Preliminary Report on Storm Water Runoff from Effluent-Irrigated Golf Courses

Prepared by

Environmental Resource Management Division
Watershed Protection and
Development Review Department
City of Austin

Introduction

For the past twenty years, the City of Austin has collected water quality samples from storm water runoff to characterize the quality of runoff from different land uses. 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.

At this time, four monitoring stations have been established on two golf courses. Both courses use effluent to meet a portion of their irrigation needs. Both courses also have nutrient management plans in place. One of the courses has been established for several years and has used effluent for irrigation during that time. The other course was recently established on a former effluent irrigation field.

The City has collected flow and water quality data from more than fifty runoff events from these four 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 four metals: cadmium (Cd), copper, (Cu), lead (Pb), and zinc (Zn); two types of suspended solids: total suspended solids (TSS), and volatile suspended solids (VSS); three measures of organic matter: 5-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC); and six nutrients: dissolved phosphorus (DP), total phosphorus (TP), ammonia (NH_3), nitrate plus nitrite (NO_3+NO_2), total Kjeldahl nitrogen (TKN), and total nitrogen (TN).

Analytical Methods

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 using Duncan's multiple range tests to determine if the means of the land use types were different at the 0.05 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 and Gilbert 1987). As such, the mean concentrations reported are the geometric means.

Results

With respect to metals Cd, Cu, Pb, and Zn, the runoff concentrations from effluent-irrigated golf courses were low compared to other land uses (See Tables 1-4 and Figures 1-4). For Cu, Pb, and Zn, runoff from the golf course land use had either the lowest or second-lowest concentration and, except for Pb, was not significantly higher than the runoff concentrations from undeveloped land. Cd concentrations for all land uses were fairly low, with the golf course land use falling in the mid-range and not significantly different from runoff from undeveloped land. In general, runoff from the golf course sites may be considered relatively high quality with respect to metals.

The concentrations of suspended solids, both TSS and VSS, in runoff from effluent-irrigated golf courses were second-lowest of the land uses tested (See Tables 5 and 6 and Figures 5 and 6). TSS concentrations were not significantly different from undeveloped runoff. VSS concentrations at the golf course sites were significantly higher than undeveloped areas but lower than most other land uses. In general, the solids concentrations in runoff from effluent-irrigated golf courses follow the same trends as metals.

Effluent-irrigated golf course runoff concentrations for oxygen demand parameters vary by parameter (see Tables 7-9 and Figures 7-9). Results for BOD were similar to the results for metals and solids, with golf course runoff concentrations being the second-lowest and not significantly different from runoff from undeveloped land. (BOD sampling was discontinued early in the study; therefore, there were only seven EMCs for BOD from the golf courses.) Golf course runoff concentrations of COD were in the upper to mid- range of the land uses; significantly lower than downtown runoff concentrations but higher than runoff from multi-family, commercial and undeveloped areas. The runoff concentrations of TOC from golf courses were the highest among the various land uses and were significantly higher than office, industrial, undeveloped, roadway, multi-family, and commercial land uses.

The available data indicate that for the above-described runoff pollutants, the concentrations coming from a golf course are generally low. However, runoff concentrations of nutrients are significantly higher than runoff concentrations from undeveloped land and many of the other land uses as well. The runoff concentrations of dissolved phosphorus from effluent-irrigated golf courses are more than four times higher than the runoff concentration from the next-closest land use, single-family residential, and more than twenty times higher than runoff from undeveloped land (see Table 10 and Figure 10). Total phosphorus concentrations (Table 11 and Figure 11), while not as high, follow the same general trend: the concentrations from the golf course sites were almost twice as high as the runoff concentrations from single-family and downtown areas and more than ten times higher than runoff concentration from undeveloped land.

Concentrations of nitrogen in runoff from effluent-irrigated golf courses generally followed the same trends as phosphorous, but the differences with other land uses were not as dramatic. Ammonia concentrations (Table 12 and Figure 12) in the runoff from golf courses were significantly lower than runoff concentrations from downtown land use and higher than commercial, single-family, and undeveloped land uses. Ammonia concentrations in runoff from effluent-irrigated golf courses were five times higher than concentrations from undeveloped areas. Other studies have indicated that ammonia runoff concentrations exhibit a strong positive correlation with impervious cover (COA ERM 2005 draft). Since the golf course watersheds have, for all practical purposes, no impervious cover, they would not be expected to have runoff concentration of NH_3 in the range of the high impervious cover land uses. The concentrations of nitrate+nitrite, total nitrogen, and total Kjeldahl nitrogen (Table 13-15 and Figure 13-15) in runoff from the golf course were the highest of all concentrations for the measured land uses and more than three times higher than the concentration from undeveloped areas. The concentrations of NO_3+NO_2 and TKN from effluent-irrigated golf courses were significantly higher than all other land uses except downtown commercial. The high levels of TKN may be influencing the elevated levels of COD and TOC in the golf courses runoff, since those parameters are affected by the organic nitrogen portion of TKN, which was highest in the runoff from effluent-irrigated golf courses. Total nitrogen concentration from the golf course runoff was significantly higher compared to all other land uses and approximately three times higher than undeveloped areas.

Discussion

It appears that the pollutants of greatest concern in runoff from the golf courses in this study are nutrients, both total and dissolved phosphorus and the nitrogen series. Fertilizer and effluent-irrigation water are potential sources of these pollutants. Both courses apply supplemental nitrogen in various forms in addition to the nitrogen in the effluent-irrigation water. Nitrate levels in effluent are limited by the discharge permit for the treatment plant, but the permit may allow concentrations as high as 8.0 mg/l and total nitrogen near 10 mg/l. Samples of the irrigation water used at these courses indicated a reduction in nitrogen concentrations when comparing the runoff to the effluent.

Golf course managers have indicated little or no phosphorus was applied as fertilizer during the monitoring period. Studies by Texas A&M University, in conjunction with the City, have indicated that phosphorus may remain at high levels for long periods in local soils after application has ceased (City of Austin, 2005). Since both of the 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. The phosphorus levels in the irrigation effluent may vary depending on the influent source to the treatment plant, but recent grab samples of the effluent-irrigation water indicate a level of 0.6 mg/l for TP and 0.4 mg/l for DP. However, phosphorous concentrations in the runoff are considerably higher, indicating there is little sequestering of phosphorus on the golf course and that the runoff may be exporting phosphorous.

Of potentially greater concern is the larger proportion of total phosphorous that is in dissolved form and readily available for plant uptake. The ratio of dissolved to total P for most other land uses is in the range of 25-45%. This ratio is approximately 73% in the runoff from effluent-irrigated golf courses. This high proportion of dissolved phosphorus may contribute to rapid algae blooms since the phosphorus is readily available and further transformation are not required for plant use.

Nutrient loading can be particularly significant in systems such as area creeks, which have naturally low levels of nutrients. Since the volume of runoff from these sites may be small compared to the total flow in the receiving creeks during a storm event, the higher concentrations from these sites may not significantly impact storm water concentrations in the receiving creek. However, the localized influx of high concentrations of nutrients may generate localized algae blooms, some of which have been observed in Barton Creek near areas with effluent-irrigated golf course (City of Austin, 1997).

As a guide, the runoff concentrations were compared to the TCEQ secondary screening levels for freshwater streams (TCEQ, 2003). These are threshold effects levels for fresh water. While not designed to evaluate storm water runoff, they serve as a guide. The average concentrations for total and dissolved phosphorous and ammonia in the runoff from these golf courses exceed these screening levels, a condition that would trigger additional monitoring and other actions. Nitrate+nitrite also exceeded screening levels for some events, but not overall.

The main focus of this report is storm water runoff concentrations. While this report does not examine the impacts of effluent irrigation on shallow ground water, other studies have addressed this issue to some extent. City of Austin spring monitoring has noted that springs near another local golf course (not effluent-irrigated) exhibit water quality similar to the water used for irrigation, most notably in total dissolved solids. Another study (Wong et al., 1998) examined deep percolation of effluent irrigation on golf courses. This study indicated that few nutrients leach past the root zone if the irrigation was properly managed and fertilizer applications properly timed. An examination of limited data on the springs in the vicinity of these golf courses indicate elevated levels of some nutrients, but not to the extent seen in the storm water runoff. In addition, these springs may be influenced by other development.

A review of data from USGS monitoring stations on Barton Creek at State Highway 71 and Lost Creek Boulevard indicates there are no significant differences at this time in the concentration of nutrients during storm flow at these sites. Runoff from a number of golf courses enters the creek between these two monitoring stations. While there is no statistical difference in the nutrient concentration during runoff events at these two locations, there is a statistical difference in dissolved ammonia and dissolved and total nitrate+nitrite during baseflow conditions. Since a portion of the storm water runoff from golf courses (and other land uses) will infiltrate and enter the creek as baseflow through springs or other pathways, higher concentrations in that runoff may affect the baseflow concentrations when flows are lower and dilution is reduced. In addition, small localized rainfall may produce runoff from the golf course while not producing significant flow increase in the creek. Unlike large runoff events, the localized runoff during small events will not be greatly diluted by flow in the creek. The increases in baseflow concentrations may also play a role in the increased algal growth that occurs in this segment of the creek. Increases in phosphorus concentrations during baseflow in Barton Creek at both State Highway 71 and Lost Creek Boulevard are not observed; however, phosphorus increases could be masked by immediate uptake by algae growth if phosphorus is the limiting nutrient. A comparison of storm and baseflow concentrations in Barton Creek is presented in Table 16.

For a more complete picture of the impact of the golf course land use relative to other land uses, no discussion of water quality would be complete without addressing the issue of pollutant loading in addition to concentration. The amount of impervious cover associated with golf course is very low and comparable to undeveloped land. However, due to frequent irrigation and various turf management practices, the volume of runoff from a golf course may be up to 50% higher than that expected from an undeveloped area with a similarly low impervious cover. Analyses of the rainfall-runoff relationships at the City's monitoring sites is not completed, but preliminary data indicate that it is similar to other studies (Spectrum Research Inc., 1999). Table 17 is a comparison of possible annual pollutant loads from golf courses, undeveloped land and single-family (30% impervious cover) land uses. Several scenarios are used to estimate load from golf courses. The first assumes a runoff coefficient equivalent to undeveloped land (0.060); this would represent the lowest expected load. The second scenario assumes a 50% increase in annual runoff compared to undeveloped land; this accounts for the higher antecedent moisture condition resulting from irrigation. The last assumes a runoff coefficient that is double that of undeveloped land. The annual load from the golf course exceeds that from undeveloped land in all cases, as would be expected due to higher concentrations. The load from golf courses is slightly less than the load from the single-family land use in all cases, except for dissolved phosphorus.

Design and Management Considerations: Developing an Integrated Turfgrass Management Plan

Several golf course design elements and turfgrass management practices are effective in reducing negative water quality impacts from effluent-irrigated golf courses. An integrated approach to implementing these design elements and management practices can be taken by first preparing an integrated turfgrass management (ITM) plan. The ITM Plan must clearly indicate how the irrigation, nutrient, pest, and cultural management practices are integrated, and how the combination of certain management practices will best mitigate adverse water quality impacts while maintaining golf course playability goals.

The ITM Plan must first identify two types of golf course management zones ("Zones"):

- A vegetated buffer zone (VBZ) adjacent to water bodies, waterways, and other sensitive environmental resource features

- Turfgrass management zones (TMZs) delineating areas with similar site conditions and risk factors, including areas with potential for off-site transport of nutrients and pesticides

The Zones are site-specific, and therefore require on-site investigations; site specific ITM Plans can then be developed.

For the VBZ: The ITM Plan must indicate:

- how the VBZ remains in or is restored to its native condition
- how sheet flow is maintained in the VBZ prior to entering waterways; (e.g. in narrow VBZ areas, runoff can be collected and pumped to upland areas and then discharged through the most stabilized sections of the VBZ)
- how activities are limited:
  - fertilizers and pesticides must not be applied; mowing is limited, allowing native grasses, forbs, and shrubs to be established
  - irrigation by hand is allowed for maintenance of native vegetation
  - clipping from tees and greens must not be disposed of in the VBZ.

The ITM Plan must indicate the integration of the following irrigation, nutrient, and pest-management practices for TMZs:

- Control amount, rate, and timing of irrigation
- Irrigate with the strategy of 75% to 100% evapotranspiration (ET) replacement, to limit irrigation water's ability to transport contaminants off-site
  - to waterways, in surface water runoff,
  - to springs and seeps, in subsurface lateral flows,
  - to soils, shallow aquifers, and groundwater by deep leaching below root zone
- Do not irrigate
  - while vegetation is dormant
  - during periods of rainfall or periods of soil saturation
  - if ET rate will be exceeded.
- If irrigation cannot occur (see above), either
  - store the effluent
  - hold-and-haul the effluent, or
  - maintain an area of winter vegetation for irrigation during winter months, with application rates commensurate with winter vegetation ET rates
  - determine how often irrigation will not occur by developing a water balance, including all water inputs
- Control timing of fertilizer and pesticide applications, and integrate alternate nutrient and pest best management practices (BMPs)
  - apply fertilizers and pesticides only as needed
  - limit use of mobile forms of nutrients and pesticides
  - increase use of slow-release N-fertilizer formulations, and less mobile, degradable pesticides

- establish nutrient budgets and turfgrass quality goals
- check phosphorus and nitrogen balances frequently, as well as the water balance; e.g. high concentrations of phosphorus may result in iron chlorosis
- maintain healthy, dense turfgrass
- maintain a complete integrated pest management program
- identify pest population thresholds at which pesticides may be applied
- identify and evaluate BMPs and alternate practices

While the preceding management practices can and should be easily taken on an existing golf course, other elements should be considered during the design phase. These design elements will further reduce environmental impacts.

- Limit discharge to creeks and shallow groundwater; drain runoff internally to ponds where possible
- Line tees, greens, and ponds to protect groundwater
- Address runoff and drainage problems with structural and non-structural BMPs to protect surface water resources
- Maintain a wide, natural undisturbed VBZ; limit access and activity in the VBZ
- Maintain sheet flow through the VBZ.

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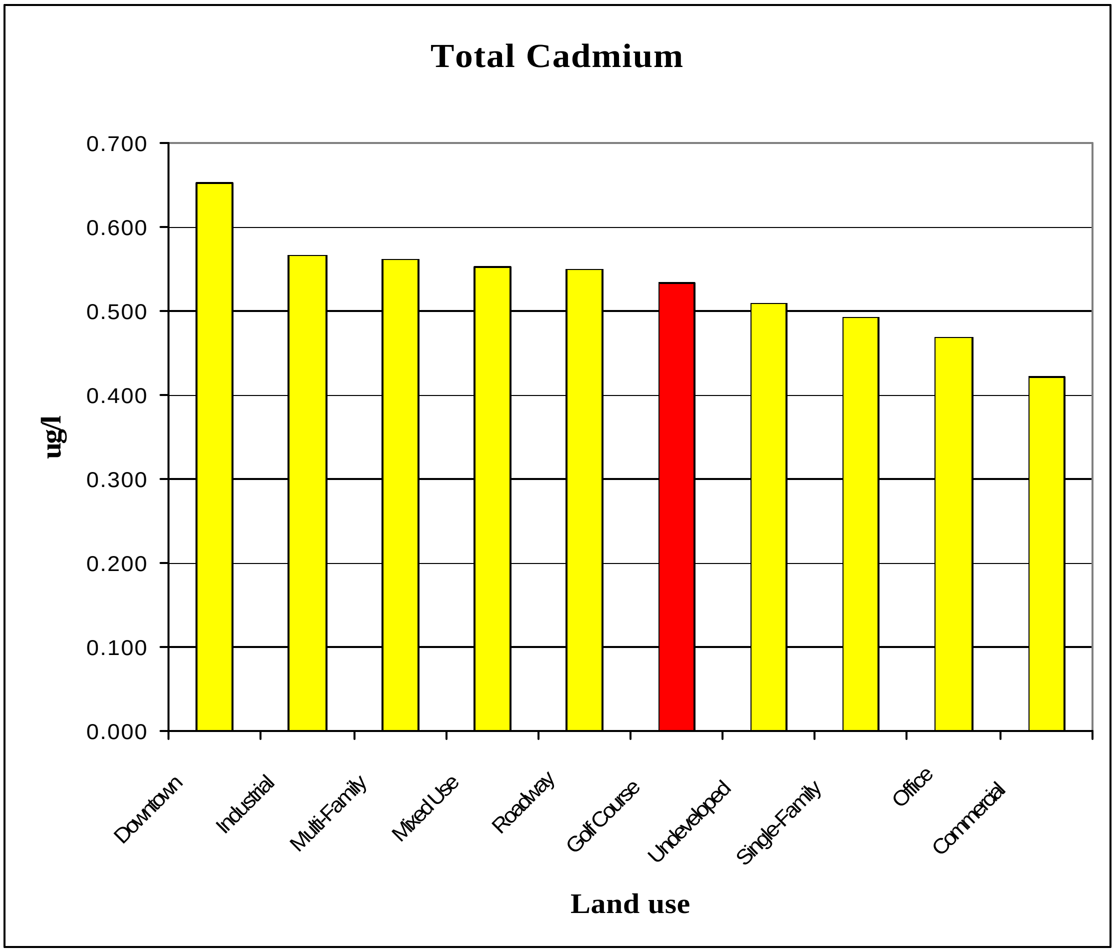

Figure 1: Cadmium concentrations in storm water runoff for various land uses.

Table 1: Cadmium concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (ug/l)	Number of Events	Grouping
Downtown	0.651	66	a
Industrial	0.565	109	ab
Multi-Family	0.562	11	ab
Mixed Use	0.553	59	ab
Roadway	0.549	19	ab
Golf Course	0.533	50	abc
Undeveloped	0.508	88	abc
Single-Family	0.493	260	bc
Office	0.469	54	bc
Commercial	0.422	11	c

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

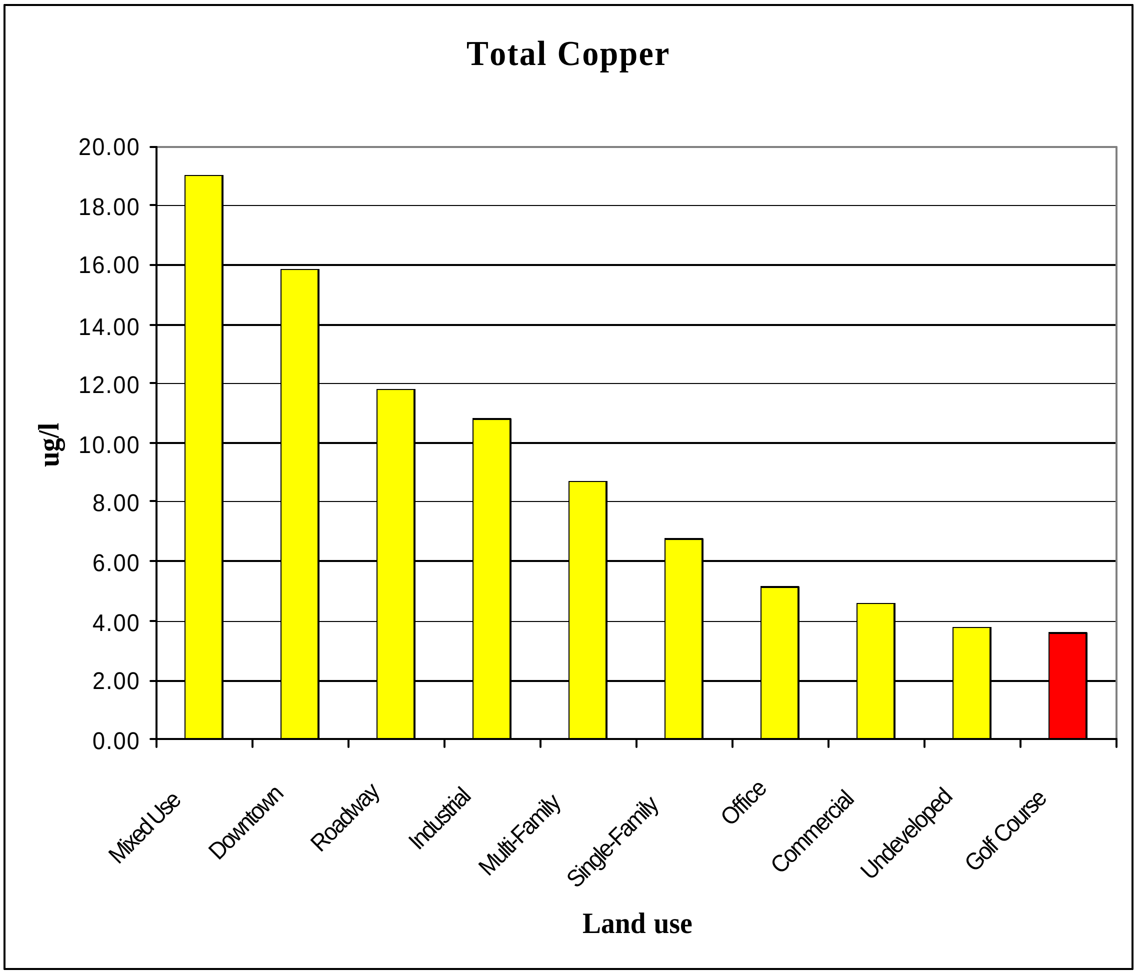

Figure 2: Copper concentrations in storm water runoff for various land uses.

Table 2: Copper concentration in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (ug/l)	Number of Events	Grouping
Mixed Use	19.01	59	a
Downtown	15.82	84	a
Roadway	11.79	47	b
Industrial	10.79	111	b
Multi-Family	8.72	40	bc
Single-Family	6.78	333	cd
Office	5.18	56	de
Commercial	4.62	51	ef
Undeveloped	3.79	112	f
Golf Course	3.61	50	f

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

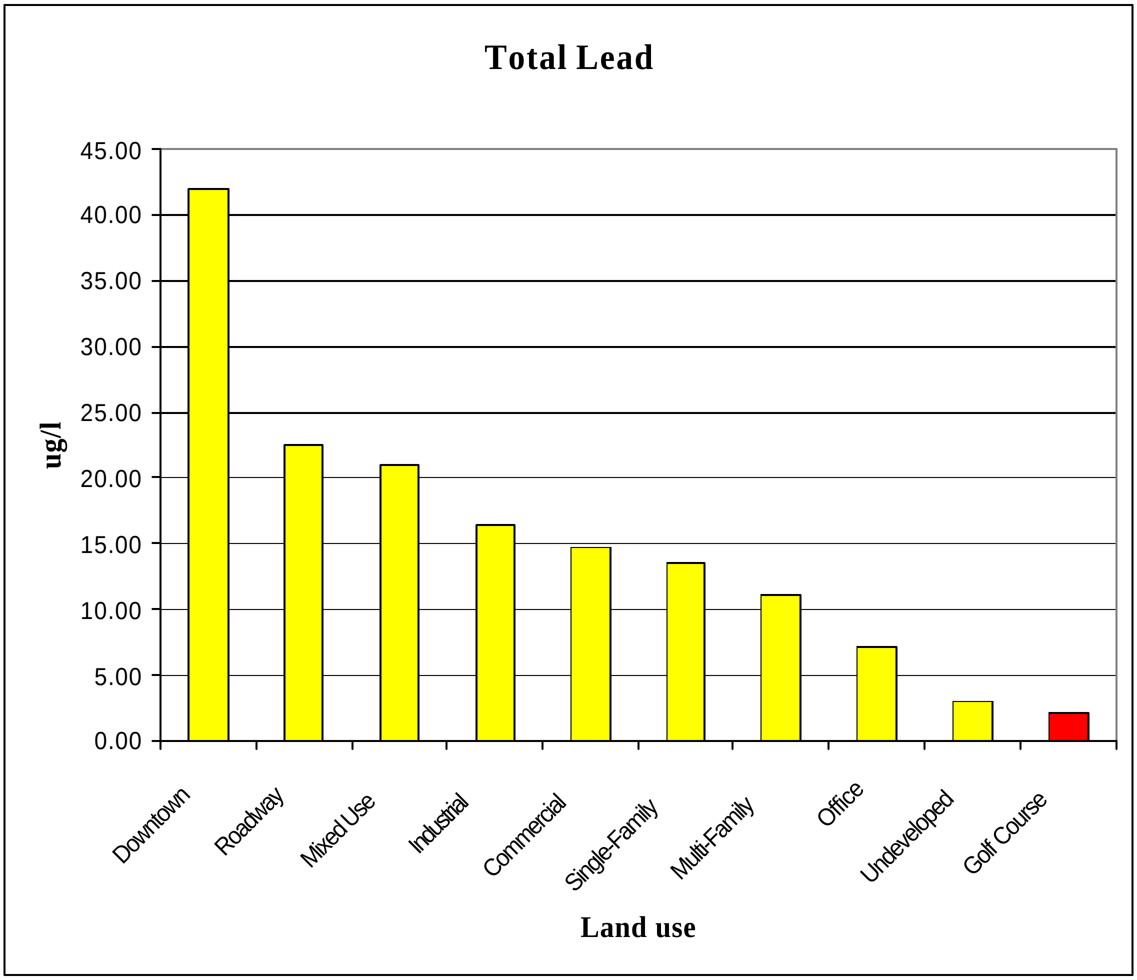

Figure 3: Lead concentrations in storm water runoff for various land uses.

Table 3: Lead concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (ug/l)	Number of Events	Grouping
Downtown	42.02	83	a
Roadway	22.64	58	b
Mixed Use	20.99	59	b
Industrial	16.47	109	bc
Commercial	14.68	51	cd
Single-Family	13.51	331	cd
Multi-Family	11.19	40	d
Office	7.12	57	e
Undeveloped	2.98	111	f
Golf Course	2.09	51	g

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

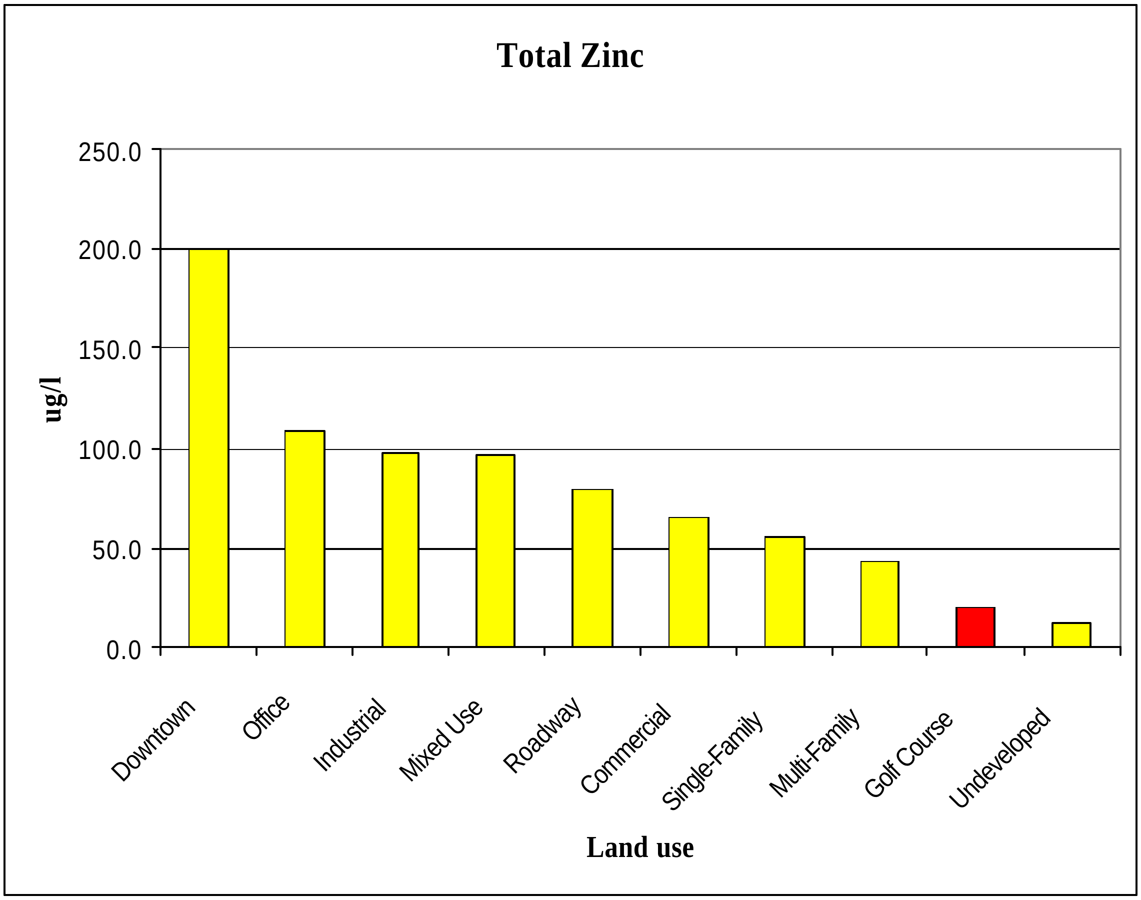

Figure 4: Zinc concentrations in storm water runoff for various land uses.

Table 4: Zinc concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (ug/l)	Number of Events	Grouping
Downtown	200.12	84	a
Office	109.08	57	b
Industrial	98.09	111	bc
Mixed Use	97.00	60	bc
Roadway	79.55	67	cd
Commercial	65.06	52	de
Single-Family	55.22	334	ef
Multi-Family	43.25	41	f
Golf Course	20.49	50	g
Undeveloped	12.47	111	h

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

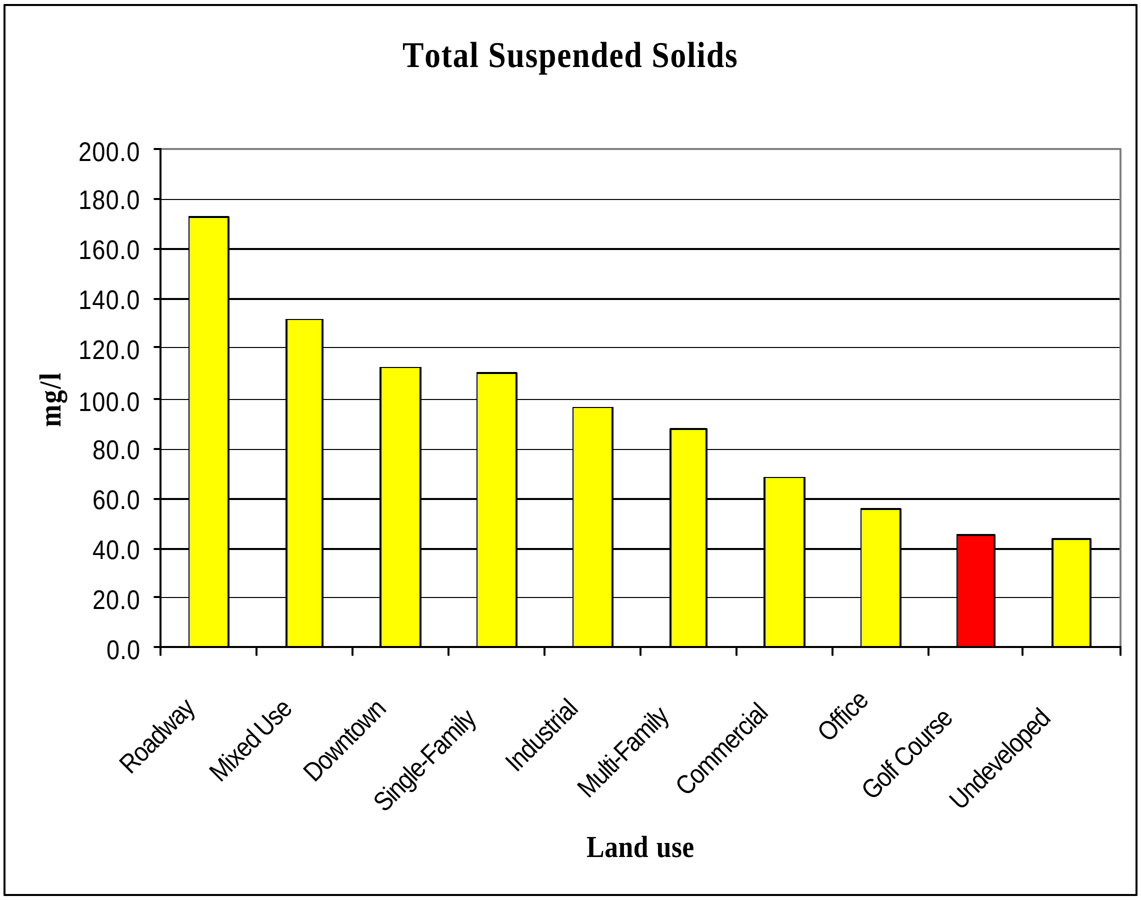

Figure 5: Total Suspended Solids concentrations in storm water runoff for various land uses.

Table 5: Total Suspended Solids concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Roadway	172.91	66	a
Mixed Use	131.99	59	ab
Downtown	112.70	103	b
Single-Family	110.29	353	b
Industrial	96.43	122	bc
Multi-Family	87.94	46	bc
Commercial	68.18	60	cd
Office	55.91	63	de
Golf Course	44.85	52	e
Undeveloped	43.34	113	e

* Land uses with a grouping letter in common are not significantly different at the 0.05 level

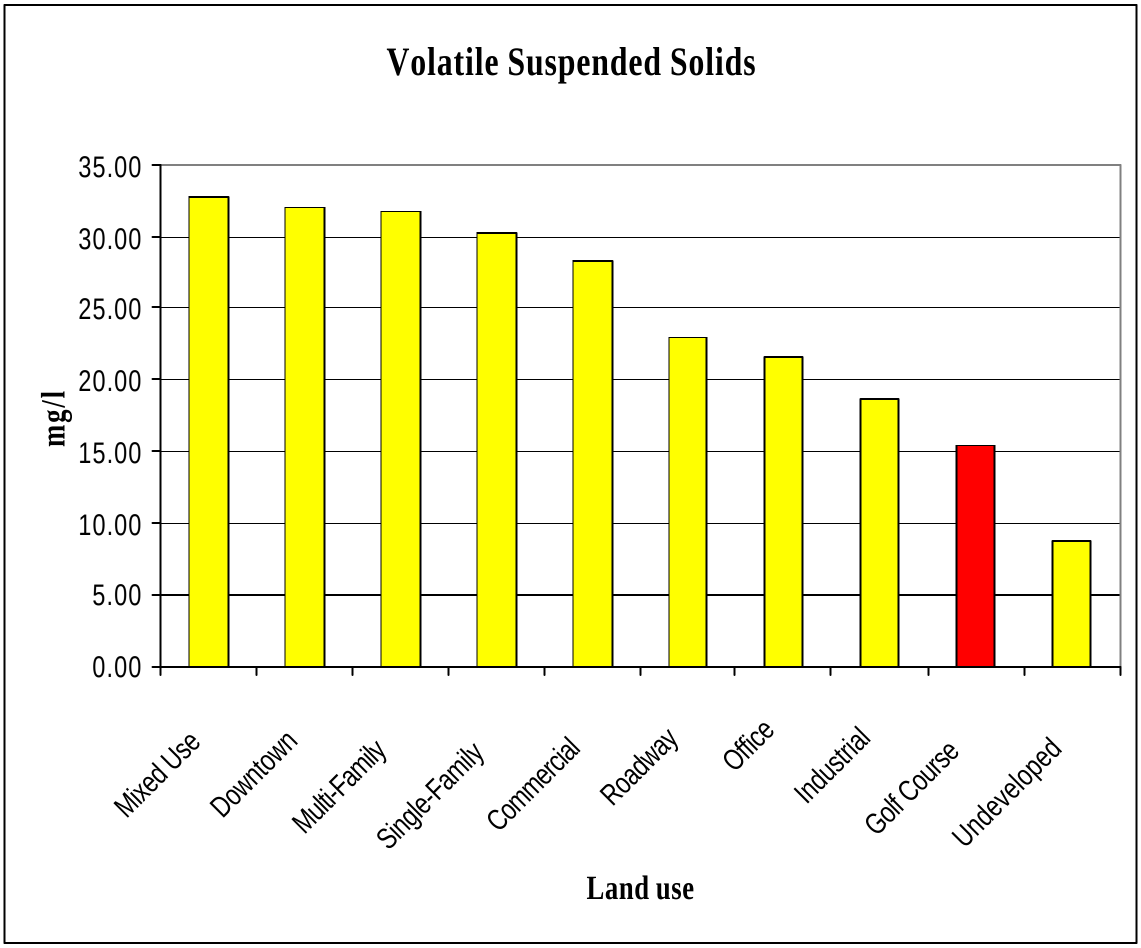

Figure 6: Volatile Suspended Solids concentrations in storm water runoff for various land uses.

Table 6: Volatile Suspended Solids concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Mixed Use	32.78	49	a
Downtown	32.10	86	a
Multi-Family	31.80	17	a
Single-Family	30.25	272	a
Commercial	28.36	21	ab
Roadway	22.93	19	abc
Office	21.58	64	abc
Industrial	18.67	119	bc
Golf Course	15.43	52	c
Undeveloped	8.70	90	d

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

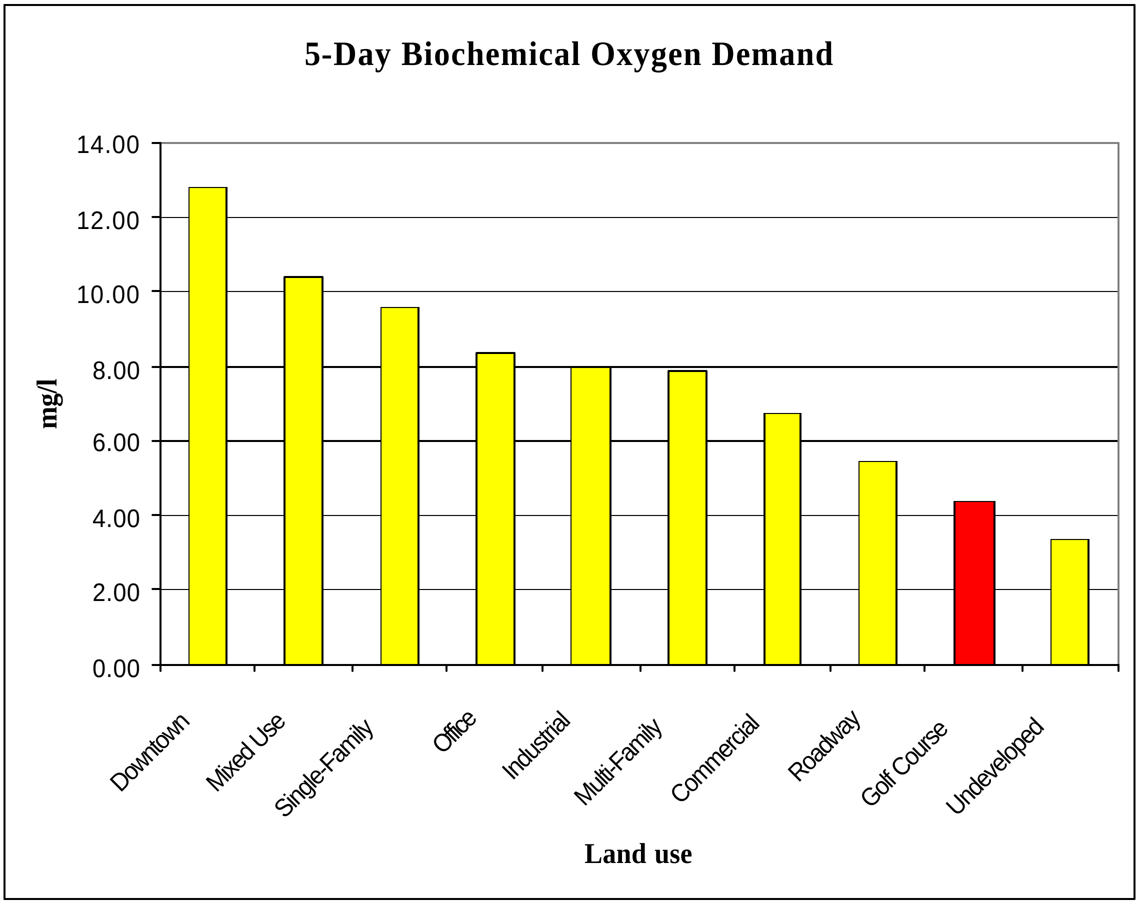

Figure 7: Biological oxygen demand concentrations in storm water runoff for various land uses.

Table 7: Biological oxygen demand concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Downtown	12.78	98	a
Mixed Use	10.37	44	ab
Single-Family	9.59	271	ab
Office	8.38	42	abc
Industrial	7.98	116	abc
Multi-Family	7.91	42	abc
Commercial	6.76	57	bcd
Roadway	5.43	46	cde
Golf Course	4.36	5	ed
Undeveloped	3.36	64	e

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

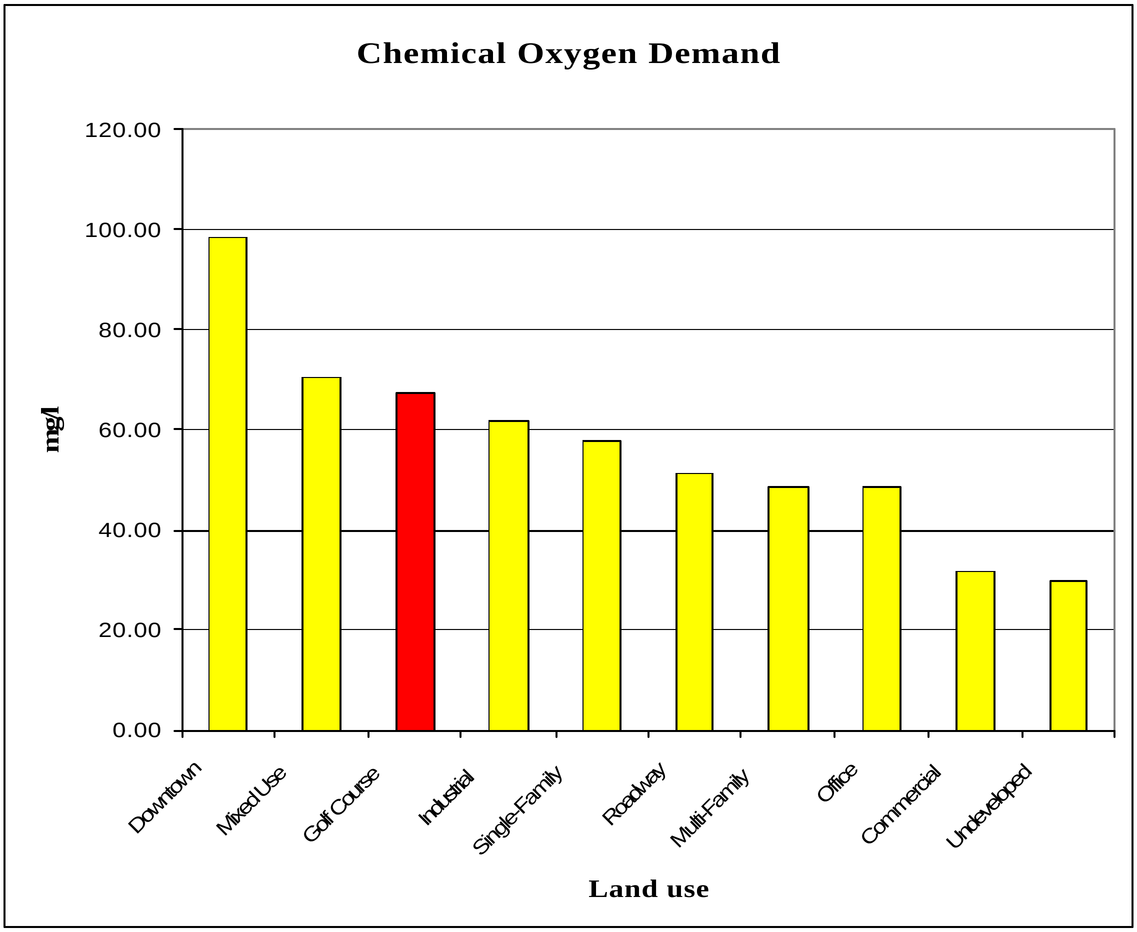

Figure 8: Chemical oxygen demand concentrations in storm water runoff for various land uses.

Table 8: Chemical oxygen demand concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Downtown	98.32	106	a
Mixed Use	70.46	61	b
Golf Course	67.67	52	bc
Industrial	61.78	121	bcd
Single-Family	57.73	353	bcd
Roadway	51.33	67	cd
Multi-Family	48.85	48	d
Office	48.72	65	d
Commercial	31.58	61	e
Undeveloped	29.91	112	e

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

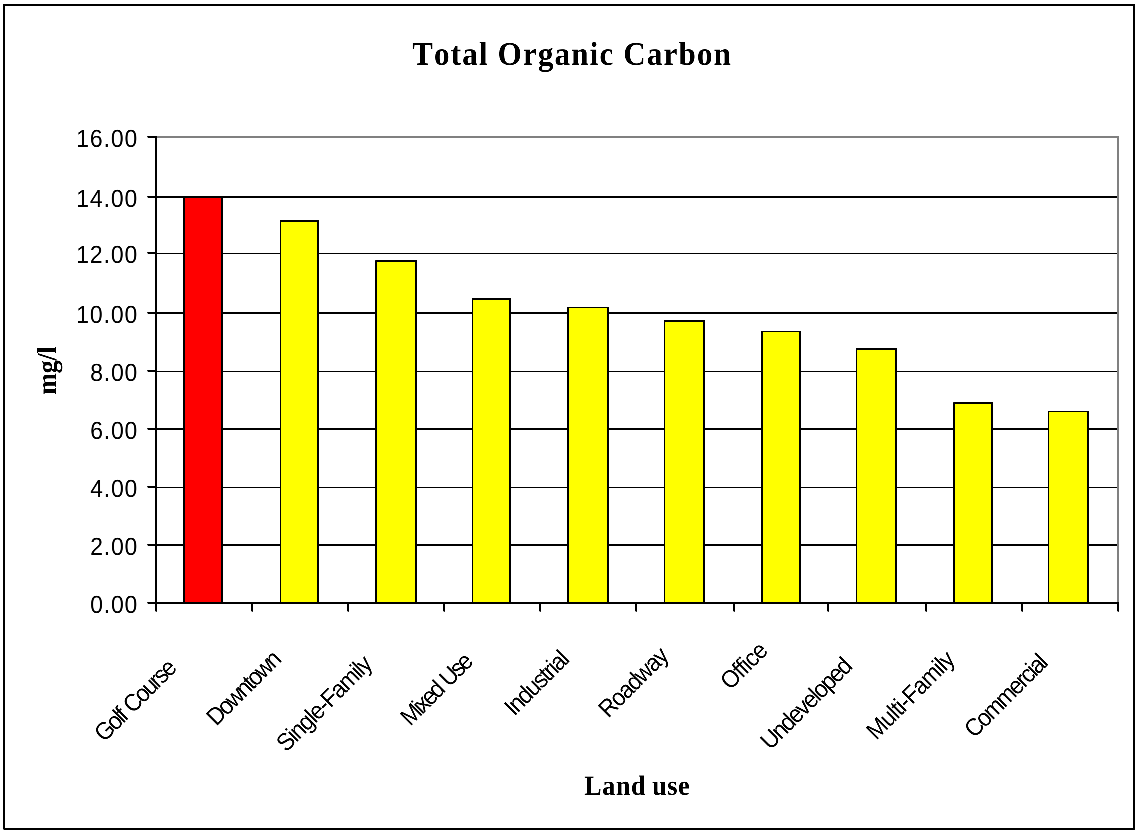

Figure 9: Total organic carbon concentrations in storm water runoff for various land uses.

Table 9: Total organic carbon concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Golf Course	13.97	50	a
Downtown	13.15	93	ab
Single-Family	11.75	330	abc
Mixed Use	10.47	56	bcd
Industrial	10.15	116	bcd
Roadway	9.69	61	cd
Office	9.36	60	cd
Undeveloped	8.75	111	de
Multi-Family	6.91	39	ef
Commercial	6.60	55	f

- Land uses with a grouping letter in common are not significantly different at the 0.05 level.

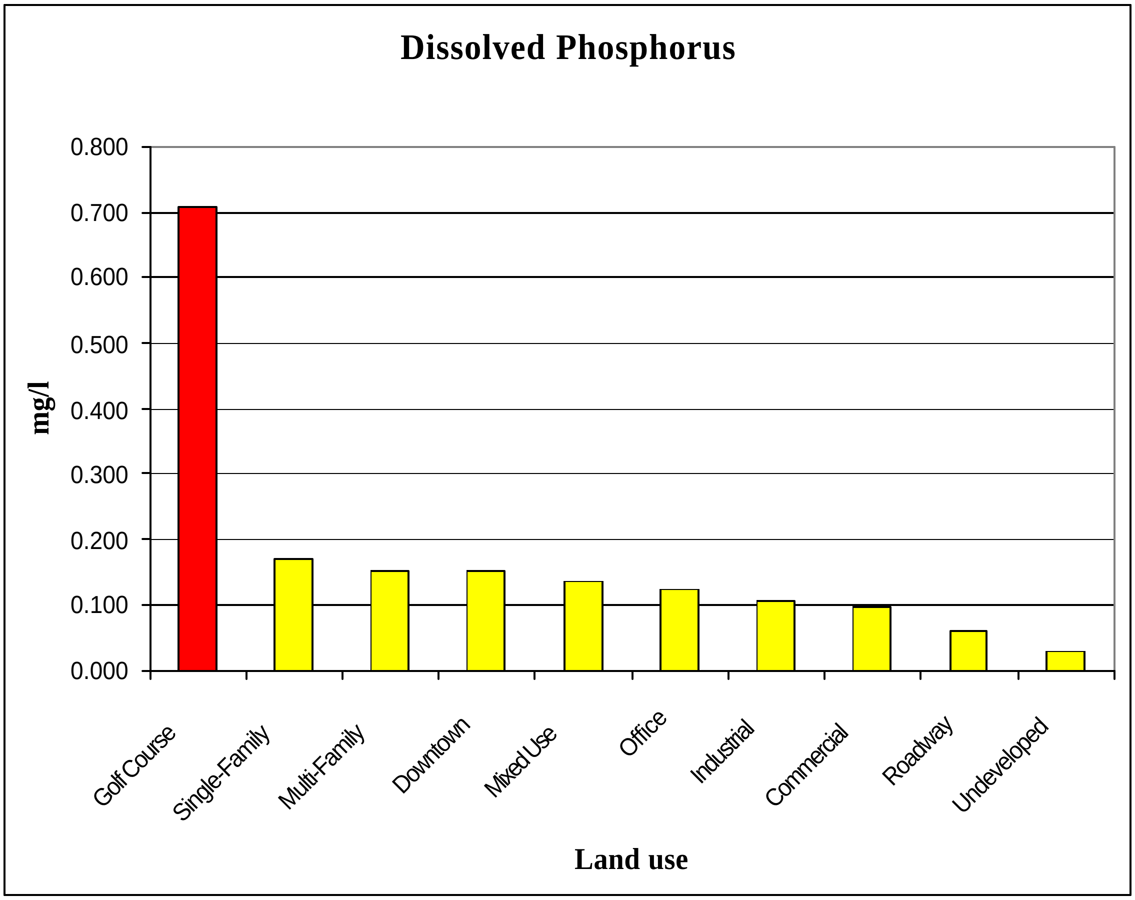

Figure 10: Dissolved phosphorus concentrations in storm water runoff for various land uses.

Table 10: Dissolved phosphorus concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Golf Course	0.708	50	a
Single-Family	0.170	269	b
Multi-Family	0.154	19	bc
Downtown	0.153	84	bc
Mixed Use	0.135	52	bcd
Office	0.125	63	bcd
Industrial	0.106	119	cd
Commercial	0.097	17	d
Roadway	0.060	31	e
Undeveloped	0.030	83	f

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

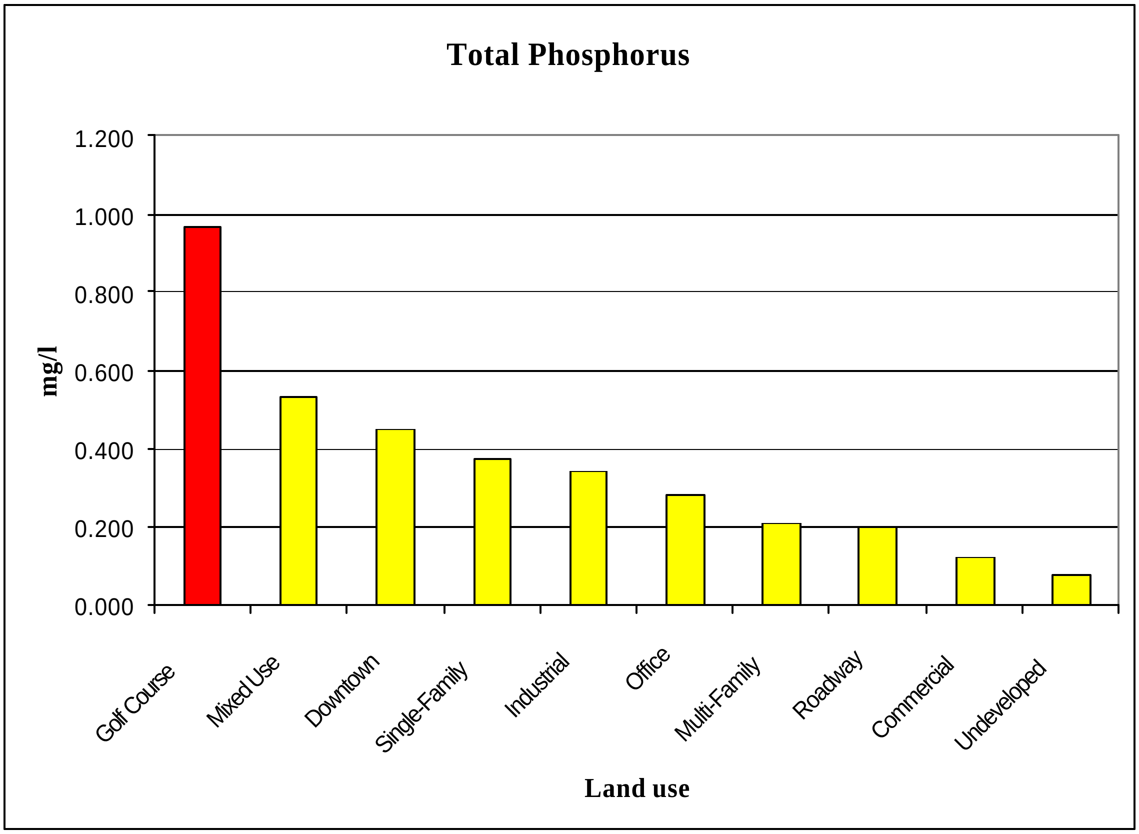

Figure 11: Total phosphorus concentrations in storm water runoff for various land uses.

Table 11: Total phosphorus concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Golf Course	0.968	52	a
Mixed Use	0.534	61	b
Downtown	0.452	107	bc
Single-Family	0.379	352	cd
Industrial	0.340	120	cd
Office	0.284	65	de
Multi-Family	0.212	47	ef
Roadway	0.200	61	f
Commercial	0.122	60	g
Undeveloped	0.079	111	h

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

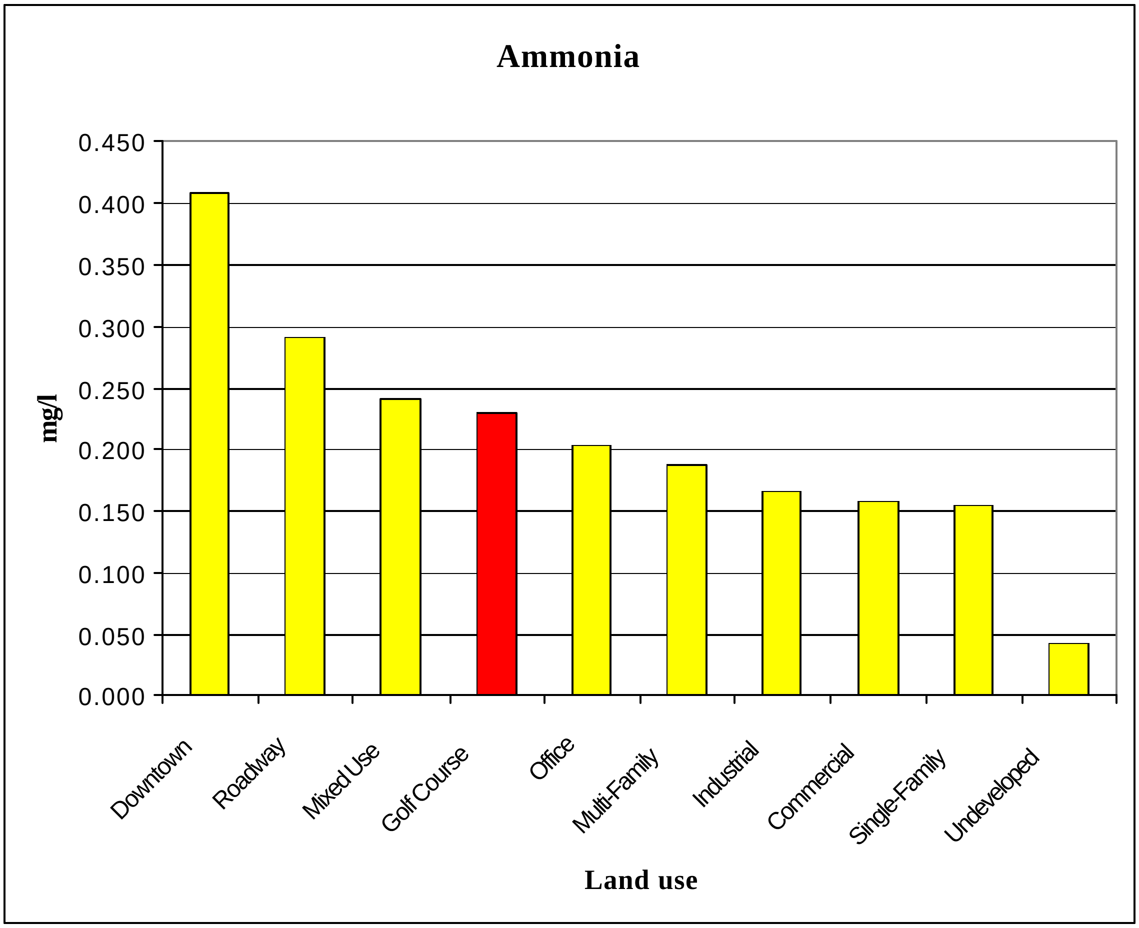

Figure 12: Ammonia concentrations in storm water runoff for various land uses.

Table 12: Ammonia concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Downtown	0.410	98	a
Roadway	0.291	47	b
Mixed Use	0.242	58	bc
Golf Course	0.229	51	bcd
Office	0.203	63	cde
Multi-Family	0.188	43	cde
Industrial	0.166	118	ed
Commercial	0.157	62	e
Single-Family	0.154	340	e
Undeveloped	0.042	111	f

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

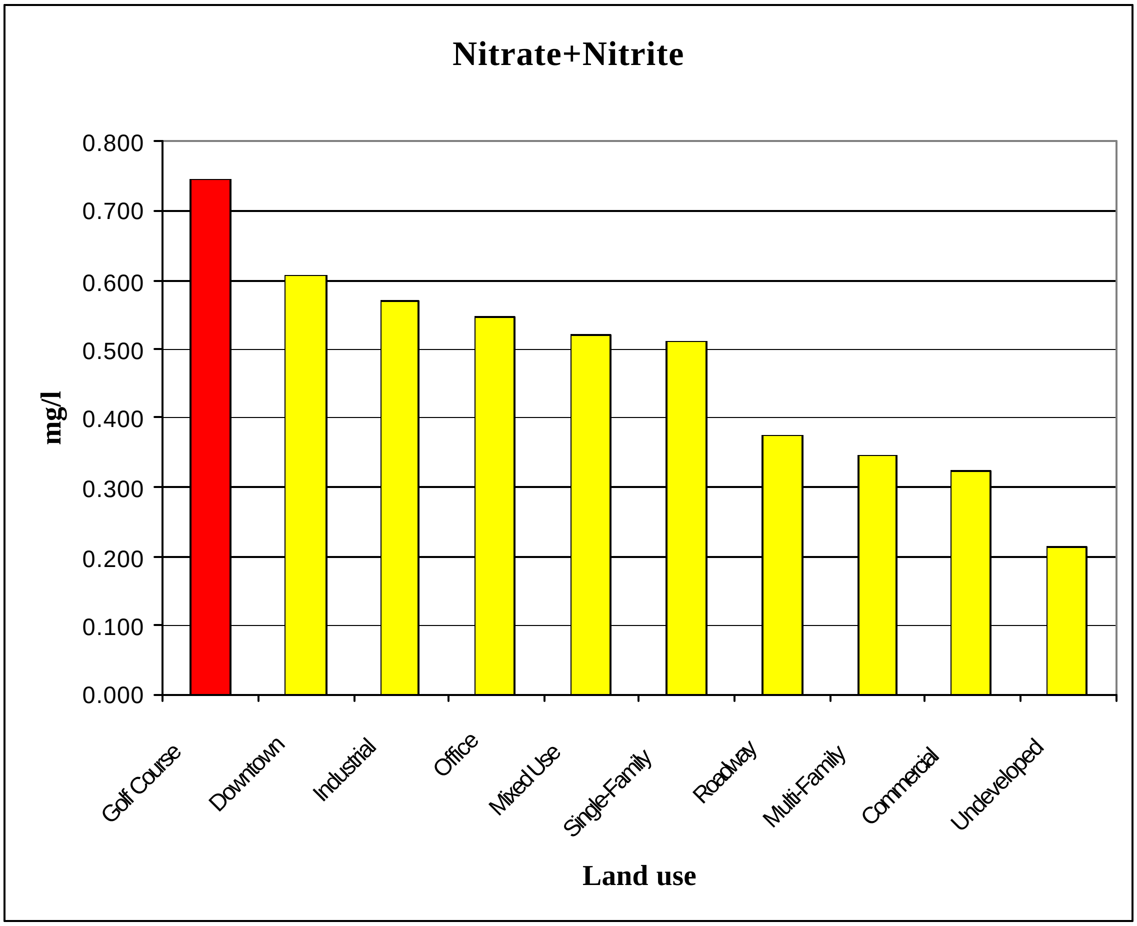

Figure 13: Nitrate+Nitrite concentrations in storm water runoff for various land uses.

Table 13: Nitrate+Nitrite concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Golf Course	0.745	51	a
Downtown	0.607	103	ab
Industrial	0.569	121	b
Office	0.546	64	b
Mixed Use	0.521	61	b
Single-Family	0.510	351	b
Roadway	0.375	60	c
Multi-Family	0.344	45	c
Commercial	0.324	62	c
Undeveloped	0.215	112	d

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

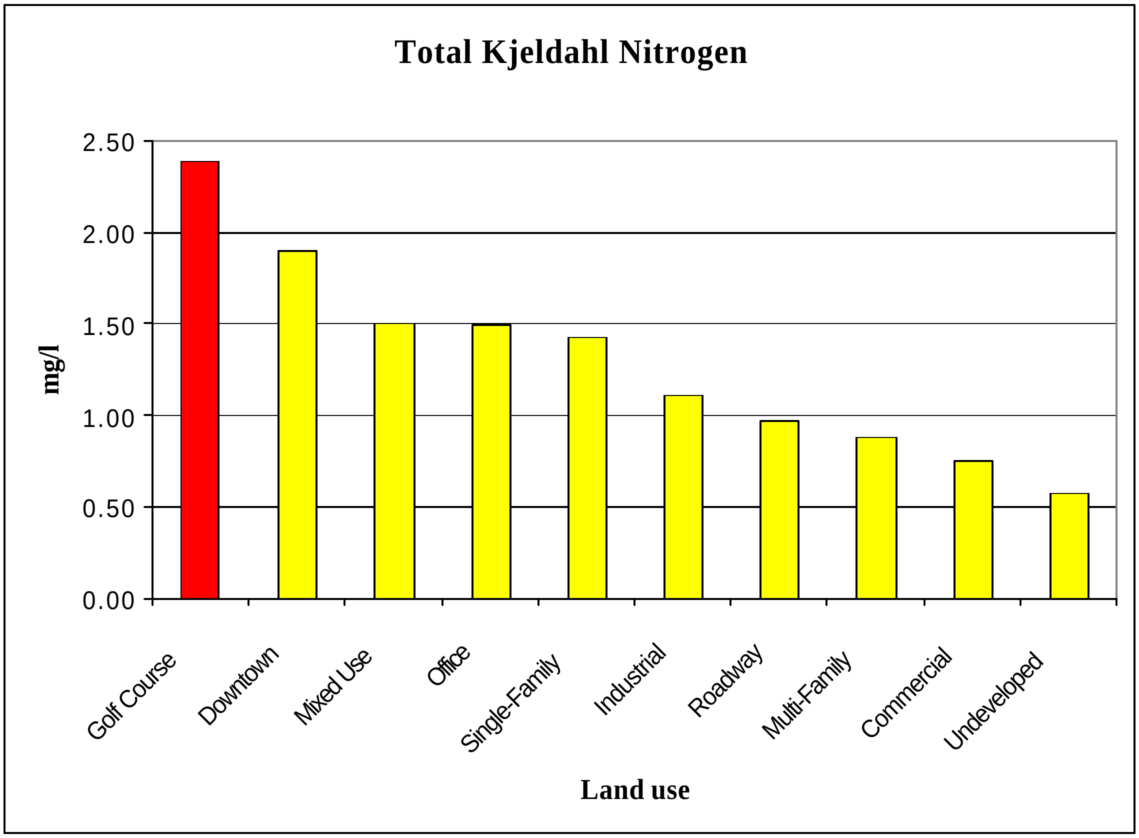

Figure 14: Total Kjeldahl nitrogen concentrations in storm water runoff for various land uses.

Table 14: Total Kjeldahl nitrogen concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Golf Course	2.38	51	a
Downtown	1.90	106	ab
Mixed Use	1.50	61	b
Office	1.50	65	b
Single-Family	1.43	354	bc
Industrial	1.11	123	dc
Roadway	0.97	59	de
Multi-Family	0.88	46	de
Commercial	0.75	58	ef
Undeveloped	0.58	111	f

* Land uses with a grouping letter in common are not significantly different at the 0.05 level.

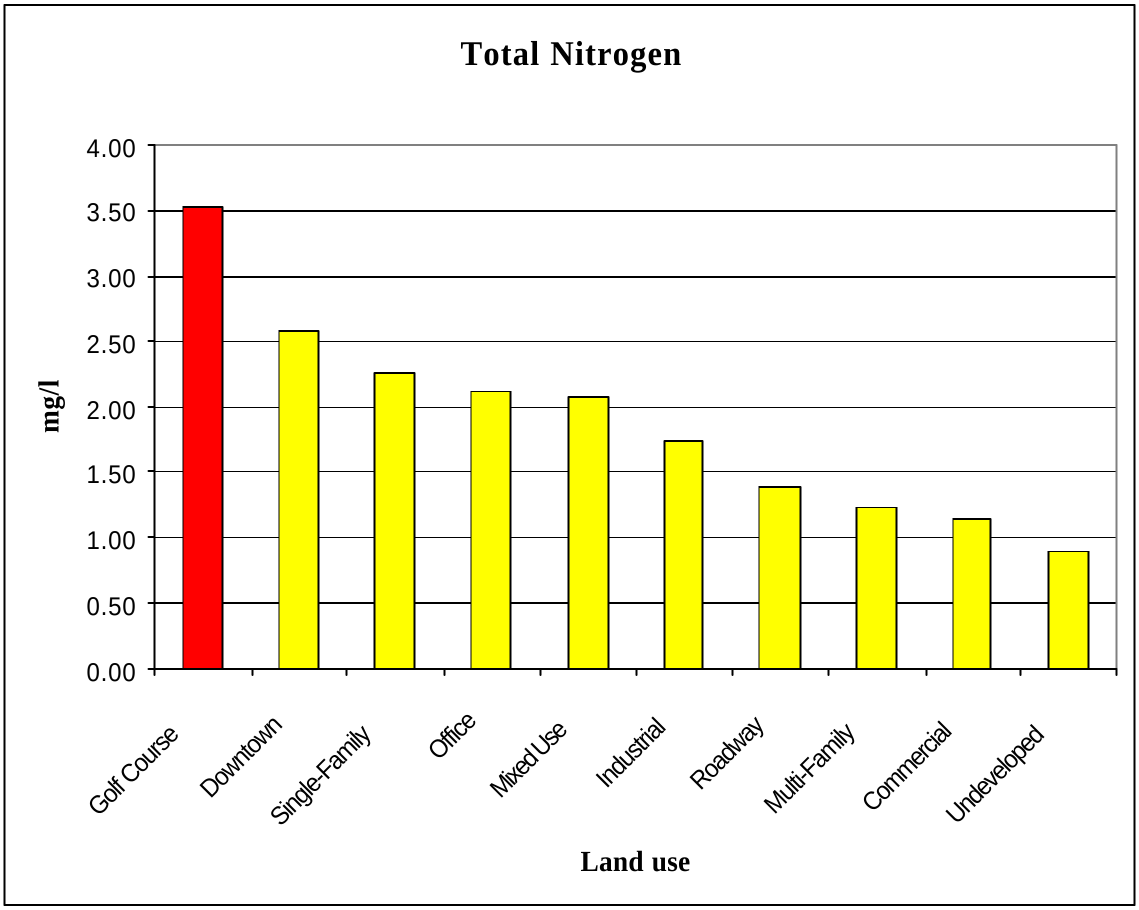

Figure 15: Total nitrogen concentrations in storm water runoff for various land uses.

Table 15: Total nitrogen concentrations in storm water runoff for various land uses. Result shows geometric mean for all events in that land use class.

Land Use	Geometric Mean (mg/l)	Number of Events	Grouping
Golf Course	3.53	51	a
Downtown	2.58	102	b
Single-Family	2.26	320	b
Office	2.12	64	bc
Mixed Use	2.08	61	bc
Industrial	1.74	120	cd
Roadway	1.40	57	de
Multi-Family	1.23	43	e
Commercial	1.14	58	e
Undeveloped	0.89	109	f

- Land uses with a grouping letter in common are not significantly different at the 0.05 level.

Table 16: Storm and baseflow nutrient concentrations in Barton Creek at State Highway 71 and Lost Creek Boulevard.

Pollutant	Barton Creek @ State Highway 71		Barton Creek @ Lost Creek Blvd.	
	Storm Flow (mg/l)	Baseflow (mg/l)	Storm Flow (mg/l)	Baseflow (mg/l)
Dissolved Ammonia	---	0.022	---	0.029
Total Ammonia	0.028	0.035	0.027	0.064
Total Nitrate	0.162	0.260	0.223	0.253
Dissolved Nitrate+Nitrite	---	0.074	---	0.115
Total Nitrate+Nitrite	---	0.099	---	0.221
Total Nitrogen	---	0.298	---	0.361
Dissolved OrthoP	---	0.016	---	0.017
Total OrthoP	---	0.025	---	0.025
Dissolved Phosphorus	0.033	0.031	0.037	0.034
Total Phosphorus	0.119	0.026	0.114	0.034
Total Kjeldahl Nitrogen	0.841	0.195	0.837	0.203

Table 17: Estimated annual loads from golf course, undeveloped and single-family land uses, lbs/acre/year.

Pollutant	Golf Course (Rv=0.06)	Golf Course (Rv=0.09)	Golf Course (Rv=0.12)	Undeveloped (Rv=0.06)	Single-Family (Rv=0.30)
Dissolved Phosphorus	3.20	4.81	6.41	0.14	3.86
Total Phosphorus	4.38	6.57	8.76	0.36	10.23
Ammonia	1.32	1.98	2.64	0.19	3.56
Nitrate+Nitrite	3.37	5.06	6.74	0.97	11.55
Total Kjeldahl Nitrogen	10.76	16.15	21.53	2.62	33.85
Total Nitrogen	15.99	23.98	31.97	4.01	47.96