Water Quality Report

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Introduction

The M Trail, a beloved hiking destination near Bozeman, Montana, draws countless outdoor enthusiasts each year. However, the increasing popularity of this area brings growing environmental challenges, particularly concerning water quality and stormwater management. Impervious surfaces, such as the M Trail parking lot, disrupt natural water infiltration processes, resulting in excessive runoff that contributes to erosion, pollution, and habitat degradation in nearby waterways like Bridger Creek. This creek, part of the Lower Bridger Creek watershed, is already classified as impaired due to issues such as nutrient loading, algae growth, and sedimentation, which threaten its ecological health and recreational value (EPA, 2021). Addressing these challenges requires innovative and sustainable solutions that balance development needs with environmental stewardship.

This paper proposes three targeted interventions to mitigate the environmental impacts associated with the M Trail area: the construction of swales, the establishment of vegetative riparian buffers, and the optimization of the existing vault toilet system. Swales are designed to capture and filter stormwater runoff, reducing the volume of pollutants entering nearby water bodies (Leroy et al. 2016). Riparian buffers provide critical protection by stabilizing streambanks, trapping sediment, and enhancing biodiversity (Duni, 2024). Lastly, improving the aerobic decomposition process in the vault toilet system can reduce odors, enhance user experience, and alleviate pressure on wastewater treatment systems.

By implementing these strategies individually or in combination, the ecological integrity of Bridger Creek and the Lower Bridger Creek watershed can be significantly improved. Beyond local benefits, these efforts demonstrate a replicable model for integrating sustainable practices into recreational area management, setting a standard for environmental responsibility and resilience.

Swales

Why Swales could benefit the M Trail Parking Lot

Adding a swale to the M trail parking lot in Bozeman, Montana, especially if plans proceed for a larger parking area west of the current lot, would bring valuable benefits. The increased impervious surface from an expanded lot may lead to more stormwater runoff, heightening risks of erosion and pollution for nearby areas. A swale, strategically placed along the lower perimeter of the new lot, would help capture and filter this runoff, allowing water to slowly infiltrate back into the ground rather than overwhelming local drainage systems. While permeable parking lots can provide substantial environmental benefits, they often face logistical challenges; convincing city planners and engineers to approve such a project may prove difficult due to cost and maintenance concerns. In contrast, a swale offers a simpler, cost-effective enhancement that could be more easily integrated into existing and expanded parking areas, minimizing runoff impacts and aligning with sustainable development goals.

Introduction to Swales

In Bozeman, Montana, water management is a critical issue. As we expand impervious surfaces like concrete and asphalt to cover more land, natural water cycles are disrupted. Rainwater, instead of percolating into the ground, flows over these surfaces, leading to increased erosion, flooding, and pollution in water bodies. Swales, which are designed to address these challenges, are shallow, gently sloping ditches that capture and direct water runoff, filtering pollutants and recharging groundwater. Unlike conventional stormwater management systems that rely on pipes and drains to transport water away rapidly, swales harness natural processes to slow down, filter, and redistribute water. As such, swales represent a sustainable and low-cost solution for managing stormwater while supporting natural ecosystems and reducing human impact on local water cycles.

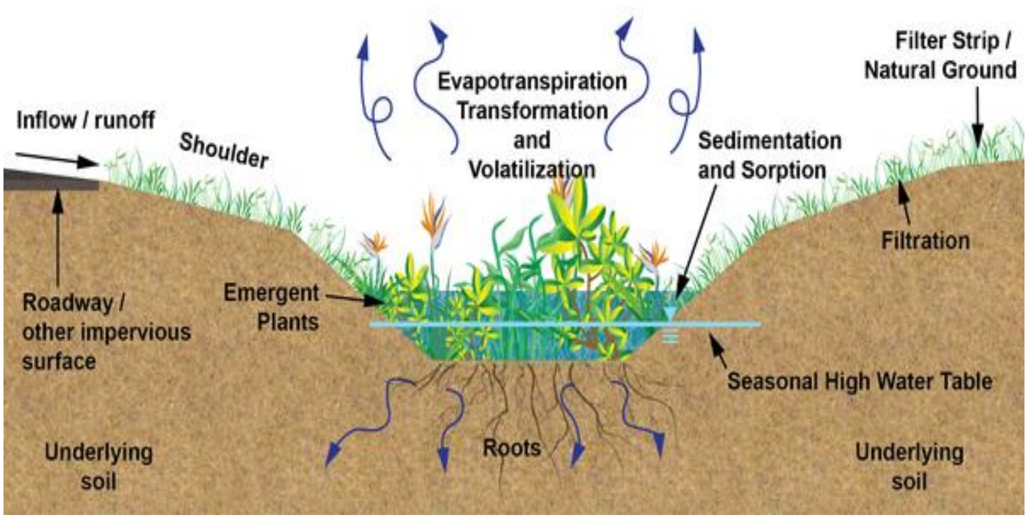

Figure 1: A basic diagram representing the basic functions of a swale (Ekka & Hunt, 2020)

How Swales Work

The primary function of a swale is to capture and filter water runoff, particularly during heavy rainfall events. Positioned strategically in landscapes to intercept stormwater, swales slow water flow, allowing sediment and pollutants to settle. Water then infiltrates gradually into the ground, replenishing groundwater supplies instead of being diverted directly to storm drains and water bodies, where it would increase flood risks and carry contaminants. Through this process, swales act as natural filters, breaking down pollutants and absorbing nutrients that could otherwise harm aquatic ecosystems (Leroy et al. 2016). Additionally, the vegetation planted along swales aids in this filtration process by stabilizing soil and creating a barrier that traps sediments and other particles in the stormwater. Vegetation also takes up excess nutrients, which reduces the risk of algal blooms in downstream water bodies.

Types of Swales

Swales come in various designs tailored to suit different landscapes, climates, and runoff characteristics. A common type is the vegetated swale, which is lined with grasses, shrubs, and other native plants that aid in filtration and enhance biodiversity. The vegetation not only helps in filtering pollutants but also provides habitat for small wildlife, making these swales ecologically beneficial. In regions with infrequent rainfall, dry swales are a popular choice; They are typically unlined and constructed to handle low volumes of water, allowing for quick infiltration without staying saturated for prolonged periods. This type of swale is ideal for arid and semi-arid climates, where water needs to be kept but not pooled. Conversely, in areas with high rainfall, wet swales are more suitable, as they hold water for extended periods, creating conditions for specific aquatic plants that can thrive in saturated soils (Winston et al., 2012).

Each type of swale offers unique benefits depending on the local environment. The choice of swale design considers factors like soil type, slope, expected rainfall, and surrounding land use. For instance, a vegetated swale on a gentle slope with native grasses can significantly reduce runoff speed and volume, while a wet swale with ponded areas may serve as a temporary water reservoir during intense rainfall events, slowly releasing water back into the ground.

Environmental and Practical Benefits of Swales

Swales are gaining traction in sustainable urban design for the variety of environmental and practical benefits they provide. One of the most significant advantages is improved water quality. By filtering pollutants from runoff, swales help protect rivers, lakes, and other water bodies from contamination. Urban runoff often holds sediments, oils (Hong et al., 2006), heavy metals (Monrabal-Martinez et al., 2018), and other pollutants picked up from roads and paved surfaces. As water flows through a swale, these pollutants are trapped and naturally broken down, preventing them from reaching and harming local ecosystems.

Swales are also great for controlling soil erosion, especially in areas with steep slopes or loose soils. As water flows through a swale, it loses momentum due to the gentle slope and vegetation cover, reducing the risk of erosion. This is particularly important in urban areas where exposed soil becomes more vulnerable to degradation. By protecting soil stability, swales also prevent the loss of valuable topsoil and reduce sedimentation in downstream water bodies, which can smother aquatic habitats.

Flood mitigation is another crucial role played by swales. During heavy rain events, stormwater systems often struggle to handle large volumes of runoff, leading to flash floods that can damage infrastructure and endanger communities. Swales absorb some of this water, dispersing it across the landscape and releasing it gradually. This reduces the peak flow rates that overwhelm storm drains and lowers the risk of flooding.

Designing Effective Swales

Creating an effective swale requires careful planning and consideration of site-specific factors (Ekka et al., 2021). The slope of a swale should be gradual to ensure that water moves slowly, maximizing infiltration and filtration. Steeper slopes may lead to erosion within the swale, undermining its stability and effectiveness. Soil type is another important consideration. Loamy or sandy soils that allow for better water infiltration are ideal for swales, while clay soils may require amendments to improve permeability. Additionally, vegetation choice is critical; Selecting native plants that are well-suited to the local climate and soil conditions ensures the swale will thrive with minimal maintenance. Native plants are typically more resilient, providing long-lasting filtration and erosion control with fewer inputs.

Furthermore, swales should be integrated into the landscape in a way that complements existing topography and water flow patterns. Rather than imposing a rigid design, swales are most effective when they follow the natural contours of the land, blending seamlessly with the surrounding environment. Proper placement and design will enable the swale to capture and distribute runoff efficiently, minimizing impacts on other land uses and structures.

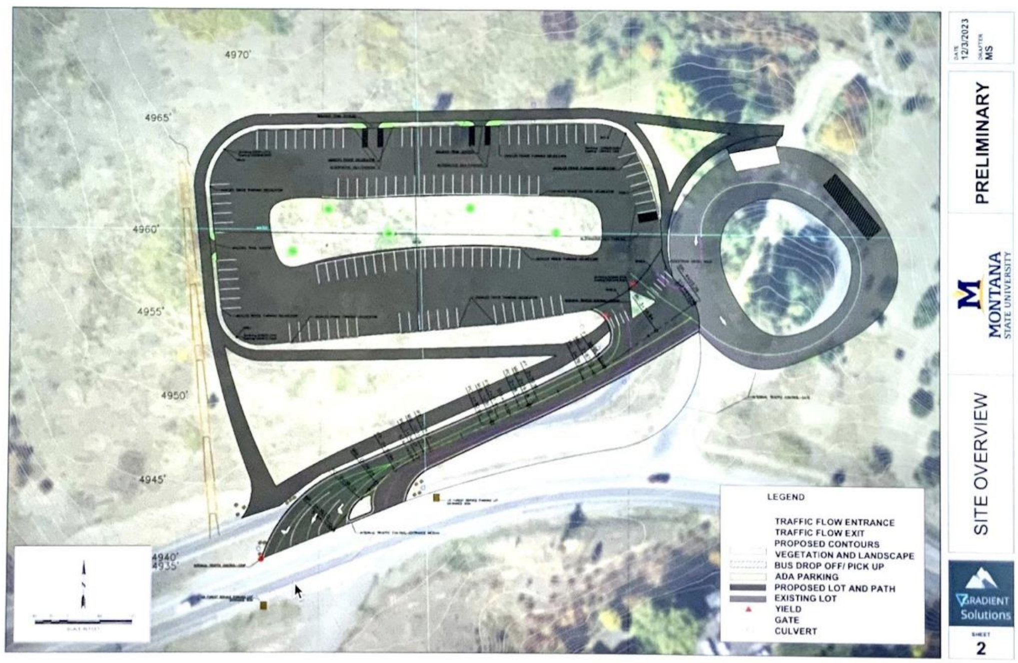

Figure 2: The proposed capstone project to add to the current M Trail parking lot (Montana State EENV Capstone Fall, 2023)

<u>Riparian Buffer</u>

Watershed of Interest

Bridger Creek is in the Lower Bridger Creek watershed and flows into the East Gallatin River. This is important to consider, given that conditions in Bridger Creek impact downstream areas, like the East Gallatin, which is a valued system in Bozeman. According to the How's my Waterway page, Bridger Creek is impaired for both aquatic life and recreation (Figure 3). The water here is primarily used for drinking, aquatic life, and recreation and has identified issues of algae, nitrogen, and/or phosphorus. As of 2021, agricultural and drinking water quality had not been assessed. The impaired parameters for aquatic life include nitrate/nitrite and the primary contact recreation includes chlorophyll A and nitrate/nitrite. No other parameters were evaluated for the impaired parameters (EPA, 2021).

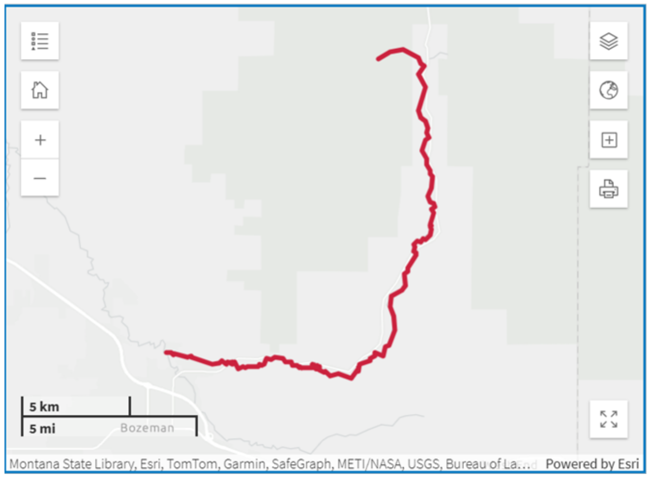

Figure 3: Bridger Creek, our waterbody of interest (EPA, 2021)

Importance

Considering changing conditions, a healthy riparian area can sustain species life through functional connectivity (Fink and Scheidegger, 2018), which may apply to the Bridger Creek systems, per construction plans by past engineering capstone projects. With the establishment of a new parking lot, urban runoff may increase, which significantly contributes to worsening water quality (Müller et al., 2020). Buffer zones can reduce nitrogen and phosphorus concentrations in a system through assimilation, biogeochemical processes such as denitrification, and sorption and precipitation through soil interactions (Frątczak et al., 2019).

Riparian Proposal

We suggest the establishment of both a riparian buffer next to the creek and extra vegetation between the M and the river (Figure 4). Vegetative buffers filter out sediment and contaminants from runoff, preventing such things from entering the waterbody. Additionally, vegetation near streambanks can aid in stabilizing the banks, reducing erosion and therefore excess sediments from entering the stream. Some ecological services include the dispersal of seeds, mitigation of drought and floods, cleaning of water by filtering and entrapping sediment, cycling and transporting nutrients, supporting biodiversity, generating and renewing soils, moderating water temperature, and sequestering carbon dioxide (Duni, 2024). The types of vegetation needed will be different near the water than near the M, as the environmental conditions shift. Near the water, it may be hard to establish new vegetation due to the steep topographic conditions and limited space. Based on these limitations, upland species should not be the focus but rather obligate and facultative wetland plants. A survey of current vegetation needs to be done, followed by implementing native shrubs and grasses to increase root stability and aboveground entrapment of nutrients and sediment. As for the second buffer, on the other side of the road, the focus will not be on riparian vegetation, as it is no longer in the riparian zone, and would instead be a more general buffer. Ideally, this could implement new tree growth, though trees take time to establish and grow, limiting effectiveness during the potential parking lot construction. When considering vegetation in the upper zones, refer to the Plants and Wildlife sections of the other M Trail Capstone Reports, as applicable recommendations have been made.

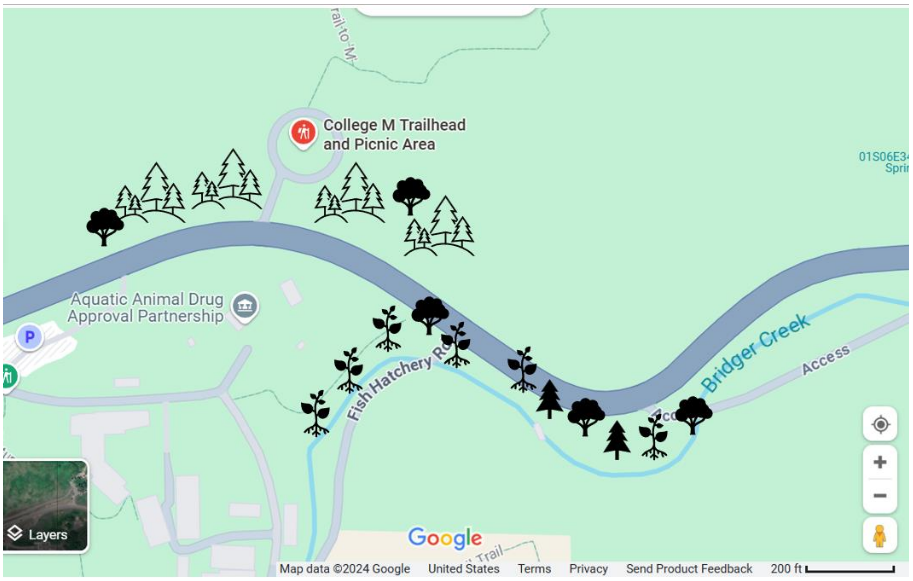

Figure 4: General image standing for proposed buffer areas, base map from Google Maps

What is a Riparian Area?

A riparian zone is the transition between aquatic and adjacent terrestrial ecosystems, characterized by soils and vegetation that require some state of saturation (*Riparian Ecosystem Diversity Evaluation, 2007*). Some key characteristics of a riparian ecosystem include shade, down and standing wood, unique features, riparian biota, soils quality and ground cover, and vegetation species composition (*Riparian Ecosystem Diversity Evaluation, 2007*).

Vegetation to Consider

When considering vegetation, we looked at the Montana Field Guide for Riparian Vegetation. Bridger Creek is suitable with the Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland system. Within this system, there is a dominance of trees and diverse shrubs, dependent on seasonal flooding.

Table 1: List of common vegetation in Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland ecosystems (Field Guide to Montana's Wetland and Riparian Ecological Systems)

Plant Type	**Common Name**	**Scientific Name**
Tree	Black cottonwood	*Populus balsamifera spp. trichocarpa*
Tree	Narrowleaf cottonwood	*Populus angustifolia*
Tree	Boxelder maple	*Acer negundo*
Tree	Douglas-fir	*Pseudotsuga menziesii*
Tree	Peachleaf willow	*Salix amygdaloides*

Tree	Rocky Mountain juniper	*Juniperus scopulorum*
Shrub	Rocky Mountain maple	*Acer glabrum*
Shrub	Thinleaf alder	*Alnus incana*
Shrub	Redoiser dogwood	*Cornus sericea*
Shrub	Douglas hawthorn	*Crataegus douglasii*
Shrub	Common chokecherry	*Prunus virginiana*
Shrub	Skunkbush sumac	*Rhus trilobata*
Shrub	Yellow willow	*Salix lutea*
Shrub	Woods' rose	*Rosa woodsii*
Shrub	Silver buffaloberry	*Shepherida argentea*
Shrub	Shrubby cinquefoil	*Dasiphora fruticosa*
Shrub	Common snowberry	*Symphoricarpos albus*
Graminoid	Bluejoint reedgrass	*Calamagrostis canadensis*
Forb	Yarrow	*Achillea millefolium*
Forb	Fireweed	*Chamerion angustifolium*
Forb	Swamp willow herb	*Epilobium palustre*
Forb	Common cowparsnip	*Heracleum macimum*
Fern	American ladyfern	*Athyrium filix-femina*
Fern	Oak fern	*Gymnocarpium dryopteris*

Bridger Creek Study Area

Bridger Creek is a part of a larger system, as it flows directly into the Gallatin River. Unfortunately, buffer width has proven to be a small yet significant factor in nutrient removal (Mayer et al., 2005). Based on a literature review by the Environmental Protection Agency (EPA), buffer width and nitrogen removal in forested systems show a variety of effectiveness; As low as 5 meters of a buffer has reduced more than 85% of nitrate levels, a 10-meter buffer reduced nitrate levels in the groundwater by 52%, and other work has shown that buffers 10-50 meters have removed up to 99% nitrate concentrations (Figure 5). Forested systems may be less effective with extreme nitrogen loading and increased hydraulic conductivity, which would require a wider buffer zone (Mayer et al., 2005). The results of the EPA study showed that wider buffer zones are more likely to effectively remove nitrogen, but there are other influences like flow pattern and vegetation type that help decide buffer width. Specifically, forest buffers are more effective than grass buffers, in terms of nitrogen removal (Mayer et al., 2005).

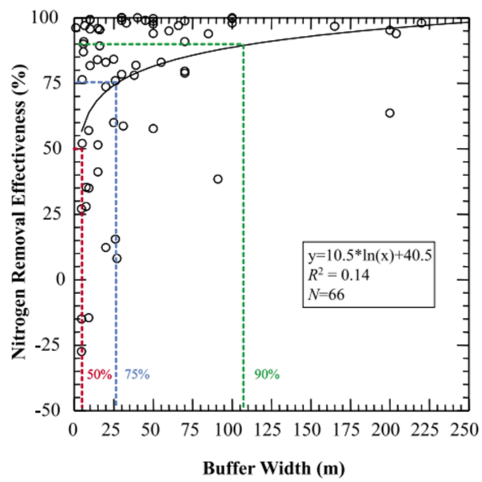

Figure 5: Relationship of nitrogen removal effectiveness to riparian buffer width where lines show probable 50%, 75%, and 90% nitrogen removal efficiencies (Mayer et al.)

Next Steps

The incorporation of a riparian buffer will benefit Bridger Creek and, in turn, will benefit surrounding systems such as the Gallatin. In terms of planting, we recommend a combination of seeding, cutting, and nursery stock. The seeding of grasses should take place in late fall or early spring for optimum germination and transplanted plants should be planted during the dormant season (*Riparian Plant Acquisition and Planting, 2012*). Given the minimal scope of the study site and steep slopes, hand seeding is suitable. Effective riparian growth is often associated with the direct planting of dormant hardwood cuttings, as many important riparian plants root well from stem cuttings (*Riparian Plant Acquisition and Planting, 2012*). Refer to the Riparian Plant Acquisition and Planting factsheet or another credible guide for information cutting techniques for riparian restoration. Plugs are also a transplant option, where seeds are grown in Styrofoam blocks, which can later be planted as plugs. As for transplanting nursery plants, larger plants are typically more expensive but can compete well with other herbaceous vegetation (*Riparian Plant Acquisition and Planting, 2012*). The incorporation of new vegetation will be determined by the available funding.

Vault Toilets : A proposal

Introduction

Vault toilets are common sanitation solutions in rural, remote, and public recreation areas in the United States. These toilets are intended to contain waste in a sealed tank, thereby preventing groundwater contamination and minimizing odors. However, vault toilets have foul-smelling gases resulting from poor ventilation -- leading to anaerobic processes in the waste storage vault. Anaerobic decomposition is inefficient in this system not only because it is slow and produces noxious gases, but also because its end result is waste that is considered as hazardous according to the EPA. (Kathryn 406-522-2536, USFWS Bozeman, Montana) This has environmental consequences primarily because the release of ammonia results in air pollution. In addition, the release of methane has consequences for climate change because it is a greenhouse gas and therefore contributes to global warming. For users of vault toilets, exposure to these harmful gases such as hydrogen sulphide (H_2S) and ammonia can cause respiratory irritation, headaches, and nausea (Richardson, 1995) (Chen et al., 2019) (Heldal et al., 2019) and is often a breeding ground for disease-causing pathogens such as E.coli, cholera or salmonella (Barker & Bloomfield, 2000) (Austin & Cloete, 2008).

Such odors cause users to avoid vault toilets and consequently defecate and urinate outside thereby contaminating the environment. Open defecation increases exposure to diseases (e.g., diarrhoea, cholera, and typhoid) by contaminating food, water, and soil, while attracting vectors such flies and rodents that spread pathogens (Odagiri et al., 2016). This pollution harms ecosystems, disrupts biodiversity, and renders water and land unsafe for use (Amadi E.C., et al., 2024).

Improving aerobic conditions can, however, enhance decomposition and reduce odors, therefore enhancing environmental sustainability and user experience. Even though this is an issue across the country, it is especially relevant at the college M of Montana State University on the Bridger mountainside. Although the M trail is a popular destination with an approximate average daily usage rate of 400 hikers, only 0.6% of visitors identified sanitation as a concern (Lawson, 2021) (M Area Intercept Survey, 2024). This suggests that sanitation, and specifically toilets, are often viewed as lower-priority issues, despite their essential role in public health and environmental impact.

Montana State University (MSU), with its strong environmental science and engineering programs, has a unique opportunity to improve the vault toilet system on the M trail. Addressing this issue not only serves to enhance the experience for trail users but also allows MSU to demonstrate its capacity for practical and important innovation. Furthermore, an upgraded and relatively inexpensive vault toilet model (presented below) could be adapted and implemented at similar sites across the nation.

The problem

As discussed above, the current “design" of vault toilets often leads to the accumulation of odors in the user compartment due to the predominance of anaerobic conditions within the waste storage vault. In typical vault toilet systems, waste is deposited into a sealed, non-ventilated or poorly ventilated chamber, where the absence of adequate oxygen circulation promotes anaerobic microbial activity. This anaerobic decomposition process produces noxious gases such as hydrogen sulphide, methane, and ammonia, which can easily migrate into the user compartment through openings, such as the toilet seat area. Moreover, the limited air exchange and ventilation in the vault toilet design exacerbate the issue by allowing these noxious gases to accumulate, rather than being efficiently vented to the outside environment. The design also often lacks mechanisms to promote aerobic microbial activity. This occurs as a result of the accumulation of a biosolid layer that prevents air from circulating through the sludge in the waste storage compartment. As a result, users are frequently exposed to unpleasant odors, particularly in high-use or warmer environments, where biological activity and gas production are heightened. Figure 1 below illustrates the design flaws and air flow problems that consequently arise.

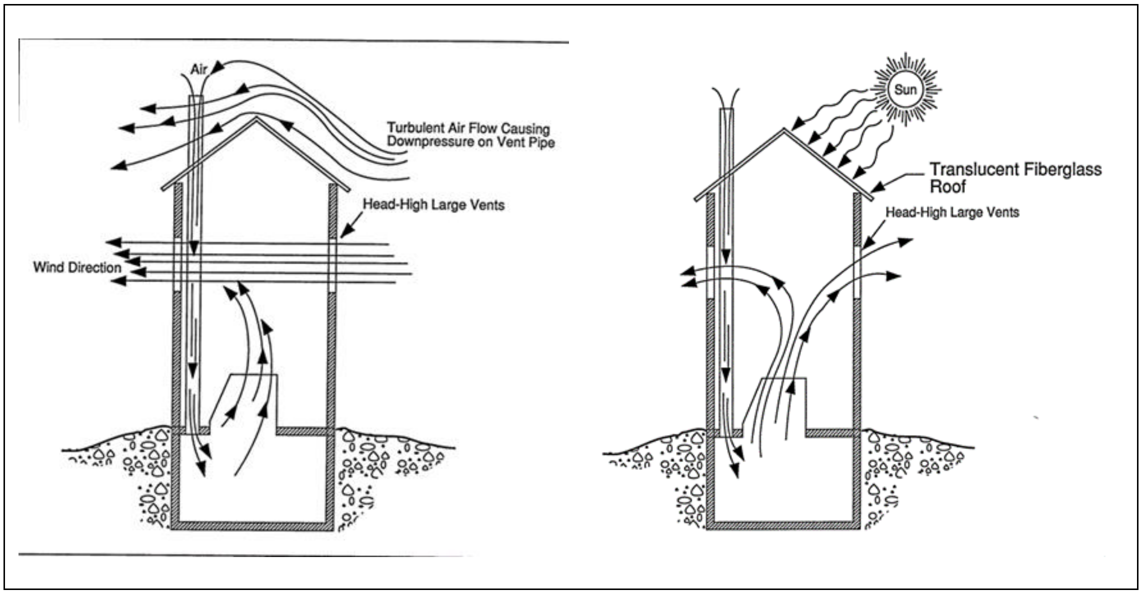

Figure 1. Odor problems resulting from turbulent flow creating down pressure on the vent pipe. Solar radiation heats up air inside causing it to rise and escape through the air vents leaving the air from the vault to replace the air in the use compartment (Cook, 1991).

The Proposed Solution

To vastly reduce and possibly eliminate the noxious odors and create a healthier, more environmentally friendly toilet for users, a new vault toilet design which may be called the MSU "M" vent toilet is proposed. This design includes a motorized exhaust fan and mixer in the form of a flocculator which will be installed in the toilet's vent stack and vault respectively. The exhaust fan will work to continually provide air to the vault by removing the air from the toilet and allowing fresh air to replace it. Additionally, the flocculator will mix the waste. The combination of the fan and flocculator will create an aerobic environment for the microbes thus eliminating the biosolid layer, speeding up aerobic decomposition and eliminating the accumulation of methane, hydrogen sulphide, and ammonia. These factors will result in a relatively odorless, hygienic, and environmentally sustainable vault toilet.

According to the Montana Mechanical Ventilation code, 50 – 70 CFM (cubic feet per minute; the rate at which volume of air moves past a fixed point) is required to be moved for every square foot in a public restroom (Chapter 4 Ventilation: Ventilation, Montana Mechanical Code 2012 | UpCodes, 2015). According to these codes, 70 CFM should be moved if the fan works intermittently.

The vault toilet at the college M is a public restroom and is approximately 64 ft^2 This means that 4480 CFM of air will need to be exhausted from the vault toilet intermittently according to equation 1 below.

$$\text{Exhaust air (CFM)} = \text{Area (ft}^2) \times \text{CFM per ft}^2 \qquad \text{Equation 1.}$$

$$\text{Exhaust air (CFM)} = 64\text{ft}^2 \times 70\text{CFM/ft}^2$$

$$\text{Exhaust air (CFM)} = 4480\text{CFM}$$

To accomplish this, an electric powered fan will be used to move the exhaust air out of the vault and user compartment through the vent. This will address the odor issues that are inherent with the vault toilet. The power needed to run the fan is calculated below in Equation 2.

$$W = \frac{Q * \Delta P}{n_f}$$

Where,

Equation 2.

$$W: Power\ required\ for\ the\ fan\ (watts)$$

$$Q : Airflow\ rate\ (cubic\ metres\ per\ second, \frac{m^3}{s})$$

$$\Delta P : Pressure\ rise\ across\ the\ fan\ (pascals, Pa)$$

$$n_f : Efficiency\ of\ the\ fan\ and\ motor\ (dimensionless, typically\ 0.5\ to\ 0.8)$$

First, we must convert CFM to cubic meters per second,

$$1ft = 0.3m$$

$$I\ minute = 60seconds$$

$$1CFM\left(\frac{1ft^3}{1minute}\right) * \frac{0.3m}{1ft} * \frac{0.3m}{1ft} * \frac{0.3m}{1ft} * \frac{1minute}{60s}$$

$$1CFM = 0.00045\frac{m^3}{s}$$

It is also necessary to determine the pressure rise across the fan. This number is usually different across various systems, depending on fan size and system requirements; but for typical ventilation systems, it is usually between 120 to 490 pascals (Tang, 2019). Fan efficiency must also be determined. This can range from 0.5 to 0.8 based on different manufactures (A Technical Bulletin for Engineers, Contractors and Students in the Air Movement and Control Industry. Codes & Standards Understanding Fan Efficiency Grades (FEG), n.d.). When these values are inserted, it will be observed that the fan will need approximately 604 Watts of energy to run as shown in equation 3 below.

Given that,

Equation 3.

$$Q = 4480CFM$$

$$\Delta P = 200Pa(assumed\ for\ moderate\ duct\ resistance)(Tang, 2019).$$

$$n = 0.7\ (70\%\ efficiency\ based\ on\ values\ from\ Greenheck.com\ Codes\ \&\ Standards\ CS/104-13)$$

First, we convert Q from CFM to cubic meters per second,

$$Q = 4480CFM * \frac{\frac{0.00045m^3}{s}}{CFM} = \frac{2.114m^3}{s}$$

Then we insert those values to determine the power needed to run the fan,

$$W = \frac{Q * \Delta P}{n_f}$$

$$W = \frac{2.114m^3/s * 200Pa}{0.7} = 604\ Watts$$

Additionally, an agitator in the form of a horizontal shaft flocculator will be included in the vault compartment beneath the user compartment. This flocculator shown below will feature a motorized crank mechanism that will also take advantage of electricity (Temirlan Mukashev, 2015).

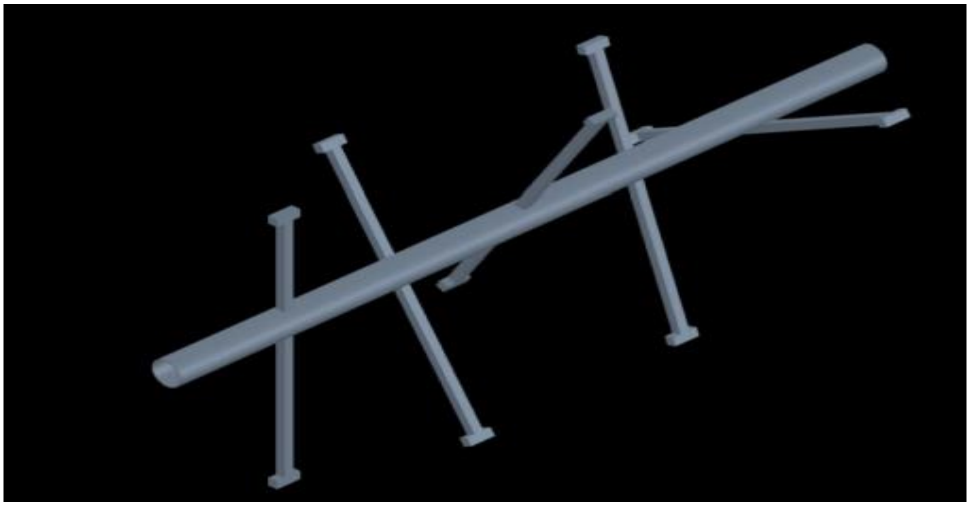

Figure 2. An agitator in the form of a horizontal shaft flocculator to mix the waste therefore breaking apart the biosolid layer (Okeng, 2016).

The flocculator will serve to disrupt the buildup of biosolids, facilitating air circulation to establish aerobic conditions and thereby enhance the composting process.

The following calculations illustrate the amount of energy in Watts needed to power the flocculator.

Equation 4.

$$P = \frac{C_D A_p \rho (V_r^3)}{2}, \text{ where}$$

$$P = \text{power imparted (W)}$$

$$C_D = \text{paddle coefficient of drag (typically 1.8)}$$

$$A_p = \text{area of paddles } (m^2)$$

$$\rho = \text{density of water } \left(\frac{kg}{m^3}\right)$$

$$V_r = \text{velocity of paddles relative to water } \left(\frac{m}{s}\right), \text{ typically 70 to 80\% of } V_p$$

$$V_p = \text{paddle velocity}$$

$$r = \text{distance from center of shaft to center of furthest board/blade(m)}$$

$$N = \text{rotational speed (rotations per second)}$$

If we use the dimensions of ConVault's 1000-gallon vault (*Tank Sizes*, 2024)where L=3.02m, W= 1.42m, and H= 0.914m we can approximate the dimensions of the horizontal flocculator where the L= 1.5m, the entire width containing the full length of the paddles would be W= 0.8m where each paddle would have a width of W= 0.4m, and a Length of L= 0.2m. These dimensions are illustrated in figure 3 below.

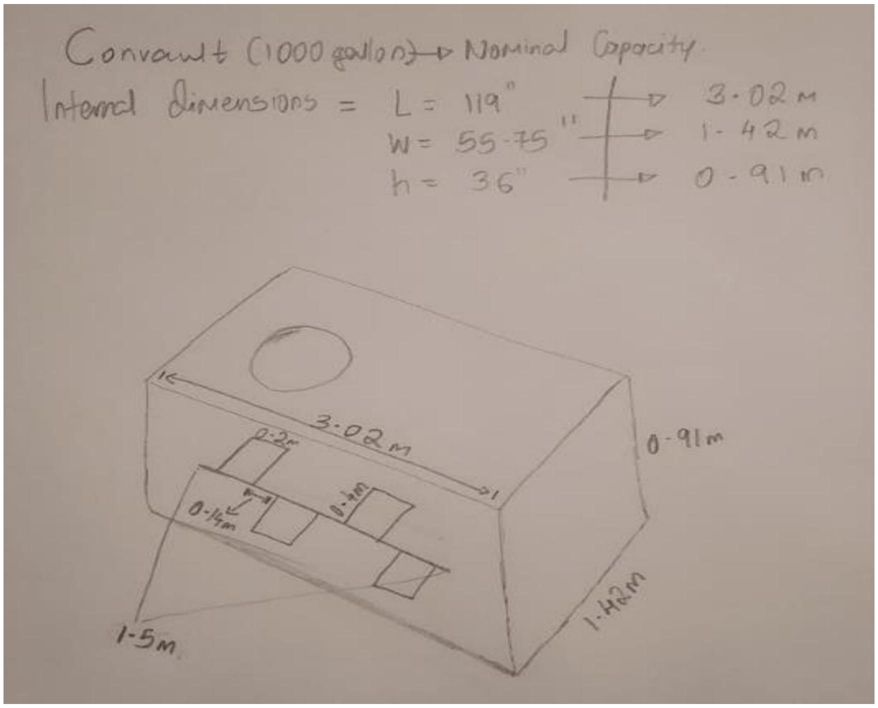

Figure 3. Illustration showing the agitator dimensions proposed for the vault toilet. Sketch by author: Esther Maina.

By substituting the given data into the power imparted by a paddle equation above,

$$A_p = 0.2\text{m} * 0.4\text{m} = 0.08\text{m}^2 \text{ (paddle area)}$$

$$r = 1.5\text{m (distance from shaft center to paddle blade)}$$

$\rho \approx \frac{1050\text{kg}}{\text{m}^3}$ (approximation for turbid wastewater, slightly denser than pure water (Schuler & Jang, 2007))

$C_D = 1.8$ (typical coefficient of drag for paddles((Drobny, 1963))

$\text{N} = 20\text{rotations per minute} = \frac{20}{60} =$
0.333 rotations per second (slow mixing standard for flocculation((Drobny, 1963))

Paddle tip velocity: $V_P = 2\pi r N$

$$Vp = 2\pi \cdot r \cdot N = 2\pi \cdot 1.5\text{m} \cdot \frac{0.333\text{rot}}{\text{s}} = \frac{3.14\text{m}}{\text{s}}$$

$$\text{Velocity of paddles relative to water}: \; V_r = 0.75 * V_p$$

$$V_r = 0.75 * V_P = 0.75 \cdot \frac{3.14\text{m}}{\text{s}} \approx 2.36 \, \frac{\text{m}}{\text{s}}$$

The power equation is :

$$P = \frac{C_D A_p \rho (V_r^3)}{2}$$

Substitute the values :

$$\mathrm{P} = \frac{1.8 * 0.08m^2 * \frac{1050kg}{m^3} * (\frac{2.36m}{s})^3}{2} = 1041.75W$$

The power necessary to run the fan and the flocculator is estimated to be 1,645.75 Watts. The MSU "M" vent toilet, is designed such that it can accommodate one 600-Watt solar-powered centrifugal exhaust fan, accompanied by an electric powered horizontal flocculator in the vault, featuring a 520Ah 48V lithium battery and a 16-foot cable. The exhaust fan can move between 1707 to 6640 CFM of air. This means that the fan can easily handle the 4500 CFM of air that the MSU "M" vent toilet needs to exhaust. The fan is also relatively quiet, meaning that noise pollution is not a factor.

Solar panels will be used to power this system. Two 550-Watt bifacial panels will be installed. These panels can handle wind loads of up to 2400Pa and snow heavy snow loads of up to 5400Pa. (cite) The total amount of power that these panels will provide is 1100 Watts (*Renogy Solar: Over 400-Watt Solar Kits*, 2024). Even though this falls below the power requirement that both the fan and flocculator need, which is 1645 Watts, we find that this is still sufficient, given that both the fan and flocculator will be run intermittently.

Running the fan and flocculator intermittently will ensure that the biosolid layer is not only broken but does not form and that enough air passes through the vault to aid in aerobic decomposition therefore reducing the odors. The battery to be used can last for up to 12 hours after being fully charged in sunlight, supplying electrical power for ventilation and agitation during nighttime or on cloudy days (Solar Battery Bank Sizing Calculator for Off-Grid, 2021). The system automatically adjusts the power supply mode based on the sunlight conditions.

The design

Figure 4 below is a sketch of the possible design for the improved vault toilet system that includes a horizontal flocculator. To install the horizontal flocculator, a hole will first be dug alongside the ventilation duct, extending deep into the ground where the vault is positioned. This hole will provide access for a second, horizontal hole to be dug into the side of the vault, allowing for the flocculator to be inserted from a lateral angle. Once the flocculator is positioned, the opening will be sealed to prevent any leakage or air exchange with the vault. Care will be taken to place the flocculator in a way that leaves space for any plumbing connections to the toilet, ensuring no obstructions when pumping of the waste build-up eventually needs to be done.

This new toilet design will be automated, incorporating sensors to monitor temperature, humidity and gas production in order to switch on--when certain thresholds are met. A microcontroller will also be implemented and can be programmed to monitor sensors and control both the fan and flocculator. For example, if humidity > 60%, then the system will turn on the fan, and run flocculator for 5 minutes every 12 hours. The sensor and microcontroller mechanism that controls the agitator will be located in a small compartment adjacent to the vent duct, outside the user area. This layout allows for efficient cable management, so solar electric power can supply both the ventilation fan at the top of the duct and the agitator/flocculator motor for optimal operation.

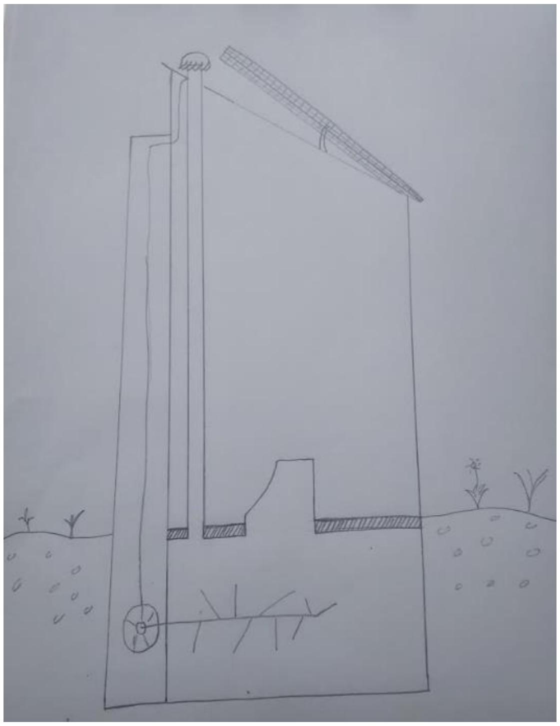

Figure 4. A sketch of the proposed MSU "M" vent toilet design. Sketch by author: Esther Maina.

Additionally, biodegradable bamboo-based toilet paper will be incorporated into the waste compartment to modify the C:N ratio, facilitating enhanced composting as a function of reduced anaerobic conditions. The C:N ratio of human waste is approximately 6–10:1, usually very low in carbon and high in nitrogen (Cook, 2010). For optimal microbial activity and odor control, a C ratio of 25:1 to 30:1 (by incorporating bamboo-based toilet paper) is necessary. This supports aerobic decomposition, minimizes nitrogen loss as ammonia, and reduces odor.

The vault toilet currently gets pumped 2 to 3 times a year and the waste is usually disposed of in a faraway landfill because it is classified as hazardous waste (Kathryn 406-522-2536, USFWS Bozeman, Montana). By incorporating this new design, the waste would no longer be categorized as hazardous and can be disposed of in a cheaper and more efficient way such as to a local wastewater treatment facility and possibly even used for manure in agriculture.

Visits to the vault toilet at the college M by USFWS managers usually occur twice a week in the summer and once a week in the winter (Kathryn 406-522-2536, USFWS Bozeman, Montana). The goal is to keep the toilet low maintenance by replacing conventional toilet paper with bamboo-based alternatives and implementing an automated sensing unit. This unit could be placed at the U.S. Fish and Wildlife Service (USFWS) offices across the road from the MSU "M" vent toilet. This approach ensures a healthier, environmentally sustainable toilet while protecting water quality around the college M. The total cost for this design is estimated at $15,000, including human resources.

In 2023, the USFWS received $3.7 billion in funding, which includes $2 billion in discretionary appropriations and $1.8 billion in permanent appropriations primarily allocated to states for fish and wildlife conservation (US Department of the Interior, 2023). The $2 billion in discretionary funds means this project comfortably fits within the USFWS's budget. Water quality protection is particularly critical given the creek located downhill and the nearby fish hatchery.

This proposed solution offers a low-maintenance, affordable way to address these concerns and presents an opportunity for MSU and the USFWS to showcase their innovation. If successful, this design could serve as a model for nationwide implementation.

Conclusion

The integration of swales, riparian buffers, and waste management systems can provide significant environmental benefits in redesigning the M Trail. Swales help manage stormwater, reduce flooding, and improve water quality by filtering pollutants. Riparian buffers add additional protection through filtering pollutants, stabilizing stream banks, and mitigating flow. Additionally, enhancing vault toilet systems with better ventilation and composting mechanisms can reduce odors, therefore improving user experience and easing pressure on wastewater systems. Together, these solutions address critical environmental concerns and promote sustainable infrastructure. All three methods can be used together or separately to improve water quality at the M trail.

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