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Wastewater Treatment and Disposal Alternatives for Mesa Lot Restrooms
FINAL

January 13, 2023

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1. INTRODUCTION

Several wastewater treatment schemes have been evaluated as part of the feasibility study for a new visitor-serving restrooms at the Mesa Lot in Point Reyes Station. This facility would be near the existing Toby's Playground restroom and wastewater treatment system, which is frequently overloaded by a large number of visitors and has an undersized treatment system and leach field. This new treatment and disposal system would be located on the currently undeveloped Mesa Road Lot, southwest of the existing restrooms and would expand the capacity of the existing Toby's playground restroom. The purpose of this report is to present a technical evaluation of several wastewater treatment and disposal alternatives while considering the feasibility of installing it at the proposed site. Two additional studies have been conducted by Sherwood Design Engineers as part of the feasibility study for the Mesa Lot, in order to provide a basis for selecting alternatives. The Needs Assessment[1] used existing leach field, septic pump out, and portable toilet data to calculate existing wastewater flows. These flows were combined with the visitor projections from the "Visitor Needs Assessment for West Marin", prepared by AECOM in 2017, to project these flows 30 years in the future. Additionally, Sherwood prepared a slide deck and report[2] presenting 12 case studies for ecologically-based wastewater treatment systems. Information gathered from these case studies was used to evaluate alternatives in this report.

This report provides a summary of both treatment and disposal alternatives. Section 2 provides a summary of the wastewater alternatives evaluated for the site including:

- Moving Bed Biofilm Reactor (MBBR)
- Membrane Bioreactor (MBR)
- Anaerobic Baffled Reactor (ABR) w/ Membrane Aerated Biofilm Reactor (MABR)
- Trickling Filters and Treatment Wetland
- Engineered Design: Anaerobic Media Tanks and Treatment Wetland
- Composting Toilets

Section 2 also includes a discussion around tertiary treatment and disinfection. These extra treatment steps may be required depending on the effluent requirements, described below in the regulatory requirements section.

[1] Point Reyes Station, Toby's Playground, Wastewater Treatment Needs Assessment, Sherwood Design Engineers, 2022.
[2] Point Reyes Station, Mesa Lot Case Studies for Ecologically-Based Onsite Wastewater Treatment Systems, Sherwood Design Engineers, 2022.

Section 3 provides a summary of the disposal alternatives evaluated for the site including:

- Leach Field
- Subsurface Drip
- Composting

The disposal alternatives evaluated, excluding composting, can be matched with any of the treatment alternatives contemplated in Section 2. The selection of the correct combination of treatment and disposal alternatives ultimately selected for this site will be based on the quantitative and qualitative criteria described below, and regulatory requirements.

Quantitative criteria included equipment capital expenditure (CapEx), operating costs (OpEx) and space requirements. Lower costs and space requirements were ranked more favorably. Qualitative criteria included reliability and performance, operational requirements, operator skill level required, permitting requirements, and potential for odor and nuisance complaints.

There were several constraints that limited the selection of the treatment system. The nature of the site as a public restroom in an area highly impacted by tourism and events results in wastewater flows with a high degree of variability. The system selected must have the capacity to meet maximum day flows typically seen during events in the area, with enough turn-down to operate effectively at the minimum flow rates. Public restroom facilities also have wastewater that is higher strength than residential wastewater. Wastewater flows to size a new restroom were calculated using data from the existing Toby's Playground restroom and projected for 30 years, as described in the Needs Assessment Report[3]. The results of these projections are shown in Table 1.

Table 1 - Wastewater Flows at Toby's Playground Restroom.

Year	Average Annual Day Flow gal/day	Maximum Day Flow gal/day
	Existing	
2022	1,700	5,100
	Projected	
2052	2,200	6,500

Characteristics of the incoming wastewater are assumed to be typical of a rest area. These flows are more concentrated than residential flows and have relatively high nitrogen loading. For example, domestic wastewater can be characterized as 35 mg/L of TKN per the General Order (Data from Table 4-3, USEPA Wastewater Treatment/Disposal for Small Communities, Manual, September 1992, EPA/625/R-92/005), while TKN measured at the Caltrans Dunnigan Safety Roadside Rest Area (citation) was eight times as high, at 280 mg/L.

Regulatory Framework and Effluent Requirements

The California State Water Resources Control Board (SWRCB) implemented an OWTS policy in May of 2013 that establishes state-wide regulation and management measures for OWTS. It sets minimum standards and allows for individual counties and agencies to adopt their own standards through the Local Area Management Plan (LAMP). The systems proposed at the Mesa Lot fall under the County of Marin

[3] Point Reyes Station, Toby's Playground, Wastewater Treatment Needs Assessment, Sherwood Design Engineers, 2022.

LAMP, as this applies to any OWTS under 10,000 gpd. In this case, the permitting and oversight of this system will be delegated by the SWRCB to local agencies.

While oversight is delegated to local agencies, the LAMP does not have specific effluent requirements. Therefore, the County may require the project to comply with the limits set out by the SWRCB General Order WQ 2014-0153-DWQ. This Order specifies the discharge requirement for small domestic wastewater treatment systems and applies to OWTS under 100,000 gpd. The treatment requirements of this General Order are dependent on the technology performance of the treatment equipment selected and are summarized in Table 2 below:

Table 2 - Effluent Limitations for Wastewater Treatment from General Order

Activated Sludge, MBR, or similar		
Constituent	**Unit**	**Treatment Goal**
BOD	mg/L	30 (monthly average), 45 (7-day average)
TSS	mg/L	30 (monthly average), 45 (7-day average)
Wastewater Pond or Tickling Filter[1]		
Constituent	**Unit**	**Treatment Goal**
BOD	mg/L	90[2]
TSS	–	Not Applicable

BOD denotes biochemical oxygen demand; TSS denotes total suspended solids; MBR denotes membrane biological reactor.

[1] Limit applies when treated wastewater is applied to a Land Application Area (LAA) or to a subsurface disposal system.

[2] The limit is based on a 65-percent reduction of incoming BOD. An incoming BOD of 350 mg/L was used to calculate this value.

The General Order also includes effluent limits based on threats to groundwater, but only for flow rates greater than 20,000 gpd, and therefore does not apply to this project.

Additional effluent limits may be required, as some of the leach field or subsurface drip systems will be sited within a 1,600’ drinking water well buffer set by North Marin Water District[4] (NMWD). To protect the drinking water supply, new wastewater systems within the buffer will be required to meet a high level of treatment, and any treatment train with processes that cannot be designed with secondary containment may not be acceptable at all, based on discussions with the NMWD. NMWD has indicated treatment will need to meet the State’s Recycled Water Standards established in California Code of Regulations, Title 22 for disinfected tertiary recycled water. Further discussions between the County and NMWD are recommended to understand how the buffer zones were defined and how these impact treatment requirements. In order to meet limits set for tertiary disinfected recycled water (Title 22 CCR Division 4 §60301.230), the following effluent treatment goals are proposed for the treatment system as included in

[4] Point Reyes Coast Guard Well 4 Source Water Assessment, North Marin Water District, 2013.

Table 3, in addition to those set forth in Table 2. The alternatives presented in this report were selected to meet these requirements.

Table 3 - Additional Effluent Limits for Wastewater Treatment to meet Title 22

Constituent	Unit	Treatment Goal
Turbidity[1]	mg/L	2 NTU (media filtration) 0.2 NTU (membrane filtration)
F-specific bacteriophage MS2, or polio virus	-	5-log removal (99.999%)

[1] Title 22 turbidity limits will result in a lower TSS than the limit provided in General Order.

Disposal systems proposed at the site are regulated by Marin County Code (MCC), and also described in the County of Marin LAMP. The requirement is to provide dual drainfields, each providing 100% of the required absorption area to be installed. To comply with this requirement, Sherwood proposes both a subsurface irrigation system and a leach field, with each designed to accommodate 100% of the projected wastewater effluent flow.

More specifically, MCC Section 600: Standard Septic System Regulations, will apply to the leach field system, and dictates the loading rate based on the percolation test results at the site. MCC Section 800: Alternative Septic Systems Regulations applies to the subsurface drip dispersal system, and similarly dictates the loading rate. Furthermore, it requires projects which propose alternative disposal systems to dispose of >1,000 gpd to provide a Cumulative Impact Study. This will apply to the proposed project, and includes an assessment of nitrate loading. The results of a cumulative impact assessment may require nitrate or nitrogen removal via the treatment system selected.

2.0 TREATMENT ALTERNATIVES

Six treatment alternatives are discussed in this section and the key factors that impact the design are summarized in Table 4 at the end of this document.

- (1) Moving Bed Biofilm Reactor (MBBR)
- (2) Membrane Bioreactor (MBR)
- (3) Anaerobic Baffled Reactor (ABR) w/ Membrane Aerated Biofilm Reactor (MABR)
- (4) Trickling Filters and (4a) Vertical Treatment Wetland
- (5) Engineered Design: Anaerobic Media Tanks and (5a) Horizontal Treatment Wetland
- (6) Composting Toilets

All treatment systems have been selected to meet the effluent requirements outlined above. If all treatment and disposal areas can be located outside the NMWD buffer, the system would just need to meet the requirements of the General Order, and the treatment systems proposed would no longer need to include tertiary filtration or disinfection.

(1) **Moving Bed Biofilm Reactor (MBBR)**

The existing system at the restroom consists of Orenco AdvanTex AX-20 units followed by a leach field. Sherwood's recommendation for pursuing a similar option would include using Orenco's AX-Max system to meet the projected flow rates, shown in Figure 1. This is a package system that uses a primary tank, packed bed reactor for BOD removal and nitrification, anoxic denitrifying MBBR unit with carbon feed, and polishing packed bed reactor to achieve an effluent of less than 10 mg/L BOD, TSS, and TN. Typically MBBRs require more space than a membrane bioreactor (MBR, discussed below) because they utilize a clarifier; however clarifiers can be replaced with a direct filtration step, in which case the system is similar in size to the MBR alternative.

This system would require the addition of tertiary filtration and disinfection, which is described later in this report. The benefits of this system are that the County is already familiar with Orenco's technology, and these types of systems provide a very high-quality effluent with a small footprint.

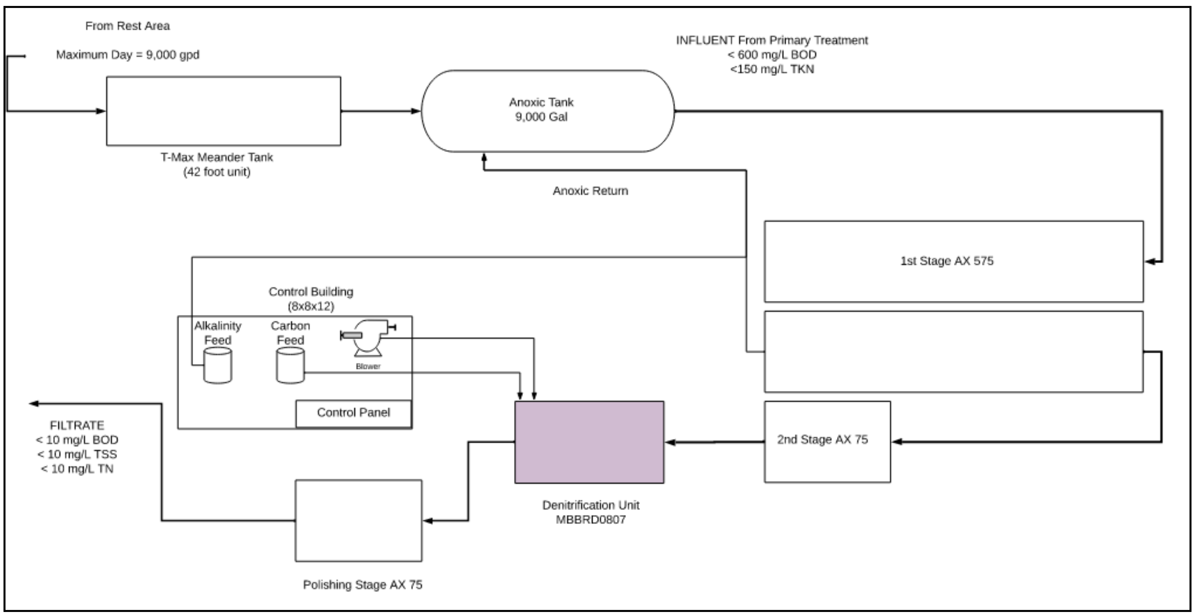

Figure 1: MBBR Package Plant.

(2) **Membrane Bioreactor (MBR)**

MBRs are a popular technology used for remote onsite reuse applications. In MBRs, membranes separate solid from liquid, keeping the biomass within the bioreactor before discharging the treated effluent. A benefit of this type of system is a small footprint, since secondary clarifiers are not necessary. However, the large blower required to push air through the membranes means this is one of the highest energy demand alternatives. A benefit of the overall process is that it includes ultrafiltration membranes, so an additional tertiary filtration process is not necessary. Kubota manufactures a small package plant, shown in Figure 2, which uses an MBR for nitrification and definitrication to provide similar effluent quality to MBBR. The system may be able to meet the treatment goal of less than 10 mg/L of total nitrogen if influent concentrations are less than 50 mg/L.

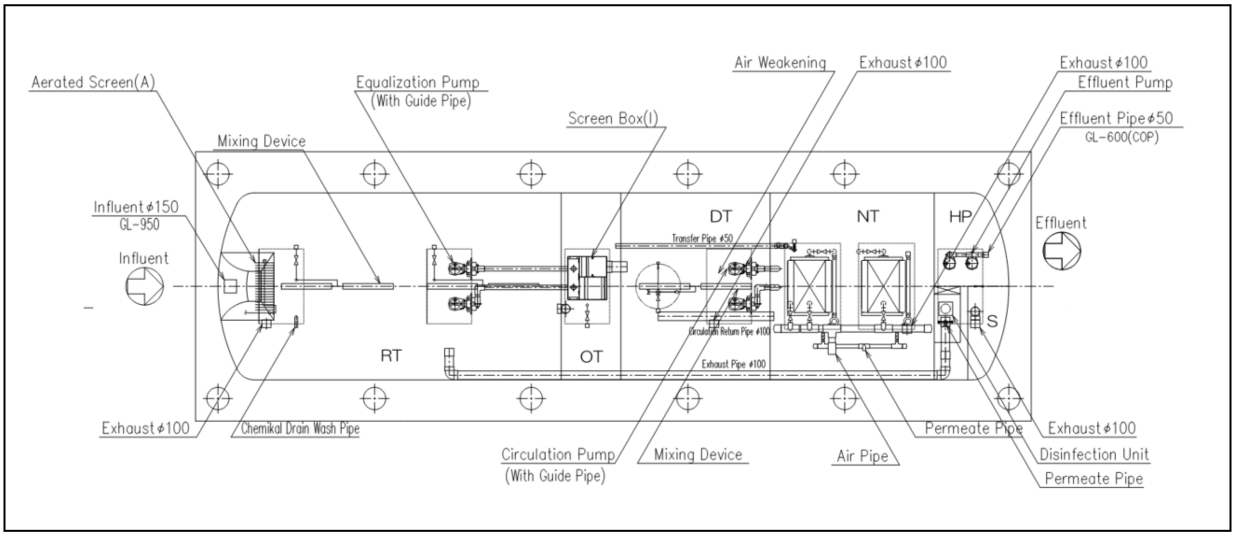

Figure 2: MBR Package Plant.

(3) Anaerobic Baffled Reactor (ABR) w/ Membrane Aerated Biofilm Reactor (MABR)

A water reuse system is being proposed at the nearby Point Reyes Coast Guard site where recycled water is proposed for reuse in irrigation onsite. The treatment system is a similar size and consists of primary treatment via an anaerobic baffled reactor (ABR) and secondary treatment with a membrane aerated biofilm reactor (MABR). ABRs are an improved septic tank which provides primary treatment. MABRs are an emerging technology that use a combination of suspended growth and biofilms that adds process stability during periods of fluctuating loads and reduces the need for additional aeration tanks. The MABR system is provided in a shipping container while the ABR would be buried. This system can also achieve a high nutrient removal via the MABR process, which provides simultaneous nitrification and denitrification, and can produce an effluent with less than 10 mg/L of BOD, TSS, and TN, depending on influent water quality.

The Aspiral MABR system, manufactured by Fluence, has many international installations for similar applications at rest areas. The process train in Figure 3 is an example of a process that would meet treatment requirements at the site.

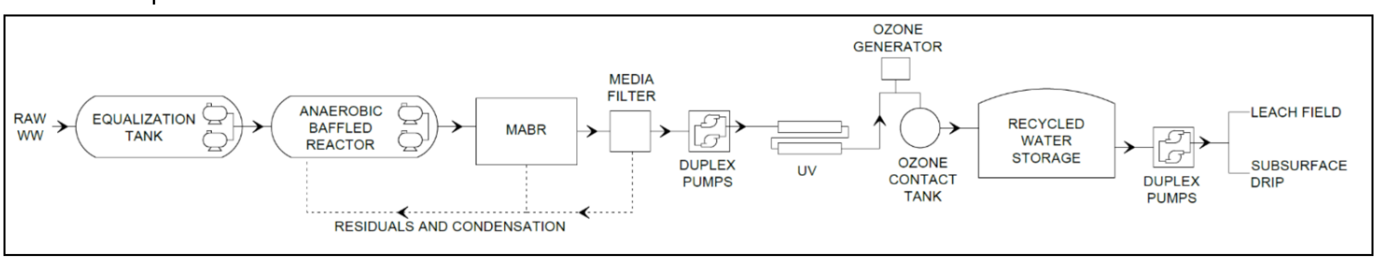

Figure 3: Treatment Process with ABR and MABR. Full process meets Title 22 requirements.

(4) Trickling Filters and (4a) Vertical Treatment Wetland

A wetland could be combined with trickling filters upstream and tertiary filtration and disinfection downstream to provide an acceptable effluent. An example is shown in Figure 4. Trickling filters can be designed in buried tanks outside the buffer zone and would remove BOD and TSS to secondary standards prior to wetland treatment. Trickling filters are a low maintenance and low energy secondary treatment option. Compared to the alternatives presented here, trickling filters will have the largest footprint and are not a good choice for reuse options that require low nitrogen limits. The sludge generated from trickling filters typically is returned to a primary treatment tank and does not require additional off haul to deal with residuals. The primary tank still needs to be pumped periodically.

Treatment wetlands, which use plants and microorganisms for pollutant removal, are a low maintenance option that provide the benefit of an educational opportunity, and have aesthetic appeal. Wetlands would provide additional removal of BOD, TSS, turbidity, and nitrogen removal, and would help with polishing if the system is hit with a heavy flow. A benefit of the system is that unlike the package plant system, wetlands do not produce treatment residuals that will require pumping out and subsequent disposal periodically.

In terms of configuration, an open surface wetland is not a good choice for this site due to space constraints. A gravel-bed, horizontal or vertical flow wetland provides treatment in a more compact footprint. A horizontal subsurface wetland is shallow while a vertical wetland is deeper with a distribution system on top and a recirculating filter. A horizontal wetland provides both nitrification and denitrification which contributes to nitrogen removal. A vertical wetland provides mainly nitrification and thus does not provide the same level of nitrogen removal, but has the benefit of a reduced footprint. Topography of the site may also limit design of a horizontal subsurface wetland, which flows by gravity. A vertical flow wetland may be a good option for the site where space is limited, and could be combined with anaerobic technologies to achieve the effluent treatment goals.

Concerns of effluent overflow or leakage from wetlands could be mitigated in several ways, but more discussion with NMWD is necessary to understand these implications. It’s expected that NMWD will likely not allow wetlands within the 1,600’ buffer. The area for a typical horizontal subsurface wetland at the projected flows is expected to be at least 0.25 acres for a hydraulic residence time of 3-5 days, which would require the wetland to be within the buffer.

Figure 4: Example of trickling filters with an engineered wetland. From the Portland Hassalo on 8th project.

(5) Engineered Design: Anaerobic Media Tanks with (5a) Horizontal Treatment Wetland

Because of the unique wastewater streams from rest areas, off-the-shelf designs are often not suitable, and specialized treatment facilities are sometimes needed. A design that has been piloted successfully at the Randolph E. Collier Safety Roadside Rest Area (SRRA), shown in Figure 5, which meets modern discharge limits with more rigorous nutrient removal requirements.

In this design, multiple buried tanks installed in series emulate baffles, creating an anaerobic baffled reactor. This provides high TSS removal, and promotes optimal biological conditions in the anaerobic media filters for additional BOD and COD removal. In the anaerobic media tanks, influent flow upward through media and a subsurface wetland is used for polishing of the effluent.

The configuration was selected to optimize performance and reliability, with minimal operation and maintenance needs, and automated operation.

This system would also provide good sludge volume reduction allowing for less maintenance and pump out of solids. Diverting urine from the urinals may be necessary as a technique to meet regulatory requirements for nitrogen reduction or may be desirable in the future for nutrient recovery.

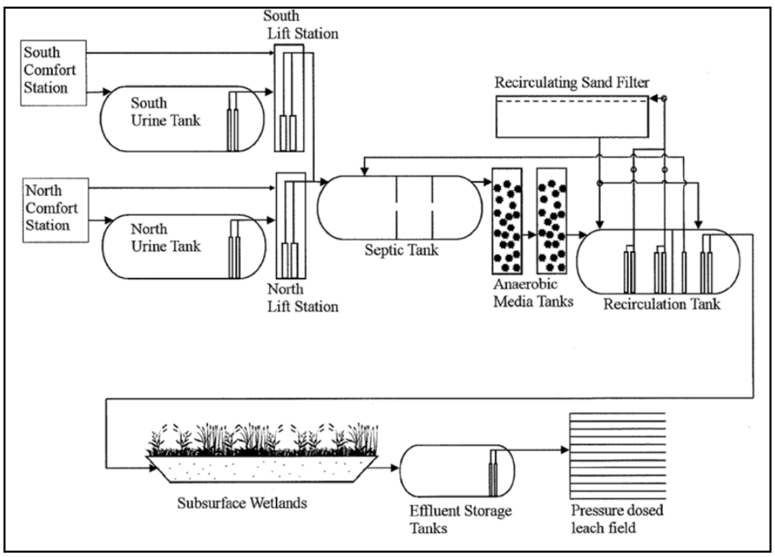

Figure 5: Treatment system engineered for high-loading at a Caltrans rest area.

The same considerations described above for a treatment wetland would also be considered for this alternative. However, an alternate treatment technology to provide an additional treatment and polishing, could be used in lieu of a wetland system.

(6) Composting Toilets

Composters use natural biological decomposition to convert human waste into a potentially reusable end-product. A composting toilet system would allow the County to reduce effluent flows to the irrigation and/or leach field. Typical maintenance activities include adding wood chips and turning the composting waste weekly. The County will need to find a disposal option for the finished compost, which can be tested and approved as Class A.

Composters are typically served by foam-flush or vacuum-flush toilets. Case studies for similar systems using foam-flush toilets often replace them with vacuum-flush due to maintenance and user experience issues. Sherwood investigated five sites which use composting toilets to develop a report on case studies for similarly-sized treatment systems. This included interviews with facilities operators at the Occidental Arts and Ecology Center (OAEC) and Architectural Nexus SAC office. As described in the case study memo[5], lessons learned from operating this type of treatment system revealed a high level of operator interference to maintain the composting process, odor control fans, and the specialized toilets. At one project, the Bullitt Center in Seattle, WA, composting toilets were removed after 7 years of operations due to ongoing maintenance issues.

A large number of composting units are needed to meet the maximum day flows at the Toby's Playground restroom. One manufacturer, Clivis Multrum, recommends 12 units, which are each approximately 50 sq.ft. each, shown in Figure 6. In addition, because there is no connection to the sanitary sewer, leachate or liquid from the system will be conveyed to a greywater system.

Waste to the composters can be conveyed by gravity if there is a basement in the building, or pumped if not. A grinder or macerator pump is recommended if waste is conveyed. Regardless of the way waste is conveyed, access to the composters for maintenance and unloading of finished material is an important design consideration. Also due to the biological processes required during composting, the temperature of the composter should not drop below 65 ºF, therefore heating of the composters would be required.

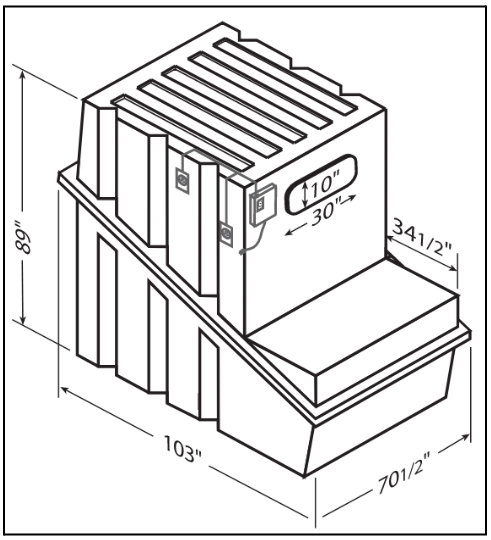

Figure 6: A single composter unit. Multiple units would need to be combined to meet the flows at the Toby's Playground restroom.

Tertiary Filtration and Disinfection System

For all the systems above additional treatment will be required to meet the defined treatment goals and the requirements of Title 22. Specifically, tertiary filtration and disinfection should be added to produce an effluent that is classified as disinfected tertiary recycled water. The MBR system is an exception to this as ultrafiltration is integral to the treatment technology. Only disinfection will be required downstream of this system. Membrane or media filtration can be provided to provide tertiary-level treatment. For this application, media filtration is recommended as the lower-maintenance option. Media filters can be

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[5] Case Studies for Ecologically-Based Onsite Wastewater Treatment Systems, Sherwood Design Engineers, 2022

automatically backwashed while membranes require more-involved chemical cleaning, usually through a clean-in-place method. Constraints of media systems are that flow rates may be too low for media filters. The State Water Resources Control Board has conditionally accepted other technologies for filtration, including cloth filters or non-granular media filters, but these products are typically used in higher flow, municipal applications. One way to tackle this issue is to use a batch treatment method to push the flows through at a higher rate to accommodate the minimum design flows. Adding a sump and pump system after the secondary treatment would allow the system to operate the filters at a higher flow rate.

After the multi-media filter, effluent will flow to a disinfection process. The disinfection level required could be achieved by two closed-vessel ultraviolet (UV) light disinfection units. The two UV units will be plumbed in series with the ability to take one unit offline for maintenance while keeping the other unit in operation. For the disinfection process, UV technologies which are conditionally accepted by the DDW are approved for flow rates much higher than the existing sites. Lamps will need to be installed in series to achieve the log-reduction required.

An ozone treatment system can be added after the UV, which would provide advanced oxidation to remove trace contaminants, including pharmaceuticals and other contaminants of emergency concern (or CECs).This oxidation step is not required as part of the NMWD or Title 22 requirements, however may alleviate any concerns of CECs in the effluent. If this alternative is chosen for concept design, additional research should be performed on the fate of CECs and soil contact or “soil matrix treatment”. Addition of an ozone system will allow for any level of disinfection credits provided there is enough contact time.

Chlorine disinfection could be an effective alternative to the high energy intensity and operational requirements of a UV disinfection and/or ozone system. Title 22 allows for chlorine disinfection if there is a post-filtration chlorine contact time not less than 450 milligram-minutes per liter, with a minimum contact time of 90 minutes. This could be achieved at maximum day flow by providing an approximately 500 gallons of contact tank volume and a chemical dosing system for sodium hypochlorite. Recommended design would achieve this volume in series to mimic a plug-flow reactor and minimize short circuiting.

3.0 DISPOSAL ALTERNATIVES

Three disposal alternatives are described in the following sections. Both the subsurface drip and leach field options can be utilized with any of the treatment alternatives presented, and can be combined to provide redundancy required by the LAMP. The composting option is specific only to the use of composting toilets.

Subsurface Drip

The disposal system could be a hybrid system consisting of subsurface irrigation with a 100% redundant leach field for use during wet weather. With the treatment alternatives outlined above, the wastewater will be treated to a level suitable for indoor non-potable reuse, and could be used for toilet flushing at the new restroom, if allowed. The benefit of a subsurface drip system is that it provides a level of benefit to landscaping and is likely allowed to be within the NMWD buffer because it provides more soil matrix treatment than a leach field.

The estimated area required for a subsurface drip irrigation system with the capacity to dispose of 100% of effluent is 10,800 sq. ft, shown in Figure 7. An application rate of 0.6 gal-day/sq.ft. was determined via percolation testing performed in November 2022. The system should comply with the Marin Code for

Siting and Design Criteria for Subsurface Drip Dispersal. If subsurface drip irrigation is within the buffer, Title 22 effluent requirements will need to be met. Based on a preliminary feasibility analysis of the site, irrigation will be within this buffer. Some of the issues associated with a subsurface drip irrigation dispersal system include clogging of the disc filters and gopher damage.

Leach Field

The estimated area required for a leach field, which can handle 100% of the wastewater flow is 11,500 sq. ft., shown in Figure 7. Whether this system is gravity or pressure-dosed depends on the site topography. The existing leach field at the Toby's Playground site is pressure-dosed. It is recommended that a new leach field be installed outside of the buffer to the maximum extent possible. An estimated application rate was determined via percolation testing performed in November 2022, and is 0.75 gal-day/sq.ft. The system should comply with Marin County code Regulations for Design, Constructions and Repair of Individual Sewage Disposal Systems. To meet LAMP requirements, the area of leach field shown would need to be combined with the redundant subsurface drip area shown in Figure 7. If the NMWD buffer is reduced or eliminated, the entire disposal system could be a leach field only, as long as it's expanded to include 100% redundancy.

Composting

If composting toilets and an associated greywater treatment system is selected, the estimated leach field area required would be reduced to 1,300 sq. ft.

Disposal of the finished composted material will be required periodically. The volume and frequency of disposal is highly variable on the site conditions and use. Sherwood interviewed one office facility, which served 30-40 employees, which only emptied their composters once in a three year period. The facility staff admitted they believe their system is oversized and that usage rates were impacted by a partially remote workforce. Applying the flow and disposal rates from this facility to get a comparative estimate, Sherwood roughly estimates that the composters in the new restroom facility would need to be emptied twice per year.

4.0 CONCLUSIONS

Based on information discussed in sections above, the following summarizes the findings of the treatment and disposal assessment, presented in Table 4. The area requirements of the recommended systems are shown in Figure 7. Composting toilets (6) or a horizontal wetland (5a) were eliminated from consideration, for reasons discussed below. The engineered system described in alternative (5) is also eliminated due to space constraints.

There are several reasons that composting toilets are not recommended. Sherwood's interviews with the operators of facilities with composting toilets revealed a high level of operator interference, which is not ideal for a remote site. Specific training is required, meaning that staff would need to be dedicated to this facility. The County will need to find a disposal option for the final composted product, which in nearby Sonoma County, was required to be land applied in a fenced-off area, and not beneficially reused. A separate liquid steam, consisting of leachate from the composters, must be handled with a separate treatment system, further complicating operations. If a composting toilet is not used, then the disposal option for all other treatment options would be for subsurface drip and leach field disposal.

Wetland systems are low-energy and low-maintenance, and would be one of the more aesthetic alternatives. The site constraints and land area required for a potential process including a horizontal wetland may push the treatment system and more of the disposal field into the NMWD buffer zone, which is unlikely to be accepted by local regulators. A treatment system designed with a vertical wetland would maintain the smallest footprint, and has the highest potential to fit within the buffer.

Figure 7 illustrates the approximate area requirements for the treatment alternatives and disposal requirements presented here. When slope and structure setback are considered, the footprint of all treatment equipment and disposal areas will not fit within the site outside of the NMWD buffer. This will impact the treatment requirements, as discussed in the Regulatory Framework and Effluent Requirements section. No additional hardscape development of the site can occur in any of these areas, including the disposal areas. As discussed earlier in this report, the subsurface irrigation system could be located within the buffer zone as long as Title 22 requirements are met, which would allow for more area available for development of the site that will provide public benefit.

If Title 22 effluent requirements need to be met, Sherwood's recommendation is a package plant with MBBR or MBR treatment option, which will provide an alternative with a small footprint, reliability, and proven high level of treatment. The MBR has high O&M cost due to the use of membranes, which are not necessary to achieve the treatment goals for this site. An MBBR system with a downstream media filter would meet treatment goals and have a relatively lower O&M requirement due to lower energy costs and simpler maintenance. Chlorination would be the lowest O&M requirement option for disinfection.

For disposal options, both a leach field and subsurface drip system, each with 100% capacity, are recommended to provide complete redundancy.

The next steps are to better understand the treatment goals from the NMWD and other local regulators. The treatment system selected should be able to meet the treatment goals with the least amount of maintenance and a high level of reliability.

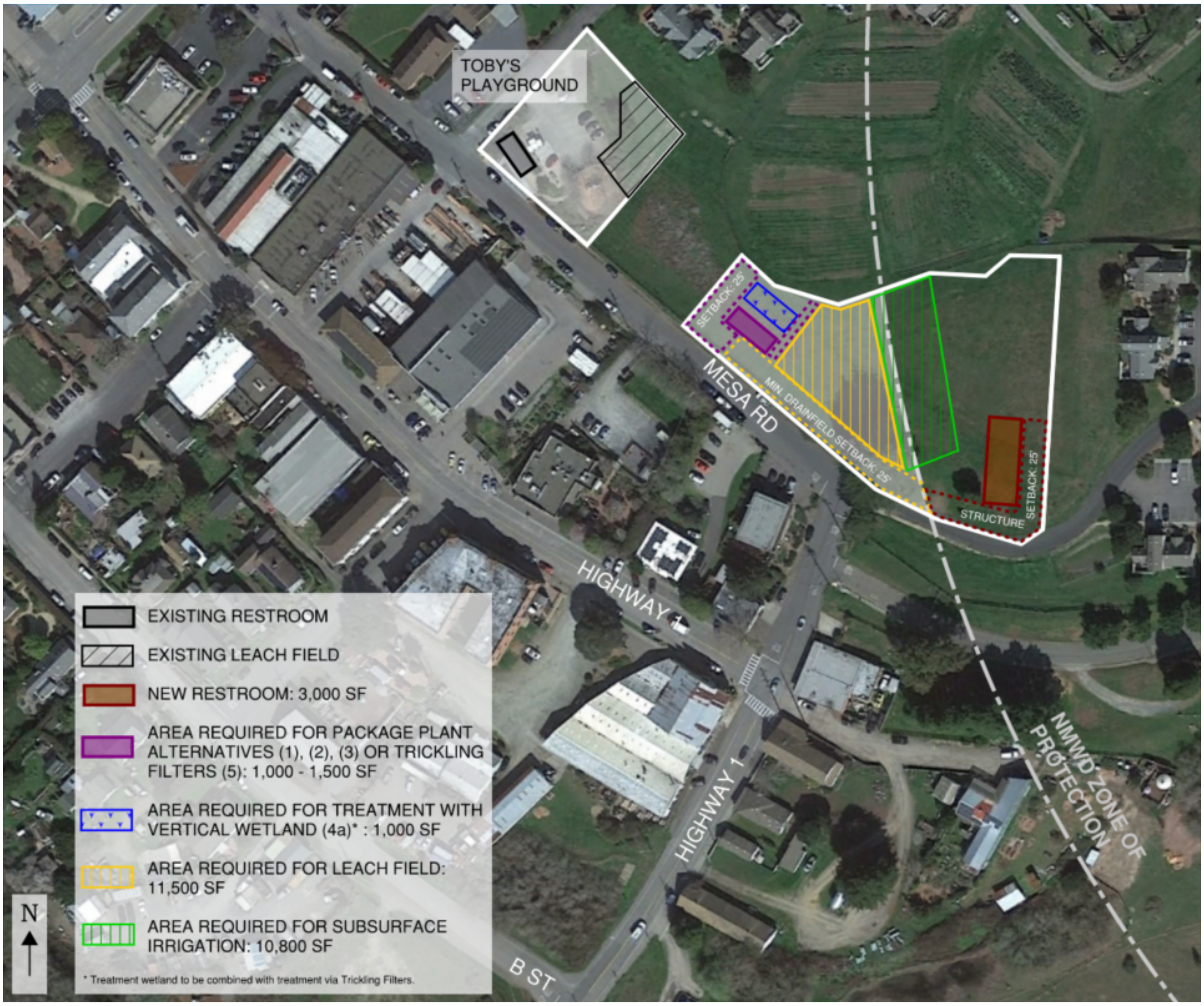

Figure 7: Estimated areas required for treatment and disposal alternatives.

	Manufacturers	Land Area Requirements	Capital Expense (CapEx)	Operational Costs (OpEx)	Reliability + Performance	Operational Requirements (Operator skill level)	Permitting Requirements	Odor and Noise
(1) Moving Bed Biofilm Reactor (MBBR)	*Orenco (AX-Max)*	**Smallest space requirement.** 500 sq. ft. Mobile-sized unit is a shipping container. Can be buried. Additional space would be needed for tertiary filtration, disinfection, and recycled water storage.	**High capital cost.** $1.2 M total project cost including construction estimate.	**Medium/high O&M cost. Lower when compared to MBR system.** Operators visit the site on a quarterly or semi-annual basis. Low compared to other similar technologies. Biggest operating expense is energy use.	**Proven technology. High reliability and treatment.** Many US installations for similar applications. Produces high-quality effluent. MBBR provides flexibility over fluctuating loads.	**Medium**. Certified Class III Operator required per California regulations. County staff are already familiar with Advantex system at the site.	Tertiary filtration and disinfection would need to be added to meet Title 22 requirements per NMWD.	**Medium odor and noise potential.** System is enclosed which will limit pump noise and odor under typical operations. Additional odor control system should be included.
(2) Membrane Bioreactor (MBR)	*Kubota (KM-SG-NP-1)*	**Small space requirement.** 800 sq. ft. Tanks can be buried. Additional space for disinfection required.	**Highest capital cost.** $1.6 M total project cost including construction estimate.	**High O&M cost.** Largest operating expense is energy use. MBR uses more energy for aeration than MBBR or MABR options. Estimated that an operator would visit every two weeks. Requires membrane replacement every ~10 years.	**Proven technology. High reliability and treatment.** Often installed in remote areas to treat small flows. Highest number of installations for this application compared to other technologies considered here.	**Medium**. Certified Class III Operator required per California regulations.	Tertiary filtration and disinfection would need to be added to meet Title 22 requirements per NMWD.	**Medium odor and noise potential.** System is enclosed which will limit pump noise and odor under typical operations. Additional odor control system should be included.
(3) ABR w/ Membrane Aerated Biofilm Reactor (MABR)	*Fluence (Aspiral)*	**Medium space requirement.** 800 sq. ft. MABR in shipping container above ground. Additional space would be needed for tertiary filtration, disinfection, and recycled water storage.	**High capital cost.** $1.5 M total project cost including construction estimate.	**Medium/high O&M cost. Lower when compared to MBR system.** Mass transfer efficiency reduces energy demands and O&M costs significantly compared to other secondary treatment systems.	**Emerging technology.** A combination of suspended growth and biofilms adds process stability during periods of fluctuating loads and reduces the need for additional aeration tanks, offering space savings.	**Medium**. Certified Class III Operator required per California regulations.	Tertiary filtration and disinfection would need to be added to meet Title 22 requirements per NMWD.	**Medium odor and noise potential.** System is enclosed which will limit pump noise and odor under typical operations. Additional odor control system should be included.
(4) Engineered design: Anaerobic Media Tanks and (4a) Vertical Treatment Wetland [1]	*Engineered solution, varies*	**Large space requirement.** 2,800 sq. ft. including equipment, vehicle access. 1,000 sq. ft. for vertical flow wetland. [2]	**Medium capital cost.** Varies for engineered system. $178,000 per acre for treatment wetland only.	**Medium O&M cost.** $20,000//yr for energy costs, routine monthly maintenance, and annual solids removal. Constructed wetlands require basic maintenance throughout the duration of the life of the treatment train, but no highly technical equipment or chemicals are required. Filter media is replaced every 8 - 15 years.	**Custom design optimizes reliability and performance.** High level of nitrogen removal. Products selected minimize maintenance. Disadvantage is that performance of wetlands is less consistent than conventional treatment.	**Medium**. Certified Class III Operator required per California regulations.	Tertiary filtration and disinfection would need to be added to meet Title 22 requirements per NMWD. Treatment wetlands will likely not be allowed within the 1,600' well buffer.	**Medium odor and noise potential.** System is enclosed which will limit pump noise and odor under typical operations. Additional odor control system should be included.
(5) Trickling Filters and (5a) Horizontal Treatment Wetland	*Trickling filters in buried Xerxes tanks.* *Wetland would be a custom engineered design.*	**Largest space requirement if horizontal wetland used.** 1,500 sq. ft. for trickling filter tanks and pumps 0.25 acres required for a horizontal subsurface flow wetland. Topography of site is a constraint, this system flows by gravity. 1,000 sq. ft. for vertical flow wetland is more feasible.	**Lowest capital cost.** $150,000 for trickling filter tank, including construction $178,000 per acre for treatment wetland only.	**Low O&M cost.** Operations and maintenance expenses are low. Treatment occurs passively, resulting in low energy use. No residual biosolids. Constructed wetlands require basic maintenance throughout the duration of the life of the treatment train, but no highly technical equipment or chemicals are required. Filter media is replaced every 8 - 15 years.	**High level of reliability with the tradeoff of a lower level of treatment.** Require a minimum amount of flow, but can handle fluctuations. Performance of wetlands is less consistent than conventional treatment.	**Medium**. Certified Class III Operator required per California regulations.	Treatment wetlands will likely not be allowed within the 1,600' well buffer.	**Low odor and noise potential.** Potential for odor and vector issues if system is not operated correctly.
(6) Composting Toilets	*Clivus Multrum (M35 - twelve composters)* *Phoenix*	**Medium space requirement.** 900 sq. ft. for composters and access only. Additional space required for the greywater/leachate system.	**Low capital cost.** To meet maximum day flow, the manufacturer recommends 12 composting systems. Composters: $450,000 Greywater system: $25,000	**Medium/low O&M cost.** Expect higher O&M costs than flush toilets or septic systems, due to maintenance requirements. Requires vacuum flush toilets. Composter area must be heated to a minimum of 65 degrees F.	**Medium to low reliability.** Able to handle variability of flows.	**Medium/low.** System is not complex, but a specialized level of training required.	**No permitting pathway for composting toilets in Marin County.** There are systems operating in Sonoma County and in Sacramento. Will need to work closely with regulators. Must dispose of finished compost.	**High odor potential. Low noise potential.** Potential for odors if venting fans are not carefully designed and protected from failure. Vacuum flush system is louder than a conventional flush toilet.