THE EFFECTS OF MULCH ON STORMWATER TREATMENT AND MAINTENANCE EFFORT IN BIORETENTION SYSTEMS

Introduction

This 2-year study seeks to evaluate mulch's role in bioretention best management practices. This memo reports pollutant removal from stormwater runoff when mulch is used as a top layer in bioretention cells. Additionally, we aim to see how different kinds of mulch attenuate stormwater flows through bioretention systems, alter soil moisture conditions, and provide dissolved carbon to the bioretention ecosystem. Finally, a separate memo was prepared to highlight the effects of mulch choice on weeding and plant growth.

Three types of mulch, medium bark mulch, button bark mulch, and arborist chips, were compared to a no-mulch control within replicated bioretention cells located at Washington State University's Puyallup Research and Extension Center. With this test facility of 16 bioretention cells (Figures 1 & 2), each of the three mulch types was replicated four times, and their performances were compared against those of four no-mulch cells. We define treatment performance as the ability of a bioretention cell to remove/sequester stormwater pollutants, store water in the form of soil moisture, and reduce runoff volume. All the cells were dosed with a synthetic blend of stormwater during 6 artificially generated storm events. Artificial stormwater was applied to each cell with a network of pumps and pipes, using water that has been dosed artificially with 7 common analytes.
Methods (in brief)

All sixteen bioretention cells were retrofitted in Summer 2017 and replanted in November 2018 with a common plant palette. All sixteen cells were lined, re-plumbed, and instrumented to measure inflows and outflows. The bioretention cells are built with the default bioretention soil mix (BSM), which is 60:40 sand: compost as specified in the Stormwater Management Manuals published by the Washington State Department of Ecology.

Three types of mulch overlaid the surface of the bioretention cells at depths of 2 to 3 inches:

1. Medium bark mulch (fir and ash)
2. Button bark mulch (cedar and fir)
3. Arborist chips (mixed)

Each mulch type was replicated four times and compared against a control of four bioretention cells with no mulch. Artificially dosed storm events comprising specific stormwater pollutants were added to the dosing water and applied to the 16 test cells, with influent and effluent pollutant concentrations measured through sampling and laboratory analyses. These influent and effluent concentrations were used to quantify pollutant removal efficiencies associated with mulch type.

Stormwater runoff was collected from 72,084 ft$^2$ of impervious surface on the WSU Puyallup facility and stored in a common dosing cistern. Stored stormwater was mixed with chemicals to meet the range of influent loading rates to represent urban stormwater pollutant concentrations.
We tested for the following parameters for each storm dosing event in the influent and effluent from the bioretention cells.

1. Nitrate – Nitrite (target influent value: 0.3 mg/L)
2. Total Phosphorous (target influent value: 0.3 mg/L)
3. Dissolved Copper (target influent value: 0.1 mg/L)
4. Dissolved Zinc (target influent value: 0.1 mg/L)
5. Total Petroleum Hydrocarbon (target influent value: TPH 15 mg/L)
   TPH was analyzed as Diesel Range Organics (TPH-DRO) and Motor Oil Range Organics (TPH-MOR). These two analytes were chosen based on the dosing protocol listed in the QAPP where diesel and used motor oil were added to the influent.
6. Total Suspended Solids (target influent value: 150 mg/L)
7. Dissolved Organic Carbon (measured only in effluent)

Pollutant removal efficiencies were quantified by measuring inflow volume, outflow volume, influent concentrations based on flow-weighted samples collected at the influent sampling station (Figure 1), and effluent concentrations based on flow-weighted sampling at the 16 bioretention cell outlets. For each storm, flow-weighted aliquots were composited into one composite storm sample at every one of the 17 sampling stations.

Inflow and outflow volumes were used to characterize how mulch affects water retention in each cell. The results show water quality and quantity treatment of the whole bioretention system, not just the mulch layer. Soil moisture levels in the bioretention media were measured at two locations in each cell at a depth of 30 cm below the mulch surface – one close to the stormwater inlet into the cell, the second close to the effluent outlet below grade.
Figure 2: Images of plant growth from one cell (clockwise from top left) starting in November 2018 to September 2021.
**Results**

**Considerations Impacting Data Analyses**

1. The estimations of stormwater (volumes and peak flows) mitigated by the bioretention cells were calculated using the cistern pump data to calculate the total influent volumes and influent peak flow rates.

2. Cells 102 and 103 had leaks that made hydrologic calculations (outflow volume and outflow peak flows) impossible to calculate. As a result, these were omitted from all hydrologic calculations; however, water quality data from these two cells were retained and used.

3. Storm volumes for the first storm (0.2-inch) only: Storm volumes data is biased high due to an undosed water pulse sent to all the bioretention cells before the actual synthetic storm pulse. As a result, flow from the water pulse was still draining from the cells as the actual 0.2-inch synthetic storm event began. Figure 3 shows the synthetic event in a transparent grey box with preceding water pulse flows. Because the water pulse contributed to total outflows measured in the subsequent storm, the volume data for this first synthetic storm were omitted to compensate for this error, but peak flows were retained.

![Figure 3: Water pulse prior to 0.2-inch storm was carried out too close to the design storm (grey transparent rectangle) invalidating storm volume calculations for this event.](image-url)
Dosed Storm Events

Figure 4: Cistern where stormwater is collected, and pollutants are dosed (left). A series of weir boxes are connected to each of the bioretention cells via underground pipes. The image on the right shows one of those pipes serving as an influent source to a bioretention cell.

This study comprised six artificial storm events conducted between March 2020 and September 2021. These events are listed chronologically in Table 1. Storm events varied by magnitude, but all occurred over 6 hours. Storms comprised a sequence of 9 pulsed events, with each pulse taking 20 minutes and each pulse separated from the next pulsing event by 20 minutes of no pumping. Intermittent pumping of dosed water from the cistern ensured similar delivery times and consistent loading to cells at varied (hydraulic) distances from the cistern. The magnitude of each pulse gradually increased and then decreased, with the middle pulse (5th pulse) corresponding to the highest pumped flow rate. Ultimately, the total volume of dosed water pumped out of the cistern for the 1.0-inch storm was five times more than the 0.2-inch storm. More details are available in the QAPP – Table 8.2 and Figure 7.

Table 1: Storm event dates, magnitude, and potential issues.

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<th>Storm date</th>
<th>Storm size (inches)</th>
<th>Noteworthy issues</th>
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<td>Charging event and natural storm before synthetic storm impacted volume calculations</td>
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Soil Moisture

Each bioretention cell was instrumented with a soil moisture sensor 30 cm below the cell surface at both inflow and outflow locations. The control cells' soil moisture was consistently the lowest at both inflow and outflow locations. However, there is a clear separation of soil moisture values at the outflow locations amongst the three mulch treatments – cells with arborist chips having the highest soil moisture values, and medium bark, the lowest of the three mulch types tested. Soil moisture values measured over the study period are shown for the inflow locations in Figure 5 and the outflow locations in Figure 6.

Figure 5: Average soil moisture values by mulch type measured at inflow locations.

Figure 6: Average soil moisture values by mulch type measured at outflow locations.
Bioretention Hydrology

Six artificial storm events were studied, with storm events ranging from 0.2 inches to 1.0 inches. Average outflows for the 1.0-inch storm for each of the three mulch treatments and controls cells are presented in Figure 7.

Figure 7: Example of storm event for one storm event (1.0-inch storm). Each line is the average of 4 outflow rates from 4 bioretention cells with the same mulch type.

Total storm outflows for five storm events ranged from 41.5% (Nuggets mean) of the total volume of stormwater pumped to each cell during a storm event (0.4-inch storm) to 92.7% (Controls mean, 0.8-inch storm). Outflow volumes averaged by treatment and presented as a percentage of the total volume of water pumped to a cell are shown in Figure 8. No individual mulch treatment was consistently better than other treatments or controls in reducing outflow volumes.

Peak outflows (flow rate) for six storm events ranged from 27.5% (Controls mean) of the peak pump flow rate of stormwater pumped to each cell during a storm event (0.4-inch storm) to 63.6% (Medium Bark mean, 0.2-inch storm). Outflow peak flow rates averaged across the four cells of a mulch treatment and presented as a percentage of the maximum rate at which stormwater was pumped to a cell (Figure 9). Average peak outflow rates for cells with Nuggets were consistently lower than other mulches and controls.
Figure 8: Average outflow storm volumes observed, presented as a fraction (%) of inflow, for five storm event and four mulch treatments.

Figure 9: Peak outflow for all storm events, averaged by mulch treatment, and presented as a fraction (%) of peak inflow.
Pollutant Removal Efficiencies

Pollutant removal efficiencies were evaluated for a suite of 7 analytes from six storm events. From a general perspective, no individual mulch treatment outperformed any other mulch treatment. Additionally, the role of mulch alone in removing stormwater pollutants was indistinguishable from the no-mulch controls. In other words, the pollutant removal capacity of mulch alone was likely too small to be distinguished through our research methods compared with bioretention media alone.

Finally, influent dosing concentrations were meant to be consistent across all storm events; however, this was harder to control than we expected. Hence, influent concentrations varied across storm events – influent concentrations are plotted in Figures 10 to 17. In addition, boxplots representing pollutant removal efficiencies by analyte are also presented in Figures 10 to 17.

It should be noted that the following results describe removal efficiencies from the entire bioretention cell (mulch + bioretention soil media) and not just the mulch layer alone. Also, not statistical testing of data was carried out at the time of writing this memo. The final report will include statistical testing.

**Conventional**

Total suspended sediments were consistently removed across all storm events at averaged-by-

![Graph showing pollutant removal efficiencies](image)

Figure 10: Influent concentrations (upper panels) for TSS and DOC, and pollutant removal rates across all six storms (lower panels.)
not dosed to the influent; influent concentrations reflect ambient DOC of stormwater. Negative removal rates in Figure 10 (bottom-left panel) imply that effluent DOC concentrations were higher than influent, suggesting DOC export from all bioretention cells across all treatments and storm events.

**Metals**
The removal of Dissolved Copper was in the positive ranges (>0%) for most storm events except the 0.4-inch storm. The best removal rates were observed for the smallest storm event (0.2-inch); however, there was no correlation between storm size and removal performance.

On the other hand, Dissolved Zinc removal was consistently above 90% (averaged by treatment) across all storm events and mulch treatments.

*Figure 11: Influent concentrations (upper panels) for Dissolved Copper and Dissolved Zinc, and pollutant removal rates across all six storms (lower panels.)*
**Hydrocarbons**

Diesel range organics removals were above 35% across all storm events and treatments. However, except for two storm events (0.4 and 0.5-inch storms), effluent concentrations for diesel range organics were all below detection limits.

Lube oil removals were above 60% across all storm events and treatments. However, except for one storm event (0.4-inch storms), lube oil effluent concentrations were otherwise below detection limits.

*Figure 12: Influent concentrations (upper panels) for Diesel Range Organics and Lube Oil, and pollutant removal rates across all six storms (lower panels.)*
Nutrients
Nitrate-Nitrite (N-N) effluent concentrations were consistently higher in the outflows than the inflow concentrations suggesting export across all treatments. Only the 0.5-inch event showed levels of positive N-N removals, but those were only associated with bioretention cells with mulch. Despite influent concentrations being lower than most effluent concentrations, a visual assessment of the effluent data suggests that concentrations of N-N from the control cells (without mulch) were higher than those with mulch.

Total Phosphorous in the effluent concentrations were above influent concentrations for most storm events. Some removal was seen in the 0.6-inch and 1.0-inch storm

Figure 13: Influent concentrations (upper panels) for Nitrate-Nitrite and Total Phosphorous, and pollutant removal rates across all six storms (lower panels.)
Recommendations

1. Mulch plays a critical role in preserving soil moisture in bioretention cells.

2. Of the three types of mulches examined, arborist chips appeared to have the greatest ability to maintain soil moisture. However, it should be noted that arborist chips did need to be replenished midway through the study. The arborist chips decomposed and the mulch layer was no longer providing adequate coverage.

3. We could not distinguish between pollutant removal of mulch and bioretention media for most analytes. It should be noted that that N-N and Total Phosphorous concentrations were higher in the effluent samples compared to influent.

4. Nitrite-Nitrate (N-N) concentrations in bioretention effluent were generally lower in the presence of mulch compared to the no-mulch controls. However, this finding will need to be tested if these differences are statistically significant. That step will be carried out for the final report.