A. Modeling Infiltration Rates in the Lower Santa Cruz River

A.1 Modeling Approach

For our approach we considered both empirical loss calculations and modeled infiltration rates. The modeling approach followed on the methods used by Lacher (1996) who modeled infiltration using the KINEROS2 hydrologic model, which routes flows using the kinematic wave and models infiltration using a modified Green & Ampt infiltration equation. The primary benefit of this approach is the use of one parameter to model the migration of the wave (Manning's n) and one parameter to model infiltration (saturated hydraulic conductivity). Lacher modeled flow and calibrated using data collected at Ina and Avra Valley Roads.

The approach we used was to replicate Lacher's study using the KINEROS2 model so that infiltration rates can be compared with the rates determined by Lacher. Rather than doing our own stream gauging, we used the data being collected by USGS at Cortaro and Trico Roads.

A.2 Purpose

The purpose of this study is twofold as follows:

1.) To determine how infiltration parameters have changed since they were last determined in the study described by Lacher (1996).
2.) To develop parameter values that can be used to simulate infiltration for modeling on flow and scour for determining the impacts of flows before and after the ROMP upgrades.

A.3 Methods

a. **Development of Model Geometry for Kineros2:** KINEROS2 models channels as trapezoidal features requiring a base width, length, channel side slope and profile slope. While Lidar data has proven to be an effective means to develop channel geometry for flood flow models, it did not prove to be helpful for determining the low flow channel geometry containing the effluent flows, because the lidar was unable to penetrate through the water to provide an elevation in the wet portion of the channel.

   The strategy we used was to use the most recent air photo data (2010 Pictometry, supplemented with 2008 1' orthophotos where pictometry is not available) and digitize the wet portion of the channel from the air photo.

   The channel was digitized in a series of reaches where a polygon of similar width could be identified. The length was also determined. By determining the area of the polygon and the length, a mean channel width could be determined. The profile slope was determined by identifying a point adjacent to the channel at approximately the water surface. Because the water slope is assumed to be parallel to the channel slope, and the reaches were fairly long the channel slope determined in this was assumed to be reasonable.

   Based on field observation which showed that the main flow channel had nearly vertical side slopes, a channel side slope of 0.5 (2 ft high for every ft wide) was used.

b. **Development of 'equivalent channel geometry' for split flow conditions:** Because KINEROS cannot model split flow conditions, when split flow conditions were encountered, we developed an 'equivalent channel geometry' by considering the geometry of each side of the split. In most cases, the splits had very similar flow lengths (<5% difference), so the two lengths were averaged. Likewise, since the infiltration depends on the footprint of the channel, the widths of the two splits were summed. In this way, a single channel flow width configuration.

c. **Validation with Channel Geometry:** We also performed some field checks of channel geometry to validate the values determined from digitizing the wet portion of the channel in the air photos.

d. **Preliminary Estimate of Saturated Hydraulic Conductivity (Ks) and Manning's n:** Initial parameter values came from Lacher (1996). While she determined that Ks values varied through the year we began with her values and then assumed that calibrated values would be a 'multiplier' of the initial estimate

(e.g. $Ksn_{calibrated} = Ks_o n$ x *multiplier* for channel reach n). In this way, any spatial variability identified in the initial estimate could be preserved while moving all initial estimates higher or lower.

e. **Calibration of Saturated Hydraulic Conductivity (Ks) and Manning's n for the channel.** The model was calibrated using the multiplier approach with inflow data for four different dates being calibrated to match discharge data from the USGS gauging stations for Trico Rd and validated by comparing the modeled hydrograph from Cortaro Rd with the USGS gauging station data for that site. Each of the four dates were modeled separately, because infiltration has been observed to change based on whether a scour event has occurred recently. Calibration was done using an automatic optimization procedure, which used repeated trial and error coupled using the Nash Sutcliffe statistic as a measure of success (SCEUA – Duan, 1992). The trial and error process then converged on a parameter set for each dataset

f. **Goodness of Fit Criteria:** The goodness of fit of the simulation was calculated using two different statistics as follows:
   a. Root Mean Square Error (in cfs): The root mean square error (RMSE) was calculated for each point in the hydrograph for the observed value and the modeled value as follows:

$$RMSE = \sqrt{\frac{\sum (Modeled - Observed)^2}{n}}$$

   b. Nash-Sutcliffe Model Efficiency Statistic: The Nash-Sutcliffe statistic

$$NSE = 1 - \frac{\sum (Modeled - Observed)^2}{\sum (Observed - \frac{\sum Observed}{n})^2}$$

The NSE is dimensionless. A perfect simulation will yield a value of 1.0. A value of '0' would represents a simulation equivalent to using the mean of the observed values for all simulations.

A.4 Results

a. Selected Multipliers: The following multipliers were derived using the optimization technique.

Table D.1 Selected Multipliers

	Optimal Parameter Set	
Event	**multiplier Ks**	**multiplier 'n'**
19-Feb-10	0.533	0.938
5-May-10	0.508	0.873
17-Aug-10	0.673	0.818
22-Nov-10	0.346	0.927

These values indicate that saturated hydraulic conductivity (Ks) have declined to about half (35% to 67%) of the values determined by Lacher (1996), while Manning's 'n' of the channel has remained approximately the same.

b. Selected Parameter Values: The parameter values for the events with the goodness of fit criteria are as follows:

Table D.2 Selected Parameters

			Cortaro		Trico	
Event	**Ks (in/hr)**	**Man 'n'**	**RMSE (cfs)**	**NSE**	**RMSE (cfs)**	**NSE**
19-Feb-10	0.38	0.028	15.0	0.42	7.3	0.65
5-May-10	0.36	0.026	12.8	-0.11	9.0	0.25
17-Aug-10	0.48	0.025	8.3	0.61	6.7	0.51
22-Nov-10	0.25	0.028	10.2	0.66	7.2	0.84

In this optimization, the Trico data served as calibration data, and the Cortaro data served as validation. The NSE values greater than 0.5 are generally considered to be good. For visual comparison, the plotted comparisons are shown in the figures below.

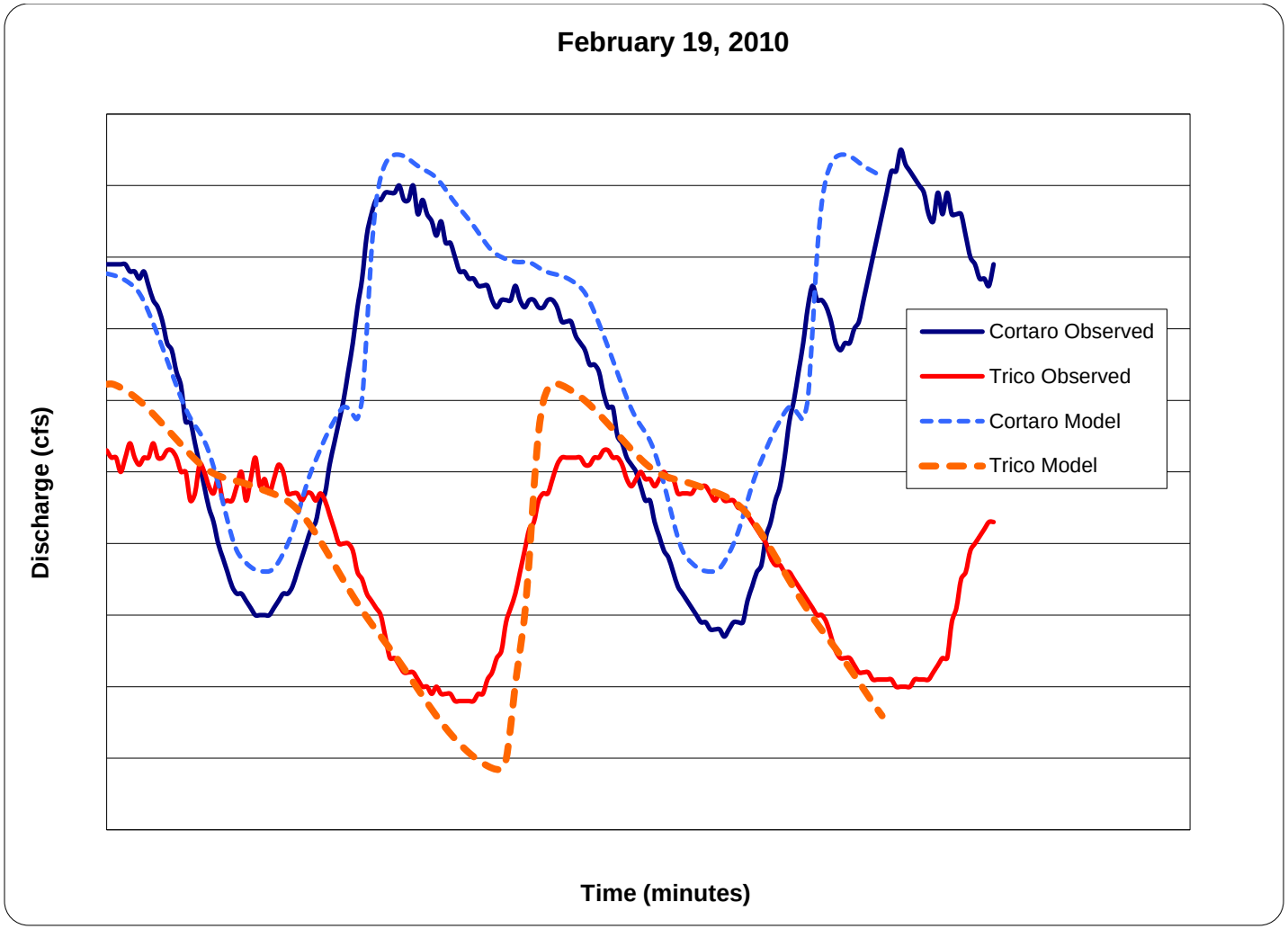

Fig. A.1 Modeling Results

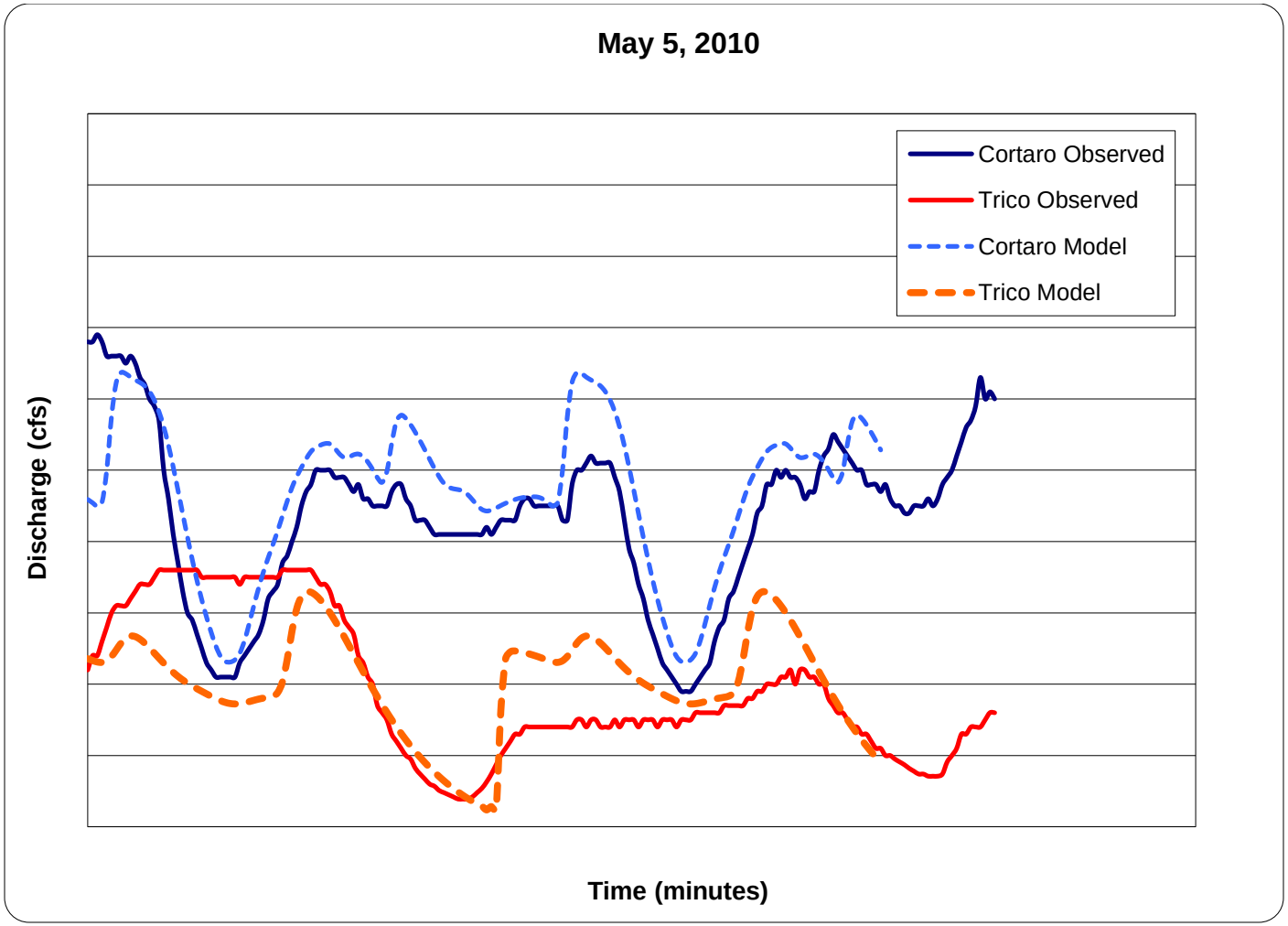

Fig. A.2 Modeling Results

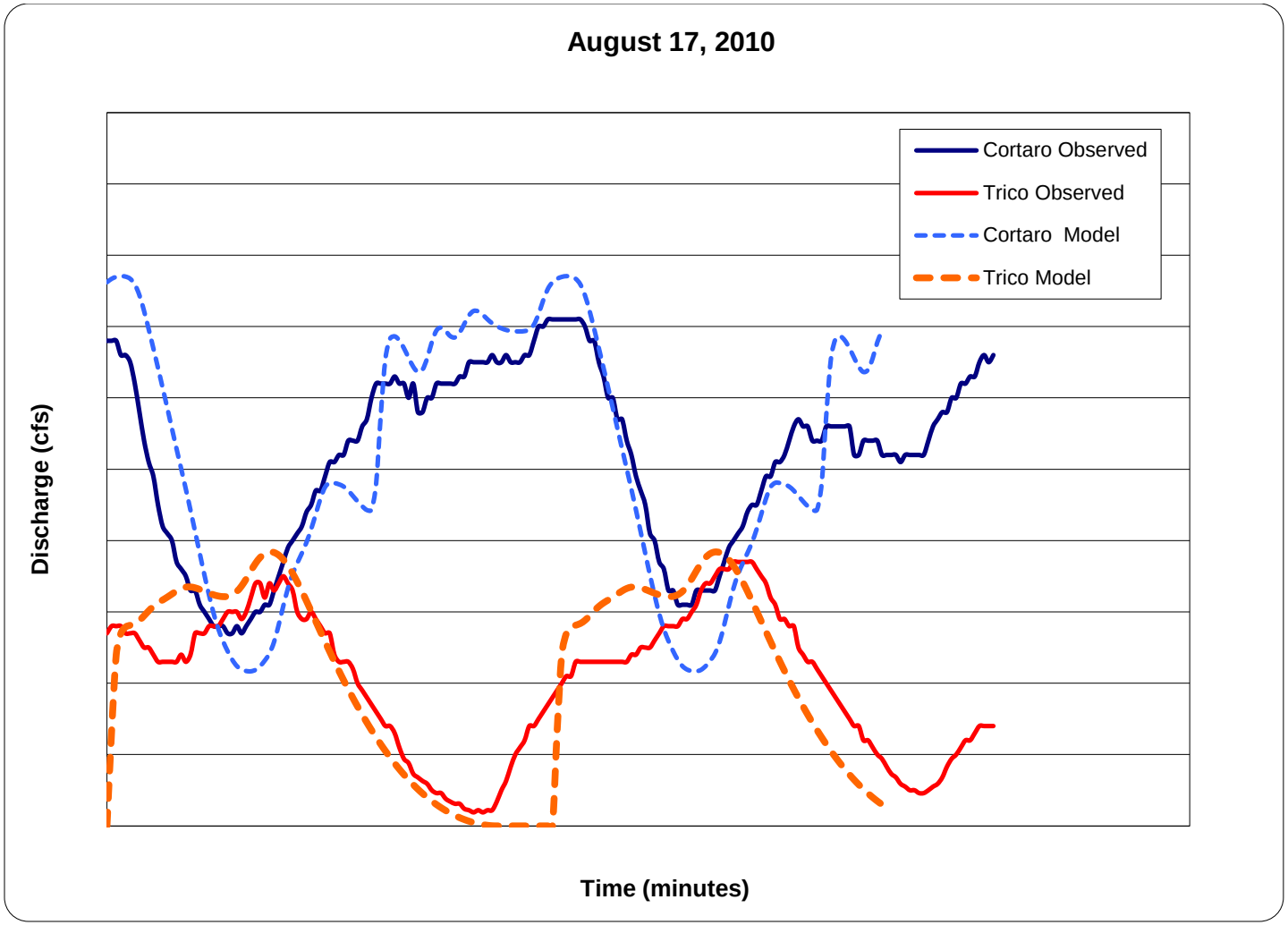

Fig. A.3 Modeling Results

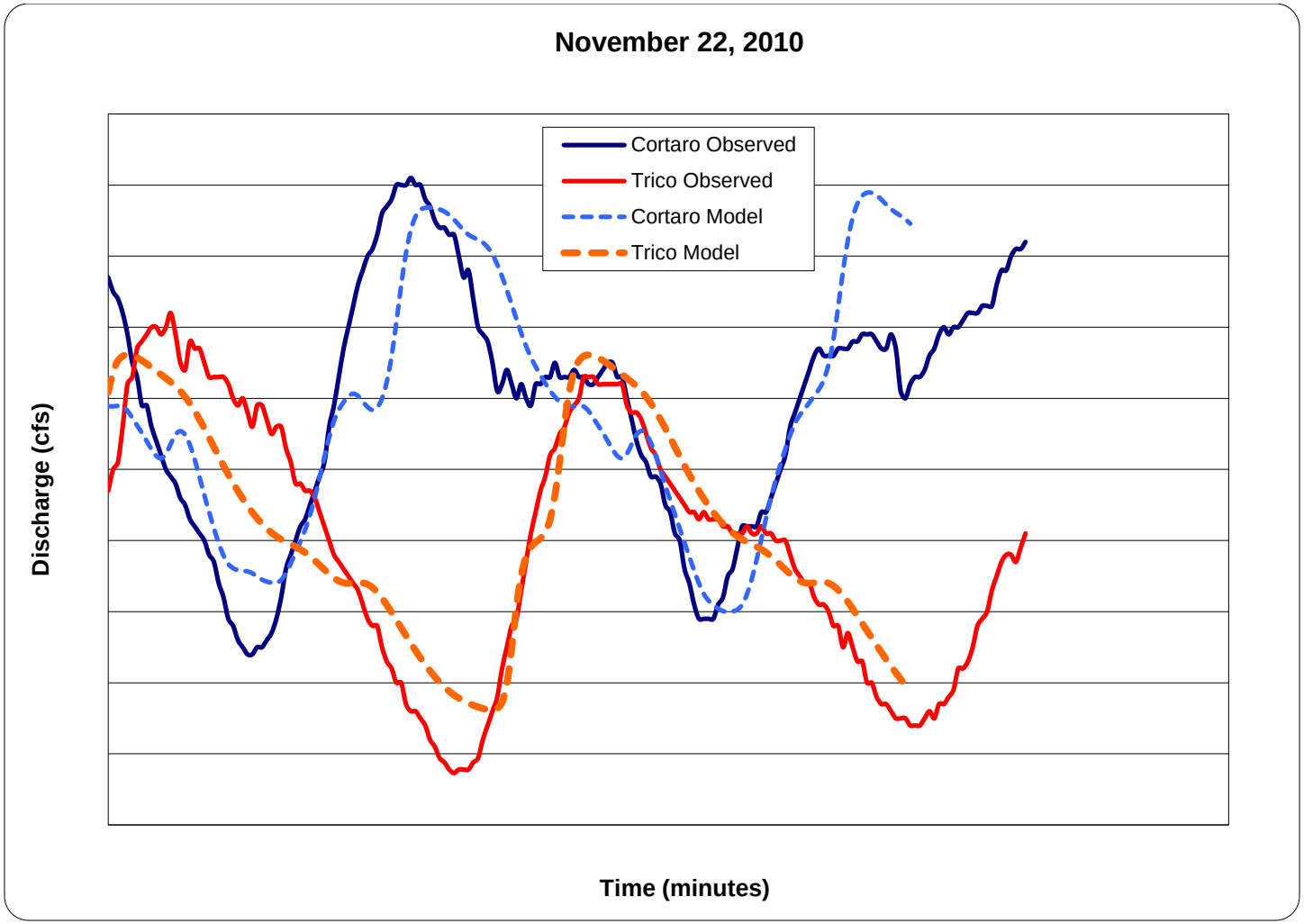

Fig. A.4 Modeling Results

A.5 Discussion

The results indicate a general trend of decreased infiltration of effluent into the bed of the Santa Cruz River in comparison to 1996. However, the values do change through the year. To understand the reason for the variability it is helpful to understand that larger events have the potential to scour the river bed and remove the clogging layer known to be present in the Santa Cruz River. Lacher (1996) determined that Ks increased by a factor of three following four larger events, the largest of which was about 3500 cfs. Likewise, Treese et al. (2009) found that events an order of magnitude less (350 cfs) were powerful enough to scour the bed in the Upper Santa Cruz River near Tubac.

In 2010, the highest flows occurred during the Monsoon, including a flow of 16,800 cfs at Cortaro Rd on 7/31/2010 (9450 cfs at Trico). Following this event, daily discharge at Trico falling almost to zero (0.7 ac-ft/day) from an average daily discharge of 114 ac-ft/day. For this reason, it is not surprising that the highest of the four Ks values occurred on August 17, 2010.

A.6 Conclusions

A modeling exercise that reproduced the study done by Lacher (1996) found that the Manning's 'n' roughness values were similar to those used by Lacher, but that saturated hydraulic conductivity was only about half. While the Ks varied through the year, and increases following the large Monsoon flow events, it returned to a value of about 0.37 in/hr. Manning's 'n' remained at about 0.02

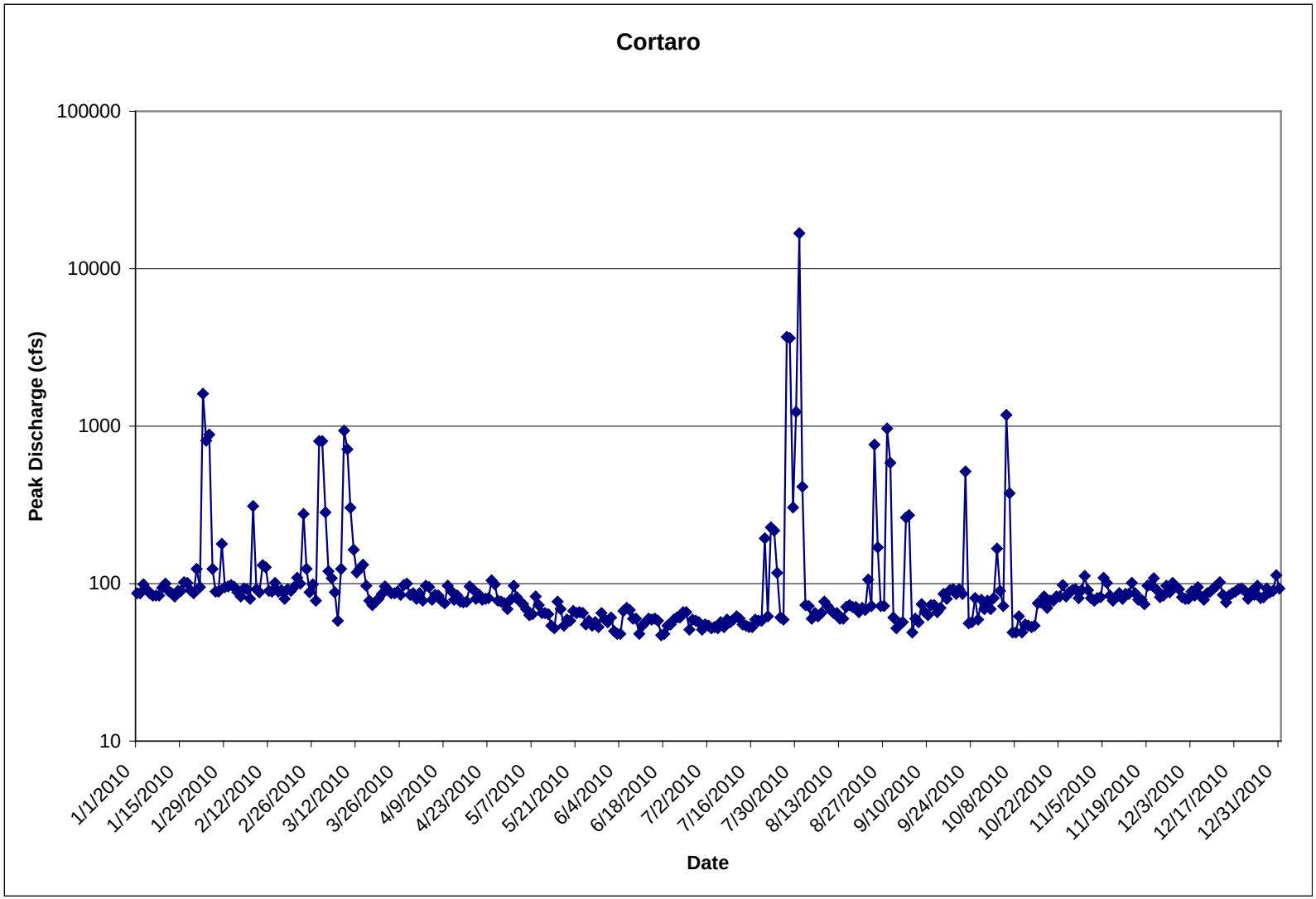

Fig. A.5 Peak Discharge Measured at Cortaro Gage

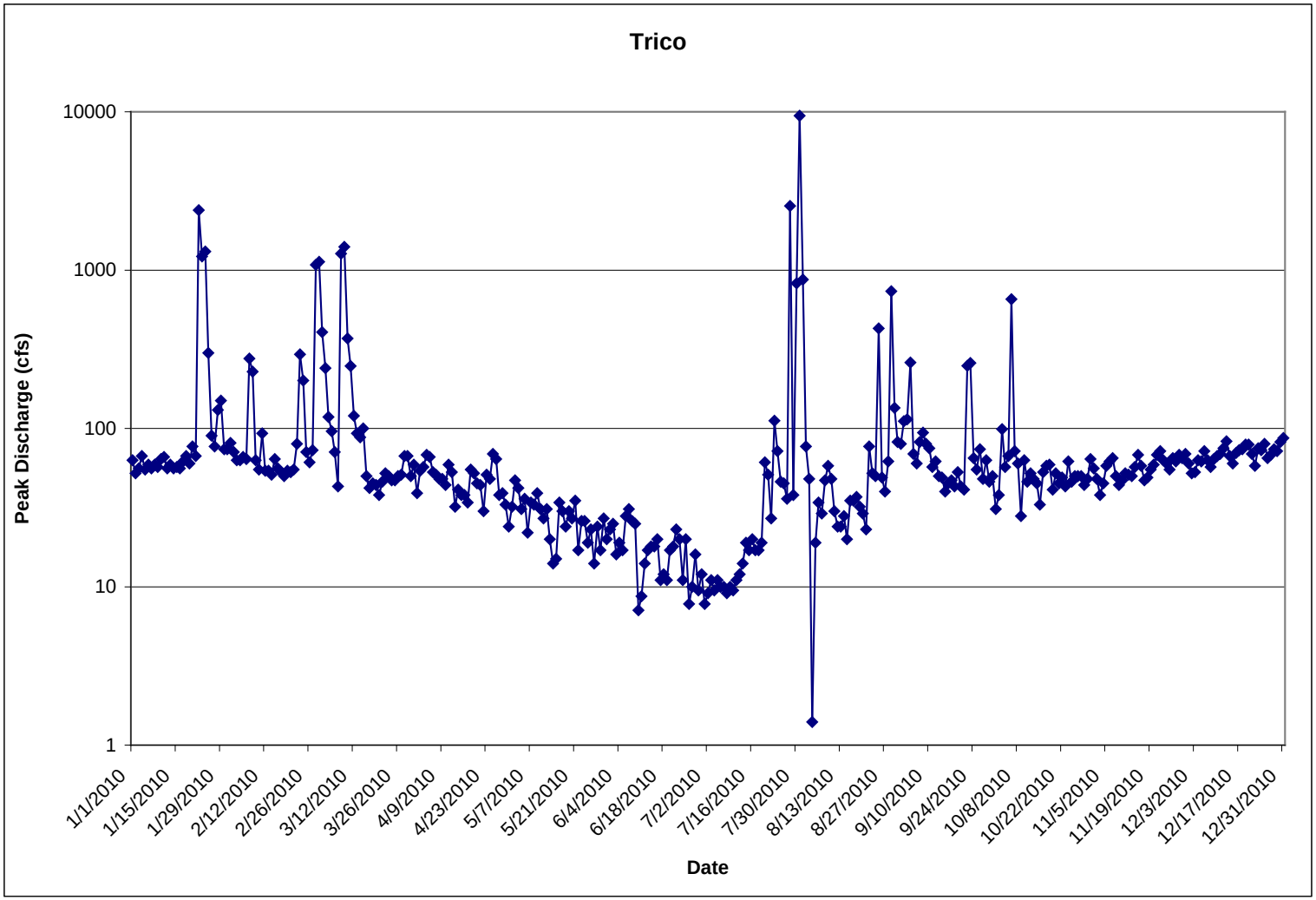

Fig. A.6 Peak Discharge Measured at Trico Gage

A.7 References

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B. Summary of Channel Geomorphology Changes

Tables B1.1-B2.2 summarize the average, minimum and maximum depth change and standard deviation in an effluent flow channel or a floodplain.

Table B1.1 Summary of Depth Changes in a Floodplain between 1998 and 2005

Reach		Average (feet)	Minimum (feet)	Maximum (feet)	Std (feet)
1	Trico-Sanders	-0.34	-17.00	11.00	1.60
2	Sanders-Avra Valley	-0.15	-19.00	19.00	1.62
3	Avra Valley-Cement Plant	-0.69	-13.00	19.00	2.15
4	Cement Plant-Cortaro	-0.06	-10.00	17.00	1.24
5	Cortaro-Ina	-4.50	-19.00	19.00	5.30
6	Ina-Sunset	0.30	-19.00	15.00	2.05
7	Sunset-Sweetwater	1.45	-19.00	19.00	5.26

Table B1.2 Summary of Depth Changes in a Floodplain between 2005 and 2008

Reach		Average (feet)	Minimum (feet)	Maximum (feet)	Std (feet)
1	Trico-Sanders	0.19	-14.00	12.00	0.85
2	Sanders-Avra Valley	-0.16	-13.00	9.00	1.31
3	Avra Valley-Cement Plant	0.22	-17.00	11.00	1.72
4	Cement Plant-Cortaro	-0.13	-17.00	17.00	1.34
5	Cortaro-Ina	0.85	-18.00	19.00	3.05
6	Ina-Sunset	0.21	-14.00	19.00	1.99
7	Sunset-Sweetwater	-1.72	-19.00	19.00	4.86

Table B2.1 Summary of Depth Changes in an Effluent flow Channel between 1998 and 2005

Reach		Average (feet)	Minimum (feet)	Maximum (feet)	Std (feet)
1	Trico-Sanders	0.06	-17.00	10.00	1.49
2	Sanders-Avra Valley	-1.03	-16.00	19.00	3.11
3	Avra Valley-Cement Plant	-0.39	-10.00	10.00	2.92
4	Cement Plant-Cortaro	-0.28	-8.00	5.00	1.96
5	Cortaro-Ina	-3.90	-14.00	14.00	4.28
6	Ina-Sunset	0.32	-19.00	10.00	2.65
7	Sunset-Sweetwater	-0.42	-19.00	19.00	7.83

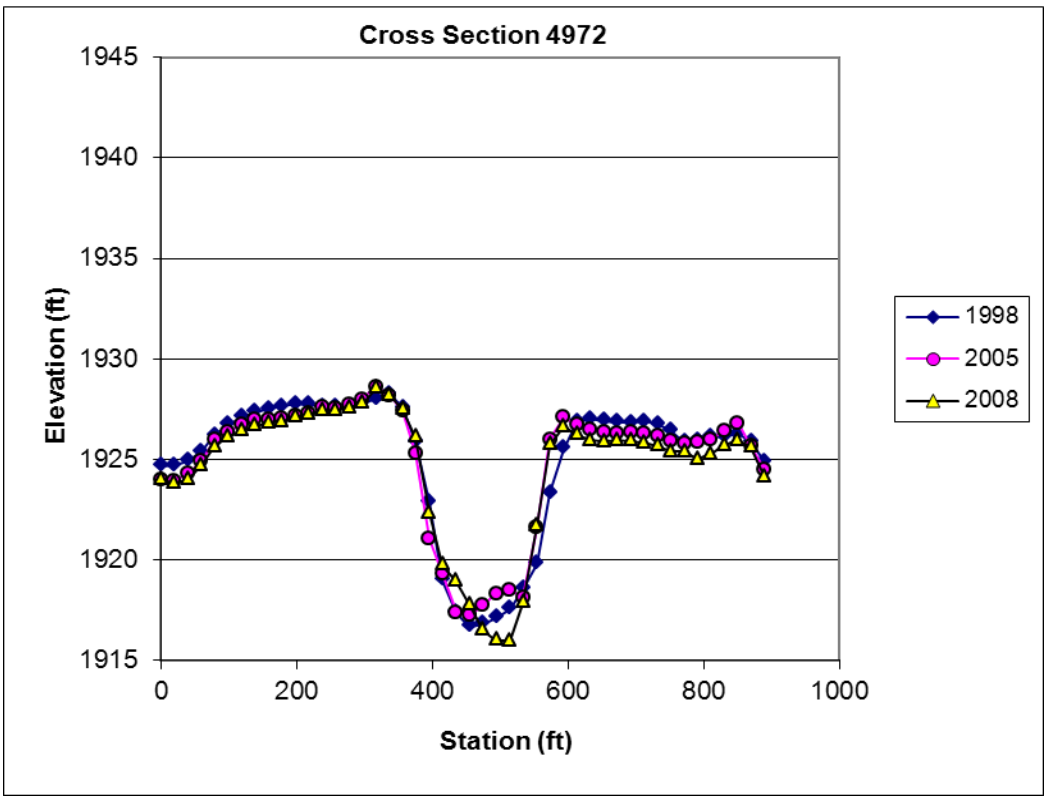
Table B2.2 Summary of Depth Changes in a Effluent flow Channel between 2005 and 2008

Reach		Average (feet)	Minimum (feet)	Maximum (feet)	Std (feet)
1	Trico-Sanders	0.03	-10.00	7.00	1.79
2	Sanders-Avra Valley	-1.80	-13.00	8.00	2.95
3	Avra Valley-Cement Plant	-0.67	-12.00	8.00	3.14
4	Cement Plant-Cortaro	-1.13	-11.00	9.00	2.34
5	Cortaro-Ina	0.03	-15.00	8.00	3.96
6	Ina-Sunset	-0.96	-13.00	7.00	2.53
7	Sunset-Sweetwater	-3.76	-19.00	18.00	6.50

C. Cross Section Profiles

Figs. C1-C7 show cross section profiles in 1998, 2005 and 2008. As mentioned before, it should be noted that the original topographic data for 1998 is not as fine as the topographic data for 2005 and 2008. The locations of the cross sections are shown in Exhibit A3. A couple of cross sections were placed in each reach. Additionally, cross sections were placed at immediately downstream of large washes with 100-yr peak discharge exceeding 2,000 cfs. Cross section station # 60486 is located immediately downstream of Canada Agua wash. Cross section station # 67120 is located immediately downstream of Picture Rock wash. Cross section station # 89768 is located immediately downstream of the confluence with Canada del Oro wash, while cross section station # 95731 is located immediately downstream of Rillito River. Cross section station # 102472 is immediately downstream of unknown wash.

Low flow channel locations were substantially changed during the study period at the cross section stations # 44429, 51522, 53911 and 76072. At the cross sections immediately downstream of Canada del Oro wash and Rillito River (89768 and 95731), both erosion and deposition occurred during the study period.



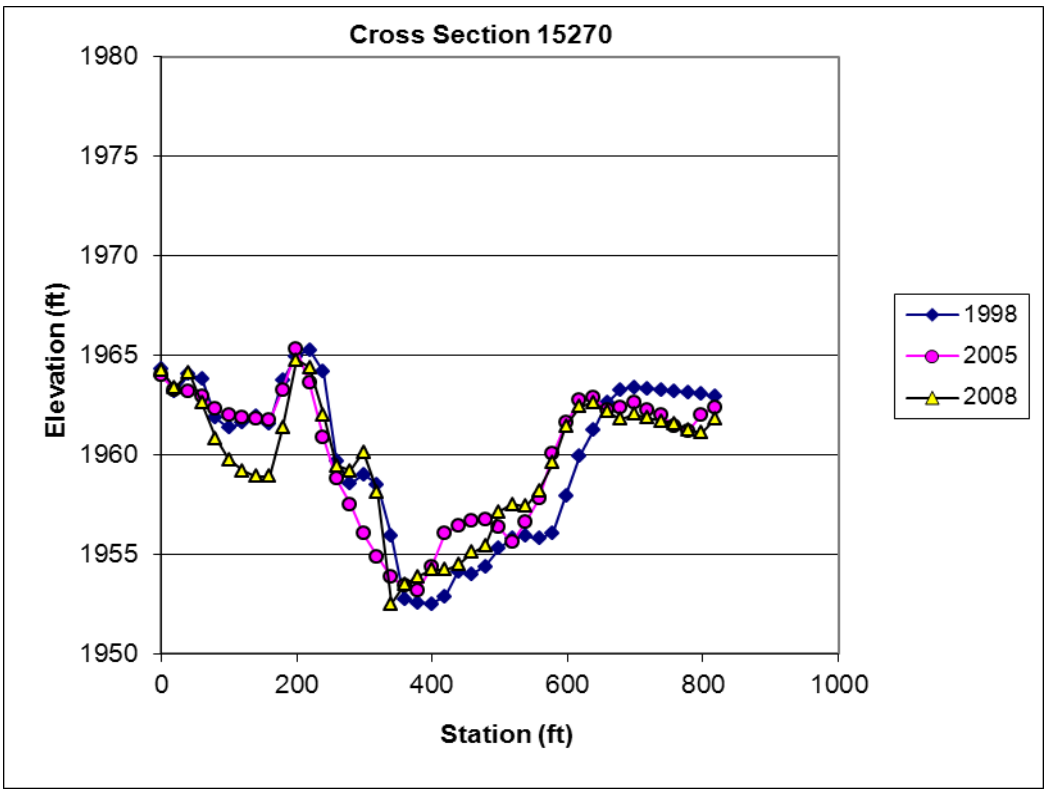
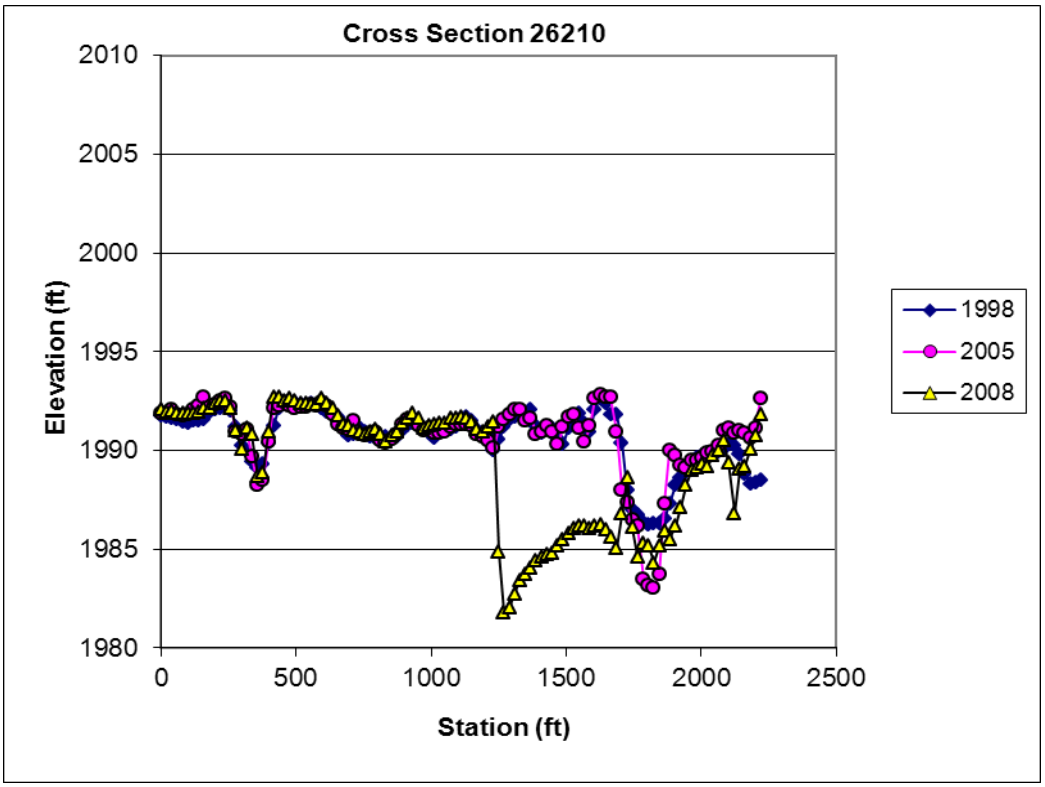


Fig. C1 Cross Section Profiles in the Reach 1



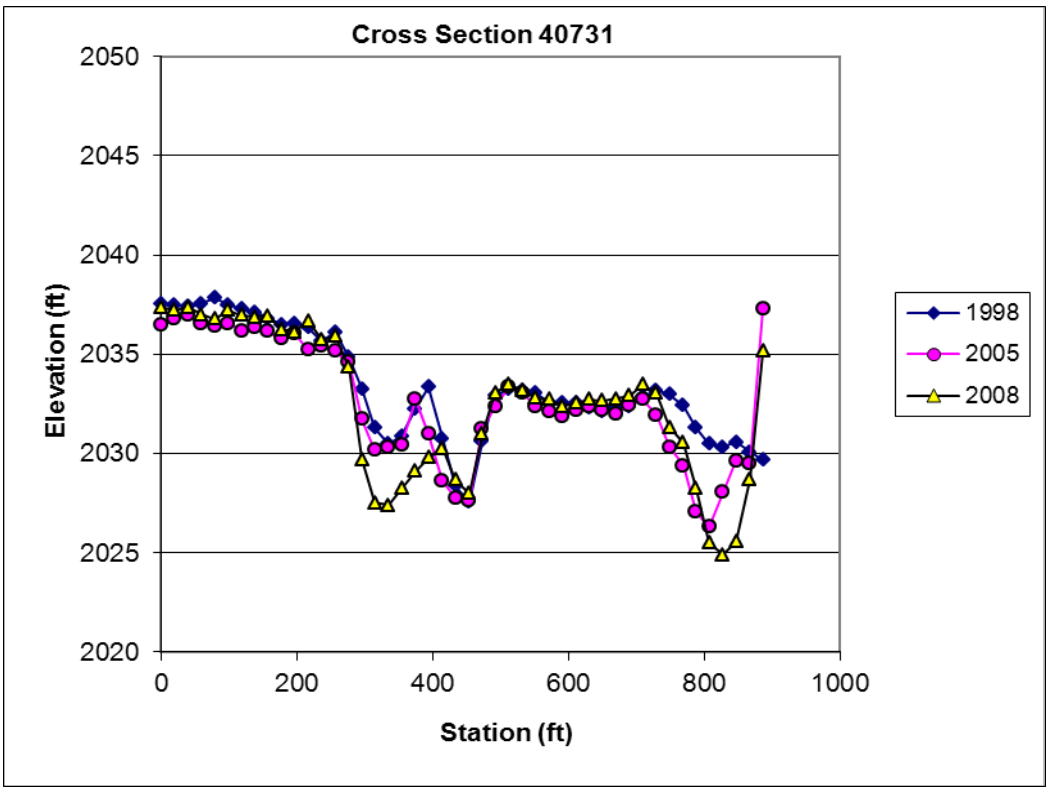


Fig. C2.1 Cross Section Profiles in the Reach 2

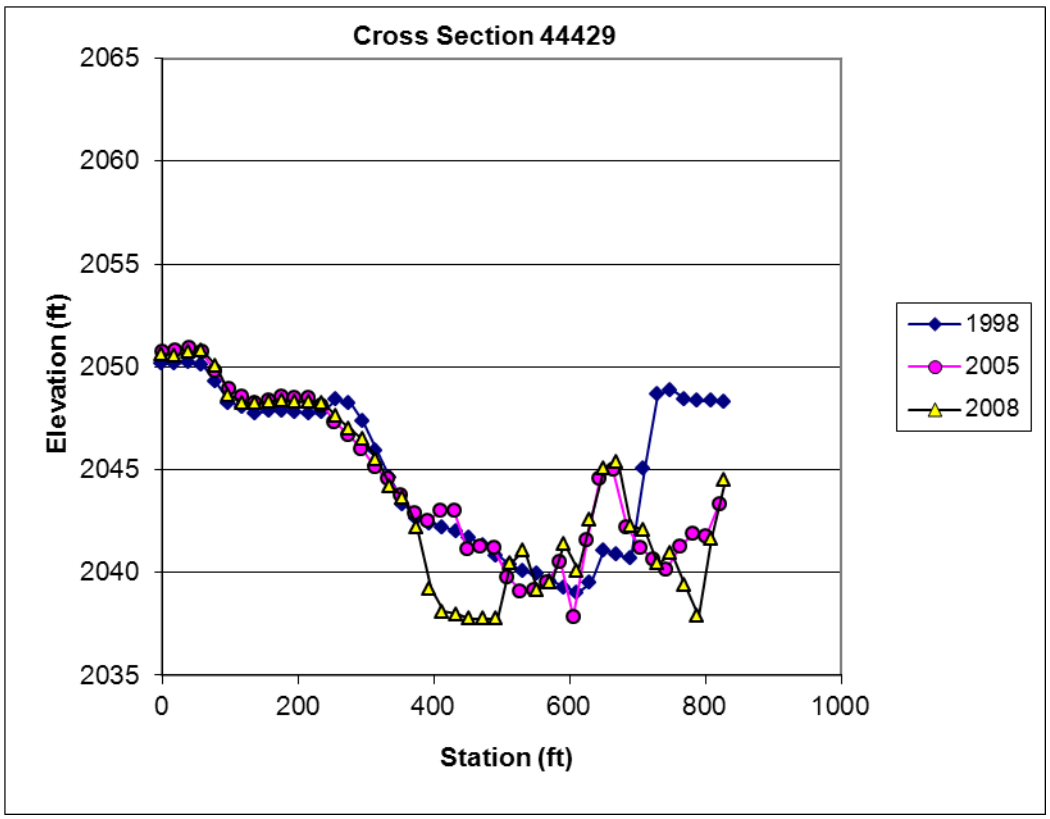
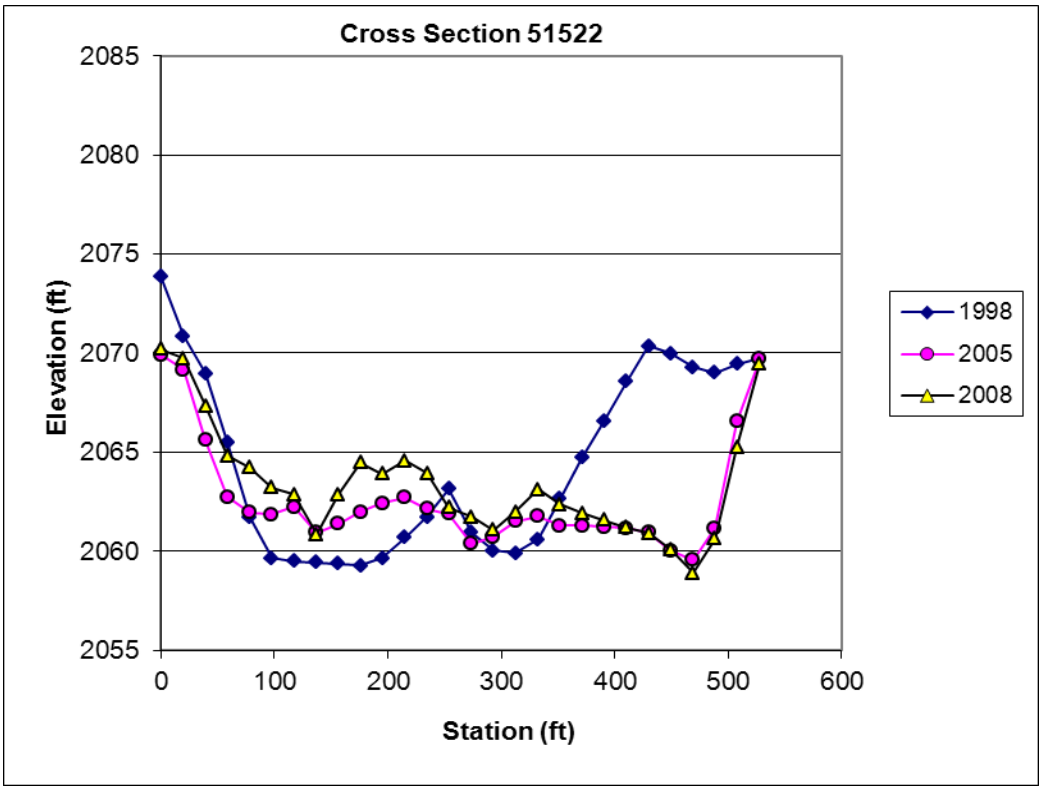


Fig. C2.2 Cross Section Profiles in the Reach 2



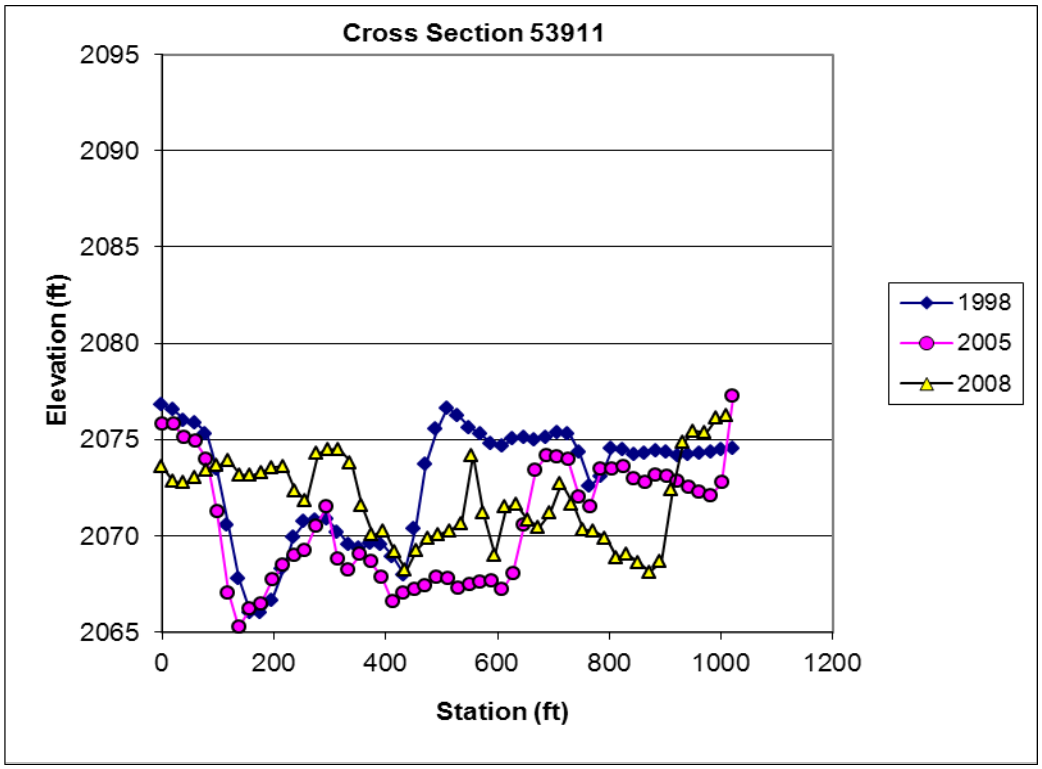


Fig. C3.1 Cross Section Profiles in the Reach 3

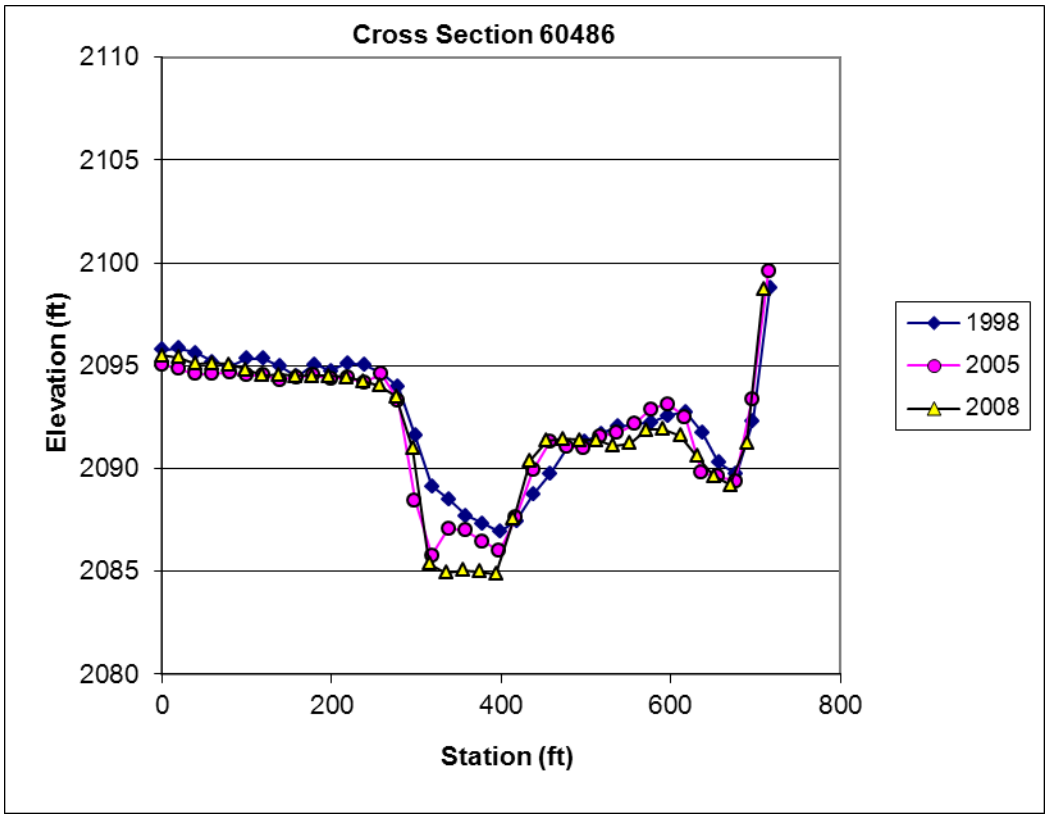
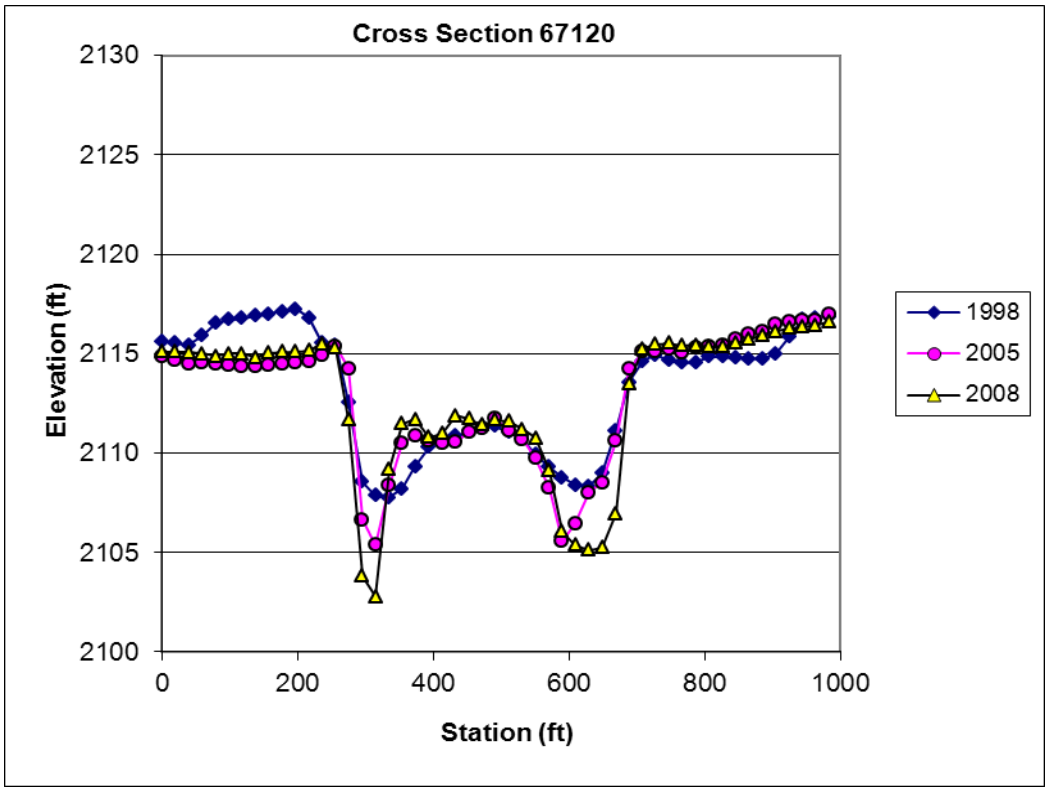


Fig. C3.2 Cross Section Profiles in the Reach 3



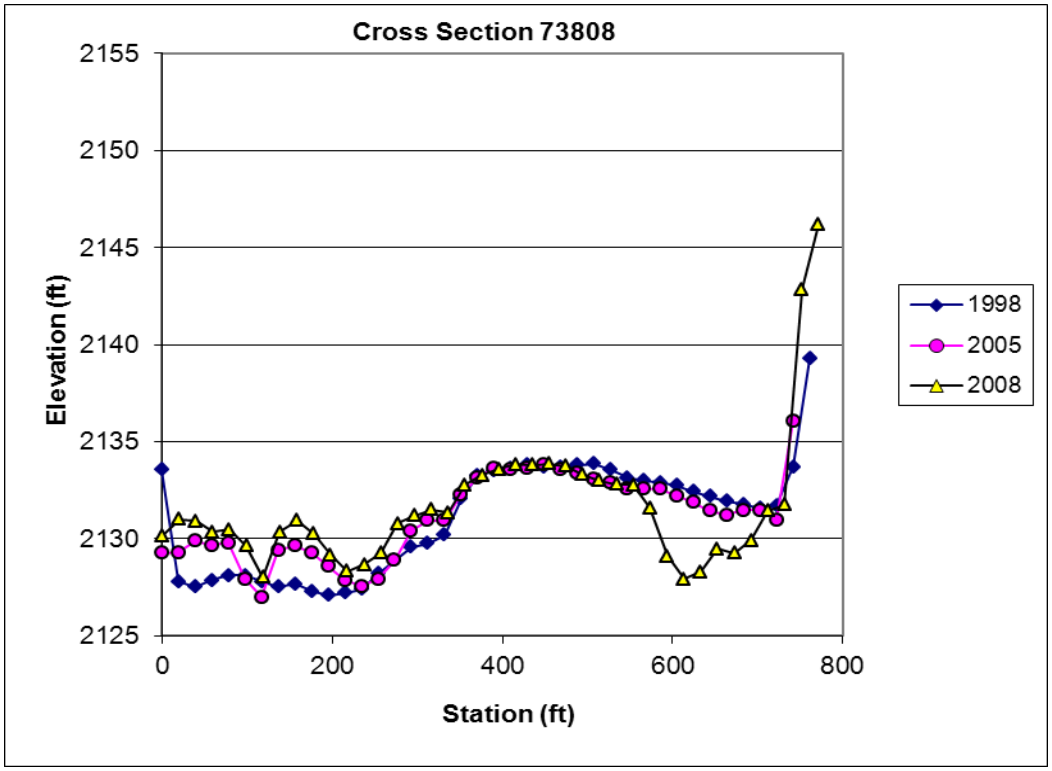
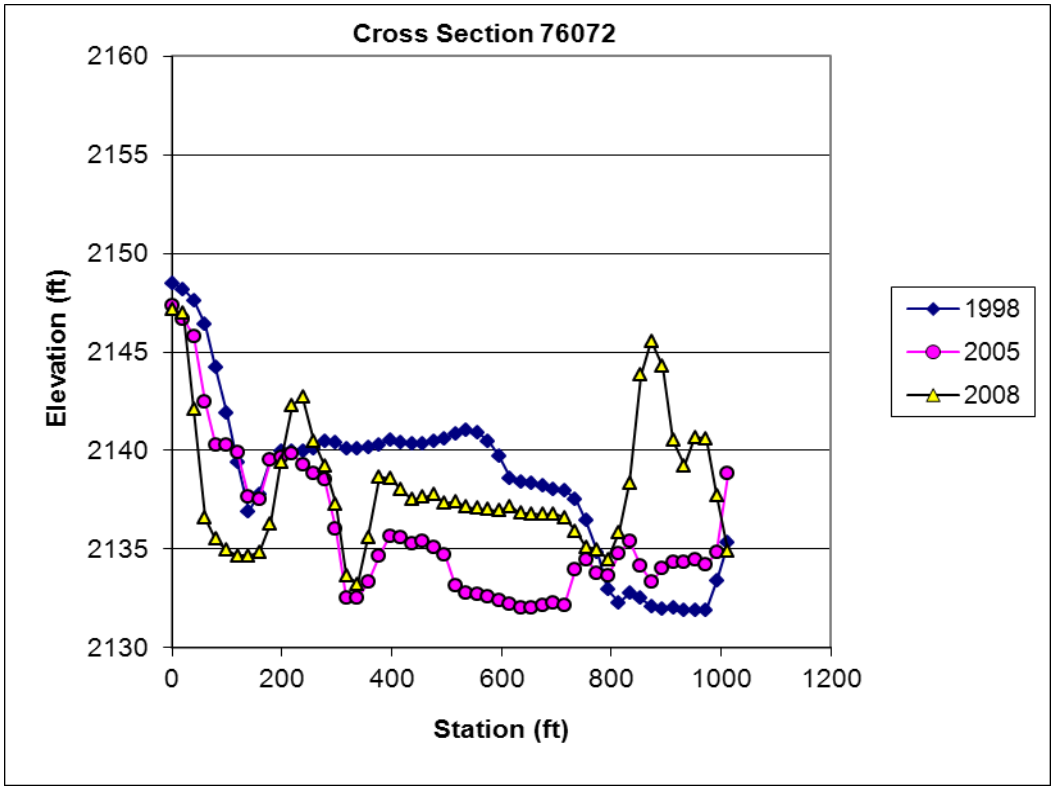


Fig. C4 Cross Section Profiles in the Reach 4



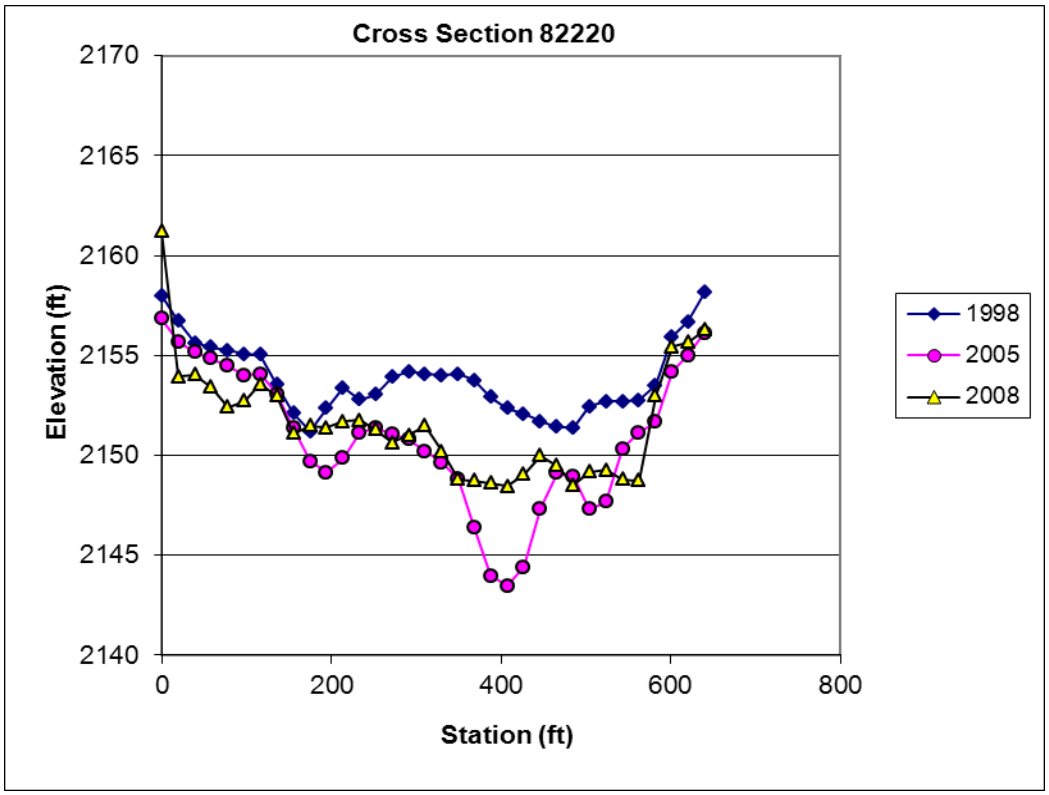
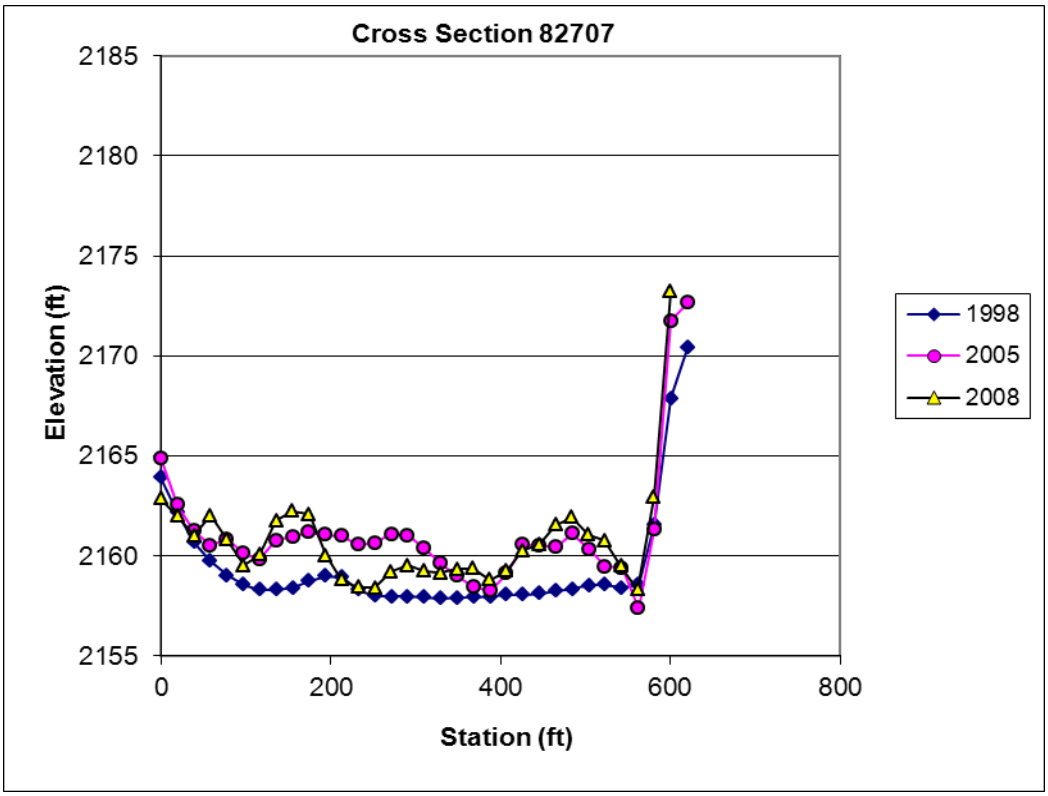
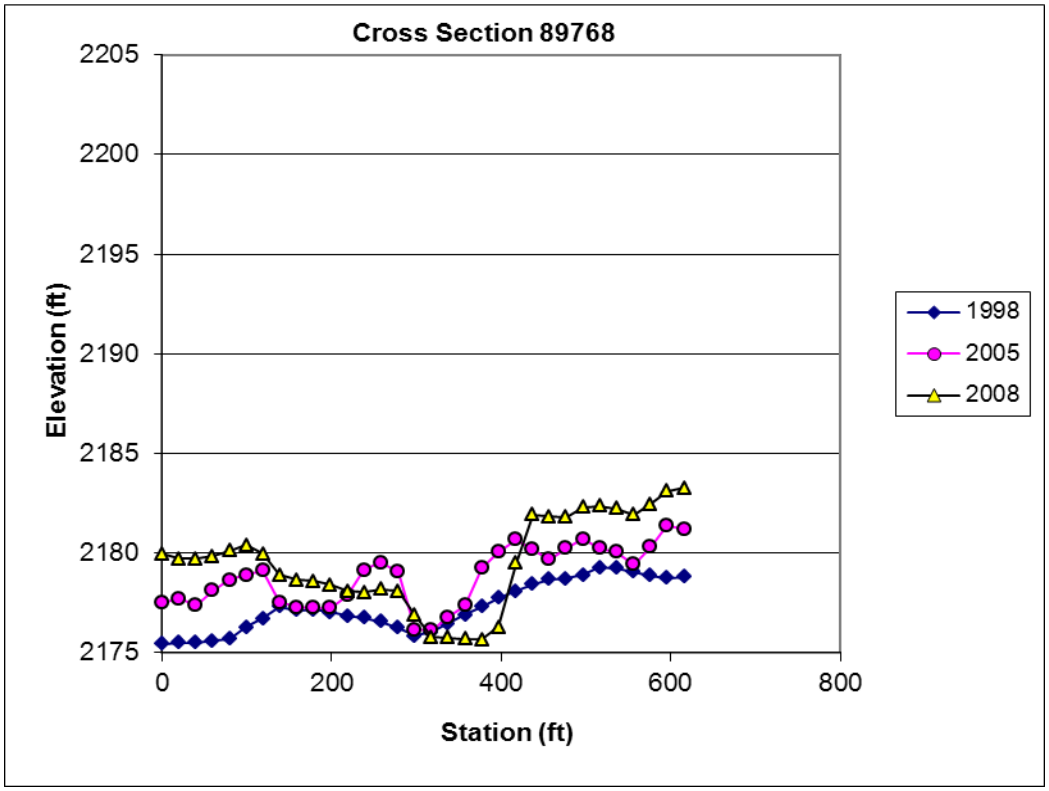


Fig. C5 Cross Section Profiles in the Reach 5





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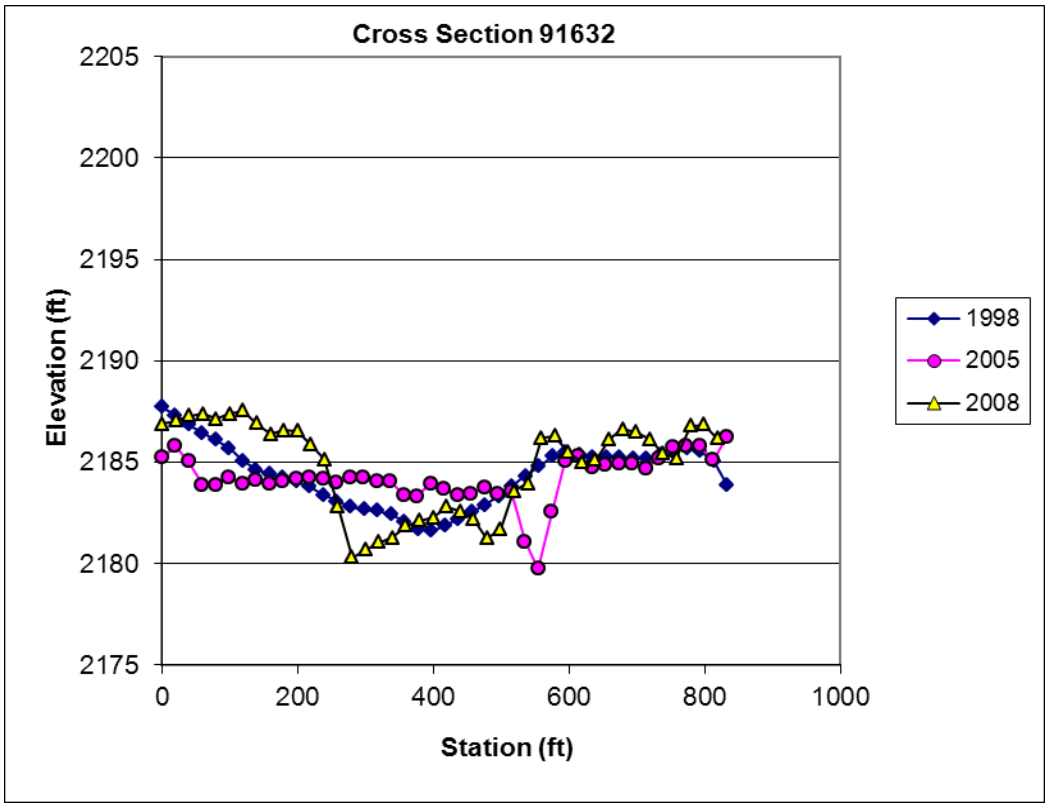


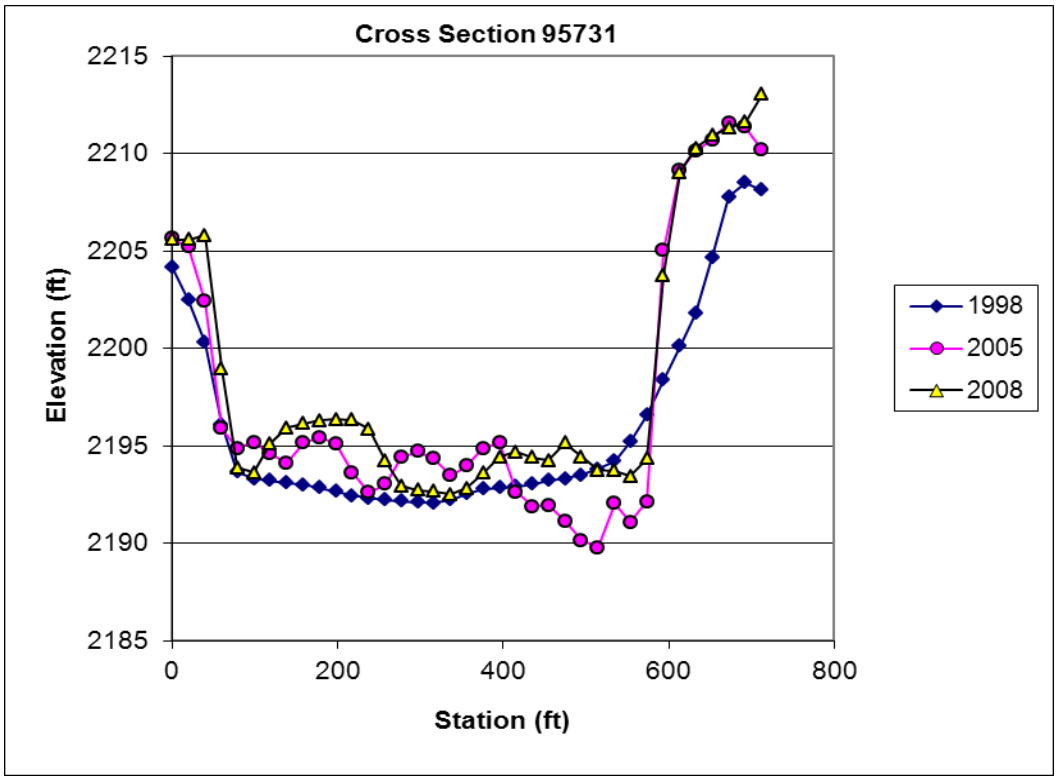


Fig. C6.2 Cross Section Profiles in the Reach 6

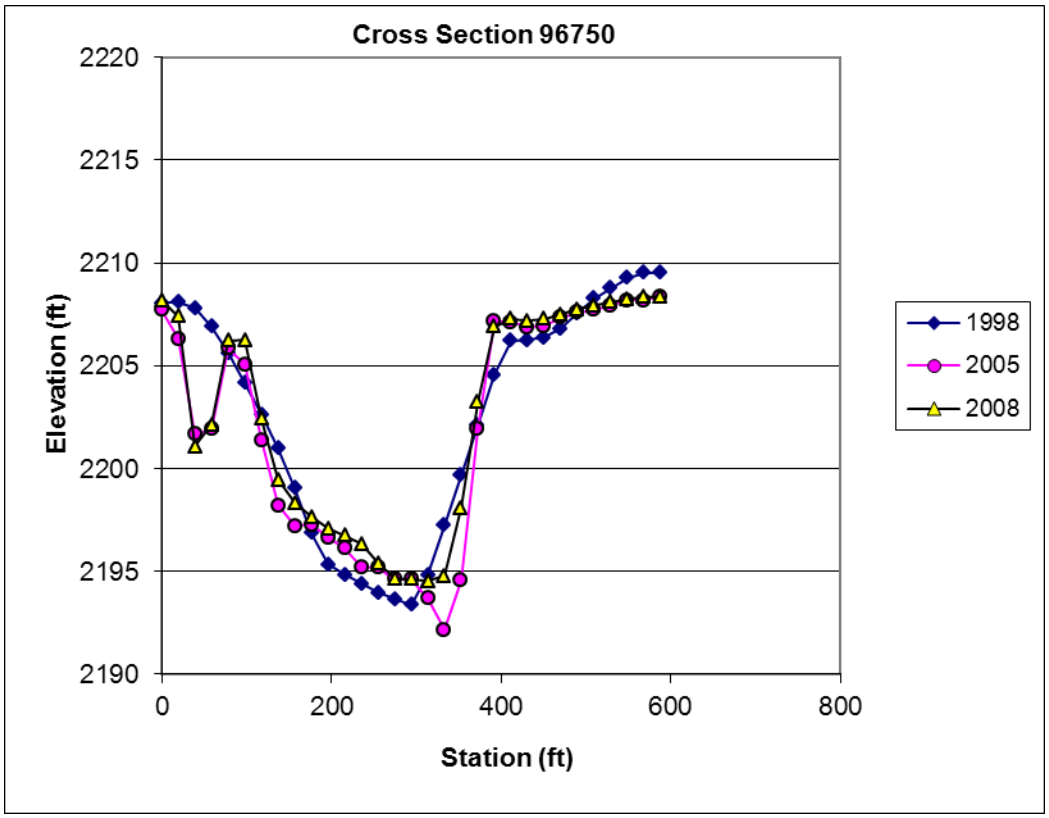
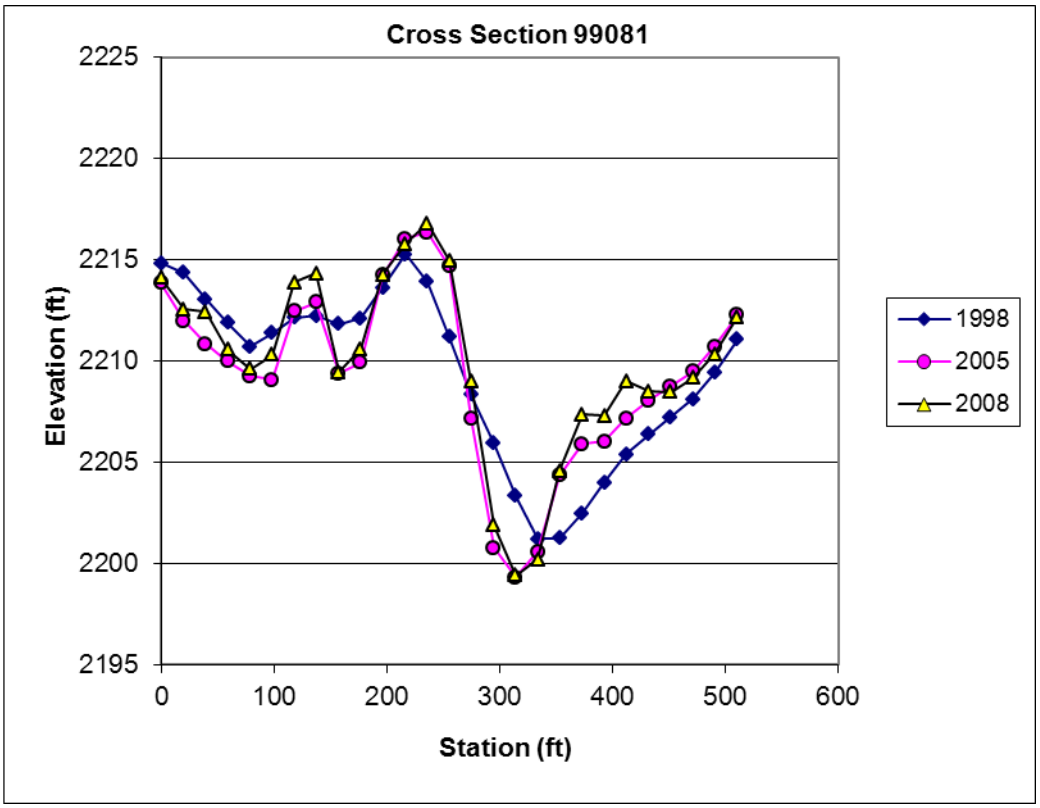


Fig. C6.3 Cross Section Profiles in the Reach 6



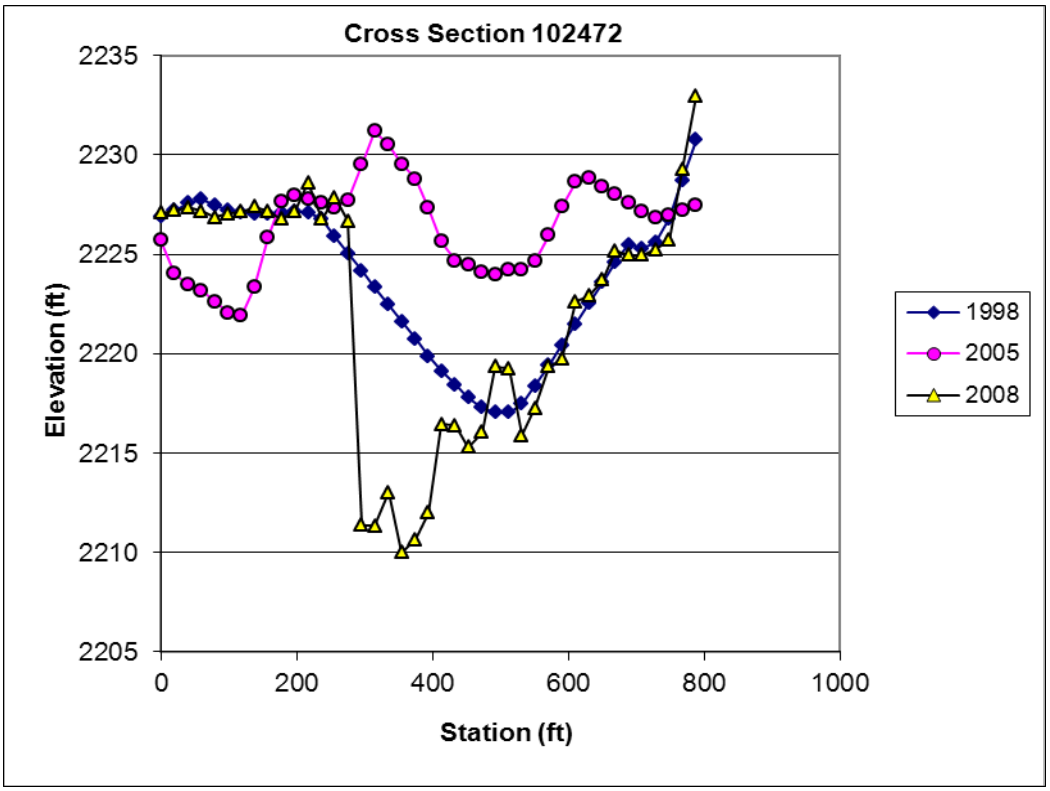


Fig. C7.1 Cross Section Profiles in the Reach 7

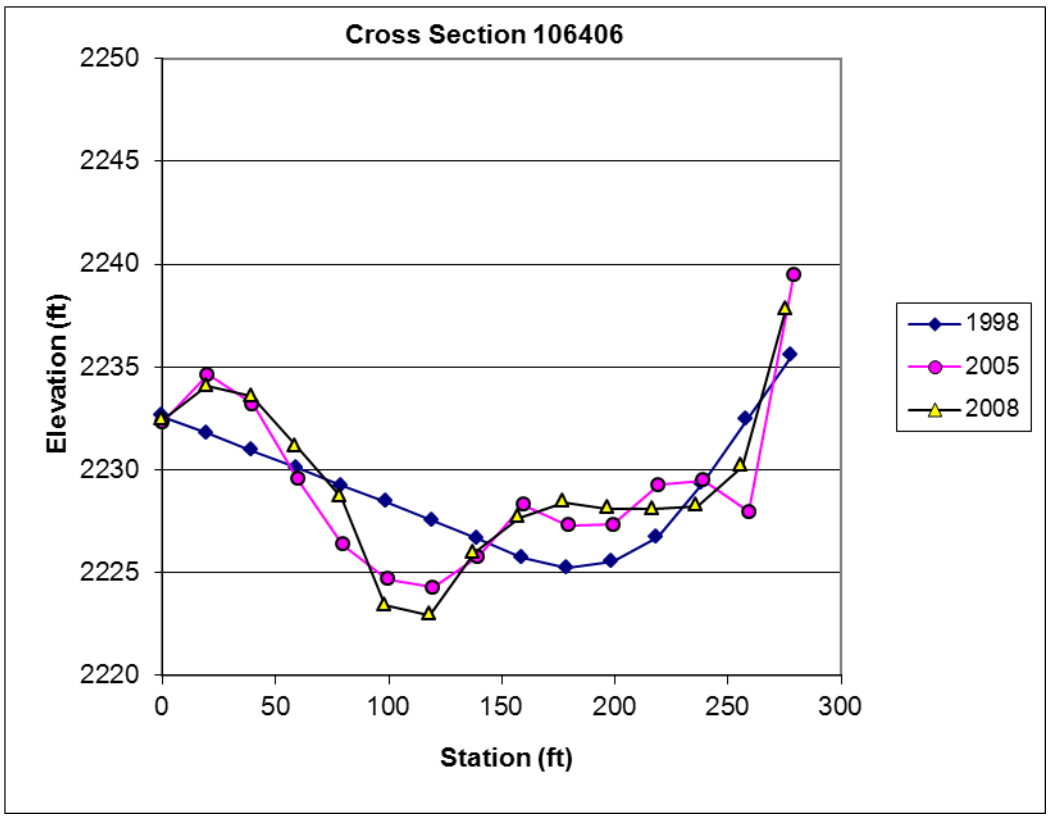


Fig. C7.2 Cross Section Profiles in the Reach 7

D. Sodium Absorption Ratio and Hydraulic Conductivity

Table D1 Effects of the SAR on Soil Physical Conditions

SAR	Infiltration	Hydraulic
Target Water Quality Range # 1.5	***Should ensure an adequate infiltration rate for soils sensitive to the formation of infiltration rate- reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having an EC < 20 mS/m***	**No significant reduction in hydraulic conductivity below inherent soil hydraulic conductivity expected in this SAR range for any soil; no hardsetting above inherent hardsetting expected in any soil in this SAR range**
1.5 - 3.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals under conditions of rainfall during the irrigation season or irrigation with water having an EC < 20 mS/m; no problem is expected with irrigation waters having on EC > 90 mS/m and slight to moderate problems at ECs in the range of 20 - 90 mS/m	No significant reduction in hydraulic conductivity below inherent soil hydraulic conductivity expected in this SAR range for any soil; no hardsetting above inherent hardsetting expected in any soil in this SAR range
3.0 - 6.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals when irrigated with water having an EC < 25 mS/m; no problem is expected with irrigation waters having an EC > 130 mS/m and slight to moderate problems at ECs in the range of 25 - 130 mS/m	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by up to 25 % for sensitive soils; Hardsetting increasingly likely to occur in sensitive soils at ECs < 6O mSg/m for SAR = 3 and < 120 mS/m for SAR = 6

6.0 - 12.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals when irrigated with water having an EC < 35 mS/m; no problem is expected with irrigation waters having an EC > 200 mS/m and slight to moderate problems at ECs in the range of 35 - 200 mS/m	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by > 25 % for sensitive soils and < 25 % in less sensitive soils, depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils will show little or no effect Small and reversible changes in hydraulics occur in sensitive soils when EC is in the range of 100 - 200 mS/m; Hardsetting likely to occur in sensitive soils at ECs < 120 mS/m for SAR = 6 and < 240 mS/m for SAR = 12
12.0 - 20.0	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate- reducing surface seals when irrigated with water having an EC < 90 mS/m; no problem is expected with irrigation waters having an EC > 310 mS/m and slight to moderate problems at ECs in the range of 90 - 310 mS/m	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by > 25 % for sensitive soils and < 25 % in less sensitive soils, depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils will show little or no effect Small and reversible changes in hydraulics occur in sensitive soils when EC is in the range of 100 - 200 mS/m; Hardsetting likely to occur in sensitive soils at ECs < 240 mS/m for SAR = 12 and < 400 mS/m for SAR = 20

> 20	Infiltration problems likely to occur in soils sensitive to the formation of infiltration rate-reducing surface seals when irrigated with water having an EC < 180 mS/m; no problem is expected with irrigation waters having an EC > 560 mS/m and slight to moderate problems at ECs in the range pf 180 - 560 mS/m	Hydraulic conductivity reduction likely to occur in soils sensitive to hydraulic conductivity reduction. A low EC in the soil solution may cause hydraulic conductivity to be irreversibly reduced by > 25 % for sensitive soils and < 25 % in less sensitive soils, depending on the particle size distribution of the soil and the type of clay mineral present in the clay size fraction. Tolerant soils will show little or no effect Small and reversible changes in hydraulics occur in sensitive soils when EC is in the range of 100 - 200 mS/m.

Data Source: South African Water Quality Guidelines, Volume 4: Agricultural Use : Irrigation, Second Edition, 1996

E. ADEQ's Santa Cruz Watershed Assessment

Santa Cruz River
Roger Road WWTP outfall - Intermittent Reach
15050301-003B
2.9 miles

Category 4B
Not Attaining

IMPAIRMENT *Ammonia (2010)*

STATUS

A&Wedw - Not Attaining • PBC - Attaining

Exceedances

Parameter	Applicable Standard	Date & Result		Designated use support, supporting evidence, comments
Ammonia	1.61 mg/L^{chronic}, 13.7 mg/L^{acute} @ pH 7.7 and temp 26.4 °C	11/15/2005	16 mg/L	A&Wedw is not attaining. 2 acute exceedances during the last 3 years of monitoring and 4 chronic exceedances during the assessment period.
	2.57 mg/L^{chronic}, 20.2 mg/L^{acute} @ pH 7.5 and temp 22.9 °C	1/23/2006	24 mg/L	
	2.14 mg/L^{chronic}, 22.0 mg/L^{acute} @ pH 7.4 and temp 26.5 °C	5/5/2006	24 mg/L	
	1.68 mg/L^{chronic} @ pH 7.5 and temp 30.0 °C	6/28/2007	20 mg/L	
Chlorine (total residual)	19 ug/L^{acute}	6/28/2007	100 ug/L	A&Wedw is inconclusive. 1 exceedance in the last 3 years of monitoring.

Monitoring Summary

Sampling period: 1/5/2004 - 6/28/2007

Site Name(s)	Site ID #	DEQ #	Sampling Agency	Purpose
Near Roger Rd WWTP	SCSCR45.57	105059	Pima County Wastewater Management	Permit monitoring
Two Miles Downstream Rogers Rd WWTP	SCSCR43.79	105060	Pima County Wastewater Management	Permit monitoring
Below Ruthrauff Road	SCSCR045.13	103623	ADEQ	Fixed Station Network, Ambient

Metals Samples	Nutrients & Related Samples	Other Samples
4 total & 2-4 dissolved: antimony, arsenic, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, nickel, zinc	2 ammonia 3-4 nitrite/nitrate, total nitrogen, total phosphorus, total Kjeldahl nitrogen, dissolved oxygen, and pH	2 *E. coli* 4 fluoride 4 selenium 4 suspended sediment 7 total dissolved solids 1 chlorine

Santa Cruz Watershed Assessments - 55

Santa Cruz

Data Gaps and Monitoring Needs

Exceedances Needing More Samples to Assess	Chlorine
Missing Core Parameters	None
Missing Seasonal Distribution	None
Lab Detection Limits Not Low Enough	None

Priority	Monitoring Recommendations
Low	Permit is currently under review. Continue monitoring for chlorine.

Impairment Discussion
As part of the Ina Road WWTP expansion and upgrade project, the Roger Road wastewater treatment plant will be replaced by a new facility that would reduce the amount of ammonia and other chemicals in treated water.

Santa Cruz River

Canada del Oro - HUC 15050303
15050301 001
8.6 miles

Category 4B
Not Attaining

IMPAIRMENT

Ammonia (2010)

STATUS

A&Wedw - Not Attaining • PBC - Attaining

SOURCE

Exceedances

Parameter	Applicable Standard	Date & Result		Designated use support, supporting evidence, comments
Ammonia	1.06 mg/L^{chronic}, 9.76 mg/L^{acute} @ pH 7.9 and temp 29.1 °C	9/12/2005	19 mg/L	A&Wedw is not attaining. 3 acute exceedances within the last 3 years of monitoring and 6 chronic exceedances within the assessment period.
	1.49 mg/L^{chronic}, 8.57 mg/L^{acute} @ pH 8.0 and temp 22.3 °C	11/15/2005	25 mg/L	
	2.92 mg/L^{chronic}, 13.5 mg/L^{acute} @ pH 7.7 and temp 17.0 °C	1/23/2006	28 mg/L	
	1.74 mg/L^{chronic}, 17.9 mg/L^{acute} @ pH 7.6 and temp 27.8 °C	5/3/2006	31 mg/L	
	2.03 mg/L^{chronic} @ pH 7.6 and temp 25.3 °C	9/11/2008	12.5 mg/L	
	2.63 mg/L^{chronic}, 12.8 mg/L^{acute} @ pH 7.8 and temp 18.0 °C	12/17/2008	18 mg/L	
Copper[d]	29.3 ug/L^{chronic}, 49.6 ug/L^{acute} @ > 400 mg/L hardness	7/29/2004	533 ug/L	A&Wedw is inconclusive. The 7/29/04 and 12/8/04 exceedances of the chronic standard were collected during storm events and therefore not inlcuded in the assessment determination.
	12.2 ug/L^{chronic} @ 143 mg/L hardness	12/8/2004	12.79 ug/L	
	11.9 ug/L^{chronic} @ 140 mg/L hardness	3/8/2005	17.23 ug/L	
Lead[d]	10.5 ug/L^{chronic}, 281 ug/L^{acute} @ > 400 mg/L hardness	7/29/2004	421 ug/L	A&Wedw is inconclusive. Only 1 exceedance of the acute standard during the assessment period.
Mercury[d]	0.010 ug/L	7/29/2004	0.631 ug/L	A&Wedw chronic is attaining. 2 exceedances during the assessment period were collected under storm flow conditions and not representative of chronic conditions.
		8/6/2004	1.19 ug/L	
Zinc[d]	379 ug/L @ > 400 mg/L hardness	7/29/2004	999 ug/L	A&Wedw is attaining. Only 1 exceedance of the chronic standard during the assessment period. Collected under storm conditions and does not represent chronic conditions.

Santa Cruz

Monitoring Summary

Sampling period: 1/6/2004 - 12/17/2008

Site Name(s)	Site ID #	DEQ #	Sampling Agency	Purpose
3.2 Miles Downstream of Ina Rd WWTP	SCSCR37.79	105063	Pima County Wastewater Management	Permit monitoring
4.6 Miles Downstream Ina Rd WWTP	SCSCR36.50	105064	Pima County Wastewater Management	Permit monitoring
Near Ina Rd WWTP	SCSCR40.94	105061	Pima County Wastewater Management	Permit monitoring
Near Marana	SCSCR034.56	101081	ADEQ	Ambient
Two Miles Downstream of Ina Rd WWTP	SCSCR39.02	105062	Pima County Wastewater Management	Permit monitoring

Metals Samples	Nutrients & Related Samples	Other Samples
1-6 total & 14-23 dissolved: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, thallium, and zinc 6-14 total & 0-4 dissolved: boron, manganese, mercury, nickel, and silver	6 ammonia, nitrite/nitrate, and total phosphorus 23 total nitrogen and total Kjeldahl nitrogen 35 dissolved oxygen and pH	6 *E. coli* 6 fluoride 5 suspended sediment 22 total dissolved solids 6-7 organic compounds

Data Gaps and Monitoring Needs

Exceedances Needing More Samples to Assess	Dissolved lead and zinc (A&Wedw)
Missing Core Parameters	None
Missing Seasonal Distribution	None
Lab Detection Limits Not Low Enough	Selenium (A&W)

Priority	Monitoring Recommendations
Medium	Collect more ammonia and dissolved metal samples once upgrades to the existing plant are completed. Use a lower lab detection limit for selenium.

Impairment Discussion
The Ina Road wastewater treatment facility has a permit variance for copper, ammonia, and chlorine starting in 2006. This variance was granted for an expansion and upgrades of the existing plant with the latest technologies to remove metals.