Functions and Plant Selection in Urban Wetlands

Nickolas Sexson

University of Florida

Soil and Water Science Department

1. Introduction

Wetlands are among the most active, diverse, and beneficial ecosystems in nature. Wetlands serve a myriad of functions from nutrient cycling and habitat creation to flood buffering and erosion control. The service provided by wetlands are disproportionately large compared to their area, with up to 40% of renewable ecosystem services being provided by wetlands that account for 1.5% of area globally (Zedler, 2003). Historically, however, wetlands have been looked upon as veritable wastelands, not fit for human occupation or development, and as a result have not always been valued proportionally to their functionality. This review will examine wetlands in an urban context with a specific emphasis on the selection of plant species for urban wetland applications both for ecosystem functions and for improvement of water quality through phytoremediation.

A case will be presented for why wetlands are important in urban environments by examining the functions and values they play in the broader context of the urban locale as well as on a larger ecological and biogeochemical scale. Wetlands in urban settings present unique challenges and obstacles largely due to the scale and proximity which increase human interaction with these ecosystems. Despite these challenges wetlands offer a unique opportunity to greatly enhance water quality, remove or degrade pollutants, and provide habitat for wildlife while also offering the potential for recreational and leisure use by humans.

The combination of hydrology and vegetation are the two biggest driving factors controlling how a wetland forms, matures, and ultimately looks to the outside observer with the hydrology being the biggest driver of the vegetation (Carter, 1997). In the case of urban wetlands the hydrology is largely predetermined by merit of wetland location and controlled diversion of runoff water. The hydrology of the area is essentially a function of the design of the urban setting around it. In the context of urban design the control of water movement near and around structures and developments takes precedent and the areas of water accumulation have inflows and outflows that reflect the design method. This means that when designing an urban wetland the biggest factor affecting the functionality and appearance is the plant species selection and it is crucial to match the plant species to the dominant hydrologic conditions.

Plant species selection becomes critical for designing a wetland that must balance all aspects of function and value. This review will examine how species can be chosen to succeed in meeting all of the requirements of urban wetland design. Emphasis will be placed on plant species that are most suited to the climate and conditions in Florida.

There are also issues that surround the topic of urban wetlands that is beyond the science of ecology and hydrology, including social perception and economics. A discussion will be presented to show how the wide variety and adaptability of wetland species can even make social and economic impacts in a beneficial manner.

2. Urban Wetlands

2.1 Functions of Urban Wetlands

Wetlands are not usually associated with the urban environment. In fact, it is quite common to believe the two as mutually exclusive. Conditions for the formation of a cypress swamp are not generally conducive to urban development due in large part to the issue of standing water. Though, from a more scientific definition, wetlands are actually quite common in and around urban and suburban locations. The national research council defines wetlands as areas with recurring or sustained inundation and having chemical, biological, and physical characteristics which result from this inundation (NRC 1995). In addition, common diagnostic features of wetlands include hydric soils and hydrophytic vegetation.

By this definition, many common stormwater retention/detention features may in fact be wetlands. Wet retention ponds, dry detention ponds, grassed swales, infiltration trenches, infiltration basins, and rain gardens are some of the more common urban stormwater management designs (EPA, 1997). Depending on the exact hydrological conditions, these types of stormwater management structures may be able to function as a wetland, not only for flood mitigation, but also for contaminant removal, habitat creation, and aesthetic appeal.

Stormwater retention basins, detention ponds, and other stormwater management structures are crucial for the management and efficient movement of stormwater. Urban areas are largely composed of impervious surfaces and as a result can have up to 5 times the runoff of a woodland per unit area (EPA, 2003). This makes catchment basins and infiltration areas crucial for handling the volume of runoff that is generated as a result of urban development. Dedicated areas for stormwater catchment help prevent flooding of developed and populated areas as well as minimize erosion due to severe flooding events.

Urban wetlands are also crucial for maintaining water quality and protecting the larger watershed. Retention ponds serve to provide the removal of solids, bacteria, metals, and nutrients from urban runoff (Leisenring et. al., 2014). Urban stormwater runoff can have large contaminant loads from sources such as pesticides, herbicides, oil and petroleum products, pet waste, and road salt (EPA 2003). Urban stormwater management systems such as retention ponds, swales, bioretention systems (rain gardens), and infiltration ditches help to treat the surface runoff before it reaches natural surface waters or groundwater. In this manner urban wetlands are crucial not only for the urban environment, but also for the protection of natural water systems and larger watersheds.

Most urban retention ponds are designed exclusively as the place for storage and accumulation of excess stormwater runoff. Therefore, in the design process, little consideration is given to criteria other than sufficient catchment capacity. Plantings are typically limited to few low maintenance species. The irony of the common design process of stormwater basins is that they are designed specifically to perform one of the major functions of natural wetlands while ignoring others. By merit of already establishing a hydrologic regime characteristic of a wetland it is merely the selection and management of appropriate wetland plant species that prevent these urban wetlands from also performing the functions of natural wetlands and offering similar if not more value than current designs to those in the urban environment.

Urban wetlands are not generally highly valued. Beyond flood mitigation they offer little perceived value. Depending upon wetland design they may range from very constructed in appearance to very natural. In general, the perceived value of the wetland increases with the aesthetic appeal and urban wetlands can use either architectural or natural design to achieve the desired aesthetic effect (UDFCD, 2010).

2.2 Design of Urban Wetlands

With the ecological function of urban wetlands well defined, some discussion must be given to the process of designing urban wetlands with plants as a primary focus. As stated earlier, one of the first steps in the design process is to address the hydrologic regime at the site. In wet retention ponds there will be a vastly different hydrologic regime than in dry detention basins. Identifying the hydrologic regime and the hydropattern for the site is crucial in determining not only which species will be appropriate, but also for determining their physical location on the site.

Of crucial consideration is the inclusion of additional construction elements to urban wetlands such as paths, walkways, boardwalks, fountains, and other constructed bodies, which may alter hydrologic conditions in areas of the wetland, segregate areas from one another, or create barriers or divisions in plant communities. These elements can be used to increase the recreational and aesthetic aspects of the urban wetland provided due consideration is given in planning.

The variety of wetland adapted plants offers a multitude of characteristics for achieving a design aesthetic. For landscape architects employing principles of color, texture, form, and scale, the multitude of wetland species provide ample opportunity for design flexibility (Whiting and De Jong, 2014).

One of the major challenges in designing urban wetlands is public acceptance. There is a common association of the word wetland with swamp. The idea of a swamp in an urban area is of questionable merit for most of the public. When looking, however, at the fact that stormwater retention basins or stormwater swales are required for areas of new development, this provides an opportunity for persuasive discussion by comparison of stormwater management plans with an intent simply to prevent flooding to those with the intent to also increase water quality by utilizing chosen plant species.

Public acceptance is crucial even if all technical, legal, and economic indicators would allow for design of urban wetlands using diverse plant species. In one survey, while retention and detention basins are seen as a benefit by many respondents (47-67%), they are also viewed as a hazard by a portion of respondents (13-19%) as compared to none who thought lakes are a hazard (Adams et. al., 1984). Interestingly, the same survey found that 94% of respondents answered positively when asked if wetlands add to the beauty, diversity, and quality of the human living environment. The overwhelming positive response suggests that public opinion of wetlands may be such that new designs and stormwater management regimes utilizing urban wetlands would be amenable to many. A more contemporary study also suggests that public perception can be different based on location and demographics among other factors (Morison and Brown, 2011). They found increased positive public perception of stormwater sensitive urban design in coastal areas, and areas with >50% vegetative cover as well as in wealthier, more educated areas. Intuitively the coastal and highly vegetated areas are likely to see more direct benefits from efficient stormwater management. The wealthy and more education population suggests that where there is economic ability to withstand additional costs and a greater understanding of the implications beyond one stormwater management area, there is also a positive outlook. This particular study is of value because it suggests the utility in educational and outreach programs to inform the public about the challenges and benefits of carefully designed or redesigned urban wetlands. As more research comes to light suggesting the negative impacts of drainage-efficiency design, it is also likely that the public's acceptance of urban wetlands as a measure of environmental protection will increase (Burns et. al., 2012).

There are already case studies of communities voluntarily adopting changes in stormwater basin vegetation and management for the purpose of increasing water quality as well as aesthetic appeal. The American Society of Landscape Architects keeps a database on stormwater design case studies in the United States (www.asla.org/stormwatercasestudies.aspx) with many cases of schools, municipalities, and private companies designing stormwater controls, including urban wetlands, to improve beauty and ecological function at developed urban sites.

3. Plants in Wetlands

3.1 Functions of plants

The role of plants in wetlands is multifaceted. Plants serve as the primary producers in the food chain of the wetland ecosystem. Plants are crucial in the biogeochemical cycling of nutrients through the wetland system, and can even effect the physical form of the wetland based on biogeochemical processes. Plants play a pivotal role in the formation of habitat for both micro and macro-organisms from bacteria through higher vertebrates. From a more surficial standpoint, plants are the most dominant visual feature in the wetland and as a result contribute the most to the overall appearance of the wetland. This concept and the degree to which plants can alter the physical appearance of a wetland can be visualized by simply looking at a cypress swamp and a wet prairie. Both are wetlands, performing the functions of wetlands, but their physical appearance is drastically different.

Plants provide many ecosystem services, not just to the immediate wetland area, but also to the larger area of the watershed, and even services that can be impactful at the global level depending on the scale of the wetland. While urban wetlands are not likely to be of scale sufficient to provide measurable global ecosystem services, their functions remain in a smaller scale. Plants, especially woody species, sequester carbon in their tissues. This carbon is largely in the form of lignin and cellulose, both of which are slow to degrade, thus making the carbon detention time in woody plant growth quite long. Plants can also sequester carbon by the accumulation of decayed plant matter as peat. Wetland conditions are favorable for the accumulation and slow degradation of organic carbon due to the prevalence of anaerobic conditions due either to standing water or saturated soil conditions. Plants function as the carbon scavenger by fixing atmospheric carbon dioxide for production of biomass. As portions of the plant die they are cycled down through the water column where they slowly breakdown due to anaerobic conditions.

In the same way that plants are able to sequester carbon it is also possible for them to scavenge and sink other elements. Some plant nutrients such as nitrogen and phosphorus, which are limiting in many non-anthropogenically modified ecosystems, are generally abundant to the point of being pollutants in urban runoff. Total nitrogen in residential runoff can be more than twice that of non-urban runoff (1900ppm vs 965ppm) and total phosphorus more than three times higher in residential vs. non-urban locations (383ppm vs 121ppm) (EPA, 1999). Many industrial, agricultural, and domestic processes generate nitrogen and phosphorus contamination that can be collected and concentrated in urban systems. The problems of nitrogen and phosphorus pollution can be quite severe and is largely a twofold problem. First is the increased population density resulting in increased inputs of nutrient pollution. A larger population represents a greater number of potential contamination sources. The second major problem is that contaminant concentration arises from the design of urban systems. Generally the runoff from an impervious urban area is collected and deposited in a single retention or detention basin. With the valuation of developable land much higher than that of a wetland type area, the emphasis is put on having as much developed area as possible with as little stormwater management area as possible. This leads to situations where large runoff areas drain to a single site, effectively concentrating contaminants in the runoff. This is true for all runoff contaminants, not just nutrient pollutants.

The plant species and design of a wetland can greatly affect the ability of the wetland to act as a sink for specific contaminants. The ability of certain plants to uptake, and retain contaminants will be discussed further. The process is very similar to carbon whereby the plant takes up nutrient contaminants for growth and converts the nutrient to plant tissue, which will eventually die and cycle through the wetland. The nature of the plants, wetland conditions, and biota can greatly affect the residence times of elements in a wetland.

Plants can also have specific values beyond their functionality in the ecosystem. No place is this more true than in an urban environment. Plants help to provide a visual link to natural systems. Plants often form the most visually noticeably component of an ecosystem due to their size, color, and permanence, permanence of course being relative to the viewing time. Plants are usually the first visual aspect noted of a natural ecosystem and so in an urban setting plants lend a feeling of nature to a landscape otherwise dominated by man-made materials and design. The color, shape, and form of plants greatly differs from those of man-made designs. Humans show an affinity for nature and natural forms (Hartig et. al., 2010). It has even been suggested that the attraction to nature and natural systems is innate in humans (Kellert and Wilson, 1993).

Plants are widely and traditionally valued as well for their aesthetic appeal. Factors such as shape, form, and color greatly affect the perception and preference of plant species. Commonly, plants with unusual form, bright colors, or prominent flowers are viewed as having high aesthetic appeal. These plants can provide visual interest and contribute to the overall experience of the observer. One of the biggest benefits of plants is their contrasting green in an urban setting. Much research has been done to evaluate the needs, desires, and effects of green space in urban environments (Kabisch et. al., 2015).

3.2 Plants for Remediation

One of the functions of plants that holds great promise in urban wetland design is the ability of plants to remediate, degrade, or otherwise reduce toxicity of pollutants or detrimental effects from physical contamination such as sediments. The wide variety of hydrophytic vegetation available for use in urban wetlands makes them crucial tools for dealing with situations unique to urban systems. Urban stormwater runoff is different from runoff in undeveloped areas in several ways. Firstly, increased impervious surfaces increases runoff volume as compared to undeveloped surfaces (Jennings and Jarnagin, 2002). Urban runoff also displays a first flush phenomenon in which contaminants are disproportionately represented in the earliest runoff during a rain event in areas with high impermeable surface area (Lee et. al., 2001). Urban runoff also has concentrations of contaminants that are higher than those of natural systems, and for many contaminants, are of levels that can significantly affect human health as well as the health of organisms and ecosystems receiving urban runoff (Brown and Peake, 2005; Makepeace et. al., 1995).

The idea for using plants for remediation of environmental contaminants has been around for many years and is well demonstrated (Salt et. al., 1998). Phytoremediation utilizes natural plant processes to remove, degrade, or sequester contaminants present in the soil or water. There are many benefits to phytoremediation. Plants are in intimate contact with the soil and water and as a result have the ability to directly interact with soil and waterborne environmental contaminants. Phytoremediation is typically a low cost operation due to the passive nature of plant growth. There is some cost associated with the initial planting and establishment of plants, but provided that the species is tolerant of ongoing environmental conditions the cost of maintaining plants is significantly lower than other remediation strategies (Chaney et. al., 1997).

Phytoremediation in urban wetlands holds much promise for improvement of water quality within the wetland and for effluent from wetland retention areas that drain into larger watershed features such as streams, rivers, and lakes. A major detrimental effect of urbanization is the decrease in water quality of runoff from impervious surfaces. When runoff carrying contaminants is received by previously unaffected water bodies there can be major environmental impacts. High nutrient loads, solids, and xenobiotics can reduce overall water quality as well as harm plants and animals that are specifically sensitive to certain compounds or changes in environmental conditions.

One of the most widely known water quality issues in Florida is eutrophication of water bodies due to increased nutrient loads, especially of phosphorus. Urbanization can be a major contributing factor to increased nutrient loads from practices such as fertilization of turfgrass and ornamental landscaping. The use of plants to improve water quality by reducing nutrient load is well established and has been demonstrated on many scales. Careful choice of species for urban wetlands allows one to select for plant species with remedial features that match the incoming contaminants based on surrounding land use for maximal improvement in water quality. If for example, phosphorus is a major contaminant of concern in a particular urban area then choosing plant species with high phosphorus uptake and retention potential could play a substantial role in improving water quality. In one design utilizing a floating wetland design, total daily loads of nitrogen and phosphorus were decreased by 87.9% and 80.9% under simulated stormwater conditions (White and Cousins, 2013). A subsurface flow system installed in Portugal reduced phosphorus (92%), ammonium (84%), and total coliform bacteria (99%) while serving as an aesthetic focal point of a tourist destination (Calheiros et. al., 2015)

Plants can also be effective in improving water quality through physical processes. Stabilization of soil both in upland and wetland areas helps reduce erosion and particulate solids in runoff water. Having highly vegetated areas around and within water retention/detention basins helps to slow runoff velocity, which in turn reduces the load of suspended solids that must settle once the water reaches a still location. Fast growing plants such as poplar trees can also help modify hydraulic gradients which can be useful for slowing or stopping contaminant plume movement (Pilon-Smits, 2005). A more recent area of phytoremediation that may increase the effectiveness of designed wetlands is the symbiotic relationship between the plants and microorganisms in the rhizosphere. Depending on the environment and extent of management, microbial activity can either be greatly enhanced by plants or vice versa. It has been successfully shown that microorganisms can be used for modification of the rhizosphere conditions to enhance contaminant bioavailability to plants, and increase resulting phytoremediation (Wenzel, 2009). The converse, too, has been shown that the presence of plants can increase microbial activity and degradation in contaminated soil (Kaimi et. al., 2006). In constructed urban wetlands the most likely contribution from microbial interactions will come from stimulated microbial activity in the rhizosphere. Intentional inoculation or modification of rhizosphere conditions for remediation purpose will likely be beyond the management measure that would take place in an urban wetland setting.

4. Plant Selection in wetlands

4.1 Importance of plant selection

Given the unique nature of urban wetlands, when designing existing systems, the importance of plant species selection cannot be overstated. Plants will be the most ubiquitous and highly interacted with part of the system not just for humans but also for insects, amphibians, birds, and other wildlife.

The plant community will also greatly affect the soil and water conditions, potentially not just in the isolated wetland system, but also in the greater watershed. For these reasons, specific considerations as to location, climate, hydrology, and contaminant tolerance should be assigned a high level of importance.

As mentioned previously, wetlands in urban areas have much higher levels of human interaction than remote natural systems. This places several additional limitations on urban system design that must also be weighed in the decision making process. Chief among these considerations is aesthetics and ease of management. If an urban wetland is designed to enhance soil and water quality and increase pollutant removal but is less aesthetically appealing than a turf grass retention/detention basin there is little chance that the public would support the design. Since urban wetlands are in easily accessible areas and are generally small, they can be more intensively managed than those in more remote locations. Consideration should be given to the hydrology of the location though as access to some plants may become obstructed during periods of high standing water such as during the wet season or after major storm events. With adequate forethought and insightful design it is possible to both minimize necessary management and also facilitate ease of access for maintenance.

With the above considerations firmly in mind, the first major design limitation when choosing plant species is the hydrologic conditions of the site. If a plant cannot tolerate the prevalent hydrologic regime of the site it will be of little value. Primary consideration should be given to the dominant hydrologic conditions and plants tolerant of those conditions should be identified. If periods of wetter or drier conditions are the most common deviation from standard conditions then plants more tolerant of conditions of common deviation should be considered as well. Figure 1 illustrates the conceptual climatic and hydrologic considerations. The majority of the plant species should fall in the central area, which is comprised of the predominant climatic and hydrology regime. It may, however, be prudent to choose species that fall further to one side of the gradient than the other depending on the site condition and anticipated changes such as future land use changes. For example, if a retention basin is currently bounded on one side by impervious surfaces and undeveloped surface on the other, but development is anticipated in that area it may be prudent to skew species selection towards species with tolerance to higher temperature and more inundation. This could improve vegetation performance if the basin is to receive more runoff and experience higher local temperature from the new development.

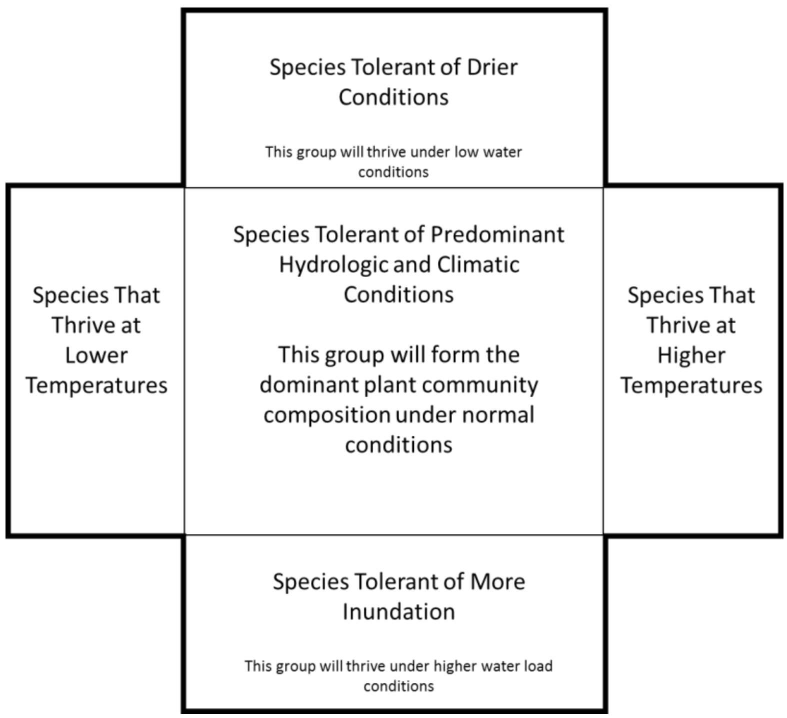

Figure 1-Conceptual diagram of hydrology and climate considerations for choosing plant species. The diagram represents a gradient of temperature tolerance from left to right and a gradient of tolerance of inundation from top to bottom. Ideal species will fall in the middle section which represents the dominant hydrologic and climatic conditions.

Consideration should also be given as to whether native or non-native species are to be utilized in the design of an urban wetland. From an ecological standpoint, it would seem prudent to utilize native species in any situation where are other factors are the same. One of the most common reasons for employing non-native species is for ornamental or horticultural purposes when the prevailing environmental conditions are conducive to the growth of a non-native plant species (FDACS, 2015).

There are debates as to whether or not all non-native species are necessarily deleterious to ecological function (Clark et. al., 2011). It is well established that certain introduced plant species can endanger native species in a habitat, which represents a significant cost, at approximately $34.6 billion annually (Pimentel et. al., 2004). Given that the potential for ecological impact of an introduced species is a topic deserving of its own discussion, the discussion of plants for use in Florida urban wetlands will be limited to native species. It should be noted, however, that if a species with a particular characteristic for remediation purposes is found and through experimentation it doesn't pose an ecological threat, one can make an argument that the species should be given due consideration in urban wetlands.

4.2 Sample Plants in Urban Wetlands

The following are several profiles of selected Florida native wetland plants for which adequate research exists to suggest that they would be tolerant or prevailing hydrologic, climatic, and contaminant conditions likely in urban wetlands in Florida. Emphasis was placed on identifying species, which would not only be tolerant of the unique conditions in urban wetland, but that would also offer benefits of enhanced soil and water quality as well as increased aesthetic appeal.

There are many identified wetland species, which may thrive in urban wetlands, but which may not have been studied for their remediation potential. There are approximately 4,200 total and 3,000 native Florida wetland species (Center for Invasive and Aquatic Plants, 2015) and accordingly it is reasonable to expect that with more research, more species of increased utility for urban wetlands will be identified.

Typha Spp.

Typha is a genera comprised of roughly 30 species including *Typha Latifolia* (Common Cattail) and *Typha Domingensis* (Southern Cattail). Typha species are fast growing, tall, and rhizotomaceous perennial plants. They tend to grow in stands, expanding via underground rhizomes, but also are prolific seeders, producing up to 250,000 seeds per plant (Sojda and Solberg, 1993). Plants can grow to 9 feet tall and have characteristic brown flower stalks. They respond well to moderate shifts in water depth but can be detrimentally effected by long periods of dry conditions or deeper inundation. The dense growth habit provides ample cover and habitat for small amphibians and birds.

Typha latifolia is one of the most widely used and studied plants in treatment wetlands (Vymazal, 2013). *Typha Spp*. are some of the most common and recognizable aquatic plants in North America. Their fast growth rate and tolerance of elevated nutrient loads enables them to outcompete other aquatic plants especially in areas of high nutrients (Newman, 1996). The fast growth rate and nutrient tolerance can be of great utility in treatment wetlands since the rapid accumulation of biomass can remove large quantities of nitrogen and phosphorus from the water and improve water quality. It is these characteristics that have led to *typha* species being so common in treatment wetlands. Beyond nutrient pollution removal, *typha* has also been shown to increase degradation of polycyclic aromatic hydrocarbons (PAHs) (Machate et. al., 1997), sequester arsenic on oxidized iron plaque in the rhizosphere (Blute et. al., 2004), and to enhance degradation of trichloroethylene (TCE) (Bankston et. al., 2002).

While tolerance of high nutrient load and the ability to remove nutrients and other contaminants from the water are beneficial qualities, especially given the high nutrient load of urban runoff, there are some drawbacks to its use. One of the biggest drawbacks is the potential for dominance in the wetland. Under optimal conditions *typha* species are able to easily outcompete other wetland plants to form dense mono-dominant stands. This reduction in biodiversity tends to reduce ecosystem functions, and also tends to make the landscape less visually appealing.

As aesthetic considerations are important in an urban setting typha species have both positive and negative features. Their leaves being tall and narrow, providing visual interest and textural variation from most urban plants. Their flower stalks, or catkins, are generally well liked and provide additional visual interest. As a single component of a more complex plant community typha species would seem well received. If typha species become dominant and exclude other plant species, the plant form no longer is contrast and instead leads to a visually uniform stand. Stands of *typha* can also accumulate large amounts of dead leaves and stalks which could lower the visual appeal of the area.

Nymphaea Spp.

The fragrant waterlily (*Nymphaea odorata*) is found in all 48 contiguous states as well as Alaska and Puerto Rico, making it one of the most climatically adaptable wetland plants. *Nymphaea Mexicana* (yellow waterlily) is similar to *N. odorata* in growth and conditional tolerance but differs most apparently in that it has yellow flowers. Nymphaea species are floating plants that prefer close to a continuous hydroperiod and water depths of 18-30 inches (Lo Galbo et al., 2014). The floating growth habit of the nymphaea species make them of particular value since they can grow in deeper water than other species, allowing higher primary production than in a system with no floating vegetation. The nymphaea species can also help add visual interest to areas of deeper water which might otherwise not have plant cover.

The ability of *N. odorata* to remove phosphorus from water is well documented and can be as high as 50% of the inflow phosphorus under favorable conditions (Mitsch et. al., 2015). This removal of phosphorus represented nearly twice the removal of phosphorus by *Typha domengensis*, suggesting that nymphaea may be an excellent species to pair with typha species since the nymphaea can grow in deeper water than *typha* and help reduce water phosphorus concentrations, which may help in managing the fast growth rate of *typha* under high nutrient conditions. It should be noted that the high quality, nutrient rich litter of *N. odorata* can lead to rapid decay of dead plant material, which can release phosphorus back into the water column. A study showed that while the release of phosphorus due to litter decomposition is expected, the total phosphorus retained in plant litter is up to 5 times higher than that of *Cladium jamaicense* or *Eleocharis cellulose* on a per weight basis (Serna et. al., 2013). These results suggest that *nymphaea* species may be very useful for retaining phosphorus from runoff water.

In addition to potential remediation uses, nymphaea species are also considered especially showy due to large fragrant flowers that are borne above the water surface. The showy nature of the plant lends it to integration in urban areas where aesthetic appeal are of special importance (Figure 2).

Figure 2-*Nymphaea Odorata* flower taken by Ann Murray of University of Florida.

Canna Spp.

The plants collectively referred to as canna lilies include many species with the two most common species in Florida being the native *Canna flaccida* and variations of the species *Canna indica*. The plant has an upright growth habit and typically grows on the edges of wet areas in stands up to 4 ft. tall (UF/IFAS, 2015). The plant can be propagated by lifting rhizomes or by seed germination. Many varieties of *C. indica* are propagated as ornamental nursery plants and are popular plants for growing in Florida with few pest or disease problems. The canna lilies can have small to large flower in a range of colors from white and yellow to dark reds. The native *C. flaccida* has large yellow flowers that are considered ornamental. The leaves of the canna species can range in color from green and yellow to red and brown with variations of shading and patterning. The ornamental nature combined with ease of cultivation make them a plant well suited to the conditions prevalent in Florida (Tjia and Black, 2003).

In addition to their highly ornamental form, canna lilies have also proven to have beneficial qualities of use for phytoremediation. Canna has been shown to actively remove nitrogen from runoff water containing fertilizer at a rate of 3 mg/kg/hr. (Govindarajan, 2008), which makes the species an attractive and effective plant for the removal of excess nitrogen from urban runoff water. Floating canna culture studies have shown nitrogen and phosphorus fixation of 16.8g/m^2 and 1.05g/m^2 respectively and a rate of phosphorus removal of 173mg/m^2-day (White and Cousins, 2013; DeBusk et. al., 1995). *C. indica* has also shown promise for removing heavy metals from contaminated soil, concentrating chromium at up to 17 times the extractible chromium concentration of industrial sludge additions (Bose et. al., 2008). They suggest that *canna indica* has the ability to grow well under adverse and high contaminant conditions including conditions of high concentration of metals including iron, copper, lead, chromium, manganese, cadmium, nickel, and zinc. It has also been shown that canna species have the potential to remediate organic compounds from pesticides to petroleum wastes such as BTEX, which was 80% removed in the root zone within 21 days. (Li et. al., 2014; Boonsaner et. al., 2011).

The adaptability and effectiveness of canna species to tolerate and remove a wide variety of contaminants coupled with its aesthetically pleasing ornamental nature make it a prime candidate for use in urban wetlands. In at least one case canna lily was used specifically on account of its showy flowers for treating waste waters at a rural tourism location in Portugal (Calheiros et. al., 2015).

Pontederia Cordata

Pontederia cordata (common pickerelweed) is a widely adapted wetland species with a native range from Nova Scotia in the north to Florida in the south, and westward to Missouri and Oklahoma. The plant usually grows to between 3 and 4 feet tall and can flower year round in Florida. The most distinguishing feature of the plant is its brightly colored purple flower spikes. In areas where *P. cordata* is highly established, the flowers can make large portions of the landscape appear purple. The plant is an emergent wetland species frequently growing at the edges of water bodies and in shallow wet prairies. Pickerelweed can even grow as a floating plant under rare circumstances (Figure 3; Clemson Cooperative Extension, 2015).

Figure 3-Pondeteria Cordata in bloom. Large stands of Pickerelweed can give the landscape a purple appearance taken by Simon Pierre Barrette via Wikimedia commons.

Days after $^{15}NH_4^+$-N added	Atom% $^{15}N_2$ in the air above floodwater	Increase in atom% ^{15}N over natural standard
	Pontederia cordata	
14	0.439±0.009	0.067
15	0.450±0.009	0.082
19	0.430±0.022	0.061
21	0.407±0.041	0.038
26	0.378±0.006	0.010
	Juncus effusus	
14	0.412±0.040	0.044
15	0.413±0.015	0.045
19	0.443±0.014	0.074
21	0.431±0.013	0.062
26	0.412±0.012	0.043
	Control (no plants)	
14	0.379±0.010	0.010
15	0.380±0.011	0.012
19	0.377±0.006	0.008
21	0.379±0.009	0.010
26	0.376±0.005	0.007

Figure 4-Isotopic determination of nitrogen gas above Pondeteria Cordata shows enhanced denitrification, especially in the early stages after ammonium additions. Table from Reddy et. al., 1989.

Pondeteria cordata is tolerant of low nutrient soils and waterbodies, but thrives in higher nutrient situations. *P. cordata* holds great promise for reducing nutrient pollution such as high nutrient runoff from urban areas. *P. cordata* has been shown to increase nitrogen removal in soils and waters where high ammonium nitrogen loads are experienced, both by increasing denitrification processes (Reddy et. al., 1989) (See Figure 4) and by assimilative uptake (Polomski et. al., 2007) and sedimentary sorption (Zhang et. al., 2016).

Sagittaria Spp.

There are many sagittaria species native to the United States and Florida. Two of the most common species are *S. Latifolia* (common arrowhead) and *S. Lancifolia* (duck potato). *S. Latifolia* seems to be the most common sagitttaria species in phytoremediation and wastewater treatment studies so most emphasis will be given to this species. *S. latifolia* is an emergent wetland plant that grows on the shallow edges of waterbodies or in persistently inundated shallows such as ditches and retention ponds.

Plants are 1-4 ft. tall and are easily identified by characteristic arrow shaped leaves. The plant has spikes of widely spaced three-petaled white flowers.

What makes *S. latifolia* interesting for urban wetlands is its tolerance to contaminants and its potential for increased water quality. *S. latifolia* showed no negative reaction to increasing nitrate loads with copper, zinc, lead, and cadmium metal contamination mixture (Kearny and Zhu,2012), which demonstrates great promise for use in mixed contaminant urban runoff areas. Studies have also shown *S. latifolia* to be effective at sequestering nitrogen from runoff in existing stormwater retention basins with the potential of nitrogen removal from a site by harvesting above ground biomass which represents on average 6g/m^2 nitrogen (Lenhart et. al., 2012). With increased nutrient loading being of major concern in urban areas, plants capable of efficient growth under mixed contaminant conditions can be beneficial for reducing nutrient loads in runoff. *S. lancifola* has been shown to be tolerant of crude oil at an application rate of up to 2 L/m^2 (DeLaune et. al., 2003) and *S. latifolia* has been shown to be tolerant of, and effective at degrading more exotic organics such as TNT and RDX explosives showing concentration reduction by 95% and 80% respectively (Van Der Lelie et. al., 2001).

Another interesting aspect of *S. lancifola's* use in urban wetlands is its ability to oxygenate the root zone. In a study of eight wetland plants, *S. latifolia* was found to have a significantly higher oxygenated root zone area than other species tested, having a radial root oxygenation zone of 56 cm^2 (Smith and Luna, 2013). The ability of the plant to create an oxygenated root zone in wetlands can increase the efficiency of microbial degradation or organic compounds including PAHs (McNally et. al., 1999). This characteristic can be helpful for increasing the degradation of hydrophobic contaminants, which are often bound to organic sediments carried to stormwater retention sites in runoff.

Plant of Interest	Contaminant Removed	Method of Removal	Rate or Quantity Removed	Additional Notes
Typha spp.	Phosphorus Nitrogen Phenanthrene Arsenic Trichloroethylene	-Phosphorus-Assimilatory uptake -Nitrogen-Assimilatory uptake -Phenanthrene- Root zone microbial activity -Arsenic- Adsorption on ferric root plaque -Trichloroethylene- Cometabolism by root zone methanotroph stimulation	-Phosphorus-0.3-0.6g/m^2 under elevated nutrient conditions[1] -Nitrogen-0.5-0.6% Dry weight basis[1] -Phenanthrene- 99.9% removal after 6.6 days from 385ppm inflow at 3L/min loading rate[2] -Arsenic- 30-1200ppm on root plaque. Root plaque found to be 40% root mass in samples.[3] TCE- 47.3% applied TCE mineralized; applied at 35μg/kg.[4]	Very common in treatment wetlands 497 out of 643 Constructed wetlands in 2013 review.[5]
Nymphaea spp.	Phosphorus	Phosphorus-Assimilatory uptake	Phosphorus- 51% of inflow; simulated stormwater loading 13-78ppm Total P[6] Litter retained 0.5-0.84mg/g P in plant tissue[7]	Floating plant species.
Canna spp.	Nitrogen Phosphorus Chromium BTEX	Nitrogen-Assimilatory uptake Phosphorus-Assimilatory uptake Translocation into root tissue Translocation into shoots	-Nitrogen- 16.8g/m^2 in mature plants[8] -Phosphorus- 1.05g/m^2 in mature plants[8] 173mg P/m^2-day [9] -Chromium- Cr translocated to roots at 17X the applied concentration at 90 days.[10] -BTEX- 80% of applied (400-495 ppm application)[11]	Very tolerant of a wide range of heavy metals. See reference 10
Pondeteria Cordata	Nitrogen	Nitrogen- enhanced microbial denitrification, assimilatory uptake, enhanced sedimentary adsorption	-Nitrogen- 122mg N/ m^2-day in mature plants [12]; 50.8% NH_4-N removed from ditches[13]; 92% of applied nitrogen[14]	
Sagittaria spp.	Nitrogen TNT and RDX	Nitrogen-Harvesting aboveground biomass TNT and RDX- endogenous enzyme activity	-Nitrogen- 6g/m^2 by harvesting biomass[15] -TNT and RDX- 95% and 80% reduction[16]	Tolerant of Copper, Zinc, lead, Cadmium[17];Tolerant of crude oil[18]; Aerates root zone[19]

Table 1-Summary of Example Species Remediation Data References: 1. (Newman et. al., 1996) 2. (Machate et. al., 1997) 3. (Blute et. al., 2004) 4. (Bankston et. al., 2002) 5. (Vymazal, 2013) 6. (Mitsch et. al. 2015) 7. (Serna et. al. 2013) 8. (White and Cousins, 2013) 9. (DeBusk et. al., 1995) 10. (Bose et. al., 2008) 11. (Boonsaner et. al., 2011) 12. (Reddy et. al., 1989) 13. (Zhang et. al., 2016) 14. (Polomski et. al., 2007) 15. (Lenhart et. al., 2012) 16. (Van Der Lelie et. al., 2001) 17. (Kearny and Zhu, 2012) 18. (DeLaune et. al., 2003) 19. (Smith and Luna, 2013)

5. Conclusions

It is evident that changes in the hydrologic flow of watersheds is greatly altered by urbanization, leading to negative environmental consequences. The traditional design of simply moving runoff as quickly away from urban areas as possible needs to be reconsidered. As best management practices move more towards treating rainwater and runoff closer to the source rather than concentrating it in a single large area, there is a reasonable expectation that wetlands will occur more frequently in urban and suburban areas. The increase in so called rain gardens and vegetative swales is already visible in newer developments with a focus towards efficient stormwater management. As more of these urban wetlands are developed, the importance of plant species selection for temporary to permanently saturated conditions will come to light.

The expected changes in stormwater management emphasize the importance of plant species selection in existing urban development as well as issues of contamination with urban runoff. Not only must selected plants cope with prevailing climatic and hydrologic conditions, but also they must tolerate a wide array of contaminants from fertilizers and pesticides, to petroleum hydrocarbons and heavy metals. The selection of plant species in urban environments also requires consideration of aesthetics and maintenance since urban wetlands will experience much more human interaction than remote or rural wetlands. There is an overwhelming amount of research that suggests the abilities of plant species to remediate, degrade, or removal of contaminants, can be used beneficially when designing urban wetlands.

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