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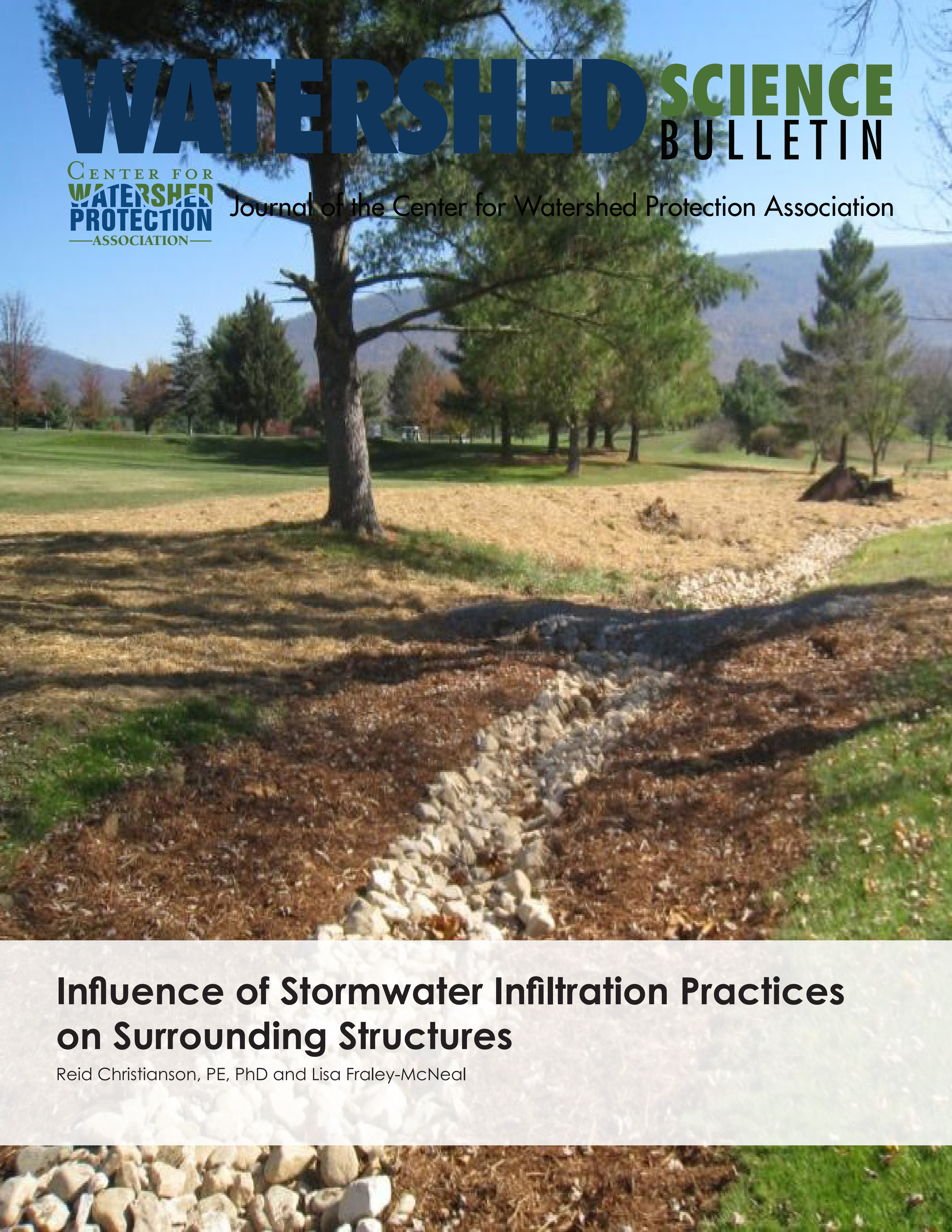

Influence of Stormwater Infiltration Practices on Surrounding Structures

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Influence of Stormwater Infiltration Practices on Surrounding Structures

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Abstract

Infiltration areas for stormwater management have the same hydraulics as natural groundwater recharge and infiltration areas designated for aquifer storage and recovery projects. Work on infiltration and groundwater movement has been going on for years, making the available knowledge base fairly wide. Differences, however, arise in the intended use of the practice/area. While the goal of groundwater recharge is to promote a more sustainable and cleaner groundwater source (possibly water banking for dry times), the goal of stormwater infiltration practices is to harvest stormwater (leading to reduced discharge volume and enhanced water quality) in order to meet stormwater regulations. For stormwater practices, concern about the appropriate design criteria generally stops at sizing the structure to meet pollutant removal goals, maintain groundwater recharge, pass extreme floods, and reduce downstream channel erosion. Investigating the impact on surrounding structures like parking lots and buildings, through exploration of groundwater mounding, provides in-depth understanding of cautions and considerations for stormwater infiltration practices. An example of a stormwater infiltration site in Mission, Kansas is provided in this paper. At the Mission site, Visual Bluebird groundwater modeling software was used to identify potential areas of concern for groundwater mounding. In addition to the modeling approach, several guidelines are also provided to help identify areas with a higher likelihood for groundwater impacts following the case study.

Introduction

Stormwater regulations across the United States stipulate runoff from developed and developing areas must be treated. Although treatment requirements vary with jurisdiction (state/county/city), stormwater infiltration has become a popular technique to address runoff volume, baseflow, peak flow rate, and water quality. Infiltration practices reroute stormwater to designated locations, with the express purpose of filtering out pollutants by various natural processes as the water moves through specially-designed filter media. The reduction of peak runoff rates helps protect receiving streams from erosion, and the infiltration of water has the potential added benefit of groundwater recharge.

In addition to the benefits of stormwater infiltration practices, there are a number of concerns associated with groundwater impacts, including localized increases in the groundwater table and seepage into nearby basements (MSM 2015; Carleton 2010). This is particularly true for practices without an underdrain where water may not infiltrate as quickly. When water is absorbed into the soil and nears the groundwater, a mound (Figure 1) forms before water flows horizontally due to an induced gradient. This process is called subsurface spreading; subsurface spreading effectively increases the soil surface

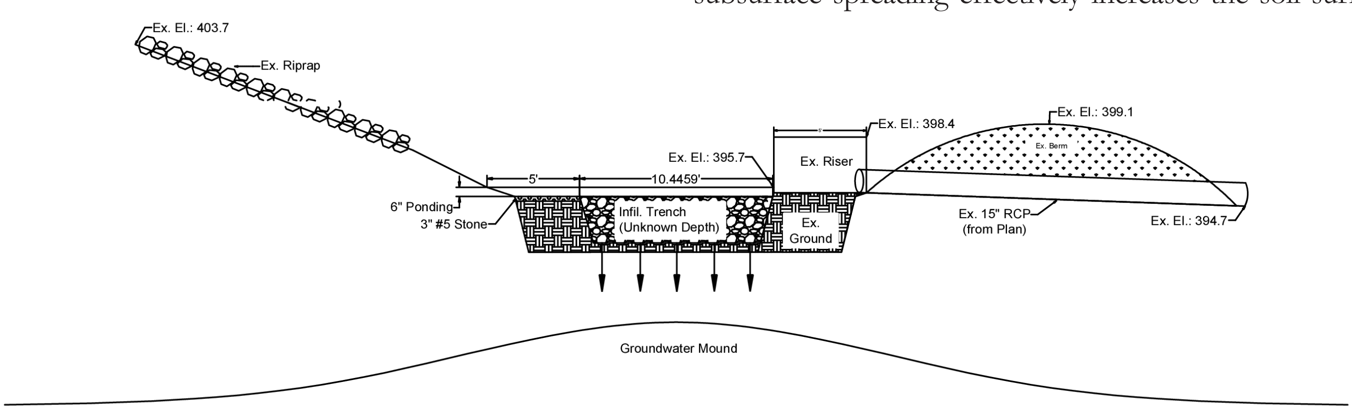

Figure 1: An example groundwater mound beneath an infiltration trench.

area available for water transport. As water moves horizontally, soil previously dry soil can experience drastic swings in water content. This changing water content in the subsoil can potentially result in soil heave or collapse and impact surrounding structures, as further described in the next section. Examples of groundwater mounding in urban areas under hypothetical infiltration basins can be found in Carleton's 2010 U.S. Geological Survey Scientific Investigations Report.

For new development, these issues are typically mitigated by minimum setbacks (MSM 2015; MDE 2009), which tend to be conservative and assure no damage will occur to surrounding structures. However, when installing stormwater management practices in response to a watershed initiative or a total maximum daily load (TMDL), previously developed land is often targeted. As this land already complied with stormwater regulations during development, any new stormwater management is considered a "retrofit," or a stormwater practice squeezed into the existing infrastructure. Minimum setbacks are often hard to achieve in available—often confined—areas. For general information about the retrofitting process, see Schueler et al. (2007). These retrofits are primarily focused on enhancing water quality and reducing the discharge volume from small storms to meet the goals of the local watershed initiative, TMDLs, or municipal separate storm sewer (MS4) permits. Evaluation of a site's stormwater retrofit potential generally ends with calculations to determine overland flow conveyance. Investigating the impact on surrounding structures, along with groundwater mounding, will provide a more in-depth understanding about the suitability of stormwater infiltration practices designed for retrofit purposes. This inspection should include soil type, linear distance to infiltration area, and amount of water infiltration.

Evaluation is needed of the potential for negative impacts due to smaller stormwater infiltration practices installed as retrofits in previously developed areas that may not be able to meet the minimum setbacks established for new development. A modeling approach is presented using an example location in Mission, Kansas to provide further insight into these practices. Although the approach requires a level of effort not normally required for new development, it provides method evaluate a site for retrofit potential when minimum setbacks cannot be met and damage to surrounding structures is a potential concern. Recognizing that a modeling approach will add to the already high expense of stormwater retrofits and may not be a feasible option, several guidelines are also provided to help identify areas with a higher likelihood for groundwater impacts.

Influence of Infiltrating Groundwater on Surrounding Structures: Background

Generally, soils are compacted before construction occurs to provide a stable foundation for building, with unstable soils removed and replaced with fill. Compaction is necessary to support loads from traffic or the weight of a building. Changing water contents in the subsoil through stormwater infiltration and subsequent groundwater mounding is a problem because expansive clays used as a base material may have an allowable 3% volume change (Department of the Army 1992) and the addition of water beneath the compacted zone could cause soil collapse (Houston, Mahmoud, and Houston 1993).

Soil Heave

The presence of expansive clays can cause foundation soils to heave (or swell) and lift nearby buildings and other structures during periods of high moisture. The processes that drive soil water content include infiltration, which moves water into the soil, and evapotranspiration (ET), which dries the soil. This swing in water content over an extended period of time can increase the soil volume change if the expansive soil is at or near the surface. Potential swell in soils can be qualitatively measured as Very High, High, Medium, and Low and is usually related to the plasticity index or liquid limit (Raman 1967, as reported by Nelson and Miller 1992; Chen 1988; Holtz and Gibbs 1956).

Soil Collapse

Another consideration with moisture content swings in soils due to infiltration practices is soil collapse. Collapse is a process where the shear sheer strength of a soil decreases during wetting and, if under a substantial load such as a building, the soil can compact (Houston et al. 2001). Though urban soils already tend to be more compacted due to development activities, the combination of concentrating water to a single location for infiltration and heavy loads provided by buildings is potentially worrisome (Ibid 2001).

Freeze/Thaw Cycle

The freeze/thaw cycle is another extremely important phenomenon in certain areas of the country. When water freezes and expands, heaving occurs, which can destroy pavement. Additionally, temperature fluctuations during the freezing process can cause ice lenses, which produce large amounts of heave (Department of the Army 1992).

This process is called ice segregation and requires a continuous supply of water to keep growing. According to the Department of the Army (1992), all fine soils (silts and clays) are susceptible to frost heaving.

Methods to Assess Impact

A modeling approach can provide insight for identifying areas where groundwater mounding—and subsequent soil heave or collapse—may be a concern. There are many current models that provide estimates for groundwater mounding, including the WhAEM2000 (Kraemer et al. 2007), GFlow (Haitjema Software 2015), and TimML (Bakker 2010) models. Historically, groundwater models are not entirely suited for stormwater infiltration practices (Warner et al. 1989) because the foci of these models tends to be bulk groundwater movement. Groundwater aquifers that are thick are able to dissipate infiltrating water. Alternatively, aquifers with low thickness are less able to dissipate the water (Carleton 2010). It is beyond the scope of this paper to develop a model or computations encompassing the proper boundary conditions that exclude the presence of an aquifer. Instead, a ground water model was used for the case study example presented in the section below from Mission, KS, to provide a rough estimate of groundwater mounding and compare the potential risks for impacts to surrounding structures. As the intent is only to assess potential risk, a groundwater model representing mounding will suffice.

Once potential groundwater mounding areas have been identified, predicted heave or collapse can be determined by calculating potential swell in layers beneath the structure and accounting for the force produced by the structure in contact with the soil. The forces produced in this process can be estimated by examining soil properties measured in a laboratory setting and a modeling approach to estimate forces (Aytekin and Wray 1993). Nelson and Miller (1992) also propose a method for this calculation, which includes a force balance, information about the soil, depth to the clay layer, depth to the water table, and total unit weight of the soil. Additionally (Ibid 1992), determining the depth of soil that is actively gaining and losing water is important in order to make estimates about how soil moisture will change under a given structure. For purposes of site investigation, a collapse versus degree of saturation relationship can be established to help determine the importance of the process on infiltration area considerations (Houston et al. 1993).

Case Study Example

The Visual Bluebird (Craig and Matott 2005) software package provides estimates of groundwater mounds, which were used for the investigation of structure stability near infiltration basins at a site evaluated for potential implementation of stormwater retrofits in Mission, KS. The evaluated site (Figure 2) included a wetland (structure A), a bioretention cell (structure B), and a dry pond (structure C). Concerns arose from building owners and operators about the installation of unlined and undrained systems. As each stormwater practice was modeled as an infiltration/recharge area, it was determined that water must pass through the soil profile at the bottom of the stormwater practice before reaching groundwater. Output from this model included groundwater flow direction and velocity (Figure 2), as well as groundwater mounding (Figure 3) and travel distance (Figure 4 and Figure 5). These visual output examples can be used to highlight potential areas of interest.

Values for model input included saturated hydraulic conductivity and depth of groundwater taken from the Soil Survey of Johnson County, Kansas (1979) with assumptions made for infiltration area saturated hydraulic conductivity. Since no actual aquifer data was used, an estimate for model input was made with a conductivity of 0.37 m/day and a thickness of 0.10 m (to minimize the effect of groundwater) was used. Saturated hydraulic conductivity of infiltration practice B was set to 0.60 m/day based off of measured saturated hydraulic conductivity data (using double ring infiltrometers in stormwater management practices) in the area, while A and C were set to 0.40 m/day since these facilities will likely be more compact.

A worst case scenario approach was taken in order to highlight areas for further investigation by assuming saturated conditions when setting up the model. Although this setup likely over-predicted groundwater mounds, results can be used to focus on areas of interest. Results showed buildings 1 and 4 and the parking lots around infiltration areas B and C (Figure 3 and Figure 4) warrant further investigation. Building 1 and the southeast corner of building 4 could possibly be impacted by swelling if too much water contacts relatively dry clay.

Considering the saturated case makes it possible to add a factor of safety to structure damage prediction since soil properties were largely unknown beyond information available in the Soil Survey. Evaluating at saturation also

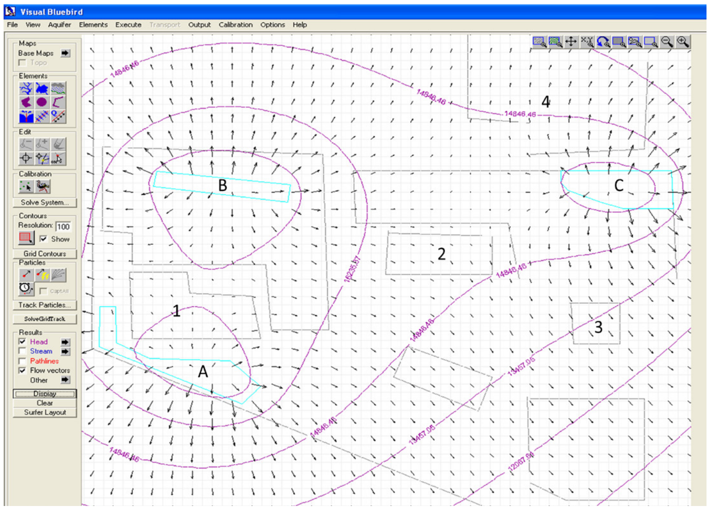

Figure 2: Flowlines with potentials (arrows indicate flow direction; longer arrows indicate higher flow velocity). This situation is considering infiltration from three sources. Numbers are buildings while letters are infiltration areas.

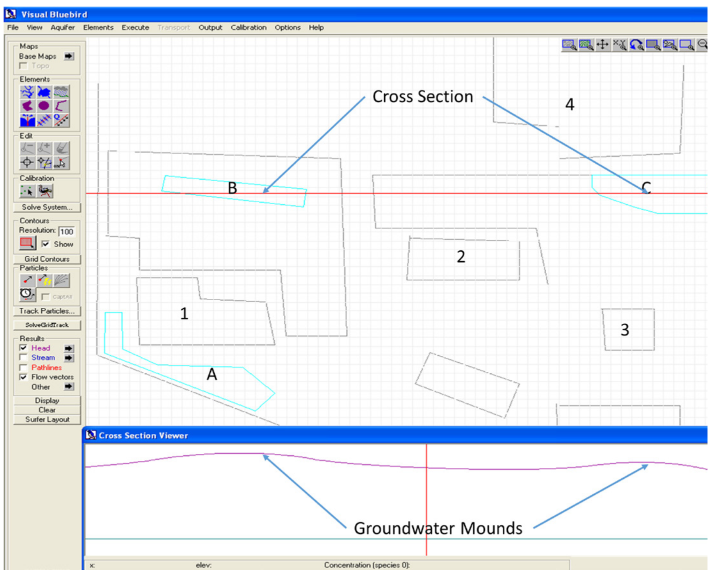

Figure 3: Cross section view of groundwater mounds considering infiltration areas B and C.

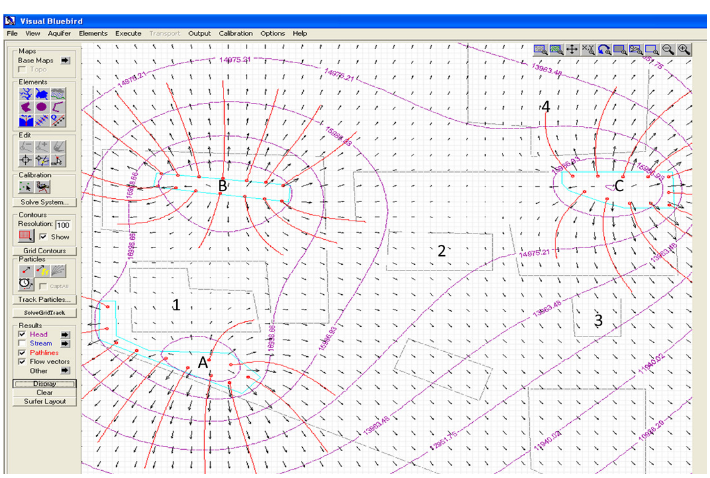

Figure 4 shows maximum water droplet movement over a one day period and shows approximately 50 m of travel.

allows for velocity calculations and minimum pollutant transport times.

Further investigation into the buildings of concern (1 and 4) involved the estimation of potential swell/collapse. For the purposes of this case study example, collapse was only considered as a contrasting condition to swelling. Freeze/thaw was not considered because it was assumed that the soil conditions at this site will be such that soil temperature is buffered and water content is low during freezing temperatures.

The potential swell/collapse calculations described in Nelson and Miller (1992) were done manually by setting up a simple spreadsheet. The difficult part of this method is the determination of soil properties. Although they can be determined from field and laboratory methods, the values used for this case study were obtained from Nelson and Miller (1992) and Chen (1988). Soils at the example site location in Kansas have a plasticity index of between 20% and 35% (Soil Survey of Johnson County, Kansas 1979), which correlates to a medium or high expansion classification. Expected volume change from dry initial soil conditions would likely be around 20% (Holtz and Gibbs 1956). To put this into perspective, 10 cm of soil swelling 20% with the sides and bottom confined (i.e. it can only expand vertically), would reach 12 cm tall after thoroughly saturated and fully expanded.

For building 4, analysis (Table 1) shows slight collapse rather than expansion might occur. This was due to the approximately 30.5 m distance between the wetted soil and the building, which allowed for swelling forces to be offset by collapse. Including infiltration practice C near building 4 results in very little structure risk.

Table 1: Heave potential for building 4. Positive potential (ρtotal)[1] indicates possible small amount of settling (collapse) but no swelling.

Soil Layer	**Depth (m)**	**ρ (m)**
Surface	0	0.00
1	3.05	0.00
2	7.62	-0.23
3	15.24	-0.09
4	30.48	0.35
	ρtotal	0.02 m 2.08 cm

[1]The magnitude of potential heave can be determined by its comparison to the depth of active soil. The positive potential (ρtotal) of 2.08 cm for building 4 in relation to a 30.48 m depth of active soil is considered small, as the potential heave is 0.07% of the active soil depth.

Using the same swell and load parameters but changing the depth of active soil to match estimated groundwater mounds under building 1 (~7.6 m) revealed the potential for nearly 25 cm (ρtotal = -24.32 cm) of heave due to swelling (Table 2). With high risk at building 1, further review of soils and more accurate groundwater mounding modeling would be needed if infiltration practices A and B were to be pursued.

Table 2: Swell potential for building 1. The negative potential indicates the possibility of upward heave due to swelling.

Soil Layer	Depth (m)	ρ (m)
Surface	0	0.00
1	0.91	0.00
2	1.52	-0.03
3	3.05	-0.06
4	7.62	-0.15
	ρtotal	-0.24 m -24.32 cm

When examining the surrounding parking lots, consideration must be placed on the depth of compaction as well as the type of material used as fill, if fill is needed. For this example fill with a low swell index (0.06) was used as opposed to the high swell index of 0.20 used for the "native" soil at this site. For comparison, Işık (2009) found a swell index range of around 0.01 to 0.13 for native soils. For reference, the swell index differs from the linear extensibility rating, mentioned previously, as it is determined using a different laboratory test (swell index being measured with a compacted and molded soil and linear extensibility measured using natural soil). Since the infiltration areas will be installed in the parking lot, the active depth will likely be increased by around 1 m due to excavation. Table 3 shows this analysis and suggests there could be considerable expansion (43.07 cm) near the infiltration areas B and C, which could damage overlying pavement. Collection of detailed soil information would be recommended below these parking lots to characterize swell potential, unless mitigation through the use of an underdrain in the stormwater management practice was included.

Table 3: Heave potential for parking lots around infiltration area B and C. The negative potential indicates the possibility of heave. Here, fill material has a low swelling index (Cs = 0.06 as opposed to 0.20 used for "native" soil).

Soil Layer	Depth (m)	ρ (m)
Surface	0	0.00
1 (fill soil)	0.91	0.00
2 (fill soil)	1.52	-0.01
3	4.57	-0.24
4	9.14	-0.18
	ρtotal	-0.43 m -43.07 cm

The addition of an underdrain would reduce potential for damage, though treatment volume may be reduced with this addition. Inclusion of underdrains was considered in Visual Bluebird for infiltration areas B and C. Results showed a near complete alleviation of mounding beneath the stormwater infiltration areas (Figure 5).

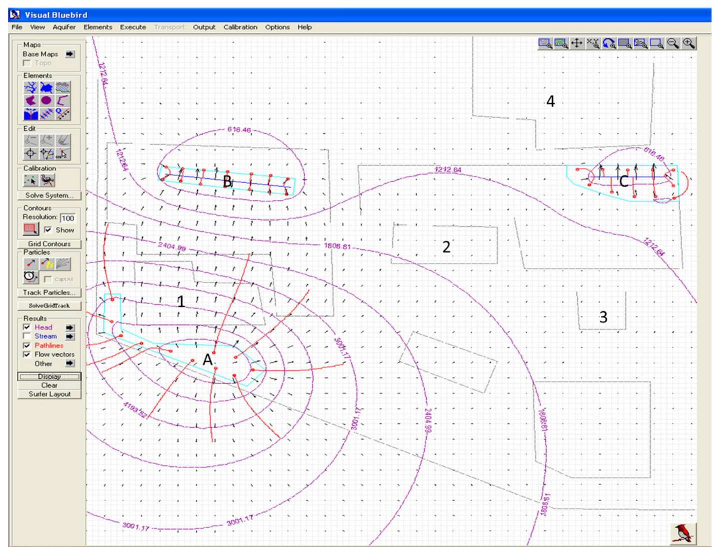

Figure 5: Estimate of underdrain impact on surrounding structures.

A rudimentary mass balance on structures B and C with an underdrain showed that for a 24 hour event with constant infiltration 0.6 m/day and field capacity of 0.2 m/m (Alam and Rogers 2001) over a 1.5 m deep structure gave 0.3 m/unit area as discharge. An undrained structure, assuming everything infiltrated, would store the entire volume. Generally, an underdrain will increase infiltration, which can reduce overflow; however, small storms may discharge because of preferential flow. Finally, underdrains have been used to alleviate ancillary issues with wet areas, such as root rot and vegetation drowning.

Summary

The modeling results for this example site in Mission, KS, indicate that buildings 1 and 4 and the parking lots around infiltration areas B and C warrant further investigation for groundwater potential impacts due to groundwater mounding. In addition, building 1 and the southeast corner of building 4 could possibly be impacted by swelling if too much water contacts relatively dry clay. With this particular site, underdrains would be recommended under infiltration areas B and C. This addition would reduce swelling of surrounding soil by removing excess water. An in-depth analysis of building 1 should be done to determine the true impact of infiltration area A to ensure the building will not experience heave. Other existing structures have little risk of damage and may be omitted from further analysis.

Conclusions and Recommendations

Retrofitting a previously developed site with infiltration practices raises a number of concerns, including damage to surrounding structures due to soil swelling (heave) and collapse, and basement seepage. It is recommended to investigate these impacts for more in-depth understanding about stormwater infiltration practices with a goal of developing technical standards for infiltration practices. An approach similar to the example provided for the Mission, KS, site can assist with initial investigations of potential retrofit sites using stormwater management infiltration practices.

However, modeling may not be feasible due its added cost or technical capabilities, therefore other site specific metrics may provide information to help identify areas where groundwater impacts may be worrisome. The development of guidelines are recommended to identify the need for further analysis using models if concerns are noted, along with additional case studies. A few metrics to consider are described below.

Soil Permeability

Saturated hydraulic conductivity, often abbreviated Ksat, is a measure of how quickly a soil can transmit water when saturated. In soil with a high Ksat, water rapidly levels out. The red areas in Figure 6a are where groundwater mounding due to stormwater infiltration practices may be an issue.

Groundwater Depth

Deep groundwater (maybe 15 m) is not necessarily a concern because the volume of water required to cause a substantial mound would likely be greater than what can be held in most stormwater infiltration practices. Groundwater depths are highly site-specific and only the potential presence of groundwater within ~2 m of the surface is available from soil survey data.

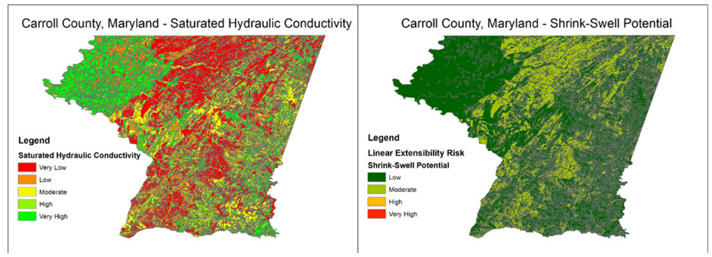

Figure 6

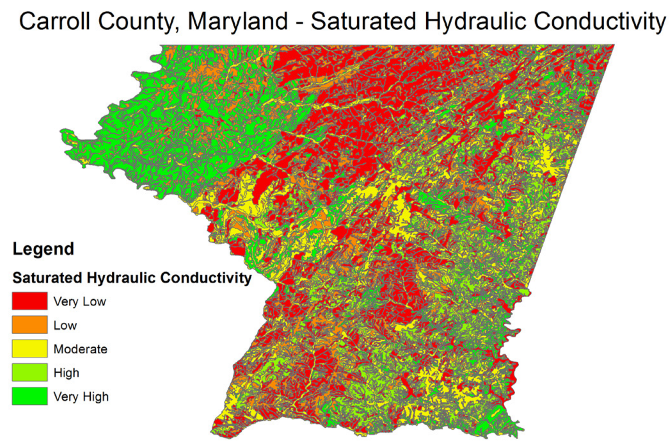

Figure 6a

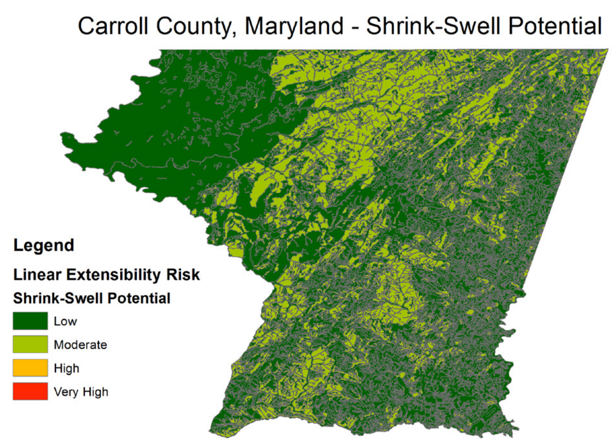

Figure 6b

Figure 6. Examples of a) saturated hydraulic conductivity and b) shrink-swell risk for Carroll County, MD. High saturated hydraulic conductivity is an indication of limited groundwater mounding due to substantial lateral water movement as the mound forms. Low shrink-swell risk indicates little risk if underlying soils are wet or dry.

Linear Extensiblity Rating

The Linear Extensibility rating, which is similar to the swell index used below, provides an indication of the potential for shrink-swell. This rating is expressed as a percentage volume change (between oven dry and field capacity—or wetter) (Soil Survey Staff 2015). A general rule, based on professional judgement, is a rating over 5% could be considered moderate to high shrink-swell potential. In an article by King (2015), a generalized national map is highlighted showing areas of potential concern. An example of how these data may look when using Soil Survey Geographic (SSURGO) data is shown in Figure 6b. Here, the majority of the county has a low risk of shrink-swell, meaning there would be little concern for structural damage. One note of caution, SSURGO does not account for non-native soil, as is the case in highly urban areas where cut and fill operations have occurred due to development (Christianson et al. 2015; Woltemade 2010).

If potential for shrink-swell has been deemed high, as suggested by SSURGO soil data or soil analysis, further risk can be assessed quickly through a modeling approach looking at a worst case scenario and, if retrofits are being compared, results may be used to help make decisions about which potential practices to pursue. Results could also be used to indicate potential placement of impermeable liners to restrict or re-direct horizontal water movement away from at-risk structures. Ultimately, this could be one more step to assure successful and long-lived stormwater retrofit practices.

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