Determination of the Critical Water Quality Conditions for the Impaired Reaches of the Santa Clara River Watershed

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1. Introduction

In this study, we evaluated the conditions that lead to high concentrations of inorganic nitrogen species (i.e. ammonia, nitrite and nitrate) in the impaired reaches and tributaries of the Santa Clara River watershed. The analysis was divided into three sections: (1) an analysis of the low flow conditions and the correlation between low flow and high concentrations of these nitrogen species; (2) an evaluation of the timing of point and non-point source discharges of these nitrogen species to the river and tributaries, to determine the possibility of high concentration peaks during the initial storm events (first flush effect); and (3) conditions where rising groundwater might be a significant contribution to total loading.

2. Low-flow analysis

The analysis focused on three reaches and a number of tributaries of the Santa Clara River where the Regional Water Quality Control Board (RWQCB) has determined that the water quality objectives have been exceeded, resulting in potential impairment of the designated beneficial uses. The low flow conditions were characterized using three different criteria:

1Q10: the lowest one-day flow with a recurrence of 10 years;

7Q10: the lowest seven-day flow with a recurrence of 10 years;

30Q3: the lowest thirty-day flow with a recurrence of 3 years.

Although the most common criterion for low flow conditions is the 7Q10, given the climatic conditions of the SCR watershed, typical of Coastal Mediterranean regions with a long dry summer and fall, followed by short intense rainfall events in the winter and early spring, we considered the 30Q3 as an additional criterion, since many of the tributaries do not have any flow for a considerable part of the year. For this study, the eleven-year period between Water Year (WY) 1989 and WY 2000 was considered, given the availability of data. Daily flow data was available at a number of gauging stations in the SCR reaches. However, there was little or no flow data for a number of the tributaries. Thus, simulation results from the WARMF model were used to estimate the daily flows for these tributaries, as well as for those time periods where the flow gauges were not operational in the SCR reaches.

The results of the low flow analysis are presented in Table 1. The 1-day, 7-day and 30-day low flows for each segment are presented in the Appendix, as well as the corresponding 1-day, 7-day and 30-day average concentrations of ammonia, nitrite and nitrate as simulated by the WARMF model. The details of the calibration of the WARMF model have been presented in the Task 2 Linkage Analysis report and the Task 3 TMDL Analysis report. As expected, most of the watershed has no flow conditions at some point of the 11-year period, and only the main segments of the SCR have some flow under the 7Q10 criterion. Even the 30-day flows in the tributaries are very low or zero.

Table 1. Low flow conditions in the SCR watershed (m3/s)

River segments	1Q10	7Q10	30Q3
SCR reach 3 (downstream)	0.16	0.17	0.7978
SCR reach 3 (upstream)	0.16	0.17	0.7976
SCR reach 7 (downstream)	0	0.02	0.5009
SCR reach 7 (mid-stream)	0	0.05	0.642
SCR reach 7 (upstream)	0	0.39	0.4724
SCR reach 8	0	0.0002	0.1447
Mint Canyon	0	0	0
Wheeler Canyon	0	0	0.0008
Todd Barranca	0	0	0.0026
Brown Barranca/Long Canyon	0	0	0

Typically, low flow conditions such as 7Q10 flows have been used in steady state models to simulate water quality under such conditions. Given that the WARMF model performs a dynamic calculation at a daily time step with variable inputs, it is not as critical to choose a particular low-flow criterion. However, we decided to evaluate the observed and simulated water quality during these periods, when there is less water to dilute any nutrient load.

Figure 1 presents a graphical representation of the correlation of simulated water quality (ammonia, nitrite and nitrate concentrations on the left column, both the original values and the natural logarithm of the concentrations) vs. simulated flow and the natural logarithm of flow (on the top row), for Reach 3 of the SCR. There is a tendency to have high nitrogen concentrations during low flow conditions. The corresponding statistical analysis, presented in Table 2, corroborates the visual interpretation.

The results presented in Table 2 indicate that the strongest correlation is between ln(flow) and ln(concentration), suggesting a power law relationship:

$$\ln(\text{flow}) = a \ln[\text{concentration}] + b \quad (1)$$

or

$$\text{Flow} = a\,[\text{Concentration}]^{b} \quad (2)$$

Figure 1. Correlation Analysis between Simulated Flow and Concentration for Reach 3

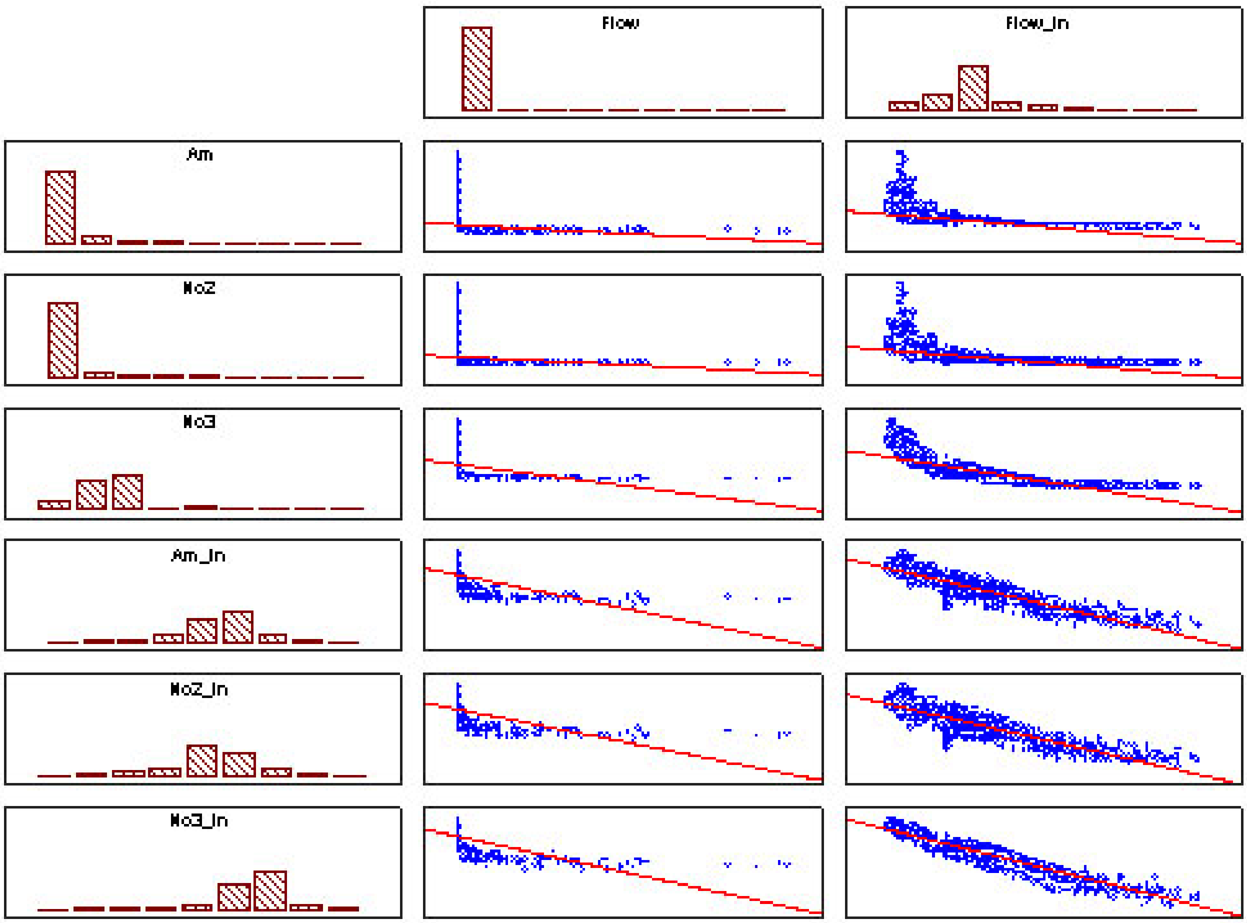


Table 2. Correlation between simulated nitrogen concentration and flow for Reach 3

	$[NH_3]$	$[NO_2]$	$[NO_3]$	$\ln[NH_3]$	$\ln[NO_2]$	$\ln[NO_3]$
Flow	-0.11	-0.11	-0.24	-0.40	-0.38	-0.49
ln(flow)	-0.54	-0.51	-0.75	-0.87	-0.83	-0.92

The corresponding coefficients (a and b) are presented in Table 3. The strongest correlation is for nitrate, followed by ammonia and nitrite. All three concentrations in general decrease with flow, indicating that the highest concentrations are typically found at the low flow conditions.

Table 3. Power law coefficients for Reach 3 of the SCR

	NH_3	NO_2	NO_3
a	0.2651	0.0954	1.7083
b	-0.7437	-0.7012	-0.456
r^2	0.749	0.6869	0.8451

Table 4 presents the power law coefficients for Reach 7 of the SCR, where one more time the relationship is one of decreasing concentration with increasing flow. The complete statistical analysis for these two reaches is presented in the Appendix.

Table 4. Power law coefficients for Reach 7 of the SCR

	NH_3	NO_2	NO_3
a	1.8899	0.4679	4.6047
b	-0.5726	-0.4178	-0.6581
r^2	0.4939	0.2615	0.8327

The reason for using simulated results (after the calibration of the model) is that the actual dataset is sparse. For example, the statistical analysis of the observed nitrate concentrations in Reach 3 of the SCR is presented graphically in Figure 2, with the corresponding statistics in Table 5. As can be seen, even with 273 data points, the correlation is weak. Nevertheless, the correlation coefficients are negative, suggesting a decreasing concentration with increasing flow, with the power law coefficients presented in Table 6.

Figure 2. Correlation Analysis between observed flow and NO3 for Reach 3

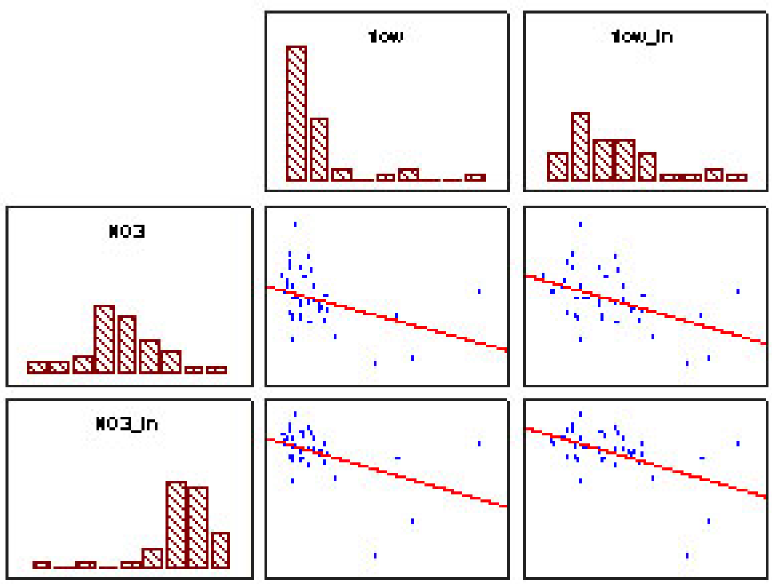


Table 5. Correlation between observed nitrogen concentration and flow for Reach 3

	$[NO_3]$	$\ln[NO_3]$
Flow	-0.38	-0.45
ln(flow)	-0.46	-0.51

Table 6. Power law coefficients for observed nitrate in Reach 3 of the SCR

a	4.3231
b	-0.5121
r^2	0.2603

3. Timing of Point and Non-Point Source Loads

Although the previous analysis indicates that there is a strong negative correlation between flow and concentration (i.e. low flow experiences the highest concentrations), we decided to evaluate whether timing of the Point Source (PS) and Non Point Source (NPS) loads would have made an important distinction at some point in the determination of critical conditions. For this analysis, we compared NPS loading to the river from the catchment to the total load in the river, to determine if and when the magnitude of the NPS could be significant to raise the overall load.

Figures 3, 4 and 5 present the magnitude of the NPS ammonia load and the total ammonia load for Reaches 3, 7 and 8 respectively. The scale of the y-axis (load) is logarithmic, given the wide differences in load magnitudes. As can be observed, the ammonia load from the catchments is usually very small relative to the total ammonia load, with a few exceptional days in Reach 7, given that any NPS ammonia loading is relatively rapidly converted to nitrate on the land surface and only reaches the river as ammonia when the NPS load is applied a few days before a significant storm event.

Figure 3. NPS and Total Ammonia Loading in Reach 3

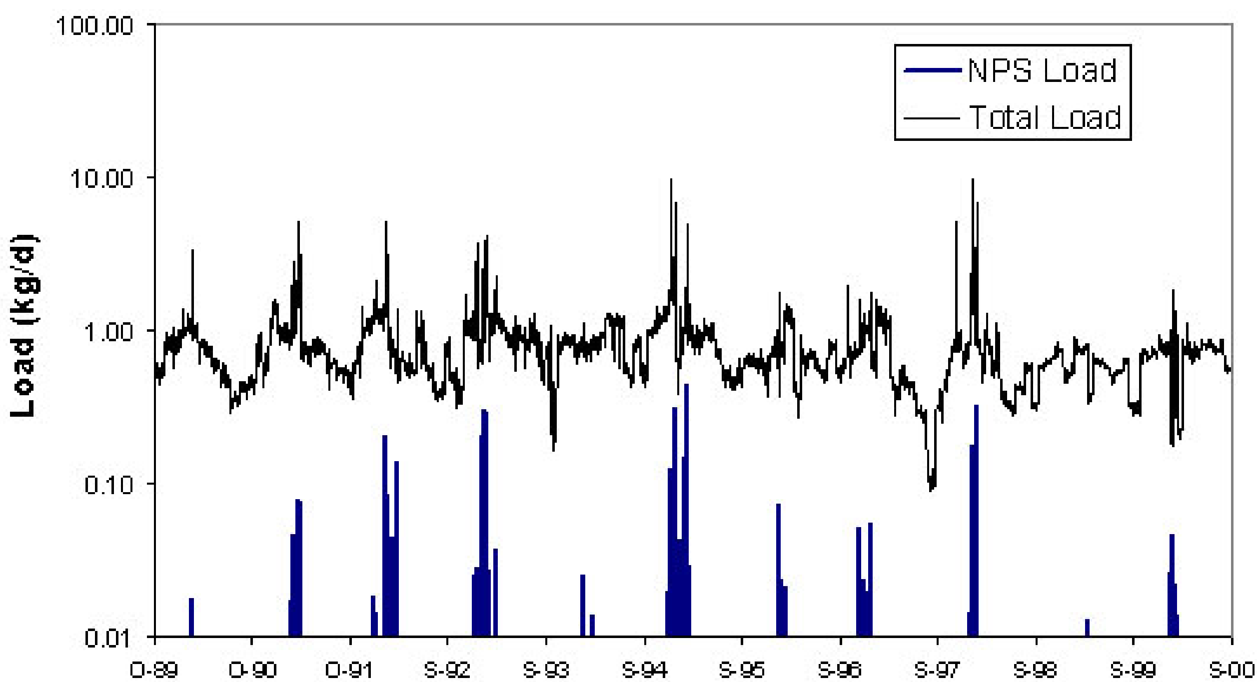


Figure 4. NPS and Total Ammonia Loading in Reach 7

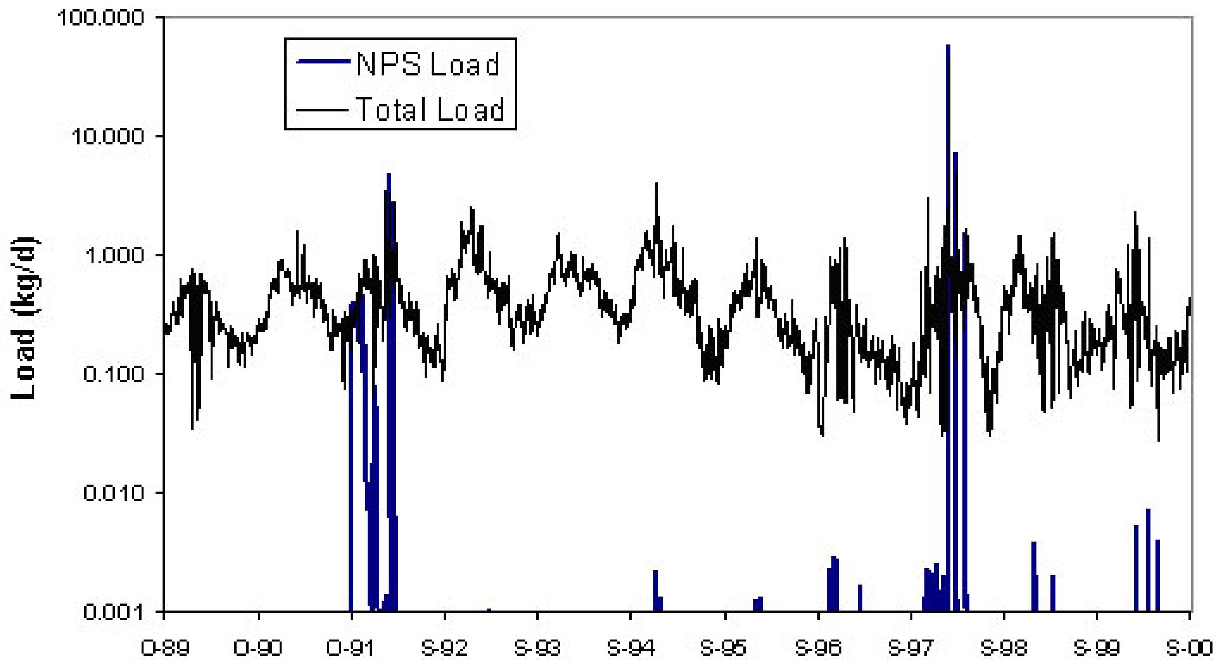
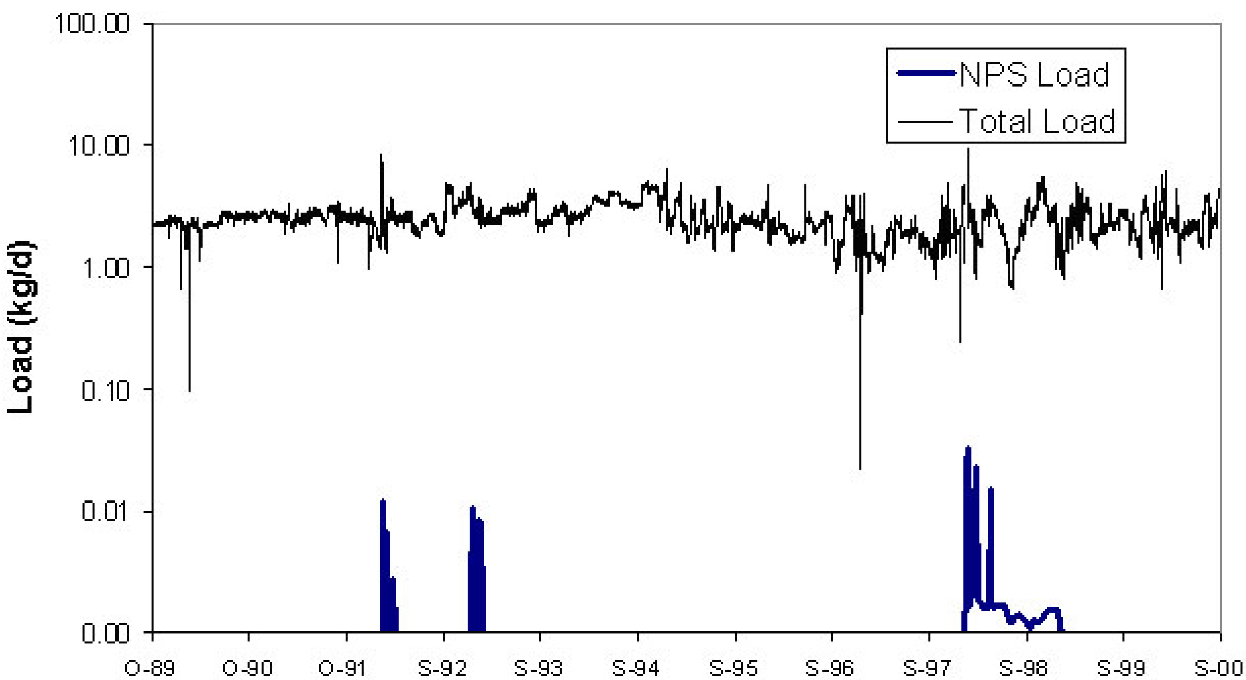


Figure 5. NPS and Total Ammonia Loading in Reach 8



Thus, nitrate loading is of more significance for evaluating critical conditions. In Figures 6, 7 and 8, the NPS and total nitrate loads in Reaches 3, 7 and 8 are presented.

Figure 6. NPS and Total Nitrate Loading in Reach 3

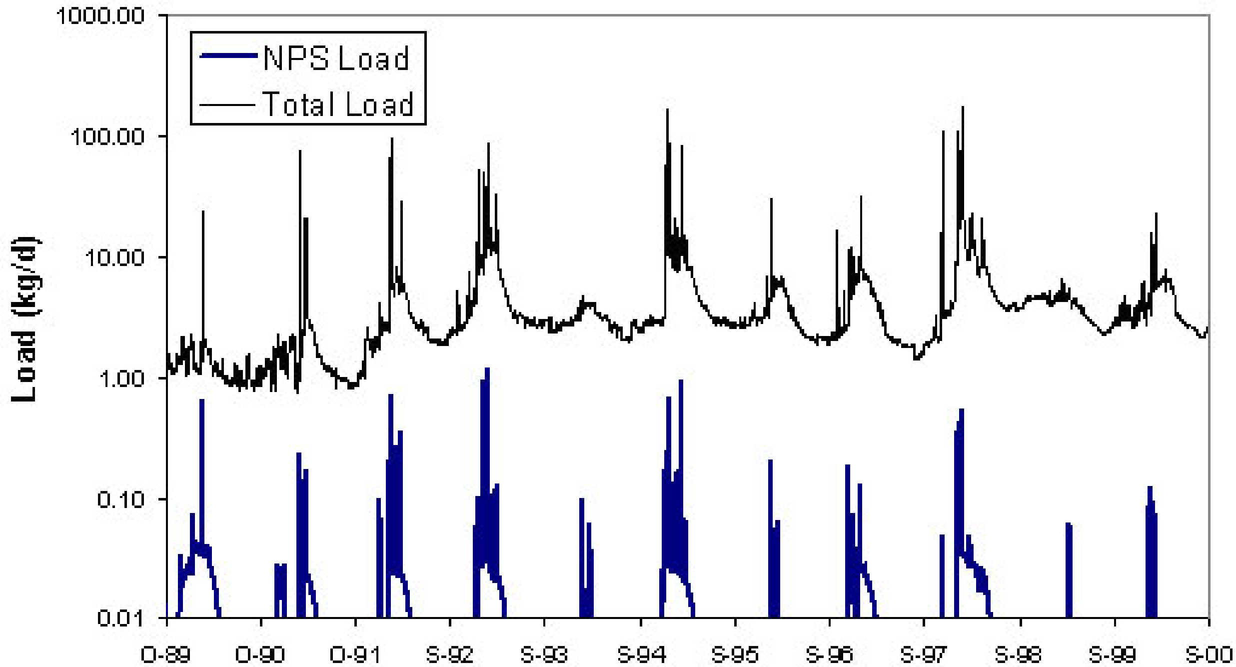


Figure 7. NPS and Total Nitrate Loading in Reach 7

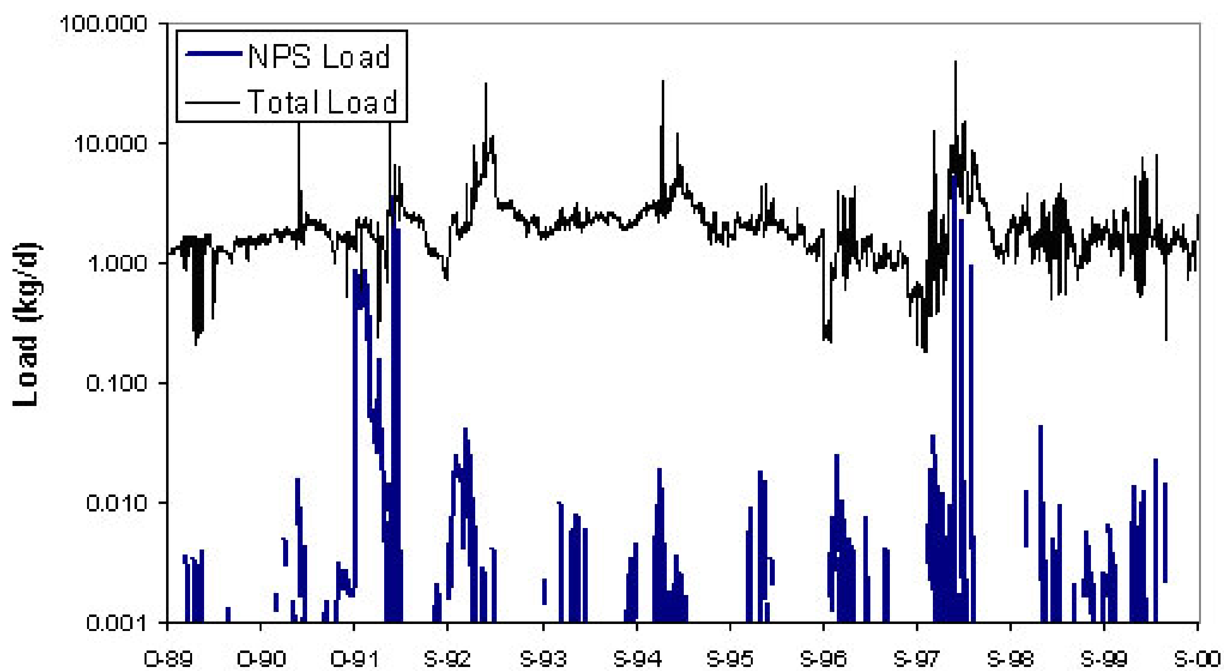
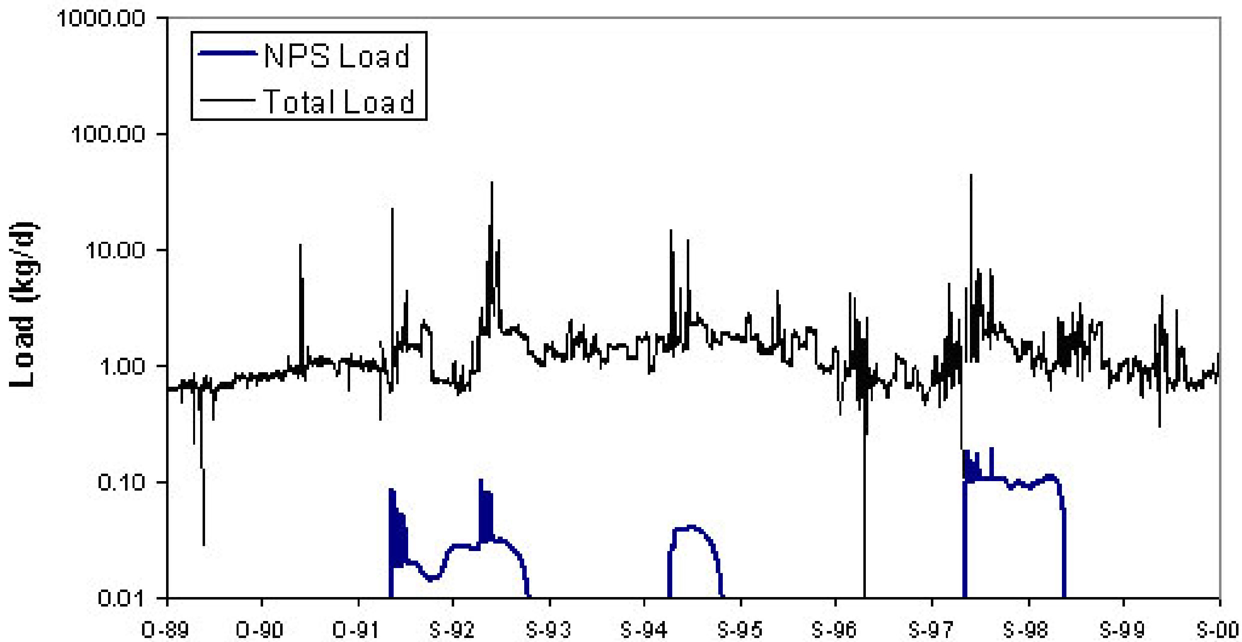


Figure 8. NPS and Total Nitrate Loading in Reach 8



To further analyze the relative magnitude of the loads, in Figures 9, 10 and 11 we present the percent contribution of NPS nitrate load to the total nitrate load for the same three reaches. From Figure 9, NPS nitrate load for Reach 3 is typically less than 1% of the total load, except for the winter months, when NPS nitrate load is typically up to 2% of the load, with an exceptional year in winter 1990, where due to the prolonged dry conditions a storm event actually contributed up to 11% of the load during a couple of days.

Figure 9. Percent NPS Nitrate Loading relative to total nitrate load in Reach 3

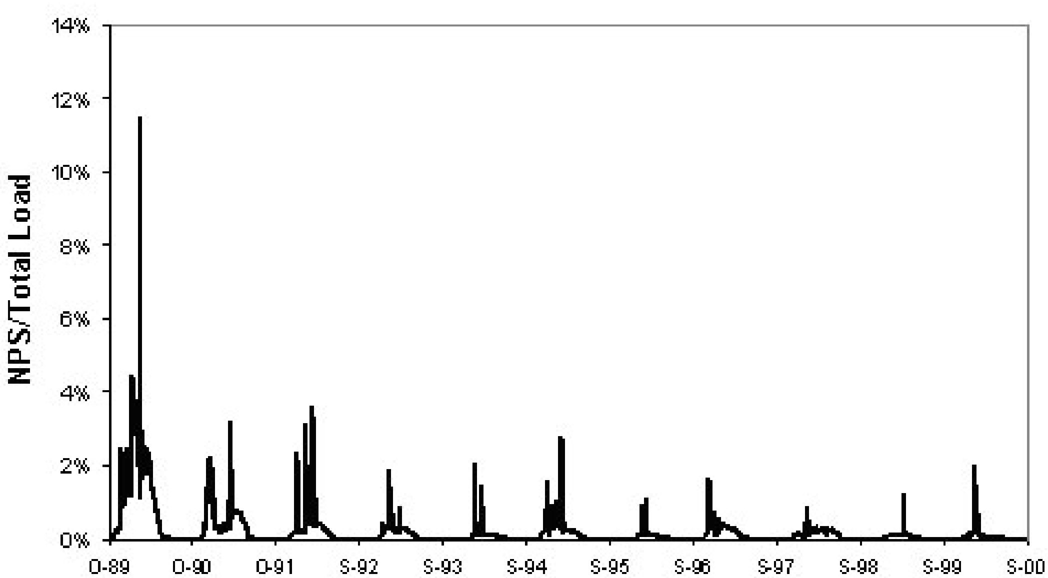


Figure 10. Percent NPS Nitrate Loading relative to total nitrate load in Reach 7

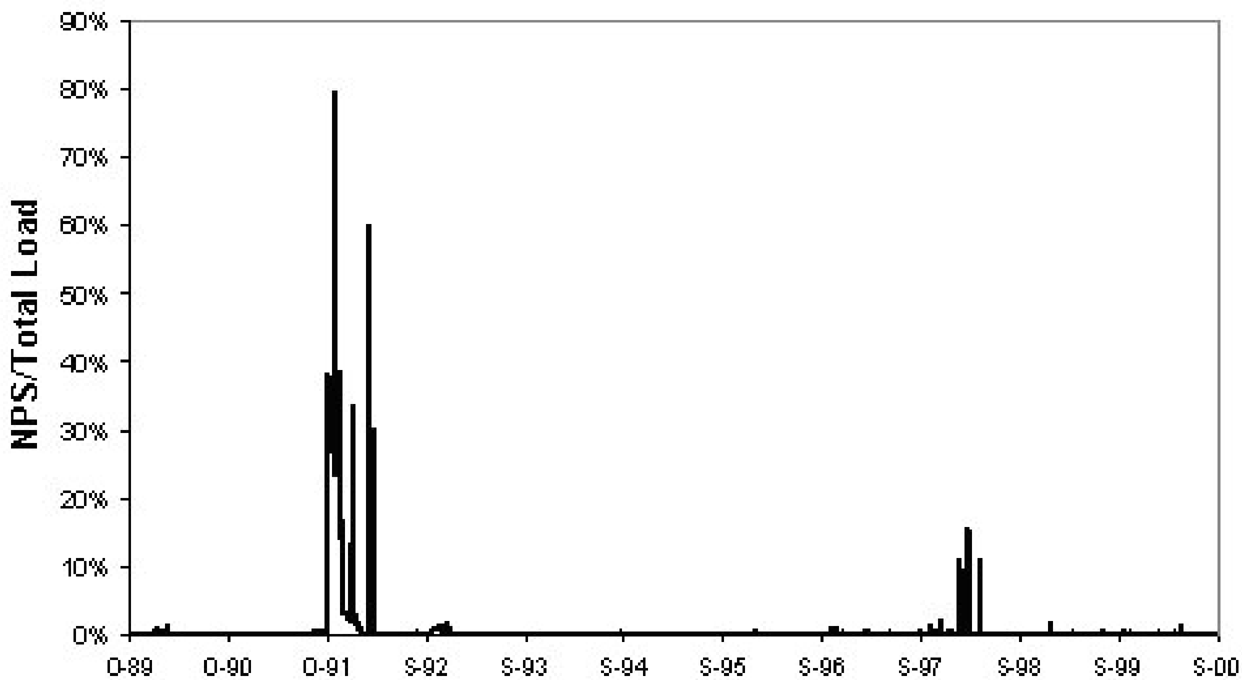
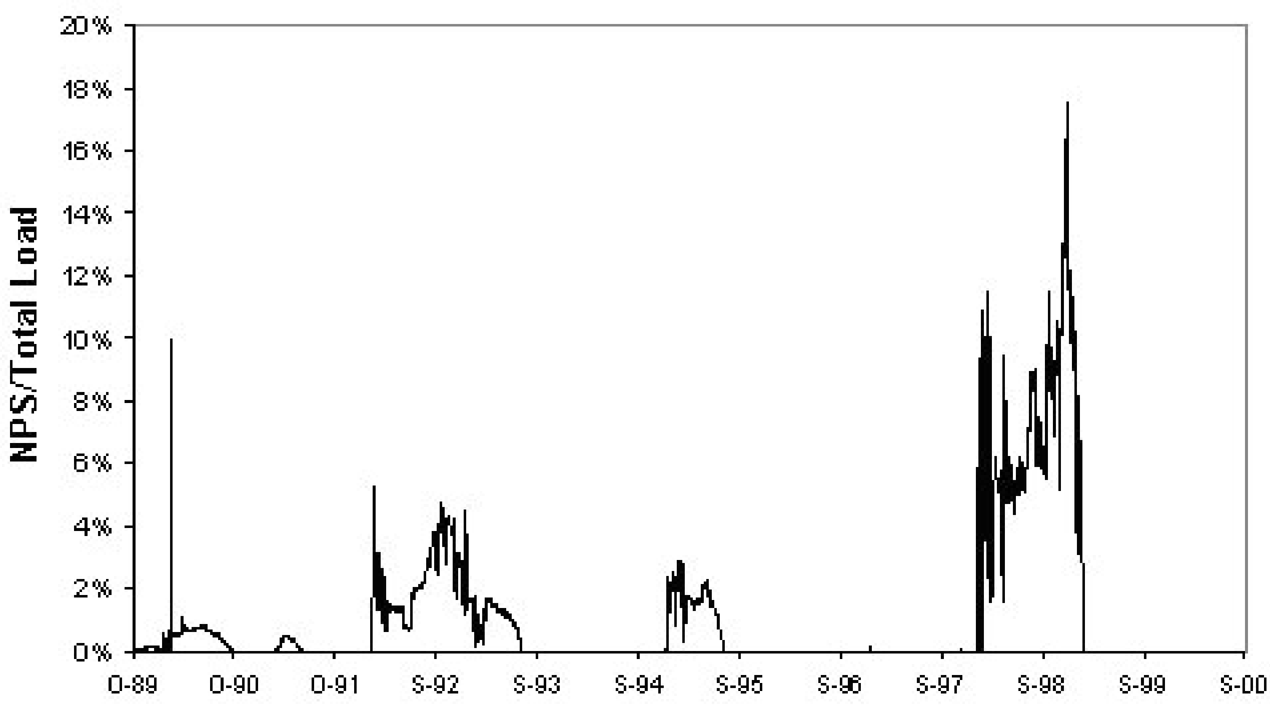


Figure 11. Percent NPS Nitrate Loading relative to total nitrate load in Reach 8



The situation is similar in Reach 7 (Figure 10), with NPS nitrate load typically less than 1% of the total load and some peak loading during storm events reaching a few more percent, with a significant exception in late 1991/early 1992, where there is a combination of high NPS loading and decreased PS loading for a few days (see Figure 7). This event again occurs at the beginning of the rainy season, and following a period of very dry rain years. This is corroborated by similar observations in Reach 8 (Figure 11), where it can be seen that the timing of the NPS loading is generally during the rainy (winter) season, with some peak NPS loads due to specific storm events. A similar peak loading occurs in late 1991/early 1992, although in Reach 8 there is also significant NPS loading during the rainy season of the 1998 El Niño year.

4. Locations with "Rising" Groundwater

There are a number of locations within the Santa Clara River where shallow groundwater surfaces at the river on a regular basis, contributing significantly to flow and water quality. There is a possibility that groundwater in some areas might have nitrate concentrations sufficiently high to increase the concentrations in the Santa Clara River. Certain areas in Reaches 3 and 7 are more likely to have such contributions, where significant Non-Point Source nitrogen loading from agriculture reaches the groundwater and then is transported towards the river.

We analyzed two regions in specific: (1) in Reach 7, the region below Old Road, through Blue Cut (County Line) and below Blue Cut; and (2) in Reach 3, the river segments between Pole Creek and Todd Barranca, passing through Fillmore and Santa Paula.

Rising Groundwater in Reach 7

The segments between Old Road and Blue Cut are generally dominated by the effluent flow and loading from the Valencia WWTP. Surface water quality in this region is available from the LA County Sanitary Districts stations RC, RD, RE and RF. Nitrate concentrations have been observed to exceed 5 mg N/L as NO_3 in the past, and the simulation results for these segments indicate that under the current conditions, there are a number of instances where this level is exceeded (Figures 12-14).

Figure 12. Nitrate concentrations at the Old Road

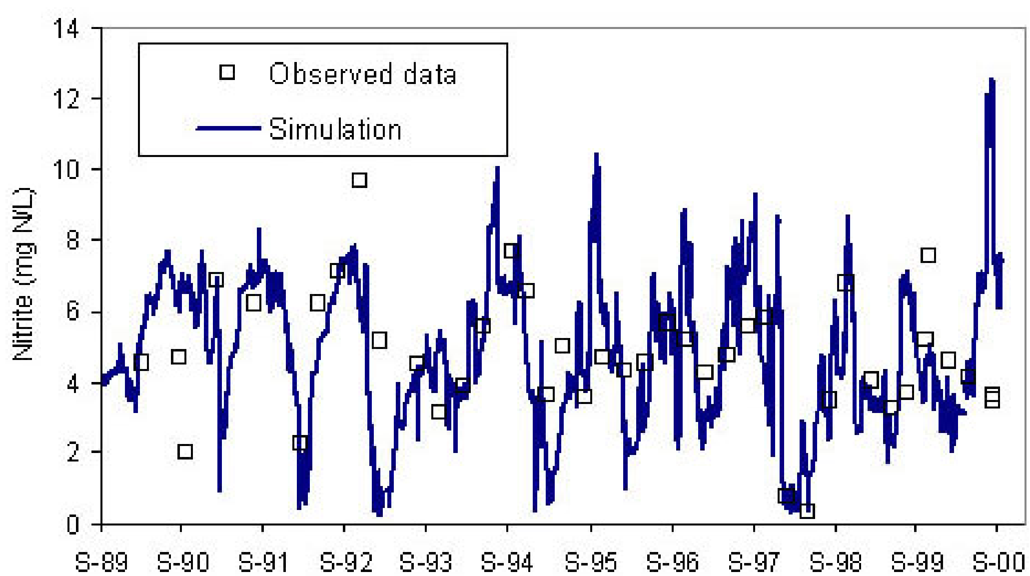


Figure 13. Nitrate concentrations at the County Line

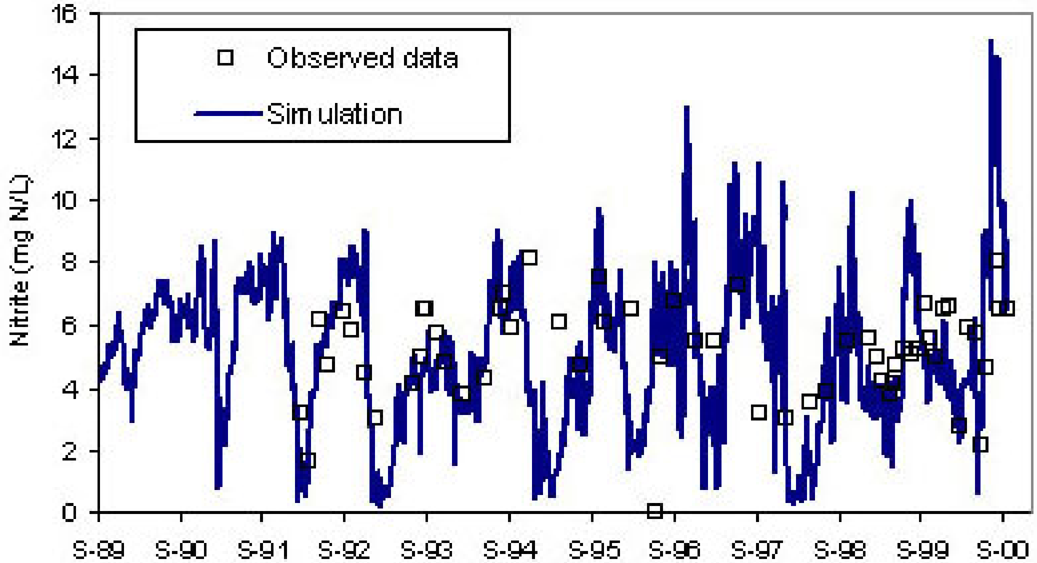
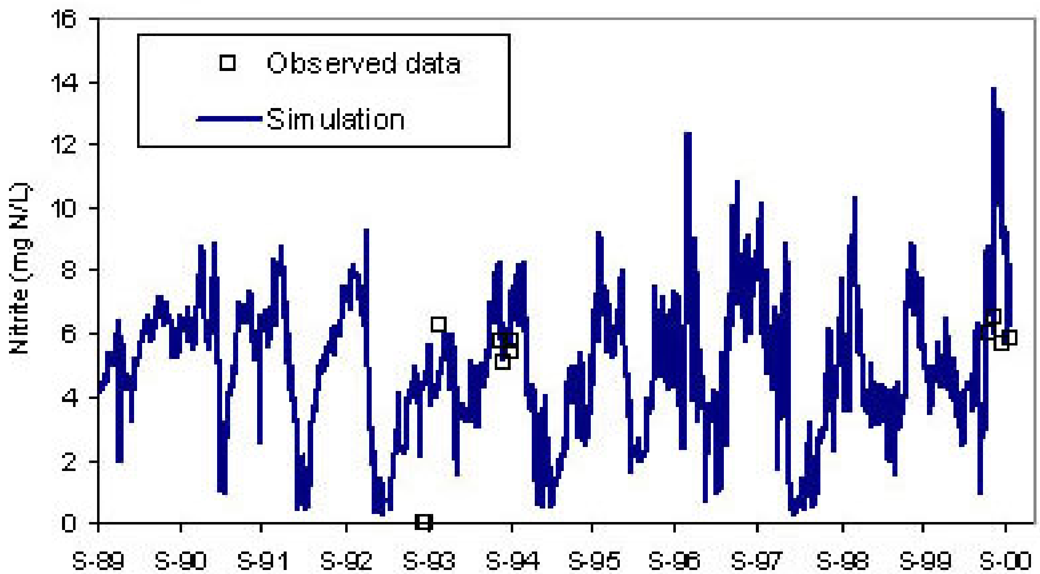


Figure 14. Nitrate concentrations below Blue Cut



The nitrate pattern at the County Line and below Blue Cut follows closely the pattern observed at the Old Road, indicating that in general the point source dominates to a large extent the nitrate concentrations. In fact, there is an increase in nitrate concentrations as the river flows downstream, which can be best seen in a comparison of the simulation results between Old Road and County Line (Figure 15) or between County Line and below Blue Cut (Figure 16).

Figure 15. Difference between simulated NO_3 at Old Road and County Line

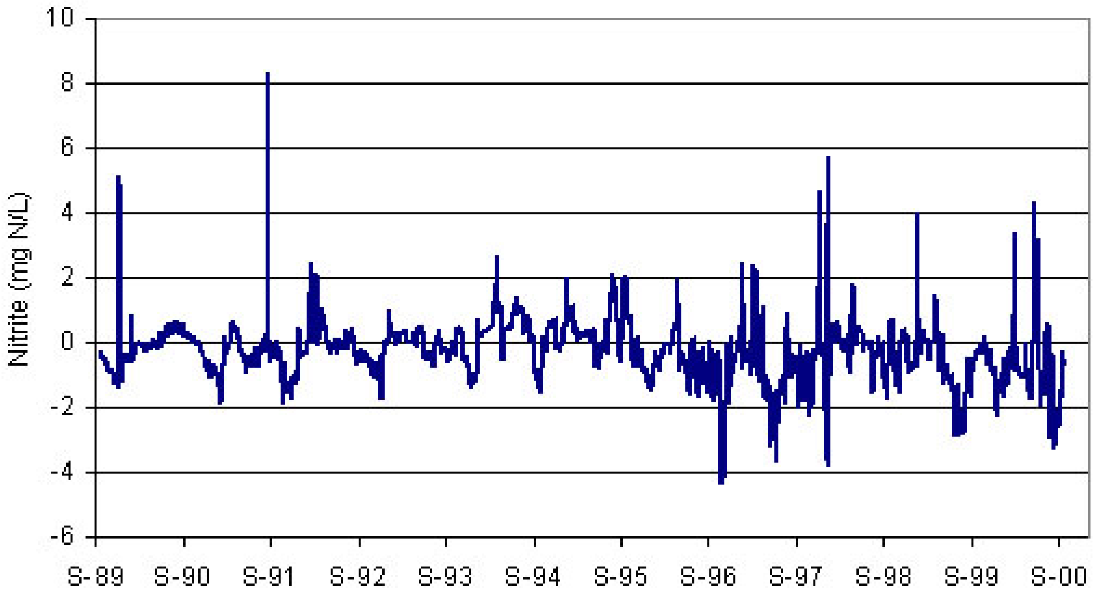
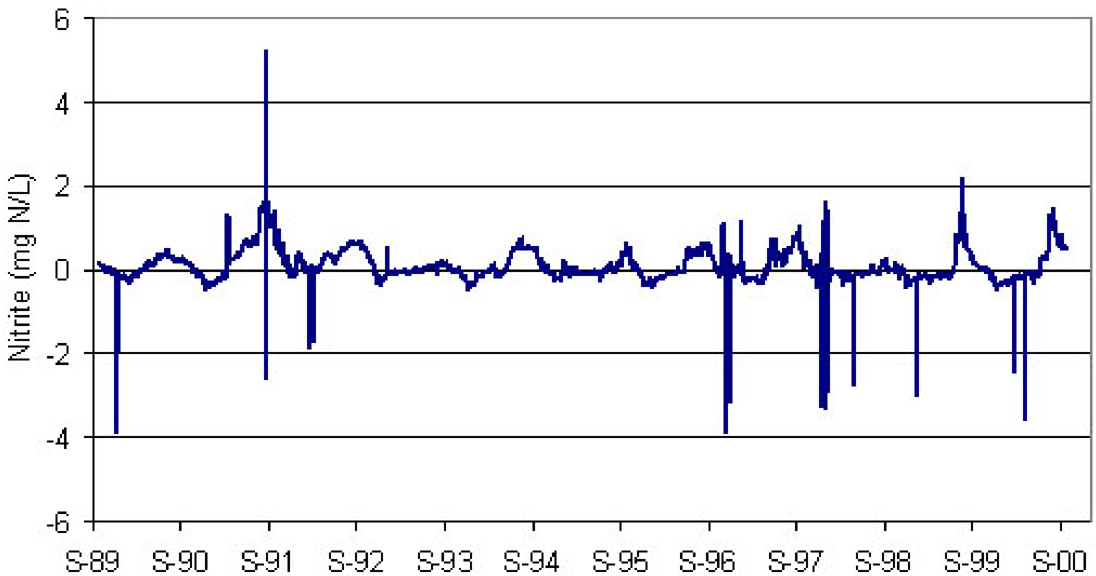


Figure 16. Difference between simulated NO_3 at County Line and below Blue Cut



Based on assimilation and other transformations, one would expect that the concentrations would decrease from upstream to downstream locations. In fact, Figure 15 indicates that most of the time nitrate concentrations increase at the County Line, with periodic dilution every winter. In the region below Blue Cut, nitrate concentrations remain fairly constant, with some periodic pulses that increase the concentrations and to a lesser degree some winter dilution. However, the increase in nitrate observed at the County Line can easily be explained by the transformation of ammonia to nitrate (Figures 17-19). About 2-4 mg N/L as NH_3 transform to nitrate in the segments between Old Road and the County Line, with some possible losses of N to assimilation and denitrification. These processes continue below Blue Cut, but there is considerably less ammonia in that region, so the effect is much smaller. Thus, without further groundwater monitoring data, it would be difficult to differentiate between these various processes.

Figure 17. Ammonia concentrations at the Old Road

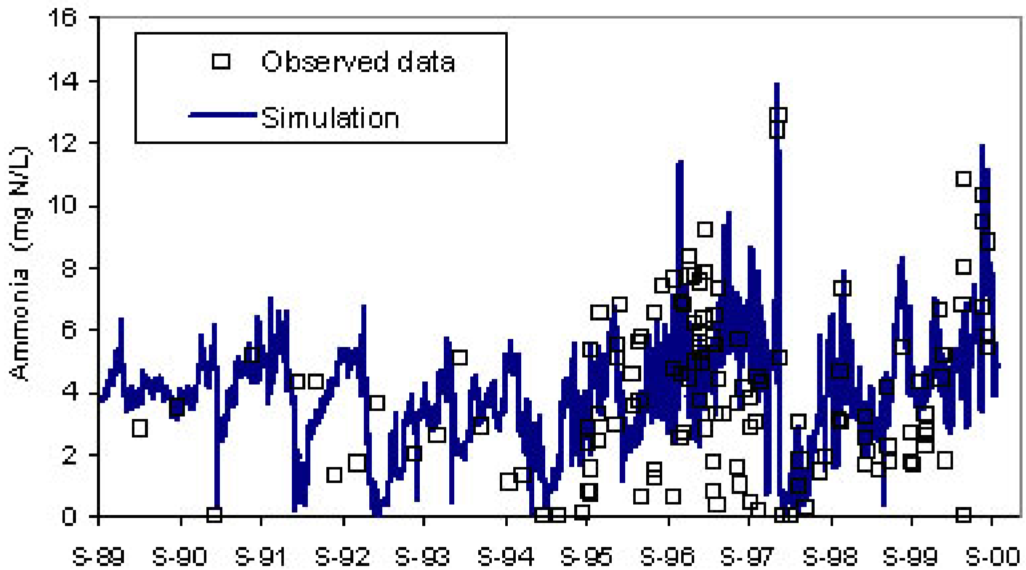


Figure 18. Ammonia concentrations at the County Line

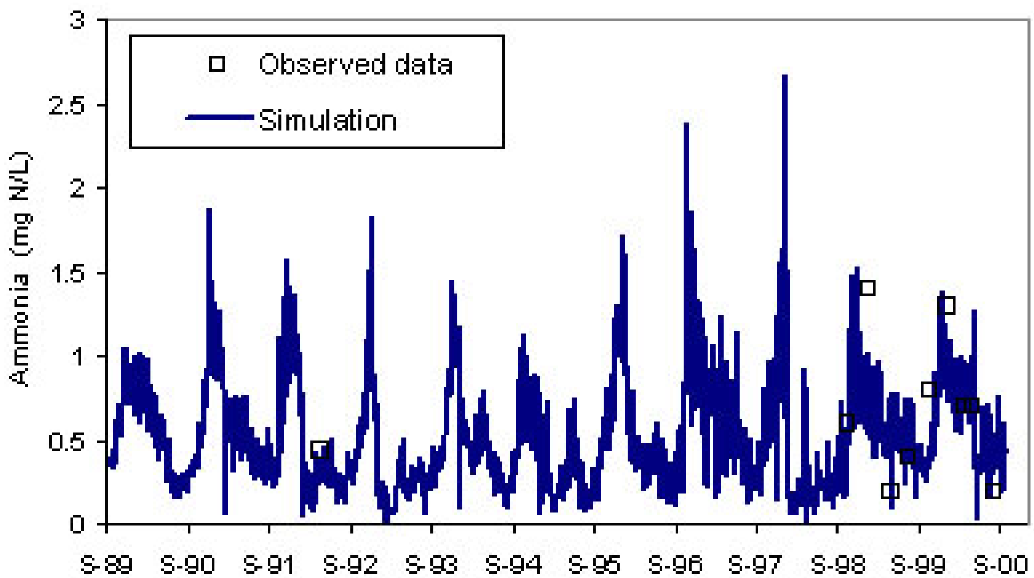
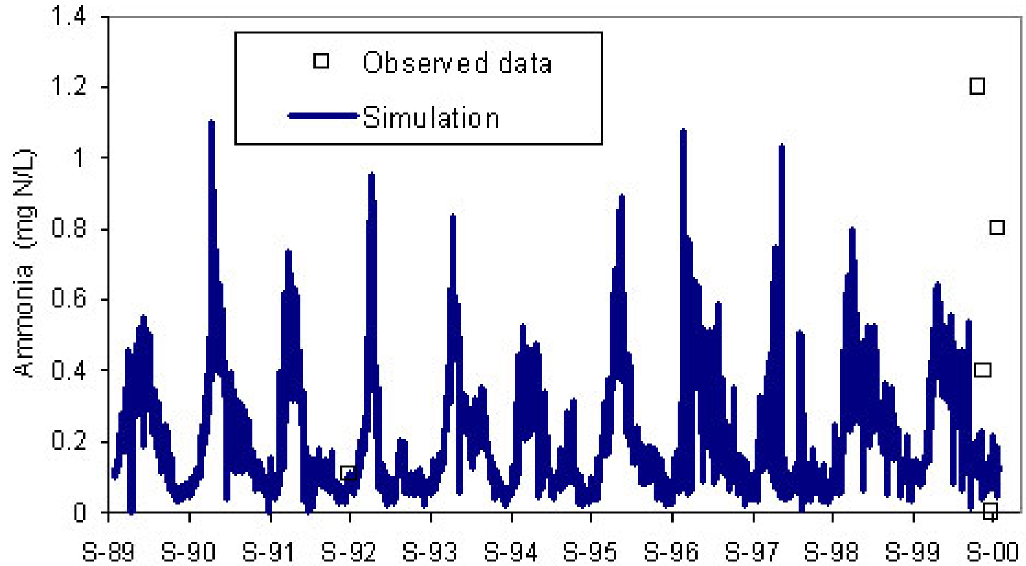


Figure 19. Ammonia concentrations at below Blue Cut



Rising Groundwater in Reach 3

Groundwater "rises" between the region above Fillmore and Santa Paula, in the vicinity of the Fillmore Fish Hatchery. The effect is captured in Figure 20, where flow in the reach above Fillmore (blue line) is significantly lower than flow at the end of the reach above Santa Paula (red line). Note that the scale on this figure is logarithmic, indicating a significant difference in flow between these two regions, due mostly to groundwater contributions. Water flow increases again at Santa Paula due to the contribution from the point source, the Santa Paula Wastewater Treatment Plant. There is essentially no difference between flow at Santa Paula and the next segment below Santa Paula. All of these river segments are within Reach 3.

Nitrate concentrations increase in late spring, summer and through the fall within these river segments, suggesting that NPS contributions in this region are important (Figures 21-24). There is a common dilution effect every winter and into early spring, which is probably due to winter storm events and delayed groundwater contributions. We present both observed data and simulation results to emphasize that this is not just a simulated condition, but that even with the relative sparseness of the observed data at some locations, the effect is relatively general with few exceptions.

In general, nitrate concentrations in the segment above Fillmore are below 5 mg N/L as NO_3, while the nitrate concentrations increase in the segment above Santa Paula and remain at the higher level through Santa Paula and below. The increase is on the order of 1-2 mg N/L as NO_3, which is sufficient to result in some exceedances of the water quality objective for this Reach. Groundwater is likely contributing to the rise of nitrate concentrations in this region. Given that ammonia loading above Fillmore is rather low, ammonia conversion to nitrate is not likely to be an important process in Reach 3. Additional studies with isotopic tracers and other dating methods should be considered to establish the contribution of nitrate from the upper watershed to the lower watershed. There is also important NPS loading in this Reach, which would by itself be an important contributor.

Figure 20. Flow in Reach 3

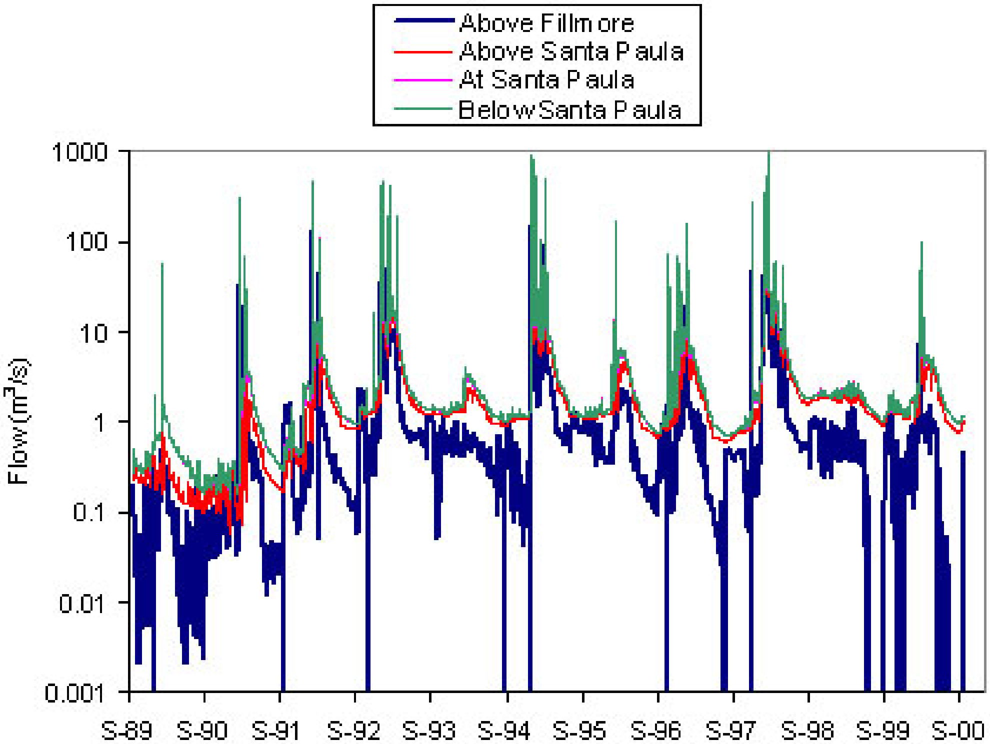


Figure 21. Nitrate concentrations above Fillmore

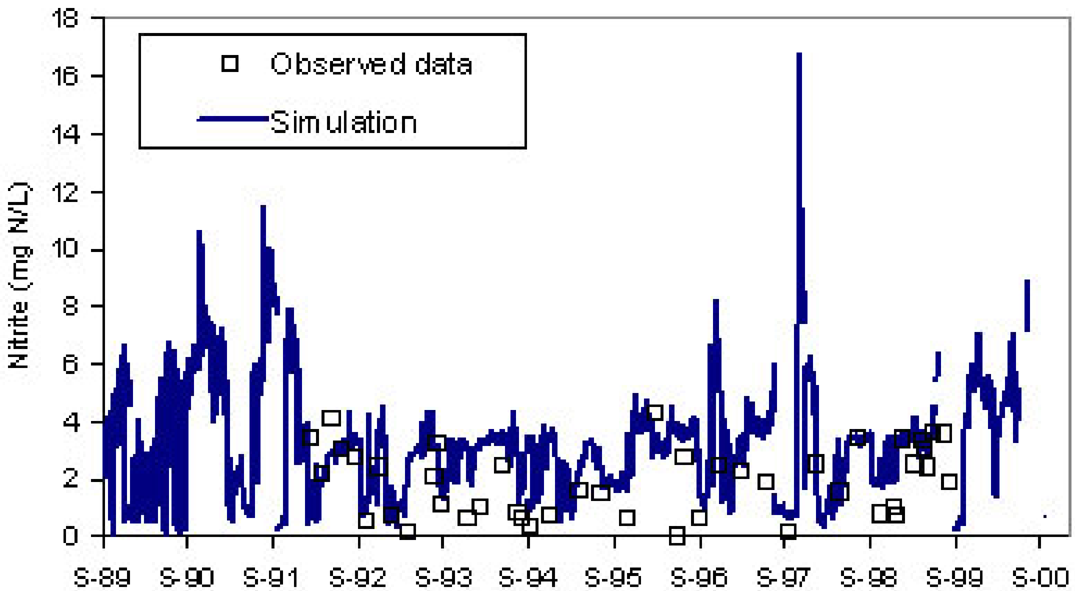


Figure 22. Nitrate concentrations above Santa Paula

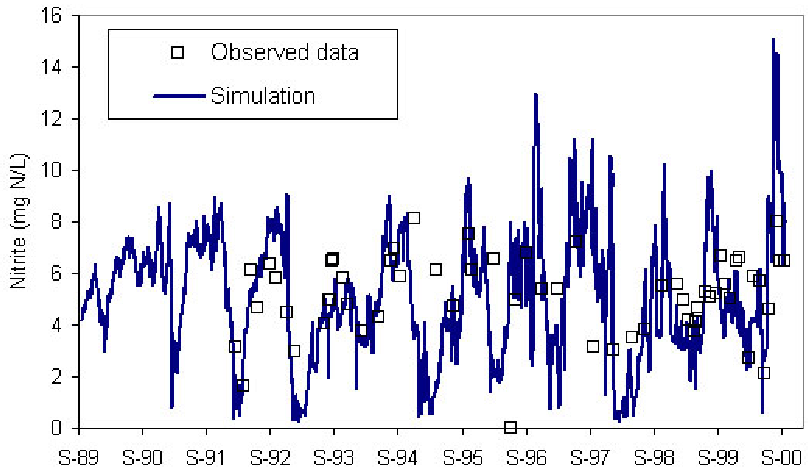


Figure 23. Nitrate concentrations at Santa Paula

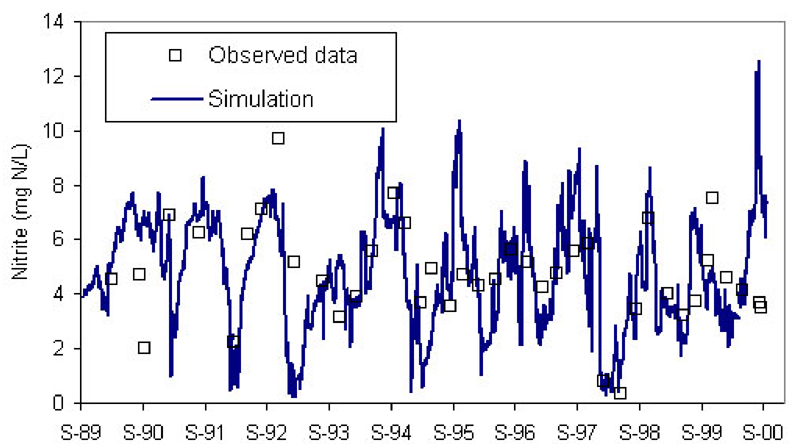
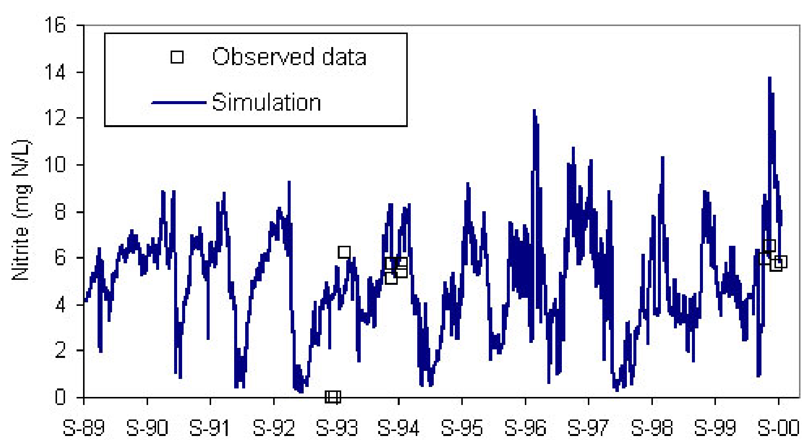


Figure 24. Nitrate concentrations below Santa Paula



5. Conclusions

The statistical correlation of flow and concentrations indicates that the highest concentrations are typically going to be found during low flow periods when there is reduced dilution. For these catchments, this is of particular importance given that in many instances there is practically no flow during significant periods of time. On the other hand, since there is no carrier medium, there is generally little or no loading occurring at this time from NPS. Thus the concern is simply that PS loading be controlled during these low flow periods so that it does not exceed the desired numerical targets.

From the timing analysis we conclude that for these catchments, NPS loading is very small in general, with only a few days in the 11-year simulation where the relative magnitude of NPS loading is of significance for water quality. These exceptionally high NPS load days occur early in the rainy season, and typically follow a period of dry years. In the case of ammonia, this is mostly a concern if the NPS ammonia load is applied right before the rain events. These findings can be used to better design Best Management Practices, with regards to the timing of the NPS loading so that it is reduced in the months before the rainy season, and in particular after a number of dry years.

The analysis of contribution from groundwater to the observed nitrate concentrations in the Santa Clara River indicates that this is more likely to occur in the lower watershed (Reach 3), and be less important in the upper watershed (Reach 7). However, it is important to note that the groundwater component of the model is spatially very simplified. It is necessary to obtain time-series data of nitrate concentrations in several wells in the area, which can then be coupled to a groundwater flow model to estimate the magnitude of the contribution from groundwater.

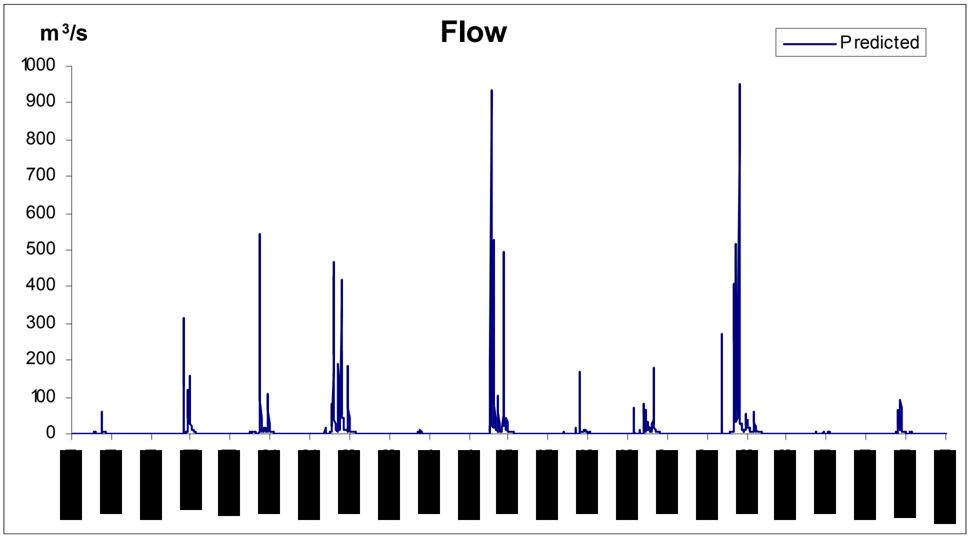
In conclusion, the most critical conditions for water quality in the Santa Clara River are low-flow conditions, in particular at the end of the dry season. The first strong storm events can cause significant short-term increases in nitrate concentrations in the river. Groundwater may be an important contributor in the lower watershed to increasing nitrate concentrations during the dry season. The groundwater contribution needs additional studies to confirm the magnitude and temporal variation of this load. These results need to be confirmed with additional monitoring data, in particular for Reach 3 where the observed data is sparse in many locations.

Appendix 1: Santa Clara River Reach 3 (downstream)

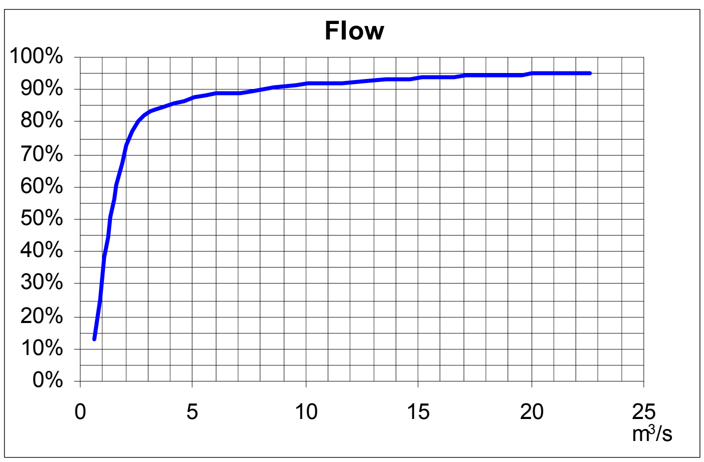
❖ Critical condition----Low flows and corresponding water quality data

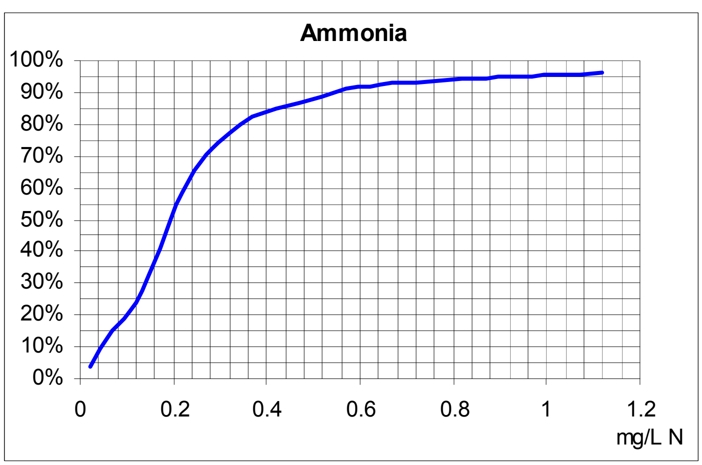
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (^oC)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0.2112	0.6152	9.6012	20.3722	0.1945	3.1651
	90-91	0.1536	1.1604	9.0677	18.5983	0.4049	4.4495
	91-92	0.3598	0.4523	9.1541	20.5063	0.1454	2.1073
	92-93	1.1957	0.1347	9.0037	18.8071	0.0466	1.3051
	93-94	1.0365	0.2910	8.6473	18.6614	0.1085	1.9669
	94-95	1.1336	0.5549	8.9348	14.8687	0.2170	2.0534
	95-96	0.7691	0.3577	8.5439	19.5447	0.1172	2.0702
	96-97	0.7154	0.1308	9.1645	20.4832	0.0409	1.6290
	97-98	0.8984	0.1773	8.9144	18.7138	0.0604	1.5648
	98-99	0.9993	0.2597	9.0745	18.0393	0.0907	1.6810
	99-00	0.9532	0.3148	8.9522	19.7660	0.1020	1.7498
7Q	89-90	0.2254	0.5937	9.5318	21.2511	0.1786	3.1012
	90-91	0.1623	1.4301	9.0628	18.0151	0.5131	4.9640
	91-92	0.5248	0.3288	9.1374	20.3197	0.1072	1.5504
	92-93	1.2188	0.1556	9.0249	18.1442	0.0553	1.3537
	93-94	1.0996	0.2905	8.6357	18.9679	0.1066	1.9603
	94-95	1.1432	0.5444	8.8858	14.4628	0.2170	2.0630
	95-96	0.8208	0.3277	8.6478	20.0872	0.1046	1.9891
	96-97	0.7556	0.1317	9.1544	20.1883	0.0420	1.5806
	97-98	0.9470	0.1936	8.9151	17.8170	0.0684	1.5614
	98-99	1.0168	0.2432	9.0689	18.5179	0.0836	1.6609
	99-00	0.9661	0.3155	8.9540	19.6560	0.1028	1.7433
30Q	89-90	0.2434	0.5918	8.8406	20.8670	0.1819	3.0511
	90-91	0.1983	1.0550	8.5805	19.7925	0.3458	4.4488
	91-92	0.6343	0.3504	9.0751	19.0431	0.1221	1.4163
	92-93	1.3974	0.1304	9.0625	16.7667	0.0493	1.3764
	93-94	1.1821	0.1582	8.9818	20.2025	0.0518	1.3016
	94-95	1.2004	0.5373	8.9159	13.7490	0.2179	2.0374
	95-96	0.8593	0.3103	8.7114	19.5376	0.1018	1.8848
	96-97	0.7978	0.1502	9.1525	19.7172	0.0489	1.5834
	97-98	0.9725	0.1488	8.8935	19.1528	0.0509	1.4171
	98-99	1.0997	0.2025	9.0914	18.3010	0.0711	1.5738
	99-00	1.0440	0.2270	9.0720	18.9763	0.0767	1.5984

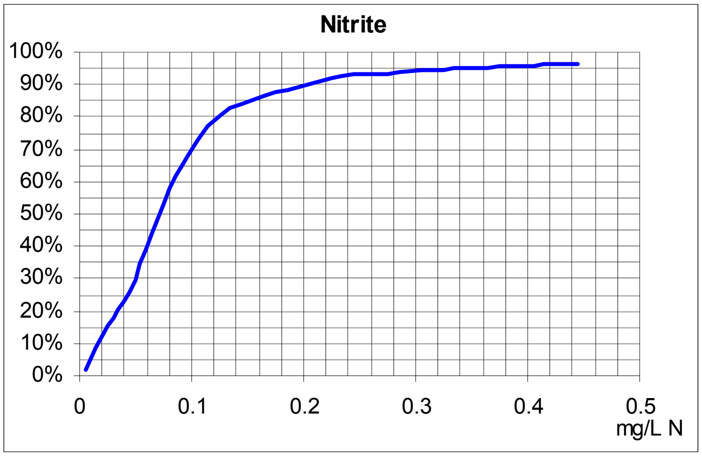
- Predicted flows

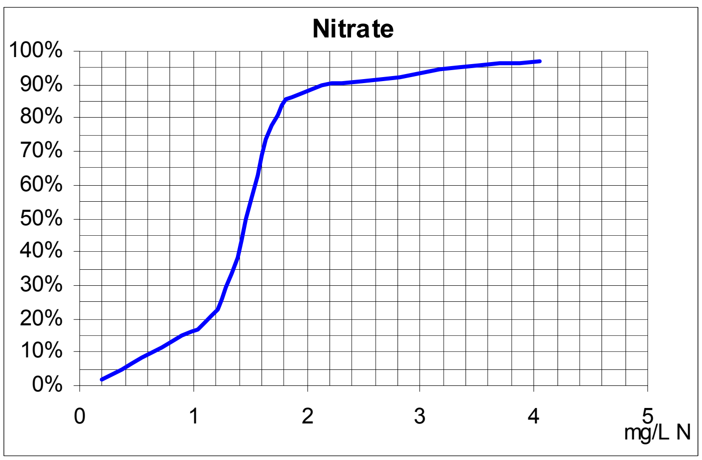


- Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.1
0.2
0.3
0.4
0.5
mg/L N

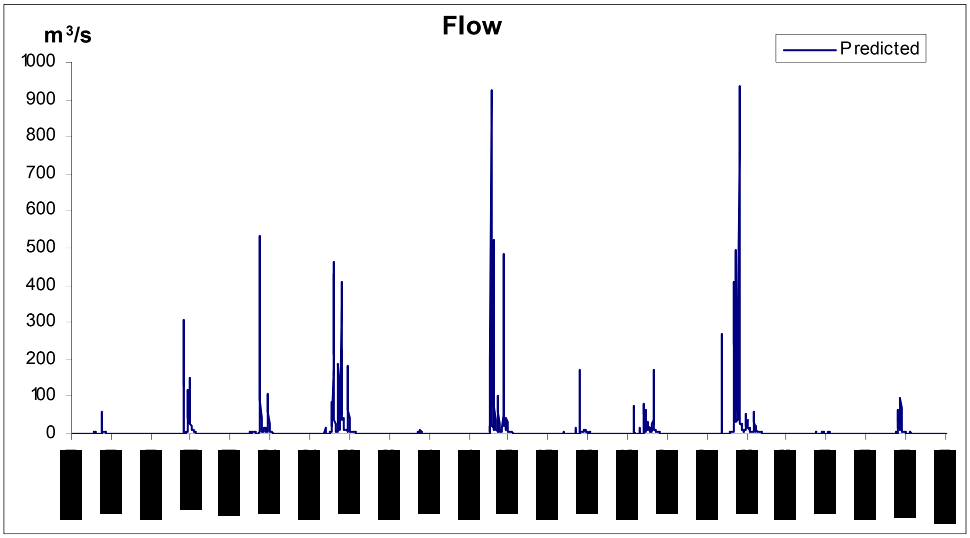

Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
mg/L N

Appendix 2: Santa Clara River Reach 3 (upstream)

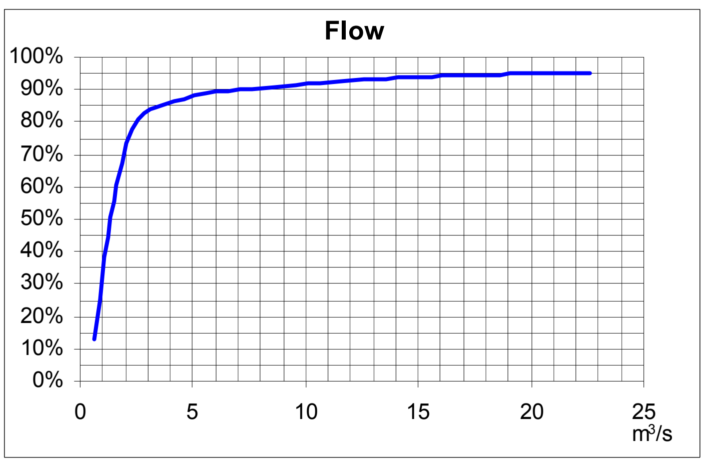
❖ Critical condition----Low flows and corresponding water quality data

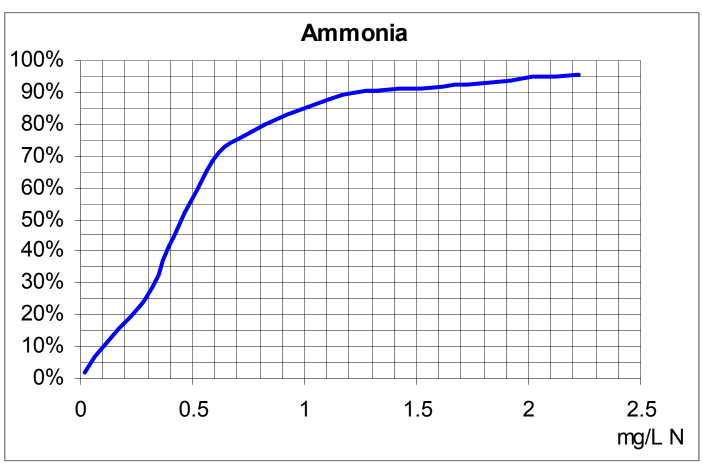
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (°C)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0.2107	1.8381	9.6211	20.4844	0.4424	4.0303
	90-91	0.1533	2.9891	9.1365	18.5656	0.7728	5.1280
	91-92	0.3536	1.0902	9.1334	22.5380	0.2576	2.5489
	92-93	1.1957	0.3461	8.9402	18.5626	0.0904	1.8829
	93-94	1.0352	0.7438	8.3951	18.6761	0.2408	2.6314
	94-95	1.1323	0.3727	8.7599	20.8299	0.1488	2.1055
	95-96	0.7683	0.9781	8.2719	19.4822	0.2340	2.7264
	96-97	0.7154	0.3835	9.1004	20.2221	0.0896	2.4813
	97-98	0.8939	0.4573	8.8191	18.6886	0.1117	2.2492
	98-99	0.9990	0.6408	9.0419	18.0622	0.1582	2.2816
	99-00	0.9530	0.8749	8.9373	19.6223	0.2081	2.2767
7Q	89-90	0.2253	1.8835	9.5575	21.3534	0.4360	3.9077
	90-91	0.1621	3.4999	9.1524	18.2539	0.9072	5.5910
	91-92	0.5259	0.9669	9.1705	20.2008	0.2543	1.8855
	92-93	1.2190	0.3830	8.9703	18.0513	0.1011	1.9176
	93-94	1.0995	0.7601	8.3744	18.9335	0.2436	2.6285
	94-95	1.1433	1.0761	8.8753	14.4604	0.3040	2.4803
	95-96	0.8204	0.9339	8.4542	19.9618	0.2198	2.6538
	96-97	0.7557	0.3762	9.0921	20.0073	0.0885	2.3937
	97-98	0.9468	0.4673	8.8259	17.8948	0.1161	2.1917
	98-99	1.0170	0.6149	9.0327	18.4481	0.1507	2.2753
	99-00	0.9659	0.8692	8.9392	19.5357	0.2073	2.2661
30Q	89-90	0.2435	1.8222	8.2293	20.9918	0.4274	3.8438
	90-91	0.1981	2.9700	8.1195	19.9988	0.7218	5.2843
	91-92	0.6347	0.9171	9.1194	19.0137	0.2422	1.6745
	92-93	1.3952	0.2931	9.0012	16.8148	0.0819	1.9644
	93-94	1.1820	0.4502	8.9177	20.0030	0.1158	1.8539
	94-95	1.2003	1.0257	8.9017	13.9282	0.2956	2.4567
	95-96	0.8595	0.8479	8.5711	19.4506	0.2026	2.5162
	96-97	0.7976	0.4155	9.0982	19.5833	0.0990	2.3466
	97-98	0.9725	0.3860	8.7885	19.1191	0.0963	2.0645
	98-99	1.0994	0.5051	9.0489	18.2575	0.1299	2.1968
	99-00	1.0443	0.5965	9.0384	18.9127	0.1475	2.1977

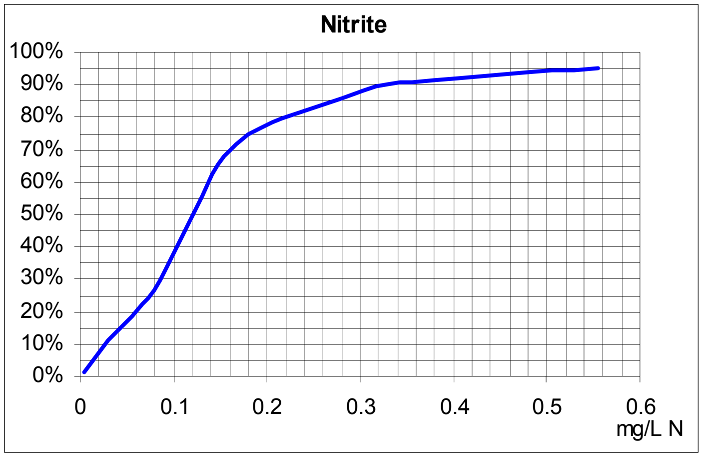
❖ Predicted flows

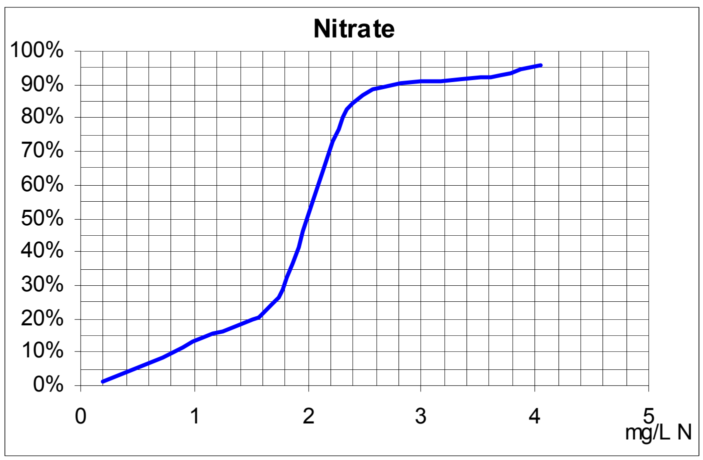


❖ Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.1
0.2
0.3
0.4
0.5
0.6
mg/L N

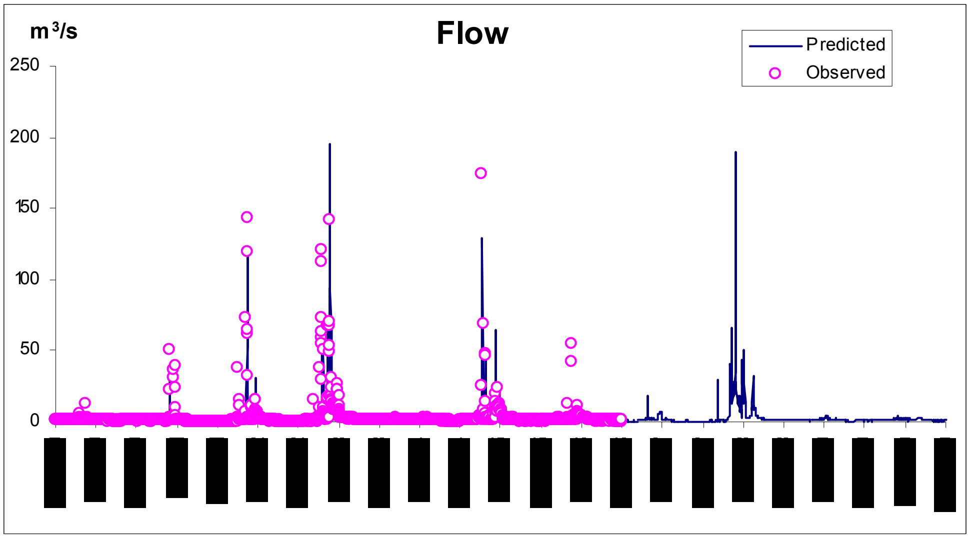

Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
mg/L N

Appendix 3: Santa Clara River Reach 7 (downstream)

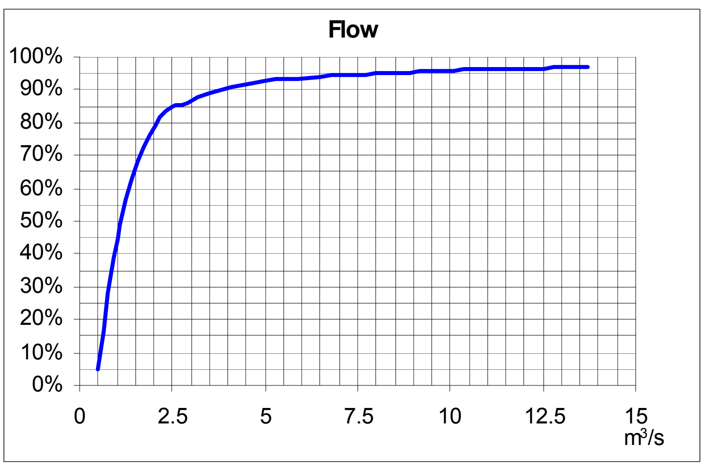
❖ Critical condition----Low flows and corresponding water quality data

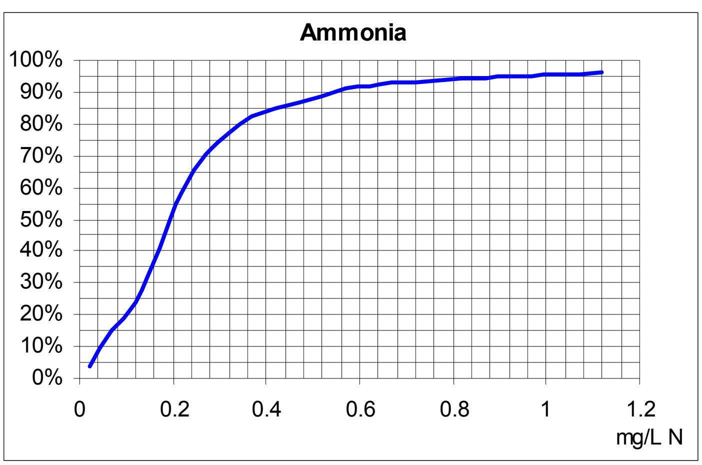
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (^oC)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0.0308	0.0220	8.6885	23.9453	0.0055	7.3480
	91-92	0					
	92-93	0.4941	0.0223	9.0395	24.3543	0.0055	6.6007
	93-94	0.5897	0.0201	9.1843	23.8311	0.0052	5.6631
	94-95	0.5480	0.0395	8.5165	23.0638	0.0110	6.9574
	95-96	0.7111	0.0239	9.0833	22.5835	0.0069	4.3463
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					
7Q	89-90	0					
	90-91	0.1031	0.0297	8.6642	23.1958	0.0081	6.8796
	91-92	0.2004	0.0194	8.7474	24.5338	0.0047	6.2386
	92-93	0.5251	0.0334	8.9784	23.2152	0.0093	6.5930
	93-94	0.6342	0.0144	9.1441	24.7425	0.0034	5.4448
	94-95	0.6962	0.0709	8.4388	21.5380	0.0233	7.1626
	95-96	0.7339	0.0234	8.7681	24.1650	0.0058	5.8517
	96-97	0.3719	0.1295	8.4196	21.8592	0.0425	11.9291
	97-98	0.5485	0.0400	9.1492	23.3260	0.0129	6.4223
	98-99	0.2316	0.0287	8.5996	24.5809	0.0069	7.8651
	99-00	0.6714	0.0237	8.8768	24.7377	0.0061	6.7540
30Q	89-90	0.6048	0.1712	8.3349	17.8444	0.0714	6.1238
	90-91	0.2021	0.0298	8.6620	23.4790	0.0082	6.6119
	91-92	0.2103	0.0397	8.6555	23.1027	0.0122	6.7918
	92-93	0.6384	0.0457	8.9602	22.4985	0.0137	7.1010
	93-94	0.6529	0.0457	8.9602	22.4985	0.0137	7.1010
	94-95	0.8396	0.0828	8.6184	20.6601	0.0294	7.3065
	95-96	0.7778	0.0174	8.7878	25.1934	0.0043	5.6839
	96-97	0.5009	0.0182	8.9246	25.7368	0.0040	8.2567
	97-98	0.5592	0.0587	8.9580	21.8451	0.0196	6.8040
	98-99	0.4911	0.0320	8.6506	24.3247	0.0084	7.2744
	99-00	0.7054	0.0394	8.6644	23.9935	0.0105	8.1936

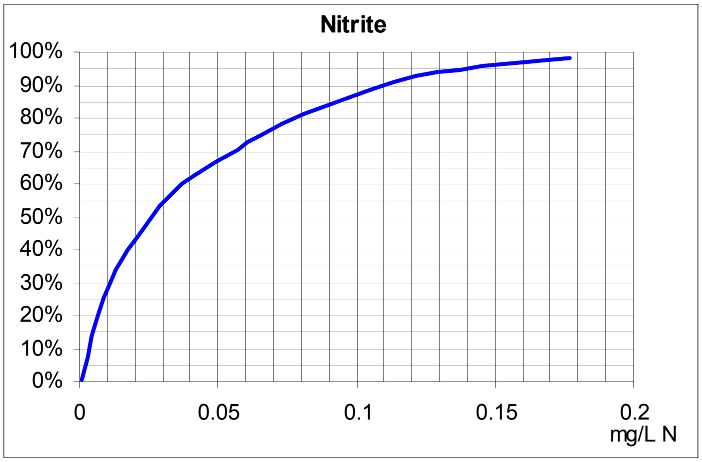
❖ Predicted and observed flows

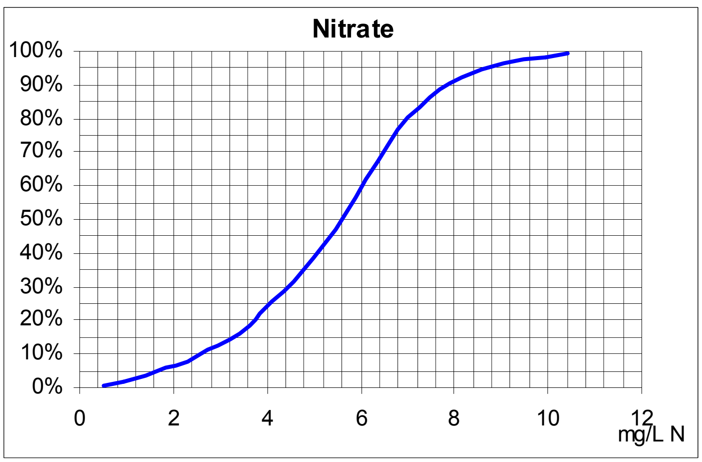


❖ Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.05
0.1
0.15
0.2
mg/L N


Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
12
mg/L N

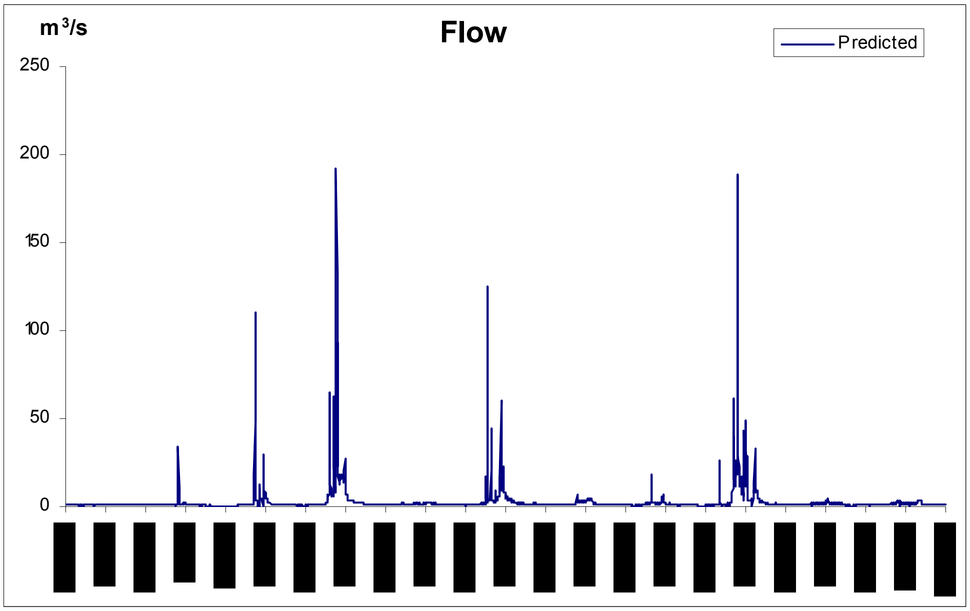
Appendix 4: Santa Clara River Reach 7 (mid-stream)

❖ Critical condition----Low flows and corresponding water quality data

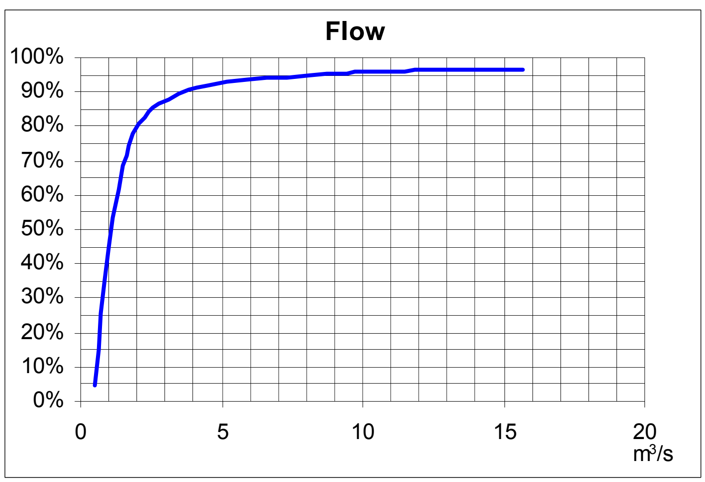
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (°C)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0.0891	0.0907	8.4610	24.9225	0.0207	7.8597
	91-92	0					
	92-93	0.5117	0.0928	8.9845	24.5485	0.0222	6.9234
	93-94	0.6008	0.0636	9.1470	24.8120	0.0147	5.6300
	94-95	0.5641	0.1435	8.1393	23.4127	0.0384	7.2623
	95-96	0.7093	0.0830	9.0761	22.9591	0.0230	4.5213
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					
7Q	89-90	0					
	90-91	0.1571	0.1112	8.4546	23.9490	0.0283	7.2935
	91-92	0.2451	0.0817	8.6031	24.8232	0.0191	6.5997
	92-93	0.5384	0.1224	8.9382	23.4200	0.0329	6.8879
	93-94	0.6415	0.0616	9.1051	25.1314	0.0140	5.7476
	94-95	0.6986	0.2177	8.0567	21.7978	0.0685	7.3993
	95-96	0.7321	0.0953	8.5892	24.5351	0.0226	6.1374
	96-97	0.3915	0.4011	7.8257	22.0960	0.1236	12.2573
	97-98	0.5455	0.1314	9.1338	23.5008	0.0387	6.7191
	98-99	0.2946	0.1218	8.2483	25.0734	0.0276	8.2389
	99-00	0.6705	0.0961	8.7272	24.9948	0.0234	7.0782
30Q	89-90#	0.5926	0.4219	8.0965	17.8675	0.1686	6.1985
	90-91	0.2471	0.1118	8.4621	23.9151	0.0290	6.9674
	91-92	0.2510	0.1346	8.4600	23.4604	0.0381	7.1226
	92-93	0.6420	0.1549	8.9236	22.6996	0.0447	7.3912
	93-94	0.6582	0.0817	8.7892	24.7553	0.0194	6.2494
	94-95	0.8319	0.2361	8.4584	20.9198	0.0794	7.5613
	95-96	0.7749	0.0741	8.6033	25.6139	0.0169	5.9906
	96-97	0.5007	0.0860	8.7655	26.0746	0.0178	8.7477
	97-98	0.5505	0.1826	8.8758	22.1358	0.0565	7.0854
	98-99	0.5255	0.1247	8.3807	24.7377	0.0308	7.6102
	99-00	0.7044	0.1515	8.3315	24.2267	0.0387	8.5454

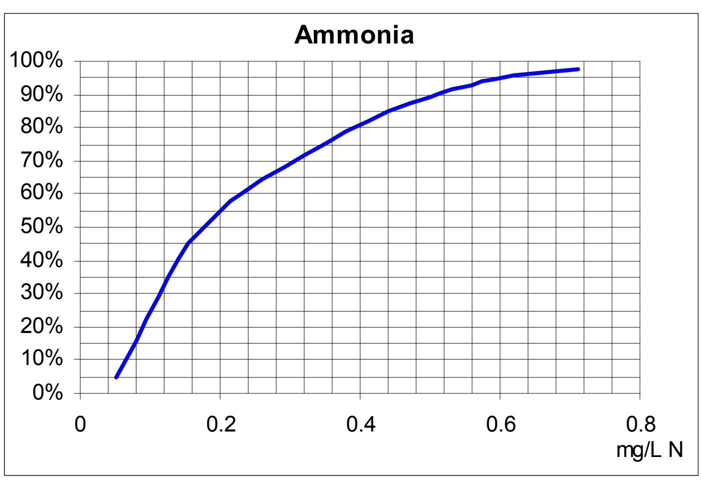
The predicted water quality data are incomplete during these periods due to the zero predicted flows

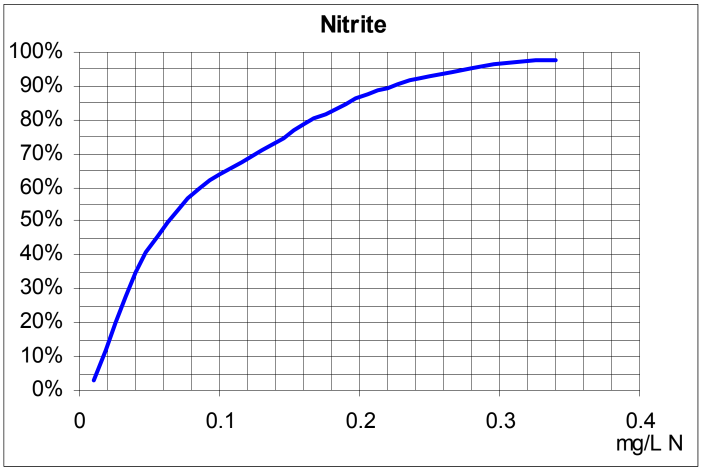
❖ Predicted flows

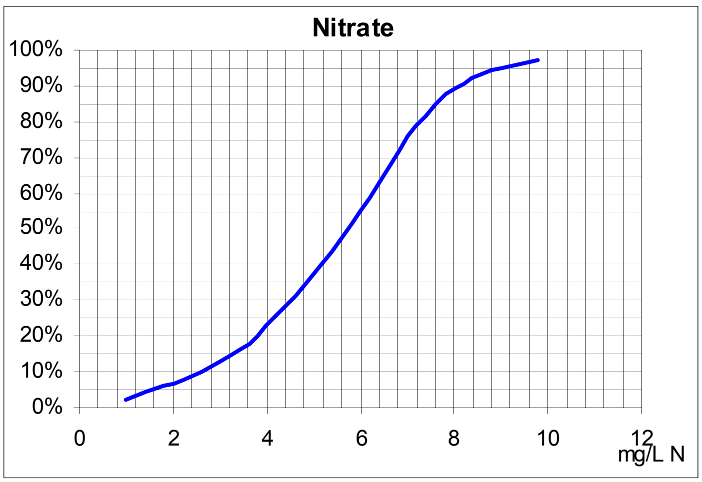


❖ Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.1
0.2
0.3
0.4
mg/L N


Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
12
mg/L N

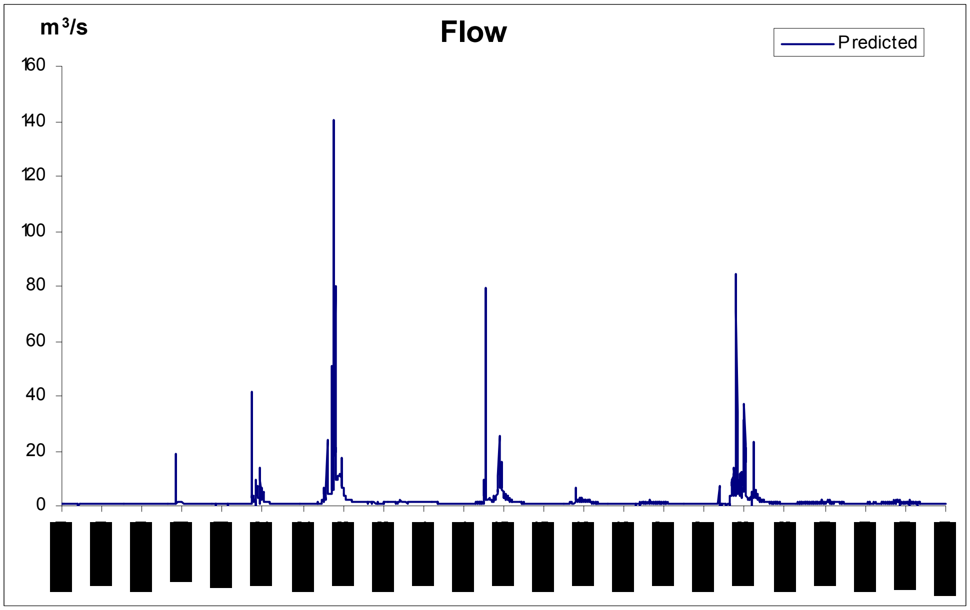
Appendix 5: Santa Clara River Reach 7 (upstream)

❖ Critical condition----Low flows and corresponding water quality data

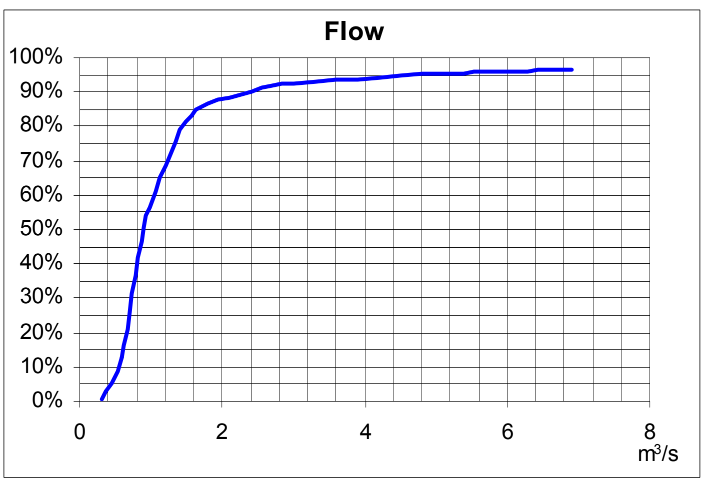
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (°C)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0.3416	2.1567	9.2623	26.09	0.3744	7.5204
	91-92	0					
	92-93	0.547	1.9069	9.4406	23.608	0.4137	5.8956
	93-94	0.6225	1.3096	9.4552	25.23	0.2454	5.1174
	94-95	0.6217	2.2126	9.1136	24.083	0.4811	5.9877
	95-96	0.669	2.2400	9.3032	25.171	0.4168	5.7803
	96-97	0.0293	2.3275	9.3304	18.793	0.6593	5.6124
	97-98	0					
	98-99	0.5172	2.2166	9.3884	15.949	0.7352	4.5716
	99-00	0					
7Q	89-90	0.3969	3.2000	9.3152	17.6089	0.8914	4.8550
	90-91	0.3894	2.0838	9.2820	24.9761	0.3985	6.7441
	91-92	0.3972	2.5558	9.3239	23.733	0.5362	7.16
	92-93	0.5770	1.9042	9.4439	23.967	0.4025	6.0346
	93-94	0.6530	1.3344	9.4241	25.386	0.2468	5.2386
	94-95	0.6848	2.4576	9.1577	22.834	0.5843	5.9131
	95-96	0.6949	1.8882	9.3293	25.03	0.3575	5.1646
	96-97	0.4412	2.3305	9.4367	26.253	0.386	7.9028
	97-98	0.4573	2.9409	9.4785	23.997	0.5653	7.4574
	98-99	0.5684	2.8474	9.232	24.776	0.5682	6.7423
	99-00	0.6369	1.9557	9.3593	25.25	0.4066	6.0859
30Q	89-90#	0.6181	2.8923	9.276	18.585	0.7814	4.7398
	90-91	0.436	1.9785	9.2873	24.585	0.3931	6.3131
	91-92	0.4209	2.0698	9.3089	24.505	0.4159	6.3858
	92-93	0.6323	2.0751	9.4948	23.427	0.4582	6.4096
	93-94	0.6612	1.6121	9.3419	25.173	0.3139	5.4867
	94-95	0.7676	2.3376	9.3372	21.84	0.5479	6.5303
	95-96	0.7315	1.6401	9.1923	26.086	0.2864	5.0393
	96-97	0.4664	2.3625	9.4239	26.337	0.3893	7.9773
	97-98	0.4724	2.4367	9.5315	23.638	0.494	6.3306
	98-99	0.6669	2.3473	9.2406	25.061	0.4618	6.2373
	99-00	0.6702	2.6661	9.2957	24.737	0.5584	6.998

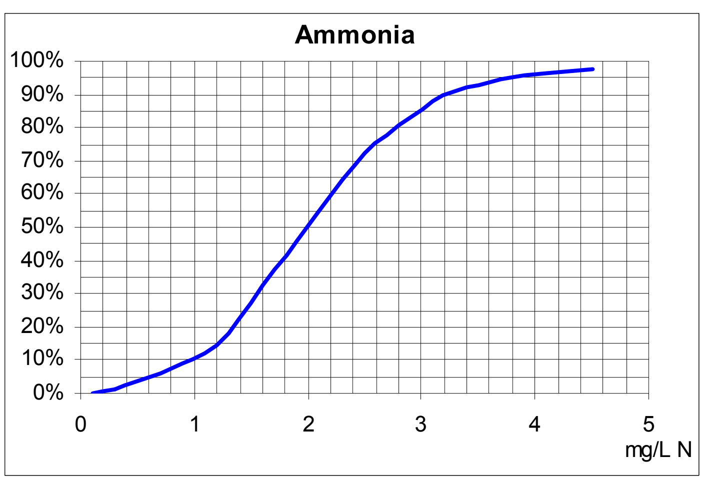
The predicted water quality data are incomplete during these periods due to the zero predicted flows

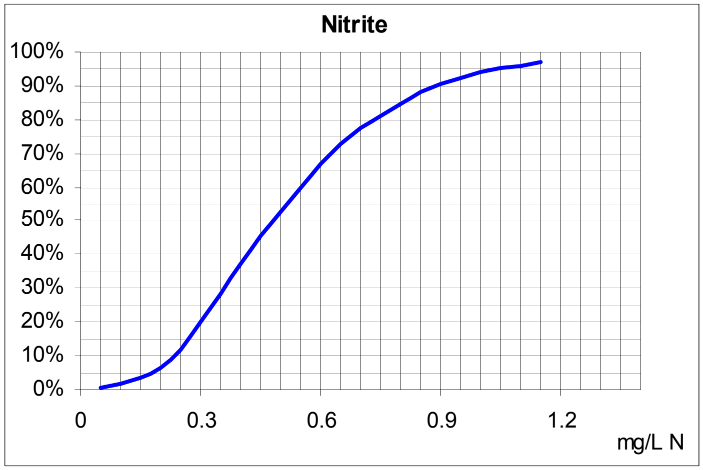
❖ Predicted flows



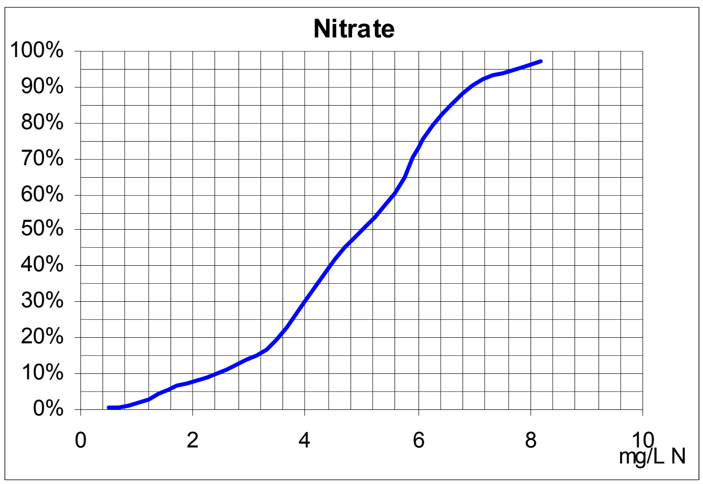
❖ Cumulative probabilities







Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.3
0.6
0.9
1.2
mg/L N



Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
mg/L N

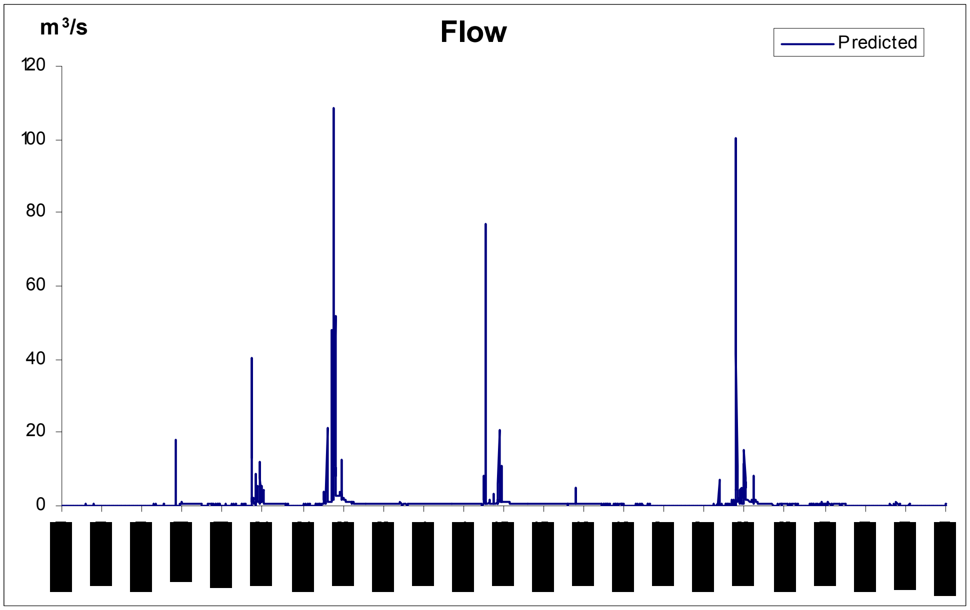
Appendix 6: Santa Clara River Reach 8

❖ Critical condition----Low flows and corresponding water quality data

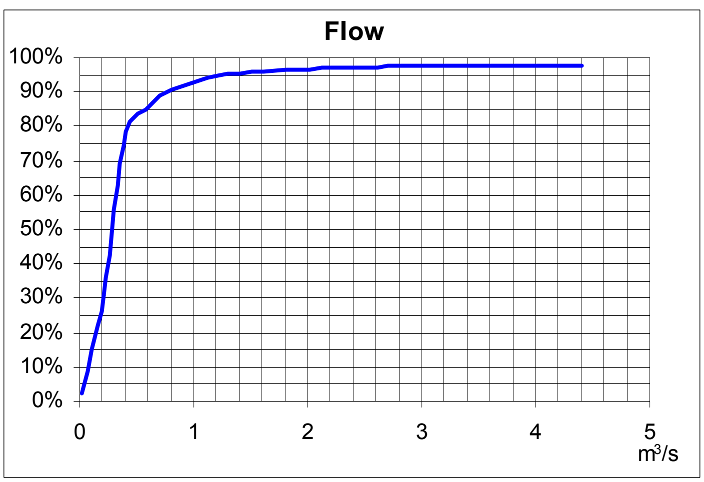
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (°C)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0.1191	0.7872	8.6367	22.2290	0.2312	5.1689
	91-92	0					
	92-93	0.2233	2.3106	7.5719	16.7125	0.8845	5.6653
	93-94	0.2679	2.8381	7.6958	13.1983	1.2390	5.7421
	94-95	0.2491	2.1822	7.7652	15.3356	1.0313	6.4279
	95-96	0.2322	0.3082	8.7767	25.2984	0.0676	3.2945
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					
7Q	89-90	0.0981	1.6850	7.6919	18.2668	0.6341	5.3609
	90-91	0.1811	2.4207	7.5788	14.3615	1.0420	5.3361
	91-92	0.0907	2.2442	7.6549	15.6949	0.9339	5.7030
	92-93	0.2438	1.6511	7.6679	19.3045	0.5656	5.5294
	93-94	0.3001	1.9441	8.0006	14.4933	0.9185	5.6980
	94-95	0.3015	1.2182	8.0494	21.1301	0.3835	6.0452
	95-96	0.2593	0.4235	8.6637	24.6419	0.1008	3.7708
	96-97	0					
	97-98	0					
	98-99	0.1090	1.1727	8.1289	22.5875	0.3343	6.9041
	99-00	0.0343	2.4911	7.7020	16.5438	1.0316	7.1370
30Q	89-90#	0.1584	2.4988	7.5651	14.6482	1.0642	5.2274
	90-91	0.2256	0.9910	8.0518	21.6100	0.3080	5.0142
	91-92	0.1447	0.8939	8.2521	22.0183	0.2609	4.6978
	92-93	0.2535	1.8987	7.5441	20.0405	0.6133	6.5734
	93-94	0.3161	0.8288	8.4448	22.7147	0.2353	5.4837
	94-95	0.3094	1.7267	7.7377	19.7504	0.5926	6.3323
	95-96	0.2680	0.3812	8.6822	25.3338	0.0843	3.6582
	96-97#	0.0158	1.1280	8.1630	18.4177	0.4385	4.6391
	97-98#	0.0507	0.9461	8.5441	21.3022	0.3027	5.5547
	98-99	0.1497	1.0118	8.1554	22.6470	0.2880	5.9150
	99-00	0.0644	1.3181	8.3092	20.1914	0.4553	6.7423

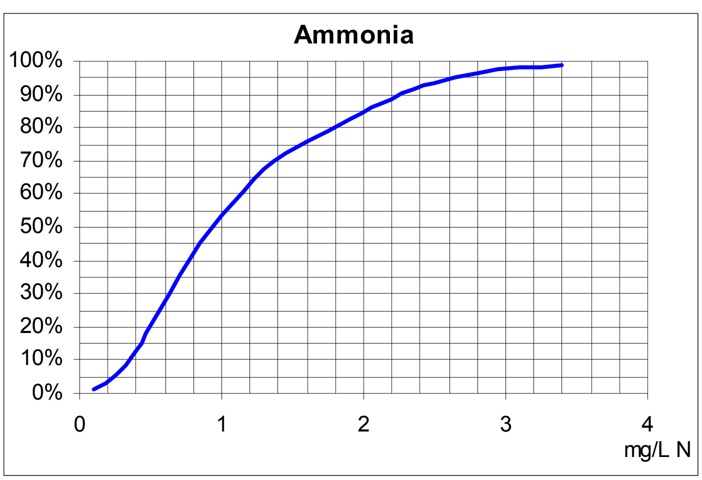
The predicted water quality data are incomplete during these periods due to the zero predicted flows

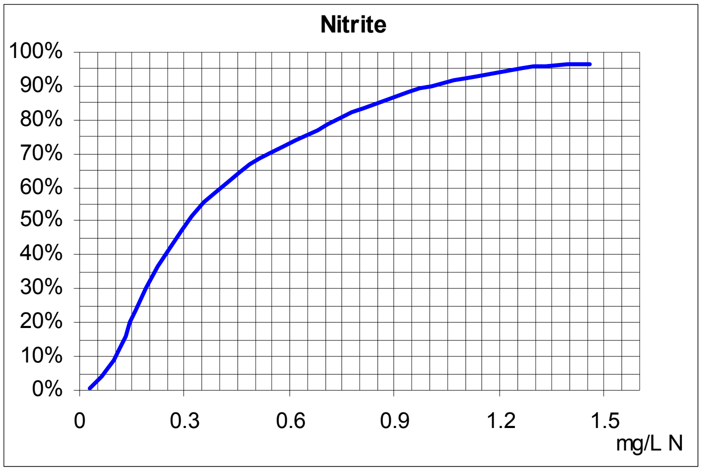
- Predicted flows

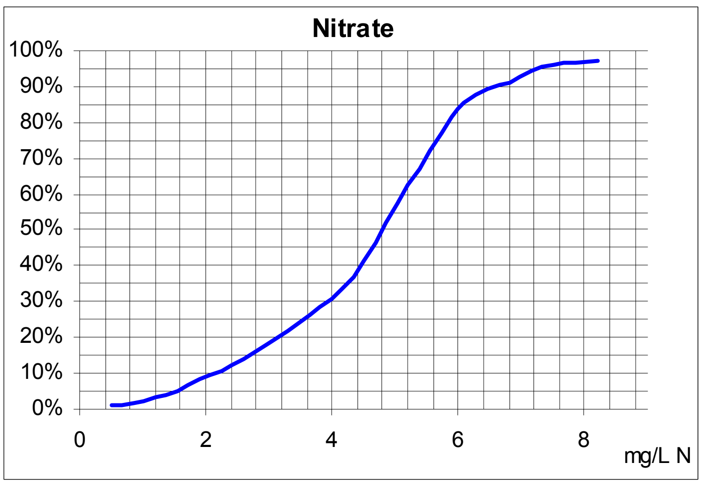


- Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.3
0.6
0.9
1.2
1.5
mg/L N

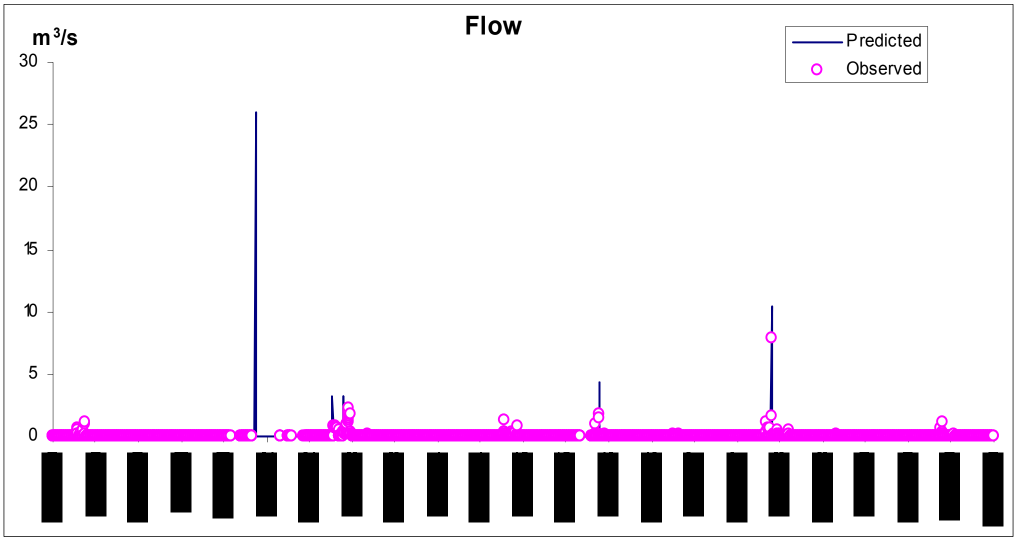

Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
mg/L N

Appendix 7: Mint Canyon

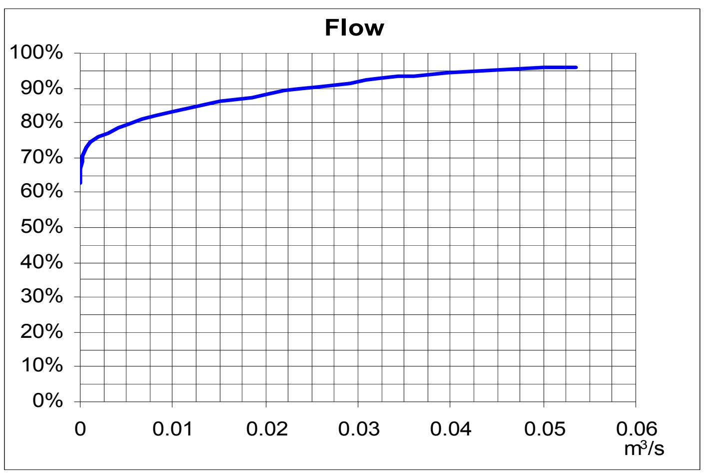
❖ Critical condition----Low flows and corresponding water quality data

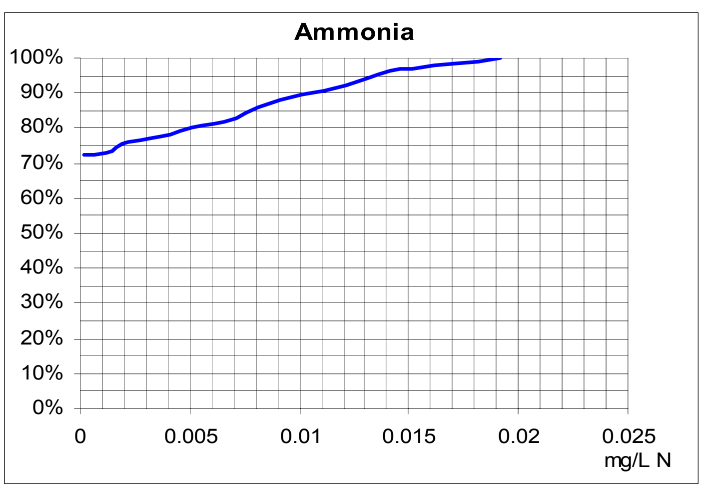
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (^oC)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0					
	91-92	0					
	92-93	0					
	93-94	0					
	94-95	0					
	95-96	0					
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					
7Q	89-90	0					
	90-91	0					
	91-92	0					
	92-93	0					
	93-94	0					
	94-95	0					
	95-96	0					
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					
30Q	89-90	0					
	90-91	0					
	91-92	0					
	92-93	0					
	93-94	0					
	94-95	0					
	95-96	0					
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					

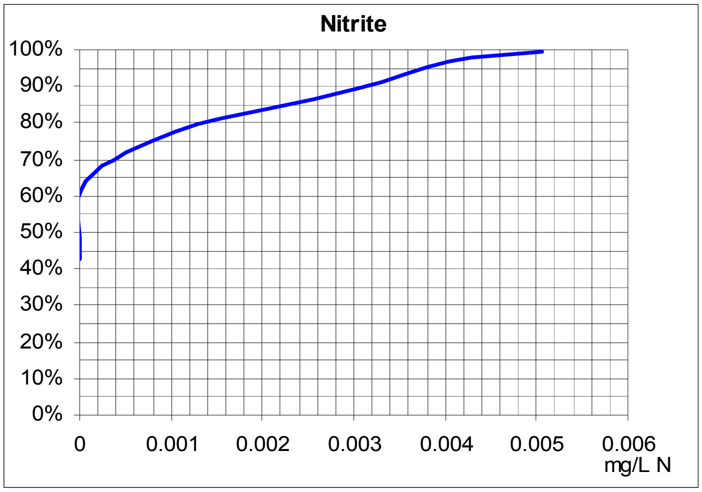
❖ Predicted and observed flows

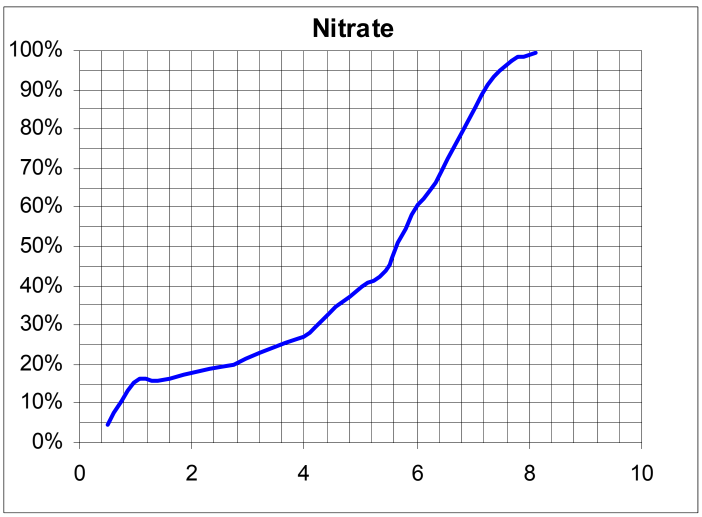


❖ Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.001
0.002
0.003
0.004
0.005
0.006
mg/L N

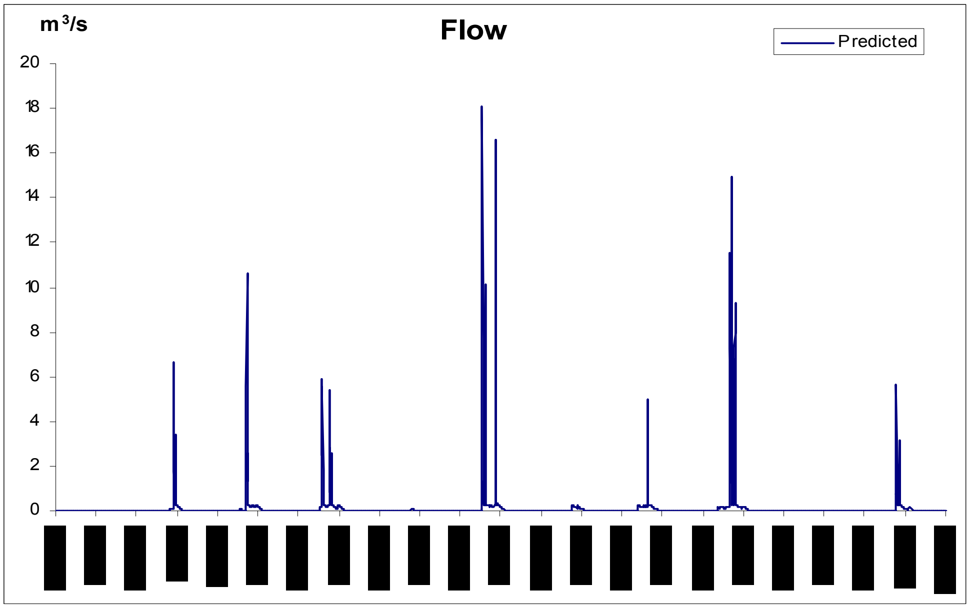

Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10

Appendix 8: Wheeler Canyon

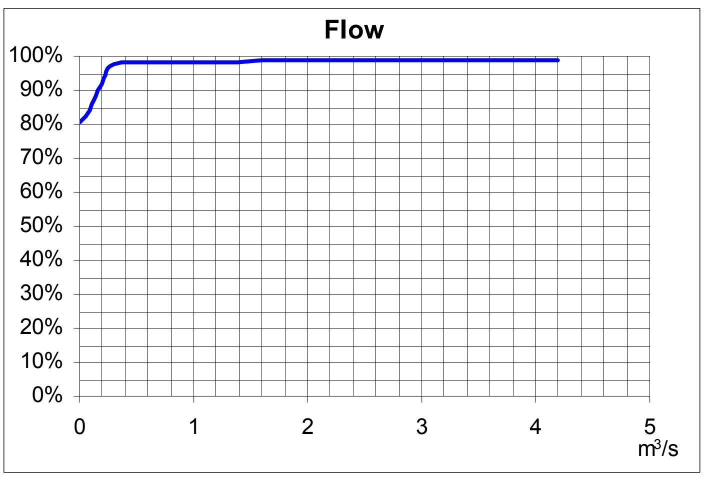
❖ Critical condition----Low flows and corresponding water quality data

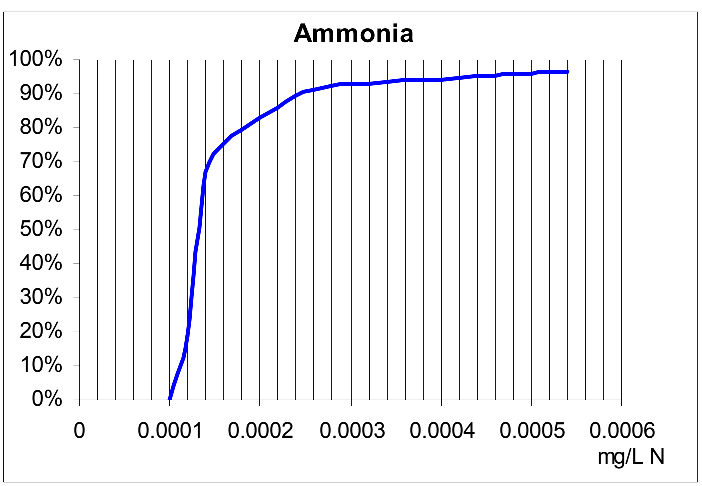
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (^oC)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0					
	91-92	0.0025	0.0001	8.4458	14.9314	0.00003	0.2803
	92-93	0.0023	0.0001	8.5168	12.8516	0.00004	0.3870
	93-94	0.0021	0.0001	8.5812	11.8287	0.00004	0.4800
	94-95	0.0022	0.0001	8.6111	11.8475	0.00004	0.4285
	95-96	0.0022	0.0001	8.6069	16.4800	0.00003	0.4819
	96-97	0.0023	0.0001	8.6087	20.8684	0.00003	0.5215
	97-98	0.0020	0.0001	8.6500	15.7473	0.00004	0.5234
	98-99	0.0006	0.0001	8.6983	19.6486	0.00003	0.6328
	99-00	0.0002	0.0002	8.7873	12.8913	0.00005	0.6640
7Q	89-90	0					
	90-91	0					
	91-92	0.0025	0.0001	8.4521	14.2461	0.00004	0.2800
	92-93	0.0023	0.0001	8.5210	12.6508	0.00004	0.3869
	93-94	0.0021	0.0001	8.5569	14.3502	0.00004	0.4797
	94-95	0.0022	0.0001	8.5945	13.5916	0.00004	0.4280
	95-96	0.0022	0.0001	8.5954	16.8640	0.00003	0.4813
	96-97	0.0023	0.0001	8.6022	21.3824	0.00002	0.5214
	97-98	0.0020	0.0001	8.6669	14.5872	0.00004	0.5228
	98-99	0.0007	0.0001	8.7110	18.5372	0.00003	0.6323
	99-00	0.0002	0.0002	8.7758	14.3077	0.00005	0.6636
30Q	89-90	0					
	90-91	0					
	91-92	0.0025	0.0001	8.4469	14.6844	0.00003	0.2789
	92-93	0.0024	0.0001	8.5105	13.5899	0.00004	0.3854
	93-94	0.0021	0.0001	8.5519	14.8375	0.00004	0.4756
	94-95	0.0022	0.0001	8.5935	13.7508	0.00004	0.4266
	95-96	0.0023	0.0001	8.6105	14.9006	0.00003	0.4775
	96-97	0.0025	0.0001	8.6207	16.0060	0.00003	0.5177
	97-98	0.0021	0.0001	8.6492	16.3416	0.00003	0.5213
	98-99	0.0008	0.0001	8.7159	17.4621	0.00004	0.6301
	99-00	0.0003	0.0002	8.7768	13.6691	0.00005	0.6582

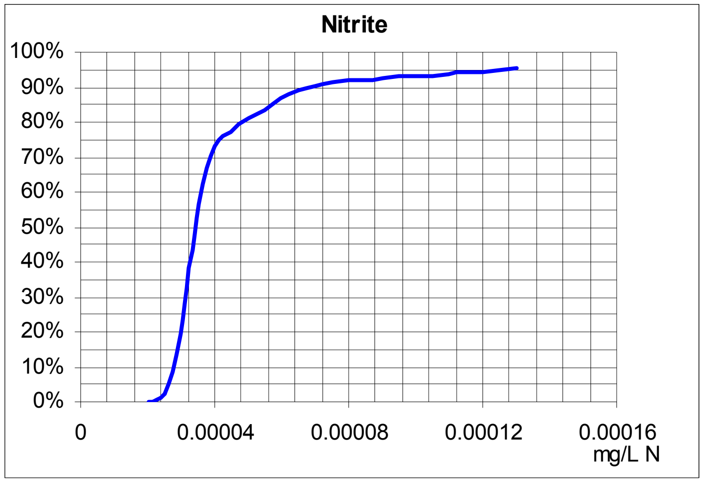
- Predicted flows

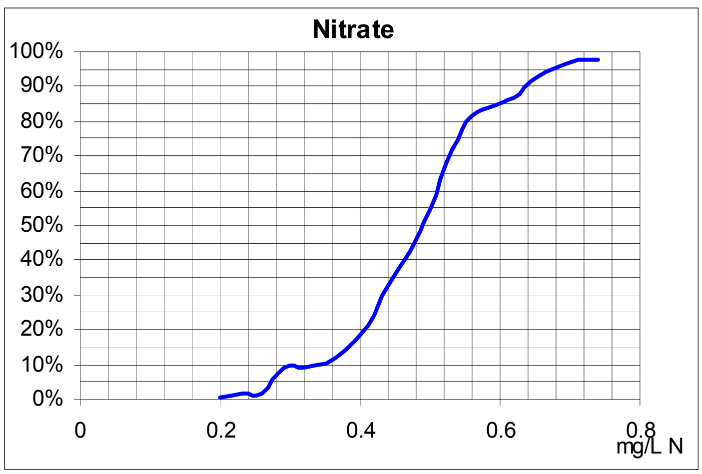


- Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.00004
0.00008
0.00012
0.00016
mg/L N


Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.2
0.4
0.6
0.8
mg/L N

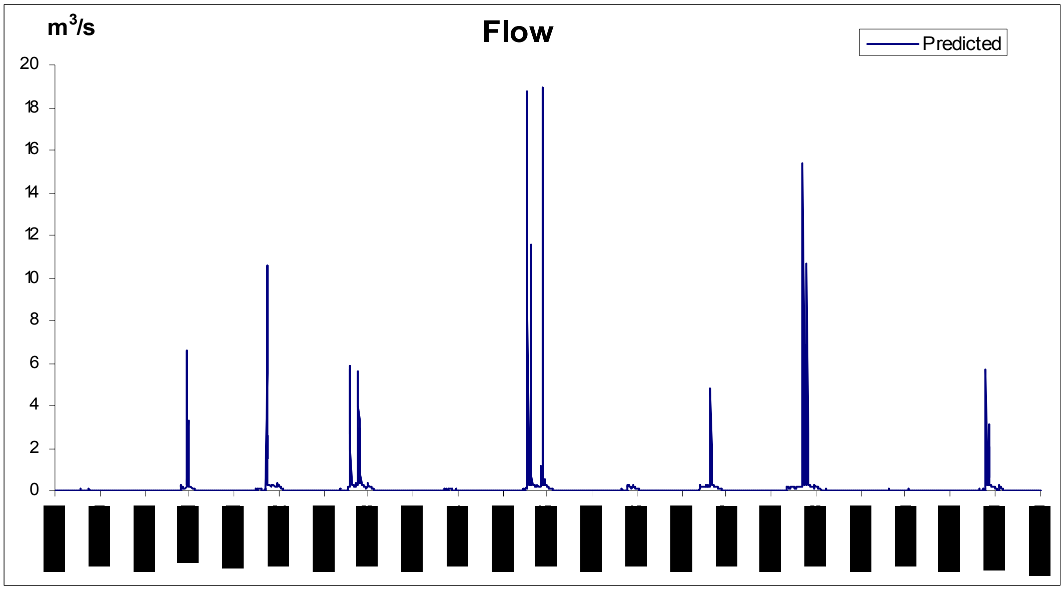
Appendix 9: Todd Barranca

❖ Critical condition----Low flows and corresponding water quality data

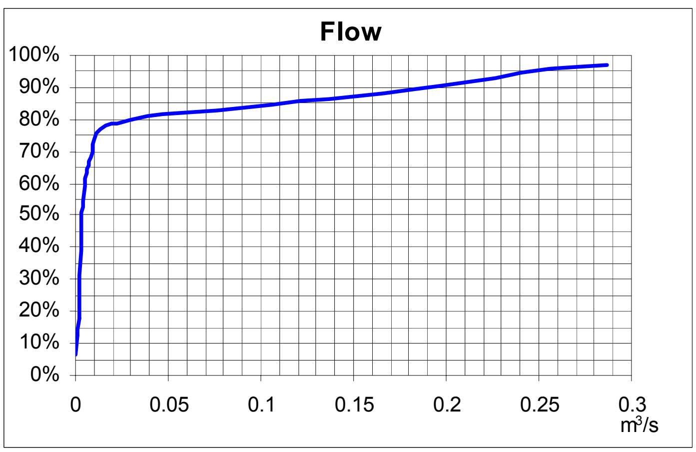
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (^oC)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0.000003	0.0027	8.5857	17.3775	0.0009	6.9787
	91-92	0.0026	0.0002	8.6226	20.2618	0.0001	0.3834
	92-93	0.0025	0.0006	8.6155	20.9501	0.0002	0.3970
	93-94	0.0024	0.0003	8.6776	17.5237	0.0001	0.4661
	94-95	0.0025	0.0034	8.7337	14.4922	0.0855	2.8210
	95-96	0.0025	0.0072	8.7301	15.6771	0.0029	0.5073
	96-97	0.0023	0.0002	8.7119	22.5720	0.0000	0.5216
	97-98	0.0021	0.0202	8.7653	16.1378	0.0082	0.6744
	98-99	0.0007	0.0002	8.8013	20.3100	0.0001	0.6313
	99-00	0.0004	0.0003	8.8548	14.9445	0.0001	0.6254
7Q	89-90	0					
	90-91	0.000005	0.0023	8.5192	17.3643	0.0008	5.4010
	91-92	0.0027	0.0002	8.6197	20.4508	0.0001	0.3833
	92-93	0.0025	0.0010	8.6363	18.7670	0.0007	0.6956
	93-94	0.0024	0.0093	8.6824	17.1810	0.0035	0.4998
	94-95	0.0025	0.0032	8.7218	15.3828	0.0770	2.7980
	95-96	0.0025	0.0279	8.7306	15.7261	0.0162	0.9284
	96-97	0.0023	0.0002	8.7092	23.0214	0.0000	0.5216
	97-98	0.0021	0.0909	8.7718	14.7029	0.0909	1.3621
	98-99	0.0007	0.0003	8.8083	19.1372	0.0001	0.6302
	99-00	0.0004	0.0162	8.8592	14.4072	0.1653	2.0548
30Q	89-90	0					
	90-91#	0.000006	0.0015	8.3975	16.9546	0.0005	2.6078
	91-92	0.0028	0.0176	8.6051	18.6526	0.0505	3.2312
	92-93	0.0026	0.0105	8.6386	17.9941	0.0065	0.7104
	93-94	0.0025	0.0316	8.6964	15.6735	0.1201	5.0736
	94-95	0.0025	0.0107	8.7031	17.3636	0.0800	3.1531
	95-96	0.0025	0.0300	8.7320	15.7864	0.0155	0.8286
	96-97	0.0025	0.0002	8.7137	22.0644	0.00005	0.5205
	97-98	0.0022	0.1091	8.7578	16.2723	0.1940	2.4299
	98-99	0.0008	0.0003	8.8158	17.7333	0.0001	0.6284
	99-00	0.0005	0.1026	8.8422	14.8816	0.5948	6.5001

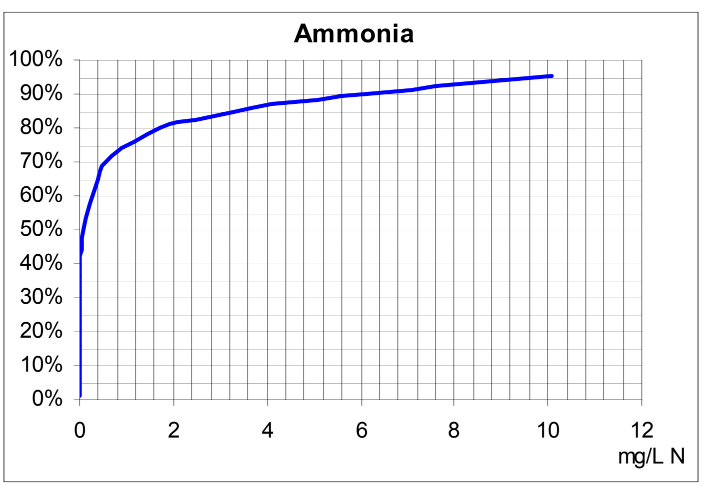
The predicted water quality data are incomplete during these periods due to the zero predicted flows

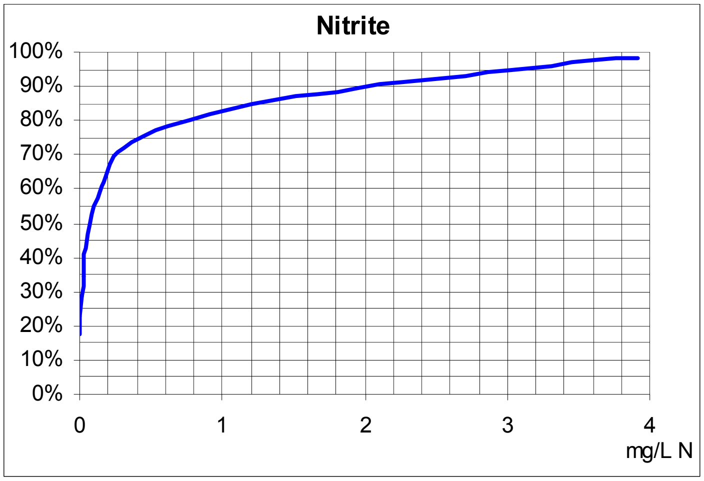
❖ Predicted flows

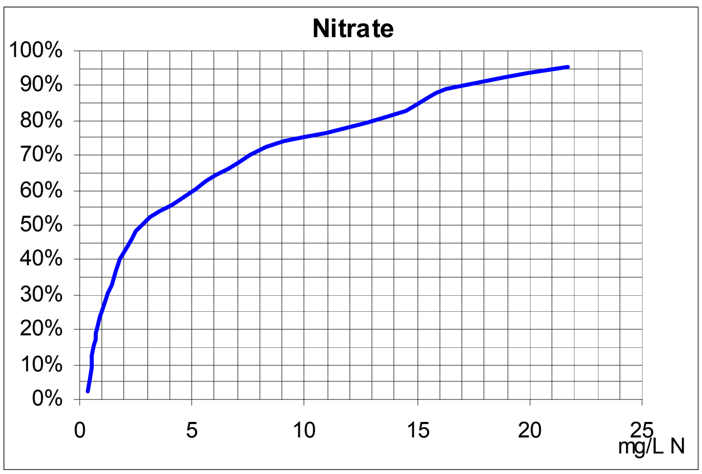


❖ Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
mg/L N

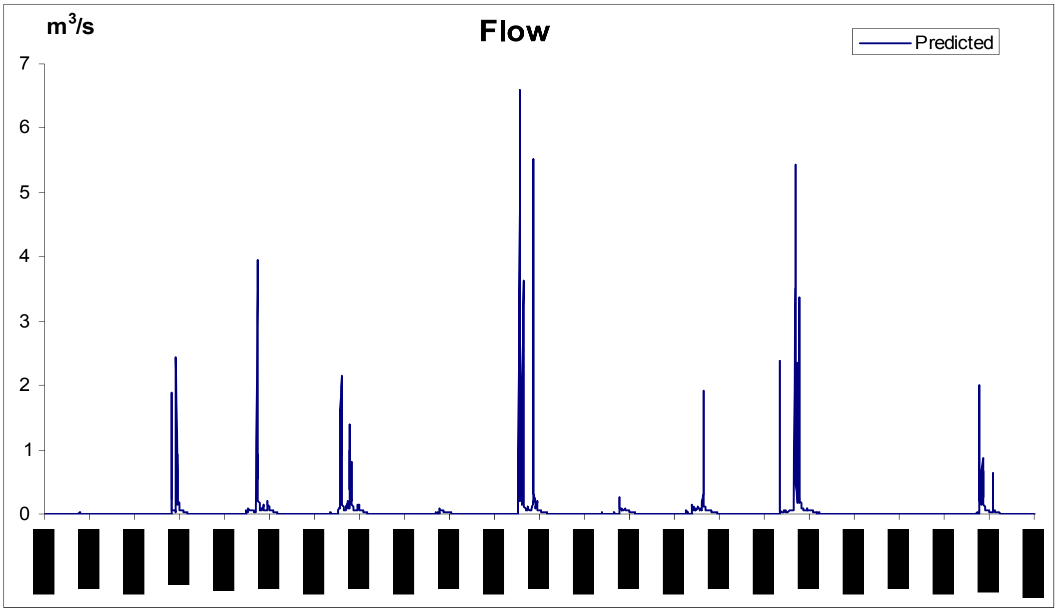

Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
5
10
15
20
25
mg/L N

Appendix 10: Brown Barrance / Long Canyon

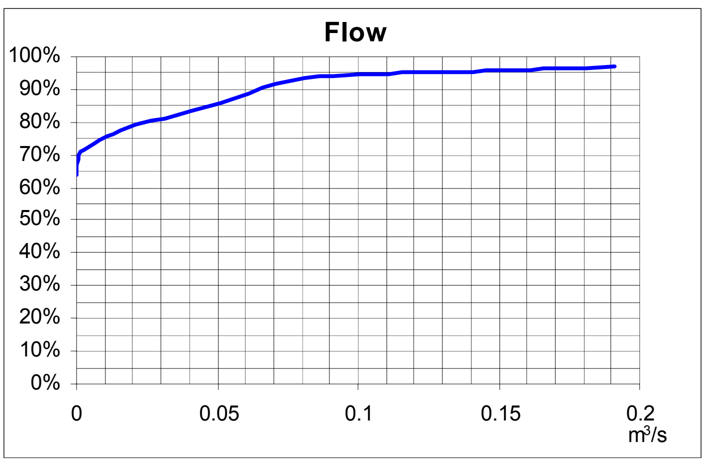
- Critical condition----Low flows and corresponding water quality data

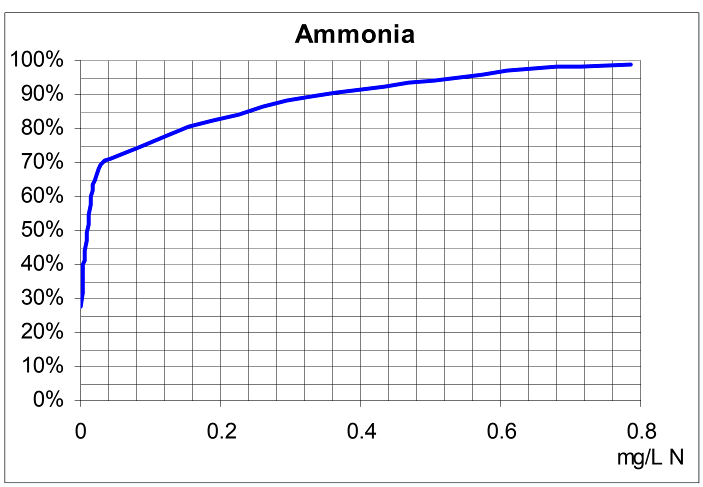
	Water year	Flow (m^3/s)	Ammonia (mg/L N)	pH	T (°C)	Nitrite (mg/L N)	Nitrate (mg/L N)
1Q	89-90	0					
	90-91	0					
	91-92	0					
	92-93	0					
	93-94	0					
	94-95	0					
	95-96	0					
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					
7Q	89-90	0					
	90-91	0					
	91-92	0					
	92-93	0					
	93-94	0					
	94-95	0					
	95-96	0					
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					
30Q	89-90	0					
	90-91	0					
	91-92	0					
	92-93	0					
	93-94	0					
	94-95	0					
	95-96	0					
	96-97	0					
	97-98	0					
	98-99	0					
	99-00	0					

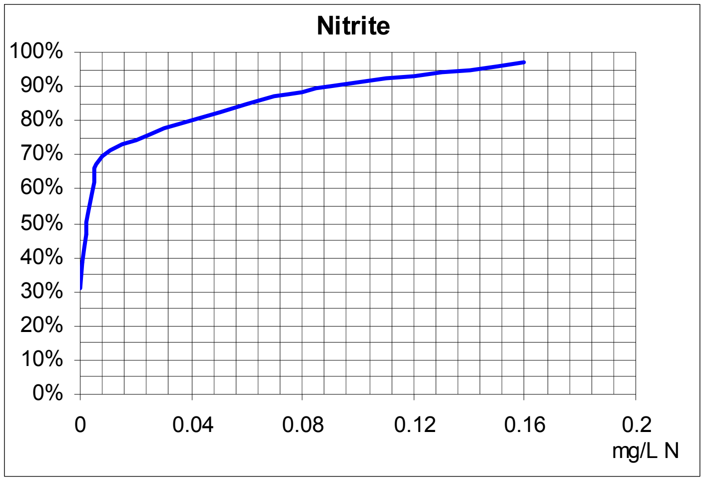
❖ Predicted flows

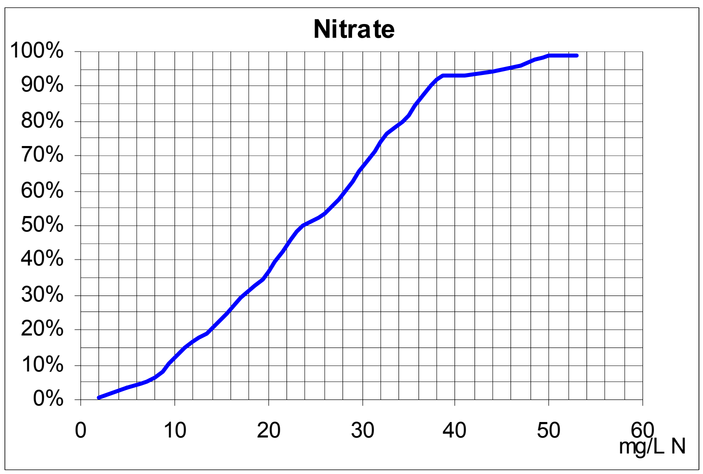


❖ Cumulative probabilities






Nitrite
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.04
0.08
0.12
0.16
0.2
mg/L N


Nitrate
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
mg/L N