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## **Stormwater Runoff Quality from Golf Courses in Austin, Texas DR-18-07, January 2018**

City of Austin  
Watershed Protection Department  
Environmental Resource Management Division

### **Introduction**

For the past twenty years, the City of Austin Watershed Protection Department (the “City”) has collected water quality samples from stormwater runoff to characterize the quality of runoff from different land uses (City of Austin 2009). During this time the City has successfully characterized the runoff quality from major land uses including commercial, single-family residential, undeveloped and industrial. In June 2000, the City began collecting storm water runoff data from effluent-irrigated golf courses to characterize runoff quality from this land use.

The City of Austin in 2005 released a report entitled “Preliminary Report on Storm Water Runoff from Effluent-Irrigated Golf Courses” (City of Austin 2005b). The report summarized data collected from four monitoring sites established on two golf courses irrigated with wastewater treatment effluent, including both fairways and greens. The report (City of Austin 2005b) concluded that the concentrations of nutrients in the runoff from these effluent-irrigated golf courses was significantly higher than runoff from other land uses. That report (City of Austin 2005b) did not address if the elevated nutrient concentrations in runoff were a result of the golf course operations or if they were a result of the effluent irrigation. A new monitoring station was established in 2006 on a local golf course that does not use effluent as an irrigation water source. This golf course does not use effluent as an irrigation source. Runoff samples were collected over the following five years. This report updates the analyses in the prior City of Austin (2005b) report and includes a comparison of the effluent-irrigated and non-effluent-irrigated golf courses.

Wastewater treatment effluent water may also be referred to as reclaimed water or recycled water (Hartwiger 2013). In 2009, a survey provided a breakdown of irrigation water sources for average 18-hole golf courses in the United States (Environmental Institute for Golf 2009). The survey indicates that effluent water is used as an irrigation source by 12 percent of golf facilities in the US. More facilities in the Southwest (37%) and Southeast (24%) regions are using effluent water as compared to other regions.

Hayes, Mancino and Peppers' (1990) study of effluent water application to turfgrass found higher sodium, nitrogen, phosphorous, and potassium in soils irrigated with effluent water than in soils irrigated with potable water. While many constituents in effluent water have a detrimental effect on turfgrass growth, some nutrients can have positive effects on soils and turfgrasses. As King, Balogh, and Harmel (2000) point out, higher volumes of nitrogen allow for the reduction of nitrogen applied from fertilizer. However, Huck, Carrow, and Duncan (2000) warn that on greens, excess nitrogen can "produce more growth than desired".

Effluent irrigation of golf courses in Austin has been previously related to water quality degradation of adjacent surface water and groundwater resources, including elevated concentrations of nutrients and dissolved solids (City of Austin 2014, City of Austin 2016). Similar water quality degradation including elevated concentrations of nutrients and dissolved solids has been observed at spring and stream monitoring locations downgradient of dedicated effluent irrigation disposal sites (City of Austin 2017).

With growing populations creating increased demand on drinking water sources and restrictions being applied, many golf courses in Texas are utilizing effluent for irrigation (TWDB 2001). The Texas Water Development Board notes that not only is effluent water a drought proof water source, but also effluent increases in volume as the population increases. A survey for effluent water use for irrigation on Texas golf courses shows that effluent water is an effective conservation measure as well an inexpensive, continuous source of irrigation water (Ray 2007). Although more conservative in its approach, the City has been providing effluent water for irrigation since the 1970's and codified their intent on reducing potable water demand in 1990 with the Water Reclamation Initiative. Austin in 2007 conserved 900 million gallons of water per year through effluent reuse (City of Austin 2007). In fiscal year 2017, Austin reused 1,364 million gallons of reclaimed water, or approximately 3.85% of all wastewater treated.

The three golf courses that the City has monitored are Lost Creek (LG), Steiner Ranch (SR), and Lions Municipal (MG) golf courses. The Lost Creek and Steiner Ranch are effluent-irrigated (EI) golf courses and Lions Municipal is non-effluent-irrigated (NEI) golf course. There are two monitoring stations at Lost Creek golf course, LGB and LGC. There are two monitoring stations at Steiner Ranch golf course, SRA and SRB. There is one monitoring station at Lions Municipal golf course, MGA.

The City has collected flow and water quality data from about one hundred runoff events from these five monitoring stations. The water quality information for each event was used to compute an event mean concentration (EMC), which is the average runoff concentration for a given runoff event. EMCs have been developed for:

- Metals: cadmium (CD), copper, (CU), lead (PB), and zinc (ZN);
- Suspended solids: total suspended solids (TSS) and volatile suspended solids (VSS);
- Measures of organic matter: chemical oxygen demand (COD) and total organic carbon (TOC);
- Nutrients: dissolved phosphorus (DP), total phosphorus (TP), ammonia (NH<sub>3</sub>), nitrate plus nitrite (NO<sub>3</sub>+NO<sub>2</sub>), total Kjeldahl nitrogen (TKN), and total nitrogen (TN).

## Results

For this report, individual EMCs from all monitoring stations with a given land use were combined, resulting in an average concentration for a given land use. These data were compared by t-test to determine if the means of the land use types were different at the 0.05 significance level. The comparisons were performed on the natural log of the data to preserve the assumption of normality in the ANOVA test since prior studies have indicated storm water environmental data are log-normally distributed (Glick 1992, Gilbert 1987). As such, the mean concentrations reported are the geometric means.

Analysis results and EMCs by land use type are presented in Tables 1-4 and Figures 1-4. Metals (CD, CU, PB, ZN) were higher in aggregated golf course runoff than undeveloped conditions. There was no difference in CD between aggregated golf course and developed runoff. CU, PB, and ZN, were lower in aggregated golf course runoff than developed runoff. Effluent-irrigated golf courses yielded higher CD and PB than non-effluent irrigated golf courses; there was no difference in runoff between effluent-irrigated and non-effluent irrigated runoff for CU and ZN.

Patterns in suspended solids were mixed. TSS from golf course runoff was not different from undeveloped areas, but VSS was higher in runoff from golf courses than undeveloped areas. TSS was lower in golf course runoff than developed areas, but VSS was not different between golf course and developed area runoff. Both TSS and VSS were lower in effluent-irrigated golf course runoff than non-effluent irrigated golf course runoff.

COD and TOC in golf course runoff were both higher than undeveloped runoff, but not different from developed runoff. There was no difference between effluent-irrigated golf course runoff and runoff from non-effluent irrigated golf courses for COD or TOC. Stormwater runoff from these areas would not be reflective of instream process like benthic algal production that would occur as a result of elevated nutrient loading to a receiving water. The runoff concentrations of TOC from golf courses were among the highest from developed land uses and were significantly higher than industrial, roadway, single-family, multi-family, and commercial land uses.

Both dissolved and total phosphorus concentrations were higher in golf course runoff than runoff from either developed or undeveloped areas. Effluent-irrigated golf course runoff is higher in both dissolved and total phosphorus than non-effluent irrigated golf course runoff. Nitrogen (NH<sub>3</sub>, NO<sub>2</sub>, TKN, TN) was higher in golf course runoff than undeveloped areas. Except for ammonia (NH<sub>3</sub>), nitrogen was higher in golf course runoff than runoff from developed areas. Concentrations of nitrate (NO<sub>3</sub>) were higher in runoff from effluent-irrigated golf courses than non-effluent irrigated golf courses, but there was no difference for NH<sub>3</sub>, TKN or TN. Nitrate is the dominant nitrogen form in wastewater treatment effluent. This suggests that golf course operations increase nutrients in stormwater runoff, and effluent irrigation of golf courses increases nutrient concentrations in stormwater runoff relative to golf courses without effluent irrigation.

Both effluent-irrigation golf courses apply supplemental nitrogen in various forms in addition to the nitrogen in the effluent-irrigation water. Although little or no phosphorus was applied as fertilizer during the monitoring period, studies have indicated that phosphorus may remain at high levels for long periods in local soils after application has ceased (City of Austin 2005a).

Since both effluent-irrigation courses had been applying effluent for a period of time prior to monitoring, phosphorus may be accumulating in the soil over time, resulting in the higher concentrations of phosphorus observed in the runoff.

## Conclusions

Effluent irrigation of golf courses impacts stormwater runoff quality in Austin.

Golf courses yield higher concentrations of metals (CD, CU, PB, ZN) in stormwater runoff than undeveloped runoff but not higher than runoff from developed areas. Effluent-irrigated golf courses yield higher concentrations CD and PB in runoff than golf courses without effluent irrigation.

Both TSS and VSS were lower in effluent-irrigated golf course runoff than non-effluent irrigated golf course runoff. COD and TOC in golf course runoff were both higher than undeveloped runoff, but not different from developed runoff. There was no difference in COD or TOC in stormwater runoff with effluent-irrigation, although stormwater runoff from a golf course would not be reflective of eutrophic instream processes like benthic algal production in a receiving water.

Golf course operations yield increased concentrations of nutrients (DP, TP, NO<sub>2</sub>, TKN, TN) in stormwater runoff than runoff from either developed or undeveloped areas. Effluent irrigation of golf courses appears to increase the concentration of phosphorus (DP, TP) and nitrate in stormwater runoff relative to non-effluent irrigated golf courses.

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Table 1: CD concentrations in stormwater runoff for various land uses.

Land Use	CD Mean Concentration (µg/L)	T-test Matrix																				
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR
Golf Course (Golf)	0.488									X	X	X	X			X	X	X	X		X	X
Effluent-Irrigated (EI)	0.555									X	X	X	X			X	X	X	X		X	X
Lost Creek (LG)	0.535									X	X	X	X			X					X	X
LGB Station	0.531																					
LGC Station	0.536									X	X	X	X									X
Steiner Ranch (SR)	0.568									X	X	X	X			X						X
SRA Station	0.595									X	X	X	X									X
SRB Station	0.539												X									X
Non-Effluent-Irrigated (NEI)	0.356	X	X	X			X	X	X							X	X		X	X	X	X
Lions Municipal (MG)	0.356	X	X	X			X	X	X							X	X		X	X	X	X
MGA Station	0.356	X	X	X			X	X	X							X	X		X	X	X	X
Undeveloped (Und)	0.359	X	X	X			X	X	X	X						X	X	X	X	X	X	X
Developed (Dev)	0.540												X			X	X	X	X			X
Commercial (Comm)	0.579													X								X
Downtown (Down)	0.795	X	X	X				X		X	X	X	X	X						X	X	X
Industrial (Ind)	0.772	X	X							X	X	X	X	X						X	X	X
Multi-Family (MFR)	1.175	X	X									X	X									X
Mixed Use (Mix)	0.733	X	X							X	X	X	X	X								X
Office (Off)	0.525									X	X	X	X			X	X					X
Roadway (Road)	0.720	X	X	X						X	X	X	X									X
Single-Family (SFR)	0.355	X	X	X			X	X	X	X					X	X	X	X	X	X	X	X

Note: "x" indicates mean concentrations are significant different between different land uses.

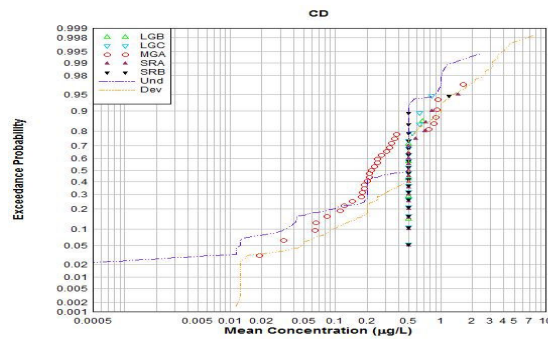
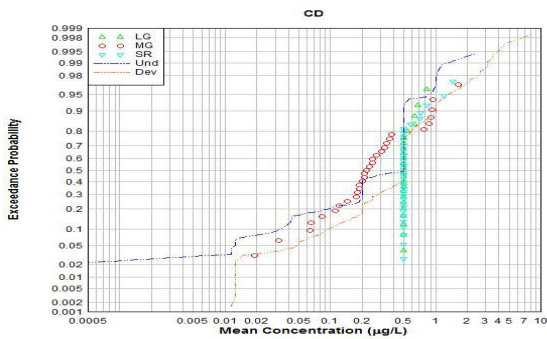
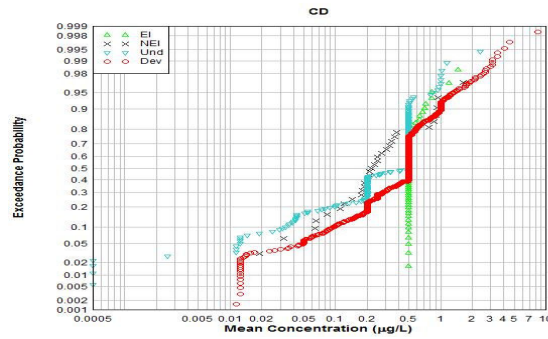
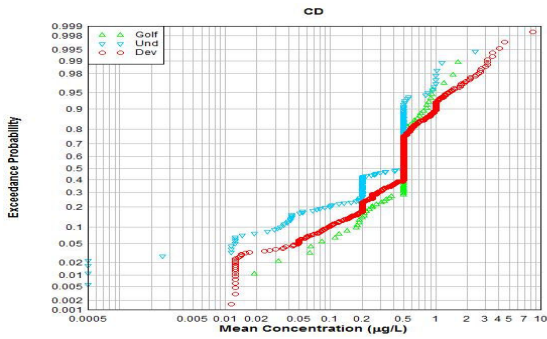


Figure 1: Probability Plots for CD.

Table 2: CU concentrations in stormwater runoff for various land uses.

Land Use	CU Mean Concentration (µg/L)	T-test Matrix																				
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR
Golf Course (Golf)	5.826			x		x							x	x	x	x	x	x	x		x	x
Effluent-Irrigated (EI)	5.288													x	x	x	x	x	x		x	x
Lost Creek (LG)	3.726	x					x	x		x	x	x		x	x	x	x	x	x		x	x
LGB Station	4.098															x						
LGC Station	3.602	x							x	x	x			x	x	x	x	x			x	x
Steiner Ranch (SR)	6.159			x									x	x		x	x	x	x			x
SRA Station	6.213			x		x							x			x	x	x	x			x
SRB Station	6.103															x	x	x	x			x
Non-Effluent-Irrigated (NEI)	6.990			x		x							x			x	x	x	x			x
Lions Municipal (MG)	6.990			x		x							x			x	x	x	x			x
MGA Station	6.990			x		x							x			x	x	x	x			x
Undeveloped (Und)	4.083	x					x	x		x	x	x		x	x	x	x	x	x	x	x	x
Developed (Dev)	14.38	x	x	x				x					x		x	x	x	x			x	x
Commercial (Comm)	7.651	x	x	x			x						x	x		x	x	x			x	x
Downtown (Down)	27.84	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x			x	x
Industrial (Ind)	19.09	x	x	x			x	x	x	x	x	x	x	x	x	x			x			x
Multi-Family (MFR)	16.36	x	x	x			x	x	x	x	x	x	x	x	x				x			x
Mixed Use (Mix)	42.01	x	x	x			x	x	x	x	x	x	x	x	x				x	x		x
Office (Off)	12.24												x			x				x		x
Roadway (Road)	16.66	x	x	x			x	x	x	x	x	x	x	x	x				x			x
Single-Family (SFR)	7.870	x	x	x			x						x	x		x	x	x	x	x	x	x

Note: "x" indicates mean concentrations are significant different between different land uses.

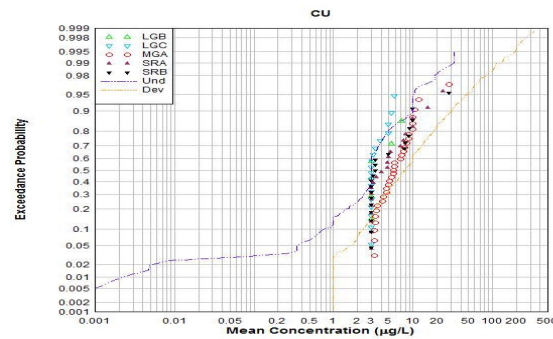
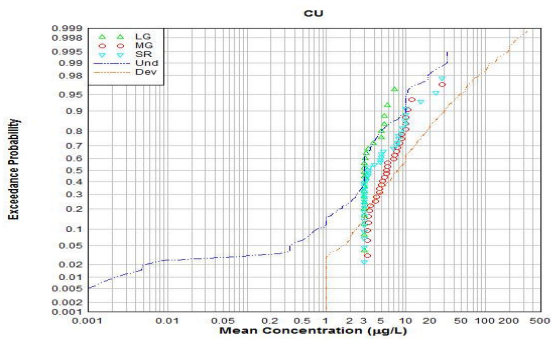
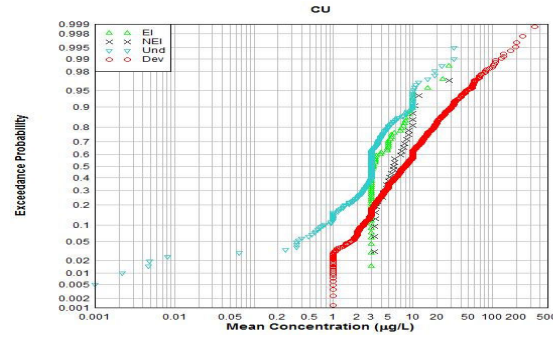
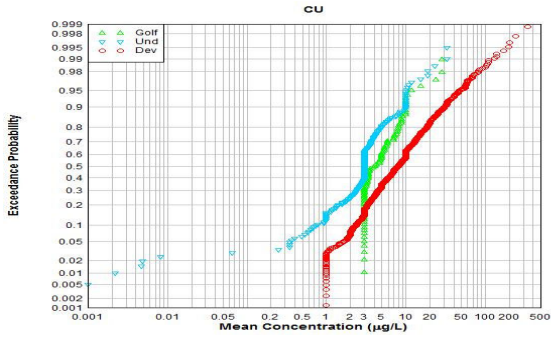


Figure 2: Probability Plots for CU.

Table 3: PB concentrations in stormwater runoff for various land uses.

Land Use	PB Mean Concentration (µg/L)	T-test Matrix																				
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR
Golf Course (Golf)	6.771		x				x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Effluent-Irrigated (EI)	2.826	x								x	x	x		x	x	x	x	x	x	x	x	x
Lost Creek (LG)	2.918									x	x	x		x	x	x	x	x	x	x	x	x
LGB Station	3.418															x			x			
LGC Station	2.751									x	x	x		x	x	x	x	x	x	x	x	x
Steiner Ranch (SR)	2.774	x								x	x	x		x	x	x	x	x	x	x	x	x
SRA Station	2.748									x	x	x		x	x	x	x	x	x	x	x	x
SRB Station	2.802									x	x	x		x	x	x	x	x	x	x	x	x
Non-Effluent-Irrigated (NEI)	15.30	x	x	x			x	x	x	x			x			x	x		x			
Lions Municipal (MG)	15.30	x	x	x			x	x	x	x			x			x	x		x			
MGA Station	15.30	x	x	x			x	x	x	x			x			x	x		x			
Undeveloped (Und)	3.483	x								x	x	x		x	x	x	x	x	x	x	x	x
Developed (Dev)	21.88	x	x	x			x	x	x	x			x			x	x		x		x	x
Commercial (Comm)	22.79	x	x	x			x	x	x	x			x			x			x		x	x
Downtown (Down)	66.44	x	x	x	x		x	x	x	x	x		x			x	x	x	x	x	x	x
Industrial (Ind)	30.82	x	x	x			x	x	x	x	x		x			x			x		x	x
Multi-Family (MFR)	17.81	x	x	x			x	x	x	x			x			x			x		x	x
Mixed Use (Mix)	30.45	x	x	x	x		x	x	x	x	x		x			x			x		x	x
Office (Off)	10.24		x	x			x	x	x	x			x	x	x	x	x	x	x	x	x	x
Roadway (Road)	35.38	x	x	x			x	x	x	x			x	x		x			x		x	x
Single-Family (SFR)	10.42		x										x	x	x	x	x		x			x

Note: "x" indicates mean concentrations are significant different between different land uses.

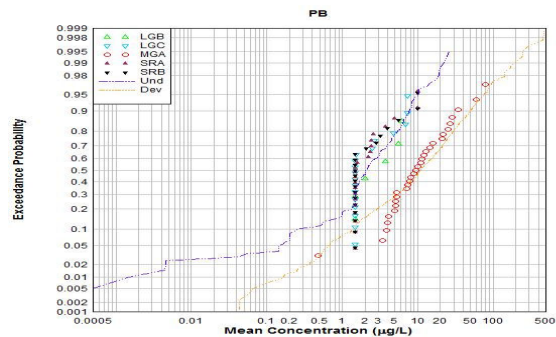
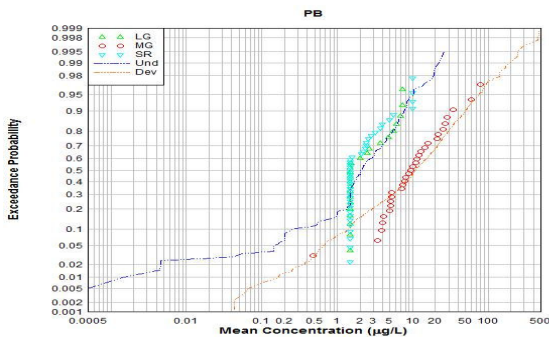
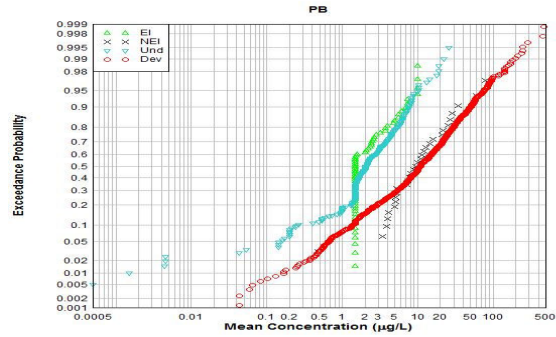
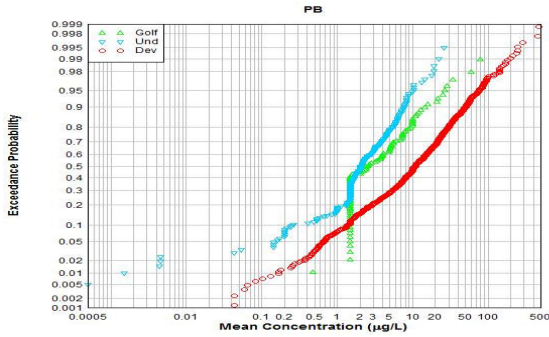


Figure 3: Probability Plots for PB.

Table 4: ZN concentrations in stormwater runoff for various land uses.

Land Use	ZN Mean Concentration (µg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	26.71							X					X	X	X	X	X	X	X	X	X	X	X
Effluent-Irrigated (EI)	24.51							X					X	X	X	X	X	X	X	X	X	X	X
Lost Creek (LG)	30.02						X	X					X	X	X	X	X	X	X	X	X	X	X
LGB Station	34.02							X								X			X	X			
LGC Station	28.69							X					X	X	X	X	X	X	X	X	X	X	X
Steiner Ranch (SR)	21.43			X										X	X	X	X	X	X	X	X	X	X
SRA Station	17.10	X	X	X	X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X
SRB Station	25.96							X						X	X	X	X	X	X	X	X	X	X
Non-Effluent-Irrigated (NEI)	31.46							X					X	X	X	X	X	X	X	X	X	X	X
Lions Municipal (MG)	31.46							X					X	X	X	X	X	X	X	X	X	X	X
MGA Station	31.46							X					X	X	X	X	X	X	X	X	X	X	X
Undeveloped (Und)	17.83	X	X	X		X			X	X	X		X	X	X	X	X	X	X	X	X	X	X
Developed (Dev)	105.6	X	X	X	X	X	X	X	X	X	X	X				X	X						X
Commercial (Comm)	85.93	X	X	X	X	X	X	X	X	X	X	X				X	X			X	X		X
Downtown (Down)	330.8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Industrial (Ind)	144.7	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X
Multi-Family (MFR)	73.74	X	X	X	X	X	X	X	X	X	X	X				X	X			X	X		
Mixed Use (Mix)	117.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X
Office (Off)	139.6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X
Roadway (Road)	112.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X
Single-Family (SFR)	54.16	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Note: "x" indicates mean concentrations are significant different between different land uses.

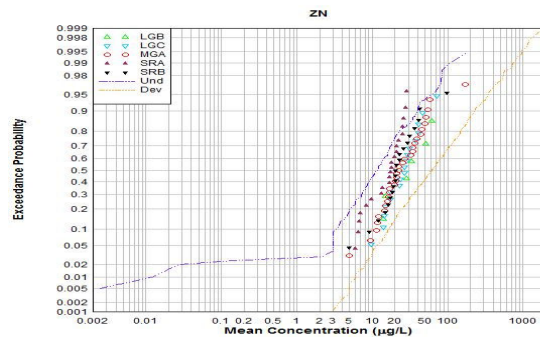
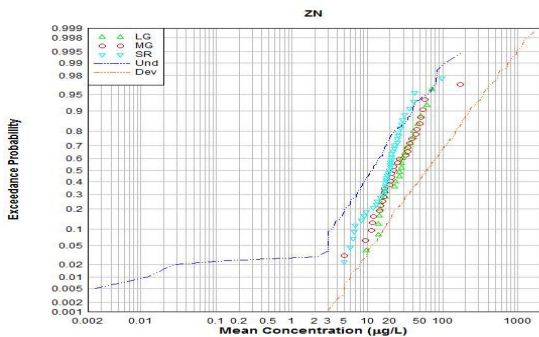
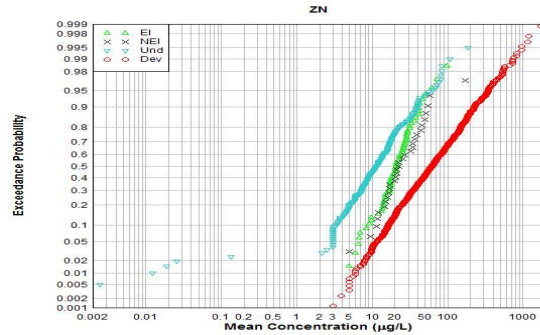
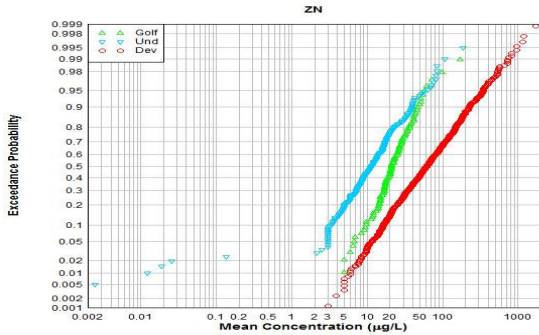


Figure 4: Probability Plots for ZN.

Table 5: TSS concentrations in stormwater runoff for various land uses.

Land Use	TSS Mean Concentration (mg/L)	T-test Matrix																				
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR
Golf Course (Golf)	104.1		x				x	x		x	x	x		x		x	x	x	x		x	x
Effluent-Irrigated (EI)	64.20	x		x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lost Creek (LG)	96.38		x				x	x		x	x	x				x			x			x
LGB Station	126.8		x						x	x	x											
LGC Station	84.55						x	x		x	x	x			x				x			x
Steiner Ranch (SR)	45.49	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x
SRA Station	25.69	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x
SRB Station	66.23						x		x	x	x		x		x	x		x				x
Non-Effluent-Irrigated (NEI)	191.8	x	x	x			x	x	x	x		x										x
Lions Municipal (MG)	191.8	x	x	x			x	x	x	x		x										x
MGA Station	191.8	x	x	x			x	x	x	x		x										x
Undeveloped (Und)	101.1		x				x	x		x	x		x		x	x	x	x	x			x
Developed (Dev)	162.2	x	x						x	x	x											x
Commercial (Comm)	137.2		x						x	x												x
Downtown (Down)	167.0	x	x	x			x	x	x			x										x
Industrial (Ind)	155.2	x	x				x	x	x			x										x
Multi-Family (MFR)	208.9	x	x									x										x
Mixed Use (Mix)	185.0	x	x	x			x	x	x			x										x
Office (Off)	95.71		x				x	x		x	x		x		x	x	x	x	x			x
Roadway (Road)	217.4	x	x	x			x	x	x			x	x	x		x						x
Single-Family (SFR)	158.8	x	x						x	x		x										x

Note: "x" indicates mean concentrations are significant different between different land uses.

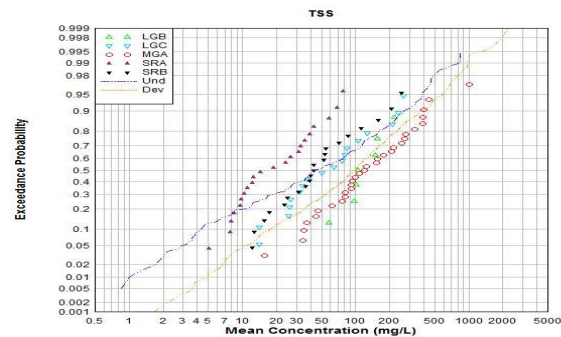
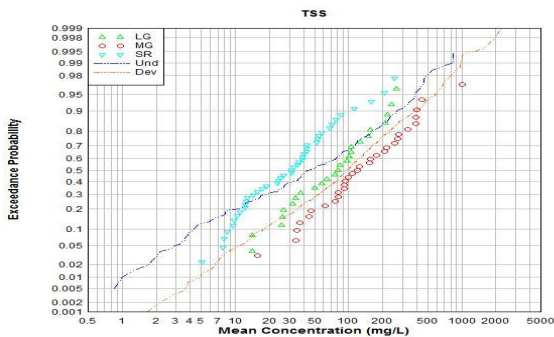
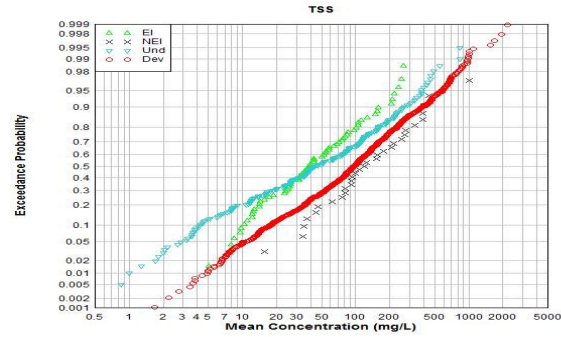
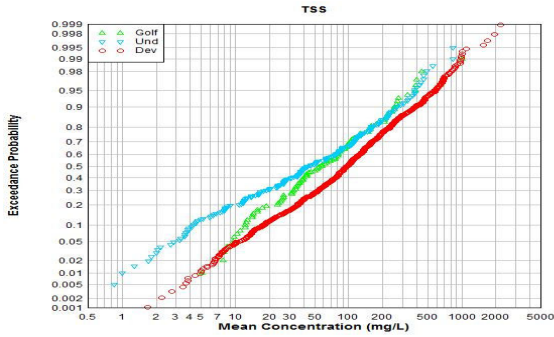


Figure 5: Probability Plots for TSS.

Table 6: VSS concentrations in stormwater runoff for various land uses.

Land Use	VSS Mean Concentration (mg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	28.68						X	X	X	X	X	X				X	X	X					
Effluent-Irrigated (EI)	21.59			X	X					X	X	X		X	X	X	X	X	X	X	X	X	X
Lost Creek (LG)	33.60		X				X	X	X				X										
LGB Station	28.61						X	X	X														
LGC Station	35.54		X				X	X	X			X											
Steiner Ranch (SR)	13.89	X	X	X	X					X	X	X		X	X	X	X	X	X	X	X	X	X
SRA Station	14.40			X	X	X				X	X	X		X	X	X	X	X	X	X	X	X	X
SRB Station	13.35	X	X	X	X					X	X	X		X	X	X	X	X	X	X	X	X	X
Non-Effluent-Irrigated (NEI)	43.31	X	X				X	X	X			X											
Lions Municipal (MG)	43.31	X	X				X	X	X			X											
MGA Station	43.31	X	X				X	X	X			X											
Undeveloped (Und)	16.57	X	X	X	X					X	X	X		X	X	X	X	X	X	X	X	X	X
Developed (Dev)	34.62		X				X	X	X			X				X	X						
Commercial (Comm)	35.43		X				X	X	X			X											
Downtown (Down)	51.93	X	X				X	X	X			X	X			X			X				X
Industrial (Ind)	30.33		X				X	X	X			X			X		X	X					
Multi-Family (MFR)	54.31	X	X				X	X	X			X	X			X							X
Mixed Use (Mix)	40.78	X	X				X	X	X			X				X							
Office (Off)	33.77		X				X	X	X			X				X							
Roadway (Road)	28.87						X	X	X			X											
Single-Family (SFR)	31.03		X				X	X	X			X			X		X						

Note: "x" indicates mean concentrations are significant different between different land uses.

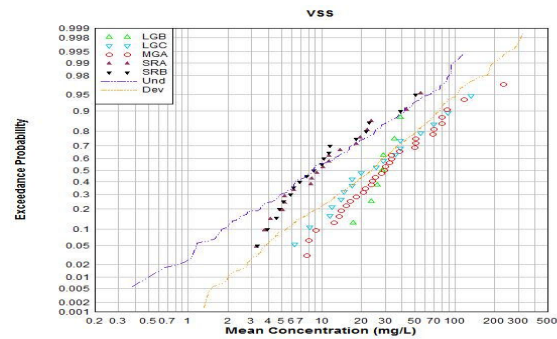
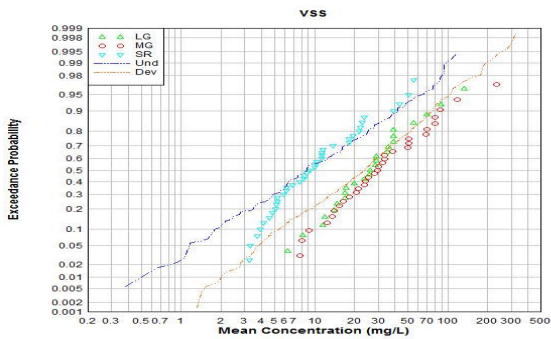
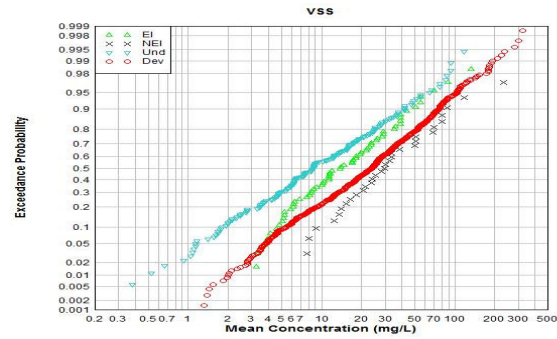
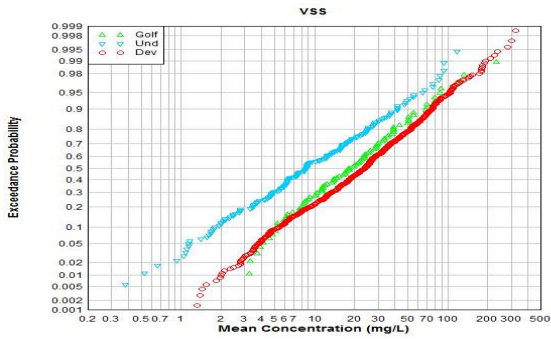


Figure 6: Probability Plots for VSS.

Table 7: COD concentrations in stormwater runoff for various land uses.

Land Use	COD Mean Concentration (mg/L)	T-test Matrix																				
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR
Golf Course (Golf)	82.92												X	X	X							X
Effluent-Irrigated (EI)	82.90												X	X	X							X
Lost Creek (LG)	91.98												X	X								X
LGB Station	50.33						X	X	X													
LGC Station	108.2					X						X	X								X	X
Steiner Ranch (SR)	77.62			X	X							X	X	X								X
SRA Station	75.86			X								X	X	X								
SRB Station	79.47			X								X	X	X								
Non-Effluent-Irrigated (NEI)	82.95											X	X	X								X
Lions Municipal (MG)	82.95											X	X	X								X
MGA Station	82.95											X	X	X								X
Undeveloped (Und)	46.36	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Developed (Dev)	81.13											X	X	X								X
Commercial (Comm)	47.77	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Downtown (Down)	162.9	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Industrial (Ind)	87.83											X	X	X								X
Multi-Family (MFR)	91.71											X	X	X								X
Mixed Use (Mix)	92.01											X	X	X								X
Office (Off)	75.25											X	X	X								
Roadway (Road)	60.24	X	X	X			X	X		X	X	X	X			X	X	X	X			
Single-Family (SFR)	68.45						X					X	X	X	X	X	X	X				

Note: "x" indicates mean concentrations are significant different between different land uses.

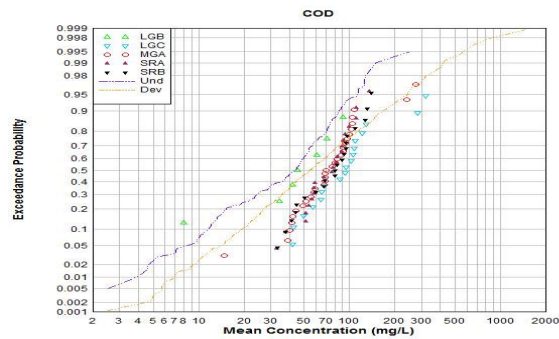
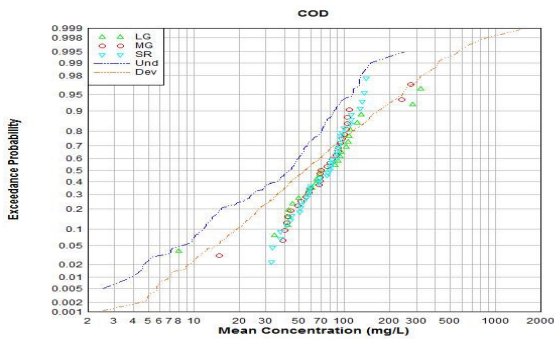
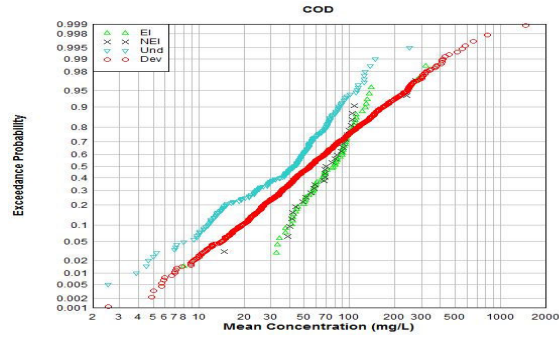
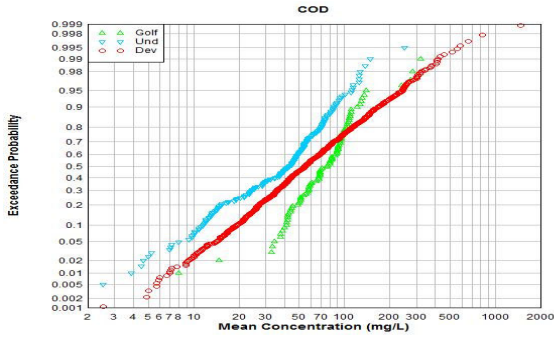


Figure 7: Probability Plots for COD.

Table 8: TOC concentrations in stormwater runoff for various land uses.

Land Use	TOC Mean Concentration (mg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	16.71			x	x								x	x	x	x	x					x	x
Effluent-Irrigated (EI)	16.27			x	x								x	x			x						x
Lost Creek (LG)	12.87	x	x				x	x	x	x	x	x											
LGB Station	9.409	x	x				x	x	x	x	x	x											
LGC Station	14.21						x	x										x					
Steiner Ranch (SR)	18.24			x	x	x						x	x		x	x	x	x			x	x	x
SRA Station	19.05			x	x	x						x	x		x	x	x	x					x
SRB Station	17.40			x	x							x	x		x		x						x
Non-Effluent-Irrigated (NEI)	17.69			x	x							x	x		x	x	x	x					x
Lions Municipal (MG)	17.69			x	x							x	x		x	x	x	x					x
MGA Station	17.69			x	x							x	x		x	x	x	x					x
Undeveloped (Und)	11.75	x	x				x	x	x	x	x	x			x	x			x				
Developed (Dev)	13.83														x	x							
Commercial (Comm)	9.605	x	x				x	x	x	x	x	x	x	x	x	x			x				
Downtown (Down)	22.70	x										x	x	x	x	x	x	x			x	x	x
Industrial (Ind)	13.53	x					x	x		x	x	x			x	x							
Multi-Family (MFR)	9.919	x	x				x	x	x	x	x	x				x							
Mixed Use (Mix)	15.68											x	x										
Office (Off)	13.48																						
Roadway (Road)	11.17	x	x				x	x	x	x	x	x				x							
Single-Family (SFR)	13.27	x					x									x							

Note: "x" indicates mean concentrations are significant different between different land uses.

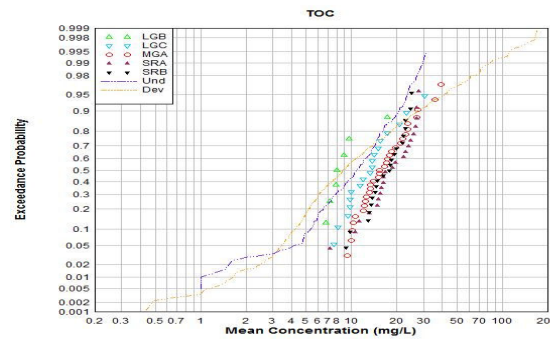
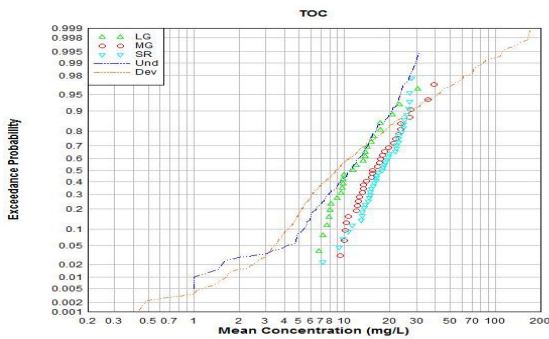
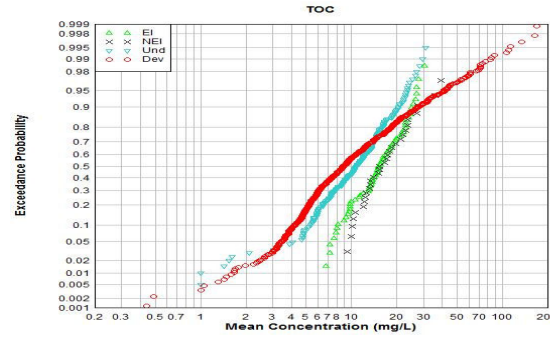
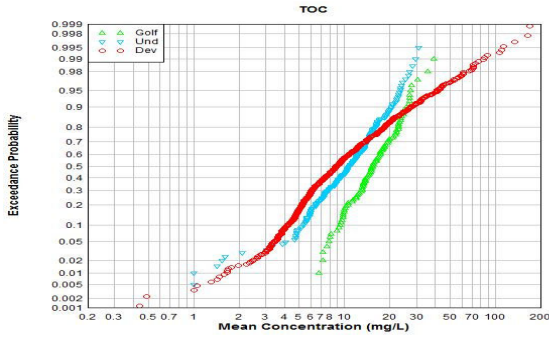


Figure 8: Probability Plots for TOC.

Table 9: DP concentrations in stormwater runoff for various land uses.

Land Use	DP Mean Concentration (mg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	0.838			X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Effluent-Irrigated (EI)	1.042					X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lost Creek (LG)	1.397	X					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LGB Station	0.754				X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LGC Station	1.646	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Steiner Ranch (SR)	0.835			X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SRA Station	0.859				X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SRB Station	0.810			X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Non-Effluent-Irrigated (NEI)	0.393	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Lions Municipal (MG)	0.393	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X
MGA Station	0.393	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X
Undeveloped (Und)	0.033	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Developed (Dev)	0.193	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Commercial (Comm)	0.117	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Downtown (Down)	0.292	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Industrial (Ind)	0.149	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Multi-Family (MFR)	0.322	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Mixed Use (Mix)	0.164	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Office (Off)	0.155	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Roadway (Road)	0.0780	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Single-Family (SFR)	0.201	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X

Note: "x" indicates mean concentrations are significant different between different land uses.

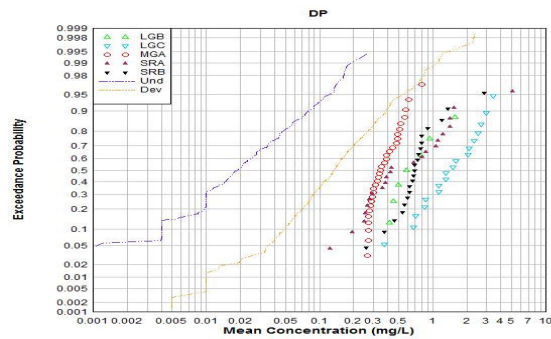
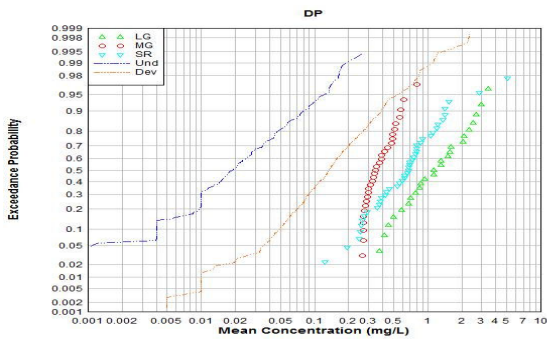
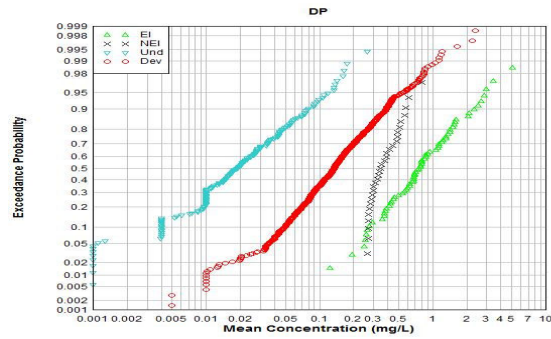
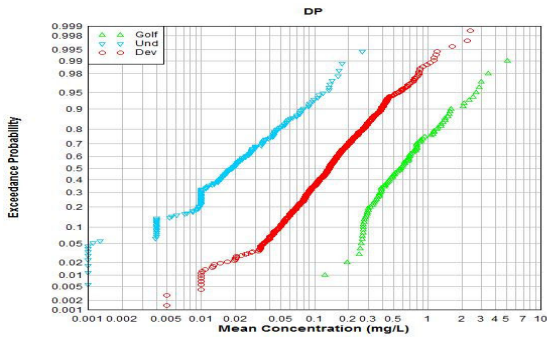


Figure 9: Probability Plots for DP.

Table 10: TP concentrations in stormwater runoff for various land uses.

Land Use	TP Mean Concentration (mg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	1.151			X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Effluent-Irrigated (EI)	1.306			X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lost Creek (LG)	1.815	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LGB Station	1.035			X	X							X	X	X		X	X	X	X	X	X	X	X
LGC Station	2.118	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Steiner Ranch (SR)	1.011			X	X							X	X	X	X	X	X	X	X	X	X	X	X
SRA Station	1.015			X	X							X	X	X	X	X	X	X	X	X	X	X	X
SRB Station	1.007			X	X							X	X	X	X	X	X	X	X	X	X	X	X
Non-Effluent-Irrigated (NEI)	0.810	X	X	X	X							X	X	X		X	X	X	X	X	X	X	X
Lions Municipal (MG)	0.810	X	X	X	X							X	X	X		X	X	X	X	X	X	X	X
MGA Station	0.810	X	X	X	X							X	X	X		X	X	X	X	X	X	X	X
Undeveloped (Und)	0.126	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Developed (Dev)	0.418	X	X	X	X	X	X	X	X	X	X		X	X									X
Commercial (Comm)	0.208	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X
Downtown (Down)	0.657	X	X	X	X	X	X	X	X	X	X		X	X		X	X						X
Industrial (Ind)	0.458	X	X	X	X	X	X	X	X	X	X		X	X		X	X						X
Multi-Family (MFR)	0.429	X	X	X	X	X	X	X	X	X	X		X	X		X	X						X
Mixed Use (Mix)	0.477	X	X	X	X	X	X	X	X	X	X		X									X	X
Office (Off)	0.368	X	X	X	X	X	X	X	X	X	X		X	X				X					X
Roadway (Road)	0.233	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X
Single-Family (SFR)	0.404	X	X	X	X	X	X	X	X	X	X		X	X									X

Note: "x" indicates mean concentrations are significant different between different land uses.

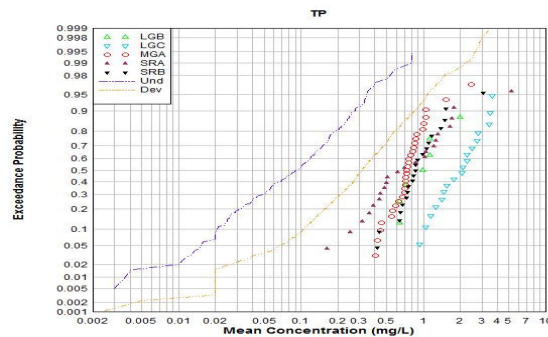
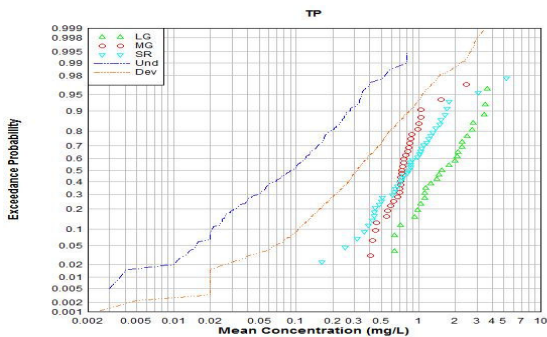
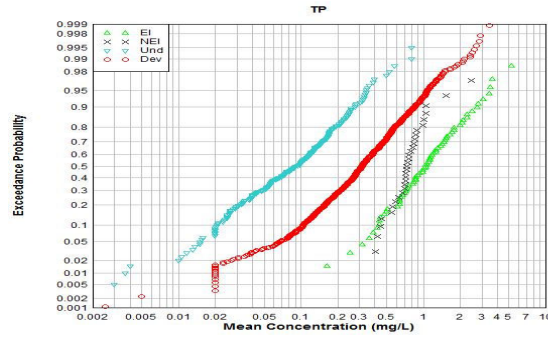
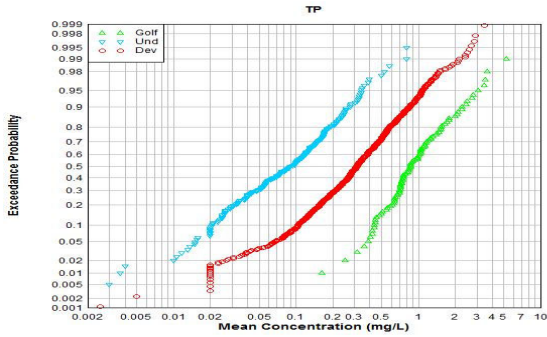


Figure 10: Probability Plots for TP.

Table 11: NH3 concentrations in stormwater runoff for various land uses.

Land Use	NH3 Mean Concentration (mg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	0.334												X		X								X
Effluent-Irrigated (EI)	0.431												X										X
Lost Creek (LG)	0.485								X	X	X	X					X						X
LGB Station	0.454								X	X	X	X					X						X
LGC Station	0.496								X	X	X	X					X						X
Steiner Ranch (SR)	0.401											X											X
SRA Station	0.435											X											X
SRB Station	0.364											X											X
Non-Effluent-Irrigated (NEI)	0.120			X	X	X						X	X		X	X	X	X	X	X	X	X	X
Lions Municipal (MG)	0.120			X	X	X						X	X		X	X	X	X	X	X	X	X	X
MGA Station	0.120			X	X	X						X	X		X	X	X	X	X	X	X	X	X
Undeveloped (Und)	0.0481	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Developed (Dev)	0.309								X	X	X	X			X								X
Commercial (Comm)	0.466											X											X
Downtown (Down)	0.650	X							X	X	X	X	X			X	X	X	X	X	X	X	X
Industrial (Ind)	0.257			X	X	X			X	X	X	X			X			X	X				X
Multi-Family (MFR)	0.310								X	X	X	X			X								X
Mixed Use (Mix)	0.350								X	X	X	X			X	X							X
Office (Off)	0.333								X	X	X	X			X	X							X
Roadway (Road)	0.299								X	X	X	X			X								X
Single-Family (SFR)	0.225	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Note: "x" indicates mean concentrations are significant different between different land uses.

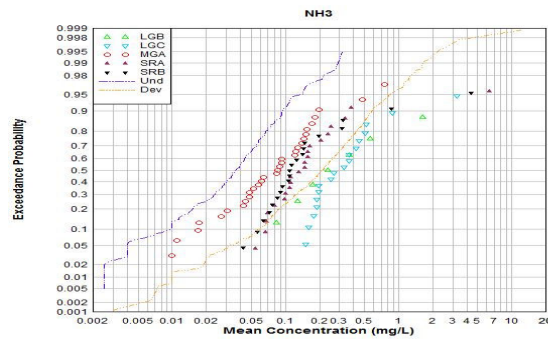
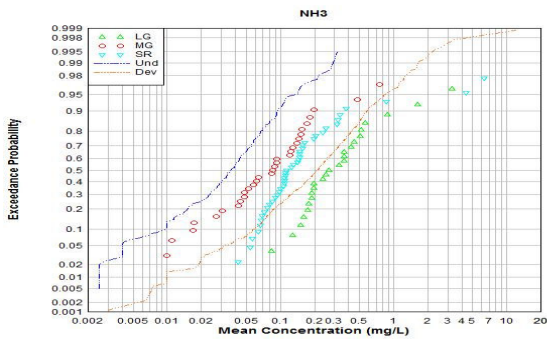
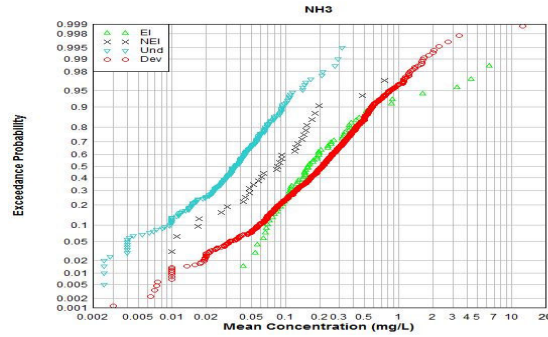
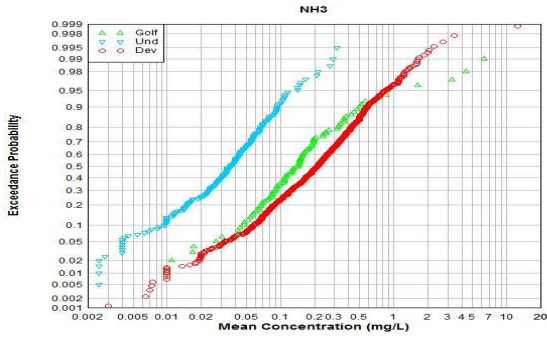


Figure 11: Probability Plots for NH3.

Table 12: NO23 concentrations in stormwater runoff for various land uses.

Land Use	NO23 Mean Concentration (mg/L)	T-test Matrix																						
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR		
Golf Course (Golf)	1.094								X	X	X	X	X	X	X		X		X		X	X		
Effluent-Irrigated (EI)	1.388									X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Lost Creek (LG)	1.500							X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
LGB Station	1.305								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
LGC Station	1.576								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Steiner Ranch (SR)	1.322									X	X	X	X	X	X	X	X		X		X	X	X	
SRA Station	0.553				X	X	X			X														
SRB Station	2.128	X								X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Non-Effluent-Irrigated (NEI)	0.449	X	X	X	X	X	X			X				X		X	X			X				
Lions Municipal (MG)	0.449	X	X	X	X	X	X			X				X		X	X			X				
MGA Station	0.449	X	X	X	X	X	X			X				X		X	X			X				
Undeveloped (Und)	0.462	X	X	X	X	X	X			X				X		X	X			X	X		X	
Developed (Dev)	0.621	X	X	X	X	X	X			X	X	X	X		X	X	X			X	X		X	
Commercial (Comm)	0.447	X	X	X	X	X	X			X				X		X	X			X	X		X	
Downtown (Down)	0.782	X	X	X	X	X	X			X	X	X	X		X	X	X			X	X		X	
Industrial (Ind)	0.767	X	X	X	X	X	X			X	X	X	X		X	X	X			X	X		X	
Multi-Family (MFR)	0.631		X	X	X	X				X														
Mixed Use (Mix)	0.624	X	X	X	X	X	X			X				X		X								
Office (Off)	0.763		X	X	X	X				X	X	X	X	X	X								X	X
Roadway (Road)	0.461	X	X	X	X	X	X			X				X		X	X			X			X	
Single-Family (SFR)	0.577	X	X	X	X	X	X			X				X		X	X	X		X			X	

Note: "x" indicates mean concentrations are significant different between different land uses.

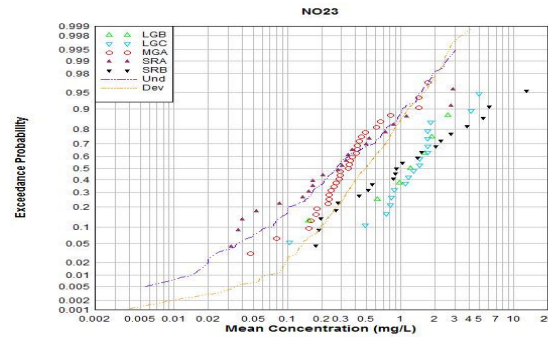
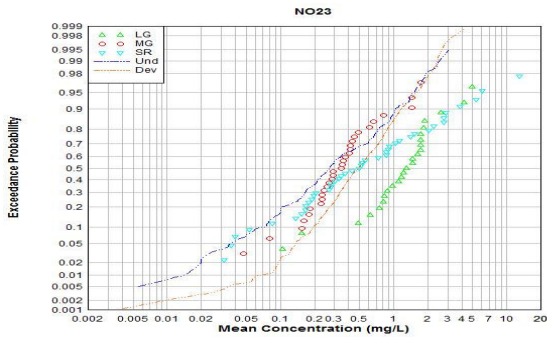
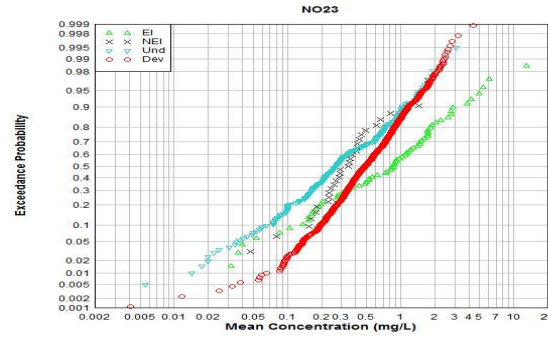
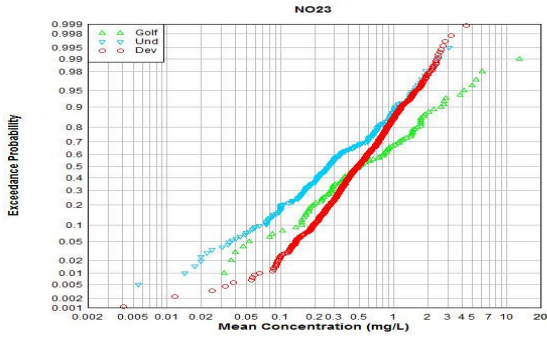


Figure 12: Probability Plots for NO23.

Table 13: TKN concentrations in stormwater runoff for various land uses.

Land Use	TKN Mean Concentration (mg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	2.892												X	X	X		X	X	X	X	X	X	X
Effluent-Irrigated (EI)	2.885												X	X	X		X	X	X	X	X	X	X
Lost Creek (LG)	3.399												X	X	X		X	X	X	X	X	X	X
LGB Station	2.604												X				X					X	
LGC Station	3.708												X	X	X		X	X	X	X	X	X	X
Steiner Ranch (SR)	2.586												X	X	X		X		X	X	X	X	X
SRA Station	2.837												X	X	X		X		X	X	X	X	X
SRB Station	2.323												X				X					X	
Non-Effluent-Irrigated (NEI)	2.907												X	X	X		X		X	X	X	X	X
Lions Municipal (MG)	2.907												X	X	X		X		X	X	X	X	X
MGA Station	2.907												X	X	X		X		X	X	X	X	X
Undeveloped (Und)	0.981	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Developed (Dev)	1.731	X	X	X		X	X	X		X	X	X	X		X		X						X
Commercial (Comm)	1.592	X	X	X		X	X	X		X	X	X	X		X								X
Downtown (Down)	2.772												X	X	X		X	X	X	X	X	X	X
Industrial (Ind)	1.493	X	X	X	X	X	X	X	X	X	X	X				X			X	X	X	X	X
Multi-Family (MFR)	1.760	X	X	X		X						X			X								X
Mixed Use (Mix)	1.900	X	X	X		X	X	X		X	X	X	X		X	X							X
Office (Off)	1.896	X	X	X		X	X	X		X	X	X	X		X	X							X
Roadway (Road)	1.000	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X
Single-Family (SFR)	1.638	X	X	X		X	X	X		X	X	X	X		X								X

Note: "x" indicates mean concentrations are significant different between different land uses.

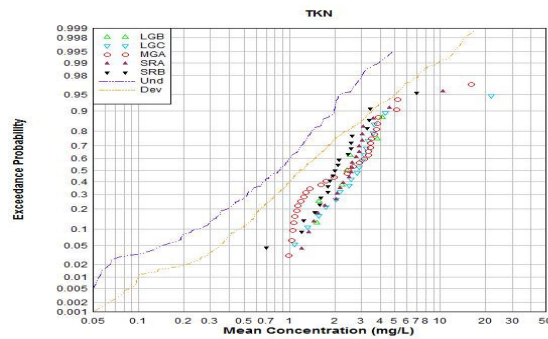
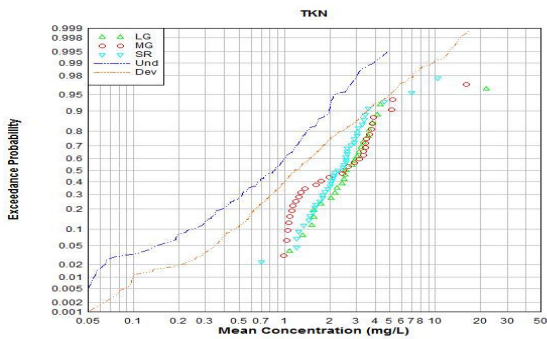
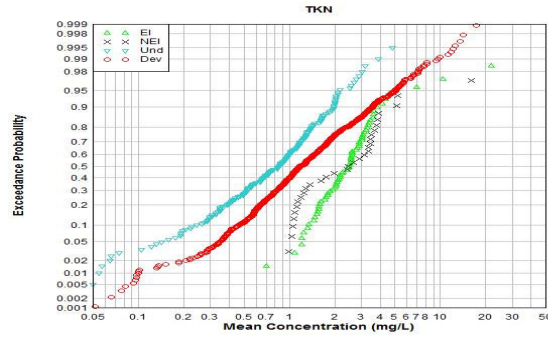
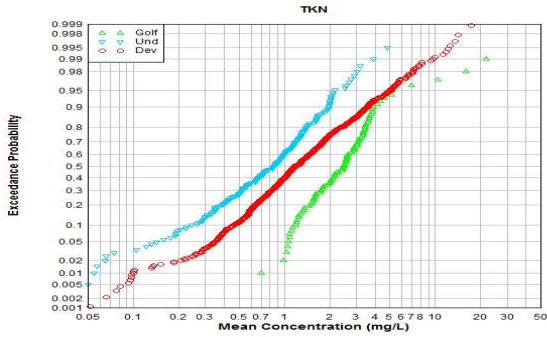


Figure 13: Probability Plots for TKN.

Table 14: TN concentrations in stormwater runoff for various land uses.

Land Use	TN Mean Concentration (mg/L)	T-test Matrix																					
		Glof	EI	LG	LGB	LGC	SR	SRA	SRB	NEI	MG	MGA	Und	Dev	Comm	Down	Ind	MFR	Mix	Off	Road	SFR	
Golf Course (Golf)	3.985												X	X	X		X	X	X	X	X	X	X
Effluent-Irrigated (EI)	4.272												X	X	X		X	X	X	X	X	X	X
Lost Creek (LG)	4.899												X	X	X		X	X	X	X	X	X	X
LGB Station	3.909												X	X	X		X					X	X
LGC Station	5.284												X	X	X	X	X	X	X	X	X	X	X
Steiner Ranch (SR)	3.908												X	X	X		X	X	X	X	X	X	X
SRA Station	3.390												X	X	X		X					X	X
SRB Station	4.451												X	X	X		X	X	X	X	X	X	X
Non-Effluent-Irrigated (NEI)	3.356												X	X	X		X					X	X
Lions Municipal (MG)	3.356												X	X	X		X					X	X
MGA Station	3.356												X	X	X		X					X	X
Undeveloped (Und)	1.456	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Developed (Dev)	2.338	X	X	X	X	X	X	X	X	X	X	X				X							X
Commercial (Comm)	1.966	X	X	X	X	X	X	X	X	X	X	X				X							X
Downtown (Down)	3.492												X	X	X		X	X	X			X	X
Industrial (Ind)	2.219	X	X	X	X	X	X	X	X	X	X	X				X							X
Multi-Family (MFR)	2.329	X	X	X									X			X							X
Mixed Use (Mix)	2.525	X	X	X									X			X							X
Office (Off)	2.669	X	X	X									X										X
Roadway (Road)	1.432	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X
Single-Family (SFR)	2.226	X	X	X	X	X	X	X	X	X	X	X				X							X

Note: "x" indicates mean concentrations are significant different between different land uses.

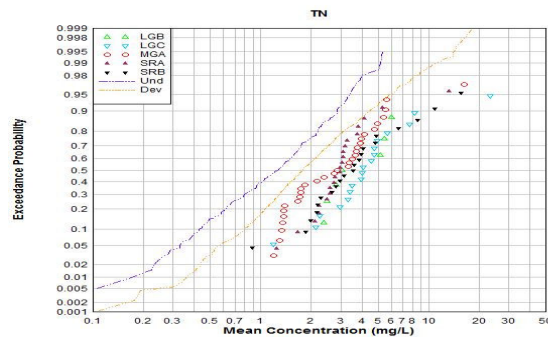
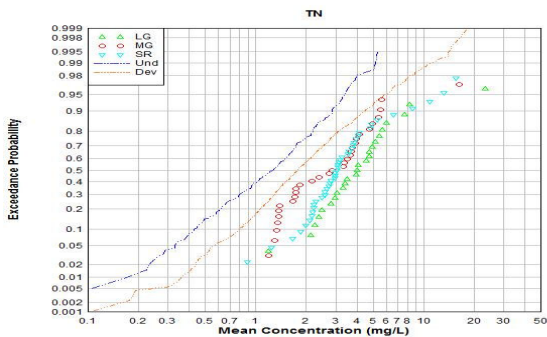
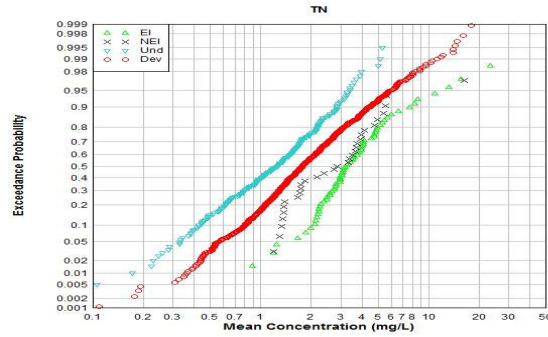
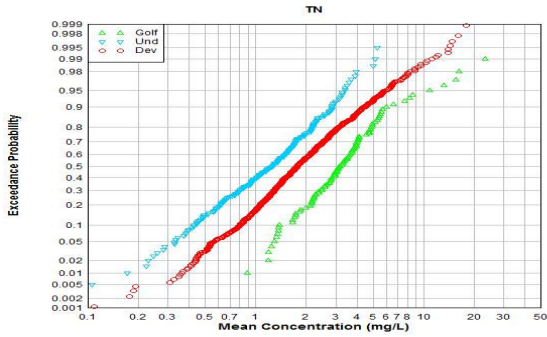


Figure 14: Probability Plots for TN.  
 Table 15: Mean Concentrations of All Pollutants for All Land Uses.

Land Use	Mean Concentration ( $\mu\text{g/L}$ for metals, $\text{mg/L}$ for others)													
	Metal				Solid		Organic		Nutrient					
	CD	CU	PB	ZN	TSS	VSS	COD	TOC	DP	TP	NH3	NO23	TKN	TN
Golf Course (Golf)	0.488	5.826	6.771	26.71	104.1	28.68	82.92	16.71	0.838	1.151	0.334	1.094	2.892	3.985
Effluent-Irrigated (EI)	0.555	5.288	2.826	24.51	64.20	21.59	82.90	16.27	1.042	1.306	0.431	1.388	2.885	4.272
Lost Creek (LG)	0.535	3.726	2.918	30.02	96.38	33.60	91.98	12.87	1.397	1.815	0.485	1.500	3.399	4.899
LGB Station	0.531	4.098	3.418	34.02	126.8	28.61	50.33	9.409	0.754	1.035	0.454	1.305	2.604	3.909
LGC Station	0.536	3.602	2.751	28.69	84.55	35.54	108.2	14.21	1.646	2.118	0.496	1.576	3.708	5.284
Steiner Ranch (SR)	0.568	6.159	2.774	21.43	45.49	13.89	77.62	18.24	0.835	1.011	0.401	1.322	2.586	3.908
SRA Station	0.595	6.213	2.748	17.10	25.69	14.40	75.86	19.05	0.859	1.015	0.435	0.553	2.837	3.390
SRB Station	0.539	6.103	2.802	25.96	66.23	13.35	79.47	17.40	0.810	1.007	0.364	2.128	2.323	4.451
Non-Effluent-Irrigated (NEI)	0.356	6.990	15.30	31.46	191.8	43.31	82.95	17.69	0.393	0.810	0.120	0.449	2.907	3.356
Lions Municipal (MG)	0.356	6.990	15.30	31.46	191.8	43.31	82.95	17.69	0.393	0.810	0.120	0.449	2.907	3.356
MGA Station	0.356	6.990	15.30	31.46	191.8	43.31	82.95	17.69	0.393	0.810	0.120	0.449	2.907	3.356
Undeveloped (Und)	0.359	4.083	3.483	17.83	101.1	16.57	46.36	11.75	0.033	0.126	0.048	0.462	0.981	1.456
Developed (Dev)	0.540	14.38	21.88	105.6	162.2	34.62	81.13	13.83	0.193	0.418	0.309	0.621	1.731	2.338
Commercial (Comm)	0.579	7.651	22.79	85.93	137.2	35.43	47.77	9.605	0.117	0.208	0.466	0.447	1.592	1.966
Downtown (Down)	0.795	27.84	66.44	330.8	167.0	51.93	162.9	22.70	0.292	0.657	0.650	0.782	2.772	3.492
Industrial (Ind)	0.772	19.09	30.82	144.7	155.2	30.33	87.83	13.53	0.149	0.458	0.257	0.767	1.493	2.219
Multi-Family (MFR)	1.175	16.36	17.81	73.74	208.9	54.31	91.71	9.919	0.322	0.429	0.310	0.631	1.760	2.329
Mixed Use (Mix)	0.733	42.01	30.45	117.1	185.0	40.78	92.01	15.68	0.164	0.477	0.350	0.624	1.900	2.525
Office (Off)	0.525	12.24	10.24	139.6	95.71	33.77	75.25	13.48	0.155	0.368	0.333	0.763	1.896	2.669
Roadway (Road)	0.720	16.66	35.38	112.3	217.4	28.87	60.24	11.17	0.078	0.233	0.299	0.461	1.000	1.432
Single-Family (SFR)	0.355	7.870	10.42	54.16	158.8	31.03	68.45	13.27	0.201	0.404	0.225	0.577	1.638	2.226