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Brief Comments on Common Plant Choices of Bioretention Based on Different Green Infrastructures (GI) Sites Characteristics

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***Abstract*—This article describes the plant selection for Bio-retention, a common category of green infrastructure, and how it relates to the functions of bio-retentions. Bio-retentions are type of green infrastructures, focusing on controlling runoffs and then infiltrations with flexible configurations, allowing different plant choices function in different ways, which are briefly commented by this article. Information from a BMP (Best-Management practice) mapping tool, including summary reports about bio-retention sites' characteristics, rainfall and runoff volume are used as primary source of data in this study. Four sites were selected with relatively integrate summary reports (with enough important information including plant coverage and rate of impervious) and summarized the reports into table form. We compare details through the summary table. Overall, designing and choosing plants for bio-retentions are many-sided, and the existing plant choices fits respective sites' characteristics. Further research can focus on subjoining parameters and applying statistical models to the summarized dataset.**

***Index Terms*—Environmental science, plant, Green Infrastructure (GI), bioretention**

I. Introduction

Green infrastructures (GI) are artificially designed features that capture, filter, and infiltrates storm water in a similar fashion as the natural ecosystems with water conservancy facilities, that protect and improve human-related watersheds and water cycles. Some common types of green infrastructures include bioswale, permeable pavement, rain garden, etc. In general, GIs are important, and becoming increasingly important, corresponding to the increasing human activities which are closely related to, and geographically near to watersheds, such like residential construction, farm irrigation, and industrial production [1]. Thus, research among GI designing is necessary. In this study, we focused on how plant choices (in other word, greening plans) adapt different sites and affect bio-retention function.

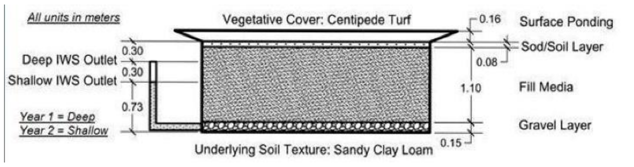

Fig. 1. Example of cross-sectioned diagram of bio-retention (Site Catawba and Site Rocky Mount, BMPDB).

Bio-retention is a category of GI, with the focus of controlling and buffering (majorly slowing down or minorly enlarging) primarily horizontal storm water runoff and secondarily infiltration. Bio-retentions do not have fixed configurations, but the design process usually considers two important factors. First, the location of the bioretention should be plain or basin with "forebay", which place is large enough for runoffs to pass by and slow down [2]. Second, the location should be covered by thick layers of soil, organic matters (OM) and plants, which providing the main forces to control the runoff [3]. Fig. 1 above is an example of engineering project of bio-retention, and Fig. 2 below depicts the hydrologic processes in a typical bioretention unit.

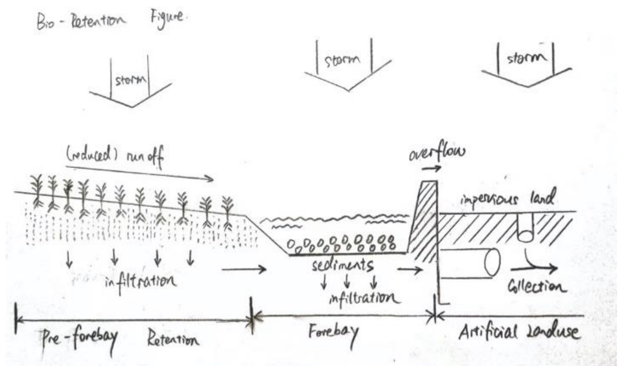

Fig. 2. Hydrologic process in a typical bioretention unit.

Also, there are other types of GIs which may be related to our topic in different scales, functioning both hydrologically and bioecologically. First, bio-swales are well-templated GI, composed by plant covering, slope, soil, gravel, and drainage from top to bottom, and are able to control large volume, vertical runoffs, which widely used in residential areas and near highways. Second, rain gardens, as residential small GI composed by eaves, paths, and shallow soil no more than 10 inches, are widely used for ornaments. Listing those GI types is not only type of introduce, but is also reminder that when designing GI, we should take varieties of information into account, including but not limited to social values (culture and identity), natural life values (plant and animal), and economical values (cost and scale) [4].

As one of the most important components of GI, plants are essential for attenuating surface runoff and allowing more infiltration [5]. On one hand, plants' root is able to grab and stabilize the soil, so water is less likely to flush the soil particles away with plants rooted, thus runoff is reduced. On the other hand, plants themselves are able to absorb quite an amount of water through vessel system and use for

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photosynthesis and transpiration, thus plants themselves reduces the initial and total amount of water which may cause runoff, and then leading to reduced runoff. [5].

Additionally, plants also bring various co-benefits. First, plants can improve air quality through photosynthesis; second, plants can keep air temperature stable by absorbing carbon dioxide and thus reducing greenhouse effect; third, plants can significantly settle down pollutants which are suspension among air and water, and fourth, plants can provide aesthetic value to local communities and create natural habitats.

Above mentioned benefits highlight the importance of plant selection during GI designing process. GI performances, especially our focus “bio-retentions”, relies heavily on design and plant selections, while not many studies have focused on the impact of plants species selection. The aim of study is thus exploring the plant selections and designations of different bio-retention sites.

II. Methods

A. Data Collection

In this study, we used data from a BMP (Best-Management practice) mapping tool facilitated by International Urban BMP database [6]. As a database initiated earlier than 25 years ago and still updating statistics in 2021, it is not only focusing on stormwater controls, but is also providing additional resources toward urban and agricultural landscape managements. The database faculties have collected data from study sites’ metadata as well as voluntarily shared monitoring data, and also equip variety of statistical/filtering/mapping tools to go through further analysis. By using this database, we have access to hundreds of summary reports about different types of GI’s performances on hundreds of sites. This tool has a lot of advantages, including but not limited to following:

First, the summary reports in the tool include detailed information on necessary variables, including plant choices, land distribution, site area, precipitation and storm volume, and inflow/outflow volume and time periods, etc. This information can help us control most of the possible variables efficiently. Second, the information necessary is publicly accessible in most aspects, so we can test the statistics equitably, and also, reviewers are able to criticize on possible errors exist. Last, the databases are updated biannually, which can both keep the statistics timely for analyzing and exclude a lot of accidental events’ influence on the study.

In the summary reports, three charts of information are helpful in our study, and are represented in different ways: first, Watershed characteristics chart, which includes Watershed name, watershed type, watershed area, watershed description, soil description, land use description and vegetation description. We can have an initial impression on the watershed itself by reading this chart.

Second, BMP design information chart. In this chart, a lot of BMP specific design information including but not limited to slope, swale length/width, plant species and maximum flow capacities are listed in detail. With the detailed information provided in this chart, we are not only able to have an initial impression on the BMP but can also list pros and cons of certain BMP design.

Third, Precipitation and volume summary chart. Climate statistics, precipitation statistics, volume statistics accompanying with annually time span for inflows and outflows (three factors) are represented in detail in table form. General statistics, including means, standard deviations and variation coefficients, are also reported. This chart is where we take the statistics to analyze and summarize.

During our analysis, we mainly extract information from the three charts introduced above from the database. What is worth to notice is that although the public BMP mapping tool can help provide a lot of information, there are also a lot of intact information shown as N/A on the summary reports (and in our analysis too) especially among east and west coast of the U.S., since the information are national secrets flagged by the website.

B. Data Analysis

First, we picked *typical* sites with summary reports with as much information represented. Throughout all 84 sites bio-retentions inside the U.S., there are about 10 sites with all of significant information, including storm relative parameters, seasonal precipitation events, seasonal inflow/outflow/overflow events, land use type and plant species choice.

Second, we chose two pairs (4 sites total) of closely related and comparable sites with characteristics summarized in Table I. Fig. 3 below are the geographycal imformations of these sites.

What is worth noting that there have already been statistically analyzed data, both present in the summary reports (also cited in Table I below) and on the website “BMP statistics analysis tool (directly below the BMP mapping tool we used)”. Therefore, it should be safe to assume the observation data analyzed in this study is statistically sound.

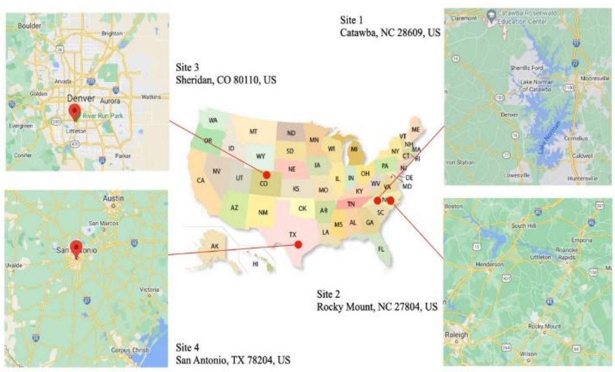

Fig. 3. Geographical locations of selected sites. White color represents urban/impervious/highway land; Green color represents plant cover; Blue color represents water bodies. Via google map.

TABLE I: SITE CHARACTERISTIC SUMMARY, INCLUDING GENERAL INFORMATION, CONCRETE AND DISCRETE PRECIPITATION RELATIVE STATISTICS, AND COMMENTS ON BIO-RETENTION DESIGNS

Site #	A1	A2	A3	A4
GI type	Bioretention	Bioretention	Bioretention	Rainwater harvesting + Bioretention
Location	Catawba, NC 28609, US	Rocky Mount, NC 27804, US	Sheridan, CO 80110, US	San Antonio, TX 78204, US
Year(s) considered	2003-2004	2009	2014-2015	2017
Common.				
Watershed area (ha)	0.53	0.247	23.5	0.0579
Retention depth (cm)	85.3	NA	45.7	NA
Retention surface area (m^2)	409	NA	397	NA
Percent impervious	46.0	76.0	58.7	100
Precipitation concrete.				
Annual storm number	63	62	32	39
Annual precipitation (cm)	40.8	40.1	13.7	28.6
Storm duration (hrs.)	9.5	9.6	11.2	8.9
storm intensity (cm/hrs.)	0.098	0.099	0.067	0.125
Period between storms (hrs.)	141	144	290	230
Precipitation Discrete.				
Precipitation events No.	13	73	28	27
Average depth (cm)	1.83	1.41	0.776	2.5
Minimum depth (cm)	0.457	0.246	0.127	0.254
Maximum depth (cm)	5.63	12.1	3.17	9.88
Standard deviation (cm)	1.42	1.58	0.631	2.52
Inflow discrete.				
Inflow number	13	73	52	25
Average volume (L)	79470	27537	42000	4368
Minimum volume (L)	27631	379	1000	0
Maximum volume (L)	190427	295569	395000	27936
Standard deviation (L)	47937	39941	69000	7218
Outflow discrete.				
Outflow number	13	73	28	25
Average volume (L)	85817	84	17000	5548
Minimum volume (L)	26608	0	0	0
Maximum volume (L)	222179	4617	128000	69315
Standard deviation (L)	56434	566	31000	15466
Comments.				
Description 1 on inflow and outflow	Inflow and outflow arrangements are average through the year.	Inflow and outflow arrangements are average through the year, when inflow is far heavier than outflow.	Inflow and outflows concentrated between May to September, and a few during October. Inflow is heavier.	inflow prefer October when outflow prefer March; 25 overflow events happened with low volume.
Description 2 on vegetation	Daylily, mulch, "various water tolerant plants"	Centipede turf in grassed medians & shrubs/perennials in bioretention cell	Sand bluestem; Sideoats grama; Prairie sandreed; Indian rice grass; Switchgrass; Western wheatgrass; Little Bluestem; Alkali sacaton; Sand dropseed	All area impervious, with tree canopy coverage

III. Discussion

A. Separately Comments and Brief Comparison on the Sites

1) Site 1 information

Catawba is a watershed located in south-east America, near to Gulf of Mexico. Lake Norman is located downstream the watershed and Catawba River flows from northeast to southwest. The climate of the location is just between temp-monsoon climate and temp-oceanic climate, which means precipitation is average all year long, and the volume of precipitation is neither flood nor drought.

According to the report, the land of the site is 46 percent impervious, which means the outflow including infiltration are slightly more than the inflow, and the overflow is not likely to happen frequently. Thus, the main target of the bioretention is to slow down the surface runoff and also keep the water flowing down in a high quality (introducing oxygen and reduce pollutants) [7].

Let's see the plant choices. Daylily is the representative plant of "water interactive plant" of the site, marked by the report. There are three major advantages for its effect: first, daylily is with wide and long stripe-shape leaves, which means both high transpiration and high photosynthesis, thus fit this site's feature that needing the plants to provide oxygen for the outflow [8]. Second, daylily is with fleshy and deep root, which stores water and able to reach deep to catch water, thus can reduce infiltration heavily [9]. Last, since the plant is perennial, these two features can help daylily be more water tolerant and survive in a medium-high density in this site, which corresponding to the report's content- "the plants covering do not reduce from 2004 to 2005".

2) Site 2 information

Rocky mount is quite near with site 1. What is different is, this site is located downstream to Lake Norman, closer to the ocean, and according to Dewangan and Merotra [10], more area urbanized which means more area impervious (76 percent). These characteristics calls for the main target of this bio-retention, that is buffer the inflow and overflow.

Compared to the first site, this site chooses two types of representative different plants, including 1) centipede turf grasses and 2) shrubs. Centipede turf grasses' advantage is high resistance to all kind of harm, including frost, flood, sandstorm, and drought, according to Hirata and Kunieda *et al.* [11]. Also, it can form very dense turf, which have higher ability to absorb water near the ground than daylily. Thus, it is a more effective buffer plant compared to daylily [Hirata 2010]. Shrubs, in another aspect, according to Shihang and Lixia *et al.* [12], mainly function on its root system, which is able to split in high rate and bent. This root system, can help split soil particles smaller, improving the soil water capacity and slowing down the flows [12]. These two types of plants, corresponding to other water tolerant plant like daylily, are able to reach target above.

3) Site 3 information

Site 3 is located near Denver, Colorado with no major water source, such as lakes or rivers near it. Theoretically, the climate of Colorado is known as continental Semi-Arid, since it is located in central America. However, the actual climate is closer to "temperate monsoon climate", as we see there are medium amount (less than site 1 and 2, of course) of precipitations and storms, and flows are even heavier than prior sites.

This climate, which is partially different with theoretical condition, may reason from below points, referring from Kyle and Reza *et al.* [13]: first, this site is located on the trans-section of oasis and hills, where temperature near ground differs. This difference will cause convection and precipitation. Second, this site is located on eastern foot of Rocky Mountains (major mountains of America). A necessary reason of a location with characteristics of monsoon climate is to locate on the eastern foot of mountains. Last but the most important, the watershed area is far larger than previous watersheds (~50-100 times larger), so the total counted precipitation is expected to be a high value.

We can notice that most of the listed plant choices belongs to the family Poaceae. They are with similar characteristics and benefits on the bio retention, according to Claudia and Cosimo *et al.* [14]. Let's use Sand bluestem as example to describe how the plant choice can benefit the site, referring from Claudia and Cosimo *et al.* [14]:

Sand bluestem is perennial grass which can reach more than 2 meters high and can grow in high density. Both the height and the density mean the temperature near ground will be stabilized due to isolated air between the stems. Also, there will be heavy shade near the ground, helping the site to reduce heat radiation accepted thus evaporation. The root of the plants are fibrous roots, when the primary root is thin and deep, allowing the plants grow in high density; and the fibrous root systems are wide and complex, allowing the plants improve the soil water capacity and then reduce infiltration.

Another important point is that Poaceae plants are with important biology niche [14]. Under wild conservation area/retention sites, this plants family can act as high-quality pasture and staple food for the animals, helping stabilize the ecosystem.

4) Site 4 information

Similar to site 3, site 4 is also with no lakes or rivers near it. However, the site is closer to the ocean (Gulf of Mexico). Thus, the precipitation will be somewhat more frequent than site 3, similar to site 1. In the other word, we can say that site 4 will be like the combination of site 1 and site 3, and both sites' climate features apply on it.

For this site, we can notice that the landscape is fully impervious, which means that the infiltration rate is low, and this area generate higher inflow as compared to other less impervious areas. This is common in urbanized area or residential area, which matches what we see on the map and the summary reports.

As for the view of designing GI, this site is a counter example-low density tree coverage is not as good as high-density grass coverage: first, grass plants often develop higher density root system, increasing organic matters concentration in the soil, improving water capacity of the soil, thus stabilize the hydrology of the site and reduce overflows/soil erosions [14]. Second, High density grass plants will be more able to stabilize temperature near ground, thus reduce convection and adjust precipitation.

Tree coverages, however, have their advantage according to Bei and Liang *et al.* [15]: first, tree coverages will need less and lower frequency maintenance than grass coverage, which reduce the cost. Second, in urban/residential areas, the tree coverages will satisfy more human needs, including tidiness, shades, and less grass-pests (ticks, as example). Last but the most important, tree coverages do meet the basic needs when we build bio-retentions-adjusting runoff, although with different mechanisms compared to tallgrasses, according to Qiao and Zou *et al.* [16].

In conclusion, for site 4, we know that low density tree coverage is not good as high-density grass coverage when considering hydro-adjusting performance of GI, but it is with human-based advantages when utilized in urban/residential areas.

B. Potential Errors and Further Research

It is worth noting that there are two limitations in this research: on one hand, due to limited human power and relatively small database (less than 100 available sites), majority of the results that we had drawn are specific to the sites and hard to recurrent, objectively due to the limitation announced above. On the other hand, parameters analyzed in this study is also limiting, including only site basic information, precipitation information and plant choice information. Instead of building a whole statistical model, we could only choose to report the plant choices for the sites one by one, in order to include as many parameters and connections as possible.

Considering the limitations mentioned above, a few potential improvements can be made in the future. One of the improvements is that we can also create scatter plots and apply linear regression tests on a single site and a long time period, to test if the specific plant choice meets the specific need of the site. Above all, we should try to find a larger database (more than 1000 sites and across over 50 years) with variety of sites, in order to found some statistically significant results.

IV. Conclusions

As a conclusion of this study, although only four sites are compared and analyzed in detail, we have reviewed a lot of GI examples to learn how and why plant choices are important when designing bio-retention. During the process, we have analyzed precipitation, flow volumes, land use and site locations, and tried to explore GI performances related to climate, site characteristics, GI design and plant physiology structures, etc. All these factors affect the GI performance to some extent, while plant selection is the one that has been least studied about. Future study on this topic could bring tremendous benefit to storm water management design and planning projects.

Conflict of Interest

The author declares no conflict of interest

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