# Biomass allocation of 40 wetland plants and predictions of functioning in stormwater management research facilities

Botany 670: Adaptive Restoration Lab
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This report consists of two parts,
the results of an experiment concerning biomass allocation of 40 native wetland plants and
recommendations for employing native species in stormwater management facilities.

Disclaimer: The data in this report were collected by many individuals, and investigator error was not evaluated. Some root weights were outliers, and we plan to re-test them for sediment residue and correct the database. For purposes of the Botany 670 class, however, we assume that patterns reported herein are those that were strong enough to outweigh variations caused by individual error. Note that conclusions drawn on a 4-month experiment might not hold for longer-term growth in field conditions. We encourage further research with these and additional native plant species.

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# Part 1: Biomass allocation of 40 wetland plant species

## Introduction

The University of Wisconsin, Madison, Arboretum has several opportunities to employ native wetland plants to reduce erosion and enhance infiltration in several proposed stormwater management facilities. Our objective is to recommend plants that could minimize erosion in and around stormwater conveyance channels and increase water infiltration in stormwater infiltration basins. Our investigation focuses on plant roots, which might anchor soil and/or create vertical channels for downward water flow.

Extant research on plant roots can be roughly divided into two categories: studies that address root architecture (i.e. the spatial arrangement and geometry of roots in the substrate) and studies that address root distribution (i.e. the presence or absence of roots by associated metrics) (Lynch 1995). Root characteristics have been investigated for only a limited number of species, and much of the work has taken place in laboratory settings, with few real-world applications. Our goal is to combine qualitative observations of root architecture with quantitative measures of root biomass to determine which species among 40 Wisconsin wetland natives might have utility in stormwater management.

Soil with living plant roots exhibits less erosion than soil devoid of roots (Mammo and Bubenzer, 2001), and plants with more roots resist uprooting better than those with few roots (Bailey et al., 2002). While ground cover (plant shoots) can also decrease erosion and sediment runoff, roots contribute the majority of these services (DeBaets et al., 2006; Zhou and Shangguan, 2007). Additionally, water infiltration into the soil increases linearly with root growth (Zhou and Shangguan, 2007).

Reduction of erosion due to roots is especially important in plantings with immature shoots, and root density can be increased by increasing seeding density (Gyssels and Poesen, 2003). Gyssels et al. (2005) described the quantitative effects of roots on erosion, finding that among existing papers, soil loss decreases exponentially with a linear increase in a general root “parameter”. In a more specific case, the most change in soil detachment was realized at relatively low root density and root length density, in keeping with the exponential nature of the relationship (DeBaets et al., 2006).

Studies in root architecture suggest several characteristics for selecting plants best suited for erosion control. DeBaets et al. (2007b) found that finely branched roots are more effective at reducing soil erosion than large roots, but did not differentiate between different modes of branching. They concluded that root density and diameter are the most relevant measures for assessing erosion control capabilities of different plants.

Some aspects of roots are changeable (exhibiting plasticity). Anderson et al. (2007) show that root diameter responds to soil texture and defoliation of above-ground plant structures. Dunbabin et al. (2004) conclude that plants growing in environments with a high, static nutrient input exhibit finer-scale nutrient exploration, greater morphological plasticity, and dichotomous (fine, highly branched) root morphology.

Because plants grown in the wild show greater erosion-reducing potential than laboratory-grown plants (Gyssels et al., 2005), we highlight experiments conducted in naturally occurring systems. In prairie systems, increases in root to shoot ratio are linked to decreases in the available nitrogen, and prairie species display a range of variation in root characteristics rather than division into discreet groups (Levang-Brilz and Biondini, 2003). Additionally, in floodway systems, vegetation distributes corresponding to discreet habitats that differ in microtopography and hydrology (Mallik et al., 2001). In their survey of Mediterranean vegetation, DeBaets et al. (2007a) found that shrubs surviving in areas with high erosion had higher root density than shrubs in areas with little erosion, and noted that plants with a dense mat of fine roots near the soil surface exhibited the most erosion-reducing potential.

Research on the erosion-reducing performance of plants with different rooting characteristics finds application in the design of stormwater control systems. We helped Josh Brown complete an experiment designed to guide the planting of a facility at the Arboretum that aims to support research on how best to manage stormwater. Previous discussions on facility design raised two key issues we address:

(1) the ability of groupings based on taxonomy and life history to predict functions such as root growth, and

(2) the effect of topsoil addition on plants, which DNR required as a "best management practice" (Thompson and Luthin, 2004).

By addressing these issues, we extend our purpose beyond academic inquiry to immediate application. First, we suggest that plant groups based on taxonomy and life history do not predict patterns of functioning (especially root growth). The plants we grew came from three taxonomic groups (grasses, non-grass graminoids, and forbs) and the later divided into two life-history groups (short-lived/colonizing forbs and long-lived perennial forbs), for a total of 4 groups and ten species per group. While plants are often classified into functional groups, generalizations are often inaccurate (Jaksic, 1981). Using several quantitative measurements of plant growth, we test our *a priori* groups for differences in functions.

Second, we suggest that topsoil addition is not beneficial and could even be harmful in stormwater conveyance channels. Nutrient additions can increase opportunities for invasion by *Typha* x *Glauca* and *Phalaris arundinacea* (Woo and Zedler, 2002; Kercher and Zedler, 2004) and increase shoot growth over root growth. We hypothesize that root:shoot ratios will decrease with topsoil addition. If so, plants grown with topsoil would be more susceptible to uprooting in the stormwater control facility during flood pulses.

# Methods

### *Species Selection and Planting*

Species were drawn from a list of native wetland species previously created (Botany 670 Class Report 2006), most of which had a coefficient of conservatism of 5 or lower (the more weedy species). Josh Brown planted seeds in the Botany Greenhouse during spring 2007 in shallow trays of germination medium. Of the 59 species planted, 40 (Table 1) germinated in large enough numbers to transplant into 12 replicate pots. Transplanting took place between July 6 and July 15, 2007, into 8-liter pots that were 43 cm tall and approximately 20 cm x 20 cm at the top and 15 cm x 15 cm at the base. They were then grown outdoors at the Arboretum Mesocosm Facility.

### *Experimental Design*

The microcosm experiment consisted of 480 pots divided into 2 treatments, subsoil and topsoil. The subsoil treatment was made by filling the large pots with a "subsoil" mixture of 75% sand and 25% topsoil (the latter taken from the planned stormwater channel site at Secret Pond). The topsoil treatment was made by filling the large pots with the subsoil mixture in the bottom 25 cm of the pot and adding 15 cm of 100% topsoil to the top of the pots. Each of the 40 species was planted in 12 pots, 6 replicates of the topsoil treatment pots and 6 replicates of the subsoil treatment pots (2x6x40). Once all the species were planted in their respective treatments, the

480 pots were randomly assigned to one of 30 tables, each with a total of 16 pots. The pots remained in this placement throughout the experiment.

### *Plant Growth*

The experiment ran from July 6, 2007 until November 4, 2007 (when the last plant was harvested). During that time period, the plants were exposed to natural environmental conditions. Each pot received roughly the same amount of rainwater, wind exposure, sunlight, and temperature. The pots were watered twice per day during the first 3 weeks in and then once per day except after significant rain events. Each pot was watered the same amount during daily watering.

### *Harvesting of Plants*

We harvested microcosms between September 23 and November 4, 2007. Each species was harvested within a week with the exception of some *Carex* pots (Table 2). We cut shoots at the soil level and placed the aboveground biomass into a paper bag for transport to campus for drying. We then tipped the pot upside down onto a wire screen tray. We pulled the pot was pulled up to expose the top 15 cm of soil, and cut it from the lower 25 cm using a serrated kitchen knife. We then poured the bottom 25 cm into a separate wire screen tray. We used spray hoses to wash soil and organic debris (present in the topsoil) away from the roots. We recorded the number of roots >1 mm diameter that extended past the 15 cm mark, then placed the root material from the top 15 cm of the pot into a separate paper bag. We handled the root material from the bottom 25 cm in the same way. We placed all bags into drying ovens set at 65ºC for at least 30 hours and recorded dry weight to the nearest 0.1 g.

*Statistical Analysis*

PC-Ord (v 5.08) was used to generate NMDS ordinations. All other statistical analyses were run using R 2.6.0 to (R Development Team 2007) identify significant differences between the soil treatments. Two-way ANOVA tests were performed to identify significant differences between subsoil and topsoil treatments and between functional groups for root:shoot ratio, total root mass, total shoot mass, total biomass, root mass in the top 6" of soil, and root mass in the bottom 12" of soil. Two-way ANOVA tests were also used to test for significant differences between the ten species with the highest and lowest average root:shoot ratio, shoot mass, and upper root:lower root ratio in subsoil. One-way ANOVA tests were performed to test for significant differences between treatments within an individual species for root:shoot ratio and shoot mass. A linear regression was used to identify significant relationships between shoot mass, standing height, and canopy diameter.

## Results

The harvested species varied greatly in their growth characteristics and their responses to topsoil. Average total biomass for a species ranged from 5.5 to 27.6 g when grown in subsoil and 6.7 to 94.7 g when grown in topsoil, with total dried biomass (mean ± Standard Error) of 15.3 g (±0.77) and 26.3 g (± 1.38), respectively. Species root:shoot ratios varied from 0.5 to 11.5 when grown in subsoil and 0.2 to 12.2 in topsoil, with averages of 3.7 (±0.19) and 3.0 (±0.18), respectively. The topsoil and subsoil treatments as a whole were significantly different in root:shoot ratio (ANOVA, $p = 0.008$). Individually, nine of the species had significantly greater root:shoot ratios in subsoil than in topsoil (ANOVA, $p < 0.05$) while only two of the species, *Penthorum sedoides* and *Elymus virginicus*, had greater root:shoot ratio in topsoil than in subsoil (Table 2).

The *a priori* groups (grasses, graminoids, short-lived forbs, and long-lived forbs) were not significantly different from one another in root:shoot ratio, except that graminoids differed from colonizing forbs (ANOVA-Tukey Post Hoc, $p = 0.02$). The groups did not differ from one other in total root mass or total shoot mass (ANOVA, Tukey Post Hoc, $p > 0.05$ for each relationship) (Figure 1).

An ordination (NMDS) of species based on the nine measured characters, shoot mass, total root mass, aboveground root mass, belowground root mass, root:shoot ratio, upper root:lower root ratio, aboveground relaxed height, aboveground stretched height, and aboveground canopy width included both the topsoil and subsoil treatment measurements for all 40 species. Neither showed any clear separation of groups by taxonomy, life history or otherwise.

Total biomass was significantly greater for plants grown in topsoil then those grown in subsoil (ANOVA, $p = 0.0001$) (Figure 2). Total root mass, root mass in the top 15 cm of soil, and root mass in the bottom 25 cm of soil were also significantly greater for species grown in topsoil than for those grown in subsoil (ANOVA, $p = 0.003, 0.003, 0.02, < 0.001$, respectively).

Plants grown in topsoil had significantly greater shoot mass than plants grown in subsoil (ANOVA, $p < 0.001$) (Figure 3). Twenty-one of the species had significantly greater shoot mass in topsoil than in subsoil (ANOVA, $p <0.05$). Shoot mass was significantly correlated with stretched height (cm) (Linear regression, $p < 0.001$, $R^2 = 0.37$) and canopy diameter (Linear regression, $p < 0.001$, $R^2 = 0.31$).

The ten species with the highest average root:shoot ratio (grown in subsoil) were significantly different from the ten species with the lowest average root:shoot ratio (ANOVA, $p < 0.001$) (Figure 4). The ten species with the highest average shoot mass and highest average upper root:lower root ratio were also significantly different from the ten species with the lowest average shoot mass and lowest average upper root:lower root ratio (ANOVA, $p < 0.001$ for each) (Figures 5 and 6).

Contrary to expectation, we found a negative correlation between harvest order and total dry biomass, although it was not a tight relationship (Linear regression, $m = -0.30$, $p < 0.001$, $R^2 = 0.055$) (Figure 7). If there were a positive relationship between biomass and length of growing period, it was masked by differences in total biomass among species.

## Discussion

Several findings suggest how data on shoot and root biomass can be used to predict native plant functioning in a stormwater conveyance channel

### *Functional Groups Should be Based on Tests of Function*

The four *a priori* groups, consisting of grasses, graminoids, short-lived forbs, and robust perennial forbs, did not form discrete functional groups. Using ANOVAs, we saw that these four groups showed no significant differences in total root or total shoot mass. The only significant difference was between the root:shoot ratio of colonizing forbs and graminoids (Figure 1). Even for those groups, variation was high, and several members of the two groups had near-identical root:shoot ratios. Some colonizing forbs and other species with low root:shoot ratios might be less able to control erosion in a stormwater conveyance channel than species with high root:shoot ratios. But we are uncertain of the generality of this prediction, since different substrates or hydrological condition could alter species' performances. The lack of strong, consistent differences between the grasses, graminoids, and long-lived forbs suggests that direct tests of function are needed to identify functional groups, rather than assuming that taxonomic relatiohships or structural attributes will consistently infer function. While groups based on taxonomy may share phylogenetic relations, and groups based on life history characteristics might share life spans, but these similarities do not necessarily lead to distinct functions in an ecosystem.

The Botany 670 class of 2006 suggested testing these four *a priori* groups in the planned stormwater channel. With our findings that these groups are not functioning differently in the microcosm study, we advise that the stormwater channel not be planted using these species' groups as primary test assemblages. Instead, we provide a separate list of species based on the data collected during the summer and fall of 2007 that group the species by erosion, infiltration, and light competition functional groups. Our group lists and suggestions for field (channel) experiments are found in Part 2.

Because the four *a priori* groups differed little in root:shoot ratio, we conclude that groupings based on taxonomy (grasses, graminoids, forbs) or life history (short- vs. long-lived forbs) have little predictive value for our purpose.

### *SubsoilTended to Increase Root:Shoot Ratios*

Because the native species are intended for planting on the base and banks of a stormwater conveyance channel, plants would need to have enough root biomass to hold the soil while preventing erosion and a small enough canopy biomass to not be at risk of a flood event uprooting the plant. Species with high root:shoot ratios should perform better. Of the 40 species, 23 species tended to have higher average root:shoot ratio in the subsoil treatment and 17 species had a higher root:shoot ratio in the topsoil treatment. Most of those trends were not significant, however. We found that 9 species with significantly higher root:shoot ratio in the subsoil treatment and only two (*Penthorum sedoides* and *Elymus virginicus*) with greater root:shoot ratio in the topsoil treatment (Table 2). We predict that more species will hold soil in a channel with subsoil at the surface than in a channel with topsoil added. Our findings are consistent with reports in the scientific literature, and data on our native species could help contractors argue against adding 15 cm of topsoil to the cleared land prior to planting experimental treatments. It could also help agencies reconsider requirements for adding topsoil. Without topsoil addition, projects would import fewer nutrients and fewer nutrients would leach from the soil and cause eutrophication problems in downstream waters.

### *Low Ratios of Upper Root:Lower Root Biomass Might Predict Infiltration*

Comparing upper root:lower root biomass, the 10 species with the highest ratio (*Mimulus ringens, Muhlenbergia mexicana, Aster simplex, Spartina pectinata, Veronicastrum virginicum, Verbena hastate, Penthorum sedoides, Poa palustris, Desmodium canadense,* and *Lobelia siphilitica*) differed significantly from the 10 species with the lowest ratio (*Panicum virgatum, Bidens frondosa, Agropyron trachycaulum, Aster puniceus, Lycopus americanus, Bidens cernua, Andropogon gerardii, Carex stricta, Helenium autumnale,* and *Elymus virginicus*measurement of biomass ratio describes species that have the majority of their root biomass in the top 15 cm of soil and those that have a similar amount of root biomass in the top and bottom soil profiles. A plant with a high upper root:lower root ratio (with a mean of ~6) could be best at preventing erosion, since surfaced roots have been shown to hold a larger amount of soil. Plants with a low upper root:lower root ratio (with a mean of ~1) have similar root mass near the surface and lower in the soil profile. That type of root distribution could be more effective in infiltrating stormwater, since large deep roots might create channels that extend deep into the ground. Infiltration is a valuable quality for stormwater facilities; any reduction in surface-water flow will decrease the nutrient influxes to downstream marshes and lakes (e.g, Lake Wingra in the Arboretum's Secret Pond site).

### *High Shoot Biomass Could Predict Increased Drag, and Potential for Light Competition*

Plants grown with in the topsoil treatment had an overall greater total biomass (root and shoot biomass) than those grown in the subsoil treatment and they had more total shoot biomass. We attribute these results to increased nutrients available to the plants in the 15 cm of topsoil. The amount of nutrients found in topsoil was likely much larger than that in the sandy subsoil, although we do not have those data yet. A plant that lacks an available nutrient pool will tend to generate a much larger root network and a smaller canopy, and plants with a ready pool of nutrients near the surface will send up more shoot biomass, instead of more roots (Ericsson, 1995). Plants with a larger shoot biomass would likely create greater drag and, when associated with lower root biomass, would allow stormwater to uproot plants. We thus recommend species with lower shoot biomass for stormwater conveyance channels.

The 10 with the lowest shoot biomass (*Juncus torreyi, Carex stricta, Scirpus cyperinus, Veronicastrum virginicum, Carex tribuloides, Elymus virginicus, Acorus calamus, Andropogon gerardii, Lobelia siphilitica,* and *Calamogrostis Canadensis*) might persist longer in the channel, based on performance during their first growing season. The 10 species with the highest shoot biomass will have the greatest chance of being pulled from the channel during its early years when they have not had a chance to develop a sound root system. On the other hand, these larger-canopy species may be more capable of competing with *Phalaris arundinacea*, an aggressive invasive species that grows tall rapidly and is currently present at the channel construction site. We predict that a native species with rapid height growth would have a better chance of outcompeting *P. arundinacea* for space and/or light, if it can stay rooted in the channel.

### *Further Analysis and Mesocosm Experiments are Needed*

While our work has generated many new findings, we recommend further analysis to understand the function of native plants as individuals as well as assemblages, including growing them under conditions similar to those of a stormwater conveyance channel. We suggest growing selected members of the list of 40 species individually in a mesocosm flume experiment to test our prediction that species with high root:shoot biomass will hold the soil better than those with low root:shoot ratios. We also suggest growing plants in mesocosms to test their ability to infiltrate water, expecting plants with a upper root:lower root ratio of around 1 to show increased infiltration compared to those plant species with a high ratio upper root:lower root biomass. For all further experiments, we suggest the use of the subsoil treatment only for its positive effect on root growth.

If the stormwater conveyance channel is constructed prior to summer 2008, the recommendations for testing species could be implemented in field test plots (cf. Part 2).

# Tables and Figures

Table 1**:** The 40 species planted, their common names, morphological/taxonomic groups, and the abbreviation used in each of the figures.

| **Common Name** | **Genus and Species** | **Abbreviation** | **Morphological/Taxonomic Group** |
|---|---|---|---|
| Slender Wheat | *Agropyron trachycaulum* | AGR TRA | Grasses |
| Big Bluestem | *Andropogon gerardii* | AND GER | Grasses |
| Blue Joint | *Calamagrostis canadensis* | CAL CAN | Grasses |
| Canada Rye | *Elymus canadensis* | ELY CAN | Grasses |
| Virginia Rye | *Elymus virginicus* | ELY VIR | Grasses |
| Fowl Manna | *Glyceria striata* | GLY STR | Grasses |
| Leafy Satin | *Muhlenbergia mexicana* | MUH MEX | Grasses |
| Switch Grass | *Panicum virgatum* | PAN VIR | Grasses |
| Fowl Blue | *Poa palustris* | POA PAL | Grasses |
| Cord Grass | *Spartina pectinata* | SPA PEC | Grasses |
| Sweet Flag | *Acorus calamus* | ACO CAL | Graminoids |
| Porcupine Sedge | *Carex hystericina* | CAR HYS | Graminoids |
| Lance Sedge | *Carex scoparia* | CAR SCO | Graminoids |
| Fox Sedge | *Carex stipata* | CAR STI | Graminoids |
| Tussock Sedge | *Carex stricta* | CAR STR | Graminoids |
| Awl Sedge | *Carex tribuloides* | CAR TRI | Graminoids |
| Barn Fox Sedge | *Carex vulpinoides* | CAR VUL | Graminoids |
| Torrey's Rush | *Juncus torreyi* | JUN TOR | Graminoids |
| Green Rush | *Scirpus atrovirens* | SCI ATR | Graminoids |
| Wool Grass | *Scirpus cyperinus* | SCI CYP | Graminoids |
| Swamp Aster | *Aster puniceus* | AST PUN | Colonizing Forbs |
| Panicled Aster | *Aster simplex* | AST SIM | Colonizing Forbs |
| Bur Marigold | *Bidens cernua* | BID CER | Colonizing Forbs |
| Beggar's Tick | *Bidens frondosa* | BID FRO | Colonizing Forbs |
| Yellow Avens | *Geum aleppicum* | GEU ALE | Colonizing Forbs |
| Sneezeweed | *Helenium autumnale* | HEL AUT | Colonizing Forbs |
| Blue Lobelia | *Lobelia siphilitica* | LOB SIP | Colonizing Forbs |
| Horehound | *Lycopus americanus* | LYC AME | Colonizing Forbs |
| Monkey Flower | *Mimuls ringens* | MIM RIN | Colonizing Forbs |
| Stonecrop | *Penthorum sedoides* | PEN SED | Colonizing Forbs |
| Blue Vervain | *Verbena hastate* | VER HAS | Colonizing Forbs |
| Marsh Milkweed | *Asclepias incarnata* | ASC INC | Robust Perennial Forbs |
| New England Aster | *Aster novae-angliae* | AST NOV | Robust Perennial Forbs |
| Showy Trefoil | *Desmodium canadense* | DES CAN | Robust Perennial Forbs |
| Joe Pye-Weed | *Eupatorium maculatum* | EUP MAC | Robust Perennial Forbs |
| Early Sunflower | *Heliopsis helianthroides* | HEL HEL | Robust Perennial Forbs |
| Black Eyed Susan | *Rudbeckia hirta* | RUD HIR | Robust Perennial Forbs |
| Grass Goldenrod | *Solidago graminifolia* | SOL GRA | Robust Perennial Forbs |
| Ironweed | Vernonia fasciculata | VER FAS | Robust Perennial Forbs |
| Culver's Root | Veronicastrum virginicum | VER VIR | Robust Perennial Forbs |

Table 2: The 11 species that were significantly different in root:shoot ratio based on a One-Way ANOVA test. The two species with significantly greater root:shoot ratios in topsoil are shown in bold.

| Species | Group | Abbreviation | Subsoil Mean | Topsoil Mean | p value |
|---|---|---|---:|---:|---|
| *Andropogon gerardii* | Grasses | AND GER | 11.559 | 4.883 | 0.002 |
| *Carex hystericina* | Graminoids | CAR HYS | 6.067 | 2.769 | 0.035 |
| *Carex stricta* | Graminoids | CAR STR | 9.671 | 2.393 | 0.002 |
| *Carex tribuloides* | Graminoids | CAR TRI | 7.642 | 1.993 | 0.005 |
| *Carex vulpinoides* | Graminoids | CAR VUL | 6.167 | 2.07 | 0.003 |
| ***Elymus virginicus*** | **Grasses** | **ELY VIR** | **2.77** | **12.919** | **0.015** |
| *Heliopsis helianthroides* | Robust Perennial Forb | HEL HEL | 6.828 | 3.505 | 0.024 |
| *Juncus torreyi* | Graminoids | JUN TOR | 4.344 | 1.718 | 0.010 |
| *Lycopus americanus* | Colonizing Forb | LYC AME | 4.888 | 2.689 | 0.032 |
| *Panicum virgatum* | Grasses | PAN VIR | 3.593 | 1.866 | 0.034 |
| ***Penthorum sedoides*** | **Colonizing Forb** | **PEN SED** | **3.369** | **4.141** | **0.036** |
| *Poa palustris* | Grasses | POA PAL | 4.573 | 1.663 | 0.046 |
| *Scirpus cyperinus* | Graminoids | SCI CYP | 3.68 | 2.836 | 0.035 |

Table 3: Order in which the species were harvested (see Methods).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | DES CAN | 11 | PEN SED | 21 | CAR STI | 31 | GLY STR |
| 2 | BID CER | 12 | SPA PEC | 22 | CAR TRI | 32 | JUN TOR |
| 3 | BID FRO | 13 | ACO CAL | 23 | SCI ATR | 33 | AST PUN |
| 4 | ASC INC | 14 | AGR TRA | 24 | PAN VIR | 34 | HEL HEL |
| 5 | RUD HIR | 15 | GEU ALE | 25 | EUP MAC | 35 | VER HAS |
| 6 | LYC AME | 16 | ELY CAN | 26 | POA PAL | 36 | SOL GRA |
| 7 | MIM RIN | 17 | CAR HYS | 27 | ELY VIR | 37 | VER VIR |
| 8 | MUH MEX | 18 | CAR SCO | 28 | AST NOV | 38 | SCI CYP |
| 9 | CAN CAN | 19 | CAR STR | 29 | AST SIM | 39 | VER FAS |
| 10 | AND GER | 20 | CAR VUL | 30 | HEL AUT | 40 | LOB SIP |

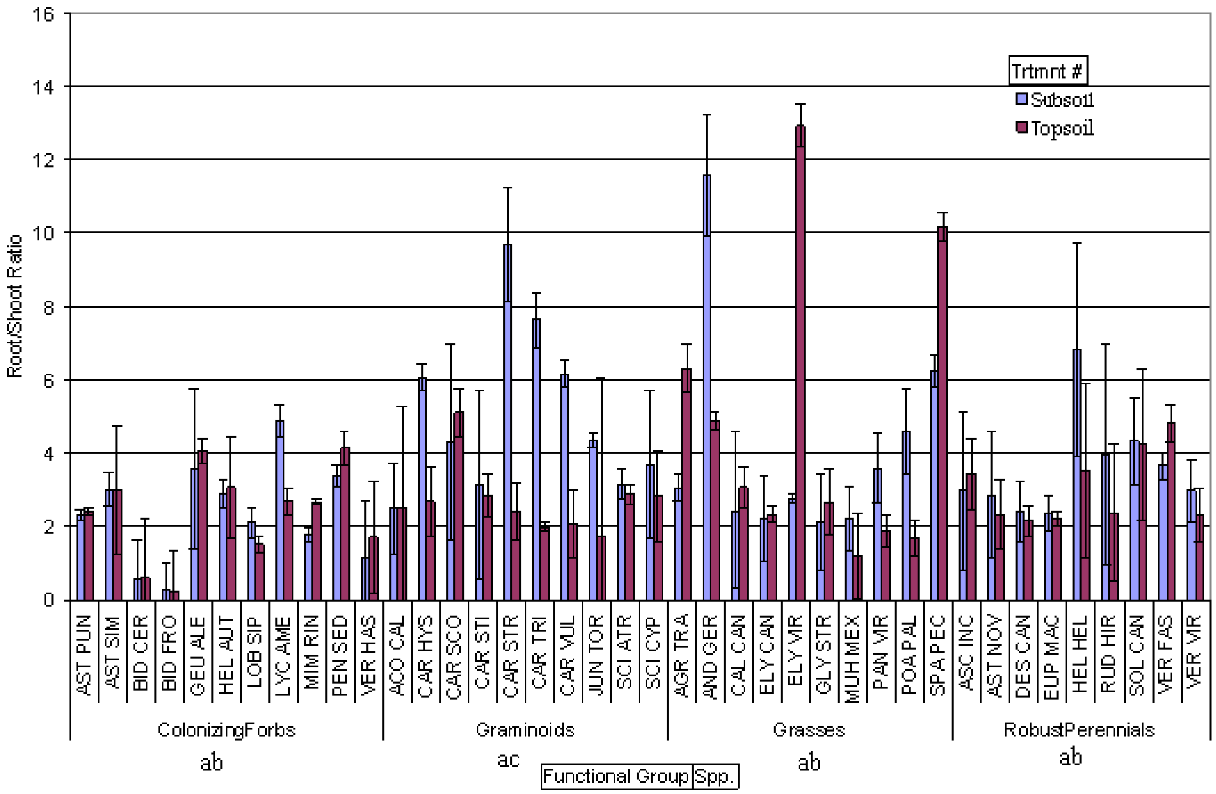


Figure 1: The topsoil and subsoil treatments as a whole were significantly different in root:shoot ratio (ANOVA, p = 0.008). The functional groups were not significantly different from one another in root:shoot ratio, except that graminoids differed from colonizing forbs (ANOVA, p = 0.02). Values presented are the averages of the replicates of each treatment. Error bars represent the standard deviation of the four to six replicates of each treatment for each species.

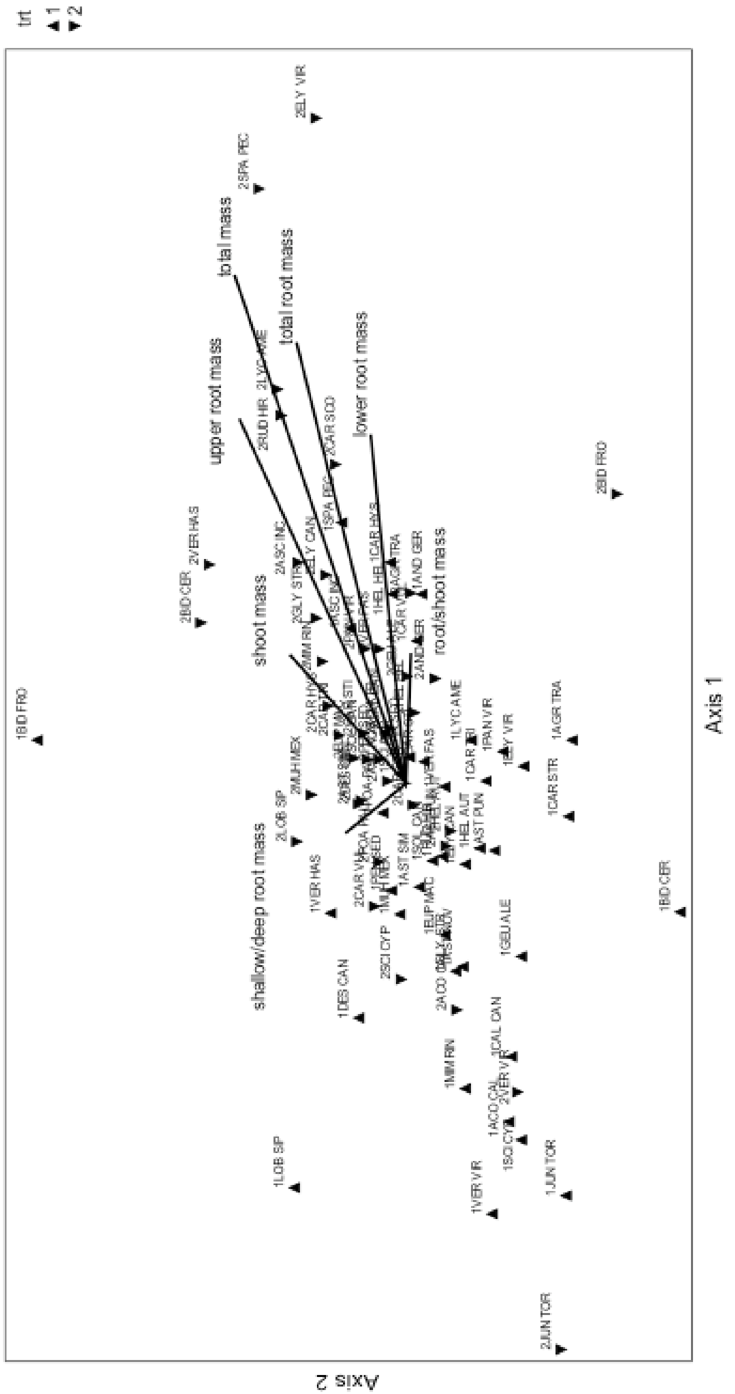


Plate 1: NMDS ordination of 40 species grown in subsoil (treatment 1, pyramid) and with topsoil (treatment 2, inverted pyramid). Species did not sort into clusters, although many species’positions shifted when grown with topsoil. Ordination performed by S. J. Hall.

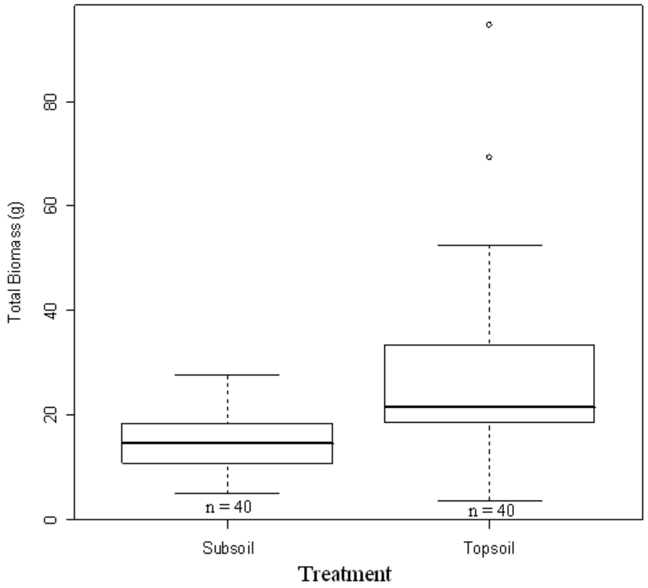


Figure 2: Total dry biomass (g) was significantly greater for plants grown in topsoil than in subsoil (ANOVA, $p < 0.001$).

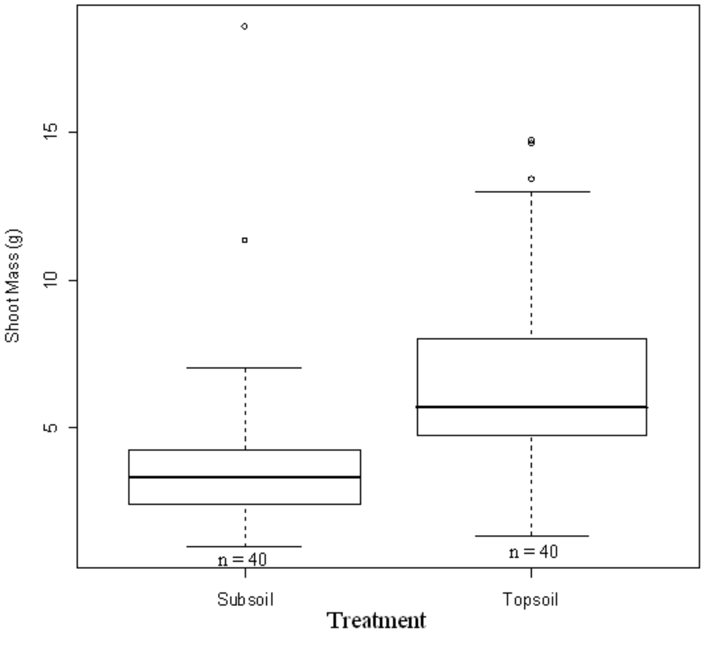


Figure 3: Plants grown in topsoil had significantly greater dry shoot mass than plants grown in subsoil (ANOVA, $p < 0.001$). Shoot mass (g) was significantly correlated with standing height (cm) (Linear regression, $p < 0.001$, $R^2 = 0.37$) and canopy diameter (cm) (Linear regression, $p < 0.001$, $R^2 = 0.31$).

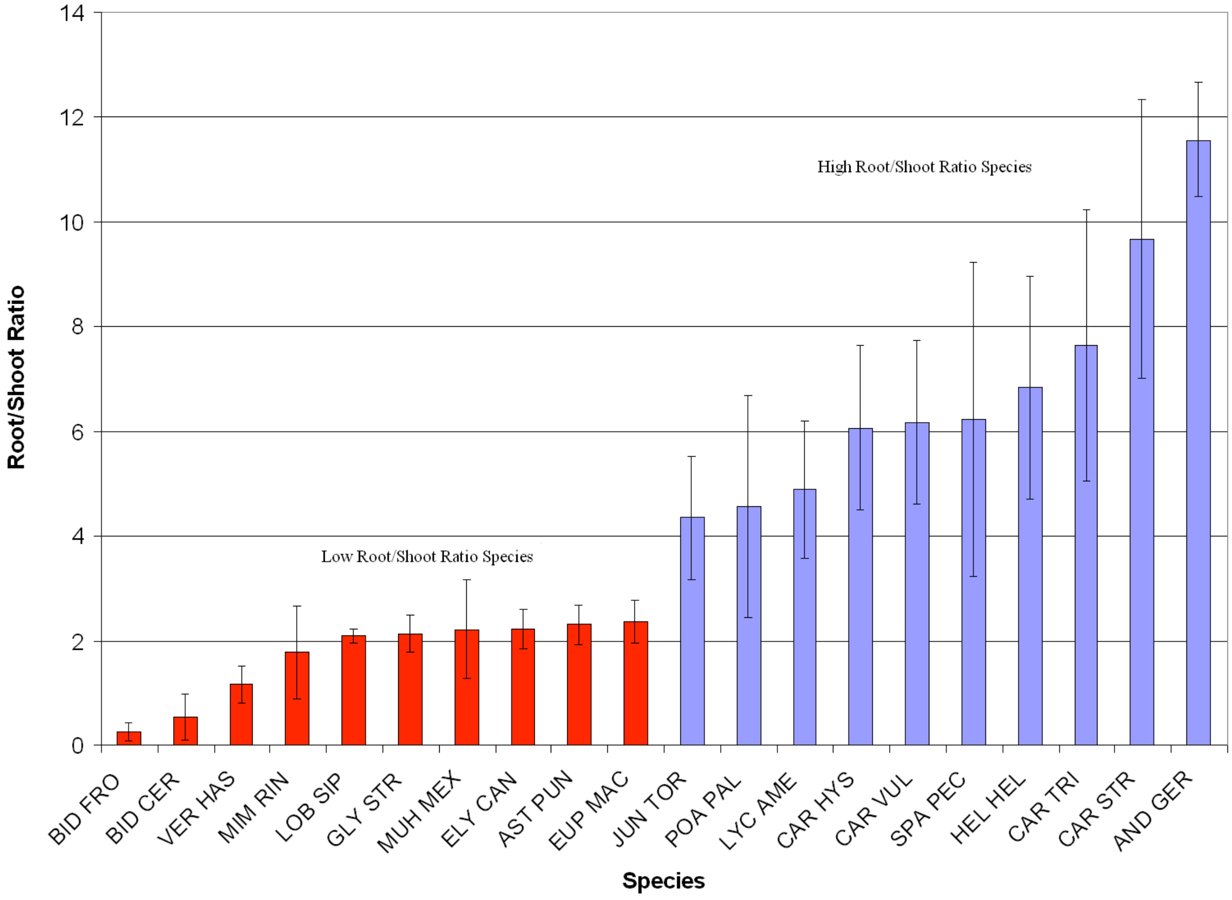


Figure 4: The ten species with the greatest average root:shoot ratio (grown in subsoil) were significantly different from the ten species with the lowest average root:shoot ratio (ANOVA, $p < 0.001$). We expect the high root:shoot ratio species to be most effective at erosion control and tolerance of rapidly flowing water pulses.

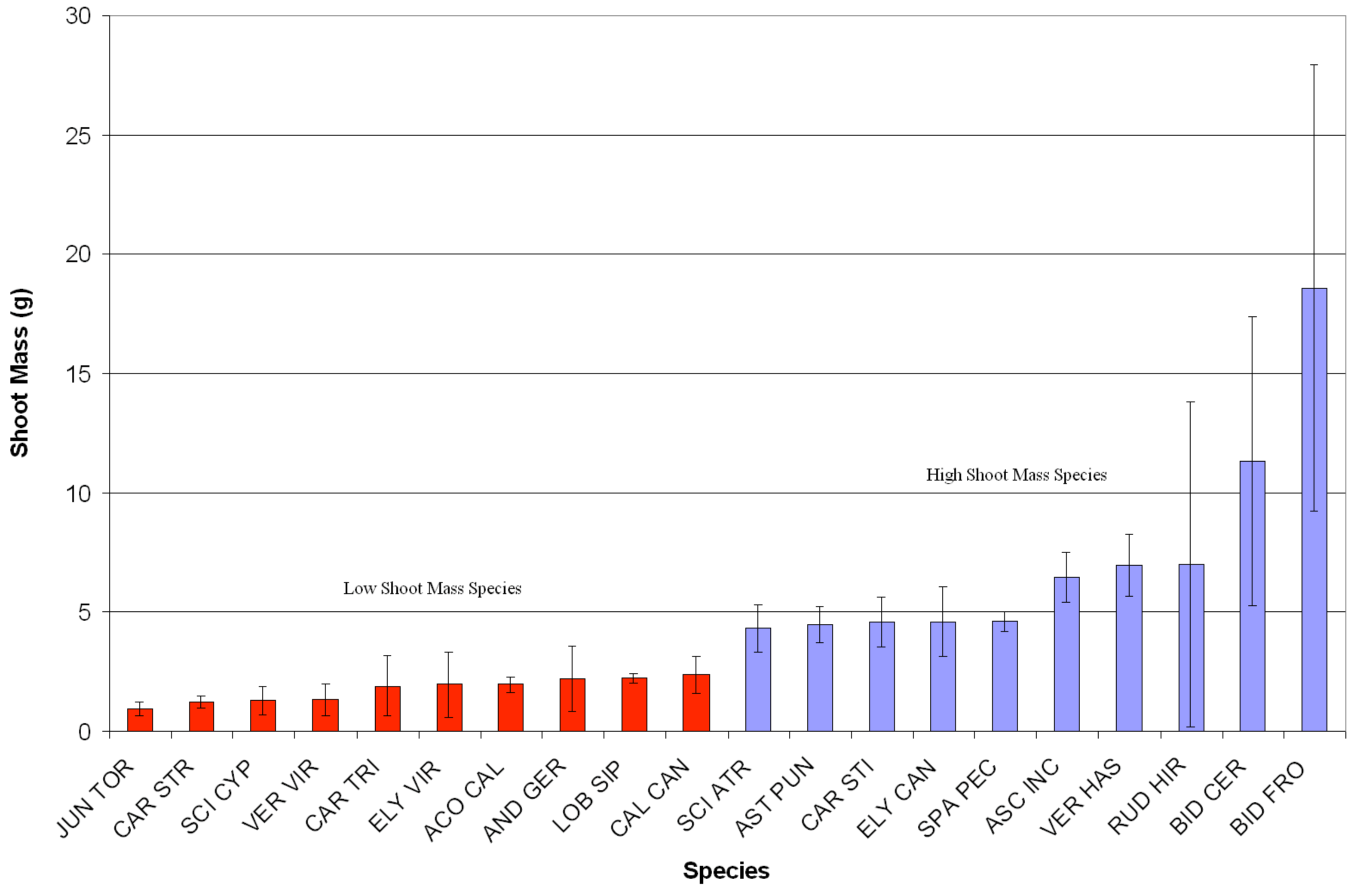


Figure 5: The ten species with the highest average shoot mass (grown in subsoil) were significantly different from the ten species with the lowest average shoot mass (ANOVA, $p < 0.001$).We expect those species with the greatest shoot mass to be competitive aboveground (i.e. when *Phalaris arundinacea* is present.)

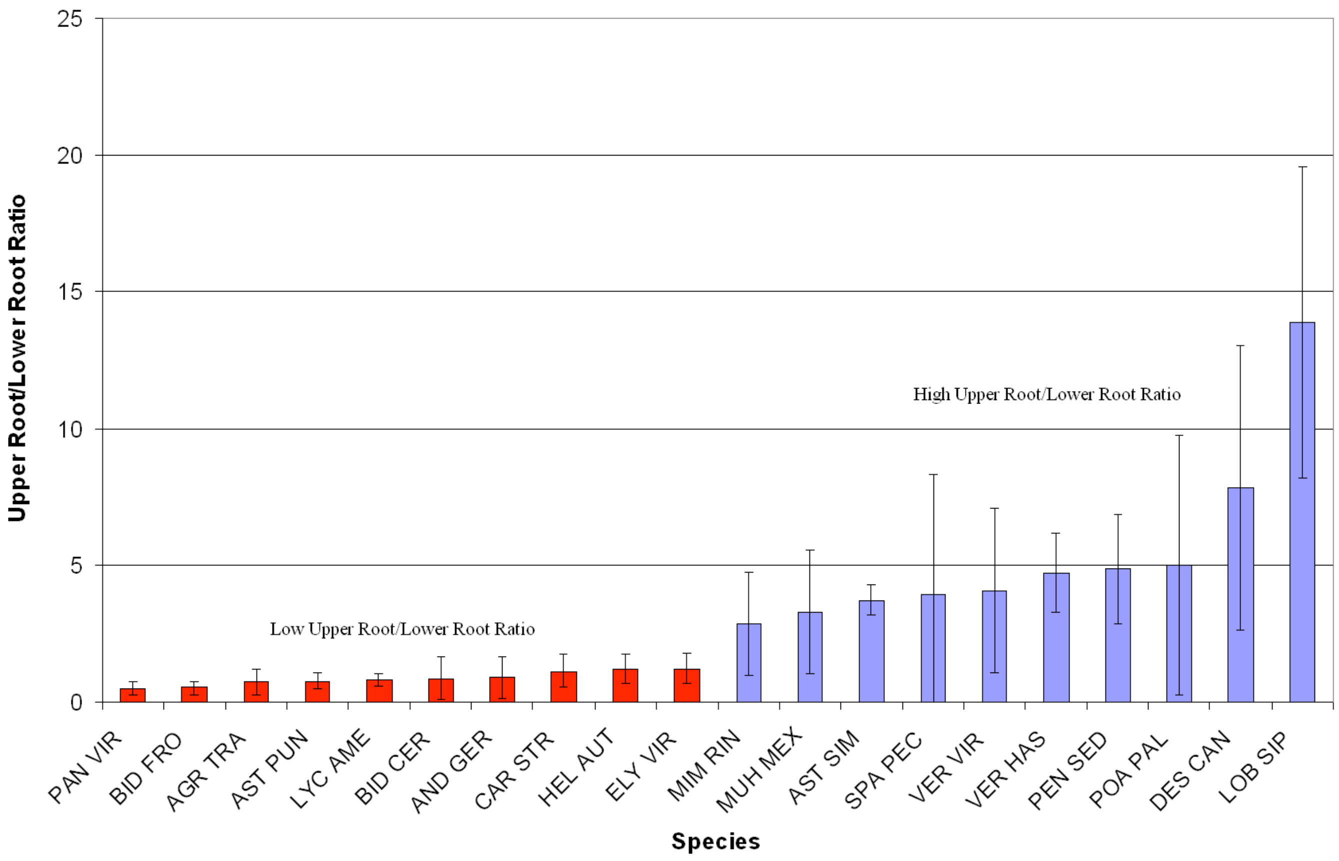


Figure 6: The ten species with the highest average upper root:lower root ratio (grown in subsoil) were significantly different from the ten species with the lowest average upper root/lower root ratio (ANOVA, $p < 0.001$). Those species with a high upper root:lower root ratio are considered better suited for erosion control, while those species with a low upper root:lower root ratio might be better suited to increase water infiltration.

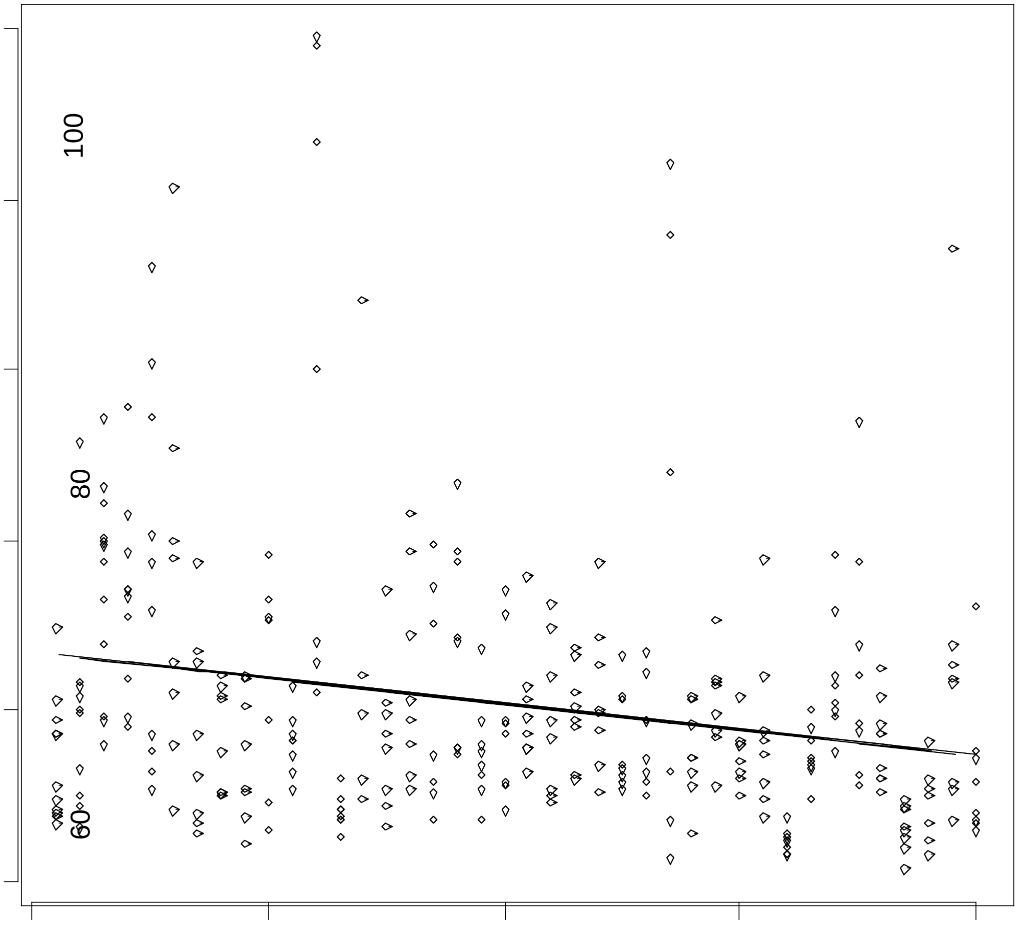


Figure 7: Total dry biomass was negatively correlated with the order of harvest (between 23 September and 4 November 2007), contrary to expectation (Linear regression, $m = -0.30$, $p < 0.001$, $R^2 = 0.055$).

# Part 2: Recommendations for employing native species in stormwater management facilities

## Introduction

With urbanization comes increased area of impermeable surfaces such as paved roads and buildings (Lee et al, 2006). At the same time, many wetlands are filled and built upon, reducing their ability to provide ecosystem services, such as flood protection and water filtering (Kohler et al, 2004). With more impervious surfaces and less natural flood protection, it becomes necessary to collect and treat stormwater in order to protect remaining wetlands and associated water bodies from excess nutrients (phosphorous and nitrogen), sediments, and pollutants (trash, metals, pesticides, oil, and other chemicals) (Hogan and Walbridge, 2007).

Stormwater management began with flood control and moved to include retention capability to reduce nutrient, sediment and toxin loading in waterways (Hogan and Walbridge, 2007). Techniques for reducing and managing stormwater include: porous pavement, belowground concrete or plastic chambers, infiltration trenches (rain gardens, grass swales), aboveground retention basins, dry and wet detention basins, and constructed wetlands (Hogan and Walbridge, 2007). Some of these are very small in scale (rain gardens); others are large (retention or detention basins). Small facilities can help, but large urban areas require more extensive stormwater management planning with two goals: First, temporarily store and infiltrate large amounts of water to alleviate flood pressures and reduce sedimentation and contamination in natural waterways. Second, utilize ideal plants achieve this goal (Bonilla-Warford and Zedler, 2002). Ideal plants should be robust, perennial, easy to propagate, have dense root and rhizomes, tolerate dry and wet periods, and be native (Bonilla-Warford and Zedler, 2002).

Early stormwater designs called for non-native or aggressive species, such as reed canary grass (*Phalaris arundinacea)*, cattails (*Typha* spp.*)*, bulrushes (*Scirpus* spp.) and sedges (*Eleocharis* spp.*)* (Lawrence and Breen, 1998; Bonilla-Warford and Zedler, 2002). Many of these species have invaded natural wetlands (especially *Phalaris)* by spreading vegetatively, tolerating both drought and flood conditions, and forming monospecific stands (Campbell and Ogden, 1999). Invasive species monotypes have limited habitat value and therefore are no longer considered ideal plants for stormwater management designs (Bonilla-Warford and Zedler, 2002).

Here we suggest further ways to test predictions in Part 1 by utilizing the recommended native plants in an actual stormwater facility where infiltration and erosion control can be measured. Three recommendations are given for experimental plantings in the Secret Pond Stormwater Management Research Facility (SMRF) at the Arboretum: one has six narrow channels, one has four channels, and one has a single wide channel. Our recommendations are not set in stone and can be modified or combined accordingly.

# Methods

Species recommended for planting were determined by ranking species for multiple characteristics that could contribute to achieving the specified ecosystem service. (1) For erosion control, we ranked species by average upper root mass, root:shoot ratio, and upper root:lower root ratio, which were than averaged overall for the final ranking based on all three categories. (2) For infiltration, we ranked species of their average lower root mass, root:shoot ratio, and lower root:upper root ratio, which were than averaged overall to obtain the final ranking based on all three categories. (3) For competitive ability, we ranked species on their total biomass and root:shoot ratio, which were than averaged to obtain a final ranking across both categories. (4) The average ranking without competition represents those species most and least likely to control erosion and enhance infiltration in the absence of competition. We calculated this from an average of the erosion control rankings and infiltration rankings.

# Results

Table 4: The native plant species (from a total of 40) most likely to provide erosion control and infiltration, with and without aggressive competitors, such as reed canary grass.

| Species | Erosion Control Ranking | Species | Infiltration Ranking | Species | Competitive Ranking | Species | Average Ranking Without Competition |
|---|---|---|---|---|---|---|---|
| SPA PEC | 4.33 | AND GER | 3.00 | AND GER | 2.50 | SPA PEC | 4.11 |
| POA PAL | 5.33 | LYC AME | 6.33 | SPA PEC | 3.00 | HEL HEL | 8.22 |
| CAR TRI | 9.33 | HEL HEL | 7.00 | HEL HEL | 3.50 | AND GER | 9.44 |
| HEL HEL | 11.00 | PAN VIR | 7.33 | CAR VUL | 6.00 | POA PAL | 9.44 |
| CAR SCO | 11.33 | CAR STR | 7.67 | RUD HIR | 7.50 | CAR VUL | 9.56 |
| PEN SED | 11.33 | CAR VUL | 9.33 | POA PAL | 10.00 | CAR TRI | 9.67 |
| CAR VUL | 12.00 | CAR HYS | 13.00 | CAR HYS | 10.00 | RUD HIR | 11.67 |
| SOL CAN | 12.33 | RUD HIR | 13.33 | LYC AME | 10.00 | CAR SCO | 12.44 |
| RUD HIR | 13.00 | VER FAS | 13.33 | CAR TRI | 10.50 | CAR HYS | 13.00 |
| CAR HYS | 13.33 | CAR STI | 13.67 | CAR SCO | 10.50 | ASC INC | 13.22 |
| ASC INC | 13.33 | AGR TRA | 13.67 | ASC INC | 14.00 | SOL CAN | 14.56 |
| AND GER | 13.67 | SPA PEC | 14.00 | CAR STR | 14.00 | CAR STR | 15.33 |
| AST SIM | 13.67 | CAR TRI | 15.33 | CAR STI | 14.00 | LYC AME | 16.22 |
| SCI ATR | 15.67 | HEL AUT | 15.33 | SCI ATR | 14.50 | PEN SED | 16.44 |
| DES CAN | 18.00 | AST PUN | 15.33 | VER FAS | 15.00 | SCI ATR | 16.78 |

Table 5: The species least likely to provide the specified goals.

| Species | Erosion Control Ranking | Species | Infiltration Ranking | Species | Competitive Ranking | Species | Average Ranking Without Competition |
|---|---|---|---|---|---|---|---|
| BID FRO | 39.67 | LOB SIP | 38.67 | LOB SIP | 36.00 | BID FRO | 36.44 |
| BID CER | 37.67 | VER HAS | 36.33 | MIM RIN | 35.50 | BID CER | 34.11 |
| AST PUN | 32.33 | DES CAN | 36.00 | ACO CAL | 32.50 | ELY VIR | 29.67 |
| ELY VIR | 32.00 | MUH MEX | 34.67 | GLY STR | 32.00 | ACO CAL | 28.89 |
| AGR TRA | 31.33 | MIM RIN | 33.67 | VER VIR | 31.50 | MIM RIN | 28.78 |
| CAL CAN | 28.67 | VER VIR | 32.00 | CAL CAN | 31.00 | CAL CAN | 28.56 |
| ELY CAN | 28.67 | GLY STR | 29.00 | ELY VIR | 31.00 | GLY STR | 27.89 |
| PAN VIR | 28.33 | PEN SED | 28.67 | DES CAN | 30.00 | AST PUN | 27.33 |
| ACO CAL | 28.00 | EUP MAC | 27.33 | MUH MEX | 29.50 | LOB SIP | 27.11 |
| HEL AUT | 27.33 | AST SIM | 27.00 | EUP MAC | 29.00 | AGR TRA | 27.00 |
| MIM RIN | 26.00 | ACO CAL | 26.33 | VER HAS | 28.50 | ELY CAN | 26.78 |
| GLY STR | 26.00 | AST NOV | 25.33 | BID CER | 27.50 | VER VIR | 25.56 |
| GEU ALE | 25.00 | JUN TOR | 24.67 | AST NOV | 27.00 | VER HAS | 25.56 |
| AST NOV | 24.00 | SCI CYP | 24.33 | ELY CAN | 27.00 | AST NOV | 25.33 |
| EUP MAC | 23.00 | CAL CAN | 24.33 | SCI CYP | 26.00 | MUH MEX | 25.33 |

# Suggestions for experimental plantings in stormwater conveyance channels

Several options for configuring the Secret Pond stormwater conveyance channel were discussed by Arboretum stakeholders during the course of our project. The earliest (Figure 8) was abandoned when the proposed stormwater pond (to be located downstream of the channel) was rejected for reasons of unstable underlying soil and excessive cost. Nevertheless, experimental plantings designed for the early channel were re-considered in light of findings in Part 1.

*Single Channel Suggestions*

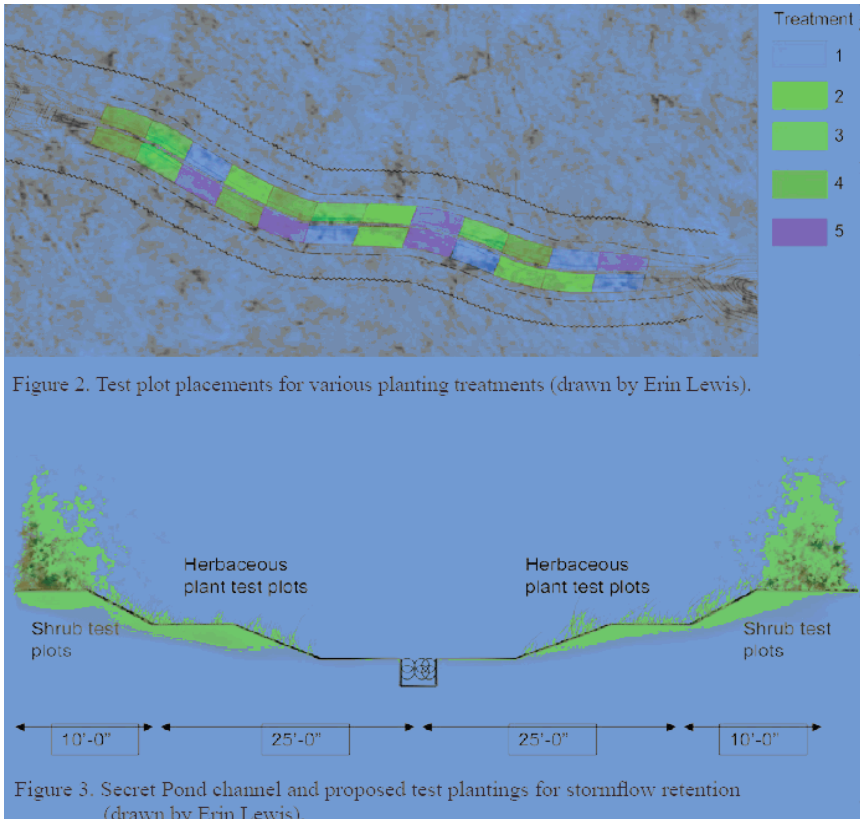


Figure 8: Secret Pond channel and proposed test plantings for storm-flow retention (drawn by Erin Lewis), taken from Zedler et al. (2006).

An early design of the Secret Pond stormwater control system consisted of single channel and re-excavation of Secret Pond to collect sediment entering the Arboretum at the Manitou Way outflow. Each side of the channel was to have been divided into a number of experimental plots for testing different planting treatments (Figure 8).

The single channel design is advantageous in a number of ways: the broader channel would direct water into a more sheet-wise flow and reduce down-cutting, reduced water speed could result in increased infiltration, and the broad channel would more closely resemble the historically-existing sedge meadow on the site. The single channel also has several drawbacks, however. In the single-channel design, there would be no way to prevent water flow to the channel for maintenance or planting. It would also be difficult to isolate treatments in a single-channel design. In contrast, a multiple-channel design could divert water in a number of ways to control flow (as an experimental variable), or to increase the ease of planting and maintenance by reducing or ceasing flow in one channel. Besides the functional and experimental requirements of the system, channel design is also constrained by budgets and location. If the project spills over into the adjacent wetland, additional permits could be required for certain designs.

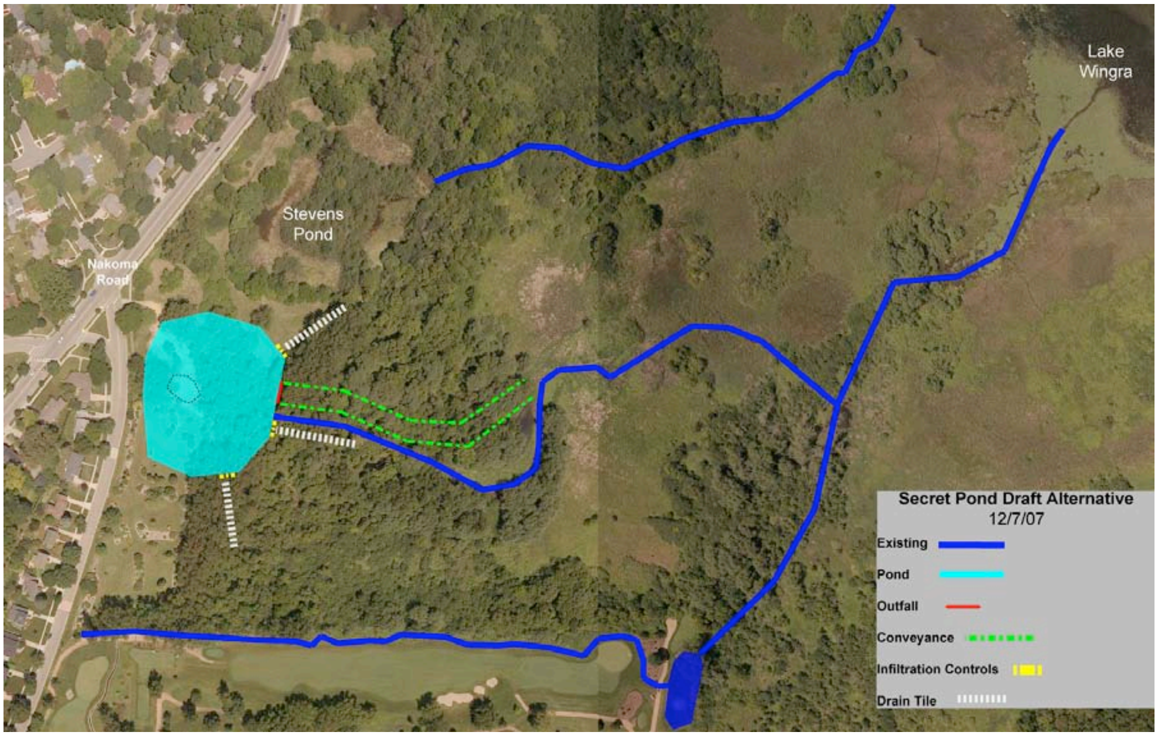


Figure 9: Recently proposed (12/2007) single channel design for Secret Pond. Created with input from Joy Zedler, Kevin McSweeney, Dave Liebl and Ken Potter.

A recently proposed single-channel design (Figure 9) consists of the sedimentation pond, outflow channel, experimental plots, and several additions. Specific modifications include connecting the single channel with experimental plots to the existing channel close to Lake Wingra. In this planting design, the existing channel could be preserved during construction and planting of the experimental channel and filled in with excavation spoil at the end of the project. Alternatively, the existing channel could be partially preserved, or a buried pipe could be installed following the existing channel to act as an alternative waterway for emergencies or maintenance of the experimental channel.

We propose 45 specific assemblages (seed mixes) for this channel. The first 44 treatments would be planted in 4-m$^2$ plots with 8 replicates each for a total of 352 experimental plots. The 44 treatments encompass our hypothesized species lists as follows:

- high infiltration and erosion reduction,
- low infiltration and erosion reduction species,
- high competition with *Phalaris arundinacea* and other invasives,
- low competition with *Phalaris arundinacea* and other invasives,
- each of the 40 species planted individually, and

[a] all 40 species in equal abundance.

The experimental plots would be placed in a randomized block design, with blocks being positions along the channel. The 45th treatment, a mix of all 40 species in equal abundance, would be planted as a matrix in the spaces around all other experimental plots.

The proposed design (Figure 9) includes buried perforated-tile outflows from the sedimentation pond or outflow channel. Branched underground tile systems would allow tests of storm-fed groundwater seeps to support native fen vegetation, as well as tests of the utility of tile fields to infiltrate stormwater.

While this design is not fully developed, various stakeholders see it as a viable option, because it offers stormwater management and a diversity of experimental opportunities.

### *Four-Channel Option*

The four-channel design (from Dave Liebl, 12/2007; Figure 10) has a long narrow pond north of the Arboretum arbor-vitae garden. The four channels exit the bottom half of the pond, with two on each side. The channels are of unequal length, as some connect to existing streams in the surrounding area. The southwest channel is the shortest of the four; its length would be the maximum for “replicate” experimental channels.

We suggest splitting each “replicate” channel into two experimental plots for a total of 8 (4 channels x 2 plots). We suggest applying four planting treatments: high erosion control (HE), low erosion control (LE), high infiltration (HI), and low infiltration (LI). Each treatment would have 2 replicates. In order to test the effect of native species on erosion control, we propose testing two assemblages—those predicted to provide high erosion control (HE) and those predicted to provide low erosion control (LE). To test species’ effect on stormwater infiltration, we propose testing species predicted to provide the highest infiltration (HI) and those predicted to provide the lowest infiltration (LI). The lists of species for each of these four treatments is in Table 4 (HE in column 2 and HI in column 4) and Table 5 (LE in column 2 and LI in column 4).

Each of the 8 treatment plots would be randomly assigned one of the 4 treatments (2 HE, 2 LE, 2 HI, 2 LI) (Figure 11). These plots would be planted with an equal number of each species from the list and planted at an equal density. Monitoring stations would be set up at the top, bottom, and midway point for each plot to test for erosion and infiltration, respectively. The remaining length of each channel (excluding the SW channel) would be planted with an even mix of the 40 species at varying densities. One channel would contain the 40 species planted at a low density (LD), one with a medium density (MD), and one with a high density (HD) of both seeds and plugs (Figure 11). Again, erosion and infiltration monitoring stations would be set up along the remaining length of these three channels.

This stormwater channel system allows us to test both erosion and infiltration of species hypothesized function differently in stormwater management. It also allows for the observation of the effectiveness of varying seeding/planting densities. The downside to this plan its minimal replication. The large differences in channel length preclude sizable replicates. The planned channels also differ in sinuosity and slopes.

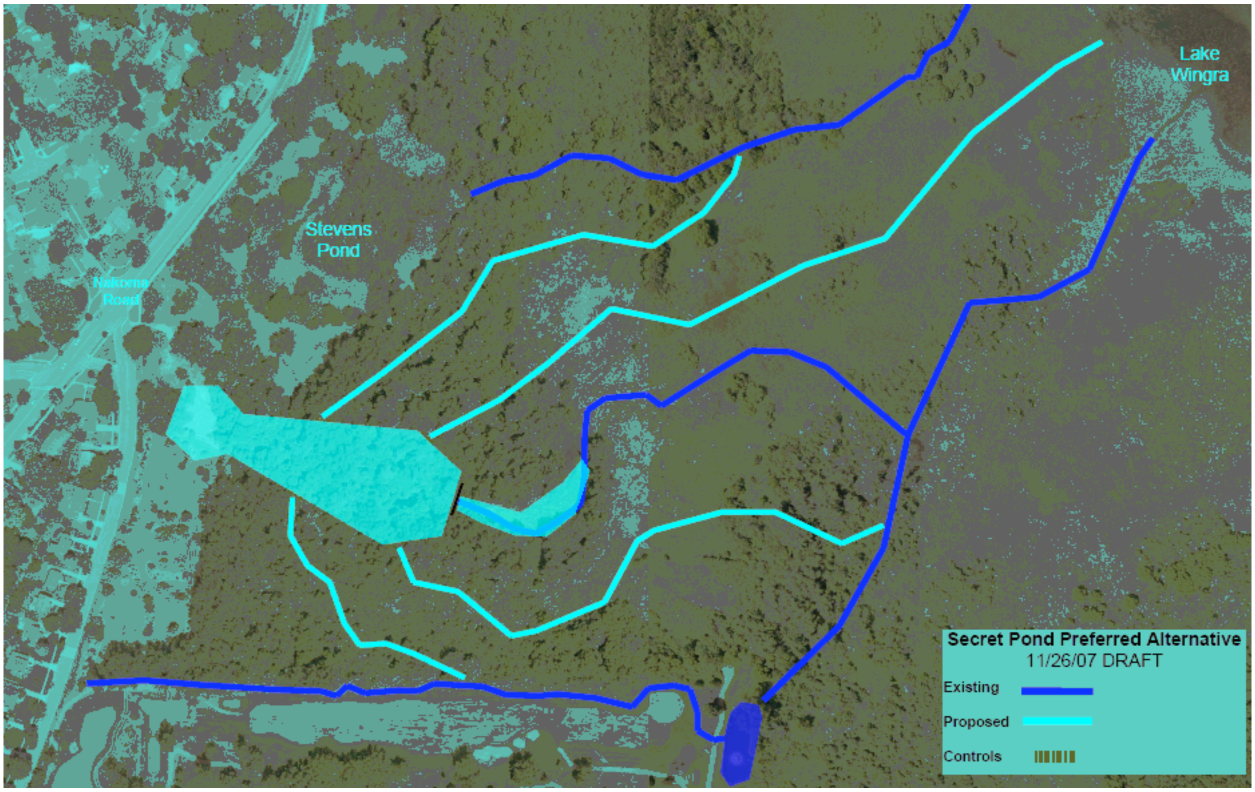


Figure 10: Proposed four channel stormwater conveyance scheme. Drafted by Dave Liebl (2007).

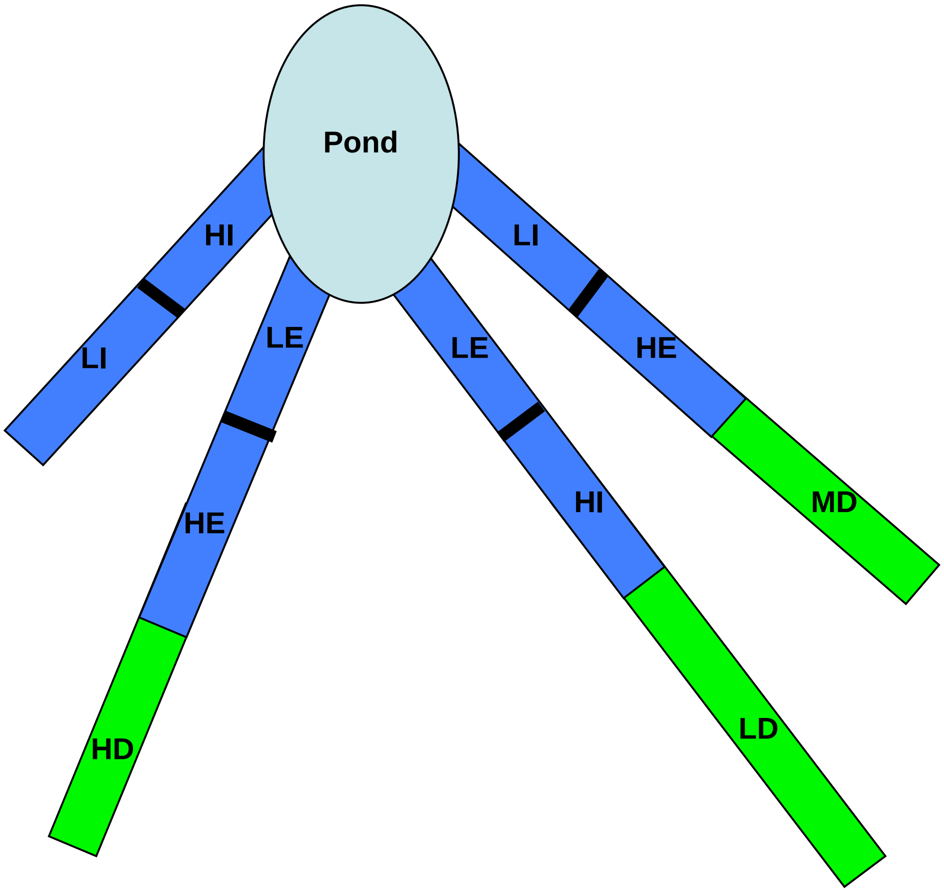


Figure 11: Four channel stormwater conveyance channel experimental plan. Four treatments of upper stream are high infiltration plants (HI), low infiltration plants (LI), high erosion control plants (HE), and low erosion control plants (LE). The lower stream treatments for the three longer streams are plantings of all 40 species at high density (HD), medium density (MD), and low density (LD).

### *Six-Channel Option*

The six-channel concept (Figure 12) has many positives for research, because it allows channels to be treated differently with three replicate channels. An entire channel could be planted with one treatment and replicated (n=3). For more experimental treatments, the channels could be split into 2-3 segments. Another benefit of six channels is that the volume of water in each channel would be lower, and experimental plantings might not be washed out by the energy of peak water flows.

Figure 12: Conceptual Idea for 6 Channel Stormwater Facility

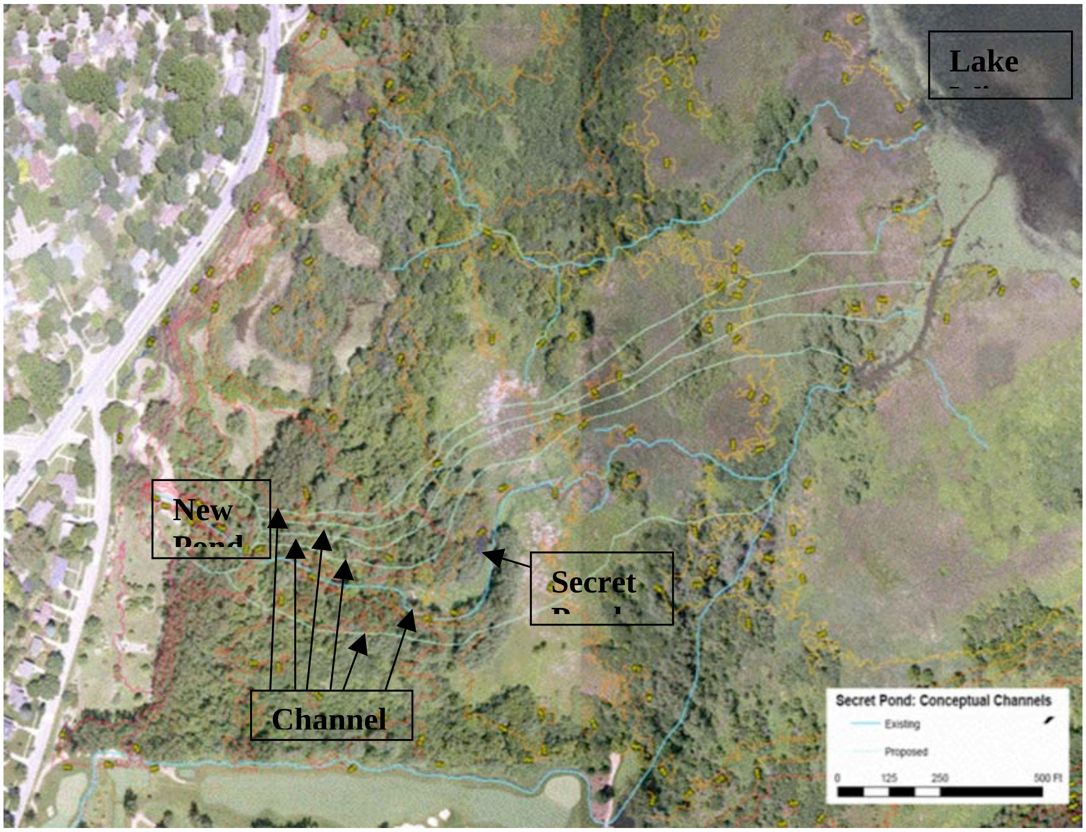
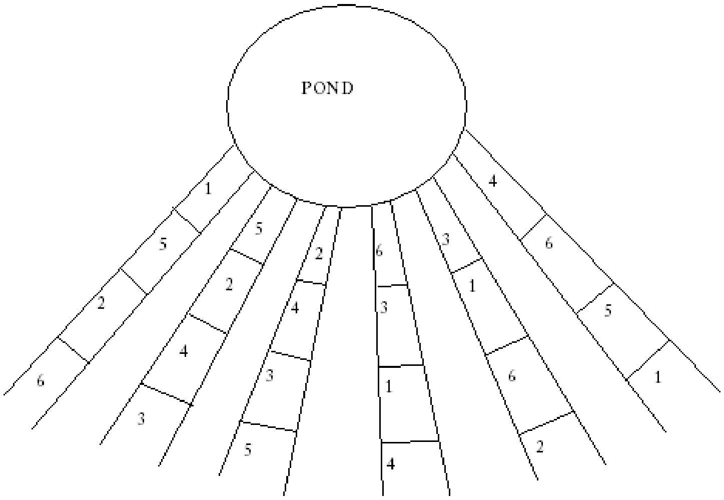


Figure 13: Simplified diagram of plantings. 1) a mix of the top 15 average ranking species (for both erosion and infiltration), 2) the bottom 15 average ranking species, 3) the top 15 for competition, 4) the bottom 15 for competition, 5) a mix of all 40 species, and 6) each of the 40 species in separate mini plots.



Experimentation could test the predictions of the microcosm experiment by splitting each channel into fourths and having six treatments:

- the top 15 ranked species (both erosion and infiltration rankings),
- the bottom 15 ranked species,
- the 15 ranked tops for competition,
- the 15 ranked bottom for competition,
- a mix of all 40 species, and
- each of the 40 species planted individually in mini-plots.

These 6 treatments would be placed in a stratified random order within the channels so that no channel has two of the same treatments, and that no treatments are the same distance from the newly installed retention pond (cf. simplified layout in Figure 13). Experts should be consulted on techniques to use in measuring infiltration, soil stabilization, and removal of nitrogen and phosphorus from the water.

The negatives of having 6 channels include increased costs and potential for public dissent against tree removal and construction. Access to areas between conveyance channels would also be impaired, potentially hindering research and land care.

## Conclusions

Each of the proposed stormwater channel plans allow the planting of experimental plots to test plant species or assemblages for their ability to control erosion and infiltrate stormwater. While engineers need to calculate how best to convey the stormwater, we recommend that the choose an option that has high probability of remaining vegetated. That option will depend on the characteristics of both water flows and vegetation.

Vegetation can best be managed by not adding topsoil to the constructed channels.

- Not adding topsoil will limit the amount of nutrients and solids leaching and flowing from the topsoil into Wingra Marsh and Lake Wingra.
- Not adding topsoil will increases root biomass and decrease shoot biomass. With the anticipation of occasional large surges of high flowing water through the channel, we predict that a plant is more likely to remain rooted if the plant has a smaller shoot. We expect erosion control and infiltration to increase with an increase in root biomass.
- More species had a significantly higher root:shoot ratio in the subsoil treatment than the topsoil treatment, so we expect more plant species to improve erosion control and infiltration if grown in subsoil.

With less erosion, the channels should release less contaminants into Wingra Marsh and Lake Wingra. With more infiltration of stormwater, some of the nutrients should move into the groundwater, potentially decreasing or delaying eutrophication downstream. The overall result should be less surface water inflows of higher water quality.

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