

Rationale

Extent of turf: 50 million acres of turf in the U.S. (Morris, 2003)

Fact: “Turf is the most intensively managed system in the urban landscape” (Shuman et al. 2000; Smith and Bridges, 1996; Walker et al., 1990)

Knowledge gaps: very few peer-reviewed published studies



Rationale

Perception: “As green and lush as those yards and that course stay year round, nutrient and pesticide losses have to be greater than losses from farm lands.” (Delaware County Ohio Farmer) (Kohler et al. 2004; Shuman, 2002; Peacock, et al., 1996; Smith and Bridges, 1996; and Pratt, 1985)

Waco Herald Tribune (March 1, 2009) – “We never talk about one of the major problems with Lake Waco: golf courses. Golf courses use many times more organo-phosphate fertilizer and water than they need. Where does all this excess fertilizer end up? Lake Waco.” Nate Goldenberg, guest column

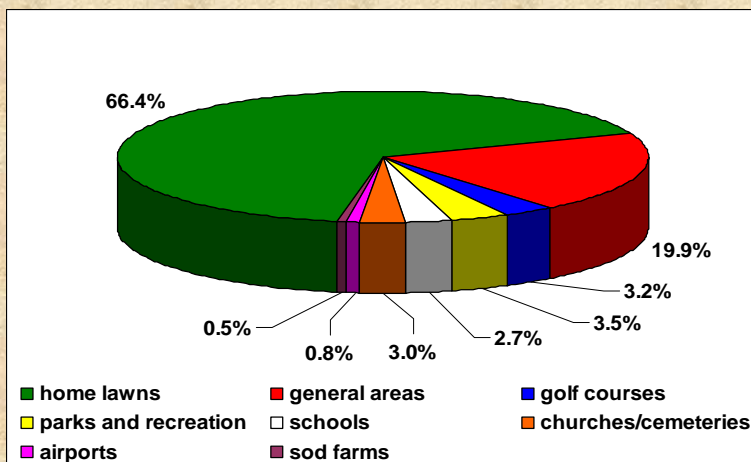


Turf/sod: managed surface layer of soil, grass plants, and the plant's matted roots

- Home lawns
- Roadsides
- Parks and recreation
- Golf courses
- Schools
- Sod farms
- Airports
- Cemeteries and churches
- Commercial property



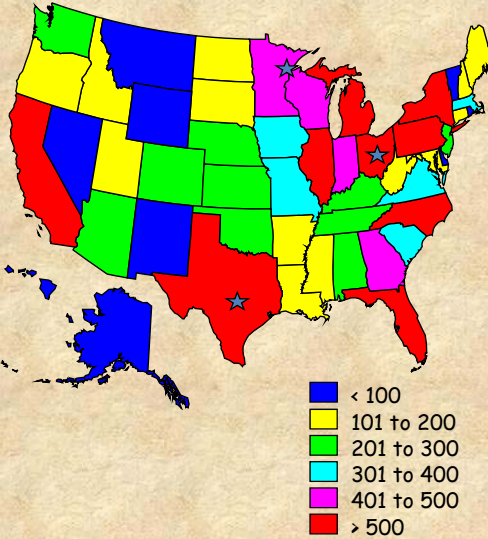
Where is the Turf?



Average percent allocation of turf based on statewide surveys from New York (New York Agricultural Statistics Service, 2004), Illinois (Preston, 2002), Virginia (Beddow et al. 2001), Iowa (Iowa Agricultural Statistics Service, 2001), Wisconsin (Wisconsin Agricultural Statistics Service, 2000), North Carolina (Phipps, 1999), Maryland (University of Maryland, 1996), Florida (Hodges et al., 1994), and Ohio (Sporleder et al. 1991). The general area description includes roadsides, commercial property, and municipal classifications.

Objective: Collect and Assemble Data Sets (Golf Course Turf)

- Austin, TX: Morris Williams Municipal Golf Course
 - 1998-2003
 - Hydrology, N, P
- Duluth, MN: Northland Country Club
 - 2003- present
 - Hydrology, Tile drainage, N, P, Pesticides, Sediment
- Columbus, OH: Royal American Golf Links
 - 2006-present
 - Hydrology, N, P, Pesticides, Sediment



(Source: National Golf Foundation, 2003)

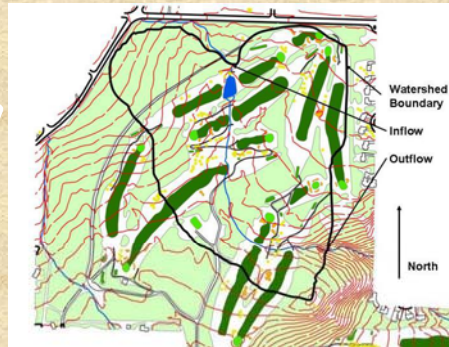
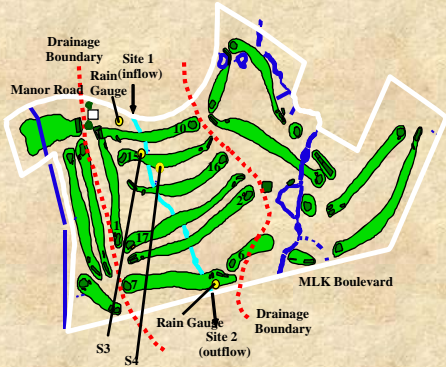
Turf Management (P inputs)

- 56% of 90 million homeowners apply fertilizer (Augustin, 2007)
- Fertilizers
 - 22 to 175 lbs elemental N/acre/year
 - phosphorus application rates are highly variable
 - Inorganic forms: 16-73 kg P₂O₅ /ha/yr (7-32 kg P ha/yr)
 - Organic forms: 39-122 kg P₂O₅ /ha/yr (17-54 kg P /ha/yr)
 - Atmospheric deposition
 - From precipitation: 0.15 kg/ha (Easton and Petrovic, 2008)
 - Wet and dry deposition: 0.77 kg /ha/yr (Jaworski et al., 1992)
- P input on suburban ecosystems: 2-10 kg/ha/yr (Soldat & Petrovic, 2008)



**Morris Williams
Municipal Golf
Course (Austin, TX)**

**Northland Country Club
(Duluth, MN)**



Site characteristics from two golf course watersheds, MWMGC and NCC.

	MWMGC (Austin, Texas)	NCC (Duluth, Minn.)
Grass	Tifdwarf 419 bermudagrass (<i>Cynodon dactylon</i> (L.) Pers × <i>C. transvaalensis</i> Burt-Davy)	Creeping bentgrass (<i>Agrostis palustris</i> Huds. <i>A. stolonifera</i> L.)
Climate		
Temperature	Avg. min (4°C); avg. max (35°C)	Avg. min (-9°C); avg. max (25°C)
Precipitation	810 mm	980 mm
Growing season	273 days	220 days
Management	Moderate	Moderate to intense
Area	29.0 ha	21.8 ha
Greens	0.7 ha (10 greens)	0.3 ha (8 greens)
Tees	0.3 ha (7 tees)	0.5 ha (8 tees)
Fairways/roughs	8.2 ha (7 fairways)	12.04 ha (8.5 fairways)
Open/grass areas	6.5 ha coastal bermudagrass (<i>C. dactylon</i> (L.) Pers)	--
Woodlands	13.24 ha scrub/live oak (<i>Quercus virginiana</i> (Mill.))	8.96 ha mixed northern hardwoods

Slopes
Elevation change



Soil mapping units, extent of coverage, and NRCS hydrologic soil group classification for soils located in the study areas of MWMGC and NCC.

Soil Mapping Unit	Dominant Texture	NRCS Hydrologic Soil Group	Extent of Unit (ha)	% of Total Area
MWMGC ()				
Black+ Urban, 1% to 3% slope	Gravelly clay	D	8.0	27.6
Travis + Urban, 1% to 8% slope	Gravelly loamy sand over sandy clay/sandy clay loam	C	21.0	72.4
NCC ()				
Barto-Geylsolon-Rock outcrop complex, 0% to 18% slope	Gravelly sandy loam	D	1.7	8.0
Sanborg-Badriver complex, 3% to 18% slope			20.1	92.0



Phosphorus Management

Annual average actual commercial phosphorus application rates

	MWMCG (Austin, TX)	NCC (Duluth, MN)
	kg ha ⁻¹ (lbs/1000ft ²)	kg ha ⁻¹ (lbs/1000ft ²)
greens	133.2 (2.7)	65.0 (1.33)
tees	32.0 (0.7)	77.8 (1.59)
fairways	16.0 (0.3)	52.8 (1.08)

Range of P application rates for home lawns

Inorganic forms: 16-73 kg P₂O₅ /ha/yr

Organic forms: 39-122 kg P₂O₅ /ha/yr



Instrumentation and Data Collection

MWMCG (Austin, TX)

- ISCO 6700 samplers (installed 1998)
- inflow and outflow points
- 15-minute continuous flow level
- Time composite samples during storm flow analyzed for $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and $\text{PO}_4\text{-P}$
- Weekly grab samples for base flow analyzed for $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, and $\text{PO}_4\text{-P}$

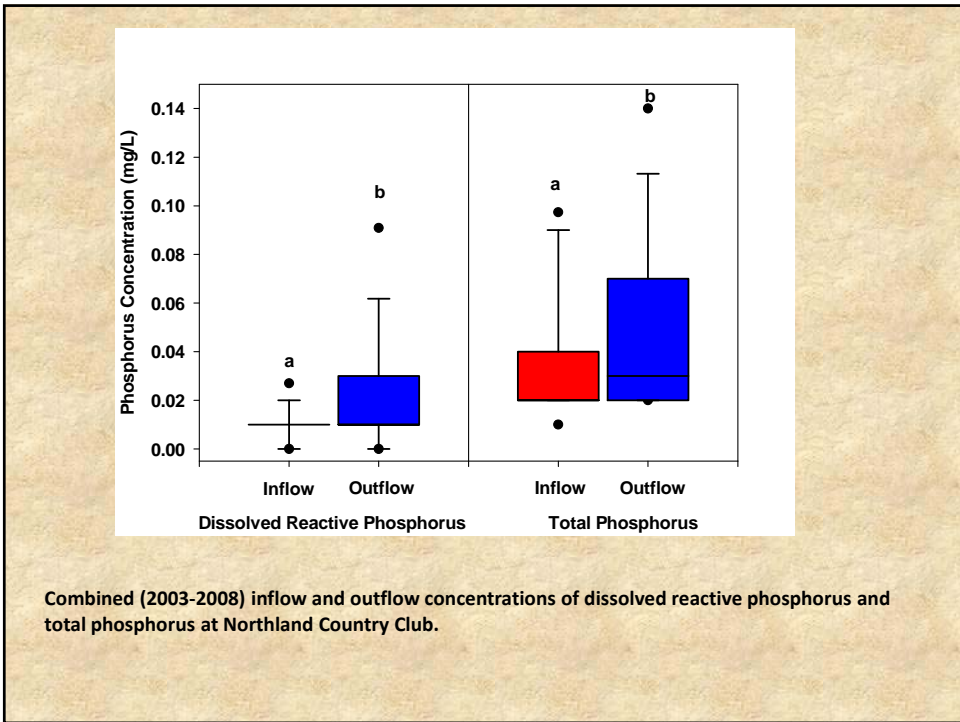
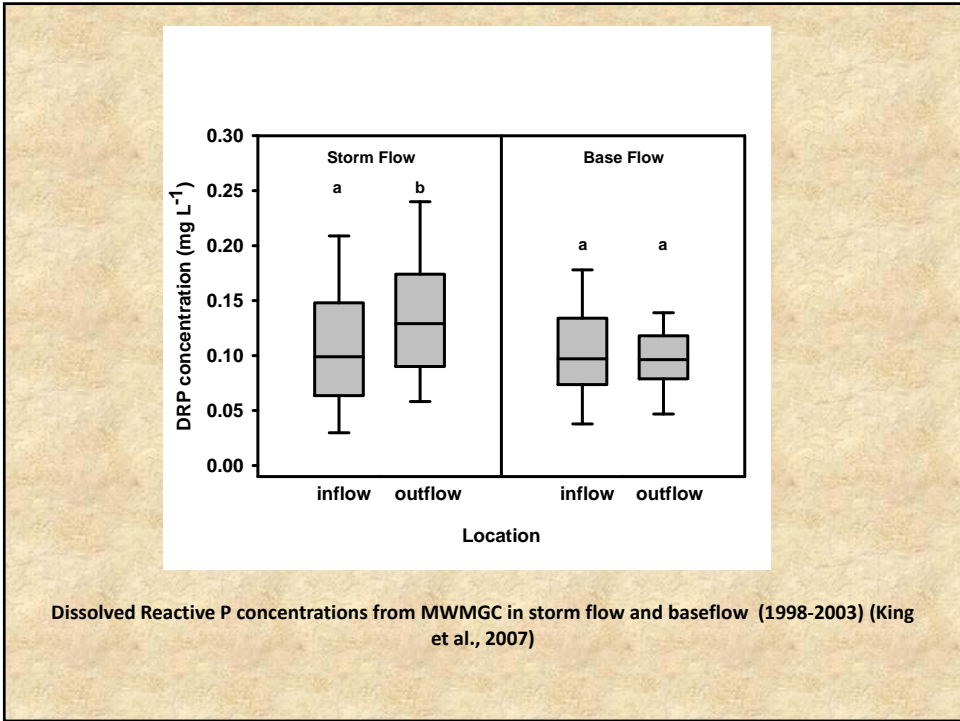


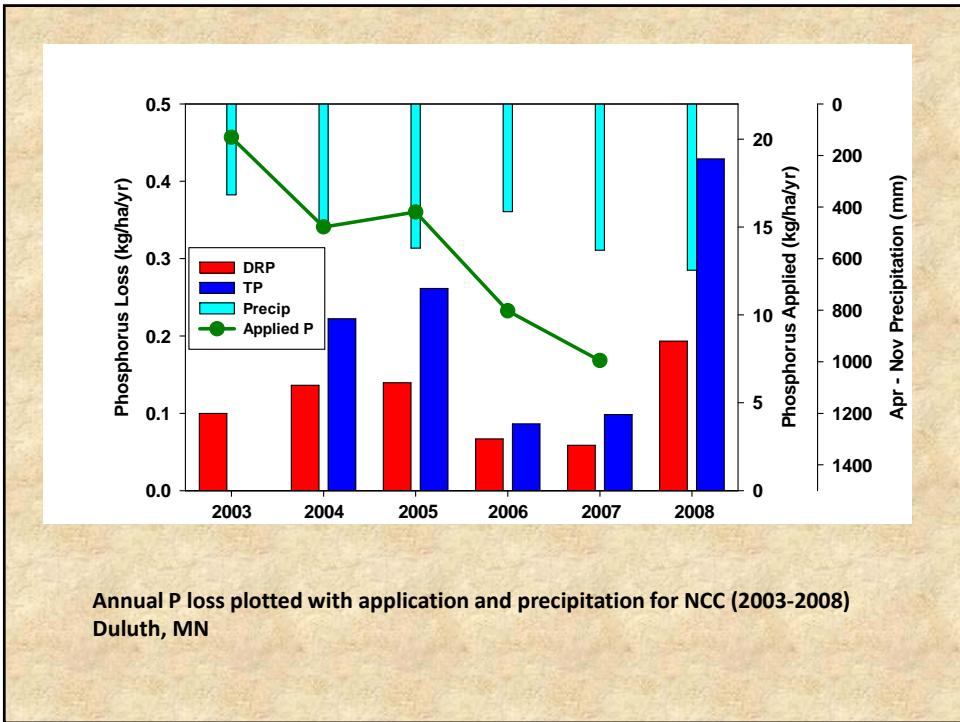
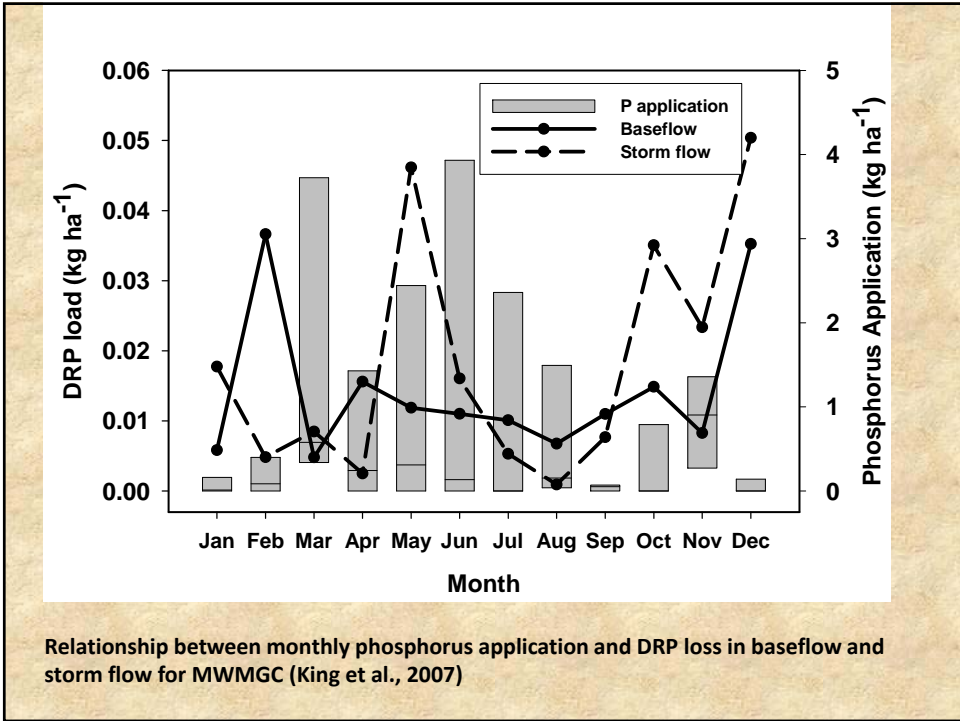
Instrumentation and Data Collection

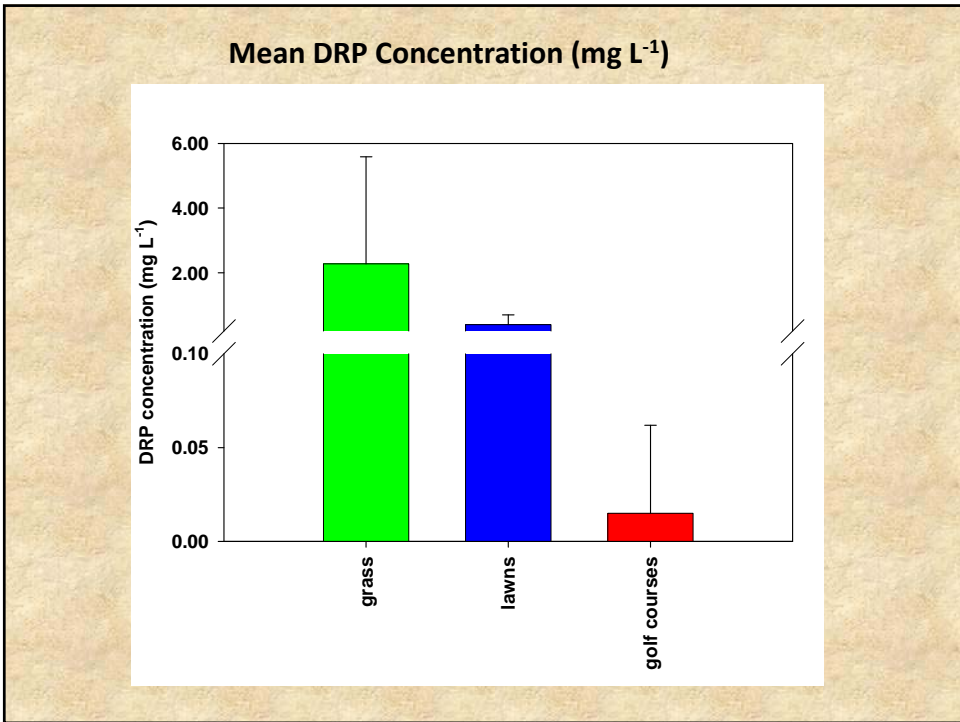
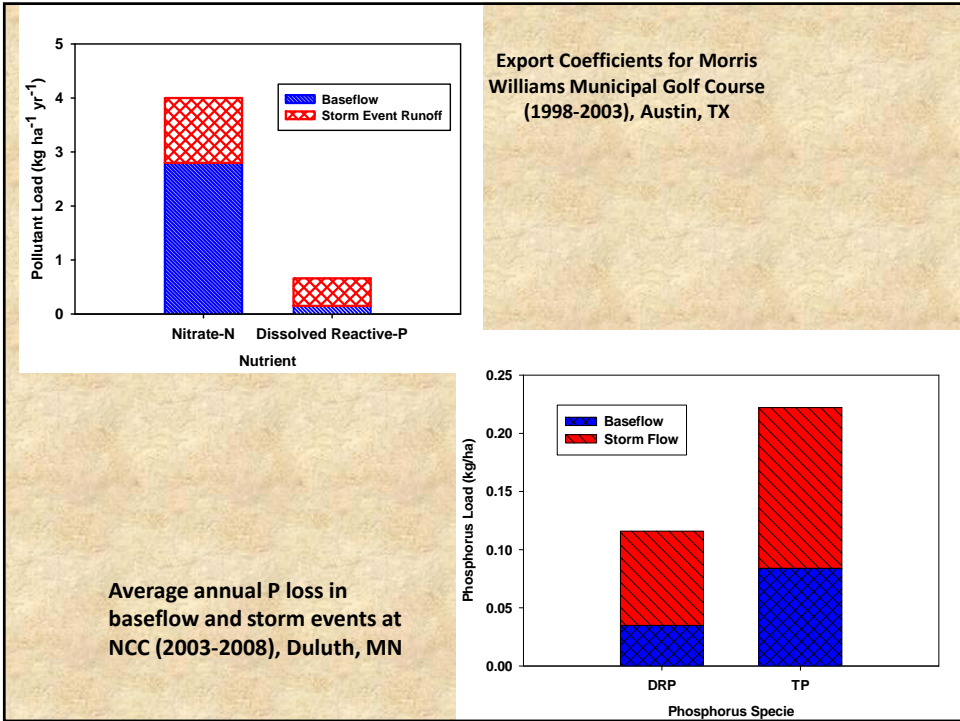
NCC (Duluth, MN)

- Surface (June 2002) and subsurface (April 2004)
- 3 ft H-flumes located at the inlet and outlet
- Flow metering inserts installed on subsurface tiles
- Isco 6712 automated water samplers w/ 4230 bubblers
- Discharge data collected on a 10-minute interval (base flow and storm flow)
- Water samples collected on a flow proportional basis and analyzed for $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$, TN, TP, and pesticides)
- Sampling period (April 15 to November 30)

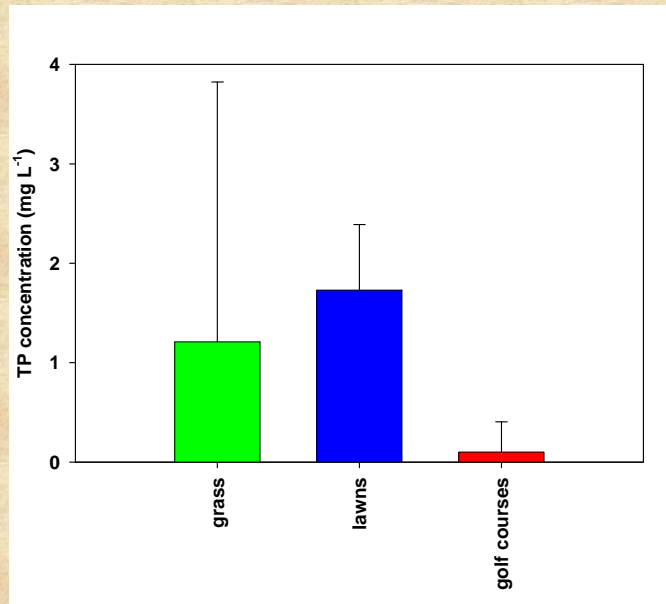




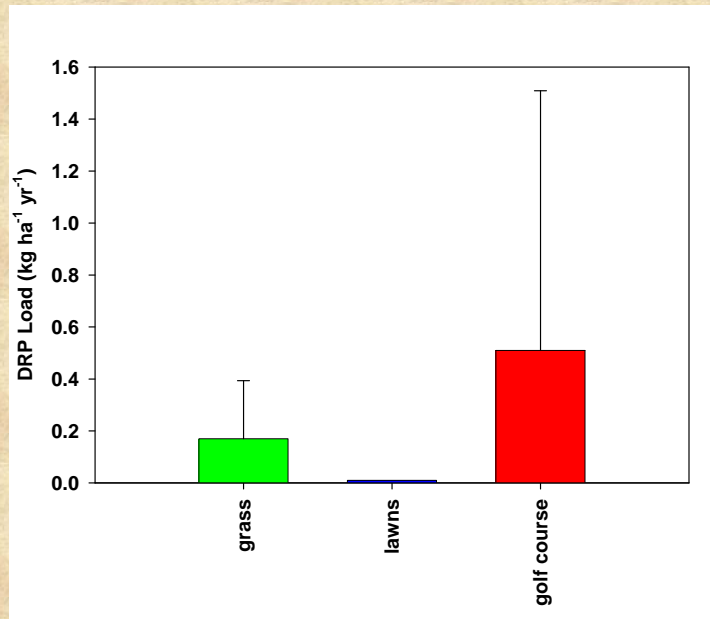




Mean TP Concentration (mg L⁻¹)



DRP Loads (kg ha⁻¹ yr⁻¹)



Best Management Practices

Fertilizer BMPs

post application irrigation (Shuman, 2004)
- 10% P reduction in runoff

slow release formulations (Easton and Petrovic, 2004; Quiroga-Garza et al, 2001)

graduated buffer height (Bell and Moss, 2005)
- 11% P reduction in runoff

incorporation (Pote et al., 2006)

wetlands (Reicher et al., 2005; Kohler et al., 2004)

buffer width (Cole et al., 1997)

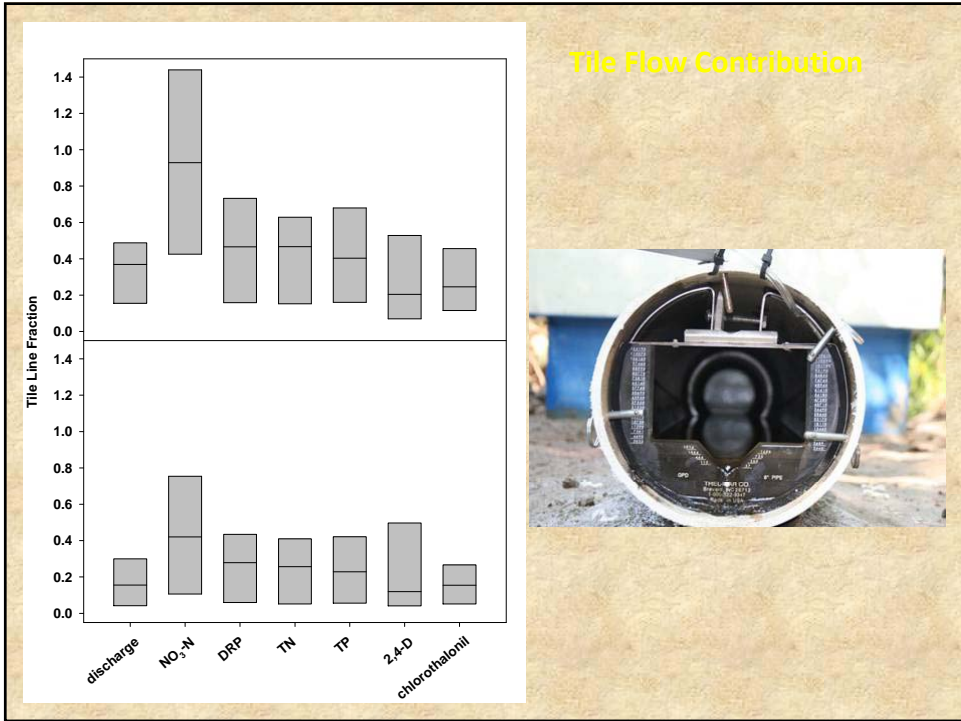
soil testing (Anderson et al., 1989)

filter cartridges on tile lines (King et al., unpublished)
- 58% reduction in DRP concentration



How do golf courses compare?

Reference	Land use	Area	DRP	TP	Duration	Study Location
			----- kg/ha/yr			
Timmons and Holt, 1977	Native prairie	89.6 m ²	0.02	0.11	5-yrs	Big Stone County, MN
Coulter et al. 2004	95% agriculture; 5% urban	327 ha	0.28	1.13	1 year	Fayette County, KY
	43% agriculture; 57% urban	506 ha	0.12	1.14		
	99% urban; 1% agriculture	226 ha	0.07	0.66		
Dennis, 1986	residential (43.4% lawns: 41% forest)	3.5 ha	---	1.4	8 events	Augusta, ME
	forest (97.3% forest: 2.2% lawns)	2.4 ha	---	0.2		
King et al. 2001	golf course: storm events	29 ha	0.3	---	22 events	Austin, TX
	golf course: baseflow		0.05	---	13 months	
Kunimatsu et al.	golf course	53 ha	1.6	3.04	2-years	Japan



Ridgewood CC: Waco, TX

