FEASIBILITY OF A SUSTAINABLE CONSTRUCTED WETLAND TO TREAT WASTEWATER FOR THE CITY OF JULIAETTA, IDAHO

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Small communities have a small tax base, limited funding, limited staffing, and must still meet all federal and state requirements for the treatment of wastewater. Many small communities in the United States are facing the challenging problem of how to replace aging rural infrastructure like wastewater treatment systems with limited resources. This is compounded by increasingly stringent water quality standards for treated effluent. Constructed wetlands provide a cost-effective solution for wastewater treatment that can be applied to small communities and provide sustainable benefits that traditional engineered systems cannot, such as wildlife habitat, energy savings, irrigation water, and recreation area. Case studies of effective wastewater treatment wetlands are presented. Cost, effectiveness, and benefits of constructed wastewater treatment wetlands are compared to traditional systems to demonstrate the value and feasibility of constructed wastewater treatment wetlands. Permitting and funding logistics are discussed, with specific examples from a rural community in Idaho.

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DEDICATION

This work is dedicated to my brother and sisters, who have each faced great adversity with strength and dignity. You exemplify the meaning of determination.

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CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Small towns in Idaho have aging wastewater infrastructure that no longer meets treatment standards of federal or state water quality. Replacement and repair of traditional wastewater treatment infrastructure is costly and project costs run in the millions of dollars. Small towns do not have a large tax base to fund wastewater treatment system upgrades or replacement. They also face difficulties like staffing, and often have one or two staff members to operate and maintain the wastewater system at all times. It is also difficult for small towns to attract and retain staff with skills, experience, and/or certifications to operate and maintain a wastewater treatment system.

Constructed wetlands are an alternative method of wastewater treatment that can meet or exceed efficiencies of traditional systems while providing human and ecosystem benefits. Further, constructed wetlands cost less to construct and maintain than traditional treatment systems. Cost, effectiveness, and benefits of constructed wastewater treatment wetlands are compared to traditional systems to demonstrate the value and feasibility of constructed wastewater treatment wetlands. Permitting and funding logistics are discussed, with specific examples from the rural community of Juliaetta, Idaho.

1.2 Purpose

These problems are common throughout Idaho and across the United States. There are 187 cities in Idaho with a population fewer than 5,000 people (Cubit Planning 2018) and uncounted unincorporated communities and rural developments using centralized wastewater treatment systems. The purpose of this project is to address the needs of small communities to replace aging wastewater treatment systems with limited funding and staff typical of small towns.

Access to safe drinking water and adequate sanitation are basic principles of a sustainable city (ElZein, Abdou, and ElGawad 2016). Failure to meet water quality standards impacts more than one community –cities small and large obtain drinking water from rivers that receive treated wastewater. For example, the City of Juliaetta obtains drinking water from the

Potlatch River 6.4 km (4 miles) downstream from where the City of Kendrick discharges its treated wastewater. The City of Lewiston (population 32,820) obtains 80% of its drinking water from the Clearwater River, 37 km (23 miles) downstream from Juliaetta's wastewater discharge (Figure 1). Failure to meet water quality standards for treated wastewater directly impacts the need and cost for other communities to obtain clean drinking water, since cleaning polluted water to drinking water standards is expensive.

Constructed wetlands have been successfully used worldwide to treat wastewater, even in cold climates like the Pacific Northwest, but are not common in the United States and none exist in Idaho. In areas where sustainability is valued and/or required by local development regulations, constructed wastewater treatment wetlands have greater appeal and acceptance, such as the Port of Portland's Living Machine. In areas where sustainable development methods are not required, they are frequently regarded as costly or unnecessary if they are considered at all. Despite this lack of popularity, research related to the cost and effectiveness of constructed wetlands demonstrates they are sustainable, cost effective, and efficient alternatives to traditional wastewater treatment systems (Deeptha, Sudarsan, and Baskar 2015).

When properly constructed, wetlands effectively remove excess nutrients and solids from wastewater. Furthermore, constructed wetlands contribute ancillary benefits (Figure 2) that traditional engineered systems cannot, such as lower cost, lower energy demand and maintenance, attractive aesthetics, aquatic and wildlife habitat, recreation area, and resource conservation.

As landscape architects, we lead the stewardship, planning, and design of our built and natural environments ("About ASLA | Asla.Org" 2018). Current practice in landscape architecture addresses issues in urban water management through the use of green infrastructure. In rural areas, applications of green infrastructure are lacking and frequently receive little or no public support. Constructed wetlands, as a built and natural environment, provide the perfect opportunity to apply stewardship, planning, and design to treat wastewater and fulfill a need to apply sustainable water management practices to rural issues.

1.3 Scope and Goals

The thesis researches methods and critical components of constructed wetlands, as well as challenges and solutions to permitting and funding. The cost and benefits of a constructed wastewater treatment wetland compared to traditional treatment methods is researched to demonstrate the multiple advantages of constructed wetlands over traditional systems. The goal of this comparison is to encourage communities, design professionals, and permitting agencies to implement this technology when existing systems require renovation and/or replacement.

This project specifically researches effective design and construction methods for a constructed wastewater treatment wetland for the City of Juliaetta. Although Juliaetta's population has remained stable for more than 20 years, average population growth of 2% y^{-1} (Figure 3) is assumed to accommodate potential future growth and increase functional longevity of the system.

The constructed wastewater treatment wetland must meet federal and state discharge permit requirements, including water quality standards. It must also be maintained by two staff employed by the city, be affordable to construct and maintain, and be sustainable by the community for the lifetime of the system. Properly designed, the constructed wastewater treatment wetland should fulfill the five beneficial uses of water designated by the Idaho Administrative Code – Idaho Administrative Procedure Act - IDAPA 58.01.02.100 "Water Quality Standards", 1) Aquatic life, 2) Recreation, 3) Water supply, 4) Wildlife habitats, and 5) Aesthetics.

Under Idaho Administrative Rules, water held in a private treatment system is not recognized as providing these five beneficial uses. Nevertheless, constructed wetlands can and do provide them and receiving bodies of water benefit from them.

1.4 Methodology

Literature and case studies provide data relating to the capability of constructed wetlands to treat wastewater to meet state and federal water quality standards. Interviews with communities, regulatory agencies, and engineering firms practicing wastewater treatment system design and planning provide additional data regarding construction and operational costs (Figure 4).

Case studies were selected in cold climate areas in the United States to demonstrate that constructed wetlands can meet federal and state permitting standards for treated effluent. Cold climate systems possess design elements that can be applied to the City of Juliaetta, which also experiences below freezing winter temperatures. Case study methods used to mitigate or overcome challenges are analyzed to inform a design proposal for Juliaetta's wastewater treatment system. The cost, effectiveness, and benefits of a constructed wastewater treatment wetland are compared to traditional systems to demonstrate the value and feasibility constructed wetland systems have to offer (Figure 5).

CHAPTER 2 LITERATURE ASSESSMENT AND REVIEW

2.1 Process

There are two parts to the literature review: 1) Acquisition and assessment of the literature, and 2) Review of selected sources to acquire the theory, processes, techniques, and pitfalls revealed in the studies.

Scientific literature was acquired by searching with the use of keywords and refined as shown in Table 1. Specialized equipment and other uncommon applications include microbial fuel cells, bioreactors, biofilters, and integrated household wetlands which do not meet the criteria of sustainability and affordability for this project. For this reason, these 15 articles were not evaluated for their application to the City of Juliaetta.

The literature assessment revealed five primary topics: 1) Types and general function of constructed wastewater treatment wetlands, 2) Aeration, hydraulic loading, and hydraulic retention, 3) Plants, 4) Substrate, and 5) Temperature (Figure 6).

In addition to researching scientific literature, I reviewed federal, state, and local government sources to evaluate regulatory standards, permitting, and funding options available to rural Idaho communities like Juliaetta. A review of each topic is presented below. Conclusions of each topic create a set of design criteria to structure the application phase of the graduate project.

2.2 Types and General Function of Constructed Wastewater Treatment Wetlands

Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, filter media, and their associated microbial assemblages to improve water quality (US EPA 2017). Constructed wetlands have become a popular method of wastewater treatment for small communities and remote locations around the world due to their low energy needs and fewer operational requirements compared to conventional wastewater treatment systems. (Wu, Zhang, *et al*. 2015). They can produce quality effluent and at lower power requirements than conventional activated sludge systems (Redmond, 2012). Variables such as temperature, pH, and the availability of dissolved oxygen can affect pollutant removal processes such as plant uptake, precipitation, and microbial processes (Wu, Zhang, *et al*. 2015), but constructed wetlands can still be operated successfully during winter seasons in cold climates. Operational strategies of constructed wetlands for cold climates include selecting suitable plant species, prolonging the hydraulic retention time, deepening the wetland bed, and providing thermal insulation, artificial aeration, and wastewater storage (Valipour and Ahn 2016).

Many advancements have been made in the effective removal of contaminants by constructed wetlands, and a variety of constructed wetland treatment types are implemented (Wu, Zhang, *et al*. 2015). Constructed wetlands generally fall into two categories based upon hydrology: 1) Free water surface wetlands, and 2) Subsurface flow wetlands. Free water surface wetlands are similar in form and appearance to natural wetlands (Figure 7). They consist of a shallow depth of water over a substrate that is saturated by water in the wetland (Wu, Zhang, *et al*. 2015). This creates an environment suitable for emergent, submergent, or floating plant species and anaerobic conditions for microorganisms. Free water surface wetlands are rarely used to treat effluent directly from septic tanks due to the potential for direct contact between humans and hazardous bacteria (Austin & Yu, 2016). They are commonly used for secondary or tertiary treatment of wastewater. Because of their similarity to natural wetlands, they can provide numerous benefits to humans and wildlife in the form of recreational areas, educational programs, and wildlife habitat. Free water surface wetlands are effective at removing organic matter and suspended solids from wastewater by vegetation, but performance is restricted in cold climates after seasonal dieback of vegetation (US EPA 1999). Due to the long hydraulic retention time in free water surface systems, algal activities are often expected during warm seasons. The presence of algae in free water surface constructed wetland is believed to contribute to high pH and dissolved oxygen (DO) levels. A positive effect of increasing pH is the inactivation of *Escherichia coli* and total coliforms. A negative effect of increasing pH (7.5 to 10.5) is decreased total nitrogen (TN) removal efficiency due to plant decay and inhibition of microbial activities by nitrite-oxidizing bacteria and denitrifiers (Yin *et al*. 2016).

Subsurface flow wetlands are different in that wastewater flows horizontally or vertically through the substrate (Figures 8-10). Subsurface flow wetlands can be further categorized based upon this flow direction as horizontal subsurface flow, vertical subsurface flow, or a hybrid system, which is a combination of both (Wu, Zhang, *et al*. 2015) and takes advantage of the benefits that each system has to offer. Subsurface flow wetlands have some advantages over free water surface wetlands, such as lack of odors, mosquitos, and minimal risk of human contact with contaminants (US EPA 1993). Subsurface flow wetlands effectively remove organic material, suspended solids, microbial pollution, and heavy metals and are better insulated against cold, but may have a shorter life span than free surface flow wetlands due to substrate clogging (Wu, Zhang, *et al*. 2015).

The French reed bed (Figure 10) is a vertical subsurface flow system that is unique in that it receives raw wastewater without the use of a septic or Imhoff tank for primary treatment. Pretreatment consists of grit removal followed by an equalization tank which traps oil and floatables and ensures consistent distribution to the wetland reed beds (Rizzo & Bresciani, 2018). Raw effluent is then distributed on the surface of the first stage reed bed for a period of three to four days followed by a resting period of about one week (Masi *et al*. 2017). During the resting period, effluent is alternately distributed to one or more additional first stage reed beds with similar hydraulic loading and resting periods, preserving aerobic conditions and preventing odors (Rizzo & Bresciani, 2018). Sludge slowly accumulates on the top layer of the reed bed (10-20 mm y^{-1}) and is removed in 10 or more years. Effluent from first stage reed beds is sent to a pumping station which feeds second stage reed beds in a manner similar to the first stage (Masi *et al*. 2017). Subsequent stages vary depending upon the level of treatment desired and may include free water surface wetlands, chlorination, or other tertiary treatment methods.

Over 4000 French reed bed systems are in operation in France, the oldest of which is almost 30 years. The design has even been used to treat wastewater for a population equivalent of 20,000 people in the city of Orhei, Moldova (Masi *et al*. 2017). A distinct advantage of the French reed bed design is the reduced cost of operation and maintenance (even compared to other constructed wetlands) because a septic tank and annual sludge disposal is not needed (Rizzo & Bresciani, 2018). If topography permits, costs can be further reduced by utilizing gravity flow to reduce energy needed to pump water.

Hybrid constructed wetlands can effectively remove organic matter and suspended solids. The removal of nutrients such as nitrogen and phosphorous depend upon system properties and operational conditions. Hybrid constructed wetlands improve pollutant removal by covering the limitations of both horizontal and vertical systems, creating conditions for aerobic nitrification and anaerobic denitrification processes (Sayadi *et al*. 2012). Hybrid constructed wetlands are very efficient in removing TN. The most common combination for hybrid systems is a vertical flow to horizontal flow system. A three-stage hybrid constructed wetland has also been used to treat municipal sewage with a total surface area of 10.1 m^2. Overall removal efficiencies were 92.5%, 83.8%, 96.0%, 88.8% and 79.9% for five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), NH_4-N (ammonium), and TN, respectively (Vymazal & Kröpfelová, 2015). Hybrid constructed wetlands add stability to the overall treatment process and are recommended when stringent treatment standards need to be met (Oirschot, Wallace, and Deun 2015).

The removal of pharmaceuticals and antimicrobials from wastewater is becoming increasingly important to wastewater treatment. A 2012 study found that aerated subsurface flow constructed wetlands offer a significantly higher removal of sulfamethoxazole and trimethoprim (common antibiotics) than nitrifying activated sludge treatment and nitrifying trickling filter treatment (Gorsalitz 2012). Horizontal subsurface flow constructed wetlands can also remove chemicals such as endocrine disruptors or surfactants like linear alkylbenzene sulfonate (Vymazal, 2009).

2.3 Aeration, Hydraulic Loading Rate, and Hydraulic Retention Time

Aeration is commonly used in the secondary treatment of wastewater in traditional wastewater treatment plants. It is important to the removal and aerobic digestion of organic matter by microorganisms. These beneficial bacteria utilize oxygen to digest organic matter found in wastewater. This process (Figure 11) results in the reduction of organic matter (biodegradation) and the transformation of organic nitrogen into ammonia (ammonification), then nitrite, and nitrate (nitrification) and finally nitrogen gas (denitrification). Denitrification is conducted by anaerobic bacteria which convert nitrate to nitrogen gas. Removal of particular pollutants are associated with groups of aerobic and anaerobic microbes. Aerobic zones increase the overall rate of nitrification while anaerobic zones facilitate denitrification and the reduction of sulphate (Faulwetter *et al.*, 2009).

The reduction of organic matter can occur in anaerobic conditions, but is more rapid in aerobic conditions (Austin & Yu, 2016). Natural aeration can be accomplished with very little or no energy demand through the use of vertical aeration pipes, increased water surface area, filling and draining gravel beds, and hydraulic gravity-flow features such as waterfalls. Plants increase the likelihood for aerobic processes, and vertical flow and forced aeration constructed wetlands favor aerobic microbial groups while horizontal subsurface flow will favor anaerobic groups (Faulwetter *et al.*, 2009).

In temperate climates, colder seasonal temperatures slow microbial activity, and artificial aeration has been studied as a means to compensate for lower microbial performance in cold temperatures (Zhang *et al*. 2010). Artificial aeration of subsurface flow constructed wetland is now a recognized method of improving wastewater treatment efficiency. Research shows that multilevel drop aeration devices supply higher dissolved oxygen than a direct drop aeration process (Zou *et al*. 2012). Subsequent research has shown that intermittent aeration results in the most successful removal of COD, ammonium, and TN (Uggetti *et al*. 2016). Aeration also contributes to a decrease in clogging and prevention of preferential flow patterns by increasing temperature and mixing (Wang *et al*. 2017).

Another study indicated that, even with limited artificial aeration, nitrification was very effective for ammonium removal (Pan *et al*. 2012). In permanently saturated conditions, the removal of ammonia is limited by a lack of dissolved oxygen. Seasonal changes affect ammonia removal, but decreases during the winter are not large (Vymazal 2011a).

Hybrid constructed wetlands have been constructed in various combinations in an effort to maximize efficiency of treatment by enhancing aerobic and anaerobic processes. One system combines a vertical subsurface flow and horizontal subsurface flow with natural aeration ditches to increase the concentration of dissolved oxygen in the horizontal bed. Effluent can be recirculated back to the vertical portion to enhance the biological denitrification effect (Zhai *et al*. 2011). Another constructed wetland consisted of a three-stage hybrid system that provided suitable conditions for nitrification and denitrification. Effluent was recirculated beyond the second wetland unit and water was returned to the first unit (Vymazal & Kröpfelová, 2015). Recirculation enhances aerobic microbial activity (Wang *et al*. 2017) and is frequently cited as a means of improving water quality.

Other research found that intermittent aeration combined with a step feeding strategy greatly improves the removal of organics, ammonium nitrogen, and TN. Continuous aeration limited TN removal (though organic removal and nitrification were enhanced), and the positive effect of plants was confirmed (Fan *et al*. 2012). Aeration enhances removal of TN, ammonia, carbonaceous BOD, COD, and phosphorus retention (Redmond, 2012; Redmond, Just, & Parkin, 2009), stimulates biofilm development at the inlet of planted beds, and also seems to reduce mineral matter accumulation (Chazarenc *et al*. 2009).

Different aeration times have been studied to determine optimal aeration time and rate to maximize efficiency and lower the cost of treatment. Results in a vertical subsurface flow constructed wetland study showed that the optimal aeration time and aeration rate were 4 h d^{-1} and 1.0 L min^{-1}, which could create the appropriate aerobic and anoxic regions in constructed wetlands. Longer aeration time (6, 8, and 10 hours) led to an aerobic environment, while shorter aeration time (1 and 2 hours) resulted in anoxic conditions. Alternating these conditions results in organics reduction and nitrogen elimination (Wu *et al*. 2016).

Flow rate and depth of water through the constructed wetland – hydraulic loading – affects efficiency of contaminant removal by increasing or decreasing the contact time with media. It also determines the type of plant materials used. The feeding mode (intermittent or continuous) of influent to the constructed wetland influences oxidation and distribution into the wetland. Intermittent feeding (also called batch feeding or tidal flow) promotes more oxidized conditions than continuously fed systems. An optimal hydraulic loading scheme allows the formation of a proper sludge layer on top of the bed and an increase in loading rates, improving removal efficiencies over time (Masi *et al*. 2017). Sedimentation tank treatment efficiency is especially dependent on the design and operation of HLR because increases in HLR affect the settling of sediment (Rozkošný *et al*. 2011).

All constructed wetlands are efficient in removing organic matter and suspended solids, but the required hydraulic retention times (HRT) differ. The removal efficiency of nitrogen and phosphorous can be influenced by plant species, oxygen availability, COD/N ratio, temperature, HRT, and high sorption capacity media of the wetland bed. Low HRT of a system can reduce overall capital cost due to low footprint area requirement in comparison with other constructed wetlands (Valipour and Ahn 2016). As hydraulic load rate (HLR) decreases, average pollutant removal efficiencies increase (Tunçsiper 2009). Studies show that nutrient removal is higher using a longer (8 hour) HRT than controls with a shorter (4 hours or less) retention time (Chavan, Dennet, and Marchand 2008).

Organic loading rate and HLR are critical to controlling the activity of microbial biofilms in vertical subsurface flow wetlands. (Pelissari *et al*. 2017). A hybrid subsurface flow wetland in the Czech Republic demonstrates that the HLR is critical to efficient treatment. The system combines mechanical pretreatment (screening and filtering) with horizontal subsurface flow reed beds and a stabilization pond (Rozkošný *et al*. 2011).

A stacked wetland design and intensification with different aeration methods was studied as a means to reduce the land area needed for a constructed wetland. One study evaluated three aeration strategies on three types of constructed wetlands including vertical, horizontal, and hybrid constructed wetlands. When footprint and removal efficiency are the major guidelines for the selection of wetland type, the study concluded that the best options were tidal flow of a vertical system, effluent recirculation of a horizontal system, and artificial aeration of a horizontal system (Ilyas and Masih 2017). A cyclic system of hydraulic loading followed by a drying period with mechanical aeration can also achieve a higher HLR and decrease the footprint of the system (Yang *et al*. 2016).

Although partial nitrification can be achieved with some vertically or intermittently loaded, subsurface flow wetlands, complete nitrification cannot be achieved in passive wetland treatment systems. A tidal flow wetland system is efficient in both energy use (0.21 kWh m^{-3} d) and area requirement (5.0 m^2 m^{-3} d), compared to an aerated subsurface flow, pulse-fed constructed wetland, and mechanical activated-sludge treatment system. On a sloped site, a high level of treatment can be achieved with zero electrical energy inputs (D. Austin and Nivala 2009).

2.4 Plants

The presence of plants distinguishes constructed wetlands from unplanted soil filters or lagoons (Vymazal 2011b). Selection of plant material is critical to establishing the wetland and sustaining performance (Wu, Zhang, *et al*. 2015). Interestingly, early research indicated otherwise. One study found that typical domestic wastewater flowing through a constructed wetland resulted in similar effluent quality regardless of the presence of plants (cattails); that the main benefit of plants is their aesthetic function (Collison 2010). In another study of the effect of plant presence in constructed wetlands, plants reduced accumulated solids by 26% (*Typha angustifolia* accumulated more than *Phragmites australis,* Figures 12-13*)* but had no effect on treatment performance (Chazarenc *et al*. 2009). A study by Redmond *et al*. (2009) documented no significant difference in nitrogen removal between planted and unplanted cells.

In a different study, a three-stage experimental constructed wetland system consisting of a vertical subsurface flow gravel filtration bed without plants, a horizontal subsurface flow bed planted with *Iris australis*, and a vertical subsurface flow bed planted with *Phragmites australis* in series were fed with primary-treated domestic wastewater. The beds with plants produced effluents of better quality than the vertical bed without plants (Tunçsiper 2009). In a comparison of the performance of horizontal and vertical subsurface flow wetlands and planted with unplanted beds, planted beds performed better than the unplanted beds and the vertical wetland performed better than the horizontal beds. A combination of horizontal and vertical beds are recommended to meet stricter water quality requirements (Pandey *et al*. 2013). Valipour & Ahn, 2016, reviewed the role of plants, media materials, microorganisms, and oxygen transfer in domestic wastewater purification through constructed wetlands and found that the relationship between vegetation, substrate, and living organisms is a major mechanism of pollutant removal. *Phragmites* spp. and *Eichhornia crassipes* were strongly recommended in treating wastewater, among other species.

The ability of individual plant species to remove pollutants in a constructed wetland has also been well-researched. Zhou, Zhu, Bañuelos, & Yan (2017) studied the influence of vegetation type, different ammonium nitrate loading rates, and environmental temperatures on performance of constructed wetlands. They compared four constructed wetlands: unplanted control, *Cannabis indica* monoculture, *Lythrum salicaria* monoculture, and 50/50 *C. indica/L. salarica* monoculture. Removal of ammonium nitrate and total phosphorus in the polyculture was higher than other constructed wetlands and was almost completely removed. The polyculture also showed the best performance at an average low temperature of 9°C (48°F), indicating an advantage to avoiding monoculture plantings. One study conclusively proved that multi-culture plant species like *Phragmites* and *Typha* will help pollutant reduction and effectively treat wastewater (Deeptha, Sudarsan, and Baskar 2015). The most frequently used plant is *Phragmites australis*. Species of the genera *Typha* (*latifolia, angustifolia, domingensis, orientalis* and *glauca*) and *Scirpus* (*lacustris, validus, californicus* and *acutus*) spp. are also commonly used (Vymazal, 2011b).

Yates, Varickanickal, Cousins, & Wootton, 2016, studied how well *Carex aquatilis* would intake nitrogen to remove it from municipal wastewater with decreasing temperatures (0–5°C and 5–10°C) and light to simulate summer and fall conditions in Baker Lake, Nunavut. The planted trials outperformed controls at both temperature regimes. Ren *et al*., 2016 conducted a two-year experiment of a constructed wetland planted with *Lolium perenne*. The plant proliferated and kept evergreen, even with cold (<10°C) and non-cold (>10°C) periods. In fact, the better the growth characteristics of *L. perenne* were, the higher ammonium nitrate removal was.

Plants also aid in the removal of organics and nutrients like nitrates and phosphorous through uptake of these nutrients to support plant growth. The amount of nitrogen removed is less than 10% in the treatment of domestic sewage, and when plants decay the nitrogen re-enters the water through the decay of organic material (Austin & Yu, 2016). Because reduced nitrate concentrations are generally not required for secondary water quality effluent, the water can be re-used for irrigation to provide nitrogen to plants without the use of additional fertilizers. Vymazal (2011b) captures the important aspects of including plants in horizontal subsurface flow wetlands for wastewater treatment. Plants should be tolerant of high organic and nutrient loadings, have rich belowground organs (i.e. roots and rhizomes) to support attached bacteria and oxygenation of areas adjacent to roots and rhizomes, and have high aboveground biomass for winter insulation in cold climates and for nutrient removal via harvesting. A study of *Iris pseudoacorus*, *Brassica capestris*, *Oenanthe javanica* and *Calendula officinalis* in a constructed wetland demonstrates that roots of cold-seasonal plants have important growth advantages over warm-seasonal plants in constructed wetlands (Chen *et al*. 2013).

Wang *et al*., 2017, found that the presence of vegetation provides thermal protection against ice formations and plays an important role in the connections between oxygen and the density and activity of microbial community in the rhizosphere - the region of soil in the vicinity of plant roots in which the chemistry and microbiology is influenced by plant growth, respiration, and nutrient exchange (Figure 14).

Plant roots are an important location for microbial biodiversity, and microbial ecology controls nitrogen, carbon and sulfur cycles in constructed wetlands (Faulwetter, 2010). Operational factors of constructed wetland such as plant types, aeration, and HLR influence the environment and subsequently, microbial populations and redox (the oxidation and reduction of substances). Microbial populations and/or activity is also affected by location within the wetland – effluent, root, gravel – and plant species present (Faulwetter, 2010), with subsequent variations in effluent quality. For example, sulfate-reducing and nitrifying bacteria are influenced by plant species and season; ammonia-oxidizing bacteria are greatly impacted by season and have the greatest abundance and diversity in summer. However, the primary influence of plant presence is believed to be related to root oxygen loss and its effect on redox in the rhizosphere. Optimizing conditions in support of the microbial community should be a priority for the effective design of wastewater treatment systems (Faulwetter, Burr, Parker, Stein, & Camper, 2012).

2.5 Substrate

Substrate, or filter media, selection is critical to establishing the wetland and sustaining performance. It provides the growing medium to support plant materials and microbial life and provides surface area for colonization by bacterial biofilms while still allowing water to flood through (Collison 2010). Substrates vary in hydraulic permeability and pollutantadsorbing capacity. Mixed substrates have reactive surfaces for microbial attachments and high hydraulic conductivity which allows water to move easily through pore spaces.

Zeolite has been studied for its high adsorption capacity which improves the removal of nitrogen (Zou *et al*. 2012) and ammonium (Collison 2010). Limestone is a cheap source of alkalinity for maintaining a neutral pH environment, and also provides carbon for denitrification (Pan *et al*. 2012).

Several substrates have been studied for their ability to facilitate the removal of phosphorous. Constructed wetlands facilitate phosphorous removal by precipitation, adsorption, and biological assimilation. Adsorption and precipitation are the primary methods, and selecting a substrate medium with high phosphorous sorption capacity helps sustain phosphorous removal over time (Mateus and Pinho 2010). Small-sized substrate particles have higher adsorption capacity (Lijuan *et al*. 2017). Phosphorous removal rates decline over time due to saturation of the substrate and uptake by plant growth (Mateus and Pinho 2010). Constructed wetlands in the Czech Republic demonstrate a seasonally steady, but low, phosphorus removal because special filtration media with high sorption capacity are not used (Vymazal, 2011a). Phosphorous can be removed from wastewater through the use of selected substrates or filter media containing calcium, iron, or aluminum (Austin & Yu, 2016) and may include materials such as oyster shell, wollastonite, steel slag, or bauxite (Stefanakis, Akratos, and Tsihrintzis 2014). A hybrid filter medium possessing a high phosphorous adsorption capacity would also help to prolong the functional life of a constructed wetland (Pan *et al*. 2012).

Norwegian constructed wetland systems in rural areas reveal a high performance with respect to the removal of organic matter, biogenic elements (nitrogen, phosphorous, etc.) and fecal indicator bacteria. Norwegian systems commonly use lightweight aggregate substrate, and are typically built with a biofilter (pre-filter) followed by a horizontal subsurface bed. The majority of organic matter and nitrogen are reduced in the biofilter, while the main reduction of phosphorus concentration and fecal indicator bacteria occurs in the saturated wetland bed. These systems are relatively simple to operate and do not require special maintenance. In fact, there is only periodic control to prevent clogging of the pump and nozzles in the biofilter (Paruch *et al*. 2011).

Pollutant removal and microbial activity at different substrate depths has also been studied. In a study of a vertical subsurface flow system, COD was mainly removed by the filtration of suspended organic substances and microbial biodegradation of soluble organic substances in the upper 51 mm (2 in) filter layer. Nitrogen removal occurred mainly through adsorption in the upper 51 mm filter layer of the wetlands (Zou *et al*. 2012). A study in Austria investigated whether an additional 51 mm layer of gravel on top of the main layer of a vertical subsurface flow wetland would increase thermal insulation and temperature during cold temperatures, increasing efficiency of organic matter removal. Results indicated that oxygen transfer was reduced by the additional layer, preventing degradation of organic matter between loadings and resulting in filter clogging (Langergraber *et al*. 2009).

Clogging of horizontal system must be taken into consideration. As a wetland matures, it functions more efficiently, until solids accumulate in and clog porous spaces. Water then begins to move through less obstructed routes, creating dead zones and preferential paths. This results in reduced HRT and decreasing efficiency. The higher organic load of inlets makes them more prone to clogging. Operational strategies can be applied to increase the life of the constructed wetlands. Substances can be added (chemicals, microorganisms, nutrients, etc.) to aid in degradation of the organic material (de Matos, von Sperling, and de Matos 2018), although a 2011 study suggests that the addition of microorganisms must come from a donor system with a similar flow regime to be effective (Zaytsev *et al*. 2011).

2.6 Temperature

Cold climate areas have specific challenges to overcome due to a reduction in treatment performance under cold conditions. A number of processes are slowed as a result of cold temperature: microbial activities (nitrification/organic matter removal, denitrification), plant metabolism rate, chemical precipitation, and adsorption (Yan and Xu 2014). Wang *et al*., 2017, found that temperature has a significant effect on ammonium nitrogen and TN removal efficiencies. Cold climate does not have a significant effect on the removal of total phosphorous, TSS, BOD_5, and COD (Vymazal & Březinová, 2014). In a two-year study of the effect of cold conditions on 12 French vertical subsurface flow constructed wetlands, no impact of cold temperature was observed on TSS, BOD_5, or COD removal. Nitrogen removal was unaffected except under loads above 10gTKN/m2/d (TKN: Total Kjeldahl Nitrogen) and system operations continued with minimal air temperature of -19°C (Prost-Boucle, Garcia, and Molle 2015). Because a high HLR or organic loading rate might affect performance during cold temperatures, cold season operational strategy should include low level loading, but not so low that it results in incomplete denitrification (Yan and Xu 2014).

Despite the challenges noted above, studies have shown that cold climate wetlands can provide treatment performance comparable to tropical regions (Vymazal & Březinová, 2014). For example, a French reed bed effectively treats wastewater from a portion of the city of Orhei, Moldova (PE 20,000), despite winter air temperatures below -20°C (-8°F) and basins covered by ice and snow for several weeks (Masi *et al*. 2017). Another study of four horizontal subsurface flow systems 500 m above sea level in the Czech Republic demonstrates that horizontal systems are a reliable treatment technology even in cold mountainous and sub-mountainous regions (Vymazal & Březinová, 2014).

Wetland plant species and bacteria that survive and/or thrive in cold climates and substrates can improve function under cold temperatures, as can prolonging the HRT or providing insulation and/or artificial aeration (Yan and Xu 2014). Hardy plants provide insulation from cold temperatures and surface area to support cold-tolerant (psychrotrophic) bacteria, and selecting cold-resistant plant species enables land-covering and microbial attachment during winter. Low substrate temperature further cools water, and substrate with an ability to conduct heat (low thermal conductivity) insulates the wetland from cold air temperatures. Because biological processes are slowed by cold temperatures, prolonging HRT can improve treatment. Reducing hydraulic conductivity – the ease of which water can move through pore spaces – on cold winter days can result in clogging (Yan and Xu 2014), and moving water freezes less quickly than standing water.

The use of insulating materials should be used with caution to maintain desired aerobic and anaerobic environments. If insulating mulches are used they should be substantially decomposed so as not to increase organic loading, have a neutral pH and nutrient composition, and be high in fiber content to provide insulation (Yan and Xu 2014). Mulch that is too deep can impede oxygen transfer to the filter layer and affect nitrification (Prost-Boucle, Garcia, and Molle 2015). Ice can also insulate a wetland from cold air temperature. Operators can control water level elevation to cause the formation of an ice layer, then lower water levels to create an insulating layer of air between the ice and the water surface (Yan and Xu 2014). Even deep snow cover can provide insulation (Prost-Boucle, Garcia, and Molle 2015).

A cold filter can also affect nitrification, and without the presence of sludge or snow the filter is sensitive to changes in temperature. The presence of sludge provides insulation and can prevent the filter from freezing even at -10°C (-4°F), but low levels of material deposited during rest periods do not provide much insulation. An operational strategy for hydraulic loading, retention, and recirculation should be implemented to shield filters from freezing (Prost-Boucle, Garcia, and Molle 2015).

Numerous strategies have been studied and can be implemented to enhance the performance and effectiveness of constructed wetlands in cold climates by increasing temperatures during cold periods and creating aerobic and anaerobic conditions to maximize efficiency of biological processes. For example, thermal insulation can be provided by mulch or subsurface flow design. Hydraulic loading methods such as tidal flow (a.k.a. fill and drain) operation alternates saturation of the wetland substrate with draining of the wetland to facilitate anaerobic and aerobic microbial processes. Step-feeding gradually introduces inflow to the wetland at multiple points to enhance denitrification, and effluent recirculation is used to improve treatment. Organic carbon can be added to maximize denitrification and the removal of nitrate. Wetland plants can be harvested to aid in the removal of nutrients. Bioaugmentation – the addition of microbial cultures – can accelerate the rate of biodegradation in the wetland. The addition of earthworms can also improve efficiency and reduce the production of sludge (Wu, Fan, *et al*. 2015). These strategies can be applied at various points within the wetland system to improve overall function and effectiveness, a particularly necessary trait in cold climates.

Several common-sense rules can also be applied to reduce temperature losses: site the system with southern aspect to increase exposure to direct sunlight, bury filter-feeding pipework and valves, alternate filters twice a week to minimize filter freeze up (because the warmth of the wastewater causes the filter to warm up, but it cools during rest periods) (Prost-Boucle, Garcia, and Molle 2015).

While it is not readily apparent when discussing cold-climate regions, reducing the temperature of treated effluent prior to discharge is a significant challenge during summer months. The heat generated by decomposition of organic matter in wastewater combined with high ambient temperatures and low seasonal stream flows can result in water temperatures that are detrimental to cold water aquatic species such as salmonids. A pilot study conducted in Moscow, Idaho, proved that free water surface constructed wetlands effectively reduce water temperature. The study reports that performance could be improved by modifying flow rate, water depth, and vegetation (JUB Engineers Inc. 2015).

2.7 Permitting

There are three phases to obtaining a permit to discharge wastewater: 1) Planning, 2) Engineering, and 3) Permitting. First a Facility Plan is developed by a licensed engineer or engineering firm. The contract engineer for the City of Juliaetta is currently in the process of completing an updated facility plan for the city's wastewater treatment system. A facility plan is a planning document and engineering report that contains a comprehensive assessment of operational needs and system requirements. It includes information the IDEQ requires for a wastewater treatment facility to be eligible for state grant and/or loan funding for design and construction. The facility plan is reviewed and approved by IDEQ. It is followed by the second phase of the permitting process, the preliminary engineering report. The preliminary engineering report is completed by the community's engineer or in Juliaetta's case a contract engineer and includes plans and specifications for the proposed treatment system. This must also be reviewed and approved by engineers at the IDEQ. Finally, the community may re-apply for or request modification of an existing discharge permit. The discharge permit must be approved prior to implementation of a wastewater treatment system.

An interview with IDEQ permit writer revealed that Idaho does not have any constructed wetlands for the treatment of municipal wastewater. In order for a constructed wetland to be permitted, the system must first be included in a city's facility plan. A constructed wetland may be included in the facility plan at the request of the community or at the discretion of the engineer serving the community.

Interviews were conducted with engineers to obtain feedback directly from design professionals working on municipal wastewater projects in Idaho today. Engineers stated that one of the issues with constructed wetlands for wastewater treatment is their seasonal nature – as with natural wetlands, they are influenced by cyclical changes in temperature, precipitation, and biological processes. For example, a series of rainfall events may cause a spike in TSS and wildlife (birds) can contribute animal waste to effluent. These changes can result in variable rates of pollutant removal in a system that has less operational control compared to a mechanical system. As licensed professionals, engineers must design a system for clients that meets treatment standards as specified in the discharge permit or the client faces violations. Permitting standards are not written to accommodate seasonal variations in natural systems, despite ecological and social benefits of a wetland system over a mechanical system. Surface water discharge permits generally have a concentration and a load limit with maximum daily, average weekly, and average monthly effluent limitations and varying requirements for sampling frequency (Tables 2-3). These requirements are usually static throughout the year, which is at odds with the seasonal variability of a wetland system, whether natural or man-made. There are exceptions, such as water temperature and ammonia, which sometimes have seasonal limitations in a permit.

Opportunities exist to provide incentives to engineers and permitting agencies in regard to constructed wastewater treatment wetlands. From a regulatory standpoint, constructed wetlands can provide all five beneficial uses of water identified in IDAPA 58.01.02.100; they can directly support aquatic life, provide recreation area, maintain a sustainable water supply, provide wildlife habitat, and improve aesthetics. Although they technically do not qualify as "beneficial uses" while the water is retained in a private treatment system, the benefits are acknowledged by regulatory agencies. In reality, the benefits are felt in the local community and passed on to receiving waters such as the Potlatch River. Endangered salmonids and other aquatic life inhabiting the Potlatch River also benefit from improved water quality and lower water temperature. It is important to promote awareness of these benefits at a local level to encourage community support for constructed wetlands and include them in facility plans for treatment systems. Mechanical systems simply cannot provide all of these benefits. From an engineering standpoint, permitting standards that allow for seasonal variability of constructed wetlands would enable flexibility of design that can be applied to a wide range of site conditions. New standards for water temperature demonstrate this principal already and provide additional incentive to implement subsurface flow constructed wetlands, which can significantly lower water temperature through cooling and shading that occurs in the subsurface treatment process.

Engineers and communities also depend upon the regulatory agency to facilitate a permitting process that is timely in its review of constructed wetland technology, despite the fact that it has yet to be implemented in Idaho for wastewater treatment. The IDEQ, with its dual role as permitting agency and potential funding source, is ideally positioned to incentivize constructed wetland systems by prioritizing constructed wetland projects with demonstrable benefits over mechanical systems. The case studies presented in Chapter 3 provide tangible evidence that constructed wetlands can meet permitting standards in other cold climate states in the US.

2.8 Funding

Total cost of any treatment system includes materials, capital costs for labor and site work, and operation, maintenance, and depreciation over the life of the system. Size and complexity of the system will also affect the overall cost. When comparing the cost and benefits of a constructed wastewater treatment wetland to a traditional centralized treatment system, land acquisition, energy consumption, and ecological benefits should also be evaluated. A long-term cost–benefit analyses may improve social acceptance of constructed wetlands (Wu, Fan, *et al*. 2015)

Selection of a preliminary system design should consider long-term maintenance needs in addition to start-up costs for construction/installation. Low maintenance needs translate into large cost savings over the lifetime of the treatment system. The cost to construct, maintain, and operate a constructed wetland is an important component of sustainability. Once a preliminary design schematic is selected, project costs can be estimated using local figures for materials and labor and current cost figures for monitoring and basic maintenance activities.

The Water Environment Research Foundation published a final report in 2006 titled *Small-Scale Constructed Wetland Treatment Systems – Feasibility, Design Criteria, and O&M Requirements*, in which cost of wetland treatment systems are explained. Material costs consist of wetland system components, excluding labor/installation. Wetland systems share a similar set of construction components, the cost of which are distance sensitive because they are generally produced in regional markets. The basic construction components of a wetland system are land, site analysis/system design, earthwork, liners (when applicable), substrate, plants, hydraulic control structures, and miscellaneous components such as fences, roads, and surveying, etc. (Wallace & Knight, 2006).

Capital costs such as site work and labor are estimated as a percentage of the total cost of materials using local pricing information. The cost to operate and maintain the treatment system must also be evaluated. Operation and maintenance (O&M) costs include water quality sampling, servicing of pump and piping components, and other elements when applicable such as energy usage for system operation, vegetation removal, and pumping of septic tanks (Wallace & Knight, 2006). Systems designed for gravity flow (pumpless) operation will require very little energy input, and French reed bed designs do not use a septic tank for primary treatment, eliminating the septic pumping cost.

There are several funding options available for the design and/or construction of wastewater treatment systems (Table 4). USDA, IDEQ, and CDBG funding sources can be leveraged together to provide the required percentage of community matching funds. For example, a community can apply for IDEQ and USDA funding simultaneously, citing a 50% community match by using the funding requested/obtained from the other agency (i.e, a $60,000 project can be fully funded with $30,000 from IDEQ and $30,000 from USDA). Grants are very competitive, and a community that demonstrates commitment to completing a project by providing a portion of its own matching dollars may receive a higher priority ranking for funding than a community that does not. Most cities (large and small) rely on grant money and/or federal loans together with a local match to fund replacement or renovation of wastewater treatment systems.

Juliaetta is already utilizing funding from the IDEQ and USDA for wastewater planning shown in Table 4. With a population of 609 people, the small town should also qualify for funding from the National Rural Water Association and the U.S. Army Corps of Engineers. It may also be eligible for funding from the Idaho Department of Commerce Community Development Block Grant, if it is demonstrated that greater than or equal to 51% of the population has a low to moderate income. IDEQ also offers a Public Wastewater System Construction Loan, a low-interest loan to help build or repair wastewater treatment facilities. Together, these additional funding sources could be leveraged to finance new construction and system upgrades.

Costs of a French reed bed system for 500-1000 population equivalent in Italy was studied from 2014-2016 and provides an excellent example of costs for a community the size of Juliaetta. In this case study, cost of new construction was 364 Euros ($417 USD) per population equivalent, translating to $417,000 USD for a system with treatment capacity of 1000 population equivalent. The study also demonstrates that the primary operation and maintenance (O&M) costs of these systems is for energy, personnel for inspections, reed harvesting, and water quality samples (monitoring), with an average annual O&M cost of 5531 Euros y^{-1} ($6340 USD). It concludes that construction costs of French reed beds are in line with activated sludge systems in the Italian context, with lower O&M costs compared to classical constructed wetlands (Rizzo *et al*. 2018) primarily due to reduced sludge management.

Comparatively, the cost to renovate existing mechanical treatment systems can commonly range in the millions of dollars. In a review of IDEQ construction loans from 2015-2018 for cities with a population of less than 6,000, loans ranged from $1.09 to $30 million USD.

2.9 Conclusions and Design Implications

The review of literature, permitting requirements, and funding options demonstrates that constructed wetlands can be designed to effectively treat wastewater in small rural communities such as Juliaetta with many ancillary benefits. As proven in a study of French reed beds, there are no upper limits for the application of wetland systems for municipal wastewater treatment when land is available at a proper cost (Masi *et al*. 2017), which is often the case in rural areas like Juliaetta, Idaho. It is important to consider the critical components – wetland type, aeration and hydraulic loading, substrate type and depth, plants, and temperature – and select design elements suited to the climate, topography, and available land area at the treatment site (Table 5).

Constructed wastewater treatment wetlands are well-suited to Juliaetta, which has sufficient land available and topography that may be used with constructed wetlands to minimize energy costs. Subsurface flow constructed wetlands are better suited to locations with cold climate conditions than free water surface wetlands because they are capable of meeting wastewater treatment standards in below freezing temperatures. A hybrid vertical and horizontal subsurface flow design provides maximum efficiency of pollutant removal by supporting aerobic nitrification of organic matter and anaerobic denitrification. French reed beds offer particular benefits because the cost to install and maintain a sludge management system is eliminated. Recirculating water through a system two or more times results in further reduction of pollutants and improved water quality.

If topography of the site permits, a subsurface flow constructed wetland with multi-level drop aeration is an appropriate design, with numerous advantages of low capital and operation costs, little or no energy consumption, easy maintenance, high hydraulic loading rate, high pollutant removal efficiency, and no clogging (Zou *et al*. 2012). A lower HLR will result in more complete treatment, but this must be balanced with HRT to maximize both aerobic and anaerobic conditions for nitrification and denitrification, respectively. An optimal aeration time and aeration rate similar to 4 h d^{-1} and 1.0 L min^{-1} could create the appropriate aerobic and anoxic regions to maximize treatment efficiency. A tidal flow (batch feeding) strategy applied to a hybrid vertical-horizontal system with the ability to recirculate effluent utilizes every method currently known to improve treatment efficiency. The alternating hydraulic loading and resting periods of French reed bed systems preserves aerobic conditions and prevents odors and can be used with subsequent stages such as horizontal or free water surface wetlands for denitrification depending upon the level of treatment desired.

A lightweight, mixed aggregate used in a constructed wetland modeled after the Norwegian horizontal subsurface flow system should require little maintenance with minimal clogging while providing effective treatment. If phosphorus removal is necessary to meet current or future discharge permit requirements, then a mixed substrate with a high adsorption capacity should be used to facilitate phosphorus removal.

A polyculture of evergreen or cold-hardy plants will provide maximum treatment efficiency. Plants with well-developed roots and rhizomes provide insulation against cold temperatures, support microbial life, and provide oxygenation, all of which improve treatment effectiveness. Some species typically used in constructed wetlands (*Phragmites australis*) can become extremely invasive and native substitutions should be used instead. Native plants with well-developed roots and rhizomes are preferred to support wetland function, native wildlife, and prevent the spread of invasive introduced species.

Although cold temperatures slow nitrification and denitrification, constructed wetlands are still capable of effective wastewater treatment. Negative impacts of cold temperature can be minimized by maintaining a moderate HLR combined with longer HRT. While mulch may be used for insulation, it is not required and vertical French reed beds or horizontal Czech wetlands both provide excellent models of effective treatment without the use of mulch. Traditional methods of temperature insulation such as southern exposure and buried piping can also be applied to wetland design and should be explored in the site inventory phase. Constructed wetlands can reduce water temperature, and practical applications should be implemented in the final design to provide seasonal shade during summer months with berms planted with large trees and shrubs. Subsurface flow constructed wetlands are likely to be more effective at reducing water temperature than free water surface constructed wetlands because they are less susceptible to solar gains. Comparatively, traditional mechanical methods of cooling water require high energy inputs to operate specialized equipment such as chillers and evaporative cooling towers.

A concerted effort should be made to promote awareness of the benefits of constructed wetlands at a local level to encourage community support for constructed wetlands and include them in facility plans for treatment systems. New standards for water temperature provide additional incentive to implement constructed wetlands for wastewater treatment, and engineers would likely be more supportive of proposing this technology once a system has been permitted, constructed, and vetted in Idaho. Until then, the IDEQ is ideally positioned to incentivize constructed wetland systems by prioritizing constructed wetland projects with demonstrable benefits over mechanical systems. IDEQ should look to other states that are well-versed in permitting constructed wetlands for wastewater treatment, learn from their successes and failures, and model its permitting process and standards accordingly.

The city of Juliaetta is already utilizing IDEQ and USDA funding sources for their project. Additional information is needed to determine if the city intends to pursue any other sources. Selection of a preliminary system design should be considerate of long-term maintenance needs in addition to start-up costs for construction/installation. Low maintenance needs can translate into large cost savings over the lifetime of the treatment system. Once a preliminary design schematic is selected, project costs can be estimated using local cost figures for materials and labor and current cost figures for monitoring and basic maintenance activities.

CHAPTER 3 CASE STUDIES

3.1 Selection Criteria

Case studies guide the articulation of goals and design criteria for the application portion of the graduate project. This research method yields concepts and techniques tested by construction and monitoring of built works. Empirical evidence guides designers toward proven techniques and away from problems or design failures.

Case studies demonstrate how constructed wetlands can be utilized for the effective treatment of wastewater from communities of various sizes. Climate plays a critical role in the proper design of constructed wetlands to achieve water quality standards for effluent. Below freezing temperatures during winter months will slow biodegradation processes (US EPA 1999). Therefore, the case studies were selected for their location in cold winter climates. Design elements responsive to cold winter conditions can be extrapolated to Juliaetta, which experiences extended periods of below freezing conditions in winter months. Case studies were evaluated by population, land area, wetland type, system capacity, benefits, and challenges.

Case studies were also selected for their applicability to small communities. This characteristic makes them particularly useful in evaluating characteristics that can be useful to the City of Juliaetta, population 609. However, the small size of these communities presents a challenge to the researcher because oftentimes information about wastewater treatment systems is not readily available. Frequently there is not a public works department, but a staff of one or two individuals who maintain the wastewater system along with other city property. Very little documentation exists on the world-wide web. Much of the information about these case studies was collected through a detailed review of documentation from state regulatory agencies and interviews with local municipal departments and state regulatory agencies.

3.2 City of Prinsburg, Minnesota, Wastewater Treatment Facility

To date, the author has only found references to times before and after installation of the constructed wetland, which occurred between 2003-2007. The Environmental Assessment Worksheet prepared by the Minnesota Pollution Control Agency (MPCA) describes a construction timeline of one to two months during non-freezing conditions. This includes construction and installation of septic tanks, subsurface flow wetlands, sand filters, and mechanical removal of soil. Short-term site disturbing activities during construction included open trenching and directional boring to facilitate installation of new sewer pipes to the new wastewater treatment wetland.

Prinsburg experiences warm summers and cold winter temperatures, with a July high of 28°C (82°F) and a January low of -16°C (4°F). It receives 711 mm (28 in) of annual rainfall and 1,118 mm (44 in) of annual snowfall. The town has a population of 497 (LakesnWoods.com, 2018). The wastewater treatment system is sized to accommodate 545 people (20% population growth) by 2020 (Minnesota Pollution Control Agency 2003), and provides service to 207 households (LakesnWoods.com, 2018).

The Prinsburg wastewater treatment facility includes four constructed subsurface flow wetlands with forced bed aeration (Figure 15). Each wetland cell is 1589 m^2 (17,100 ft^2) in size (0.16 ha (0.39 ac) each; Total = 0.64 ha (1.57 ac)). The system is sized to treat up to 206 m^3 d^{-1} (54,500 gallons per day) (Minnesota Pollution Control Agency 2003).

The October 2004 treatment facility as-bid costs were $1,281,762 USD, and the collection system as-bid construction costs were $1,128,000 USD. Legal, Administrative, Engineering, Interim Interest, and Contingencies Costs brought the as-bid project costs to a total of $3,300,400 USD. System costs include the construction of city sewer lines because residents previously discharged to a centralized, underground, unpermitted wastewater collection system. The project was primarily funded by the USDA – Rural Development program, together with a mix of funding from Minnesota and the City of Prinsburg. The city pays $30,000 USD per year for contracted services for system maintenance and operation. Additionally, the city employs a public works manager and pays for sludge cleanout on an annual basis.

Prinsburg wastewater consists of domestic wastewater from residential and commercial connections (Minnesota Pollution Control Agency 2003). The wastewater treatment facility is located on land previously used for agricultural cropland located between the city and Chetomba Creek (44°56'29.53" N, 95°11'41.54" W). The wastewater treatment facility requires very little water. A small amount is needed to clean system components and for landscape watering – about 0.38 m^3 (100 gallons) every six months. Treated wastewater is discharged to Chetomba Creek via an outlet pipe. The facility also has a water reuse program where disinfected effluent is used to mix and apply agricultural chemicals through the local farmers' cooperative.

Design flows were calculated using 0.28 $m^3\ d^{-1}$ (75 gallons per day) per person for dry weather flow and 0.38 $m^3\ d^{-1}$ (100 gallons per day) per person for wet weather flow. Peak hourly flow was calculated as 2.5 times the average wet weather flow. This indicates that some stormwater is combined with wastewater effluent.

System design was based upon monitoring of the centralized water system usage in town, where flows ranged from 104 to 116 $m^3\ d^{-1}$ (27,500 to 30,700 gallons per day). Using the 2000 census data (population 458) and the average daily dry weather flow, daily water usage per person was calculated at 0.25 $m^3\ d^{-1}$ (66 gallons per day). A 206 $m^3\ d^{-1}$ (54,500 gallons per day) wet weather flow provides capacity for future growth and wet weather flow (Table 6), and was calculated using a design population of 545 x 0.38 $m^3\ d^{-1}$ = 206 $m^3\ d^{-1}$ wet weather flow (545 x 100 gallons per day = 54,500 gallons per day) (Minnesota Pollution Control Agency 2003).

The wastewater from Prinsburg is from residential, commercial, and business connections. It is characterized by concentrations of pollutants typical of domestic strength wastewater. Table 7 describes the maximum design concentrations and mass loadings per day.

The wastewater is collected by a gravity sewer system network connecting a 102 mm (4 in) service line from each home or business to the main sewer line. Treatment begins when the wastewater is pumped from these lines by two lift stations to four 76 m^3 (20,000-gallon) septic tanks. Over time, sludge accumulates in the septic tanks and requires annual pumping to remove it. Annual septic sludge accumulation from 545 people is estimated at 97 $m^3\ y^{-1}$ (25,600 gallons per year). From the septic tanks, wastewater is discharged into a metering manhole, which splits the flow evenly to four constructed wetlands. Artificial aeration is used in the wetlands to increase bacterial oxidation of organic matter. Water then flows from the wetlands to two 57 m^3 (15,000 gallon) dosing tanks which will pump the water to two sand filters. The sand filters are a vertical flow system used to further treat the wastewater. The system uses chlorine disinfection and dechlorination prior to discharging treated effluent to Chetomba Creek.

State water quality standards of the MPCA are established for Chetomba Creek based upon its classification as a Limited Resource Value Water. This classification includes several uses: secondary body contact, preserving groundwater as a potable water supply, protection and enjoyment of aesthetics, industrial consumption, agricultural uses, use by wildlife, and more. The MPCA proposed water quality limitations for effluent in 1998 which are listed in Table 8.

Wildlife frequenting the adjacent fields and creek areas include deer, raccoon, fox, skunk, rabbits, moles, gophers and mice. Birds include waterfowl, songbirds, and birds of prey. Reptiles include snakes, frogs, toads and turtles. Rodents are discouraged from the site to avoid potential damage to the wetland liner and underground piping by burrowing activity. Chetomba Creek is limited in the propagation and maintenance of fish due to the physical nature of the stream. There are not any known state-listed endangered, threatened, or species of concern on or near the wastewater treatment wetland. Quantity and quality of site runoff was expected to remain the same before and after construction.

Because the wastewater is contained below surface at all times, odors are minimized. A layer of mulch covers the wetlands and sand filters, which contains wastewater odors. Septic tank pumping generates the greatest potential for odors but is only conducted once a year over a one-week period. The subsurface nature of the system does not negatively impact aesthetics (Figure 16), and gives the appearance of a grassy field that blends well in with the rural landscape.

Site limitations include shallow groundwater and soil type. The approximate depth to groundwater at the wastewater treatment facility is only 4.6 m (15 ft), and soils in Prinsburg tend to be impermeable. Soils in the area are generally poorly drained, which makes soil infiltration of wastewater (such as standard septic drainfields) a costly and problematic method of wastewater treatment. A PVC liner was used underneath the constructed wetlands to prevent any seepage of wastewater into the groundwater supply.

The City of Prinsburg adopted a new sewer use ordinance to address the new wastewater treatment system. The city may have also adopted ordinance amendments to prohibit the connection of stormwater conveyance systems such as sump pumps, footing drains, and roof gutters to the sewer system. Combining stormwater with wastewater for treatment can complicate the treatment process and substantially increase operating costs.

Previous systems consisted of private septic tanks followed by discharge to a centralized, underground, unpermitted wastewater collection system with direct, unpermitted discharge to Chetomba Creek (Minnesota Pollution Control Agency 2003). "While most wastewater treatment facilities were designed and built for 20 years of growth, the major structural components have an expected useful life of 40 years, dependent on operation and maintenance. As these structures deteriorate beyond their useful life, effectiveness declines, leading to a greater potential for permit violations, spills, unintended discharges, and operational and maintenance expenses. Currently, 20% of Greater Minnesota's treatment facilities are over 40 years old. Without construction projects, infrastructure demands and costs will continue to increase significantly" (Minnesota Pollution Control Agency, 2018, pg. 16). Minnesota is well-prepared to permit constructed wetland for wastewater treatment, and has permitted 24 of these systems as of this writing.

Prior to selecting this method of wastewater treatment, the City of Prinsburg assessed eight combinations of wastewater collection, treatment, and disposal. The constructed wetland method was selected for three reasons: 1) Gravity sewer reduced the amount of operation and maintenance and provided flexibility for future growth, 2) Subsurface flow wetlands have low operation and maintenance fees and available land was owned by the city and located nearby, and 3) Discharge to Chetomba Creek accommodates soil infiltration limitations and is cost effective.

3.3 Minot, North Dakota, Wastewater Treatment Facility

The City of Minot's free water surface flow constructed wetland was constructed in 1991. Average temperatures range from -19 to -9°C (-2 to 15°F) in winter and 14 to 28°C (58 to 82°F) in summer (Government Websites by CivicPlus 2018). Average annual rainfall is 432 mm (17 in). Average annual snowfall is 1,194 mm (47 in) ("Climate Minot - North Dakota" 2018). The population was 47,997 in 2014, a 31% population change since 2000 (City-Data.com 2018b), due to a regional oil boom.

The total wetland portion of the system occupies a quarter section of land, or 65 ha (160 ac) (Figures 17-18). The four constructed wetland cells consist of 51 ha (126 ac). Lagoon cells are approximately 57 ha (140 ac) each.

The system treats 28,391 $m^3 d^{-1}$ (7.5 million gallons per day) of wastewater. The author was unable to obtain cost information for initial construction of wetlands. The City of Minot stated that staffing included a public works director and assistant director, two full-time employees for aeration lagoon maintenance, operation, and lab testing, and six full-time employees for general maintenance and operation of the system, pumps, and lift stations.

The wetland treatment system was constructed to upgrade Minot's previous method of treatment which consisted of a five-cell lagoon arrangement. The lagoon system suffered odor problems and the upgrades were intended to improve this system and meet permitting parameters for NH_3 (Mander and Jenssen 2002). The current system begins with two eight-acre aeration basins which receive all of Minot's wastewater. The effluent then enters five lagoon cells for further treatment and retention, after which it enters the constructed wetland system for advanced treatment. Final treatment occurs in a modified, four km (2.5 mile) long drainage way that discharges to the Souris River as shown in Figure 17 (North Dakota Department of Health 2011).

The wetland cells were constructed with five marsh-pond zones (A-E) to serve specific purposes. Zone A is a marsh designed to reduce BOD_5 and remove TSS. Zone A was designed with a 152 mm (6 in) operating depth planted with cattails (*Typha latifolia*). Zone B is a pond designed to facilitate nitrification and has an operating depth of 610 mm (24 in) planted with Sago pondweed (*Potamogeton pectinatus*) and wild celery/eelgrass (*Vallisneria americana*). Zone C is a marsh designed to facilitate both nitrification, denitrification, and nutrient removal. It has an operating depth of 305 mm (12 in) and is planted with soft-stemmed bulrush (*Scirpus validus*) and duckweed (*Lemna*). Zone D is a pond which also facilitates nitrification, denitrification, and nutrient removal. It is designed with the same depth and plant species as Zone B. The final wetland cell, Zone E, is a marsh which facilitates denitrification and removal of TSS and fecal coliform bacteria. It is designed with the same depth and plant species as Zone A. Transition zones are located between zones A-B and D-E. They consist of a 6:1 slope stabilized with the tuberous wapato (*Sagittaria latifolia*) (Mander and Jenssen 2002). Pond zones B and D include small islands for wildlife nesting and loafing.

The system was designed to equally distribute flow to all four wetland cells, but initially all flow was directed to the fourth cell in order to allow vegetation to establish in other cells (Mander and Jenssen 2002). A special condition of Minot's National Pollutant Discharge Elimination System (NPDES) permit is to complete a Mercury Pollutant Minimization Plan to evaluate collection and treatment systems and determine possible sources of mercury and identify possible reduction options

Minot's wastewater system discharges continually to the Souris River from May through December. It represents most of the Souris River flow during summer months, and therefore low NH_3 (ammonia) parameters are included in the discharge permit (Mander and Jenssen 2002). In 2018 the City of Minot advertised a Request for Qualifications (RFQ) to analyze the existing wastewater lagoons, determine if any leakage is occurring from the existing lagoon system, inspect and analyze the system for maintenance, compliance, and odor control. The RFQ included the potential for additional future work including general wastewater services, permitting review, modeling, design and construction engineering, environmental analysis, and wastewater planning. (City of Minot 2018)

In a personal telephone interview with the author, City of Minot wastewater staff discussed the need to increase system capacity in order to meet the demand generated by population growth in recent years. Staff indicated that increasing water quality standards, particularly minimum standards for the removal of NH_3, combined with the increase in connections due to growth have resulted in a need to increase system capacity and improve the level of wastewater treatment.

Minot is a cold climate location that experiences below-freezing temperatures from November to March (Figure 19). Bodies of water can accumulate ice up to three feet thick. Because of these freezing conditions, the wastewater treatment system was designed to utilize existing lagoons for storage capacity for 180 days. Wastewater flows to the wetlands from May to October and is generally covered in ice from January through March. BOD_5 and

NH_3 removal progressively decline with water temperature and removal of BOD_5, NH_3, and TSS are highest when water temperature is above 50° F (Mander and Jenssen 2002).

The Minot system is one of the largest cold-climate constructed wetlands treating municipal wastewater. Treatment efficiency of both the aerated lagoons and wetlands declines with water temperature during winter months. The system compensates for this by providing sufficient storage capacity for wastewater generated during the cold season. Adequate removal of NH_3 is the primary challenge this system faces. Because NH_3 is removed through nitrification by bacterial oxidation, the aerated lagoons achieve good NH_3 removal under warm weather conditions. The constructed wetlands also achieve good TSS and BOD_5 under warm weather conditions, but only receive low levels of effluent during this time because aerated lagoons are operated to maximize NH_3 removal. Effluent to the wetlands is increased during cold weather, but wetlands do not function as well at low temperatures (Mander and Jenssen 2002). The entire system is therefore limited at the front end (aerated lagoons) because the wetlands are not used at capacity during the most effective time of the year. Increasing the effectiveness or expansion of the aerated lagoons would facilitate higher effluent loads to the wetlands and improve system efficiency.

In addition, significant amounts of algae and duckweed are produced in the wetland and must then be removed with other suspended solids. (Mander and Jenssen 2002) The production and subsequent removal of algae and duckweed within the system does not increase system efficiency. Alternative hydrologic loading rates to the wetland system should be considered to reduce or prevent the growth of algae and duckweed. This could increase the capacity of the wetlands to remove other suspended solids and reduce BOD_5.

3.4 Boston Mills Historic District, Cuyahoga Valley National Park, Ohio

Actual date of completion for this project is unknown. A feasibility study for the system was completed in 2006 and construction is complete. It is located in the Cuyahoga Valley National Park about 34 km (21 miles) south of Cleveland, Ohio (Figure 20). Winter temperatures range from below -17 to 2°C (0 to 35°F). Summer temperatures range from 9 to 35°C (49 to 95°F) (National Park Service 2018).

The population served by the system is unknown. The Cuyahoga Valley National Park owned and maintained six structures within the Boston Mills Historic District at the time the feasibility study was conducted (2006) and planned to acquire three additional residences. The six structures include the Hines Hill Complex with Main House, Conference Center and Tenant House, the Boston Store Complex with Visitor Center, public restrooms, and offices, and four three-bedroom, two-bathroom residential properties. Average daily water usage was calculated for the structures based on records of water usage over a five-month period from October 2003 through February 2004. A 50% increase in water was added to account for summer usage, which yielded a calculation of 0.88 m^3 d^{-1} (233 gallons per day) for the Hines Hill Complex and 1 m^3 d^{-1} (300 gallons per day) for the Boston Store Complex. Total calculated water usage is shown in Table 9 (URS Corporation 2006).

Total area for the free water surface and subsurface flow wetlands is 1 hectare (2.5 ac) (URS Corporation 2006) as shown in Figure 21. Preliminary sizing was based on estimated design flow of 18.92 m^3 d^{-1} (4999 gallons per day). The sizing method assumes worst case scenario winter conditions, which requires the largest area for adequate evapotranspiration and infiltration under maximum flow conditions. Soil permeability was studied and considered. Permeability below a certain threshold would indicate a need for a larger treatment area or possible relocation to a treatment area with higher soil permeability. The free water surface wetland provides winter storage from December through March and the total volume of wastewater expected during that time is 2,186 m^3 (577,365 gallons), which is less than the storage capacity of the free water surface wetland. Normal operating depth of the free water surface wetland is 152 mm (6 in), although it can accommodate a maximum depth of 305 mm (12 in) (URS Corporation 2006).

Operation and maintenance costs include monitoring of influent and effluent water quality, water level monitoring, vegetation management, and odor control. Maintaining adequate levels of water is critical to meeting these goals because it prevents freezing and prevents odors. Vegetation is assumed to require little maintenance other than periodic inspections for invasive species and reseeding as necessary. Cost of initial construction was estimated at approximately $132,507 USD, as detailed in Table 10 (URS Corporation 2006).

The feasibility study reviews two alternative options for wastewater treatment: constructed wetlands and sub-surface drip irrigation. These options were selected based upon site-specific factors such as unrestricted public access, geology and topography, long-term operation and maintenance requirements, cost-effectiveness, and the ability of technology to treat wastewater. (URS Corporation 2006) Treatment alternatives were evaluated using several criteria: site-specific suitability, long-term effectiveness and lifespan, treatment effectiveness, technical and administrative feasibility, human and environmental health, regulatory requirements, cost (capital, operation, and maintenance), and community acceptance.

The primary goals for water treatment are a significant reduction of fecal coliform bacteria and BOD_5. These criteria and goals are universal and can be applied to virtually any community or location evaluating options for wastewater treatment. The system proposed for the Boston Mills Historic District combines the use of septic tanks with a free water surface and a subsurface flow constructed wetland (Figure 22).

Wastewater receives primary treatment through use of a septic tank, which removes settling and floating solids. Solids must be removed to prevent clogging of the entry zone into the wetland. Secondary treatment occurs in the subsurface flow constructed wetland, where BOD_5 and very small suspended solids are removed through aerobic and anaerobic processes. The final phase of treatment occurs in the free water surface wetland, where effluent receives further biological treatment and is disposed through infiltration and evapotranspiration.

Due to its proximity to the Cuyahoga River, the location of the 100-year floodplain was investigated to determine if a floodplain development permit would be needed. A site survey is typically completed as part of the design process to delineate the location of the floodplain, and in this case sufficient area outside the floodplain existed and was used for construction. Ohio EPA requires an NPDES permit for discharges, but not for on-site/zero-discharge systems. Preliminary discussions with Ohio EPA indicated that an NPDES permit would not be required for the constructed wetlands, as the final phase of treatment is infiltration and evapotranspiration. Ohio EPA does require a Permit-to-Install. An Environmental Assessment was likely required by the National Environmental Protection Agency (URS Corporation 2006).

Advantages and disadvantages of the constructed wetland are summarized in the feasibility study. It conserves water and does not require electricity or chemical additions. It is low-cost, low-maintenance, easy to implement, and allows for zero discharge. The system achieves treatment goals without exposing the public to any potentially harmful pathogens. It also provides significant aesthetic benefits because it is located in a highly visible area adjacent to the Cuyahoga River and between two highways in the Cuyahoga National Park. The naturalistic look of the treatment facility blends well with the surrounding natural environment.

Disadvantages are the need to accommodate winter conditions and prevent mosquito breeding and odors of the free water surface constructed wetland. Long-term maintenance and an Environmental Assessment may be necessary, and monitoring will be required (URS Corporation 2006).

The feasibility study demonstrates that a constructed wetland is an easy-to-implement and low-cost method of treatment for the Boston Mills Historic District's wastewater. The study states that, "Constructed wetlands are capable of meeting and exceeding treatment goals, with increasing long-term efficiency. Long-term efficiency can be maintained through proper operation and maintenance of the system" (URS Corporation, 2006, pg.7-1).

3.5 Recommendations

A constructed wetland would be an economically feasible alternative to replacing Juliaetta's centralized wastewater treatment system with another traditionally engineered system. Although constructed wetlands have not been as well accepted in the U.S. for this purpose as they have in other countries, they are recognized by the U.S. Environmental Protection Agency (EPA) as an effective form of wastewater treatment. Technologies like the Port of Portland's Living Machine can increase awareness of the benefits of using constructed wetlands to treat wastewater. In areas where sustainable methods are not widely accepted or practiced, examples like the Living Machine provide evidence of the cost savings and ecological benefits of constructed wetlands for wastewater treatment.

A hybrid system consisting of vertical and horizontal subsurface flow wetlands would be appropriate for the climate of Juliaetta, which does experience very cold winter temperatures. Designing the system for a projected future population based upon the life expectancy of the system demonstrates one of many benefits that such a system has to offer. In the application portion of this publication, the system elements and functions will be presented through a schematic design, perspectives and elevations of the site and design proposal, and calculations necessary to demonstrate the capacity and effective treatment of water to meet state and federal standards.

Treating effluent to secondary standards facilitates re-use of the water to irrigate the city park and baseball fields located nearby. This in turn could substantially assist the city in meeting more stringent water quality standards that are included in the city's 2018 NPDES permit. The cumulative effects of implementing a constructed wetland to treat Juliaetta's wastewater may even be felt downriver at the City of Lewiston, which obtains much of its drinking water from the Clearwater River. (CH2MHill 2010)

CHAPTER 4 SITE INVENTORY AND ANALYSIS

4.1 Juliaetta, Idaho

The City of Juliaetta, Idaho, utilizes a centralized wastewater treatment system (Figure 23) that was completed in 1977 and still uses much of the original equipment from that time. Replacement parts for a system this age are becoming more difficult to obtain and based upon current performance levels it is unlikely that it will be able to meet future discharge permit requirements (Keller Associates 2018). The system receives wastewater from 590 connections consisting of residential and light commercial uses. It is operated and maintained by a staff of two system operators-in-training. Treated effluent is discharged to a wetland basin adjacent to the Potlatch River (Figure 24) under an NPDES permit that was approved in 2018 (US EPA 2018b).

Juliaetta is a small town with a population of approximately 609 that has remained stable for more than 20 years (US EPA 2018a; City-Data.com 2018a). Agricultural uses drive the local economy, though many citizens commute to nearby population centers in the Lewiston-Clarkston valley and university towns of Pullman, Washington, and Moscow, Idaho, for other employment. Regional growth of population centers could increase the population of Juliaetta. A budding regional wine industry could also impact population projections. For the purpose of planning for future growth and ensuring functional capacity over the lifetime of the treatment system, population growth was projected for 20 years at a modest growth rate of 2% per year as shown in Figure 3.

The climate in Juliaetta is temperate with an average temperature of -2˚C (28˚F) in winter and 31˚C (88˚F) in summer. It is located 352 m (1155 ft) above sea level (City-Data.com 2018a). Winter is generally wet with an average of 1,219 mm (48 in) snow accumulation. The average annual precipitation in Juliaetta is 457 mm (18 in) per year (Sperling's Best Places 2018), most of which occurs from fall to spring. This results in high peak flows of the Potlatch River in early spring and extremely low flows in late summer (Idaho Department of Environmental Quality 2008). The U.S. Department of Agriculture (USDA) cold hardiness zone is 7a (PlantMaps 2018b) and the American Horticultural Society (AHS) heat zone is 3 (PlantMaps 2018a).

4.2 Existing Wastewater Treatment Facility

Juliaetta's wastewater treatment system is located at the southern (downstream) end of town and discharges treated effluent to a wetland basin adjacent to the Potlatch River as shown in Figure 25 (US EPA 2018a). The Potlach River watershed encompasses approximately 153,942 ha (380,400 ac) and drains into the Clearwater River (Figure 26). Land uses within the watershed include forestry, livestock, agriculture, rural residential, commercial, and industrial areas, and undeveloped hillsides (Idaho Department of Environmental Quality 2008).

The wastewater facility is designed to treat 303 $m^3\ d^{-1}$ (80,000 gallons per day) of wastewater. Wastewater gravity flows to the treatment facility, where a lift station pumps it through a grit removal chamber to a grinder pump. It then flows to a mechanical aeration tank, followed by a clarifier. Sludge is piped from the bottom of the clarifier into one of four sludge drying beds, from which dried sludge is removed and temporarily stockpiled on site until it is removed and composted at an off-site facility. The clarified effluent flows through a rotating microscreen for the removal of fine solids, after which it is chlorinated to remove pathogens and dechlorinated prior to discharge into an area adjacent to the Potlatch River (Figure 27).

The existing wastewater treatment system is more than 40 years old with very few updates since that time. Replacement parts for a system this age are becoming more difficult to obtain. Based upon current performance levels it is unlikely that it will be able to meet requirements of the 2018 NPDES permit. Drying beds operate at capacity during winter months and influent screening is insufficient, increasing wear on downstream processes and equipment (Keller Associates 2018). In addition, EPA has determined that Juliaetta cannot meet water temperature limits (<21.3°C) based on the updated 2018 Draft TMDL and has proposed a 13-year compliance schedule in the 2018 NPDES permit. Effluent temperature standards pose a significant challenge during summer months, when low flows of the Potlatch River can drop below 0.057 $m^3\ s^{-1}$ (2 cubic feet per second). EPA recognizes that water cooling alternatives to refrigeration, such as re-use and habitat restoration "may have additional benefits beyond reducing water temperature" (p. 17, US EPA, 2018a).

4.3 Pollutants and Water Quality Standards

Water quality standards consist of use classifications, quantitative limits, narrative criteria with quantified targets, and an antidegradation policy. 2018 NPDES permit limitations for effluent have been developed for Juliaetta for 5-day BOD_5, TSS, *E. coli*, pH, total residual chlorine (TRC), and temperature (Table 2). Standards for BOD_5, *E. coli*, and pH are unchanged from the previous NPDES permit written in 2004. Concentration limits for TSS are unchanged, but the average monthly mass limit is more stringent than before as are standards for chlorine. The previous permit did not include standards for water temperature, and this is a significant change with substantial design implications for the treatment system (US EPA 2018a). No limits are proposed for ammonia as no reasonable potential for ammonia was demonstrated, and no limits are listed for dissolved oxygen (DO) or total phosphorous (TP).

The water quality standards are set at levels that protect existing and designated beneficial uses (US EPA 2018a). Designated beneficial uses of the Potlatch River include cold water aquatic life, salmonid spawning, primary contact recreation, and domestic water supply (Idaho Department of Environmental Quality 2008). The following pollutants were identified in the 2008 Potlatch Watershed TMDL for the portion of the watershed from Big Bear Creek (at Kendrick) to the mouth at the confluence with the Clearwater River: bacteria, dissolved oxygen, ammonia, nutrients, oil and grease, pesticides, sediment, and temperature.

A Total Maximum Daily Load (TMDL) is required for water bodies that do not meet state water quality standards. A TMDL calculates the allowable amount of a pollutant that can be in the water body according to state water quality standards, and NPDES permits refer to TMDL limits once established. The allowable amount of the pollutant is called the pollutant load capacity. Once the load capacity is calculated, it is allocated among the sources of the pollutant in the watershed. The Potlatch River from Big Bear Creek to the mouth exceeds pollutant allocations for temperature and sediment (Idaho Department of Environmental Quality 2008). Low stream flows in late summer make it extremely difficult to meet minimum water temperature standards.

Idaho administrative rules (IDAPA 58.01.02.251.01 and 02) state that in water bodies designated for contact recreation, *E. coli* levels are not to exceed 126 colony forming units (cfu) per 100,000 mm^3 (100 mL) of solution as a 30-day geometric mean (State of Idaho 2018). Idaho's nutrient standard states that surface waters of the state shall be free from excess nutrients that can cause visible slime growths or other nuisance aquatic growths impairing designated beneficial uses. An in-stream dissolved oxygen concentration of 6.0 mg L^{-1} is required by Idaho's water quality standards for protection of aquatic life beneficial uses. The total phosphorus target of 0.100 mg L^{-1} has been applied in the Potlatch River TMDL. Reducing stream phosphorus concentration to below 0.100 mg L^{-1} should reduce aquatic plant growth while enhancing dissolved oxygen concentrations (Idaho Department of Environmental Quality 2008).

Idaho Water Quality Standards (IDAPA 58.01.02) do not use a numeric value to establish standards for sediment – it is limited to a quantity that does not impair beneficial uses. The effects of sediment on aquatic life are dependent on concentration and length of exposure. Therefore, targets are a monthly average of 50 mg L^{-1} TSS with a maximum daily limit of 80 mg L^{-1} to allow for natural variability (Idaho Department of Environmental Quality 2008).

In regard to temperature, natural conditions are the water quality standard and the TMDL standard is the natural level of shade and channel width. The temperature resulting from these conditions (i.e, "natural temperature") is the water quality standard, even if it exceeds the critical temperature for cold water aquatic life (Idaho Department of Environmental Quality 2008). Vegetation is an important means of providing shade to reduce water temperature. Historically, the native vegetation along the lower Potlatch River varied with elevation, aspect, soil type, and moisture content. The bottomlands of the watershed were dominated by black cottonwoods with an understory of deciduous shrubs. Because temperature is a circumstantial condition, the TMDL does not have specific load allocations for temperature (Idaho Department of Environmental Quality 2008). The 2018 NPDES permit does include specific temperature limitations, and providing shade to promote cooler water temperatures is considered an implicit part of implementation.

4.4 Site Characteristics and Analysis

The existing wastewater treatment plant is located adjacent to the 100-year floodplain of the Potlatch River according to the Federal Emergency Management Agency's (FEMA) Flood

Insurance Rate Map (FIRM) (Figure 28). The 100-year floodplain is an expression used to communicate areas of high flood risk where there is a 1% chance of flooding in any given year. The FIRM maps for this area were based upon a flood study published in 1983. Since that time, the Potlatch River and its floodplain have changed due to floods and other natural causes, resulting in a FIRM that cannot be reliably used to determine the location of the floodplain.

Flood elevations on the FIRM may be used with updated lidar elevation data (2016) to infer an approximate location of the floodplain for preliminary planning (Figure 29). Property located within the FIRM floodplain is subject to additional permitting requirements, most of which require engineering and/or surveying which adds to project costs. In order to minimize flood risk to Juliaetta's wastewater treatment infrastructure and avoid unnecessary costs, property within the extrapolated 100-year floodplain (shown as colored topo lines) will not be considered for the constructed wetland.

Soil of the site is characterized as aquic xerofluvents of 0-3% slopes (USDA Natural Resources Conservation Service 2018). This soil type occurs in floodplains and stream terraces and consists of gravelly loam from 0-178 mm (0-7 in), with stratified sand to very cobbly sandy loam from 178-1,524 mm (7-60 in) deep. It is prone to flooding and depth to the water table is approximately 457-610 mm (18-24 in) (USDA Natural Resources Conservation Service 2018), indicating that a wetland liner will be necessary to prevent untreated wastewater from leaching out of constructed wetlands. Frost depth at the site is 610 mm (24 in).

The Prinsburg case study demonstrates that partially treated wastewater can be useful to the local farmers cooperative for mixing fertilizers. This type of reuse should be investigated for Juliaetta, which is surrounded by agricultural lands above the valley. It may not be practical to transport the water uphill for application upon cultivated fields, but baseball and softball fields located north and uphill of the site may benefit from reuse (Figure 30). In addition, the region is experiencing a growing wine industry with the approval of the Lewis-Clark Valley American Viticultural Area in recent years. Hillsides downriver from Juliaetta are now flourishing with vineyards which require irrigation during summer months (Figure 31), for which surface water is drawn from the Potlatch River. If vineyards are established nearer to Juliaetta, reuse of partially treated wastewater for vineyard irrigation may become an advantageous undertaking, as the water still retains nitrate that plants can use. This would reduce the demand for surface water from the Potlatch River, which in turn preserves higher stream flows and helps maintain lower water temperature for endangered salmonid species.

There is ample opportunity on-site to plant large tree species and woody shrubs. Large deciduous trees strategically located south of the wastewater treatment facility will provide shade during hot summer months, a critical component for reducing water temperature and supporting cold water aquatic life. After leaf fall when temperatures have dropped, sun will reach the wetland and aid in heat retention, supporting biological processes that slow in cold temperatures. Planting native woody shrubs will provide shade, cover, and food sources for wildlife, not to mention aesthetic appeal.

Property lines were reviewed using the Latah County Assessor's property information available online (Latah County GIS 2018). As shown in Figure 32, the wastewater outfall is not owned by Juliaetta. The parcel where the outfall lies consists of approximately 2.2 ha (5.6 ac) under ownership of a local business, Browning Cutstock. In a telephone interview with the Assessor's Office, property such as this is valued for tax purposes at $300-1000 USD acre^{-1}, and probably on the lower end due to its location near/in a floodplain, without an approach to Highway 3 for access. Based upon this information, the property may have an assessed value of $1,680-5,600 USD. Since the property is not used by Browning Cutstock for regular business operations, it would be beneficial for Juliaetta to explore a mutually beneficial land acquisition in which Juliaetta owns and controls the existing wastewater outfall and adjacent area for future needs, and Browning Cutstock reduces its taxable landholdings without any negative impact to current operations.

CHAPTER 5 DESIGN

5.1 Principles and Techniques

The research methods of Chapters 2-3 yield concepts and techniques that guide the design toward proven methods and away from unanticipated problems or design failures. This forms the basis of design principles that can be applied to conditions faced by the City of Juliaetta. The research verifies that constructed wetlands provide a cost-effective solution for wastewater treatment that can be applied to small communities in cold climates. Constructed wetlands can remove nutrients and solids from wastewater, meet water quality standards, and provide sustainable benefits that traditional engineered systems cannot, such as wildlife habitat, energy savings, irrigation water, and recreation area.

Currently, the only advantage of traditional mechanical systems over constructed wetlands for wastewater treatment in small communities are the reduced land area needed for treatment and the acceptance/familiarity of permitting agencies with mechanical systems, which can ease the permitting process. This is particularly true in Idaho, where a single constructed wetland for wastewater treatment has yet to be permitted, and less of an issue in states such as Minnesota that are well-versed in the review, monitoring, and permitting of constructed wetlands. With any treatment system, the burden of proof lies with the community and its engineer(s) to demonstrate that water quality standards can be met and public health, safety, and welfare are not put at risk.

Juliaetta's wastewater treatment system must meet federal and state discharge permit requirements and water quality standards, be maintained by two staff employed by the city (dedicated to wastewater management only part time), be affordable to construct and maintain, and be sustained by the community for the lifetime of the system. The treatment wetland should also provide secondary benefits that traditional mechanical systems cannot, such as wildlife habitat, irrigation water, and recreation area.

5.2 Assumptions and Additional Research Needed

Federal and state water quality standards and permits require engineering by a licensed engineer and are beyond the scope of this thesis, though numerous studies and sources are referenced as a means to that end. Literature and case studies demonstrate that compared to mechanical systems, constructed wetlands provide a low energy, low maintenance, cost efficient means of wastewater treatment when adequate land area is available. The literature review includes case studies of effective wastewater treatment systems with detailed specifications for system design, aeration, hydraulic load rate, hydraulic retention time, plants, and substrate. Corresponding treatment efficiencies and effectiveness in cold climates are also detailed (Paing and Voisin 2005; Rizzo *et al*. 2018; Masi *et al*. 2017), demonstrating that state and federal water quality standards can be met and that treatment improves with the establishment of vegetation after year one. Standard maintenance of wetlands includes controlling flows during year one to establish vegetation, preventing clogging of filter media/substrate, cutting back vegetation if overgrown, and sludge management (septic pumping or sludge layer removal in French reed beds).

Collectively, this data provides a basis for the design of a constructed wetland to treat wastewater for the City of Juliaetta, Idaho. The design proposal assumes that wastewater from the City of Juliaetta is not significantly different than municipal wastewater reviewed in literature and case studies, and that similar design specifications will therefore result in similar and effective treatment efficiencies. Additionally, these criteria provide a basis from which a wastewater treatment wetland could be engineered to operate at or above the same level of effectiveness as those reviewed in literature and case studies. The use of native plants in constructed wetlands is not addressed in literature, though natives are preferred to support native wildlife and prevent the spread of invasive/introduced species as described in the project scope and goals. Additional research is needed to identify a regionally appropriate polyculture of native species that can be substituted for the invasive *Phragmites spp.* and other non-native species.

5.3 Design Conclusions

The French reed bed system is well-suited for the treatment of Juliaetta's wastewater for its reduced cost and maintenance over other constructed wetland designs. Gravity flow should be utilized as much as possible to reduce costs associated with pumping effluent (Figure 33). As a vertical subsurface flow system, it also requires less area per capita (2 m^2/person) than horizontal or free water surface systems. French reed beds can further reduce construction and maintenance costs by reducing sludge management over the lifetime of the system, requiring removal of accumulated sludge every 10 years or more (Figure 34).

The IDEQ is ideally positioned to incentivize constructed wetland systems like the French reed bed by prioritizing projects which provide ecological (habitat, reduced water temperature) and social benefits (recreation, reduced cost) compared to a mechanical system. The low cost of constructed wastewater treatment wetlands compared to costs of recently completed construction/renovation of traditional systems in Idaho should provide a strong incentive to consider wetland technology. In addition, five separate funding sources for constructed wastewater treatment wetlands are available to communities in Idaho (Table 4).

While the French reed bed will not allow direct contact recreation due to pathogens, it can be incorporated into a landscape design with recreational pathways, benches, river access and wildlife viewing that connect to the city park and ballfields (Figure 35). This plan integrates the five beneficial uses of water with effective site design for a wastewater treatment facility. Existing, mostly vacant gravel parking areas located above flood elevation provide an ideal location for new construction. Flood risk is eliminated while removing the need to disturb more land. This preserves the existing wastewater treatment system until the new constructed wetland treatment system is operational. Once the new system is operational, the original mechanical system can be decommissioned and storage constructed for water recirculation or reuse. The integration of additional storage for water reuse (irrigation of the city park or vineyards) increases flexibility for future uses. Alternatively, storage of treated water provides a convenient supply for the adjacent fire station, should the need arise.

Additional design recommendations include planting large tree species and native woody shrubs suitable for riparian and upland ecosystems (Tables 11-13). Large deciduous trees strategically located south of the constructed wetland will provide shade during hot summer months, a critical component for reducing water temperature and supporting cold water aquatic life. After leaf fall when temperatures have dropped, sun will reach the wetland and aid in heat retention, supporting biological processes that slow in cold temperatures. Woody shrubs provide shade, cover, and food sources for wildlife, not to mention aesthetic appeal for a site that is highly visible from the adjacent highway. Alternatives to potentially invasive species should include native perennial wetland grasses, reeds, and sedges to maximize treatment efficiency, diversity, and support of wildlife (Table 14). Opportunities for gravity flow of treated effluent to infiltration basins should also be investigated at the facility planning stage as a means of further cooling water temperature, providing streambank recharge, and permitting as a reuse facility. Effluent receives secondary treatment prior to infiltration and is therefore not at risk of contaminating surface water if flooding of infiltration basins should occur (Figure 36).

The design principles for constructed wastewater treatment wetlands presented here can be applied to other rural communities where sufficient space is available. Critical wetland components can be manipulated to overcome site constraints and treat wastewater to regulatory standards. Constructed wastewater treatment wetlands provide benefits of sustainable water management to rural communities worldwide.

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FIGURES

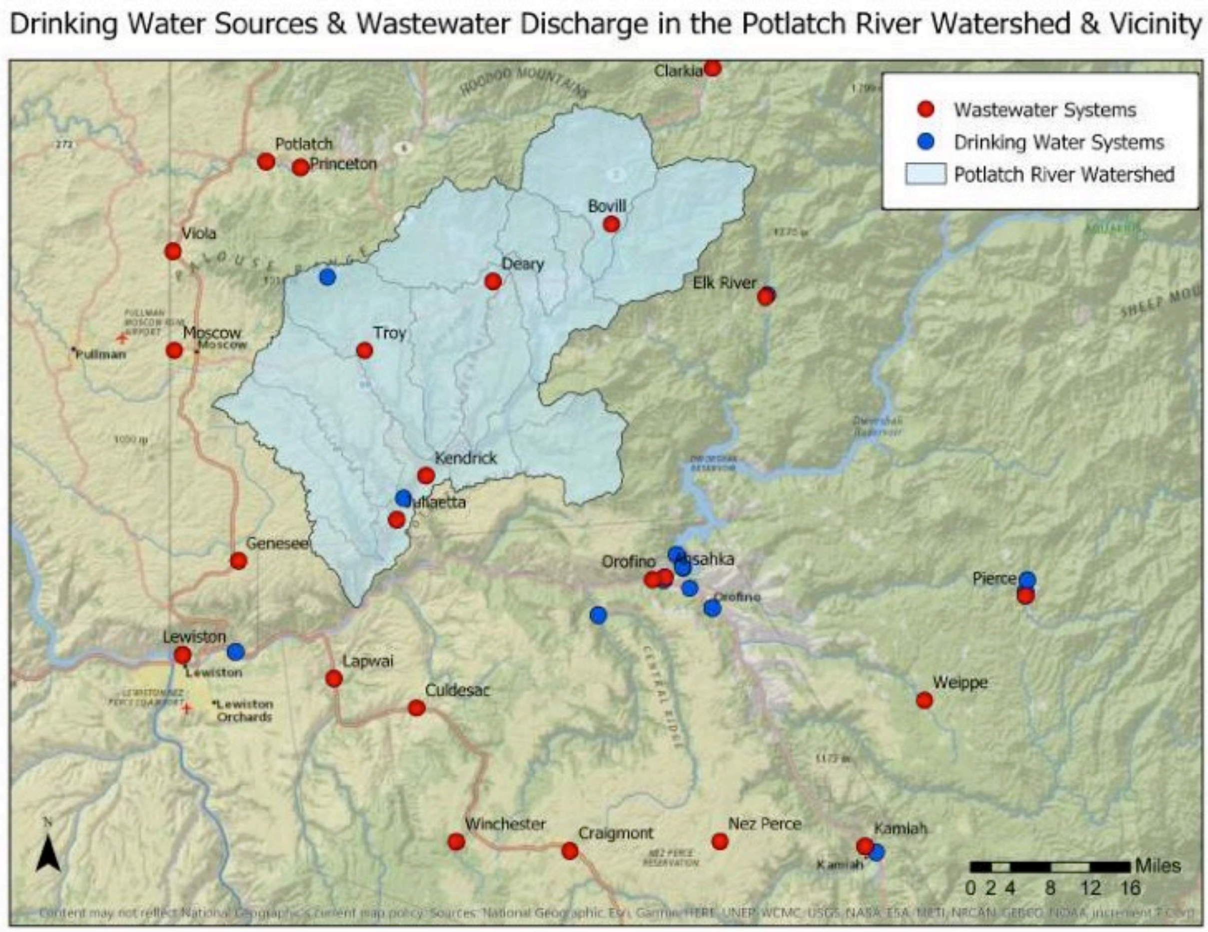

Figure 1. Drinking water facilities draw water from the same streams and rivers that receive treated wastewater.

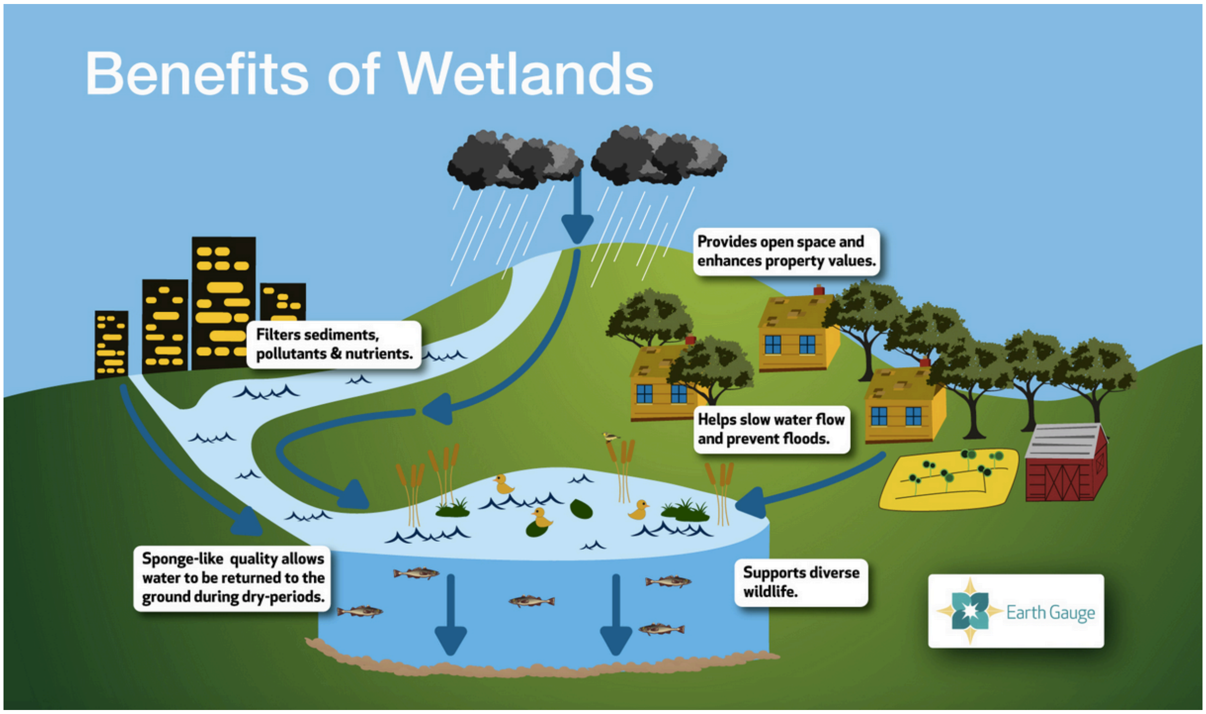

Figure 2. Wetlands offer many benefits to the public, the land, and wildlife. Earth Gauge, 2018.

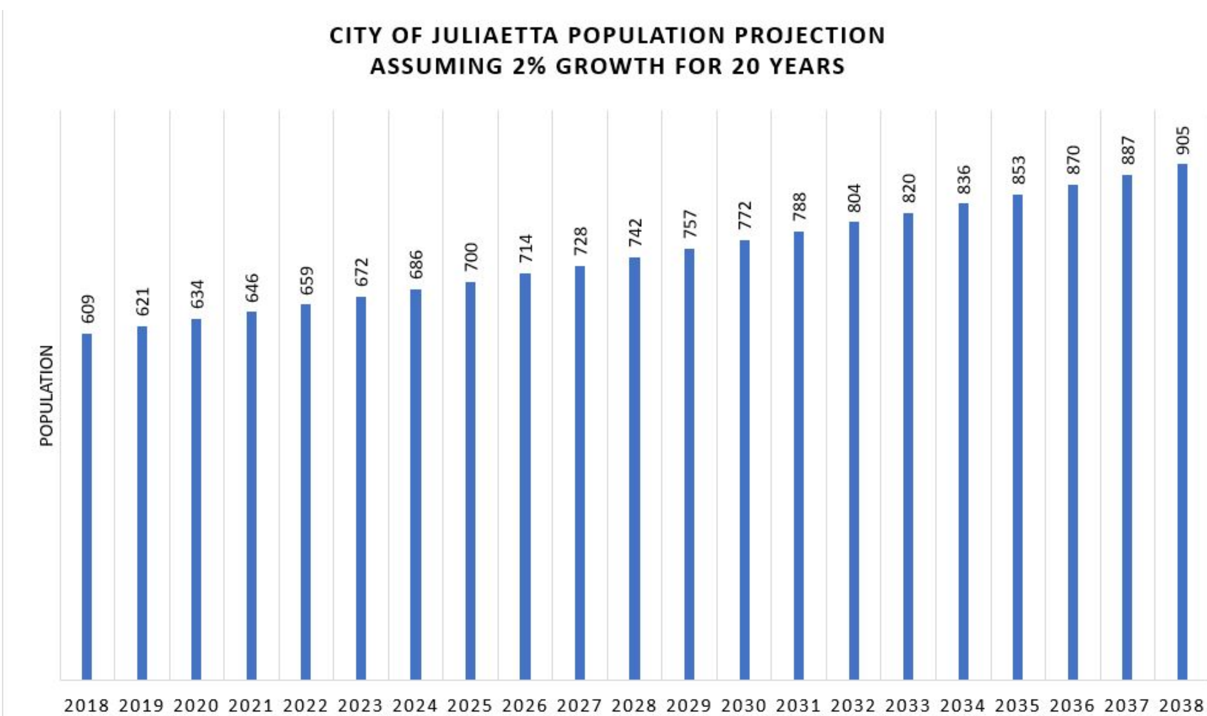

Figure 3. Juliaetta 20-year population projection.

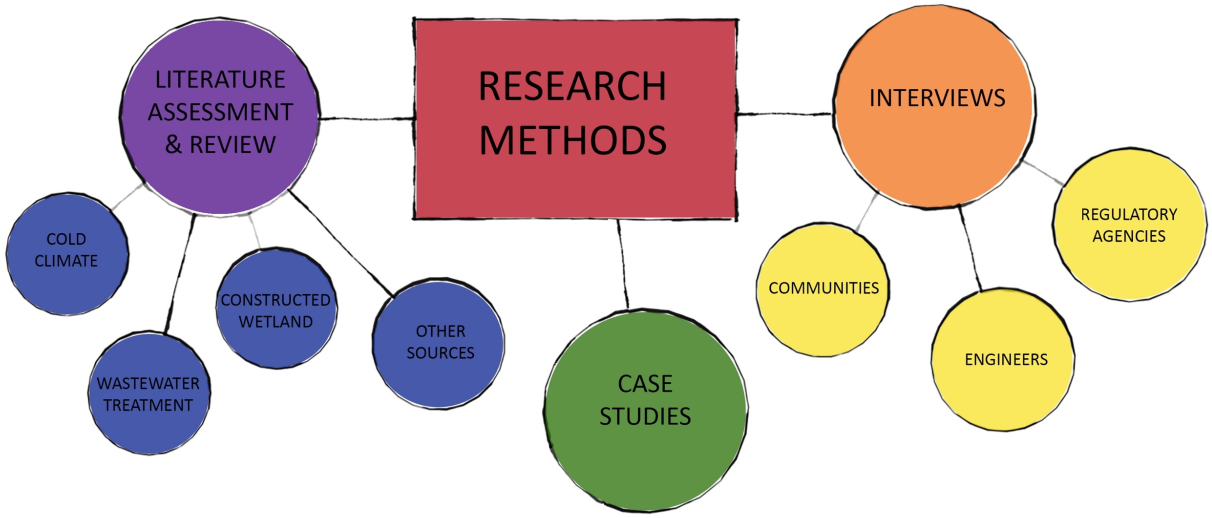

Figure 4. Diagram of research methodology.

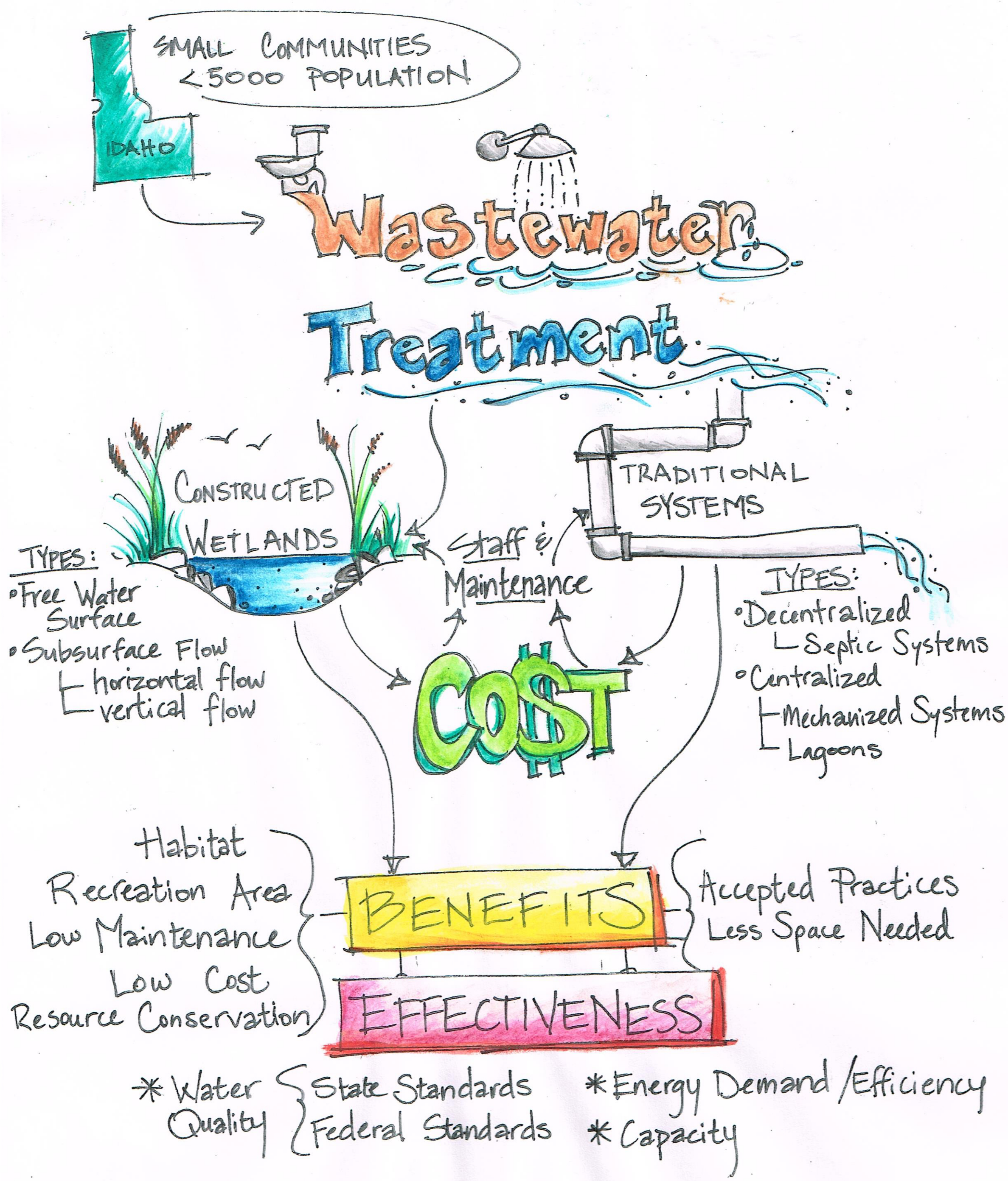

Figure 5. Diagrammatic comparison of constructed wastewater treatment wetlands and traditional wastewater treatment systems.

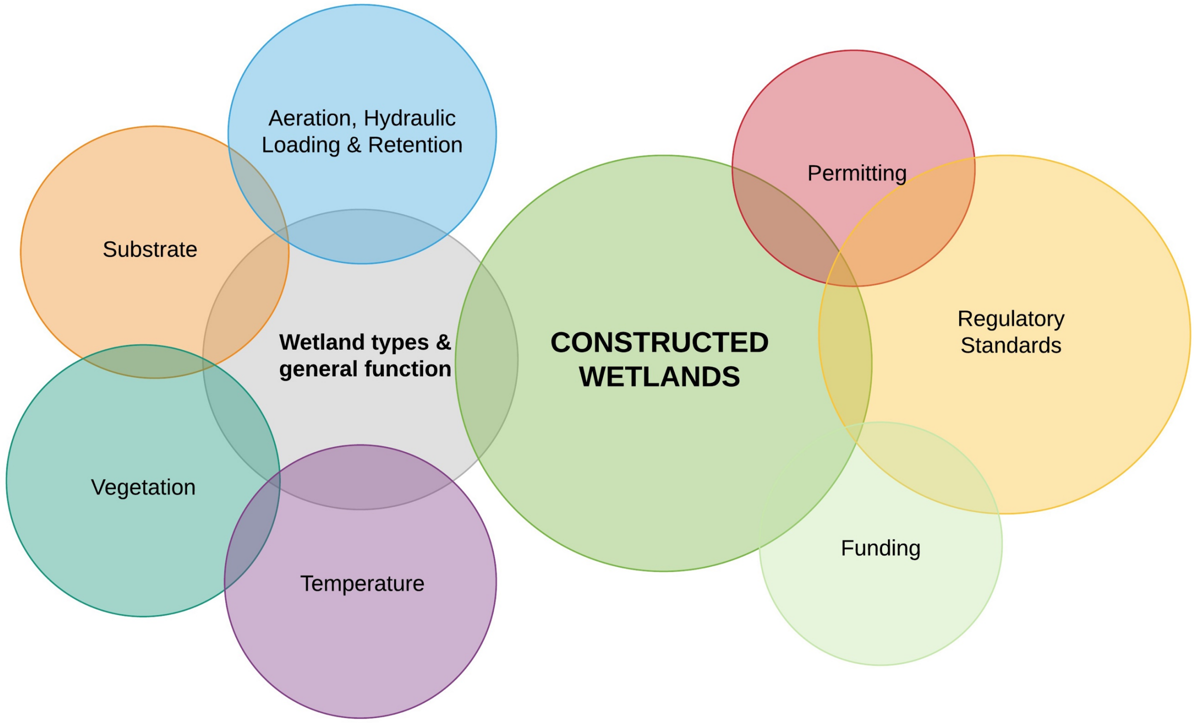

Figure 6. Literature review topics.

Figure 7. Free water surface wetland. Open source images, 2019.

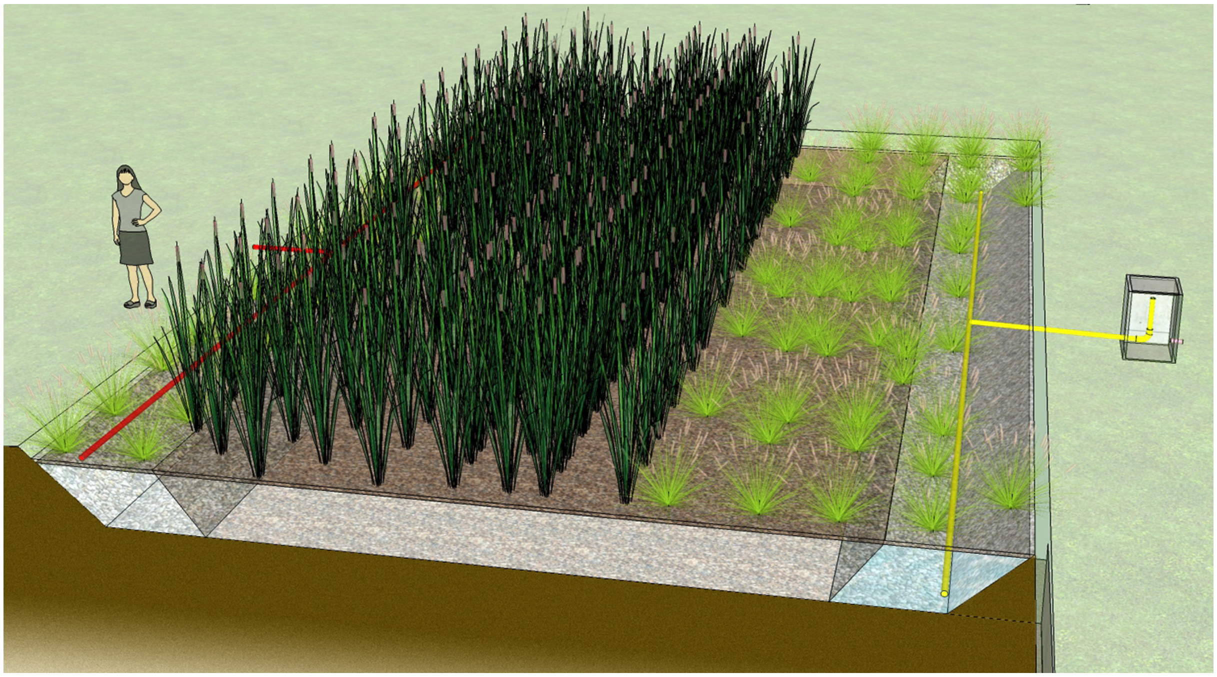

Figure 8. Horizontal subsurface flow wetland (G. Austin and Yu 2016).

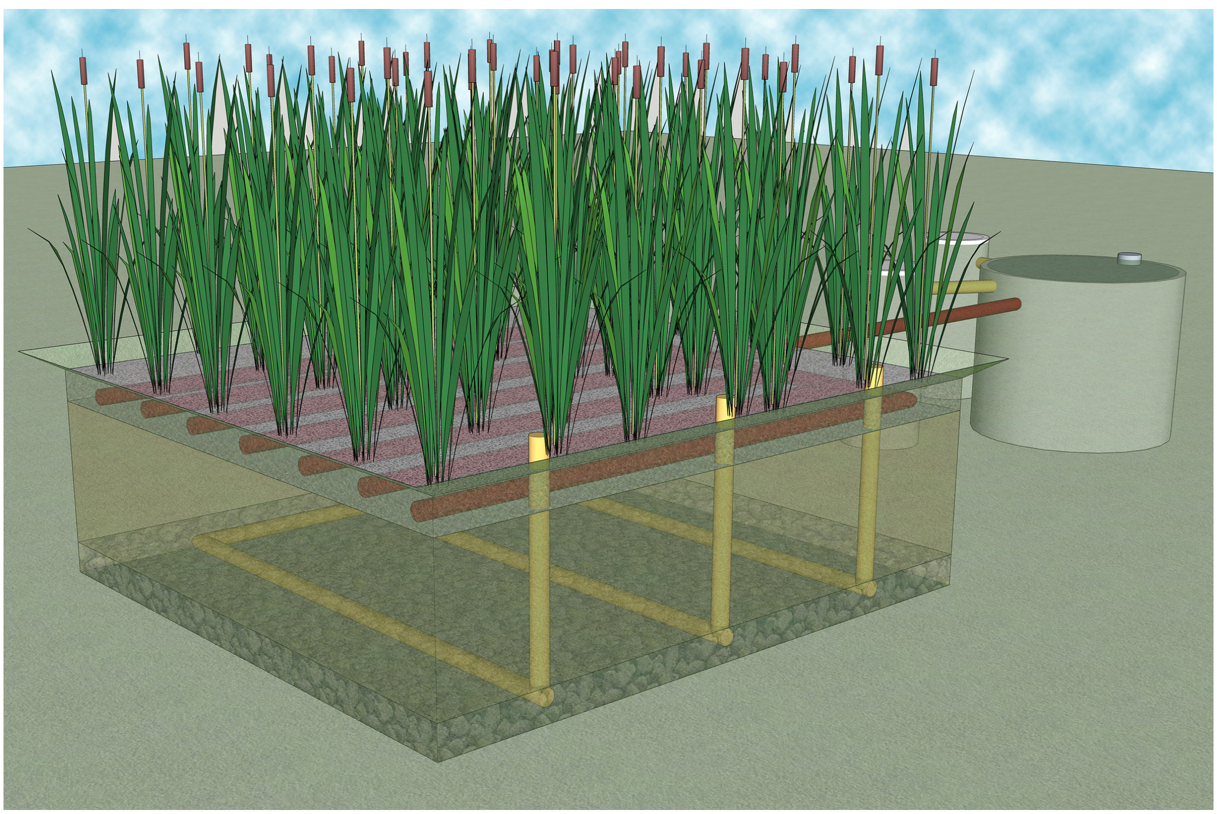

Figure 9. Vertical subsurface flow wetland (G. Austin and Yu 2016).

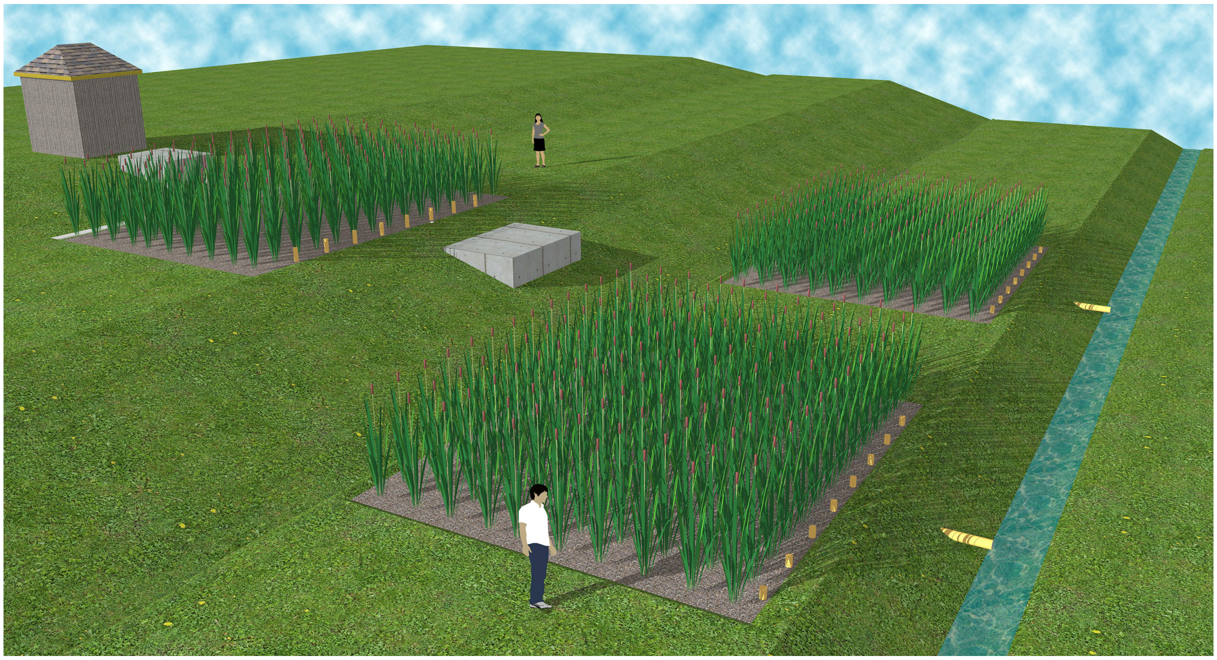

Figure 10. Vertical subsurface flow French reed bed (G. Austin and Yu 2016).

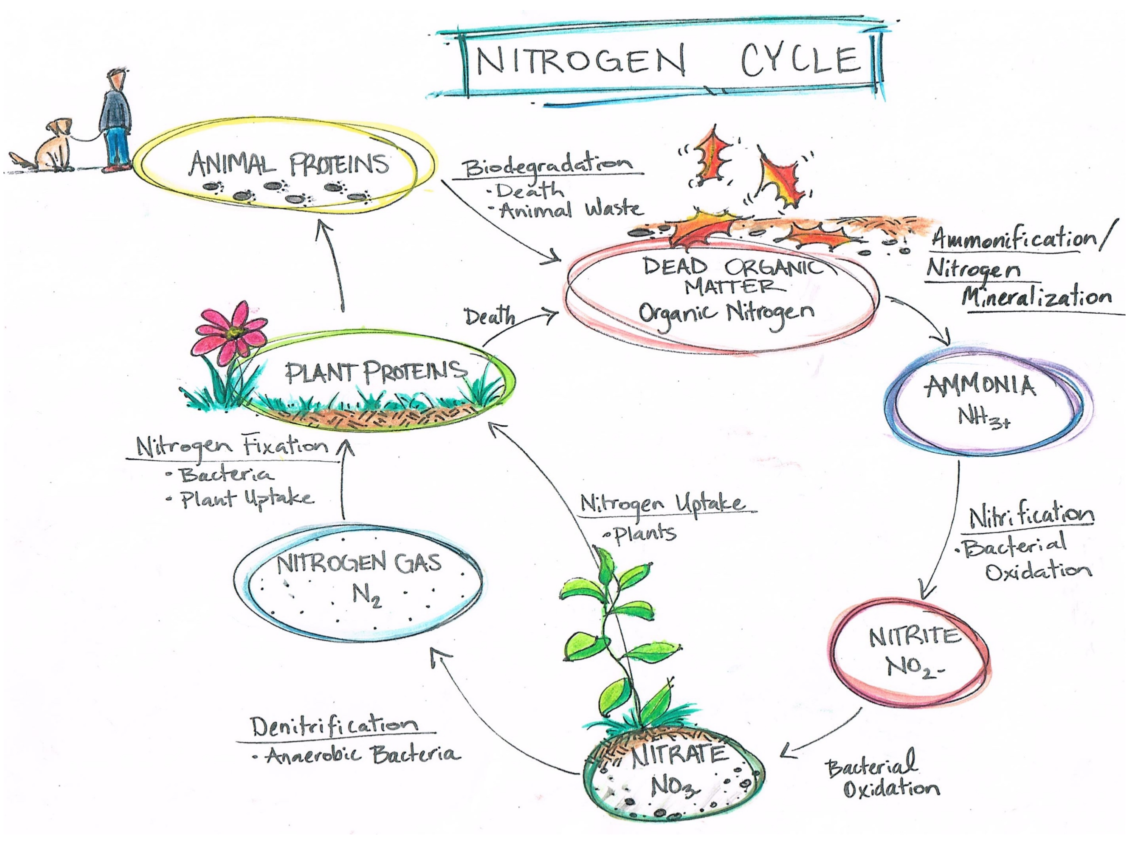

Figure 11. Aerobic and anaerobic processes facilitate nitrification and denitrification.

Figure 12. Typhus species. Open source images, 2019.

Figure 13. Phragmites australis. Open source images, 2019.

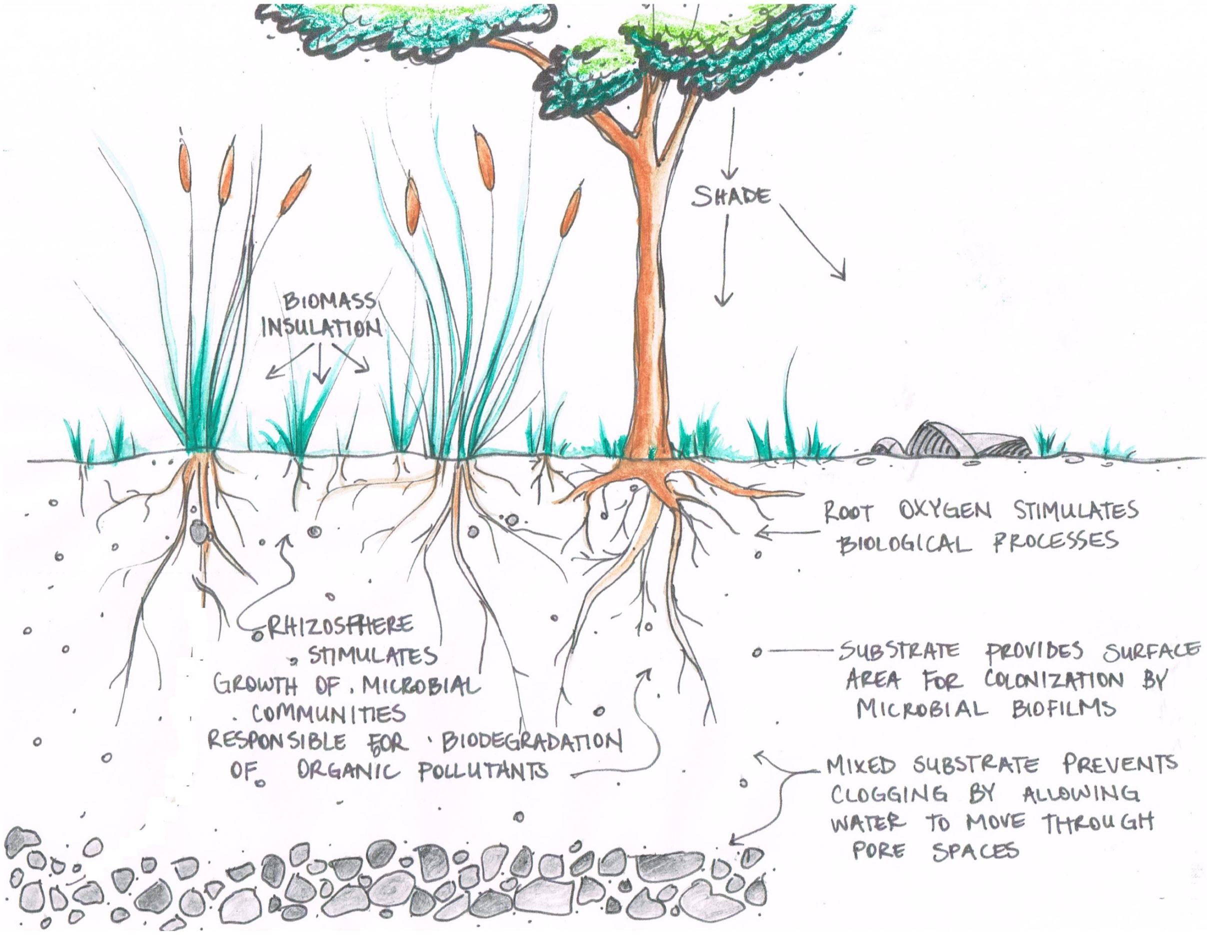

Figure 14. Plants play a critical role in the rhizosphere.

Figure 15. Aerial image of Prinsburg, Minnesota's wastewater treatment wetlands for a population of 497 (Google Earth, 2018).

Figure 16. View of a wetland treatment cell, Prinsburg, MN. City of Prinsburg, 2015.

Figure 17. Aerial map of Minot, North Dakota, wastewater treatment works. Google Earth, 2018.

Figure 18. Aerial image of Minot wetland cells. Google Earth, 2019.

Figure 19. Photo of Minot wetland cells, courtesy of North Dakota Department of Health.

Figure 20. Aerial image of Boston Mills wastewater treatment wetlands. Google Earth, 2018.

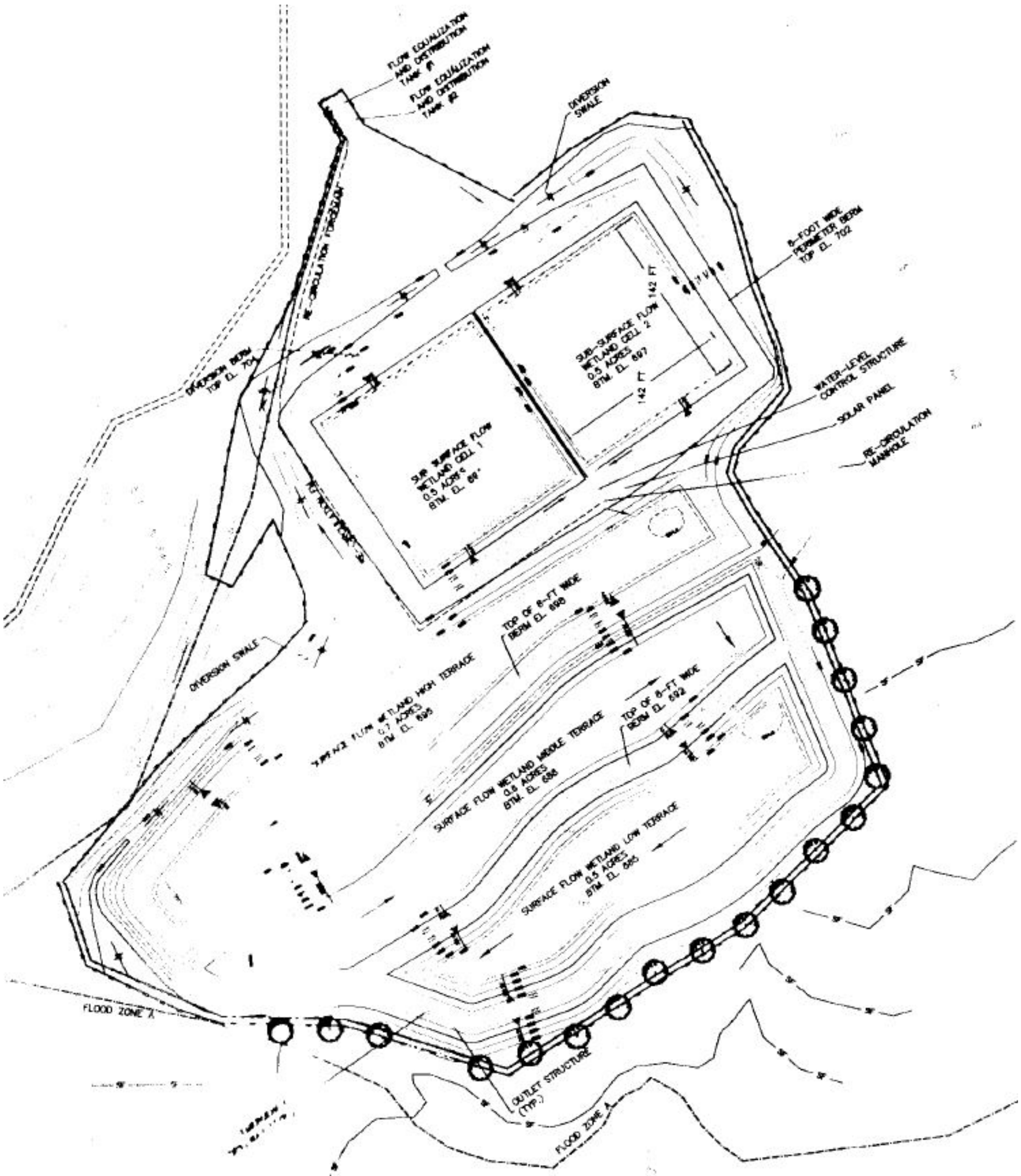

Figure 21. Construction drawing for Boston Mills wastewater treatment wetland (URS Group, 2010).

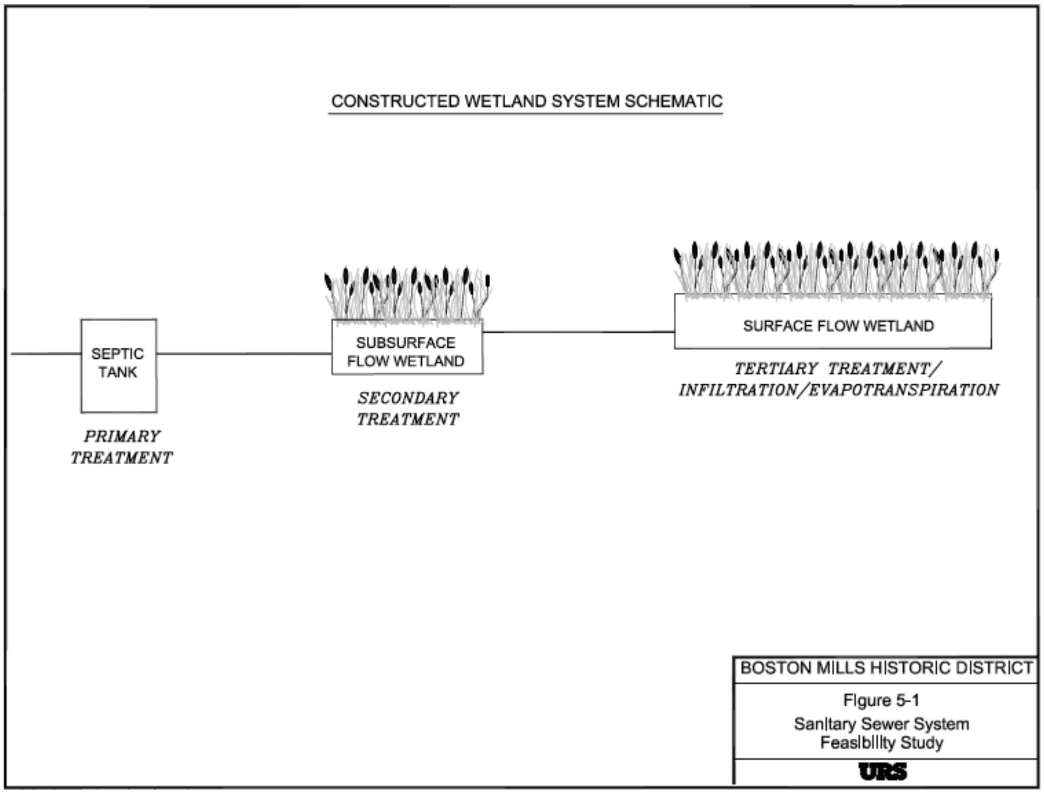

Figure 23. Schematic of the constructed wetland (URS Corporation, 2006).

Figure 22. City of Juliaetta centralized wastewater treatment plant, 2017.

Figure 24. Juliaetta's wastewater discharges to a wetland adjacent to the Potlatch River, 2017.

Figure 25. Aerial imagery of Juliaetta in the Potlatch River valley looking up river. Google Earth, 2018.

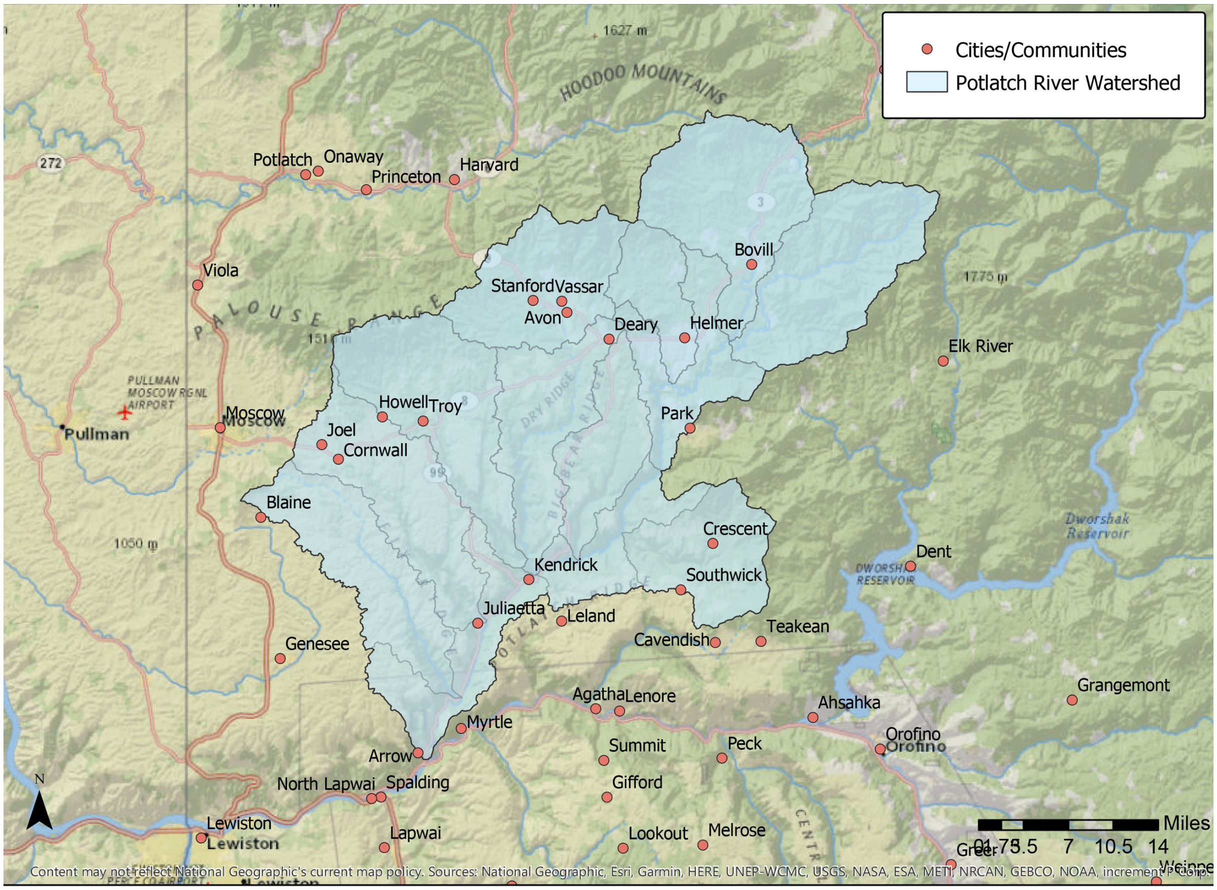

Figure 26. Potlatch River watershed in the Clearwater River basin, 2019.

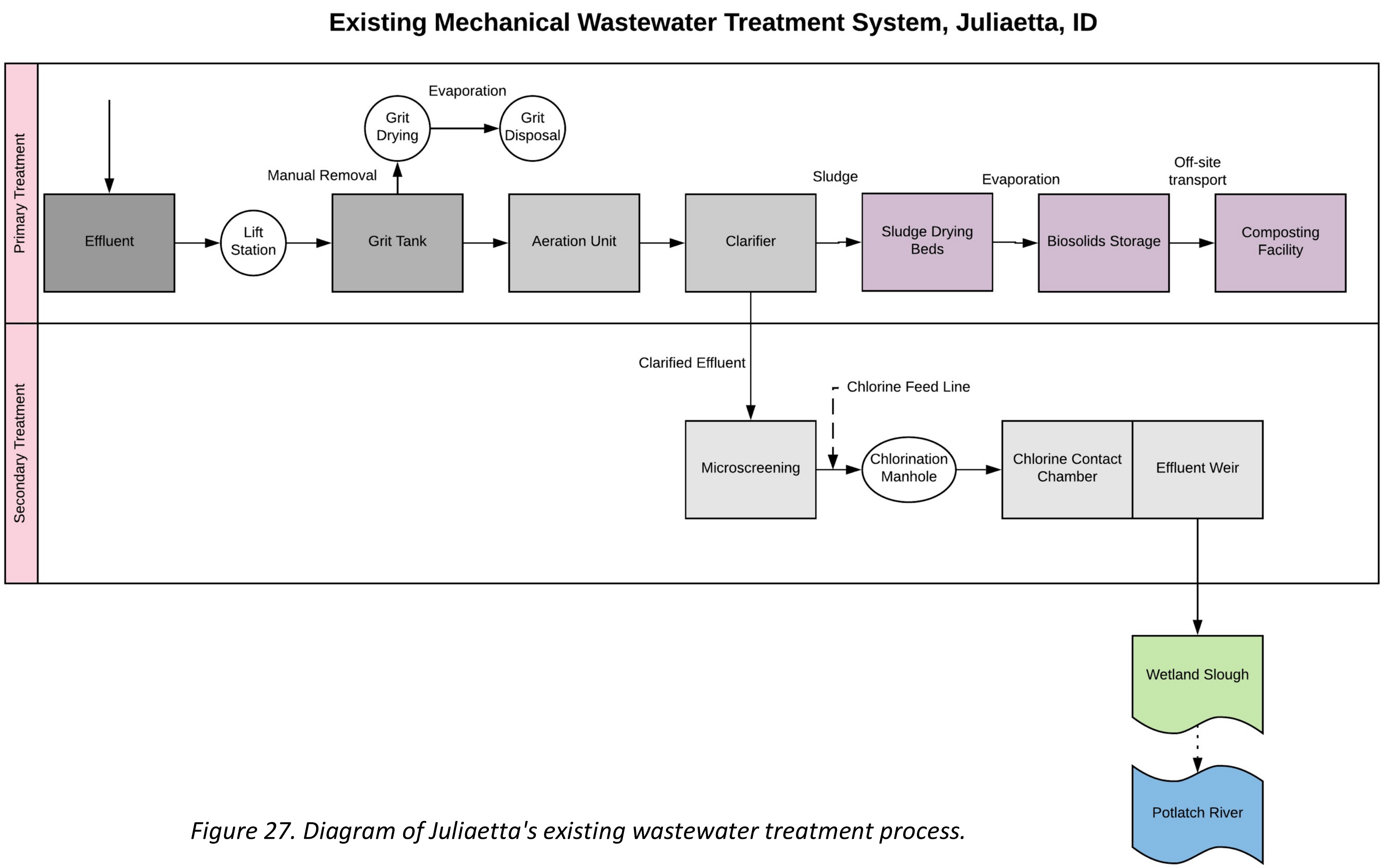

Figure 27. Diagram of Juliaetta's existing wastewater treatment process.

Figure 28. Digital overlay of 1983 Latah County and Nez Perce County FIRM maps with current aerial imagery demonstrate the high degree of inaccuracy of these 36 year-old flood maps.

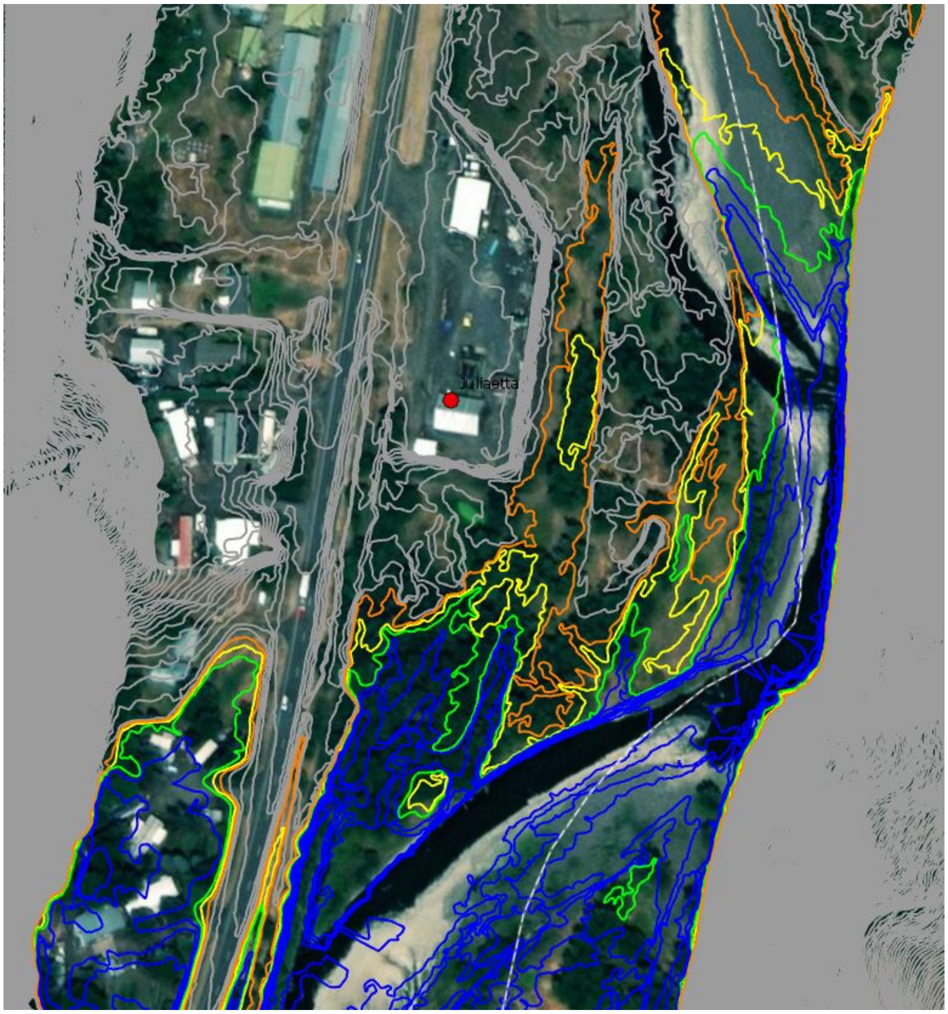

Figure 29. GIS can be used with current (2016) lidar elevation data and aerial imagery to accurately define the 100-year flood elevation.

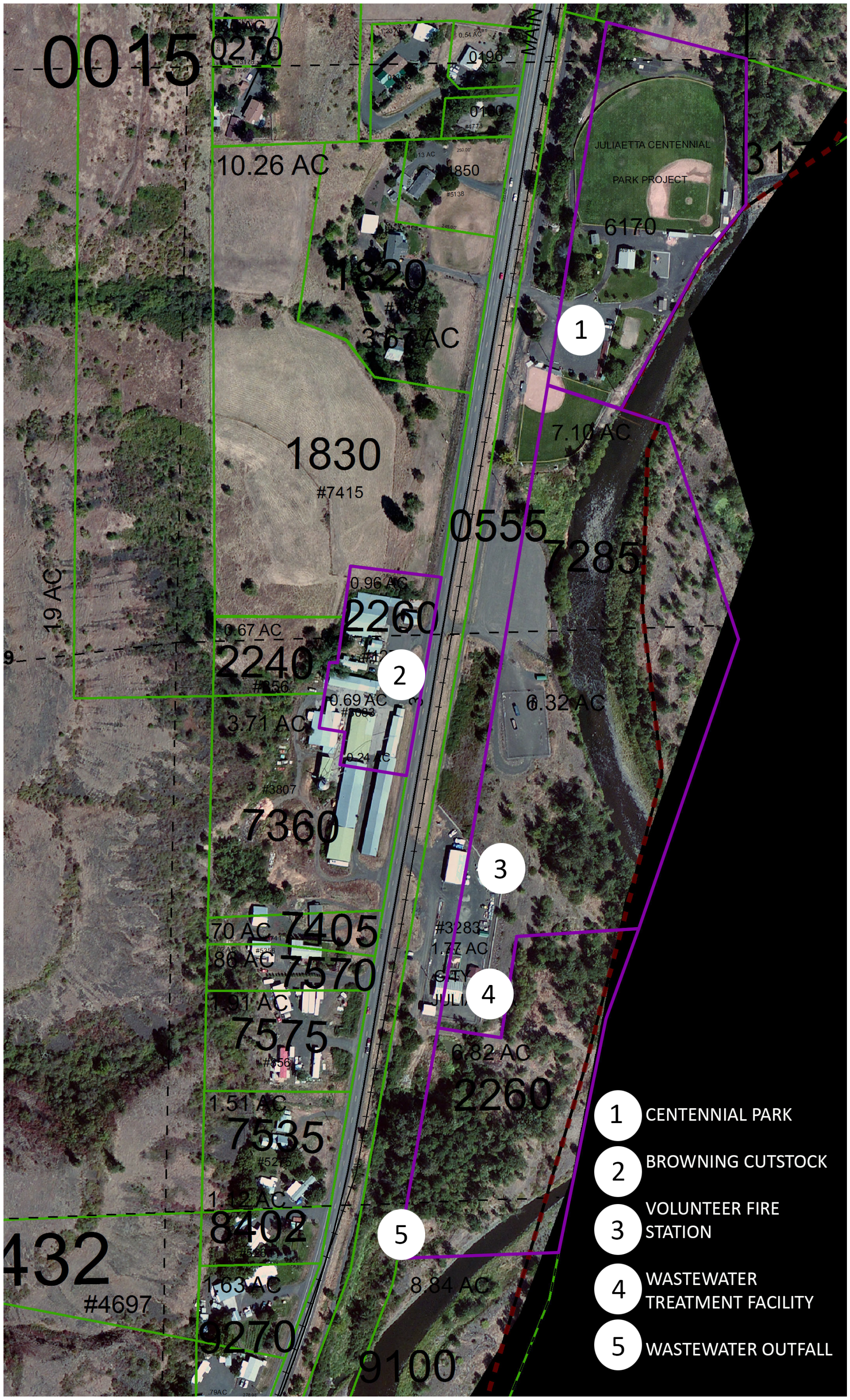

Figure 30. Map of Juliaetta wastewater treatment facility, volunteer fire station, and Centennial Park.

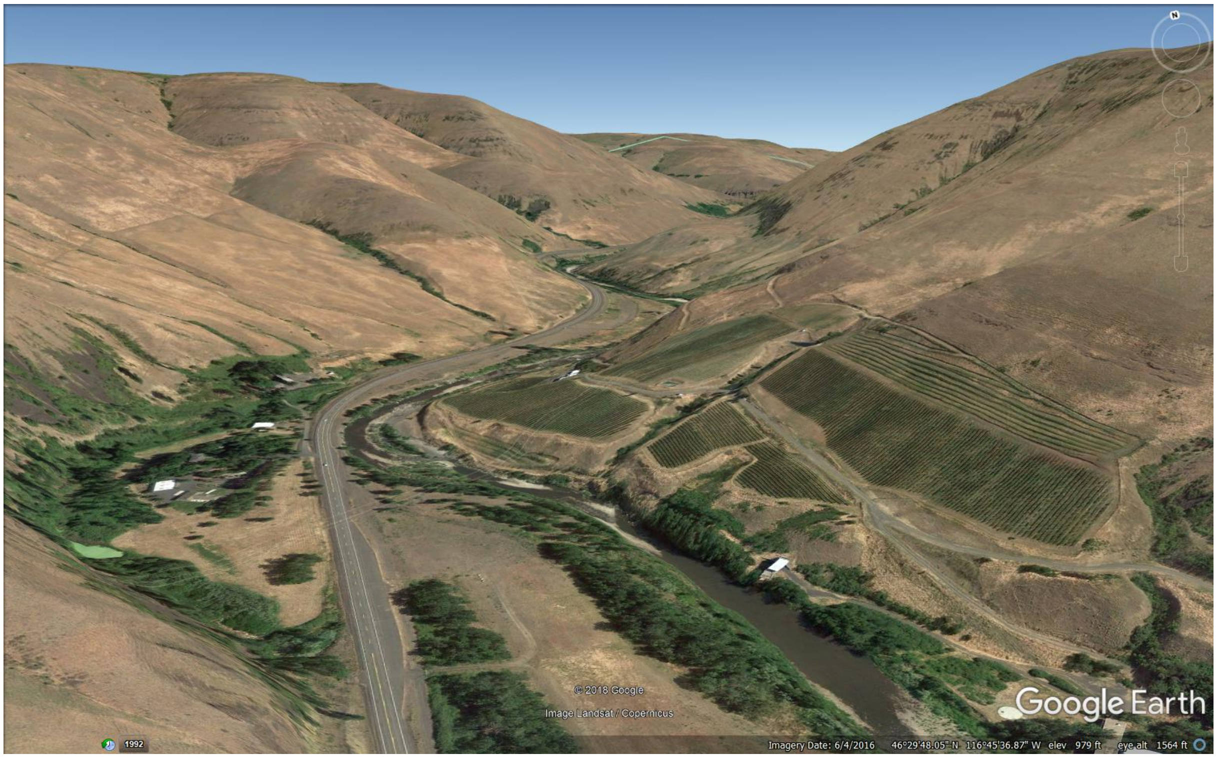

Figure 31. Aerial imagery of vineyards planted on western slopes of the Potlatch River valley in recent years. Google Earth, 2019.

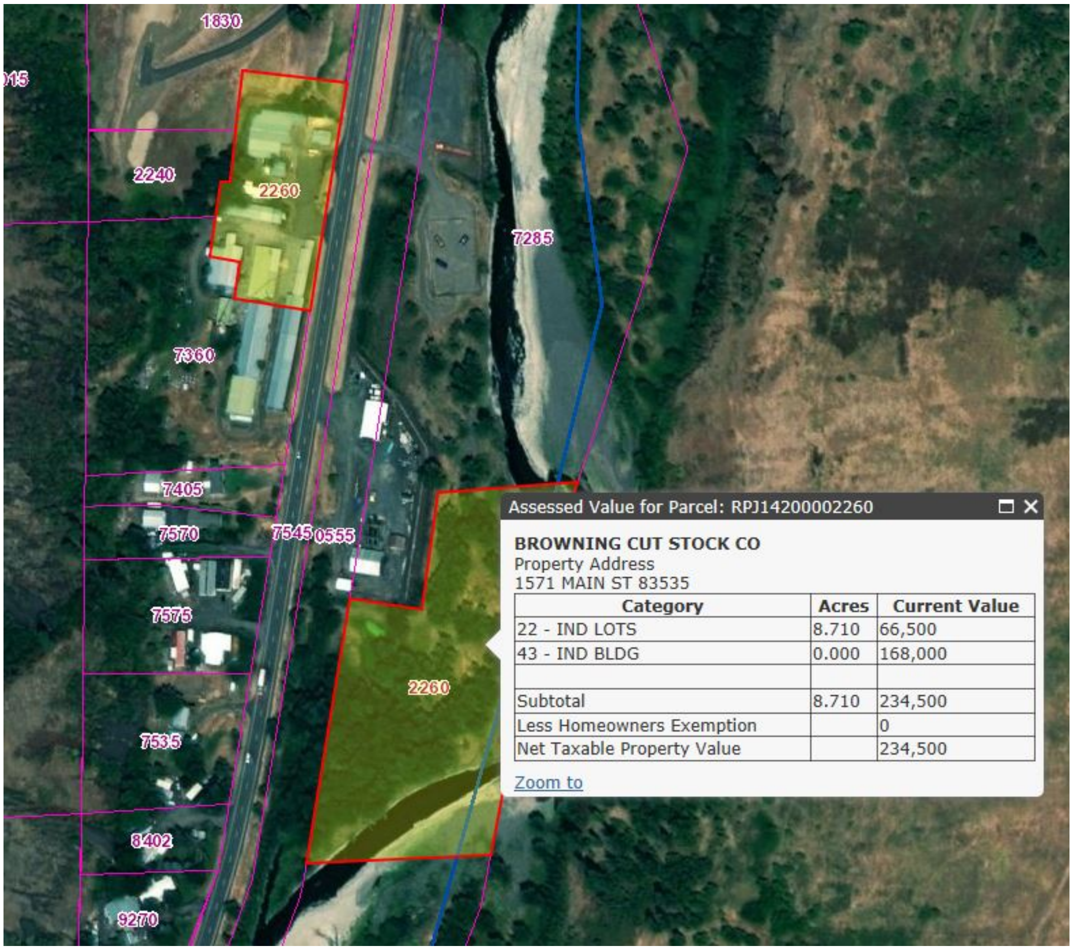

Figure 32. Latah County Assessor map and data for Browning Cutstock property located adjacent to the Juliaetta wastewater treatment plant.

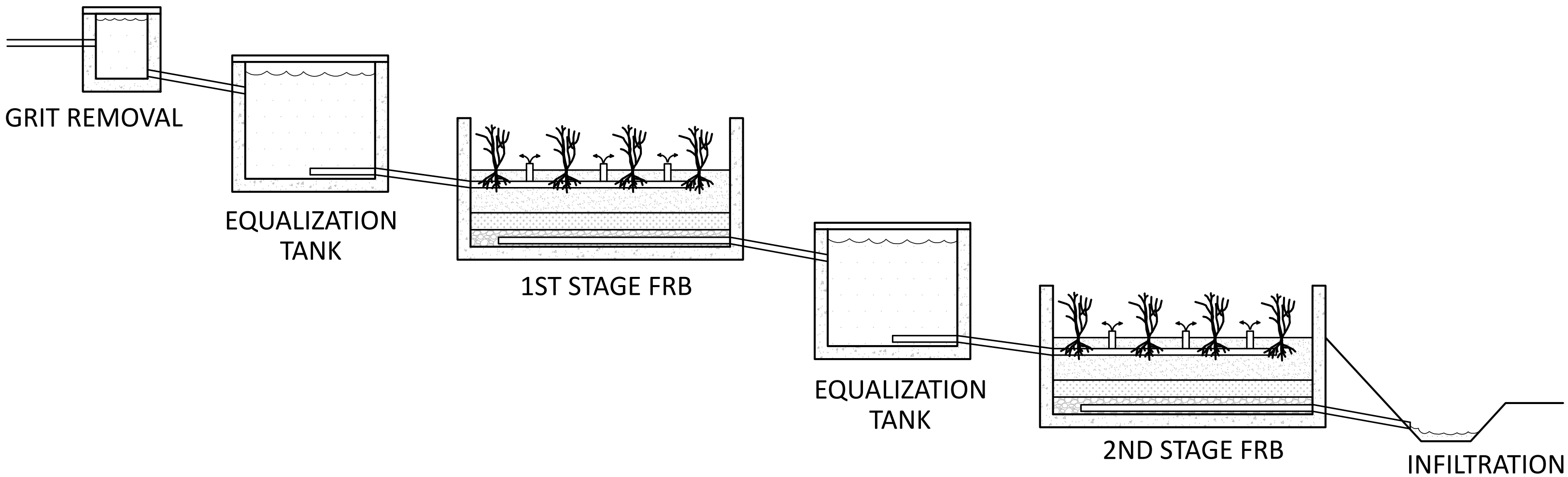

Figure 33. Schematic of a gravity flow French reed bed system.

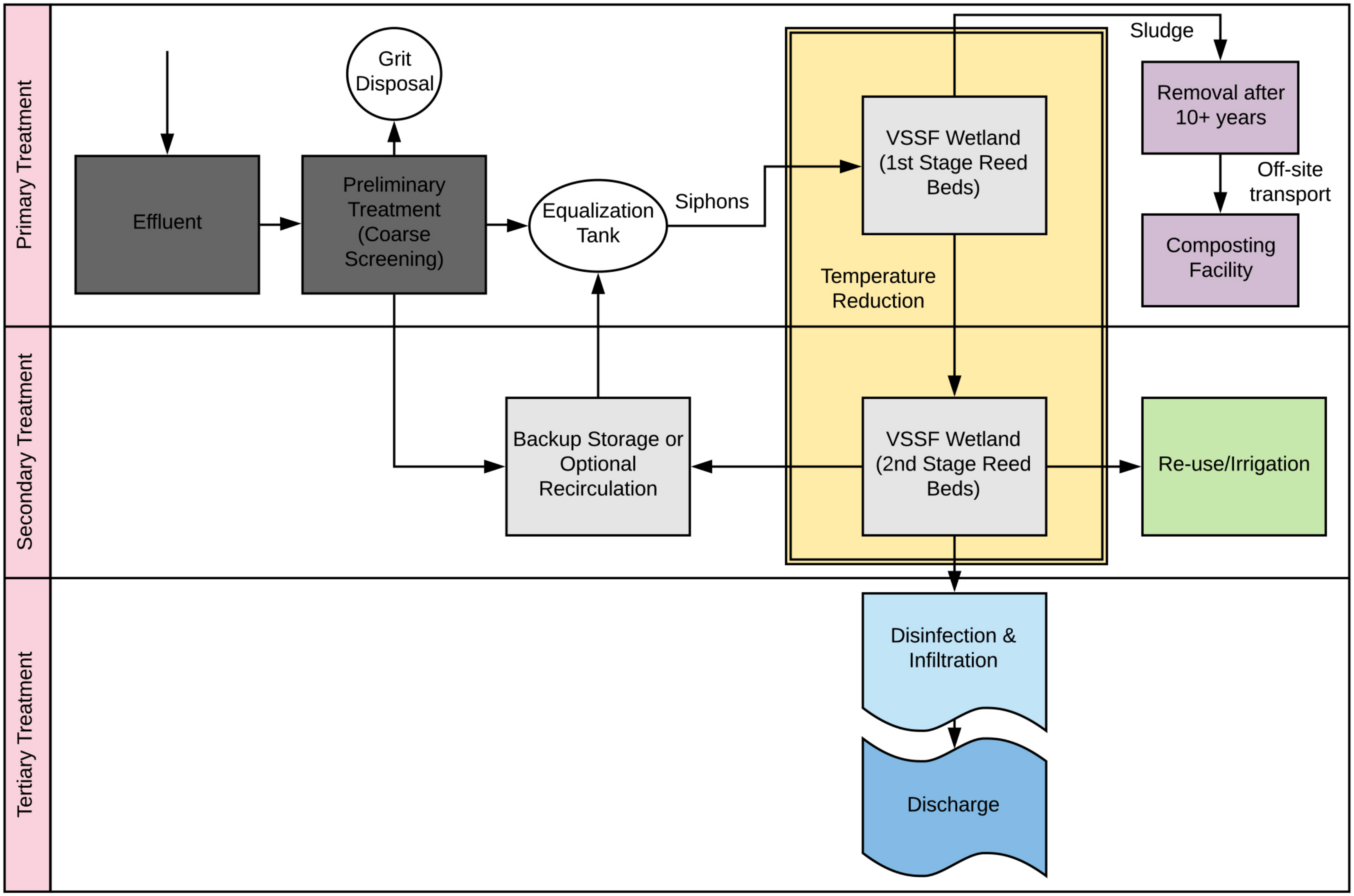

Figure 34. Diagram of a French reed bed system to treat Juliaetta's wastewater, 2018.

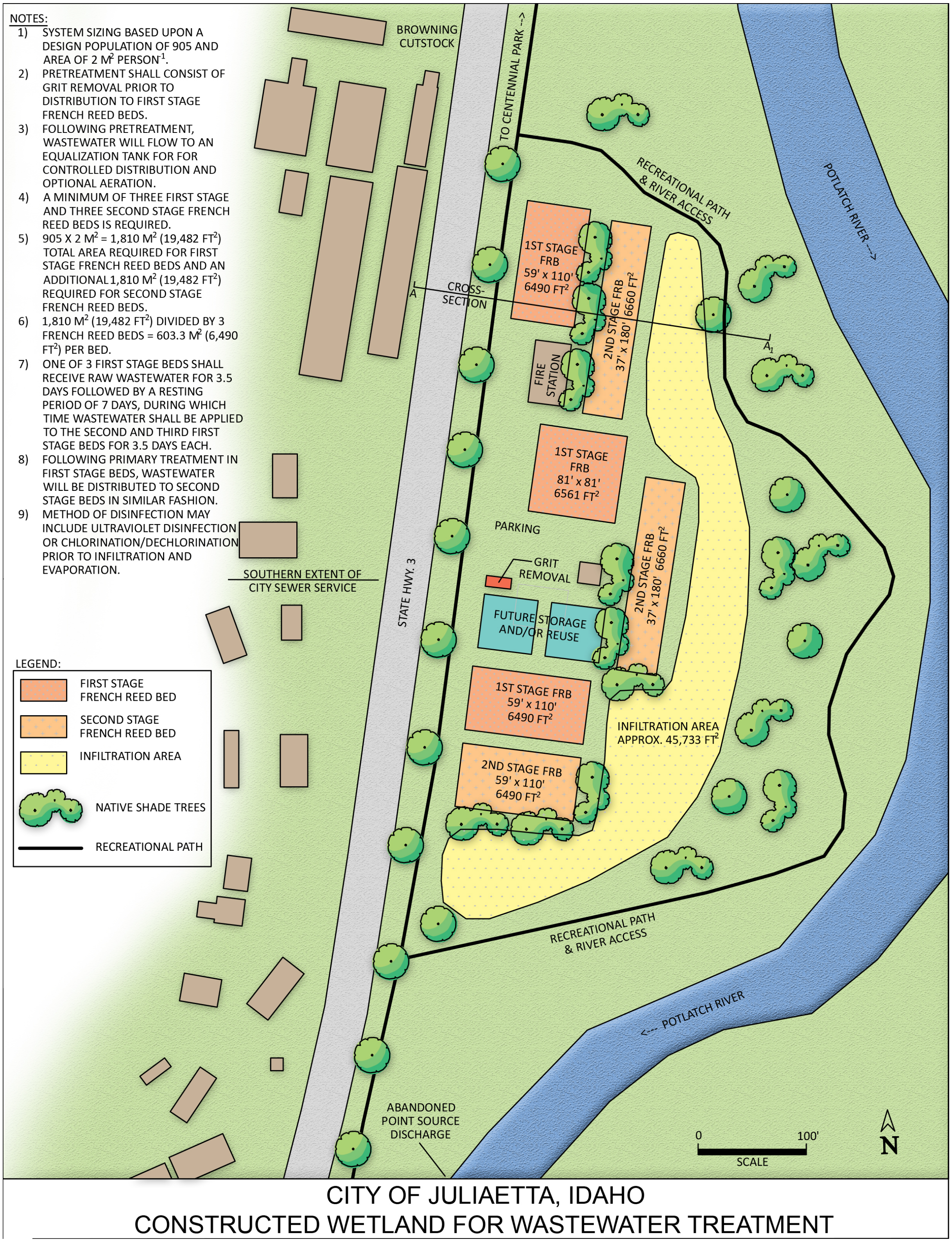

Figure 35. Conceptual landscape design incorporating recreational pathways, benches, river access, and wildlife viewing into the wastewater treatment site.

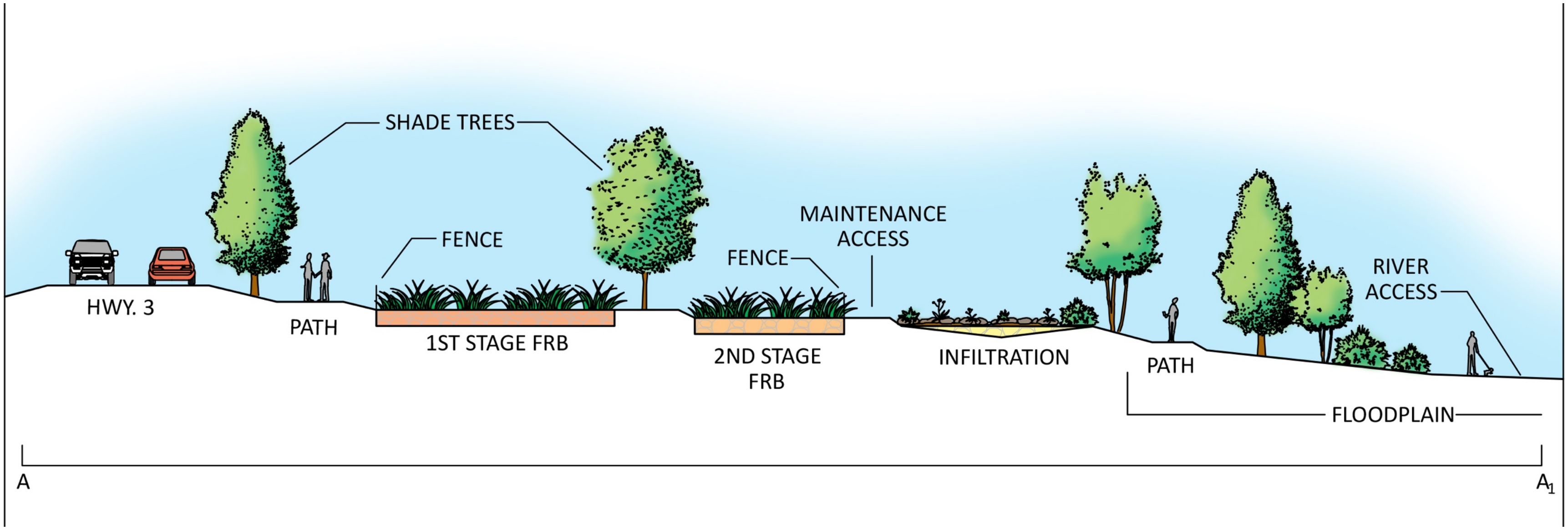

Figure 36. Section elevation illustrating integration of multiple uses above the base flood elevation.

TABLES

Table 1. Literature search results.

Literature Search and Assessment	**Results**	**Topics Revealed by Literature Assessment**	**Number of Articles**
Keyword search: constructed wetland + wastewater treatment + cold climate	349	Types & General Function	20
Eliminated results more than 10 years old	222	Aeration, Hydraulic Loading Rate, and Hydraulic Retention Time	9
Reviewed by title and eliminated items related to stormwater, agricultural or industrial use, pollution control, and warm climates	90	Plants	12
Reviewed abstracts and eliminated items not related to constructed wastewater treatment wetlands	70	Substrate	7
Discarded items concerned with specialized equipment or uncommon applications	55	Temperature	2

Table 2. Proposed effluent limits and monitoring requirements of the 2018 draft NPDES permit for Juliaetta, Idaho (US EPA, 2018a).

Parameter	**Units**	**Effluent Limitations**			**Monitoring Requirements**		
		Average Monthly	**Average Weekly**	**Maximum Daily**	**Sample Location**	**Sample Frequency**	**Sample Type**
Parameters with Effluent Limits							
BOD_5	mg L^{-1}	30	45	---	Influent and Effluent	1 $month^{-1}$	Grab
	lb d^{-1}	20	30	---			Calculation
BOD_5 % Removal	%	85 minimum	---	---	---	1 $month^{-1}$	Calculation
TSS	mg L^{-1}	30	45	---	Influent and Effluent	2 $month^{-1}$	Grab
	lb d^{-1}	18	30	---			Calculation
TSS % Removal	%	85 minimum	---	---	---	1 $month^{-1}$	Calculation
E. coli	cfu 100,000 mm^3	126	---	406 instant. maximum	Effluent	5 $month^{-1}$	Grab
	µg L^{-1}	12	---	21	Effluent	1 $month^{-1}$	Grab

Table 3. Federal secondary treatment standards (40 CFR 133.102) under the Clean Water Act (US EPA, 2018a).

Parameter	**30-Day Average**	**7-Day Average**
BOD_5	30 mg L^{-1}	45 mg L^{-1}
TSS	30 mg L^{-1}	45 mg L^{-1}
BOD_5 and TSS Removal	85% minimum	---
pH	Between 6.0 and 9.0 standard units	

Table 4.Funding programs for wastewater systems.

Agency	**Program**	**Purpose**	**Eligibility**	**Grantor/Community Match**
Idaho Department of Commerce	Community Development Block Grant	Public facilities construction and improvements – sewer, water, etc.	> or = 51% Low-moderate income communities	Minimum 50/50 to be competitive
Idaho Department of Environmental Quality	Wastewater Planning Grant; State Revolving Fund Low Interest Construction Loan	Wastewater facility planning and construction	Public entities and non-profits	50/50 planning; 100% construction
National Rural Water Association	Rural Water Loan Fund	Water/wastewater project pre-development and small capital projects	Public entities and non-profits, rural communities up to 10,000	Maximum $100,000 or 75% of total project cost
U.S. Army Corps of Engineers	Section 595 Program - Environmental Infrastructure	Rural water/wastewater improvements	Nevada, Montana, Idaho; <10,000 population preferred	75/25
U.S. Department of Agriculture – Rural Development	Technical Assistance & Training (TAT) - Water & Waste Direct Loans & Grants	Broad: construction, improvements, relocation, connections, land acquisition	Rural communities up to 10,000 population	Grant - none; Loan - 45/55

Table 5. Conclusions, design implications, and operational strategies for constructed wetlands in cold climates.

Wetland Types	Aeration, HLR, HRT	Plants	Substrate	Temperature
Surface Flow – best for secondary or tertiary treatment	Topography can be used to facilitate drop aeration	Polycultures provide higher treatment efficiencies than monocultures	Lightweight, mixed aggregates reduce clogging	Cold temperatures slow microbial processes
Horizontal Subsurface Flow – preferential for anaerobic conditions	Batch feeding can be used to control aeration and saturation	Polycultures provide better thermal insulation than monocultures	Mixed substrates provide surface area for microbial attachment	Cold temperatures can affect nitrogen removal at high HLR
Vertical Subsurface Flow – preferential for aerobic conditions	Low HLR increases treatment efficiency	Cold-tolerant plants support cold-tolerant bacteria and increase treatment efficiency	High adsorption substrates facilitate phosphorous removal	Prolonging HRT during cold temperatures increases treatment efficiencies
Vertical French Reed Bed – can be used for primary treatment	Low HRT increases aerobic conditions/nitrification	Roots and rhizomes stimulate growth and oxygenation of microbial communities essential to wastewater treatment	---	Sludge provides insulation and can prevent filter freezing, mulches can be problematic and should be used with caution
Hybrid System– eliminates limitations of a single system	High HRT increases anaerobic conditions/denitrification	Surface vegetation provides thermal insulation against ice formations	---	Site aspect, subsurface piping, and alternating filters can reduce temperature losses

Table 6. Wastewater flow projections for the Prinsburg wastewater treatment facility (Minnesota Pollution Control Agency 2003).

Prinsburg Wastewater Flow Projections	
Population Equivalent	545
Average Dry Weather Flow	155 m^3 d^{-1} (40,875 gallons per day)
Average Wet Weather Flow	206 m^3 d^{-1} (54,500 gallons per day)
Peak Hourly Flow	0.36 m^3 d^{-1} (95 gallons per day)

Table 7. Design loads for the Prinsburg wastewater treatment facility (Environmental Quality Board, 2003).

Design Loading			
Parameter	**Per Capita Factor kg (lb) per capita d^{-1}**	**Design Population**	**Total Mass Loading kg (lb) d^{-1}**
BOD_5	0.082 (0.180)	545	44.5 (98.0)
TSS	0.091 (0.200)	545	49.4 (109.0)
NH_3-N	0.003 (0.007)	545	1.7 (3.8)
TN	0.009 (0.020)	545	4.9 (10.9)
TP	0.004 (0.008)	545	2.0 (4.4)

Table 8. Minnesota Pollution Control Agency discharge standards (Environmental Quality Board, 2003).

Preliminary Discharge Standards to Chetomba Creek Issued by the MPCA		
Substance	**Continuous Discharge Limiting Concentration**	**Controlled Discharge Limiting Concentration**
$CBOD_5$	15 mg L^{-1}	25 mg L^{-1}
TSS	30 mg L^{-1}	45 mg L^{-1}
Fecal Coliform	200 organisms per 100 ml	200 organisms per 100 ml
pH Range	6.0 - 9.0	6.0 - 9.0
TP	Monitoring	Monitoring

Table 9. Boston Mills total calculated water usage (URS Corporation 2006).

Boston Mills Design Flow and Septic Tank Sizing		
Source Structure(s)	**Estimated Winter Water Use, $m^3\ d^{-1}$ (gallons per day)**	**Estimated Summer Water Use, $m^3\ d^{-1}$ (gallons per day)**
Main house, conference center, tenant house	0.59 (155)	0.88 (233)
Residence 1 – 3 bedroom, 2 bath	1.51 (400)	1.51 (400)
Residence 2 – 3 bedroom, 2 bath	1.51 (400)	1.51 (400)
Residence 3 – 3 bedroom, 2 bath	1.51 (400)	1.51 (400)
Visitor center, public restroom, offices	0.76 (200)	1.14 (300)
Residence 4 – 3 bedroom, 2 bath	1.51 (400)	1.51 (400)
Three additional residences – 3 bedroom, 2 bath	4.54 (1200)	4.54 (1200)
Total Water Usage =	**11.94 (3155)**	**12.62 (3333)**
50% excess capacity =	**17.91 (4733)**	**18.92 (4999)**
Maximum design flow =		18.92 (4999)
Minimum detention time =		24 hours
Safety factor =		1.5
Total capacity required =		28.38 (7498)

Table 10. Preliminary cost analysis (URS Corporation, 2006).

Description *(ea = each, hr = hour, ls = lump sum)*	**Unit**	**Estimated Quantity**	**Unit Cost ($USD)**	**2006 Total ($USD)**
Subsurface Flow Wetland				
Mobilization/Demobilization	ls	1	5,343	5,343
Surveying	hr	8	160	1,282
Clearing & Grubbing	ha (ac)	0.2 (0.5)	2,244	1,122
Septic Tanks	ea	2	3,206	6,412
Flow splitter	ea	1	3,206	3,206
Grading	m^3 (y^3)	765 (1,000)	4.81	4,809
Geomembrane	m^2 (f^2)	557 (6,000)	0.57	3,398
Geotextile	m^2 (f^2)	557 (6,000)	0.32	1,923
ODOT No. 57	m^3 (y^3)	344 (450)	23.14	10,411
Mulch	m^3 (y^3)	57 (75)	6	481
Water Level Control Box	ls	1	3,206	3,206
Inlet/Outlet Structures	ls	1	5,343	5,343
Plants (stock root)	ea	5,378	4.11	22,126
			Subtotal =	**69,061**
Surface Flow Wetland				
Clearing & Grubbing	ha (ac)	0.8 (2)	2,244	4,488
Grading	m^3 (y^3)	2,447 (3,200)	4.81	15,388
Emergency Spillway	ls	1	3,740	3,740
Riprap Erosion Protection	m^3 (y^3)	7.6 (10)	160	1,603
Seed	ha (ac)	0.8 (2)	5,343	10,686
			Subtotal =	**35,905**
			Wetland System Construction Total =	**$104,970**
Construction Cost Estimate				104,970
Construction Oversight				13,646
Permit to Install				5,343
System Start-up				8,548
			Total	**$132,507**

Table 11. Upland tree species native to Idaho (Idaho Native Plant Society 2019).

Upland Trees	
Botanical Name	**Common Name**
Acer glabrum	Rocky Mountain Maple
Alnus incana tenuifolia	Thinleaf Alder
Alnus rhombifolia	White Alder
Alnus rubra	Red Alder
Alnus sinuata	Sitka Alder
Betula occidentalis	River Birch
Betula papyrifera	Paper Birch
Populus tremuloides	Quaking Aspen
Populus trichocarpa	Black Cottonwood
Rhamnus purshiana	Cascara or Buckthorn

Table 12. Upland shrub species native to Idaho (Idaho Native Plant Society 2019).

Upland Shrubs	
Botanical Name	**Common Name**
Acer glabrum var. douglasii	Rocky Mountain Maple
Alnus sinuate	Sitka Alder
Amelanchier alnifolia	Serviceberry
Berberis aquifolium	Tall Oregon Grape
Cercocarpus ledifolius	Curlleaf Mountain Mahogany
Cornus sericea	Redosier Dogwood
Crataegus Columbiana	Red Hawthorn
Crataegus douglasii var. douglasii	Black Hawthorn
Holodiscus discolor	Oceanspray
Juniperus scopulorum	Rocky Mountain Juniper
Philadelphus lewisii	Syringa (Mock orange)
Physocarpus capitatus	Pacific Ninebark
Physocarpus malvaceus	Ninebark
Prunus emarginata	Bittercherry
Prunus virginiana	Chockcherry
Rhamnus purshiana	Cascara or Buckthorn
Rhus glabra	Smooth Sumac
Ribe aureum	Golden Current
Ribes niveum	Snow Currant
Ribes sanguineum	Red Flowering Currant
Rosa gymnocarpa	Baldhip Rose
Rosa nutkana	Nootka Rose
Rosa woodsii	Wood’s Rose
Salix scouleriana	Scouler’s Willow
Sambucus cerulean	Blue Elderberry
Sambucus racemose var. melanocarpa	Blackbead Elderberry
Sorbus scopulina	Rocky Mountain Ash
Symphoricarpos albus	Common snowberry
Taxus brevifolia	Pacific Yew

Table 13. Native riparian shrubs and trees (Franklin H. Pitkin Forest Nursery 2019).

Riparian Woody Vegetation	
Botanical Name	**Common Name**
Acer glabrum var. douglasii	Rocky Mountain Maple
Alnus incana var. tenuifolia	Thinleaf Alder
Betula occidentalis	Water Birch
Cornus sericea	Redosier Dogwood
Crataegus douglasii var. douglasii	Black Hawthorn
Philadelphus lewisii	Syringa (Mock orange)
Populus spp.	Poplar and Aspen
Populus trichocarpa	Black Cottonwood
Salix drummondiana	Drummond Willow
Salix exigua	Coyote Willow
Salix Prolixa	Mackenzie Willow
Sorbus scopulina	Mountain Ash

Table 14. Wetland grass, reed, and sedge species native to Idaho (Plants of the Wild 2019).

Perennial Wetland Grasses, Reeds, and Sedges	
Botanical Name	**Common Name**
Carex amplifolia	Bigleaf Sedge
Carex aquitilis	Water Sedge
Carex lanuginosa	Wooly Sedge
Carex lenticularis	Lens Sedge
Carex microptera	Small-winged Sedge
Carex nebrascensis	Nebraska Sedge
Carex obnupta	Slough Sedge
Carex simulata	Shortbeaked Sedge
Carex utriculata	Beaked Sedge
Carex vesicaria	Inflated Sedge
Eleocharis palustris	Creeping Spikerush
Juncus articulatus	Jointed Rush
Juncus balticus	Baltic Rush
Juncus effuses	Common Rush
Juncus ensifolius	Dagger-leaf Rush
Juncus tenuis	Slender Rush
Scirpus acutus	Hardstem Bulrush
Scirpus cyperinus	Woolgrass
Scirpus microcarpus	Small Fruited Bulrush
Scirpus pungens	Three-square Bulrush
Scirpus validus	Softstem Bulrush
Typha latifolia	Common Cattail