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

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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?

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)

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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 P$_2$O$_5$/ha/yr (7-32 kg P ha/yr)
    - Organic forms: 39-122 kg P$_2$O$_5$/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.

<table>
<thead>
<tr>
<th></th>
<th>MWMGC (Austin, Texas)</th>
<th>NCC (Duluth, Minn.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>Tifdwarf 419 bermudagrass (Cynodon dactylon (L.) Pers × C. transvaalensis Burtt-Davies)</td>
<td>Creeping bentgrass (Agrostis palustris Huds. × A. stolonifera L.)</td>
</tr>
<tr>
<td>Climate</td>
<td>Avg. min (4°C); avg. max (35°C)</td>
<td>Avg. min (-9°C); avg. max (25°C)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Precipitation</td>
<td>810 mm</td>
</tr>
<tr>
<td>Growing season</td>
<td></td>
<td>273 days</td>
</tr>
<tr>
<td>Management</td>
<td>Moderate</td>
<td>Moderate to intense</td>
</tr>
<tr>
<td>Area</td>
<td>29.0 ha</td>
<td>21.8 ha</td>
</tr>
<tr>
<td>Greens</td>
<td>0.7 ha (10 greens)</td>
<td>0.3 ha (8 greens)</td>
</tr>
<tr>
<td>Tees</td>
<td>0.3 ha (7 tees)</td>
<td>0.5 ha (8 tees)</td>
</tr>
<tr>
<td>Fairways/roughs</td>
<td>8.2 ha (7 fairways)</td>
<td>12.04 ha (8.5 fairways)</td>
</tr>
<tr>
<td>Open/grass areas</td>
<td>6.5 ha coastal bermudagrass (C. dactylon (L.) Pers</td>
<td>--</td>
</tr>
<tr>
<td>Woodlands</td>
<td>13.24 ha scrub/live oak (Quercus virginiana (Mill.))</td>
<td>8.96 ha mixed northern hardwoods</td>
</tr>
<tr>
<td>Slopes</td>
<td>Elevation change</td>
<td></td>
</tr>
</tbody>
</table>
Soil mapping units, extent of coverage, and NRCS hydrologic soil group classification for soils located in the study areas of MWMGC and NCC:

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

Phosphorus Management

Annual average actual commercial phosphorus application rates

<table>
<thead>
<tr>
<th></th>
<th>MWMCG (Austin, TX)</th>
<th>NCC ( Duluth, MN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg ha(^{-1}) (lbs/1000ft(^2))</td>
<td>kg ha(^{-1}) (lbs/1000ft(^2))</td>
</tr>
<tr>
<td>greens</td>
<td>133.2 (2.7)</td>
<td>65.0 (1.33)</td>
</tr>
<tr>
<td>tees</td>
<td>32.0 (0.7)</td>
<td>77.8 (1.59)</td>
</tr>
<tr>
<td>fairways</td>
<td>16.0 (0.3)</td>
<td>52.8 (1.08)</td>
</tr>
</tbody>
</table>

Range of P application rates for home lawns

Inorganic forms: 16-73 kg P\(_2\)O\(_5\) /ha/yr

Organic forms: 39-122 kg P\(_2\)O\(_5\) /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 NO$_3$-N, NH$_4$-N, and PO$_4$-P
- Weekly grab samples for base flow analyzed for NO$_3$-N, NH$_4$-N, and PO$_4$-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 NO$_3$-N, NH$_4$-N, PO$_4$-P, TN, TP, and pesticides
- Sampling period (April 15 to November 30)
Dissolved Reactive P concentrations from MWMGC in storm flow and baseflow (1998-2003) (King et al., 2007)

Relationship between monthly phosphorus application and DRP loss in baseflow and storm flow for MWMGC (King et al., 2007)

Annual P loss plotted with application and precipitation for NCC (2003-2008)
Duluth, MN
Export Coefficients for Morris Williams Municipal Golf Course (1998-2003), Austin, TX

Average annual P loss in baseflow and storm events at NCC (2003-2008), Duluth, MN

Mean DRP Concentration (mg L⁻¹)
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

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How do golf courses compare?

<table>
<thead>
<tr>
<th>Reference</th>
<th>Land use</th>
<th>Area</th>
<th>DRP</th>
<th>TP</th>
<th>Duration</th>
<th>Study Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timmons and Holt, 1977</td>
<td>Native prairie</td>
<td>89.6 m²</td>
<td>0.02</td>
<td>0.11</td>
<td>5-yrs</td>
<td>Big Stone County, MN</td>
</tr>
<tr>
<td>Coulter et al. 2004</td>
<td>95% agriculture; 5% urban</td>
<td>327 ha</td>
<td>0.28</td>
<td>1.13</td>
<td>1 year</td>
<td>Fayette County, KY</td>
</tr>
<tr>
<td></td>
<td>43% agriculture; 57% urban</td>
<td>506 ha</td>
<td>0.12</td>
<td>1.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>99% urban; 1% agriculture</td>
<td>226 ha</td>
<td>0.07</td>
<td>0.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dennis, 1986</td>
<td>residential (43.4% lawns: 41% forest)</td>
<td>3.5 ha</td>
<td>---</td>
<td>1.4</td>
<td>8 events</td>
<td>Augusta, ME</td>
</tr>
<tr>
<td></td>
<td>forest (97.3% forest: 2.2% lawns)</td>
<td>2.4 ha</td>
<td>---</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>King et al. 2001</td>
<td>golf course: storm events</td>
<td>29 ha</td>
<td>0.3</td>
<td>---</td>
<td>22 events</td>
<td>Austin, TX</td>
</tr>
<tr>
<td></td>
<td>golf course: baseflow</td>
<td>0.05</td>
<td>---</td>
<td></td>
<td>13 months</td>
<td></td>
</tr>
<tr>
<td>Kunimatsu et al.</td>
<td>golf course</td>
<td>53 ha</td>
<td>1.6</td>
<td>3.04</td>
<td>2-years</td>
<td>Japan</td>
</tr>
</tbody>
</table>