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PI: Stu Geza, Assistant Professor, Department of Civil and Environmental Engineering
South Dakota School of Mines and Technology (SD Mines), stu.geza@sdsmt.edu
Co-PIs: Dr. Menkhaus, Professor, Chemical and Biological Engineering, SD Mines, Todd.Menkhaus@sdsmt.edu
Dr. Li, Assistant Professor, Geology and Geological Engineering SD Mines, Liangping.Li@sdsmt.edu
Mr. Hoogestraat, Hydrologist, Dakota Water Science Center, USGS, ghoogest@usgs.gov

Title: Assessment and improvement of performance of septic systems in cold climates (year 1).

SUMMARY

Onsite septic systems are used for wastewater treatment for households not connected to sewers. There is a concern about surface and groundwater pollution when effectiveness becomes limited due to soil texture, soil temperature, neighborhood density, and distance to water resources. The goal of this study was to assess treatment performance of local soils and selected treatment media. Lab-scale column experiments were conducted using wastewater from Wastewater Reclamation Facility in Rapid City. The experiments were conducted inside and outside the lab to evaluate the effect of temperature. The columns outside the lab were subject to seasonal variation in temperature. Moisture content, temperature, and flow volume were monitored.

The results indicated that higher nitrate removal was observed using redwood, biochar, and woodchips, respectively, when compared to the local soils. Average *effluent* nitrate concentration was 16.3 mg/L for alluvial columns followed by cedar soil (13.1 mg/L) and sand (11.3 mg/L). The performance of biochar, woodchip, and redwood was significantly higher than the local soils with an average *effluent* concentration of 8.5, 8.3, and 6.7 mg/L respectively. The reduction in nitrate concentration relative to alluvial columns were 20%, 31%,48%,49% and 59% respectively for cedar soil, sand, biochar, woodchips, and redwood.

The performance of redwood was relatively better than biochar and woodchip. Findings from this study are useful for development of novel subsurface treatment systems, and for identifying parameters for assessing watershed-scale impacts in cold climatic regions.

Statement of regional or State water problem

Details about potential problems associated with onsite septic systems were presented when the proposal was initiated. A quarter of residents in South Dakota rely on septic systems (Hipple, 2015). Previous investigators assessed data from monitoring wells and indicated that there are concerns about groundwater contamination from septic systems in karst limestone and shallow alluvial aquifers in the Black Hills and recommended further study at micro and watershed scale (Putnam, et al, 2009, Sawyer, 2006). We conducted laboratory scale experiments to assess removal of wastewater constituents using local soils and other geomedia such as woodchip and biochar supported by USGS 104b funds. Model coefficients including sorption and reaction rates are being determined for local soils and geomedia. The coefficients developed will be used as inputs for the larger watershed scale modeling effort proposed for year 2 project. In year 2, we will focus on assessment of impacts of onsite septic systems on a watershed scale using Rapid Creek Watershed (RCW) as our testbed. A calibrated watershed model will be developed to assess the contributions of onsite septic systems to nutrient loading into surface and groundwater systems relative to other sources.

Goal in phase 1/year 1

The goal in phase 1 was to conduct a laboratory scale investigation of the potential of local soils, geological materials, and other media such as biochar and woodchip for removal of contaminants in wastewater and determine sorption and reaction coefficients.

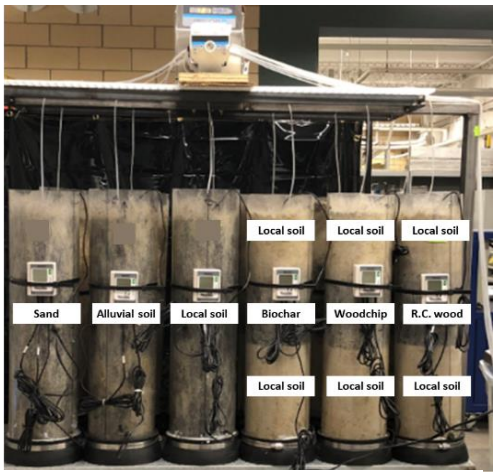

Figure 1. Media types and configurations

R**.C. wood**: Red Cedar Wood

Preparation of soil columns

The experimental column set up is shown in Figure 1. The columns are equipped with moisture and temperature sensors, flow meters, and water quality sampling points (Figure 1).

Duplicate columns for each soil and media type were prepared. Wastewater from the primary clarifier at the Water Reclamation Facility (WRF) - City of Rapid City was used to run the experiments. Local soils (i.e., alluvial, cedar canyon, and sand), and selected media types (woodchips, biochar, and redwood) were used as treatment media. A peristaltic pump was used to maintain a constant flowrate of 0.25 mL/min. Moisture content was measured periodically at the top, middle, and bottom of the column using moisture content sensors from spectrum technology. Effluents from each column were collected at three days interval and nitrate concentrations were measured using a HACH spectrophotometer (DR 2400) immediately after collection.

Collecting soil samples

We collected samples of local soils and alluvial materials from selected locations around Rapid City along potential flow path. We also obtained red cedar wood, woodchip, and biochar). Thus, the materials under investigation include pure sand (used as a control), alluvial soils, local soils from spear fish formation, and alternative media such as red cedar wood, woodchip, and biochar. A total of 12 columns are used with 6 different experimental setups in duplicates.

Wastewater samples
Wastewater effluent was obtained from Rapid City wastewater treatment plant. The samples are collected after primary treatment. The concentration are similar to data from literature on concentrations from septic tank effluent right before dispersal to soils.

Influent concentration
The average influent concentration from Rapid City Water Reclamation Facility varied from *25 to 30* mg/L. Base on the outflow concentrations, all the materials were able to treat nitrate but performances did vary. Alluvial soils are ineffective, cedar soils performed relatively better. Red wood was the most effective.

Data collection
Water quality (nutrient concentration), water content, and effluent flow rates from each of the columns was monitored daily.

Results and Discussion
The results reported include data from Dec 2019 – Feb 2020 for experiment conducted inside the lab under room temperature (Figure 2). Relatively higher nitrate removal was observed in redwood, biochar, and woodchips, respectively compared to the local soils. Among the local soils, cedar soil demonstrated the highest removal over time whereas alluvial showed the lowest removal. Figure 3 shows the average effluent nitrate concentrations. The lowest nitrate effluent concentration (6.7 $mg.L^{-1}$) was detected in redwood. The alluvial columns released 16.7 $mg.L^{-1}$ nitrate which is the maximum among all media types. Effluent concentration may increase with time, however, we anticipate the difference in performance among the treatment media will continue to be similar.

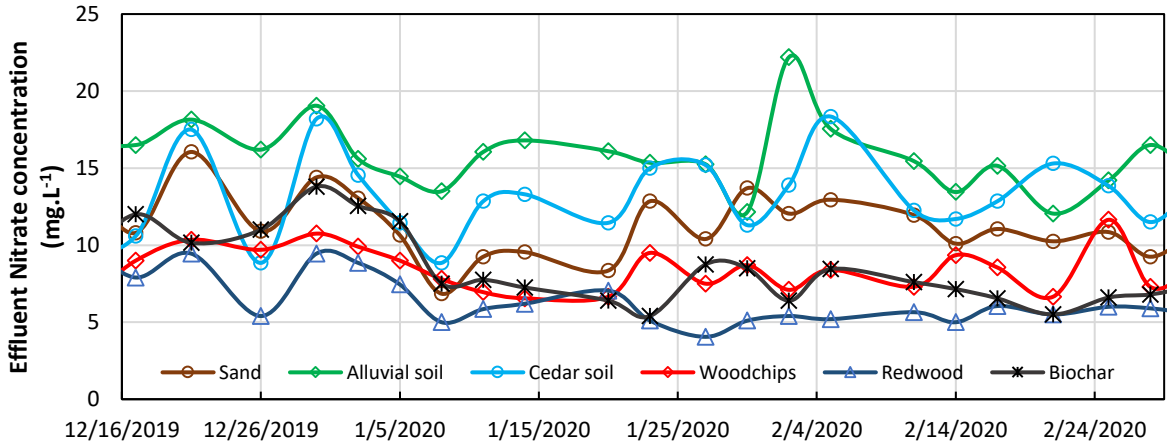

Figure 2. Nitrate concentrations in different media from Dec 2019 to Feb 2020.

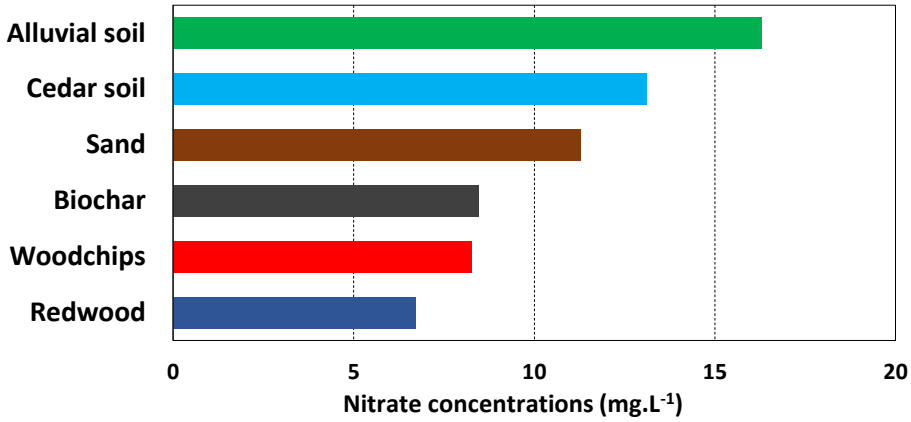

Figure 3. Effluent nitrate concentrations in different media.

To investigate the effect of temperature, we set up the columns inside the lab and outside the building (Figure 4). Average effluent concentration were relatively low during warmer period (May - October). It was also observed effluent concentrations were relatively high for the outside columns during the relatively cold period, Feb-Apr and Nov-Jan particularly for media types that are effective in removing nitrate (biochar, woodchips and redwood). Sand and alluvial soil were in effective under all conditions.

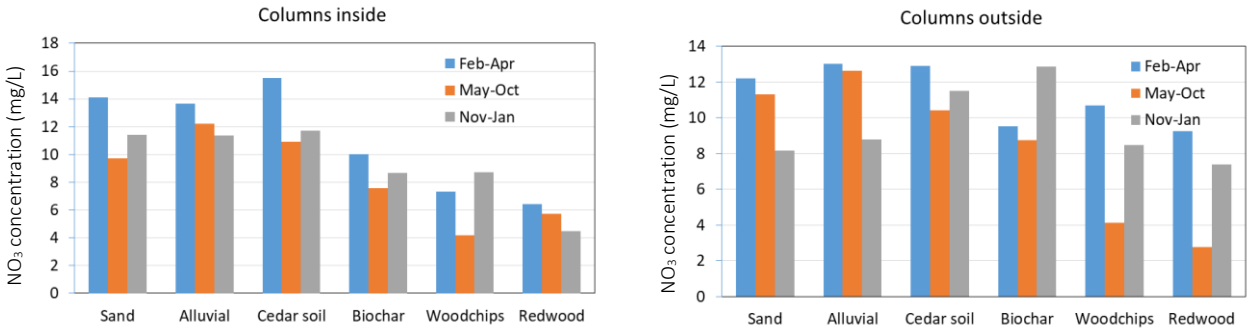

Figure 4. Column effluent nitrate concentration inside the lab (left) and outside the lab (right)

Effluent data

Data on wastewater effluent is from the wastewater treatment plant from City of Rapid City is provide in Figure 4. The wastewater sample was collected from primary effluent and includes NH_3, TSS, and BOD over years from 2017 to 2019 were collected.

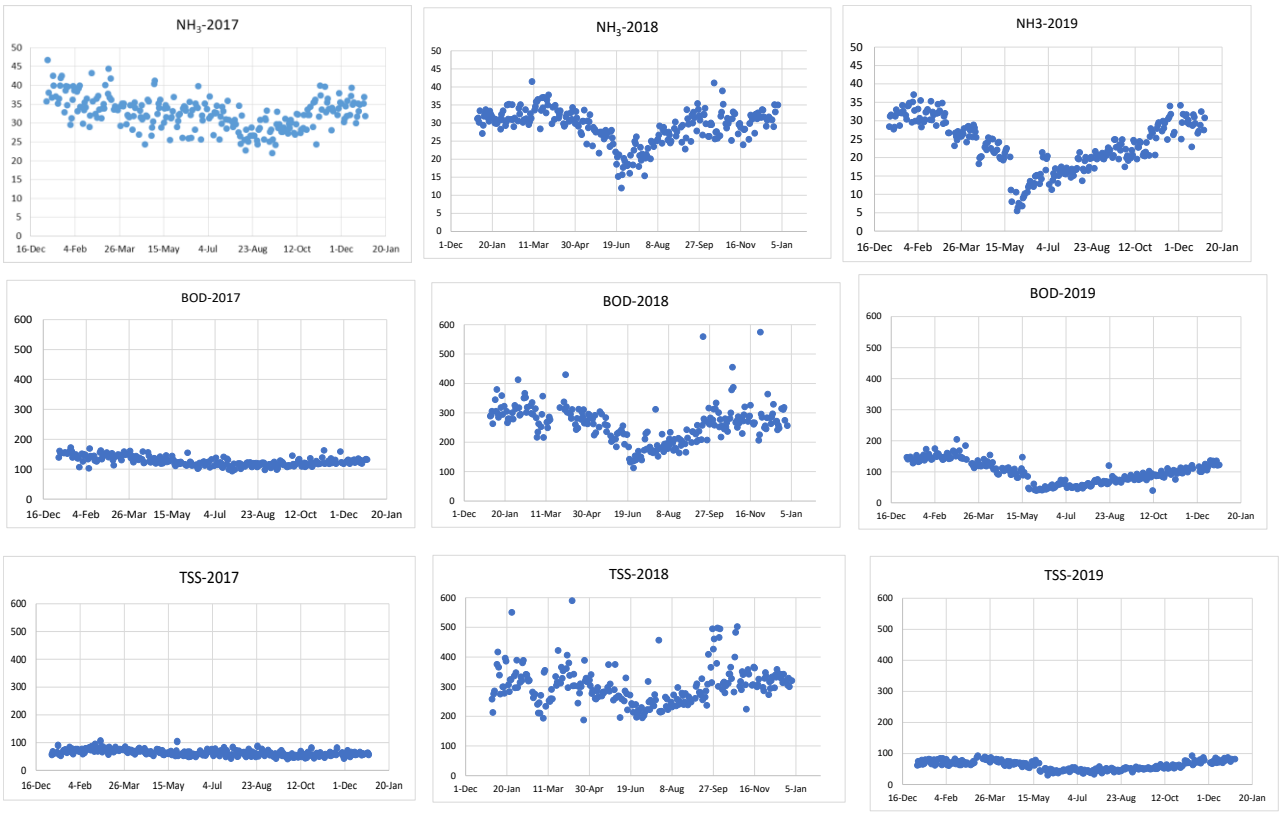

Figure 4. Variation of NH_3 ($mg.L^{-1}$), BOD ($mg.L^{-1}$), and TSS ($mg.L^{-1}$) in 2017-2019.

Ongoing research

Year 1 project: The team including a graduate is working on a thesis to be completed by December 2021. The project was extended to year 2. Additional information will be provided at the end of year 2 porject from the thesis work. The data is being used to determine sorption and reaction coefficients using a numerical model, Hydrus 2D (Simunek, et al. 2012).

Year two project involves modeling watershed scale impacts of septic systems. Thus, in year 2 the potential for surface water contamination from septic systems under vulnerable soil, geological settings, and climate conditions using coefficients generated in year 1.

Watershed model setup and calibration: We completed building a hydrology and water quality model of RCW using SWAT model (Figure 2). SWAT model has capabilities for estimating impact of onsite septic systems on nutrient loading. RCW is a complex watershed that includes urban areas and an upstream pristine Black Hills forest area. There are several USGS gage stations along RCW for hydrologic calibration. The city has data on concentrations of chemicals for few sites. Water quality data from SD DENR's is also available from monitoring network (https://denr.sd.gov/des/sw/wqmonitoring.aspx).

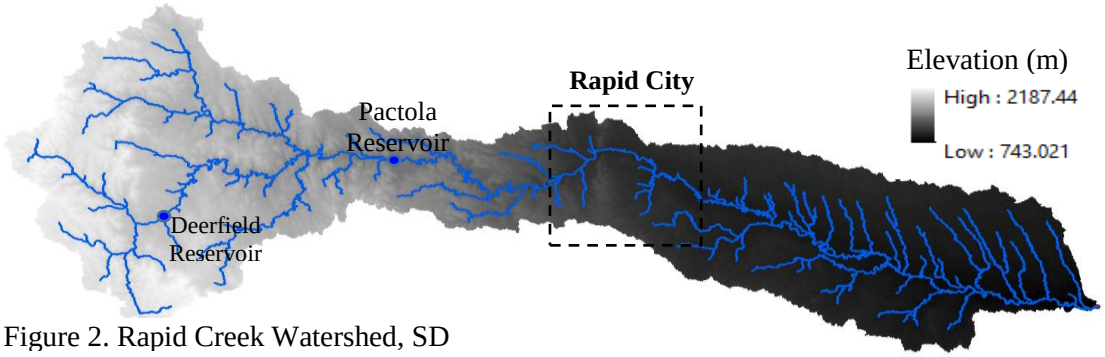

Figure 2. Rapid Creek Watershed, SD

Scenario analysis: The calibrated model will be used to evaluate scenarios relevant to the contribution of onsite septic systems to nutrient loading. Scenarios will be developed that can give insight about the potential impact of onsite septic systems on water quality. The scenarios will include (1) the effect of population growth or increase in the number of sites using onsite septic systems, (2) the impact of conversion of residential areas currently under onsite septic systems to conventional sewers, (3) assessment of nutrient loads with and without onsite septic systems, and (4) assessment of watershed scale impacts of improvement in the level of treatment at individual sites using geomedia versus local soils. For scenario 4, model coefficients developed in year 1 for local soils and geomedia will be used.

Training

Two graduate students were trained on the application unsaturated model (Hydrus 2D) and SWAT model for evaluation impact of septic systems on a site and watershed scale. The two graduate students are applying the tools towards their thesis project. The thesis will be available at the end of year 2 project (December, 2021). The watershed model developed during this study can be used as a learning tool by graduate and undergraduate students in surface water and vodose zone classes offered by the PI. Students can use the calibrated model to run scenarios of changes in anthropogenic activities such as land use change, agricultural operations or climate change and assess watershed scale impacts on hydrology and pollutant loading. The results will be shared during conferences such as Environmental & Water Resources Institute (EWRI) and National Onsite Wastewater Recycling Association (NOWRA). The findings will be published in a peer reviewed journal.

Reports:

Journal article

Experimental and modeling investigation of performance of septic systems in cold climates; in preparation, Journal of Environmental Quality.

Joshua Trap, 2021. Assessment of treatment performance of local soils and geomedia septic effluent. Thesis in progress

Chritian Heinrich, 2021. Modeling watershed scale impacts of septic systems using SWAT model

Related reports:

Vasquez, 2019. Investigation of Removal of Heavy Metals using Biochar and Nanoscale Zero Valent Iron amended Biochar, Thesis

Hasan, Geza, and Vasquez, 2019/. Removal of Heavy Metals from Urban Stormwater using Biochar and Nanoscale Zerovalent Iron Modified Biochar, 2019 Western South Dakota Hydrology Conference