Title: Evaluation of the Environmental Impact of Using Alternative Materials for Rain Garden Design

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Program(s) applying for: Either program will fit my needs and eligibility.

Have you received either the Mills Scholarship or USGS Research Program funds before? No.

Would these funds be initiating new research or supporting ongoing research? These funds would be initiating new research.

Focus categories: conservation (COV), surface water (SW), groundwater (GW)

Research category: Water Quality

Keywords: urban soils, low impact development, rain garden, bioretention media, stormwater management, water quality, recycled waste materials

Congressional District: 17th

Abstract:

Expected urban population growth in Texas over the next fifty years will likely result in a greater area of impervious surfaces that promote stormwater runoff and subsequent flooding. There is an increasing need for management strategies that protect existing surface and ground water resources and reduce water loss from urbanized areas. Rain gardens capture stormwater to improve water quality and promote groundwater recharge, but mined sand is often brought in to increase infiltration. However, the availability of mined sand is expected to decrease in the future. A need exists for research testing the suitability of alternative products, such as recycled waste materials, in rain garden design. A greenhouse experiment is proposed to address the following objectives: 1) test three novel rain garden media on their ability to capture, filter, and retain stormwater; 2) quantify the ability of different plant types to filter infiltrating stormwater; and 3) evaluate the impact of these systems on surface and ground water quality and quantity using the Soil and Water Assessment Tool (SWAT). The proposed research aims to improve rain garden design as part of a sustainable approach to urban water conservation to secure Texas water supply by reducing stormwater runoff and improving water quality.

Description of your proposed research:

Statement of critical regional or state water problem:

Texas is facing a 73% increase in population by 2070, with over half of this growth occurring in the Dallas-Fort Worth, San Antonio, and Houston areas (Texas State Water Plan, 2022). Increases in urbanization result in a greater occurrence of impervious surfaces that are linked to a decrease in on site infiltration which leads to greater runoff, increased peak discharge, and decreased time to peak discharge during storm events (Nirupama and Simonovic, 2007; Kjeldsen, 2010; Feng et al., 2021). Stormwater runoff decreases the potential for base flow and groundwater recharge and carries with it excess sediment, nutrients, and contaminants that pollute surface water (Seo et al., 2017; Jiang et al., 2019). Ultimately, urbanization has increased the frequency and severity of urban flooding (Feng et al., 2021).

The growth of urban areas in Texas is expected to coincide with both an increase in water demand and a decline in Texas' water supply (Texas State Water Plan, 2022). It is critical for action to be taken in order to curb water loss, increase groundwater recharge, and improve water quality. If water management and conservation strategies are not implemented, upwards of 25% of future Texans will have less than half of the municipal water supply they require during a drought of record (Texas State Water Plan, 2022). Surface water makes up two thirds of the total existing water supply for municipal, manufacturing, steam electric, and mining purposes in Texas (Texas State Water Plan, 2022). However, Texas is seeing a decrease in existing surface water supplies largely caused by a decrease in reservoir storage capacity due to sediment deposition from excess stormwater runoff flowing into local watersheds (Texas State Water Plan, 2022). There is an ***increasing need*** for Texas municipalities to conserve water by implementing water management strategies aimed at protecting existing water resources and reducing water losses.

Low impact development is often used to mitigate the negative effects of urbanization on stormwater management. Rain gardens are one method of low impact development that reduce runoff and filter stormwater to remove sediment and pollutants before reaching local water bodies, with the ultimate goal of increasing water supply by promoting groundwater recharge (Seo et al., 2017; Tirpak et al., 2021). Typical rain garden design features a soil media that is sand-based to promote infiltration, yet contains some fine particles and organic matter for water filtration and plant growth. To meet these requirements a soil high in sand is often brought in. However, sand scarcity and the sustainability of sand mining is an emerging issue, especially as the demand for sand in concrete, glass, and electronics production is expected to rise as urbanization increases (Asabonga et al., 2017; Torres et al., 2017). Environmental degradation has also been linked to sand mining, including changes in water and sediment transport causing stream bed elevation changes, disappearance of rivers, groundwater pollution, and harm to fish and wildlife (Piyadasa, 2011; Padmalal and Maya, 2014; Farahani and Bayazidi, 2018). Furthermore, there is also uncertainty regarding the ability of this natural resource to meet renewal rates to keep up with demand (Fig. 1) (Gavriletea, 2017). The uncertainty of the sustainability of sand in the future requires research to be conducted on the use of alternative, recycled urban waste materials in rain garden design that will conserve water by reducing losses associated with runoff and protect existing water resources to secure the future water supply for Texans. Using recycled materials also has the advantage of less waste in landfills which is important considering the amount of municipal solid waste is increasing (USEPA, 2021). Issues such as environmental and water quality concerns (Su et al., 2019; Vaverkova, 2019; Gabryszewska and Gworek, 2021) and decreasing amount of space in landfills (Poon et al., 2004; Kollikkathara et al., 2010) are another driver for the use of alternative, recycled materials.

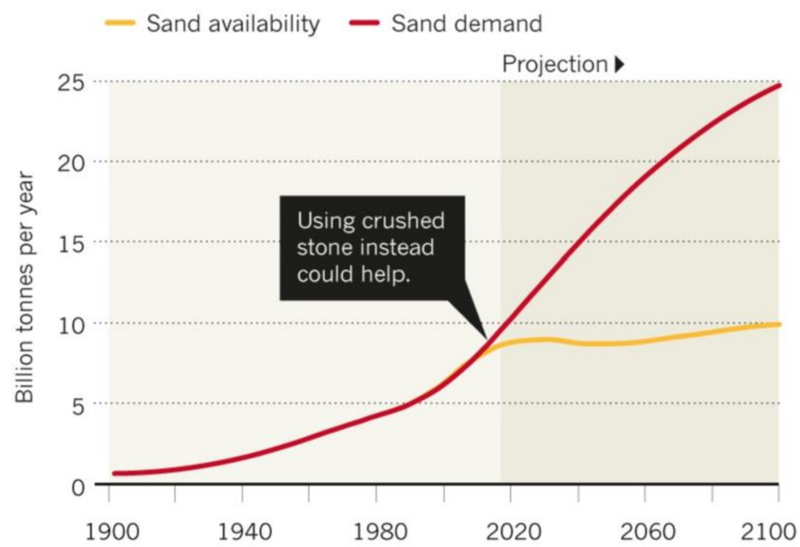

Figure 1. Projection of sand availability from 2020 to 2100. Disparities in supply and demand will require alternative materials to fill the void. Taken from Nature 2019.

Statement of expected results or benefits:

Successful completion of this project will result in a rain garden design that uses nondegradable, recycled urban waste as a soilless media to meet water conservation needs in the state of Texas and reduce pressure on sand resources. Novel information will be gained regarding the effects of the use of alternative rain garden materials on stormwater flow rates, retention times, and nutrient and pollutant removal by adsorption and plant uptake. Through watershed-scale modeling with SWAT, we will also gain insights into the long-term impacts of these designs on water and watershed quality. The potential benefits of this study include an environmentally friendly alternative to sand for rain garden design, recommendations of plant types able to best filter stormwater of contaminants, and a determination of the effects of low impact development on watersheds using SWAT with the two-fold goal of reducing local water loss and protecting existing water resources.

Nature, scope, and objectives of this research, including a timeline of activities:

The ***goal of this project*** is to provide an environmentally friendly rain garden design to enhance the capture and filtration of stormwater runoff to help secure water resources for Texas municipalities while simultaneously reducing landfill waste and pressure on sand resources. The information gained from this study has the potential to benefit Texas municipalities, as well as urban areas outside the state facing similar stormwater issues and water shortage crises. Our project goal will be accomplished through three objectives:

Objective 1: Compare three different rain garden soilless media containing nondegradable, recycled urban waste materials against 1) a typical sandy loam rain garden mix as recommended in *Stormwater Management: Rain Gardens* by Texas A&M AgriLife Extension, and 2) a sandy loam soil without rain garden features to understand how these systems capture and filter stormwater during rainfall events.

Objective 2: Quantify the ability of three different plant types: 1) perennials, 2) grasses, and 3) shrubs in their ability to remove harmful nutrients and pollutants from stormwater that infiltrates the rain garden media.

Objective 3: Evaluate rain garden design performance on surface and groundwater quality and quantity at the watershed scale using the SWAT model to determine environmental impacts and the ability of recycled urban waste to reduce local water loss and protect existing water resources.

Timeline:

Month	Task
Sept-Nov 2022	Obtain materials to construct rain garden soil columns; Preliminary tests on recycled material mixes to determine ratios of amendments to meet rain garden infiltration requirements; Assemble soil columns
Dec 2022	Grow-in period for plants to become more established
Jan-May 2023	Rainfall simulation experiments
May-June 2023	Modeling with SWAT
July-Aug 2023	Project completion, dissemination of results

Methods, procedures, and facilities:

With experience in applied soil physics, hydrology, and ecohydrology, and with guidance from *Stormwater Management: Rain Gardens* by Texas A&M AgriLife Extension, this team sets to accomplish the main objectives of this project by the following methods:

Objective 1: A greenhouse experiment will be conducted on three recycled urban waste materials, crushed concrete, blast furnace slag, and glass cullet, to test their applicability in rain garden design. Crushed concrete is concrete that has been excavated or demolished during construction that has been broken down into aggregates (Kawalec et al., 2017). Blast furnace slag is a by-product of crude iron production that has been rapidly cooled and subsequently ground or turned into granules (Bellman and Stark, 2009). Glass cullet is made from crushing post-consumer glass into a wide variety of granule sizes (Dawson, 2012). All recycled materials used will be sourced locally in Texas and mixed with Gelscape Professional (Amereq, Inc. New City, NY) and compost to create a soilless media that is an environmentally conscious alternative to "bringing in" sand. The three recycled mixes will be compared against a typical sandy loam + compost rain garden design and a sandy loam soil without rain garden features. To test these rain garden media mixes, columns (5 soil mixes × 3 plant types × 3 reps for a total of 45 soil columns) that are 90 cm tall x 15 cm in diameter will be constructed according to the guidelines of rain garden design specified in the *Stormwater Management* guide. Rain garden columns will be layered with 30 cm of gravel (2.54 to 3.81 cm diameter), 45 cm of fill mix, and 5 cm of well-aged hardwood mulch. The soil columns will contain 80 cm of sandy loam soil only. Rainfall collected at Texas A&M University will be added to the soil columns to replicate a 2.54 cm precipitation event, which reflects the storm intensity for which most rain gardens are designed for. Outflow will be collected during the rainfall event, hourly for 6 hours after, then again at 24 and 48 hours after the rainfall event to calculate infiltration rate and to test for total dissolved solids, pollutant, and nutrient concentrations. The water content of the soilless media will be monitored by weighing the soil columns daily. At the end of the rainfall simulations, a subsample will be collected from each column to determine the particle size distribution and water retention characteristics of each material. Preliminary study will be required to determine the satisfactory quantities of recycled materials necessary to meet rain garden infiltration requirements.

Objective 2: In addition to each of the soil columns described in Objective #1 there will be replicates with three plant type treatments including: perennial, grass, and shrub. Overall plant growth will be examined to determine if the recycled urban waste materials are suitable growth mediums. Each of the treatments will be tested on their ability to remove nutrients and pollutants from stormwater and the rain garden medium. A grow-in period of three weeks will be allowed for plants to become established before rainfall simulations begin.

Objective 3: In order to understand the environmental impacts of the rain garden designs tested in this study at the watershed scale, simulations will be performed with the SWAT model. We are specifically interested in the ability of these designs to improve the quality of local watersheds, such as the Lower Brazos River, and the contribution to groundwater recharge which are both critical for urban water conservation in Texas. Thus, we will focus on the effects of rain garden development in urbanized sub-watersheds within the Lower Brazos River Flood Planning Region as defined by the Texas Water Development Board (Fig. 2) for the modeling portion of the study.

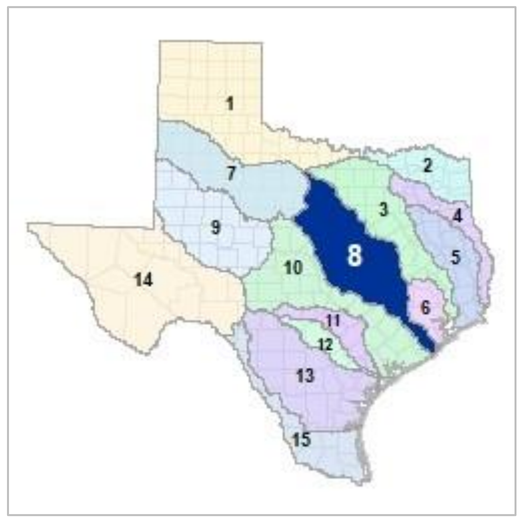

Figure 2. Texas Flood Planning Regions as defined by the Texas Water Development Board. Region 8 is the Lower Brazos Region.

Related research:

There have been several studies testing different recycled waste materials as soil amendments in rain gardens including waste water treatment residuals (Guo et al., 2015), fly ash (Zhang et al., 2018), cockle shell (Goh et al., 2017), and iron fillings (Weiss et al., 2016), among others. Blast furnace slag in rain garden design has proven to be effective at nutrient and heavy metal removal from solution (Oguz, 2004; Li et al., 2016) but less effective at reducing runoff rate (Yang et al., 2021). In a study by Rahman et al. 2016, recycled asphalt and crushed brick were deemed satisfactory when it came to meeting criteria for filter materials in bioretention systems. While recycled glass as part of a biofilter rain garden mix was shown to increase removal of total suspended solids and hydraulic conductivity, but had no significant effect on pollutant removal

(Shahrokh Hamedani et al., 2021). The ability of a recycled material to capture and filter stormwater varies greatly depending on source, components, and consistency of materials (Marvin et al., 2019). Relatively few studies have been carried out using nondegradable, recycled urban waste such as blast furnace slag, crushed concrete, and glass cullet as rain garden media, and even fewer studies have tested soilless media in rain garden design. To our knowledge, no studies have been done to test nondegradable, recycled urban waste as a soilless media for stormwater management in rain garden design. Thus, the proposed study would provide ***important new information*** useful for developing recommendations regarding rain garden design. This research aims to fill in the knowledge gaps and expand our understanding of the utility of nondegradable, recycled waste as a soilless media in rain garden design for stormwater management in Texas municipalities.

Training potential: One PhD student and one undergraduate student will be involved in this project.

Intended career path: After graduation the student plans to continue working with urban soils either at the university level or industry. She is particularly interested in understanding how engineering soils in urban areas can help improve soil function whether it is for water conservation, plant growth, environmental concerns, or recreational needs.

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