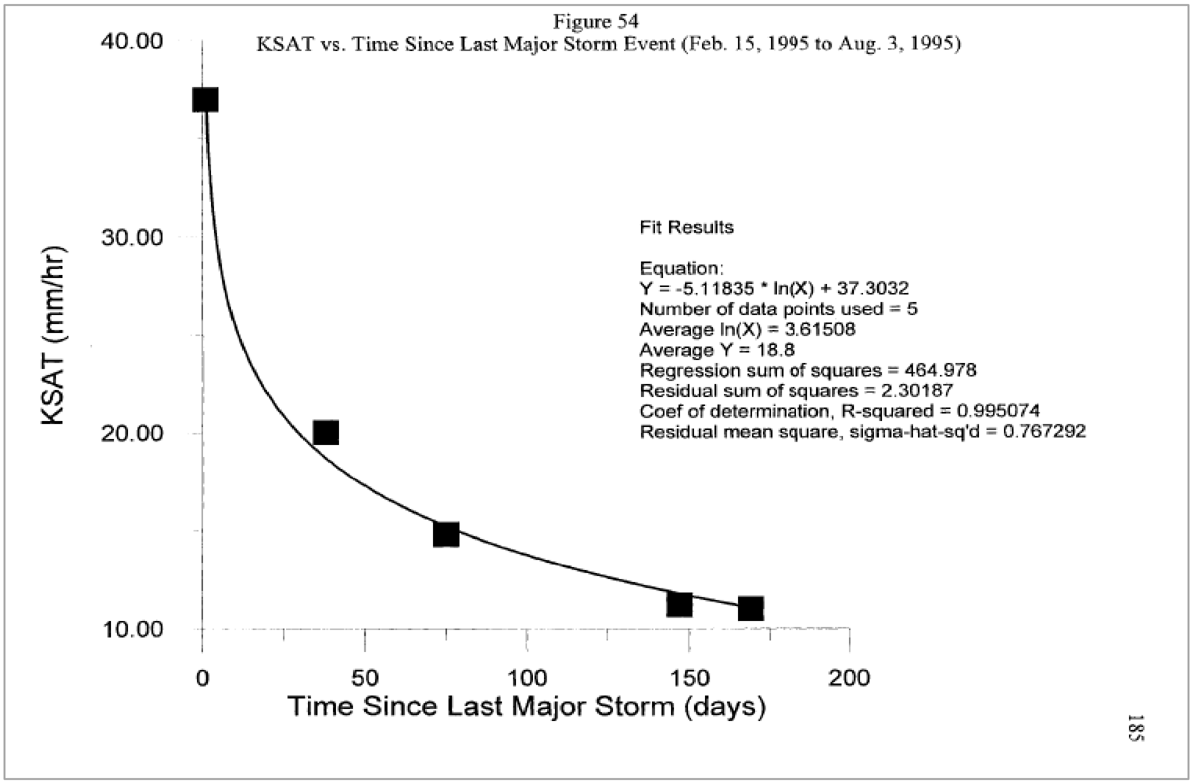


Fig. 2.11 Infiltration Rate Change Over Time (Lacher, 1996)

The time series showcases the calendar years of 1993 and 2006 having the greatest magnitude of discharge of the time period evaluated for the LSCR (Fig. 2.2). While both experienced mean daily scouring flows exceeding 10,000 cfs (Figs. 2.12 and 2.13), the results differed significantly. Following the July 19, 1993 flow, which peaked at a daily mean flow of 25,000 cfs at Cortaro, the Trico Rd gauge maintained a mean daily discharge of zero for 197 days (January 28 to August 13, Fig. 2.12). Even though a larger event with a mean daily discharge of 1150 cfs occurred 32 days after the January 19 event, on February 20, no flow was recorded at Trico Rd indicating an extended capacity of the channel to infiltrate flow.

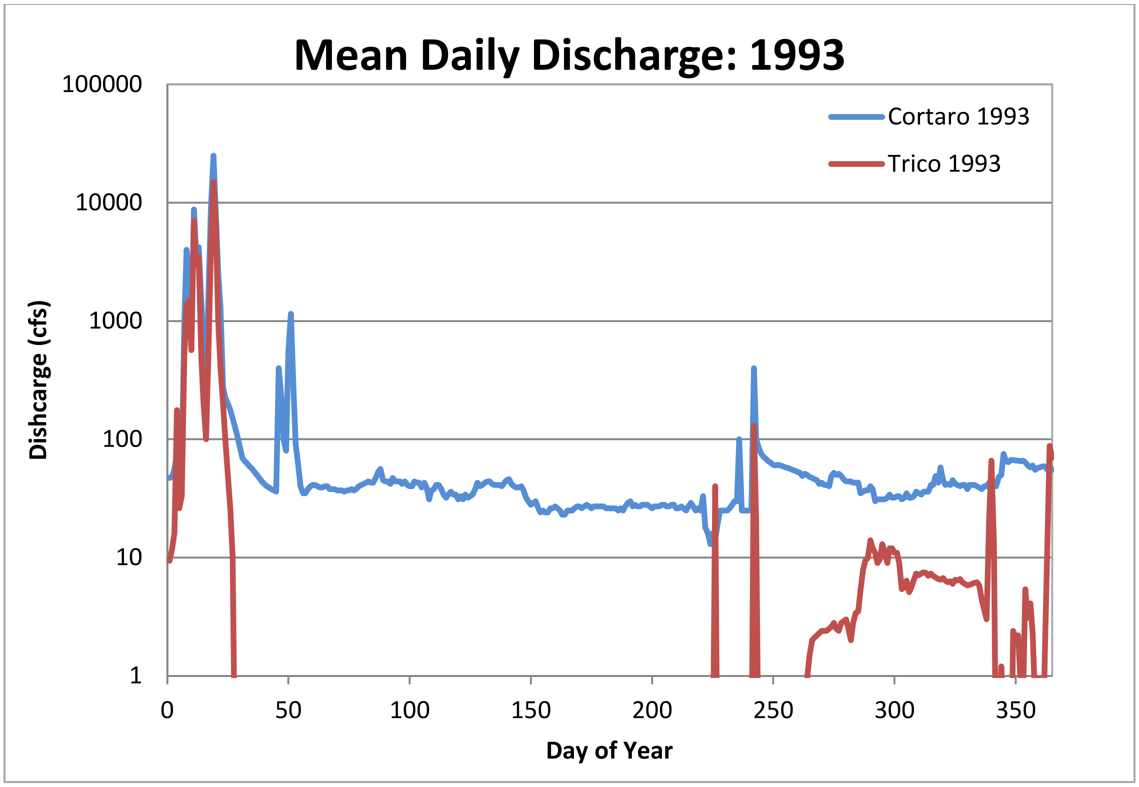


Fig. 2.12 Mean Daily Discharge at Cortaro Rd and Trico Rd Gauges, 1993

In contrast, in July 2006, the mean daily discharge peaked at Cortaro at 11,700 cfs. While other stormflow events occurred during, that monsoon season, the flow at Trico was zero for no more than five days, and returned to near-pre-event flows with 50 days (Fig. 2.13)

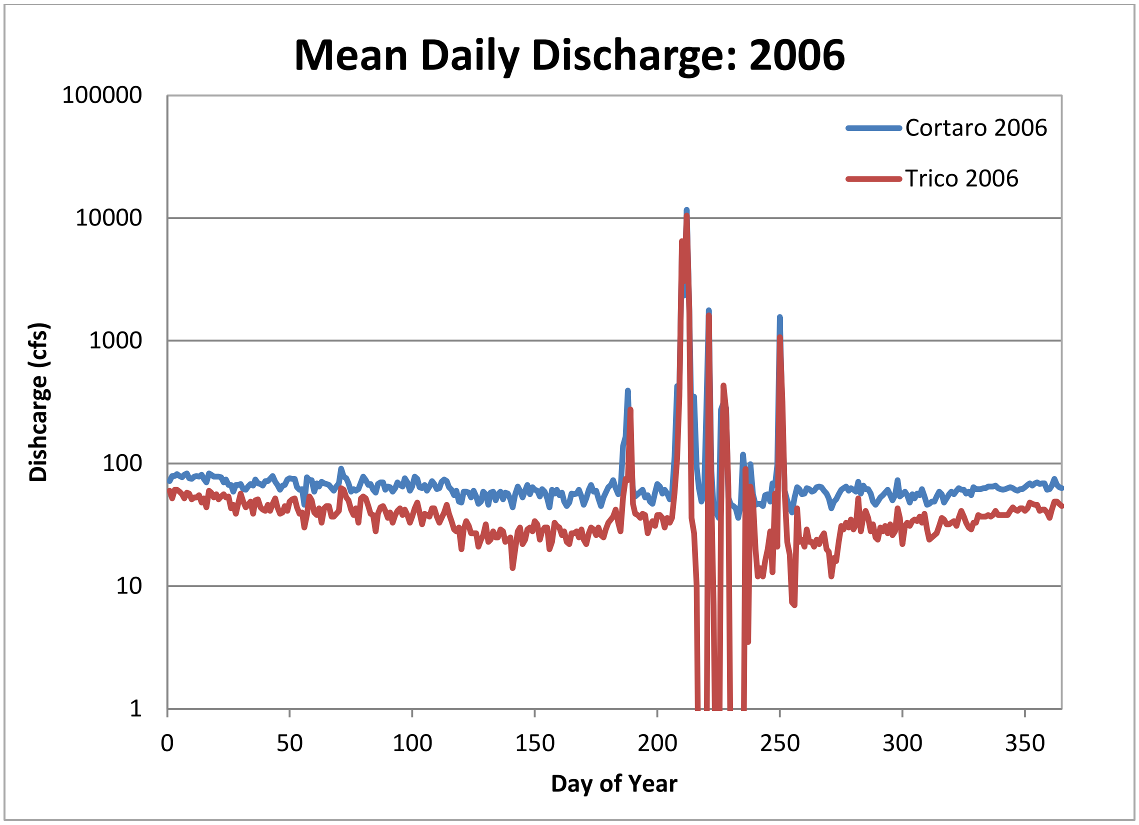


Fig. 2.13 Mean Daily Discharge at Cortaro Rd. and Trico Rd. Gauges, 2006

c. Possible Climatic Effects on Infiltration

While clearly flood events affect infiltration, the frequency of floods can be related to climate. Fall and winter events tend to reflect regional precipitation patterns, and a statewide rainfall analysis shows that the periods from 1975-1984 and 1990 to 1994 experienced some of the highest winter rainfalls of the past 100 years (Jacobs et al., 2005; Fig. 2.14). This larger regional rainfall pattern has been linked to the Pacific Decadal Oscillation, which was anomalously high in the periods of more scour events in the 1974-1984 and 1990 to 1994.

Lacher (1996) reported that infiltration increased after scouring events (Fig. 2.11). She noted that infiltration increased following an event which had a daily flow rate of least 2,200 cfs, though infiltration rates were found to be greater following a 3,000 cfs (daily) flow. Furthermore, she noted that infiltration rates declined with time since the last large event. Fig. 2.14 suggests increased infiltration rates are maintained for approximately 150 days after the latest major event.

While Lacher (1996) estimated the scouring flow to increase infiltration to be over 2200 cfs, a plot of flow rates with recharge values calculated for the managed recharge project shows increased recharge rates following events at slightly less than 2000 cfs (Fig. 2.15).

More recent studies have documented similar increasing infiltration following scour events on the Santa Cruz River north of Nogales (Treese et al, 2009); as well as in the LSCR (Case 2012). Case (2012) notes that drying the clogging layer can also cause the clogging layer to degrade, though it may come back faster when water returns.

A histogram of number of scouring events in five-year periods shows that the frequency of the scouring events over 2000 cfs varies over time, as does the time of year that the scouring events occur (Fig 2.16).

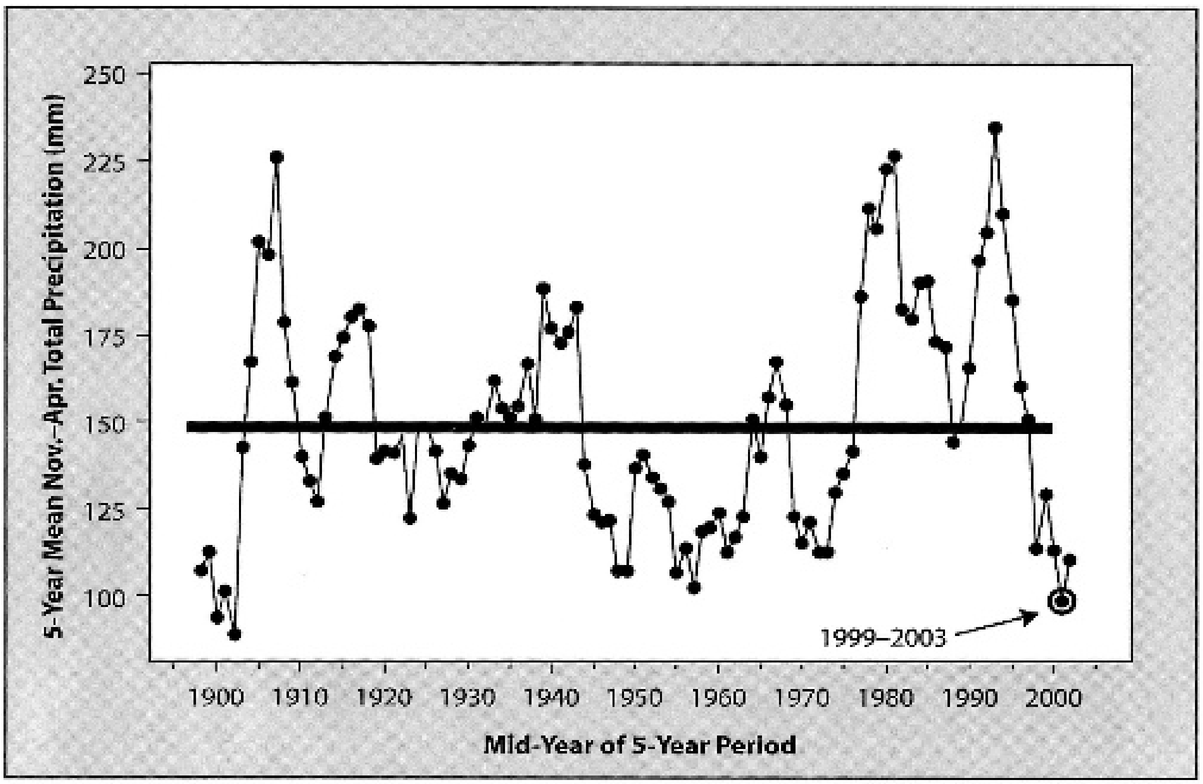


Fig. 2.14 Arizona Statewide Five-Year Average Winter Half Year (November to April) Precipitation, with the long term average five-year winter precipitation (Jacobs et al., 2005).

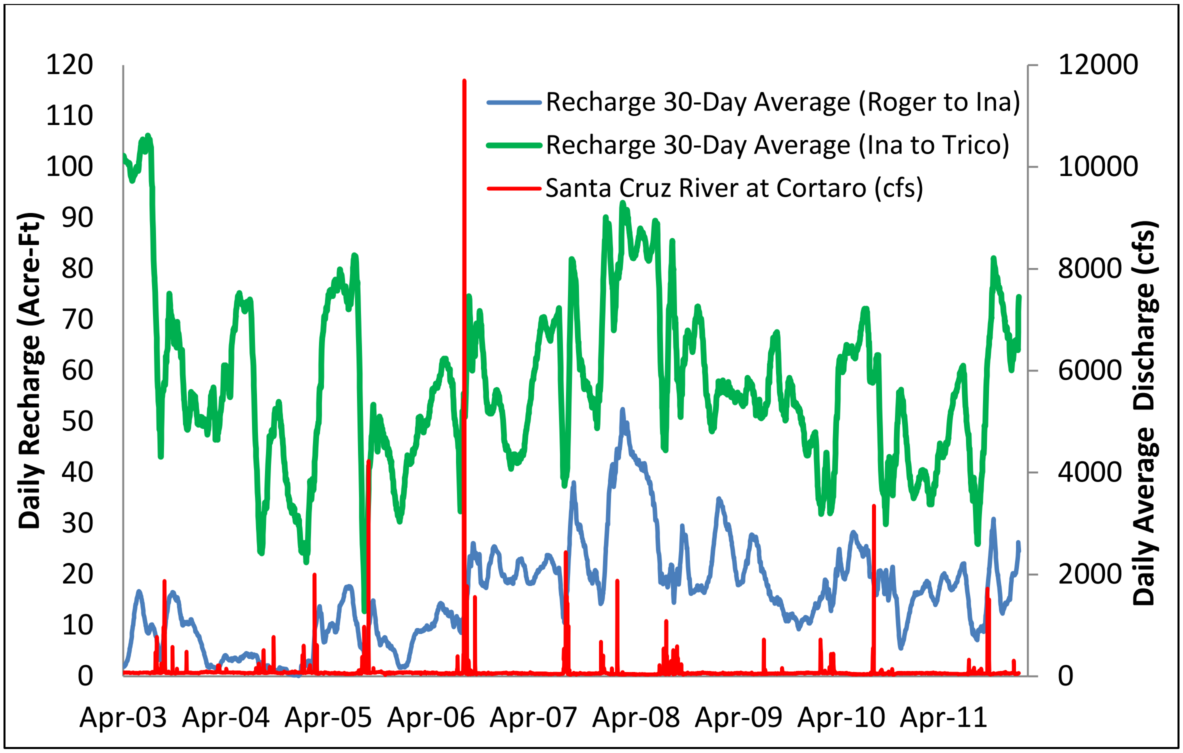


Fig. 2.15 Daily Discharge and 30-day Average Recharge

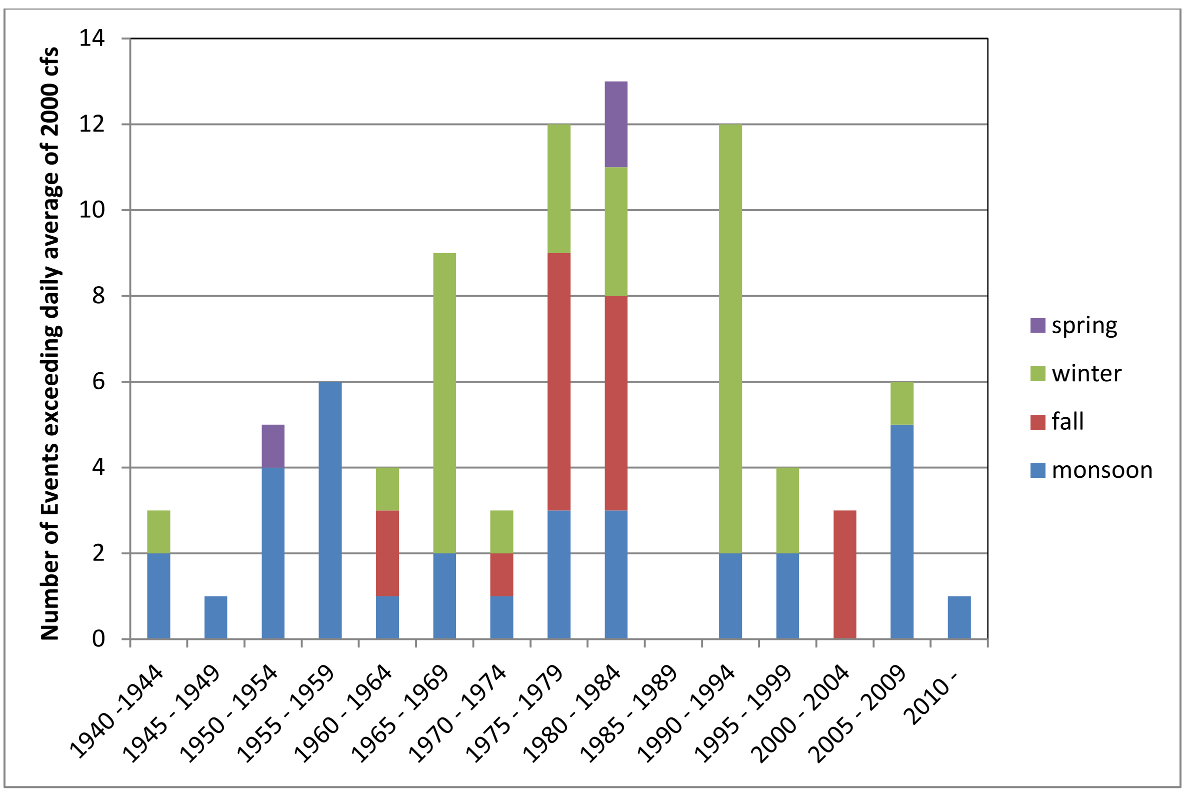


Fig. 2.16 Number of Events Exceeding Daily Average Discharge of 2,000 cfs

2.3.6 Impacts of Flow Diversion on Effluent Infiltration

Figs. 2.17 and 2.18 show the discharge measured at Cortaro Rd and Trico Rd gauges from May 1 to June 30, 2012. During the period from May 21 to June 8, 2012, the effluent flow did not reach Trico Road and USGS Trico Road gauge experienced zero discharge (Fig. 2.17). Pima County Regional Flood Control District (RFCD) had two projects to repair bank protections in the LSCR in May and June 2012 (Map 1). The first one is the excavation and dewatering the low flow channel to create a new flowpath at downstream of Cortaro Rd (approximately 1600 feet disturbance). This project was completed on May 4, 2012. The second one is a temporal diversion of a flow at upstream of Twin Peaks Rd where a split flow was observed in the past (over 6000 feet disturbance). The flow was diverted to the east branch of the low flow channel during the period from May 21 to June 4, 2012. According to a personal communication with a RFCD staff, east branch of the channel was dry before the diversion. Based on the timing that the USGS Trico Road gauge experienced no flow, it appears that the second project, the diversion of the flow to the east dry channel, caused no flow at the Trico Road gauge.

Rates of recharge for effluent flow between the USGS Cortato gauge and Trico gauge were less (~2.8 AF/mile/day) than recharge of effluent on the LSCR in the early 1990s and other wetter periods (Tucson Water, 2011). The recharge rates have increased to an average of 3.15 AF/mile/day in 2006 and 2007, as a result of large storm flows. In 2008, recharge rate was as high as 4.1 AF/mile/day (RFCD, 2011). Average recharge rate during the period from May 22 to June 7, 2012 that no flow was observed at the Trico gauge was 4.4 AF/mile/day with ranging from 3.9 to 5.1 AF/mile/day.

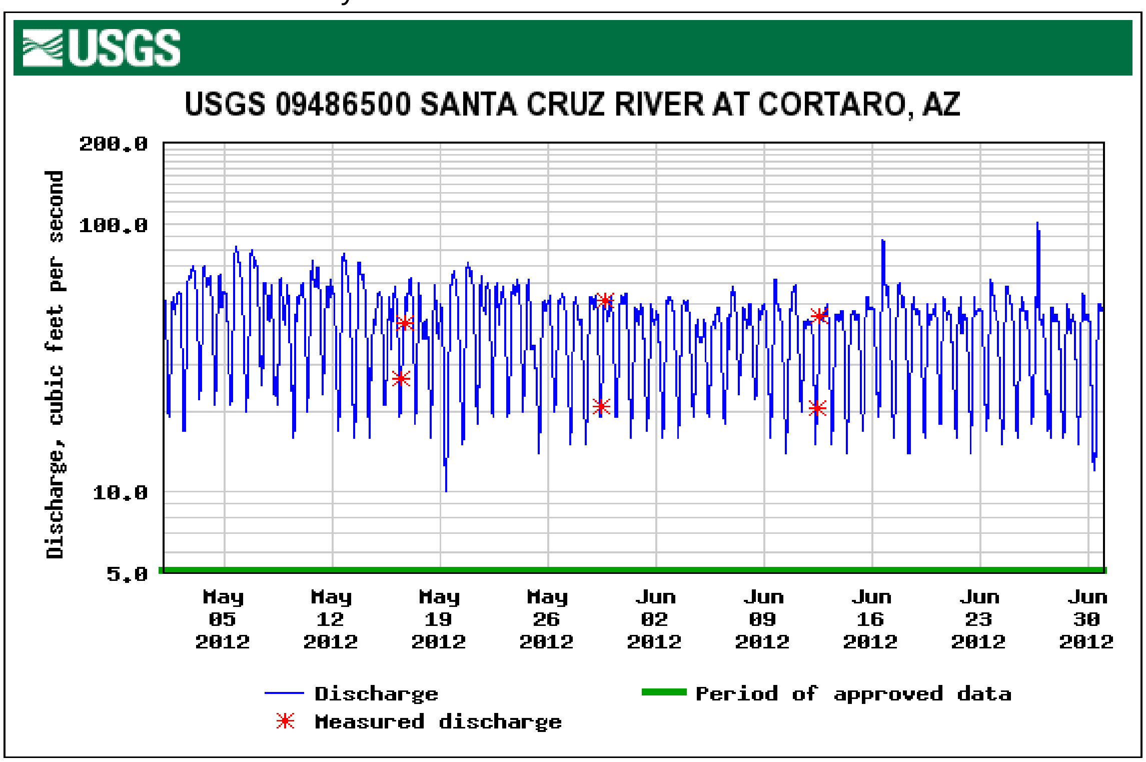


Fig. 2.17 Discharge at Cortaro Rd. Gauge from May 1 to June 30, 2012

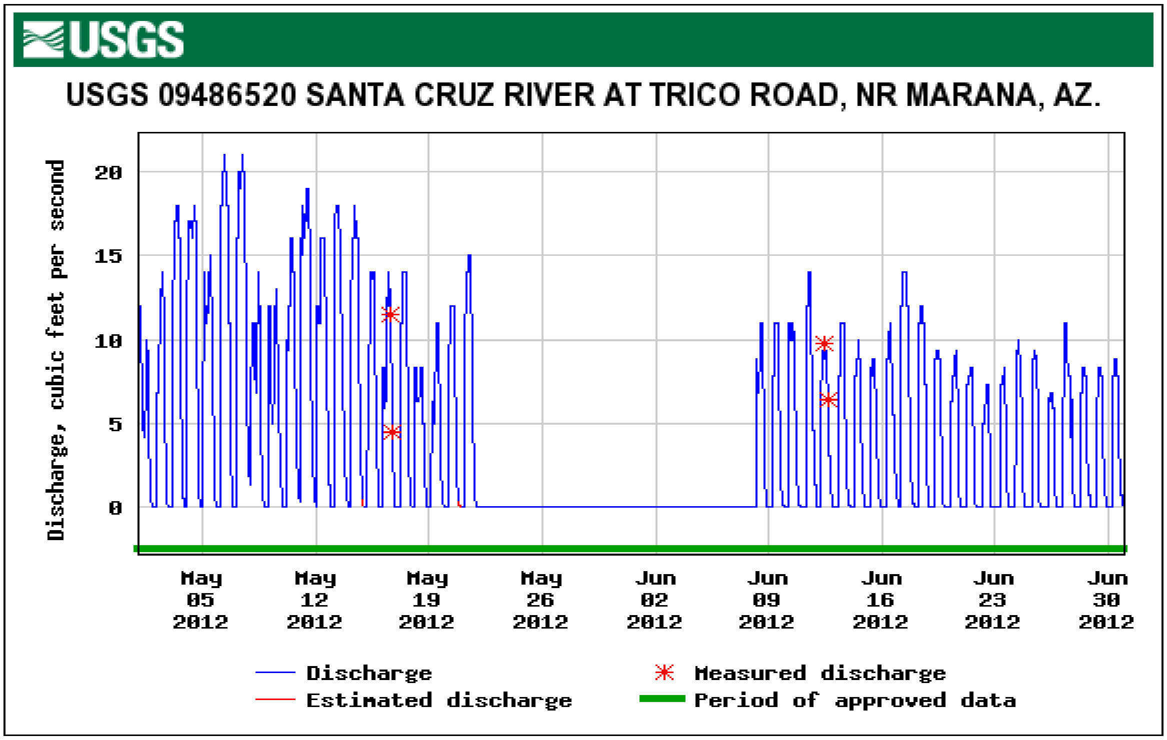


Fig. 2.18 Discharge at Trico Rd. Gauge from May 1 to June 30, 2012

RFCD measured the flow at approximately 45 feet downstream of the Twin Peaks Road Bridge on June 4, 6, 13, 20 and June 29, 2012. Fig. 2.19 and Table 2.4 show the measurement result. The flow increased with time after the blockage of the flow was removed at upstream of Twin Peaks Road.

Those results suggest that dry channel, the east branch where the flow was temporally diverted, was not covered with a clogging layer, resulting in an increase of infiltration rate.

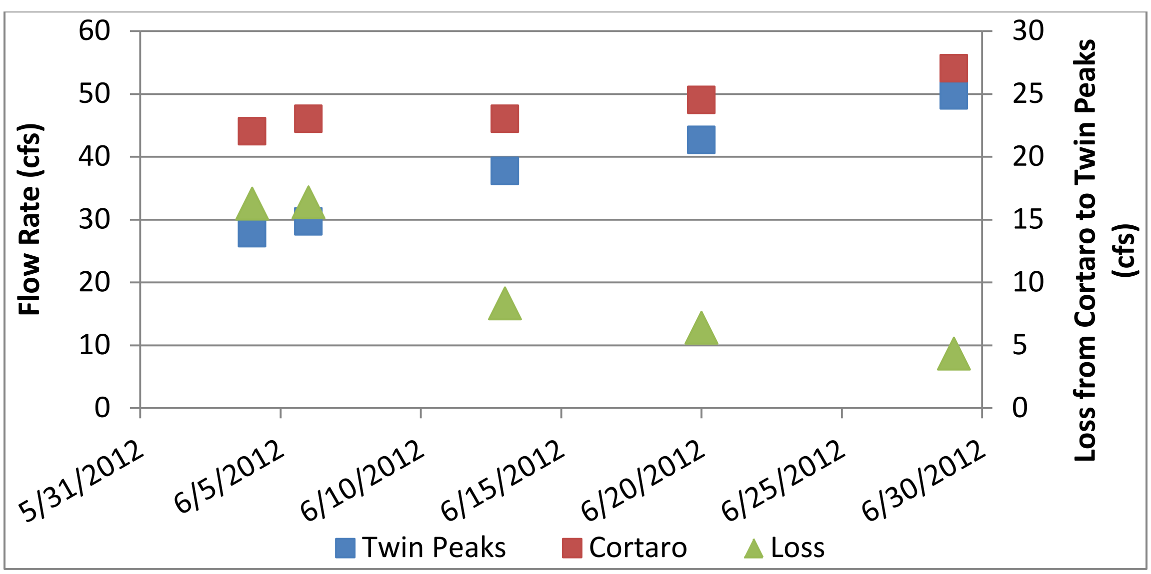


Fig. 2.19 Flows at Twin Peaks, Cortaro and Trico Roads

Table 2.4 Flow Measurement at Twin Peaks and Cortaro Road

	Twin Peaks		**Cortaro**	**Loss**		**Loss Rate**	
	Time	Discharge (cfs)	Discharge (cfs)	(cfs)	%	Triangle AF/mile/day	Fraction AF/mile/day
6/4/2012	5:15 PM	28	44	16	37%	7.7	11.8
6/6/2012	5:30 PM	30	46	16	36%	7.7	14.1
6/13/2012	5:45 PM	38	46	8	18%	3.9	6.2
6/20/2012	5:30 PM	43	49	6	13%	3.0	4.6
6/29/2012	5:15 PM	50	54	4	8%	2.0	2.6

The loss at Twin Peaks was determined during the high flow for the day, and is likely to change during the low flow part of the day. However, based on observations of the way losses have occurred through the year, a higher and lower estimate was calculated as follows:

Triangle – This method assumes that the hydrograph can be assumed to be a triangle, with low flow the same at both Cortaro and Twin peaks. The difference then is ½ flow difference summed through a day (i.e. ½ height x base).

Fraction – This method assumes that the loss through the day is proportional to loss measured at peak flow (e.g. if loss is 37% at peak, assume it is 37% of all flow at Cortaro for the day).

These calculations assume that losses occur throughout the 2.1 miles from Cortaro to Twin Peaks. However, most of the losses likely occurred in the diverted reach (especially in the first three dates), so loss rates may be about a factor of two higher for the early dates.

2.3.7 Enhanced Recharge Demonstration Project

The Bureau of Reclamation (Reclamation) launched a collaborative project with Tucson Water, Flowing Wells Irrigation District, RWRD and Metropolitan Domestic Water Improvement District to construct and operate the Enhanced Recharge Demonstration Project (ERDP) to increase recharge of treated effluent at the Managed Recharge Phase II Project (MR II) (Bureau of Reclamation, 2012). The purpose of the project is to increase recharge of effluent at the MR II under existing Arizona Department of Water Resources (ADWR) Underground Storage Facility (USF) permit number 71- 591928 and ADEQ Aquifer Protection Permit (APP) number 100630. The MR II USF is permitted to recharge 43,000 acre-feet per year (AFY) but historically has recharged less than 50% of the permitted recharge volume.

The ERDP was constructed in the LSCR in the Town of Marana (near SC-09, Map2) in January, 2011. ERDP was designed to allow a portion of the LSCR flow to divert into an abandoned thalweg for recharge via gravity flow. A hydraulic connection between the LSCR and the ERDP was excavated, lowering the bottom elevation of the abandoned thalweg. Flows into and out of the ERDP were recorded and infiltration rates were calculated. The ERDP was operated from January 28, 2011 to July 5, 2011. Unfortunately the ERDP was terminated sooner than the original plan because the ERDP washed out and the flumes and inlet were buried by sediment by summer monsoon storm flows on July 5, 2011.

Diversions into the ERDP ranged from less than 1 cubic foot per second (cfs) to approximately 5 cfs. The ERDP project was operated in a manner to discourage formation of a biologic clogging layer. Three maintenance events including improvements to the diversion inlet and drying, scraping, and ripping of the channel bottoms were completed during operation of the ERDP to promote maximum infiltration rates. The findings of the projects are i) average daily recharge rate was 0.28 AF for an undisturbed condition. Infiltration rate for the undisturbed condition averaged 1 foot per day (ft/day) with a range from 0 ft/day to 15 ft /day; ii) average daily recharge rate was 1.13 AF after channel maintenance to remove sediment. Infiltration rate for the disturbed condition (after the maintenance events) averaged 3 feet per day (ft/d), and ranged from 0 ft/day to 10 ft/day. The project found that in-channel recharge rates declines over time after the maintenance events and channel maintenance could increase recharge rates 4 to 5 times that of pre-maintenance rates. The project suggested that in-channel recharge has multiple benefits including conservation and management of water resources, maintenance and enhancement of environmental habitat and increased public recreation opportunities.

2.3.8 Diurnal Effluent Flow

Figs. 2.20 and 2.21 show diurnal effluent discharge measured at the Ina Rd. and Roger Rd. WRFs in 2010. There was little variation in diurnal discharge at the Ina Rd. WRF in 2010, while the diurnal discharge varied during a day at the Roger Rd. WRF. The peak discharge occurred around 1 pm at the both WRFs except August 17, 2010 at the Roger WRF (Figs. 2.20 and 2.21). Effluent discharge at the Ina Rd. WRF decreases until approximately 7 am, increases between 8 am to 1 pm and it remains at relatively greater rates from 1 pm to 12 am (Fig. 2.20).

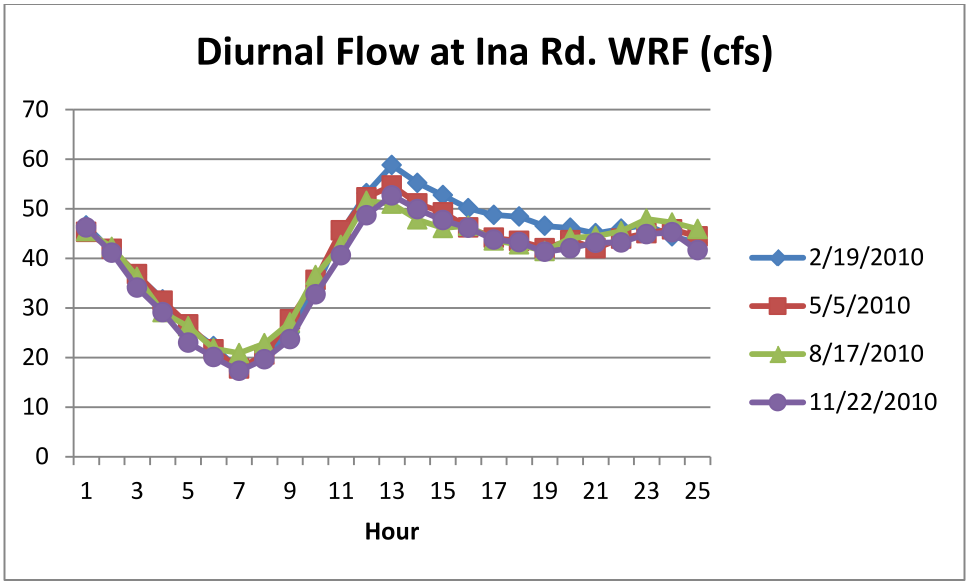


Fig. 2.20 Diurnal Effluent Discharge at the Ina Rd. WRF

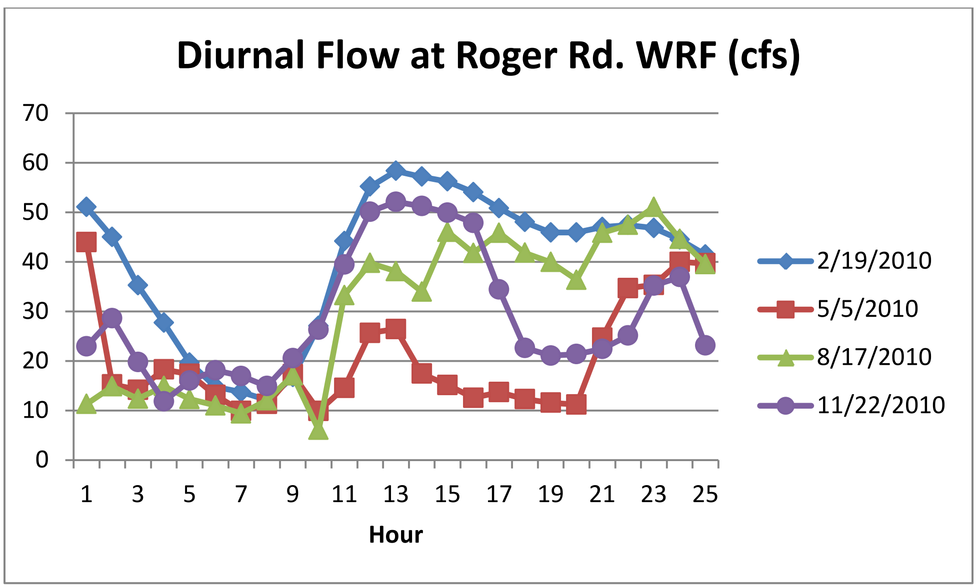


Fig. 2.21 Diurnal Effluent Discharge at the Roger Rd. WRF

2.4 Conclusion

The LSCR has been a perennial stream since about 1973 with most of the flow at Cortaro Rd being effluent-derived. Only in years with very large flood events does stormflow contribute significantly to the total flow.

While stormflow is a smaller part of the total volume in the river, storm events are extremely important in partitioning the water between that which infiltrates and that which flows downstream. Scouring of the stream bed removes the clogging layer, which results in much higher infiltration following storm events.

The previous studies indicated that infiltration rate is more dependent on the number of scouring events and time since last scour event. The frequency and magnitude of scouring events can be linked to regional rainfall patterns, especially fall and winter rainfall patterns, which suggests a link to larger climate trends. The RFCD project showed that flow diversion substantially increase effluent infiltration. This suggests that infiltration rate is largely controlled by a clogging layer.

The reduction in nutrients discharged from the Nogales international treatment plant has coincided with an increase in infiltration rates in that portion of the river, which suggests a reduction in nutrients will cause a reduction in biological clogging.

In the LSCR we can expect that a reduction in nutrient discharge will improve infiltration rates, but it is unknown whether it will exceed the rates observed by Gaylean from 1991 to 1993.

A 10-year running average of monthly losses clearly demonstrates a continuous reduction in infiltration in the LSCR. From 1991 to 2000, the LSCR experienced an average monthly loss rate of 3174 AF-month; from 2001 to 2010 the average monthly loss rate was reduced to 2094 AF-month.

2.5 References

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