INDUSTRIAL WASTEWATER LANDSCAPES: ECOLOGICAL DESIGN AT THE CRAFT BREWERY

by

NATHAN R. METZGER

(Under the Direction of Douglas Pardue)

ABSTRACT

Traditional wastewater infrastructures fail to reclaim value from disparate urban waste streams and respond to local and regional contexts. Industry, as a source of point-source pollution, can benefit from localized wastewater treatment and reclamation. At craft breweries, on-site wastewater pretreatment is becoming a common practice. This thesis proposes a landscape-based approach to the treatment and reclamation of brewery effluent and examines the potential of treatment methods to address economic, ecological, and social systems. Projective design at a medium-sized craft brewery in Athens, Georgia is used to demonstrate how wetland technologies may be incorporated into site planning and design of decentralized wastewater infrastructures.

INDEX WORDS: landscape architecture, ecological design, craft brewery, brewery effluent, wastewater infrastructure, water reuse, decentralization, constructed wetlands, wetland technologies

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NATHAN R. METZGER

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by

NATHAN R. METZGER

Major Professor:	Douglas Pardue
Committee:	Alfie Vick
	Seth Wenger
	Brian Hollinger

Electronic Version Approved:

Julie Coffield
Interim Dean of the Graduate School
The University of Georgia
May 2015

DEDICATION

I dedicate this thesis to my parents, without whose love and support this would not have been possible.

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS v

LIST OF TABLES viii

LIST OF EQUATIONS viii

LIST OF FIGURES ix

CHAPTER

1 INTRODUCTION 1

Problematic 1

Research Purpose 1

Research Opportunity 3

Research Methods 3

Limitations and Delimitations 7

Thesis Structure 7

2 TRADITIONAL INFRASTRUCTURES AND NEW DIRECTIONS 9

Traditional Wastewater Infrastructure 9

Waste as Resource: Decentralization and Industrial Ecology 13

A Landscape Infrastructural Approach to Waste Management 15

3 THE BREWING INDUSTRY 18

The Rise of The Craft Brewery 18

The Brewing Process and Solid Waste Management 21

The Brewing Process and Water Use..23
Wastewater Management Issues 26
Wastewater Opportunities..28
Conclusion 30
4 ON-SITE WASTEWATER RECLAMATION STRATEGIES 31
Stage 1: Wastewater Pretreatment 33
Stage 2: Wastewater Polishing...46
Stage 3: Wastewater Reclamation 60
Conclusion 65
5 PROJECTIVE DESIGN AT TERRAPIN BEER COMPANY 69
Brewery Profile and Wastewater Issues 69
Current Best Practice: New Belgium Brewery 75
Feasibility of Stage 1 Treatment Systems...77
Wastewater Treatment Typologies 81
Site Considerations 86
Projective Design..93
6 CONCLUSION: EXPANDING THE SCOPE OF BREWERY WASTEWATER TREATEMENT 104
Redefining Wastewater Infrastructure 104
Moving Forward 104
The Role of the Designer 106
REFERENCES 108

LIST OF TABLES

Page

Table 1: Basic Comparison of Aerobic, Anaerobic, and MFC Systems 34

Table 2: Capital, Operational, and Maintenance Costs of Stage 1 and 2 Treatments 60

Table 3: Average Wastewater Quality at Terrapin Beer Co. for Nine Sampling Days Between 7/25/2014 and 9/30/2014 74

Table 4: Total Water and Wastewater Fees at Terrapin Beer Co. for July, August, and September 2014 75

Table 5: Sizing and Land Requirements of Stage 1 Treatment Methods at Terrapin Beer Company..79

Table 6: Stage 1 Treatment Methods Inform Wetland Function......................................81

LIST OF EQUATIONS

Page

Equation 1 Sizing Aerobic and Anaerobic Treatment Systems...80

Equation 2: Sizing Constructed Wetlands 94

LIST OF FIGURES

Page

Figure 1: Radar Diagram Evaluation Criteria 5

Figure 2: A Conceptual Framework for Evaluating the Provision of Ecosystem Services by Different Land Uses 6

Figure 3: Locations of Microbreweries, Brewpubs, and Regional Breweries, 2011 19

Figure 4: The Brewing Process and Main Waste Streams 21

Figure 5: The Brewery System: Water Use and Waste Production 24

Figure 6: Water Use During the Brewing Process 25

Figure 7: The Brewery System: Standard Pretreatment and Polishing 29

Figure 8: The Brewery System: Proposed Three-Stage Wastewater System 32

Figure 9: Evaluation Criteria 32

Figure 10: Pretreatment Phase 1 33

Figure 11: Aerobic Treatment Process 35

Figure 12: Aerobic Lagoon 36

Figure 13: Activated Sludge Reactor 37

Figure 14: Fixed and Moving Bed Reactor 38

Figure 15: Aerobic Airlift Reactor 39

Figure 16: Anaerobic Treatment Process 40

Figure 17: Anaerobic CSTR 41

Figure 18: Anaerobic Upflow Filter Bed 42

Figure 19: Anaerobic UASB....43

Figure 20: Anaerobic Fluidized Bed....44

Figure 21: The EcoVolt System....45

Figure 22: Microbial Fuel Cell – EcoVolt....46

Figure 23: Classification of Constructed Wetlands for Wastewater Treatment....48

Figure 24: Free Water Surface Constructed Wetland....49

Figure 25: Constructed Wetland Treatment of Brewery Effluent at SAB Brewery in Port Elizabeth, South Africa....51

Figure 26: Horizontal Flow Subsurface Wetland....52

Figure 27: Sidwell and Friends School Wastewater and Stormwater Systems....53

Figure 28: Constructed Wetland and Stormwater Pond....54

Figure 29: Eco-Machine....55

Figure 30: Sonoma Mountain Brewery Eco-Machine System....56

Figure 31: Eco-Machine Planted Tanks....57

Figure 32: Tidal Flow Wetland....58

Figure 33: Tidal Wetland Cells as Site Feature....59

Figure 34: Landscape Application....61

Figure 35: Release to Surface Water....62

Figure 36: Water Reuse....64

Figure 37: Reuse in Landscape....65

Figure 38: Evaluation Criteria....66

Figure 39: Treatment Stage Comparison....66

Figure 40: Terrapin Beer Company - Athens, GA....70

Figure 41: Wastewater Discharge at Terrapin 71

Figure 42: North Oconee Watershed and Sewer System....72

Figure 43: Monthly Water Use at Terrapin Beer Co. from December 2013 through September 2014 73

Figure 44: Daily Water Use at Terrapin Beer Co. from September 23, 2014 through October 13, 2014....73

Figure 45: Standard Best Practice for Wastewater Pretreatment....76

Figure 46: New Belgium Brewery Site Plan....77

Figure 47: Current Site and Potential Land Acquisitions 78

Figure 48: Economy Typology 83

Figure 49: Ecology Typology 83

Figure 50: Society Typology 84

Figure 51: Comparison of Wastewater Treatment Typologies....86

Figure 52: Spent Grain Reuse 88

Figure 53: Local Economic Connections....88

Figure 54: Ecological Opportunities....89

Figure 55: Site Photos 2/23/2015 - Ecological Opportunities 90

Figure 56: Social Opportunities....91

Figure 57: Site Photos 2/23/2015 - Social Opportunities 93

Figure 58: Proposed Site Plan for Wastewater Treatment at Terrapin Beer Company....95

Figure 59: Recommended Land Acquisition 96

Figure 60: Stage 1: Wastewater Pretreatment....97

Figure 61: Stage 2: South Side Wastewater Polishing....99

Figure 62: Stage 2: North Side Wastewater Polishing..100

Figure 63: Wastewater Flow and Stage 3 Treatment Options..100

Figure 64: Proposed Typology for Terrapin Beer Company..102

CHAPTER 1

INTRODUCTION

Problematic

Traditional wastewater infrastructures efficiently collect and transport disparate urban waste streams to centralized facilities for treatment and disposal. An extensive network of sewer pipes and pumping equipment, wastewater infrastructures have had significant impacts on urban planning (Elmer and Leigland 2013). Mono-functional and homogenous by design, wastewater, like infrastructural systems often fails to respond to local and regional contexts (Bélanger 2009). Requiring significant investments for upgrades and repair, U.S. wastewater infrastructures generate negative social and ecological impacts when they fail (ASCE 2013, Hung 2013).

Largely consisting of water, nutrients, and carbon, wastewater is a potentially valuable resource (Elmer and Leigland 2013). However, due to the magnitude and complexity of combined urban waste streams, centralized wastewater management practices often fail to reclaim value from distinct waste-generating activities (Tjandraatmadja et al. 2005). Decentralized waste management creates the potential for upstream waste reclamation and repurposing (Bélanger 2007). Industrial practices, generating large quantities of waste that often differ greatly from domestic sources, represent a prime opportunity for localized waste management and reclamation strategies that respond to economic, ecological, and social contexts (Lister 2006).

Research purpose

The craft brewery is an expanding industry in the United States that exists in communities both large and small (McLaughlin, Reid, and Moore 2014). While they stimulate local economies and engage local communities, craft breweries also increase demand on local resources and infrastructures. Requiring large inputs of clean water and discharging large volumes of wastewater, craft breweries have a growing need for stable water supplies and on-site wastewater management (Gribbins 2013, Simate et al. 2011). On-site wastewater management practices are common in the brewing industry, but are largely implemented out of necessity and are often pursued for purely economic incentives (Simate et al. 2011).

Often hosting public events and social functions, craft breweries feature a unique combination of industrial production and social interaction. Because they exist in varying urban and ecological contexts, craft breweries offer a fertile testing ground for localized wastewater management and reclamation. Seeking an integrated, holistic approach to wastewater treatment and reclamation at the craft brewery, this thesis asks the following question: *How can a landscape-based approach to design expand to scope of brewery wastewater treatment to include economic, ecological, and social functions?* In order to answer this question, a series of sub questions is presented and includes:

- What is the current state of wastewater infrastructure in the U.S. and what are future challenges?
- How well do current decentralized wastewater treatment and reclamation strategies address systems of economy, ecology, and society?
- What are the current approaches to on-site treatment of brewery wastewater and how can they incorporate a landscape-based approach to design?

Research Opportunity

Because a decentralized, landscape-based approach to wastewater treatment is dependent on site-specific conditions and local contexts, this thesis uses an existing craft brewery for investigation and projective design. Terrapin Beer Company, located in Athens, Georgia is a well-established and growing craft brewery that has an increasing need for on-site wastewater management. Reflective of a projected expansion of the brewing industry throughout the Southeast, Athens is home to four breweries and brew pubs, two of which have been established in the past two years (McLaughlin, Reid, and Moore 2014).

Research Methods

Classification and projective design, as defined by Deming and Swaffield (2011), are used as the primary research methods in this thesis, which aims to develop a landscape-based on-site wastewater treatment system that addresses the unique environmental and industrial conditions at Terrapin Beer Co. and maximizes positive impacts on systems of economy, ecology, and society. This projective design will serve as a first step in the design of a complete on-site wastewater system. To do so, existing wastewater treatment strategies are identified and evaluated based on a set of six criteria that fall into the categories of economy, ecology, and society. For the purposes of this thesis, on-site wastewater treatment is considered to occur in three stages: wastewater pretreatment, wastewater polishing, and wastewater reclamation. Strategies within each stage are evaluated based on the six criteria, which were developed by the author and are informed by material covered in the literature review in Chapters Two and Three. Criteria are presented below and fall into one of three categories: economy, ecology, or society.

ECONOMY

1. Value Reclamation assesses the level to which the treatment method reclaims value during the wastewater treatment process by offsetting operational costs of industrial processes within the brewery or for another nearby industry. Energy production, water reclamation and reuse, and nutrient reclamation are considered. High energy and resource inputs lower the feasibility of value reclamation. Capital, operational, and maintenance costs are broadly considered in Chapter XX

2. Adaptability reflects the ease with which the treatment system can be incrementally expanded and respond to changing wastewater flows and composition. Less adaptability implies greater investment necessary to expand the treatment system in the future.

ECOLOGY

3. Habitat and biodiversity examine the ability of the treatment system to enhance local habitat value and species diversity. Impacts can be directly addressed by the treatment method or can be an indirect product of the treatment method utilized.

4. Hydrologic function reflects the level to which the treatment system can positively impact local hydrologic systems. Evaporation via exposed surface water is considered to contribute slightly to hydrologic function.

SOCIETY

5. Education considers the ability of the system to educate visitors on industrial processes, resource reclamation (water, power, nutrients), and ecological function. Education is facilitated by brewery-led tours and interpretive signage, or is a product of extended interaction.

6. Experience and aesthetics reflect the ability of the system to function as a landscape feature and enhance visual aesthetics of the site. Experience is assumed to improve with increasing level and duration of interaction. It also reflects the level of visibility to on-site visitors and passers-by.

Once qualitatively evaluated, individual treatment methods are diagrammed on what is commonly known as a radar diagram, or plot (Figure 1). Foley et al. (2005), used a similar diagram (Figure 2) as a conceptual framework for comparing ecosystem services trade-offs between different land-uses.

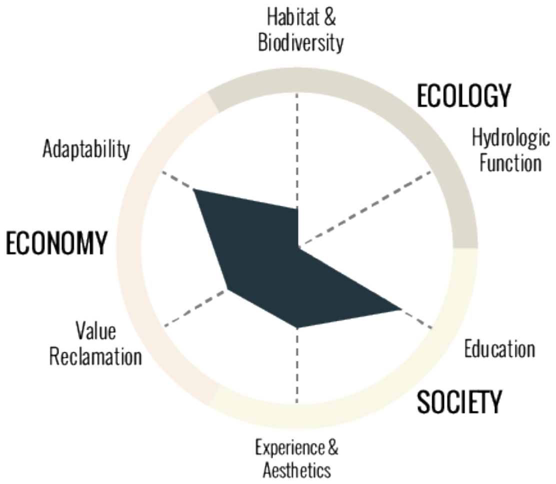
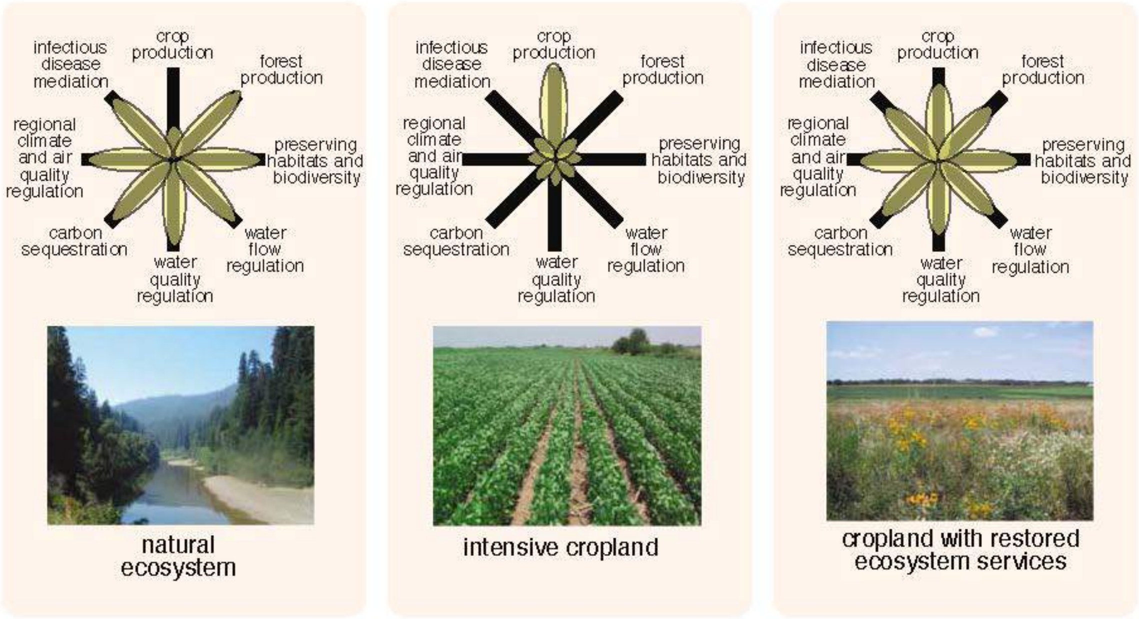


Figure 1. Radar Diagram Evaluation Criteria (diagram by author)



natural ecosystem

intensive cropland

cropland with restored ecosystem services

Figure 2. A Conceptual Framework for Evaluating the Provision of Ecosystem Services by Different Land Uses (Foley et al. 2005)

In this thesis, wastewater treatment and reclamation methods are qualitatively assessed, and axes on the radar diagrams are not normalized with common units. Radar diagrams serve to assess the level to which treatment and reclamation methods are able to address each of the criteria. Evaluation diagrams are used to classify treatment methods so that they ay be compared to one another and address site-specific concerns relating to each of the three evaluation criteria.

Following evaluation, wastewater treatment typologies are developed that aim to maximize each of the three evaluation categories and respond to the specific wastewater composition and site constraints present at Terrapin Beer Company, located in Athens, Georgia. Treatment systems are roughly sized to treat wastewater from Terrapin using well-established methods from Crites and Tchobanoglous (1998) and best available wastewater data from Terrapin Beer Company and the Athens Clarke County Public

Utilities Department. Finally, a proposed treatment system and site plan for Terrapin Beer Co. is created and evaluated on its ability to address the six evaluation criteria.

Limitations and Delimitations

Operating within the highly technical realm of wastewater treatment, but focusing on site design and qualitative assessments of treatment methods, this thesis has several limitations and delimitations.

Within the larger economic, ecological, and social framework, the development of a proposed wastewater treatment system is informed by wastewater flow and composition data from Terrapin Beer Company. Calculations rely on best-available data and do not represent a comprehensive investigation into current industrial practices. While process improvements, or eco-efficiencies, could improve the quality of Terrapin's brewery effluent, this thesis develops a wastewater treatment system based on current practices. Proposed wastewater systems do not represent fully engineered systems, but rather typologies that inform site design at a conceptual level. Economic evaluation considers the potential for value reclamation. Capital investment and start-up costs are not fully considered.

Site investigation relies on site observation and research by the author and uses best available data. It does not represent a comprehensive investigation of existing site conditions. While informed by wastewater flow data and evaluations of each treatment stage, projective site design is subjective to the author's tastes, preferences, and assumptions.

Thesis Structure

Chapter Two begins with an overview of the current state and future challenges of wastewater infrastructures within the Unites States. Industry's reliance on infrastructure for waste management is discussed, followed by an overview of the emerging practice of industrial ecology and decentralized waste management. Chapter Two concludes by identifying the need for a landscape infrastructural approach to wastewater management and the shortcomings of the current design of landscape-based systems.

Chapter Three presents an overview of the craft brewing industry, highlighting recent growth, the brewing process, and wastewater management issues.

Chapter Four defines a three-stage process for on-site wastewater treatment and reclamation. Strategies within each treatment stage are described and evaluated based on their ability to address six criteria within the evaluation categories of economy, ecology, and society.

Chapter Five first identifies the project site, Terrapin Beer Co., and presents a short brewery profile followed by the need for on-site wastewater treatment. Current best practices for on-site treatment of brewery effluent are then presented. Next, three treatment typologies are developed that aim to maximize each of the three evaluation criteria. Finally, a projective site design is developed to address Terrapin's unique wastewater composition and site constraints.

Chapter Six concludes with several suggestions for implementing on-site wastewater treatment and reclamation systems using wetland technologies at the craft brewery and discusses the role of the landscape architect in the design of on-site wastewater systems.

CHAPTER 2

TRADITIONAL INFRASTRUCTURES AND NEW DIRECTIONS

Infrastructure is defined as "the basic equipment and structures (such as roads and bridges) that are needed for a country, region, or organization to function properly" (Merriam-Webster 2015). As a collective system, infrastructures support a nation's economy and underpin the function of modern society. Cities with well-developed infrastructural systems maximize productive power and regional influence (Hung 2013).

From a design and planning perspective, infrastructural systems "have an inherent spatial and functional order" (Strang 1996, 220). The design and planning of land-based infrastructures such as transportation, energy, waste, and water has historically been the domain of engineering. These systems are largely mono-functional and have been designed to maximize efficiency for a single use (Hung 2013). As stated by Pierre Bélanger (2010, 344), "The generic, technological apparatus of modern infrastructure has largely overshadowed the preeminence of biophysical systems that underlie it."

Traditional Wastewater Infrastructure

Until the end of the 19th century, domestic and industrial wastewater was freely dumped into water bodies, polluting waterways and causing disease for downstream populations. Even as wastewater treatment practices improved during the early 20th century, urban surface waters remained polluted with municipal and industrial sewage (Elmer and Leigland 2013). Seeking to improve public and waterway health, the Clean

Water Act was enacted in 1972 and was followed by subsequent amendments. Central to the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) sought to limit point-source pollution. Wastewater treatment plants, industrial facilities, and other water discharge locations must now obtain a NPDES permit that specifies the concentration and quantity of regulated pollutants. Today, the NPDES regulates more than 200,000 discharge sources and is enforced by the U.S. Environmental Protection Agency (EPA) and its affiliated state-level departments (Elmer and Leigland 2013).

Enforcement of the Clean Water Act and the implementation of centralized wastewater collection and treatment systems throughout the 20th century greatly improved public health and had significant impacts on urban planning. Viewed as the skeleton of the modern city, the planning of sanitary systems directed the planning of communities. Centralized wastewater systems require an extensive network of sewer pipes, water mains, and pumping equipment to transport wastewater to municipal treatment plants. (Elmer and Leigland 2013)

In their Report Card for America’s Infrastructure (2013), the American Society of Civil Engineers (ASCE) rated the state of the nation’s cumulative wastewater infrastructure. Earning a D letter grade, wastewater systems are estimated to require $298 billion in upgrades over the next twenty years.

Aging pipes that require replacement and upsizing account for 80-85% of investment requirements (ASCE 2013). Installed post-World War II, in response to large population growth, many sewer pipes are nearing the end of their useful life and are susceptible to deterioration and leakage. Projections indicate that by 2020, 44 percent of the nation’s sewer pipes will be in poor or very poor condition (Elmer and Leigland

2013). Detecting and fixing aging pipes is difficult, as there is currently no national inventory on the locations or ages of sewer systems.

It is estimated that there are between 700,000 and 800,000 miles of sewer lines connecting homes, businesses, and industries to wastewater treatment facilities in the U.S. (ASCE 2013). Urban sprawl has stretched sewers across the landscape and has extended wastewater networks. While sewer pipes are most commonly designed to flow by gravity with a slope of 0.5-2 percent, pressurized pipes and pumping stations are required to transmit sewage over long distances or where topography prohibits gravity flow. Pumping stations, called lift stations, are prone to failure and require energy inputs to function. These problems become more apparent as cities grow and sprawl over the landscape. Also, a new emphasis on infill development has stressed existing wastewater networks, accelerating the need to upsize treatment plants and buried pipes (Elmer and Leigland 2013).

Capital need for sewer pipes also includes addressing combined sewer issues. Over 700 municipalities in the U.S. use combined sewer systems to transport wastewater and stormwater, and represent a major challenge to the implementation of the Clean Water Act (ASCE 2013). During times of heavy rainfall, the capacity of the combined sewer can be exceeded. To avoid the flooding of homes and streets, excess flow is released at combined sewer overflow points usually along rivers and streams. Undersized wastewater treatment facilities and combined sewer systems discharge an estimated 900 billion gallons of untreated sewage into waterways each year (ASCE 2013). In a 2009 report, the Environmental Protection Agency assessed 16% of America’s streams, of which 36% were unfit for use by fish and wildlife, 28% were unfit for human recreation, 18% were unfit for use as public water supply, and 10% were unfit for agricultural use (ASCE 2013).

Treatment plants comprise 15-20% of capital need and require expansions and upgrades to implement new process methods and technologies, adapt to future population growth, and respond to stricter federal treatment requirements (ASCE 2013). There are over 15,000 publically-owned wastewater treatment plants in the U.S., and by 2020, 22 percent of them will need to be replaced or upgraded (Elmer and Leigland 2013).

Traditional wastewater treatment combines flows from homes, businesses, and industries at centralized treatment plants. Wastewater is typically treated in a three-phase treatment process. Solids are removed from wastewater during primary treatment, while secondary treatment uses biological processes to concentrate additional organics and pathogens. Often requiring large energy inputs, secondary treatment is a carbon-negative process, discharging four pounds of carbon into the atmosphere for every pound of carbon removed from wastewater (Campbell and Ogden 1999). For final treatment, microfiltration is followed by disinfection using chlorine, UV light, or ozone. Cleaned water is often discharged to local water bodies and is regulated by the NPDES.

The original intent of wastewater treatment and regulation was to ensure the removal of pathogens capable of spreading infectious disease. However, as society uses a wider range of chemicals for medical, industrial, and agricultural purposes, additional wastewater treatment and regulatory measures are needed (Elmer and Leigland 2013). At centralized treatment facilities, combined waste streams make targeting specific pollutants difficult and inefficient. Separating waste streams allows treatment processes to address specific wastewater components. Treatment efficiencies increase and costs decrease as systems are designed for specific waste-generation activities (Tjandraatmadja et al. 2005).

Waste as Resource: Decentralization and Industrial Ecology

As opposed to large, centralized wastewater facilities, decentralized systems are multi-scalar and distributed throughout the urban landscape. Decentralized treatment allows for flexibility in function and design as processes are tailored to treat waste from specific sources (Elmer and Leigland 2013). When treating domestic wastes, decentralized systems can function from the level of single households to entire neighborhoods (Crites and Tchobanoglous 1998, Campbell and Ogden 1999).

Industrial processes often result in large amounts of waste that can vary greatly in both quantity and quality from domestic waste streams (Bélanger 2007). Before the adoption of the Clean Water Act, industries freely dumped waste into the soils, water, and air, harming environments as well as public health (Elmer and Leigland 2013). With increasing environmental regulations, industrial dependence on infrastructure for proper waste disposal has grown. As treatment standards for waste treatment have increased, so have associated costs, driving industries to seek opportunities to decrease waste production and improve waste quality.

Many industries have sought to reduce waste production and achieve economic gains by changing their products and internal processes. Known as eco-efficiencies, these measures are largely pursued at the level of the firm and focus on individual processes and production lines (Gibson and Peck 2006). Common goals include reducing resource consumption and improving product and waste quality by altering process inputs. The implementation of eco-efficiencies can also have positive secondary impacts, including enhanced brand image, higher employee morale and productivity, and better supply chain management; however, larger economic and environmental gains require the redesign of systems of production and consumption (Gibson and Peck 2006).

In an ideal system, waste is no longer seen as a burdensome byproduct, but as a valuable resource. Current systems of waste management struggle to extract value due to the magnitude and complexity of urban waste streams (Bélanger 2007). In a decentralized system of waste management, typical end-of-pipe solutions are replaced by upstream waste reclamation, where waste can be more easily separated and repurposed. Industries have sought to repurpose and recycle waste through the practice of industrial ecology. Industrial ecology is typically used to describe the interconnectedness of industries guided by ecological metaphor (Lister 2006). Just as natural ecologies cycle nutrients between species and systems, industrial ecologies seek to close material loops by using wastes from one process as inputs for another.

Seeking economic efficiency, industries pursue local connections with other businesses to reduce transportation costs and improve collaboration and communication. Eco-industrial parks aim to maximize efficiency and are designed to house networked, waste-sharing industries (Gibson and Peck 2006). Industries are recruited and incorporated into the industrial park based on their ability to contribute to material flows and waste reuse. As the practice of industrial ecology creates linkages between industrial waste streams, a more decentralized system of waste management emerges.

Wastewater consists of valuable resources including water, nutrients, and carbon. Current practices include water recycling for potable and non-potable use, nutrient extraction for use as fertilizers, and energy and heat generation from biogas (Elmer and

Leigland 2013). While decentralized wastewater treatment is common practice in industry, including the brewing industry, it is often used in response to municipal wastewater quality requirements, typically not as a practice for water reuse or value extraction (Simate et al. 2011).

A Landscape Infrastructural Approach to Waste Management

In the past, wastewater infrastructures have largely operated outside of their local contexts. Pumping stations are required to transport wastewater across watersheds, and opportunities localized treatment and reclamation are not considered. Traditional models of infrastructural development and industrial practice favor design that is rigid, homogenous, and static (Dale and Hill 2001). Built to maximize efficiency for a single use, these systems struggle when combined with other functions like stormwater management. Current models of wastewater management are also resource-intensive, requiring large amounts of clean water to flush wastes through sewer pipes and large inputs of energy to power pumping stations and treatment facilities (Tjandraatmadja et al. 2005). While effective at improving wastewater quality, the treatment process generates little value from wastewater and the potential resources it contains. Treated wastewater is released to surface waters and nutrient-rich sludge is landfilled or composted. Buried beneath the urban landscape, sewer pipes are difficult to maintain, replace, and upgrade. While necessary for urban function, this buried infrastructural system only becomes apparent when it fails, negatively affecting ecological function and leading to poor social perception (Hung 2013).

Considering projected costs for upgrading existing wastewater systems and future increases in energy costs and issues of water scarcity, a new approach to the design and planning of wastewater infrastructures is needed. Sustainable wastewater systems that reclaim value and support ecological and social function require a shift from the current mono-functional model of wastewater infrastructure that is often in conflict with its environmental context, to a condition that integrates nature and culture through locally-responsive design.

In practice, navigating the interface between nature and culture involves integrating art and science. Largely contained within the domain of engineering, the design of traditional infrastructural systems has been a scientific practice (Campbell and Ogden 1999). Movement toward a new conception of wastewater infrastructure that incorporates the larger socio-ecological system requires interdisciplinary cooperation and a focus on local environmental conditions.

Advocating for an ecological, landscape-based approach to infrastructural design, Hung (2013) identifies three key differences between traditional infrastructures and landscape infrastructures. Traditional infrastructures are single-purpose, successional, and centralized, while landscape infrastructures are multi-purpose, adaptable, and decentralized. As defined by Czerniak (2013, 20), landscape infrastructures are embedded within the visible landscape and seek to “align social and ecological concerns with instrumental and logistical systems.”

Landscape-based approaches to wastewater treatment are not new. Wetlands have long been recognized as “one of the principal ecosystems on the planet for recycling the essential elements of life” (Campbell and Ogden 1999, 2). Their application in treating domestic and industrial wastewater has been demonstrated to be an effective, low-cost method for removing pollutants. While an extensive body of technical, interdisciplinary knowledge has been developed to guide the implementation of constructed wetlands and improve their treatment efficiencies, there has historically been a lack of attention to their habitat, aesthetic, and multiple-use values (Campbell and Ogden 1999).

The design and planning of constructed wetlands has primarily been the territory of ecological design. Defined by Van der Ryn and Cowan (1996), ecological design is “any form of design that minimizes environmentally destructive impacts by integrating itself with living processes.” Historically, ecological design practitioners have focused on imitating ecological form, function, and process, and have given little attention to visual aesthetics and creative interpretation. Lister (2006) attributes this to the influence of landscape architecture on ecological design practice, which until recently, has been divided into the practice of functional, ecological design and the practice of aesthetic, artful design. While ecological design practice has succeeded in integrating nature and the functional aspects of culture, its reconciliation with artful design practice is necessary to engage the often-ignored societal element. Once functional and artful design are integrated, landscape architecture and ecological design practice gain the ability to “create entirely new, emergent, or hybridized cultural/natural ecologies” (Lister 2006, 25).

The craft brewery, existing in cities large and small, places pressure on local systems of water and waste. Featuring a unique combination of industrial production and social interaction, and with a growing need for on-site wastewater management, the craft brewery offers a fertile testing ground for a new approach to wastewater management that integrates ecological, societal and economic systems.

CHAPTER 3

THE BREWING INDUSTRY

The composition of the U.S. brewing industry has changed dramatically in the last three decades. While large traditional breweries continue to dominate the American beer market, smaller craft breweries have emerged that cater to local markets and tastes, leading to a more decentralized brewery landscape (McLaughlin, Reid, and Moore 2014). This growing industrial sector brings new challenges relating to infrastructure and waste management (Brewers Association 2012b, Simate et al. 2011). The combination of social environment and industrial production at many craft breweries generates unique opportunities for creative, integrative design.

The Rise of the Craft Brewery

Traditional breweries, such as Anheuser-Busch, Miller, and Coors, rose to meet high demand for beer following the adoption of the 21st amendment to the constitution in 1933. In order to meet the increasing demand, large breweries mass-produced a standard product, the American pale-lager. Traditional breweries have maintained the model since, with the largest producing over 100 million barrels (bbl) of beer annually (McWilliams 2014).

In 1979, the legalization of home brewing by President Jimmy Carter, paved the way for the craft brewery as states soon began to legalize brewpubs (McLaughlin, Reid, and Moore 2014). Craft breweries are characterized by their use of a variety of high-quality ingredients and methods to produce small batches of specialty beers that differ from the standard, mass-produced American pale-lager. Craft breweries range in size from small brewpubs that sell their beer on site to regional producers brewing and shipping up to 6 million barrels of beer per year (McLaughlin, Reid, and Moore 2014).

While per-capita consumption and sales by volume of beer have decreased steadily since 1981, craft breweries have sustained consistent growth. From 1984 to 2010, the number of craft breweries in the U.S. increased from 8 to 1,673. In 2013, U.S. beer sales by volume decreased by 1.9%, while the craft brewing industry grew by 17.2% (Brewers Association 2015). Several theories for this growth are reviewed by McLaughlin, Reid and Moore (2014) and include the dissatisfaction with the traditional American pale lager and the rise of the “buy local” movement that created a demand for high-quality, local goods.

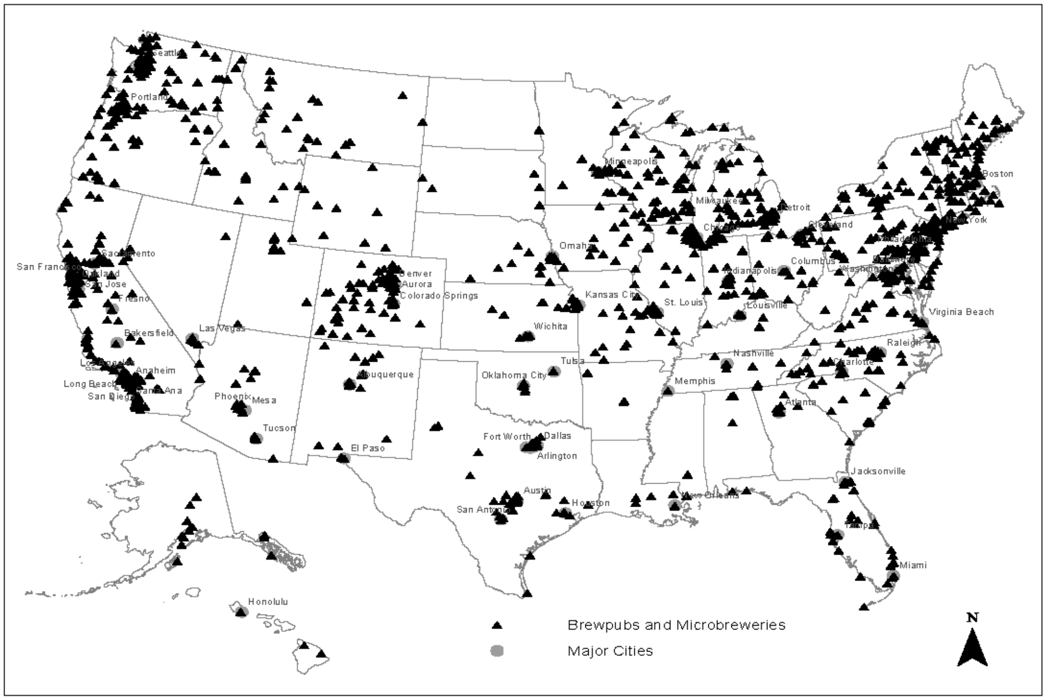


Figure 3. Locations of Microbreweries, Brewpubs, and Regional Breweries, 2011 (McLaughlin, Reid, and Moore 2014)

McLaughlin, Reid and Moore (2014), in their spatial analysis of the craft brewing industry (Figure 3), found that craft breweries have been established unevenly over space. Like large traditional breweries, craft breweries first began to appear near large urban centers between 1980 and 1990. However, between 1990 and 2011 craft breweries spread to less urban regions and to locations that previously had little or no industrial brewing activity. Mapping the 1,240 breweries currently in the planning stages, McLaughlin, Reid and Moore (2014) found that most growth over the next three years will take place in the Southeast; currently the region with the lowest number of breweries at 100.

In 2012, the beer industry's total economic impact was $246.4 billion, directly and indirectly employing more than 2 million people (Beer Institute 2013). Craft breweries, employing more workers per barrel of beer produced than large traditional breweries, help stimulate local economies (Furnari 2013). Embracing the craft beer scene as part of local culture and economy, Asheville, North Carolina credits its ten breweries in helping to bring in more than 3 million visitors to the city per year (Holl 2014). Just as breweries can help grow local economies and tourism, craft breweries are reliant on local markets. As stated by Mclaughlin, Reid, and Moore (2014, 1), "the highest quality and lowest cost craft beer originates from local production." Compared to other beverages, the freshness of craft beer decreases more quickly and it is more expensive to transport (McLaughlin, Reid, and Moore 2014).

While positive economic and cultural impacts of local craft breweries are well documented, so too are the pressures placed on resource streams and local infrastructures. The brewing process requires large inputs of clean water and access to high quality wastewater treatment. On average, 70% of incoming water is discharged as wastewater and is commonly sent to municipal facilities (Brewers Association 2012b). Higher in organic pollutants and suspended solids, but lower in pathogens and chemical pollutants, brewery effluent differs greatly from domestic wastewater and can require on-site pretreatment before it is sent to municipal facilities. While infrequently utilized, on-site waste management creates opportunities to recover value from brewery waste, both during and following the brewing process (Simate et al. 2011)

The Brewing Process and Solid Waste Management

The brewing process includes six main steps: mashing, boiling, fermenting, maturation, filtration and packaging (Brewers Association 2012a). During these processes, three solid-liquid separations occur: wort separation, wort clarification, and rough beer clarification (Van Lier 2008). Figure 4 shows the brewing process and wastes produced during each stage.

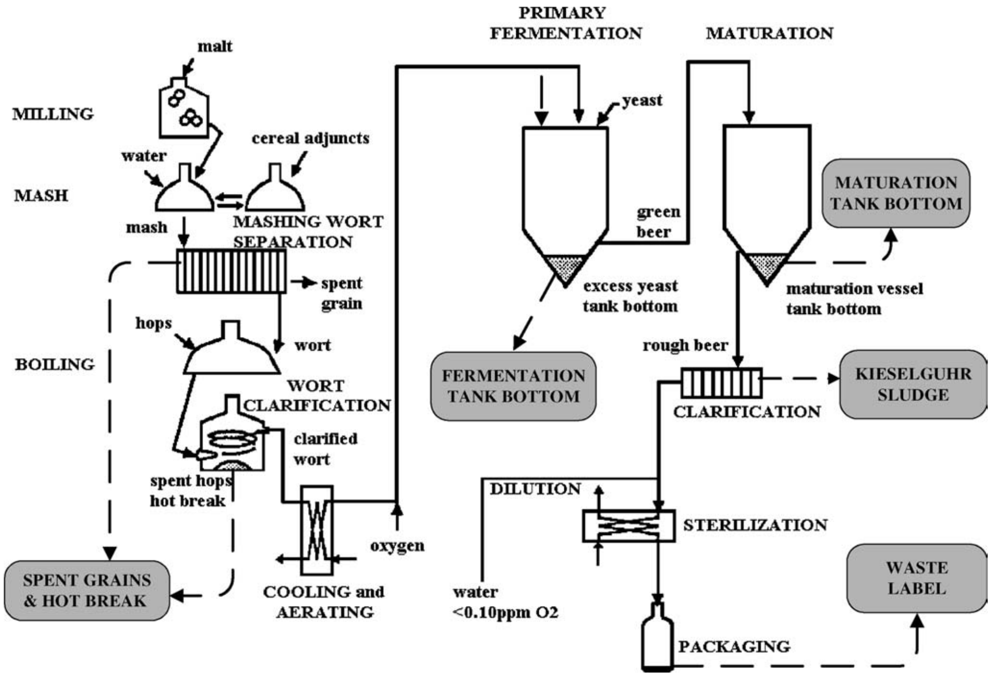


Figure 4. The Brewing Process and Main Waste Streams (Van Lier 2008)

During the mashing process, malted barley and other cereal grains are combined with hot water to extract sugars from the grains. The mash, consisting of 25-30% solid grains, must then be separated into spent grains and sugary wort (Fillaudeau, Blanpain-Avet, and Daufin 2006). Rich in protein, fiber, and other nutrients, spent grains are the largest source of solid waste for most breweries and are often sold or given to farmers for use as livestock feed (Brewers Association 2012a). Due to spoilage concerns during shipping, spent grains are often sold and used locally. Waste grains have also been used as a baking ingredient, as a soil amendment in compost, as substrate for mushroom cultivation, and as an additive in fish feed (Brewers Association 2012a, Todd, Brown, and Wells 2003, Van Lier 2008).

Following the mashing process, wort is boiled for one to two hours, during which time hops are often added. Following boiling, the wort is cooled. While uncommonly used, centrifugal or whirlpool processes can remove spent hops and other particles during the cooling process (Brewers Association 2012a). The spent hops can then be added to spent grains and sold as livestock feed. Spent hops and additional solids are more commonly disposed with wastewater, reducing effluent quality (Brewers Association 2012a). The cooled wort is then aerated to introduce oxygen and is sent to a closed fermentation vessel.

Yeast is added to wort in the fermentation tank where it begins to convert sugars to alcohol and CO_2. Following primary fermentation, partially fermented, or green beer, is often sent to a second fermentation tank for maturation. Throughout the fermentation process, yeast multiply and sink to the bottom of the tank. While many breweries discharge this excess yeast with wastewater, separation is ideal (Brewers Association

2012a). Yeast is 40% protein and contains high levels of nitrogen and phosphorus that can decrease brewery effluent quality. Separated yeast can be used in compost or can be combined with spent grains for use as animal feed (Brewers Association 2012a, Simate et al. 2011).

Following complete fermentation, rough beer is often clarified and filtered using diatomaceous earth, a naturally occurring sedimentary rock. After filtration, beer is sterilized and packaged. After filtration, the diatomaceous earth contains water and organic substances and has more than tripled in weight. This sludge, called Kieselguhr, can be difficult to dispose of, especially in Europe where it is considered a hazardous waste (Van Lier 2008). The U.S. Brewers Association recommends landfilling or composting of the Kieselguhr sludge (Brewers Association 2012a). However, new regenerable filter-aids and membrane separation techniques are poised to replace the use of diatomaceous earth and eliminate the need for disposal (Van Lier 2008).

The Brewing Process and Water Use

The brewing process requires large inputs of clean water and produces large amounts of wastewater. The typical brewing process is illustrated in Figure 5.

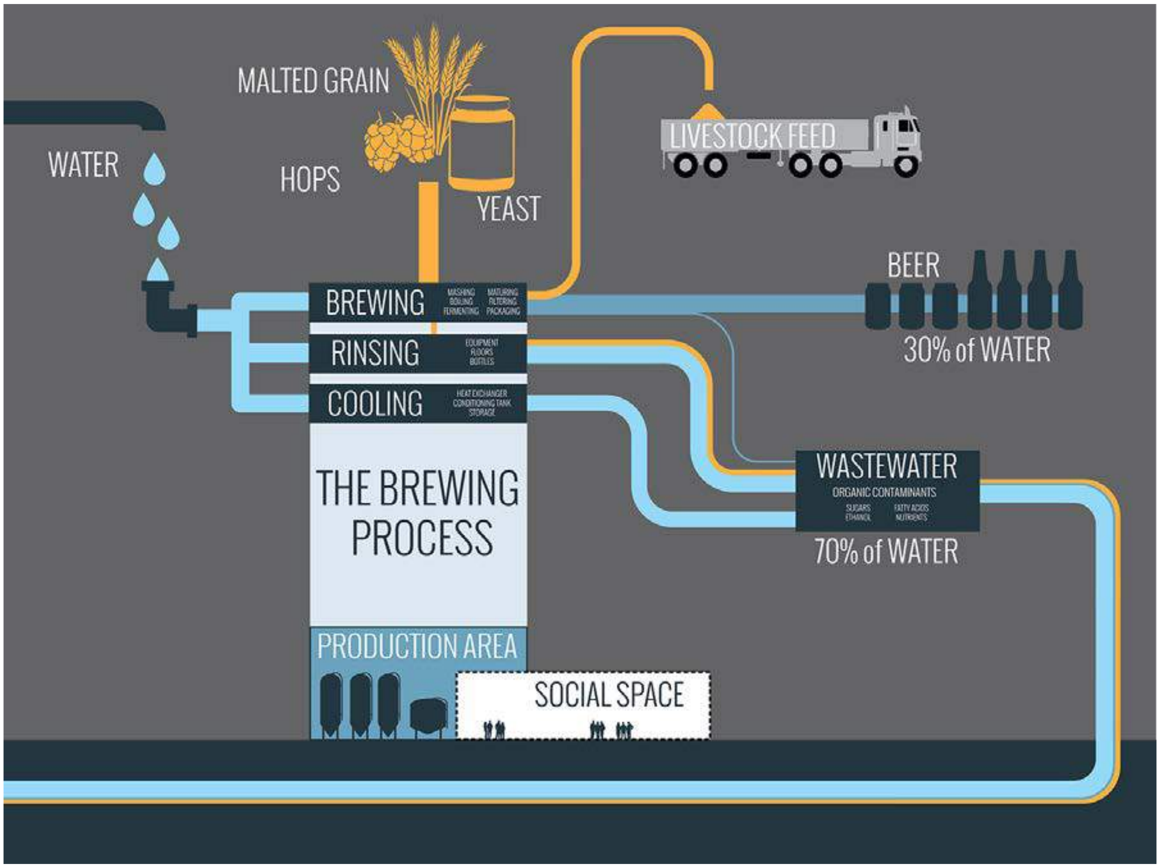


Figure 5. The Brewery System: Water Use and Waste Production (diagram by author)

Shown in Figure 6, water is used for three purposes throughout the brewing process: brewing, rinsing, and cooling (Braeken, Van der Bruggen, and Vandecasteele 2004). The brewing process typically accounts for 30 percent of water use, while rinsing and cooling processes use 70 percent of water. While water usage varies greatly between breweries depending on their size, location, and equipment, the average water usage for U.S. breweries is seven barrels of wastewater for every barrel of beer produced. Many breweries have improved this ratio to 3-5 barrels of wastewater per barrel of beer by implementing process improvements (Brewers Association 2012b).

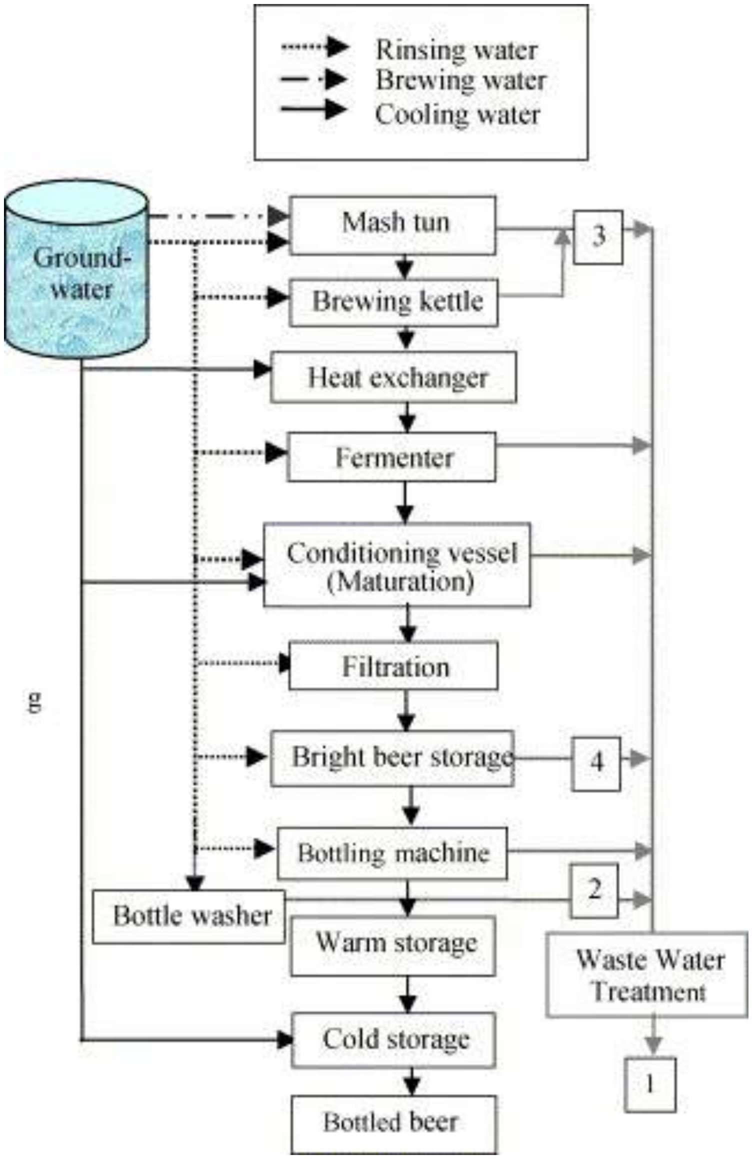


Figure 6. Water Use During the Brewing Process (Braeken, Van der Bruggen, and Vandecasteele 2004)

Most wastewater is generated during the cleaning and rinsing of brewing equipment at different stages of the brewing process. Wastewater generated from the cleaning of tanks, bottles, machines, and floors varies greatly in composition. For example, effluent from bottle washing accounts for only 3% of the total organic pollutants but accounts for up to 97% of wastewater production (Brewers Association

2012b). In contrast, wastewater from filtering and fermentation processes is very high in organic pollutants, but contributes very little to overall wastewater volume (Simate et al. 2011).

Quantity of wastewater can be reduced through the reuse of water and detergents used for cleaning. For example, water used to clean fermenters can be reused to clean the mash tun prior to disposal (Simate et al. 2011). Improving separation efficiency of solids like spent grains, hops, and yeast from wastewater can help improve effluent quality. While reducing water usage and improving solid separation can impact wastewater quantity and quality, brewery effluent is still unlikely to meet municipal discharge regulations due to the amount of dissolved organics and suspended solids (Brewers Association 2012b).

Wastewater Management Issues

Treatment of brewery wastewater primarily concerns measures of chemical and biological oxygen demand (COD and BOD), total suspended solids (TSS), and pH, which vary considerably from the domestic wastewater most municipal facilities are designed to treat. Surcharges are levied on breweries for exceeding municipal wastewater quality requirements and breweries may be required to pretreat wastewater before sending it to treatment facilities.

COD and BOD

COD, expressed in milligrams pre liter of water (mg/L) is a measure of the organic contaminants (sugars, soluble starch, ethanol, volatile fatty acids, etc.) dissolved in the brewery wastewater. Biochemical oxygen demand (BOD) represents the amount of organic substances that can be easily biologically degraded and represent 60-70% of the

COD measure in brewery effluent (Simate et al. 2011, Fillaudeau, Blanpain-Avet, and Daufin 2006). These organic substances require oxygen to break down. If high BOD water flows into a stream or river, bacteria in the river will oxidize the organic matter, consuming oxygen from the water faster than the water can absorb oxygen from the air, leading to an anaerobic state where oxygen is depleted and aquatic organisms die.

Typical domestic wastewater has a BOD of less than 300 milligrams per liter (mg/L), while typical untreated brewery effluent ranges from 1,200-3,600 mg/L (Simate et al. 2011, Crites and Tchobanoglous 1998). Wastewater treatment aims to reduce BOD so that it is not harmful to local ecologies when released to surface waters. Treatment of high BOD wastewater leads to increased costs for municipal facilities.

TSS

TSS, also expressed in milligrams per liter, is a measure of the insoluble particles floating in a sample of water. Suspended solids can be reduced through efficient solids separation and further removal can be achieved through filtration but is dependent on the quality and sizing of the filter. Typical domestic wastewater has a TSS less than 300 mg/L, while typical untreated brewery effluent has a TSS of 2900-3000 mg/L (Crites and Tchobanoglous 1998, Simate et al. 2011).

pH

PH is a measure of acidity or basicity of an aqueous solution. Solutions with a pH less than 7 are acidic and solutions with a pH above 7 are considered basic or alkaline. Wastewater treatment facilities are concerned with the pH of effluent because low pH can cause corrosion and high pH can cause deposits to occur within sewer infrastructure and equipment (Mercer 2014, Brewers Association 2012b). PH is typically adjusted through the addition of chemicals, however, capture and reuse of waste CO_2 from the brewing process has been shown to be effective in reducing wastewater alkalinity (Simate et al. 2011). Biological processes used to treat wastewater require a pH between 6 and 9. Domestic wastewater is typically neutral, while untreated brewery effluent pH can range from 3-12, depending on the stage of the brewing process and chemicals used for cleaning (Mercer 2014).

Wastewater Opportunities

As municipal wastewater facilities become more familiar with treating brewery effluent, there is a trend towards a more controlled and regulated system, often leading to higher costs for disposal or requirements for breweries to pre-treat their wastewater to a level municipal facilities can effectively manage (Brewers Association 2012b). Even if local treatment systems can easily manage the quality and quantity of brewery wastewater, local regulations for sewer discharge limits are often exceeded.

Breweries have three options when disposing of wastewater. The first option is to send wastewater to municipal treatment facilities. This can be costly, as many municipalities have implemented surcharges for exceeding effluent quality and quantity limits. Lagunitas, a large craft brewery in Petaluma, California, spent more than $1 million per year to transport water to a nearby wastewater facility as the local system could not handle the volume and strength of their effluent (Scully 2013). They have since installed an on-site treatment system to avoid costly disposal and transportation fees (Cambrian Innovation 2015).

The second option (Figure XX) is to pretreat wastewater on site, meeting quality standards before wastewater is sent to the municipal system. This requires breweries to put significant investment into wastewater systems but will reduce or eliminate surcharges imposed by the municipal facilities. A survey of 76 breweries of various sizes conducted by Brewers Association (2012b) found that most breweries discharged water to local municipalities for treatment and only half had pre-treatment facilities on site to adjust pH and remove solids. Approximately one third of the 76 breweries sampled paid an extra surcharge based on the BOD and TSS in the effluent.

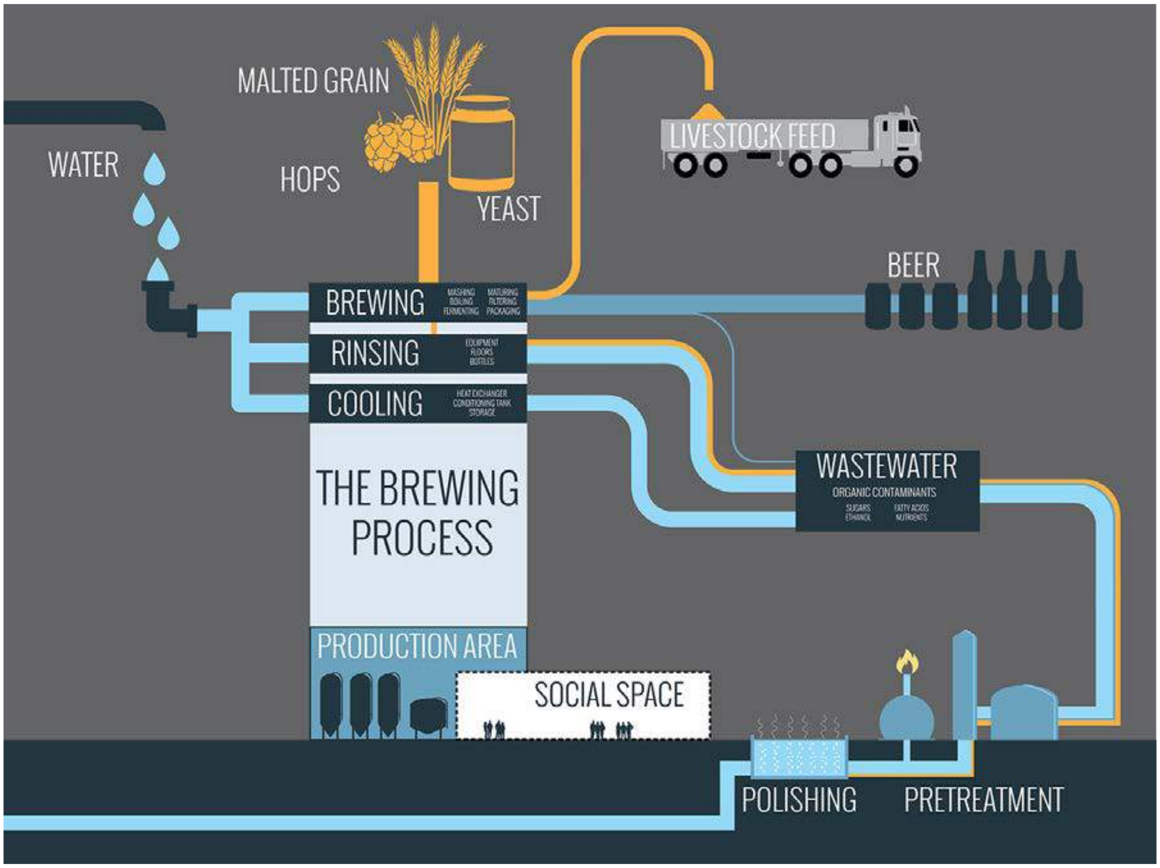


Figure 7. The Brewery System: Standard Pretreatment and Polishing (diagram by author)

The third option is for breweries to treat all of their wastewater on site, sending little or none to the municipal system and creating the potential for water reuse. While this is rarely done, Simate et al. (2011) expect to see on-site treatment systems utilized to reuse brewery wastewater as cost and demand for clean water increases in the future. Options for water reclamation and reuse are discussed in Chapter Five.

Conclusion

In the coming years, the craft brewing industry will continue to expand as new breweries are established and existing breweries increase production (McLaughlin, Reid, and Moore 2014). So too will demands on local water sources and systems of wastewater treatment. Considering 21st century issues of water shortage, increasing water cost, and infrastructural inadequacies, the future reuse of brewery wastewater seems to be unavoidable (Simate et al. 2011). Many breweries have already implemented the first stages of on-site wastewater treatment as they seek to reduce disposal costs and meet local regulations. However, many fail to extract additional value from these investments, sending treated water back to local municipalities to be re-treated. The potential for economic gain by expanding these practices to include on-site water reclamation and reuse is largely unexplored.

Concerning society, the craft brewery is a unique industrial condition. Unlike most industries, breweries often encourage public attendance via beer tastings and events. Brewery tours are also common and create an opportunity for public education on water issues and reuse practices. At the interface of society, industry, and infrastructure, the craft brewery offers a fertile testing ground for localized wastewater treatment and reuse.

CHAPTER 4

ON-SITE WASTEWATER RECLAMATION STRATEGIES

This chapter defines wastewater pretreatment methods currently available to breweries and evaluates the potential for wastewater reclamation through landscape-based treatment. On site treatment is considered to occur in three phases (Figure 8): wastewater pretreatment, wastewater polishing, and wastewater reclamation. Each of these treatment methods is evaluated on its potential to address the economic, ecological, and societal criteria shown in Figure 9.

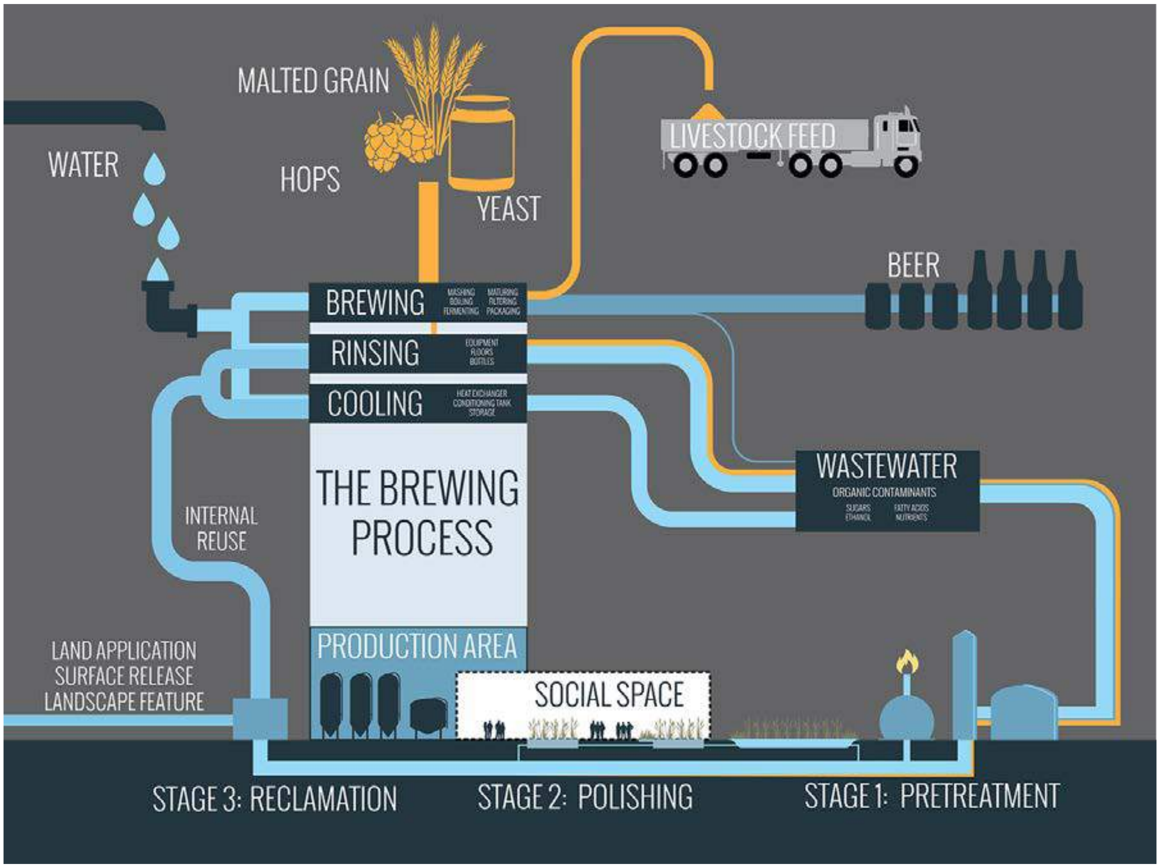


Figure 8. The Brewery System: Proposed Three-Stage Wastewater System (diagram by author)

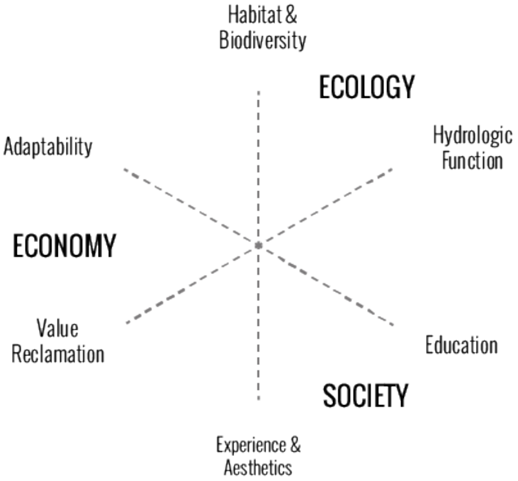


Figure 9. Evaluation Criteria (diagram by author)

Stage 1: Wastewater Pretreatment

Pretreatment of wastewater is a common practice at medium to large breweries, and usually takes place in two phases (Brewers Association 2012b). Pretreatment usually begins with the removal of solids and pH neutralization of wastewater. Solids are removed throughout the brewing process and wastewater is additionally screened prior to pH neutralization. PH is typically adjusted through the addition of chemicals or recaptured CO_2 within a buffering tank (Brewers Association 2012b). Buffering tanks can also be used to equalize wastewater flow, ensuring a more constant quality and quantity effluent flows to the secondary treatment stage and making secondary treatment more efficient. Figure 10 shows phase one the primary treatment process. While pretreatment is effective at removing large solids and neutralizing pH, additional treatment is often needed to reduce COD and TSS to acceptable levels for many municipalities.

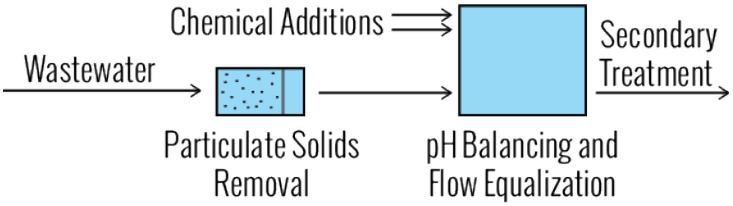
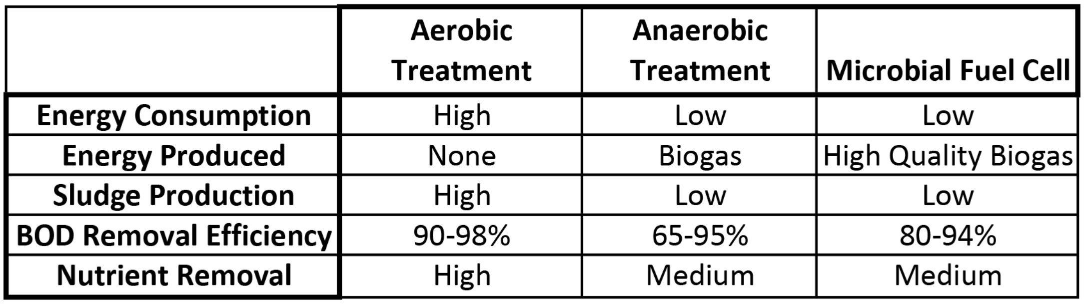


Figure 10. Pretreatment Phase 1 (diagram by author)

Secondary treatment of brewery effluent utilizes biological processes to reduce BOD, TSS, and nutrients like phosphorus and nitrogen. Three overall categories of treatment are considered in this thesis and are broadly compared in Table 1.

Table 1. Basic Comparison of Aerobic, Anaerobic, and MFC Systems *Data Sources:* (Van Lier 2008, Crites and Tchobanoglous 1998, Simate et al. 2011)



	Aerobic Treatment	Anaerobic Treatment	Microbial Fuel Cell
Energy Consumption	High	Low	Low
Energy Produced	None	Biogas	High Quality Biogas
Sludge Production	High	Low	Low
BOD Removal Efficiency	90-98%	65-95%	80-94%
Nutrient Removal	High	Medium	Medium

Treatment methods within each of these three categories are discussed in this section. Each treatment method is broadly described and is evaluated based on the six criteria presented in the research methods. Volumetric loading rates and BOD removal efficiencies are also given, and serve to inform reactor sizing and treatment efficiency. Volumetric loading rates are expressed in milligrams of COD capable of being treated per cubic foot of reactor volume per day and reflect the reactor volume needed to effectively treat a given quantity wastewater (Crites and Tchobanoglous 1998). The BOD removal efficiency is a measure of the percentage of BOD in wastewater capable of being removed by the given treatment method. Volumetric loading rates and BOD removal efficiencies for aerobic and anaerobic treatment of brewery effluent are adapted from Driessen and Vereijken (2003). Treatment diagrams presented with each method serve to illustrate the basic treatment process and show their relationship to people on site. Radar diagrams characterize each treatment method’s ability to address each of the six criteria.

Aerobic Treatment

In the process of aerobic treatment (Figure 11), oxygen is introduced via aeration or is bubbled through the wastewater, feeding bacteria as they consume suspended organic materials. The bacteria, growing large and falling out of solution, are left behind as clean water is siphoned off. The dewatered bacteria and organic wastes are called sludge and must be disposed of properly. (Brewers Association 2012b, Mercer 2014)

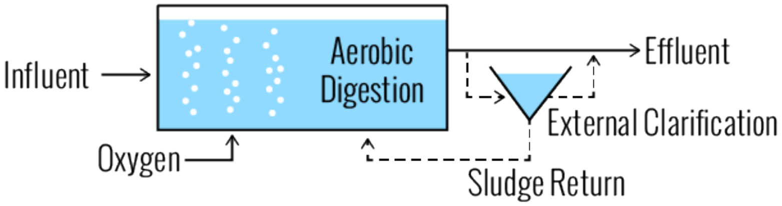


Figure 11. Aerobic Treatment Process (diagram by author)

Aerobic systems are known to have high operating costs as a result of energy-intensive aeration but effectively reduce BOD by 95+ percent (Brewers Association 2012b). They often require large basins for wastewater aeration and settling, and produce large amounts of waste sludge as basins are dewatered.

Aerobic Lagoons (Figure 12) are of simple design but require large energy inputs for aeration and accumulate large amounts of sludge over time. Lagoons have a very low volumetric loading rate of 0.01 and require large amounts of land. Despite being very effective at treating wastewater and removing up to 98 percent of BOD, they are not commonly used for treating brewery effluent due to their long retention times and land requirements (Driessen and Vereijken 2003).

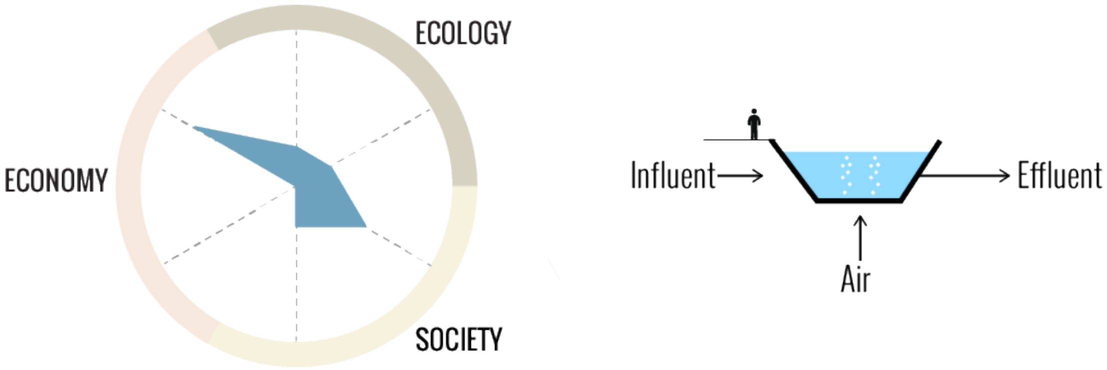


Figure 12. Aerobic Lagoon (diagram by author)

Economy: There is no potential for value reclamation with aerobic lagoons, as sludge is deposited on the bottom of the basin. However, lagoons can be expanded or aeration can be increased to treat a greater volume of wastewater.

Ecology: Aerobic lagoons are exposed to the air and contribute slightly to hydrologic function through evaporation. While they are not planted with vegetation, they may offer small amounts of habitat value along the edges.

Society: Because water in lagoons is a visible component of the landscape, they have more education value than closed tanks. While the exposed water and small amounts of peripheral vegetation could be considered aesthetically pleasing, odors can be problematic.

Activated sludge systems (Figure 13) are the most frequently used aerobic technology for treating industrial effluent (Driessen and Vereijken 2003). They require large energy inputs to aerate wastewater so that sludge is constantly suspended in solution. An external clarifier separates sludge following treatment and sludge is returned to the aeration tank or is dewatered and disposed. Effluent is usually of high quality and can be discharged to local surface waters. Having smaller land requirements than lagoons, activated sludge systems operate in open, concrete basins and have a volumetric loading rate of .03-.14 and effectively remove up to 98 percent of BOD.

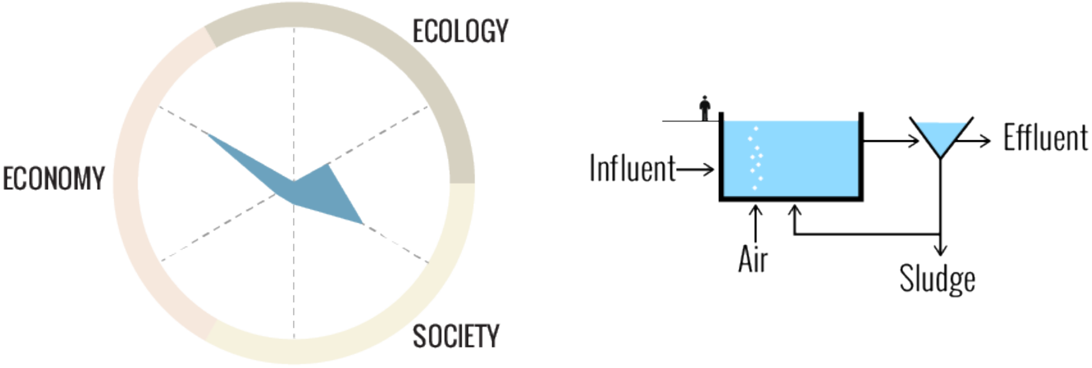


Figure 13. Activated Sludge Reactor (diagram by author)

Economy: Value recovery is greater than when using aerobic lagoons because sludge is reclaimed more easily. Additional treatment basins can be easily constructed to expand treatment capacity.

Ecology: Activated sludge systems have no habitat value, but because water is exposed at the surface, they have a small hydrologic function.

Society: Because the wastewater treatment process is visible at the surface, activated sludge systems have some educational value. While not considered visually pleasing, activated sludge systems are a visible landscape element, and odors can be more easily controlled than open lagoons.

Fixed and moving bed reactors (Figure 14) use an attached growth process to treat wastewater (Simate et al. 2011, Driessen and Vereijken 2003). Aerobic microbes grow on a filter medium, such as stone or molded plastic and consume BOD as wastewater flows by. Fixed beds, like trickling filters, can be open or closed tanks that clean wastewater as it trickles through the filter medium. Moving bed reactors are closed tanks and are constantly circulated to increase wastewater contact with the filter medium. They have a volumetric loading rate between .06 and .29 and can effectively reduce BOD by up to 98 percent.

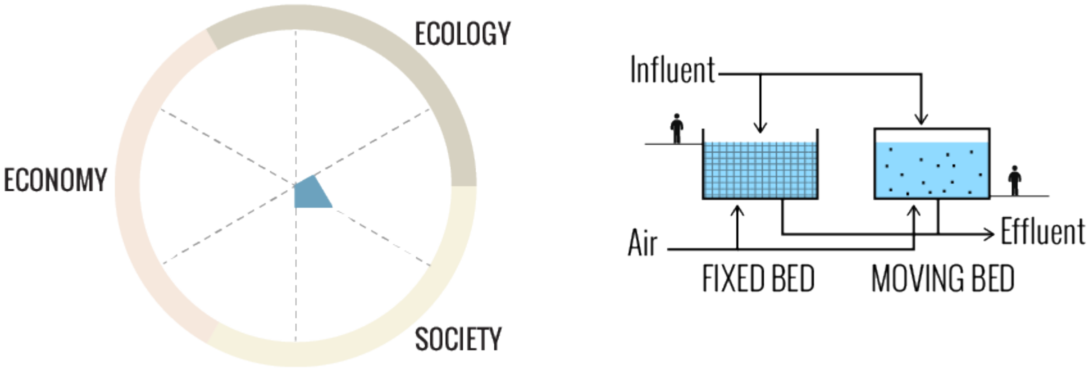


Figure 14. Fixed and Moving Bed Reactors (diagram by author)

Economy: Fixed and moving bed reactors have no potential for value reclamation and are not easily expanded to allow for additional capacity.

Ecology: Because water is not exposed at the surface, fixed and moving bed reactors have no habitat value. However, small amounts of sprayed wastewater may evaporate in open trickling filters, contributing slightly to hydrologic function.

Society: Open fixed bed reactors or trickling filters can have a slight educational and aesthetic value depending on site placement and type of filter medium used. For example, colorful river stone has more aesthetic value than a molded plastic filter medium.

Airlift reactors (Figure 15) intensively circulate a wastewater-sludge mixture, utilizing higher sludge concentrations to achieve higher volumetric loading rates of .29-.57. Like other aerobic systems, airlift reactors effectively remove up to 98 percent of BOD. Airlift reactors can also remove nearly all soluble nitrogen from effluent; however, solids pass through the Airlift system, requiring additional suspended solids treatment (Driessen and Vereijken 2003).

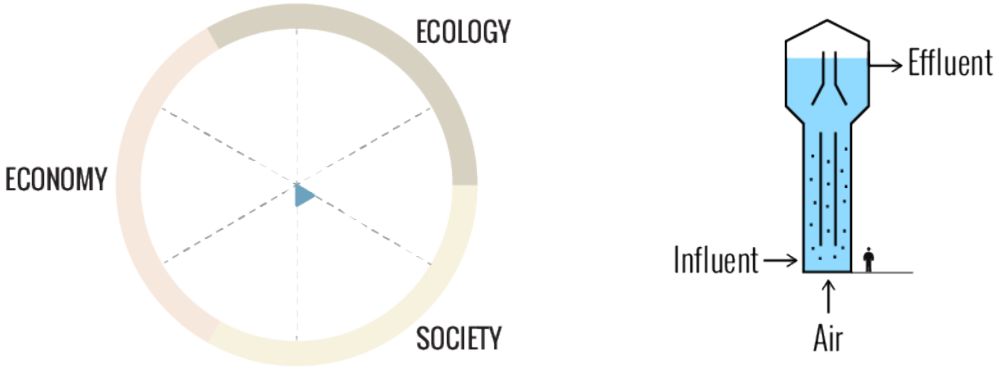


Figure 15. Aerobic Airlift Reactor (diagram by author)

Economy: Airlift reactors reclaim no value from wastewater and are not easily adapted to increasing wastewater flows.

Ecology: Because wastewater is contained within a tank, airlift reactors offer no ecological value.

Society: Large, closed tanks may function as a landscape feature but offer little aesthetic value. Because the treatment process is hidden, they also have little educational value.

Anaerobic Treatment

Anaerobic wastewater treatment systems (Figure 16) are a common practice for effective treatment of agro-industrial and beverage industry wastewater that can also provide a source of renewable energy (Van Lier 2008). Anaerobic treatment systems convert organic compounds via anaerobic microorganisms to biogas without the addition of oxygen or air**.** Biogas is composed of 55-75 percent methane and 25-40 percent carbon dioxide with traces of hydrogen sulfide and can potentially be burned to offset energy costs. Biogas is either burned off, used directly to heat boilers within the brewery, or is converted to electricity and heat via a combined heat and power unit (CHP) (Simate et al. 2011). CHPs require additional investment. Anaerobic systems have up to a 90 percent smaller footprint and produce up to 90 percent less sludge than aerobic systems (Van Lier 2008). While they produce little sludge and require a smaller footprint, anaerobic systems typically treat wastewater to a lesser degree than aerobic systems and typically have a COD removal efficiency of 80-90% (Driessen and Vereijken 2003).

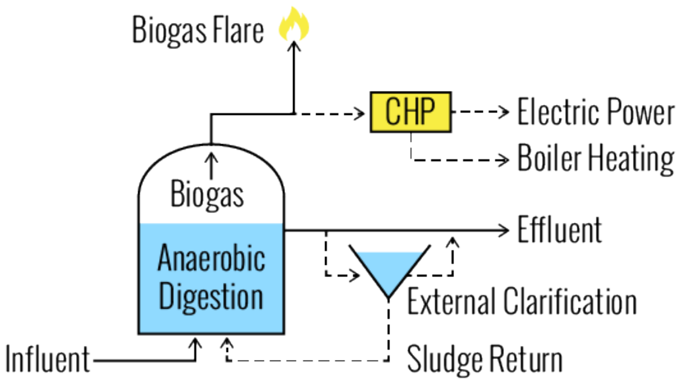


Figure 16. Anaerobic Treatment Process (diagram by author)

Continuously stirred tank reactors (CSTRs) (Figure 17) are anaerobic reactors that constantly agitate a suspended sludge mixture. Because they are constantly agitated, they require more energy input than other anaerobic systems, but may offset some energy inputs via biogas production. There is no sludge retention within the unit, but external separation is possible. Contained within a tank, CSTRs have a volumetric loading rate of .06-.29 and can remove up to 90 percent of BOD from wastewater. CSTRs tend to be used as sludge digesters and are not as suitable as other alternatives for treating brewery effluent (Driessen and Vereijken 2003).

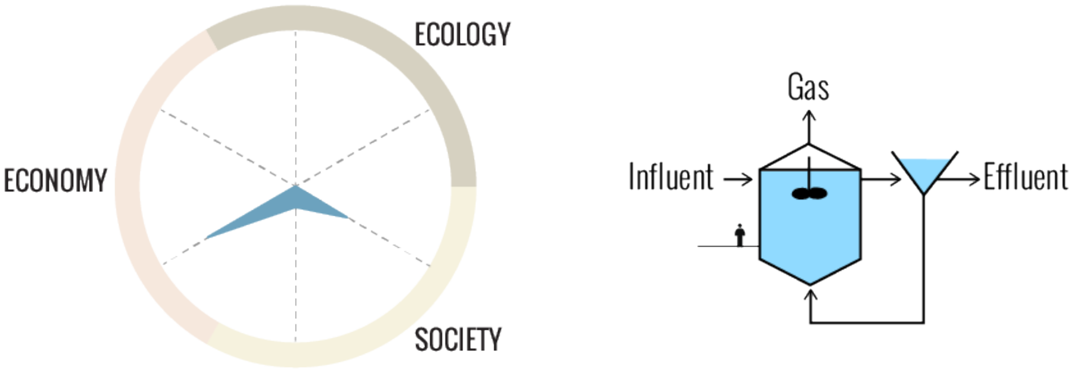


Figure 17. Anaerobic CSTR (diagram by author)

Economy: Reclaimed biogas offsets operational costs, but CSTRs cannot be expanded easily.

Ecology: Because water is contained within a closed tank, CSTRs have no ecological value.

Society: While the closed tank offers little aesthetic value, generation of biogas serves to educate visitors on the benefits of resource reclamation.

Anaerobic upflow filter beds (Figure 18) pass wastewater through a filter medium (usually sand or activated carbon) where bacterial biomass grows and retains sludge as water passes through it (Simate et al. 2011). Driessen and Vereikjen (2003) claim that upflow filter beds are susceptible to clogging which leads to ‘dead zones’ within the reactor and limits the capacity for treatment. Upflow filter beds have a similar volumetric loading rate to aerobic airlift reactors (.29-.57) and can reduce BOD by 90 percent.

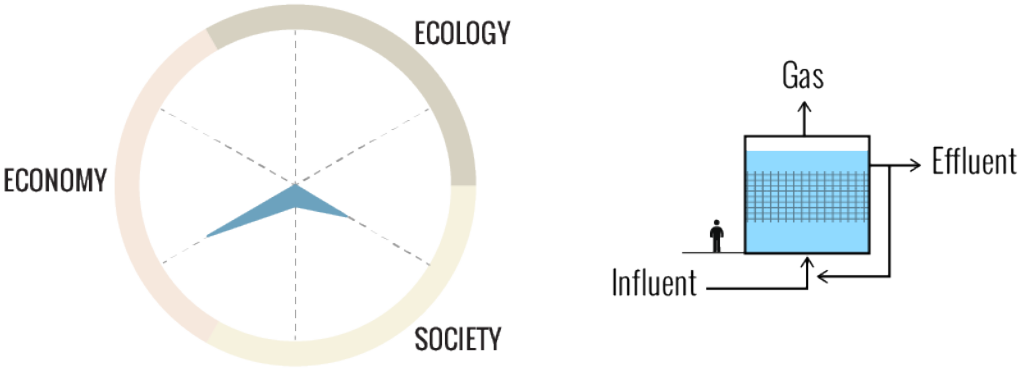


Figure 18. Anaerobic Upflow Filter Bed (diagram by author)

Economy: Reclaimed biogas offsets operational costs, but upflow filter beds are not easily adapted to increased wastewater flows.

Ecology: Because wastewater is contained within a closed tank, anaerobic filter beds have no ecological value.

Society: While the closed tank offers little aesthetic value, generation of biogas serves to educate visitors on the benefits of resource reclamation.

Upflow Anaerobic Sludge Blankets (UASB) (Figure 19) pump water through a dense mat of anaerobic sludge where microbes consume organic substrates and release biogas (Simate et al. 2011). Biogas is separated from wastewater and sludge at the top of the reactor and can be burned off or processed and used to offset energy costs. The UASB is the most widely applied anaerobic reactor for treating brewery effluent (Driessen and Vereijken 2003).

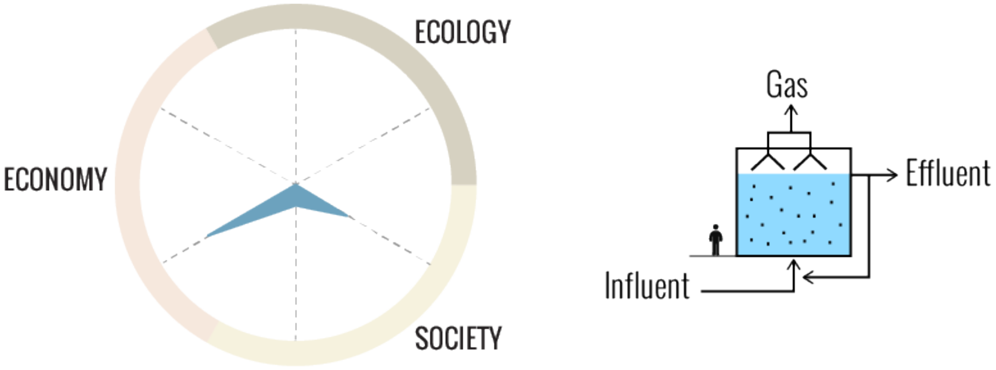


Figure 19. Anaerobic UASB (diagram by author)

Economy: Reclaimed biogas offsets operational costs, but UASBs are not easily adapted to increased wastewater flows.

Ecology: Because wastewater is contained within a closed tank, UASBs have no ecological value.

Society: While the closed tank offers little aesthetic value, generation of biogas serves to educate visitors on the benefits of resource reclamation.

Fluidized bed reactors (Figure 20) are a vertically stretched version of the UASB that have a larger loading rate. A newer fluidized bed technology, Internal Circulation (IC) reactors use a two-staged design that is essentially two UASB reactors stacked on top of one another (Driessen and Vereijken 2003). These systems are capable of high loading rates and stand 50-80 feet tall. Anaerobic reactor technology has improved greatly over the past 30 years, leading to a shift in pretreatment of industrial wastewaters from aerobic and UASB reactors to newer fluidized bed anaerobic reactors (Van Lier 2008). Newer anaerobic systems have smaller footprints and often have larger loading capacities (.86-1.72), making them an attractive option for space-limited sites (Driessen and Vereijken 2003). Fluidized bed reactors remove up to 95 percent of BOD.

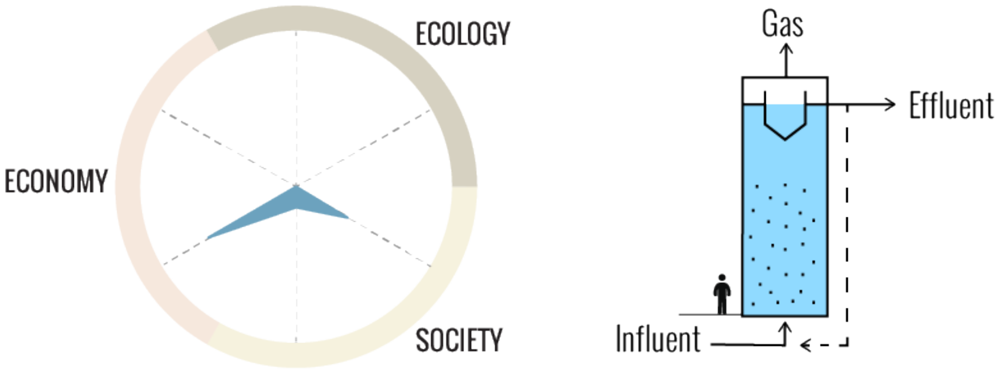


Figure 20. Anaerobic Fluidized Bed (diagram by author)

Economy: Reclaimed biogas offsets operational costs, but anaerobic fluidized beds are not easily adapted to increased wastewater flows.

Ecology: Because wastewater is contained within a closed tank, fluidized beds have no ecological value.

Society: While the closed tank offers little aesthetic value, generation of biogas serves to educate visitors on the benefits of resource reclamation.

Microbial Fuel Cells

Technologies used in the treatment of industrial wastewaters continue to be developed. The Microbial Fuel Cell (MFC) is a new technology that generates electricity directly from the organic matter in wastewater using anaerobic and aerobic processes. MFCs are capable of over 90 percent COD reduction and require little energy inputs (Wang, Feng, and Lee 2008, Simate et al. 2011). Simate et al. (2011), recommend their use in the pretreatment stage for all wastewater treatment applications.

The EcoVolt by Cambrian Innovation (Figures 21 and 22) is currently the only system available for treating wastewater using MFC technology (Rosenbaum and Franks 2014). Treatment systems operate within shipping containers, can treat flow rates as low as 2,000 gallons per day, and have footprints as small as 450 square feet (Dean 2014). Cambrian Innovation markets the EcoVolt, to breweries and other food and beverage industries. The EcoVolt produces higher-quality biogas (80-85% methane) than anaerobic systems (55-75% methane) by enhancing anaerobic digestion with bioelectric microbes (Cambrian Innovation 2014, Rosenbaum and Franks 2014). Bear Republic Brewing in Cloverdale, California recently installed an EcoVolt system to treat its wastewater. Once fully implemented, the system is expected to reduce BOD by 80-90 percent, offset energy requirements by over 50 percent, and supply enough recycled water to offset 10 percent of water needs (Cambrian Innovation 2014). Overall, the EcoVolt system is expected to deliver an annual return on investment over 25 percent.

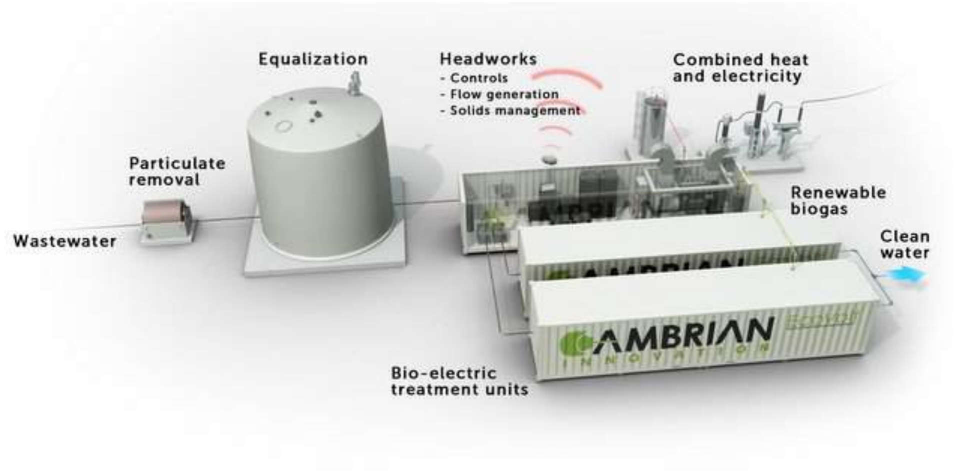


Figure 21. The EcoVolt System (Gribbons 2014)

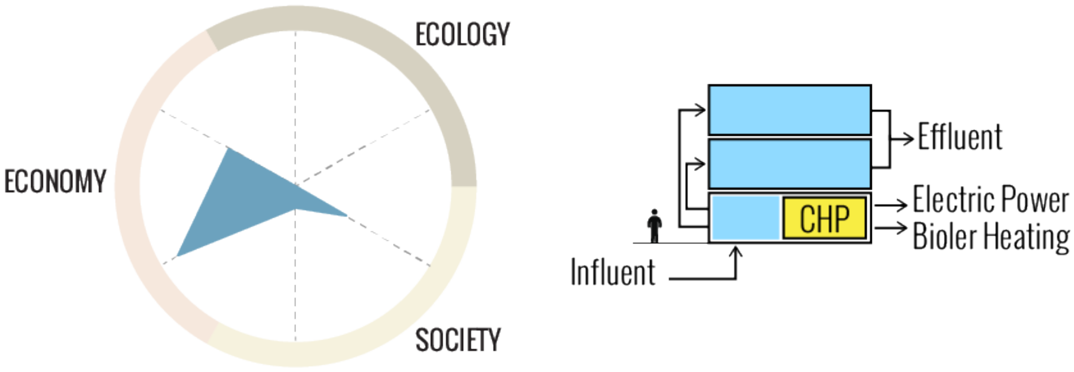


Figure 22. Microbial Fuel Cell - EcoVolt (diagram by author)

Economy: The internal CHP unit produces electricity and heat that offset operational costs. The EcoVolt system can also be easily expanded with additional containers that link together to expand capacity.

Ecology: Because wastewater treatment is contained, the EcoVolt has no ecological value.

Society: While the container offers little aesthetic value, generation of electricity and heat serves to educate visitors on the benefits of resource reclamation.

Stage 2: Wastewater Polishing

Constructed wetlands are generally low-cost options for wastewater treatment that are capable of providing multiple functions and benefits with low environmental impact (Campbell and Ogden 1999). Relying on the natural processes of vegetation, soils, and microbes, constructed wetlands are simple to build and operate, demonstrate high performance wastewater treatment, and require little energy inputs. Organic material present in wastewater is converted to plant material, returned to the atmosphere, or deposited on wetland bottoms. While constructed wetlands have been demonstrated to efficiently treat wastewater from a variety of sources, they are always preceded by at least primary treatment systems to reduce solids and prevent clogging (Crites, Middlebrooks, and Bastian 2014).

From a site design perspective, constructed wetlands can serve multiple functions and can be integrated into site programming. While dependent on site-specific parameters, constructed wetlands have been used for public recreation, education, and aesthetic enhancement (Campbell and Ogden 1999). Nearly all constructed wetlands will attract wildlife, whether they are designed to or not, as riparian zones tend to attract a diverse range of species. In fact, constructed wetlands have been shown to have higher species richness and population densities than other natural wetlands (Campbell and Ogden 1999). Common wildlife includes waterfowl and other birds, amphibians, small mammals, and a variety of aquatic and terrestrial insects; however, attraction is dependent on wetland size and type. Selecting wetland plants useful as a food source and cover, as well as providing nesting boxes and feeding stations can improve habitat value. Enhancing the transitional zone, or ecotone, from wetland to terrestrial habitat can also create a more diverse wildlife habitat (Campbell and Ogden 1999).

While constructed wetlands create opportunities for ecological and social enhancement, their value is dependent on the wetland typology. The two main types of constructed wetlands are classified according to their water flow: surface or subsurface. Each of these classifications can be separated into the various types shown in Figure 23. Hybrid systems using elements from both surface and subsurface flows are common. There are also proprietary systems that utilize constructed wetland principles for wastewater treatment.

This section describes four methods of wastewater treatment using constructed wetland technologies and presents short case studies that demonstrate their capability to treat brewery wastewaters and be incorporated into site planning and design. Each of the four methods is evaluated based on the six criteria described previously, and radar diagrams characterize each treatment method's ability to address the criteria. Treatment diagrams presented with each method serve to illustrate the basic treatment process and show their relationship to people on site.

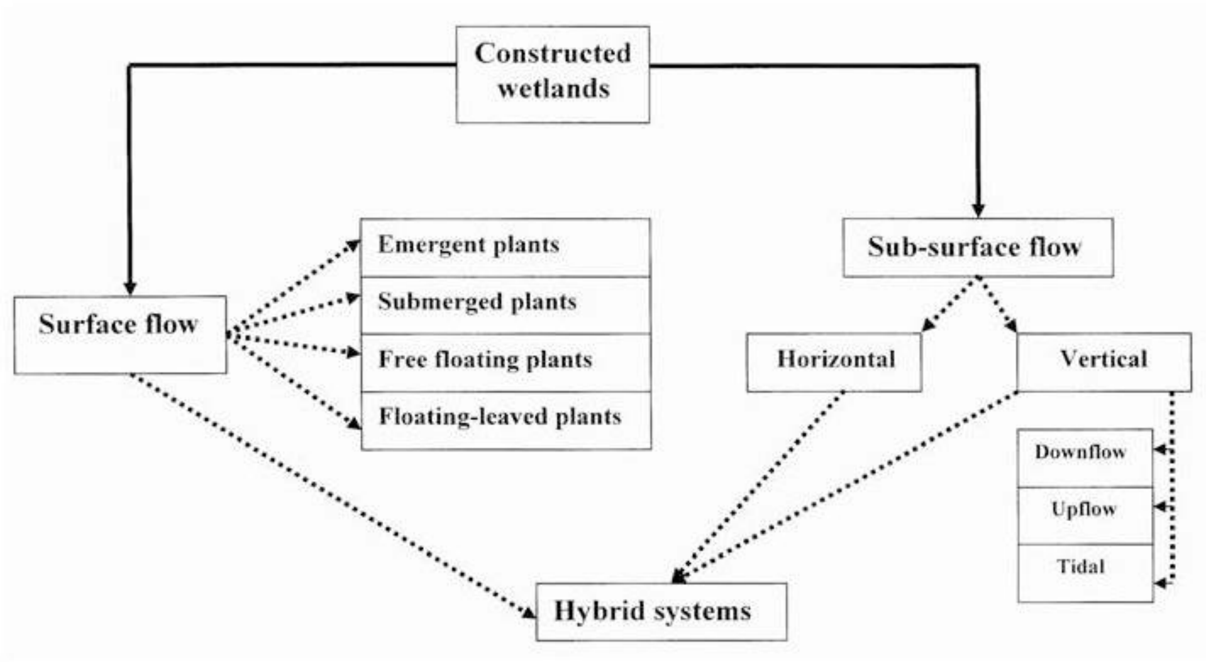


Figure 23. Classification of Constructed Wetlands for Wastewater Treatment (Vymazal and Kröpfelová 2008)

Free water surface (FWS), or surface flow constructed wetlands (Figure 24) consist of basins or channels lined with soil or other medium to support the growth of vegetation. Plant species are largely dependent on local climate and character of water being treated. FWS wetlands have been used for secondary wastewater treatment, tertiary polishing, and for the creation of wildlife habitat (Crites and Tchobanoglous 1998). Public uses, such as recreation paths and educational programs are also common features of FWS wetlands (Vymazal and Kröpfelová 2008). As seen in Figure 23, the type of vegetation differentiates FWS constructed wetlands.

FWS constructed wetland basins are lined with an impermeable barrier and are flooded to a depth of 4 to 18 inches (Crites and Tchobanoglous 1998). Wastewater is treated as it flows through vegetation by physical and chemical processes and by bacteria attached to submerged leaves and roots. The number of plant species suitable for FWS wetlands may be limited due to constant inundation (Ogden 2012). Larger wetlands are more suitable for wildlife habitat than as a landscape feature due to large masses of plants reaching up to 12 feet in height (Ogden 2012). While inexpensive when compared to mechanized aerobic or anaerobic treatment systems, FWS wetlands require large land area and have long water retention times. They can also be susceptible to odor and mosquito problems if constant water flow is impeded (Crites and Tchobanoglous 1998).

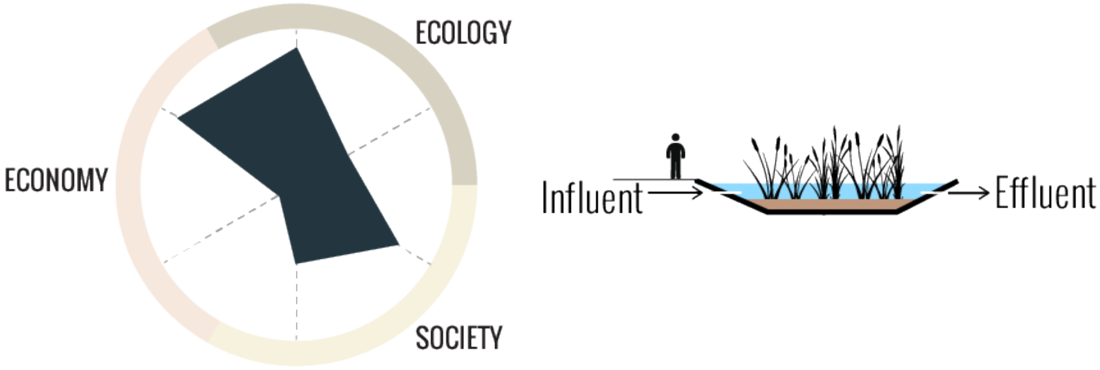


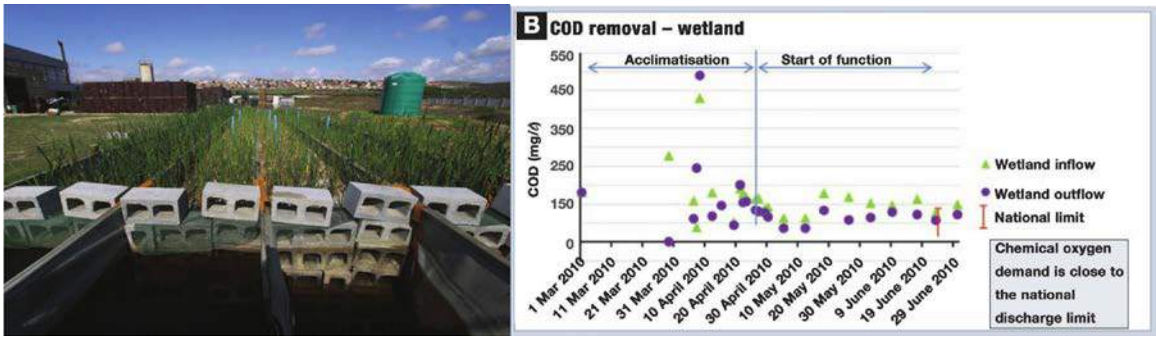
Figure 24. Free Water Surface Constructed Wetland (diagram by author)

Economy: FWS wetlands offer little value reclamation for industrial processes, but are easily expanded and adaptable to increased wastewater flows.

Ecology: Because water is exposed at the surface and supports a range of plant and animal species, FWS wetlands have high ecological value. Exposed surface water also contributes to hydrologic function.

Society: FWS wetlands have high educational value because of their ability to inform visitors on ecological function and its connection to industrial process. While they can function as an aesthetic site element, FWS wetlands are not conducive to public interaction because wastewater is exposed at the surface.

Working with Rhodes University, South African Breweries (SAB) installed a FWS constructed wetland system pilot project at its Port Elizabeth, South Africa brewery to treat its wastewater following an initial anaerobic treatment. Preceded by primary treatment, the system has successfully reduced COD, TSS, and nutrients to regulatory standards, while producing water suitable for irrigation and non-potable uses (Boswell 2011). Wetland effluent could easily be treated via reverse osmosis for use as potable water, however there was significant resistance from brewery management. While the pilot project treated only 0.15 percent of the brewery’s effluent, plans were underway, as of 2011, to expand the system to treat 30 percent of wastewater (Boswell 2011). Figure 25 shows the constructed wetland and COD levels following initial anaerobic treatment of brewery wastewater. While not designed for social or ecological function, this pilot project demonstrates the capability of constructed wetlands to handle brewery effluent.



Chemical oxygen demand is close to the national discharge limit

Figure 25. Constructed Wetland Treatment of Brewery Effluent at SAM Brewery in Port Elizabeth, South Africa (Boswell 2011)

Subsurface flow (SSF) wetlands (Figure 26) are subdivided into horizontal flow (HF) and vertical flow (VF). This thesis considers HF wetlands only. VF wetlands are discussed in terms of tidal flow wetlands later in this section. In horizontal flow subsurface wetlands, water flows through a gravel or sand medium where it interacts with bacteria attached to the gravel and plant roots in a mix of aerobic and anaerobic conditions (Vymazal and Kröpfelová 2008). HF SSF wetland systems have smaller land requirements than FWS systems and are also not susceptible to odor and mosquito problems, as water is not exposed at the surface. Disadvantages are increased cost due to the required gravel media and the potential for substrate clogging (Crites and Tchobanoglous 1998). SSF wetlands successfully produce a high quality effluent by significantly reducing BOD, TSS, and nutrient loads. BOD removal has shown to be faster and more reliable than FWS systems (Crites and Tchobanoglous 1998). SSF wetlands are more easily used as landscape features than FWS wetlands, as a wide range of plants can be grown in the gravel medium.

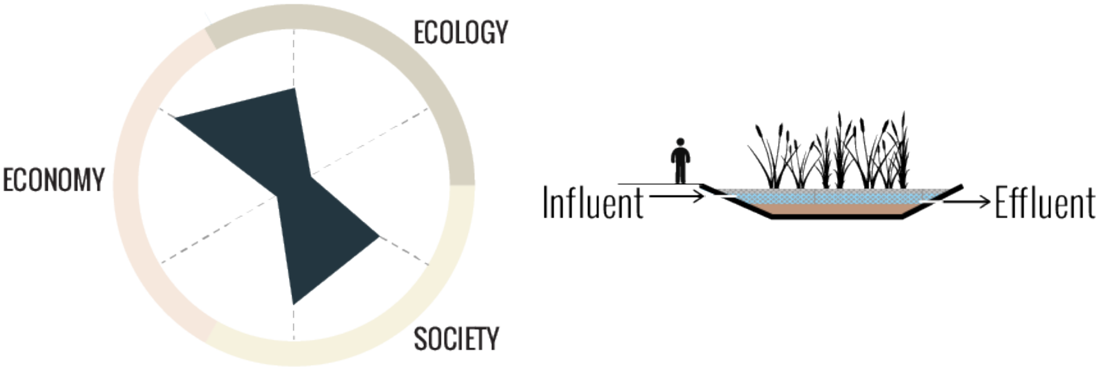


Figure 26. Horizontal Flow Subsurface Wetland (diagram by author)

Economy: SSF wetlands reclaim little value but can be easily expanded to adapt to increasing wastewater flows.

Ecology: Because water is not exposed at the surface, SSF wetlands have little hydrologic function and are not as suitable for wildlife as FWS wetlands. However, SSF wetlands can support a more diverse range of plant species than FWS wetlands.

Society: Because water is not exposed at the surface, SSF wetlands have a lower educational value than FWS wetlands. However, they can be easily used as a landscape, feature since human contact with wastewater is not an issue. Aesthetic value is high since they can support a range of plant species, especially along the wetland edge.

At the Sidwell and Friends School in Washington, D.C., a multidisciplinary team of landscape architects, architects, and engineers designed a constructed wetland system to treat and reuse domestic wastewater. Integrating architecture and landscape, the wetland system enhances the function of both by supplying building processes with recycled water and creating an educational destination for students and the public. Sewage from the building undergoes primary treatment in an underground tank and is then pumped to the horizontal flow subsurface wetland where it undergoes secondary treatment. Lined with gravel and planted with a diversity of plant species, the wetland is terraced to increase the hydrologic flow length and enhance visual appeal. The system receives up to 3,000 gallons per day and retains water for four to six days before it is recycled for use in toilet flushing and utility cooling (Biohabitats 2014, Margolis and Robinson 2007).

The design also captures rainfall from the roof and directs it to the pond. Doubling as an outdoor classroom, the pond is a year-round water feature utilizing an underground cistern to store and feed water during times of low rainfall. During times of heavy rain, stormwater overflows to a rain garden where it is infiltrated.

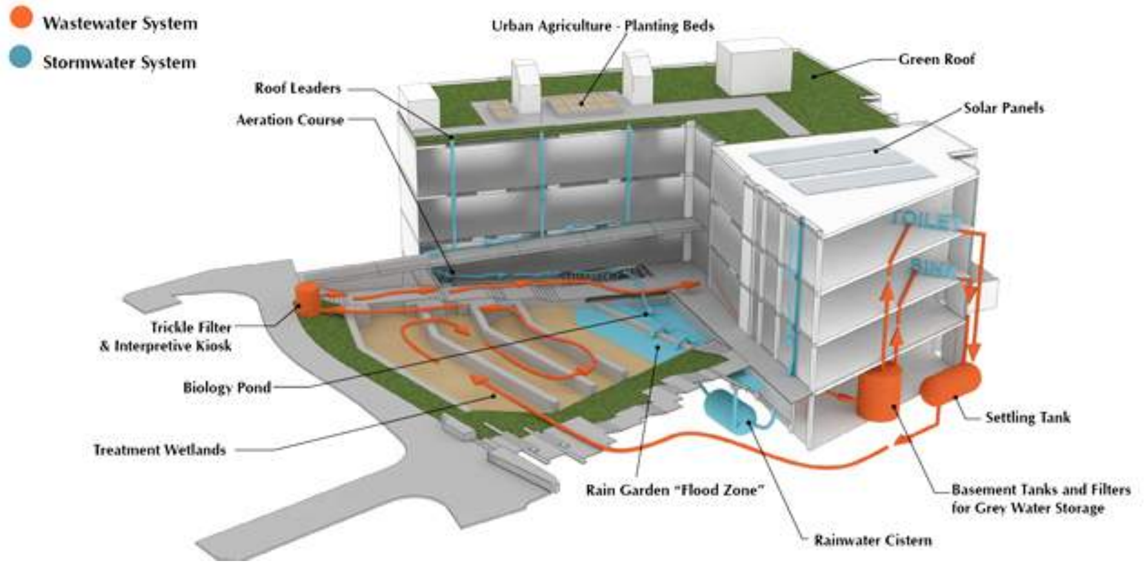


Figure 27. Sidwell and Friends School Wastewater and Stormwater Systems (Kieran Timberlake 2015)

Figure 28. Constructed Wetland and Stormwater Pond (Kieran Timberlake 2015)

Using principles of natural systems similar to constructed wetlands, proprietary wastewater treatment systems have been developed to treat wastewater from a variety of sources. These systems are typically designed and installed by individual manufacturers and their agents. They are typically contained systems, as opposed to constructed wetlands that are embedded within the landscape. Generally, wastewater undergoes aerobic or anaerobic pretreatment before entering the systems.

Eco-Machines (Figure 29) utilize a series of tanks that house floating plant masses to treat wastewater, similar to a FWS CW. Water flows through a series of tanks where biological processes improve wastewater quality. Tanks are typically indoors but may exist outside depending on local climate. Eco-Machine systems are not limited by size of wastewater flow and can be easily scaled to meet large treatment demands. They also provide an attraction and easily serve as educational tools for wastewater treatment. (Ogden 2012, Todd 2004)

Besides plants, Eco-Machines use a diverse array of organisms to improve wastewater quality, from bacteria and micro-crustaceans to clams and fish. Organisms are selected based on their ability to function within the system, but also to provide economic value. Marketable byproducts include young trees, plants, and fish both ornamental and useful in environmental remediation projects (Todd, Brown, and Wells 2003).

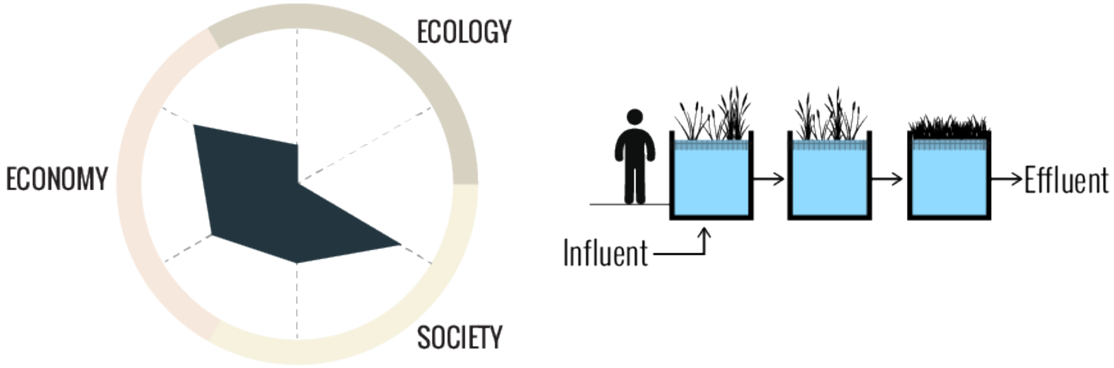


Figure 29. Eco-Machine (diagram by author)

Economy: Eco-Machines can be used to produce a diverse array of marketable products and can be easily expanded to handle larger wastewater flows.

Ecology: Eco-Machines can employ a range of plant and animal species, but are typically highly controlled and not accessible to wildlife. Because they are contained and likely indoors, they offer no hydrologic value.

Society: Because they typically operate indoors, Eco-Machines are a great educational tool. However, their ability to function as an outdoor landscape feature is limited.

Eco-Machines have been demonstrated to treat brewery effluent and other industrial wastewaters from food production, responding well to wide fluctuations in wastewater flows and strength. In 1997, an Eco Machine was installed in Glenn Allen, California at Sonoma Mountain Brewery. Capable of treating 7,800 gallons of wastewater per day, the system could be easily expanded as production increased. Disconnected from municipal sewage infrastructure, the brewery recycled or reused all of its solid and liquid waste. Treatment began with two small closed aerobic reactors followed by a series of open planted tanks for additional BOD reduction (figures 30 and 31). Resulting biosolids were composted and used as fertilizer. Cleaned wastewater was sent to a storage pond and cycled through a constructed wetland before it was reused. (Todd, Brown, and Wells 2003)

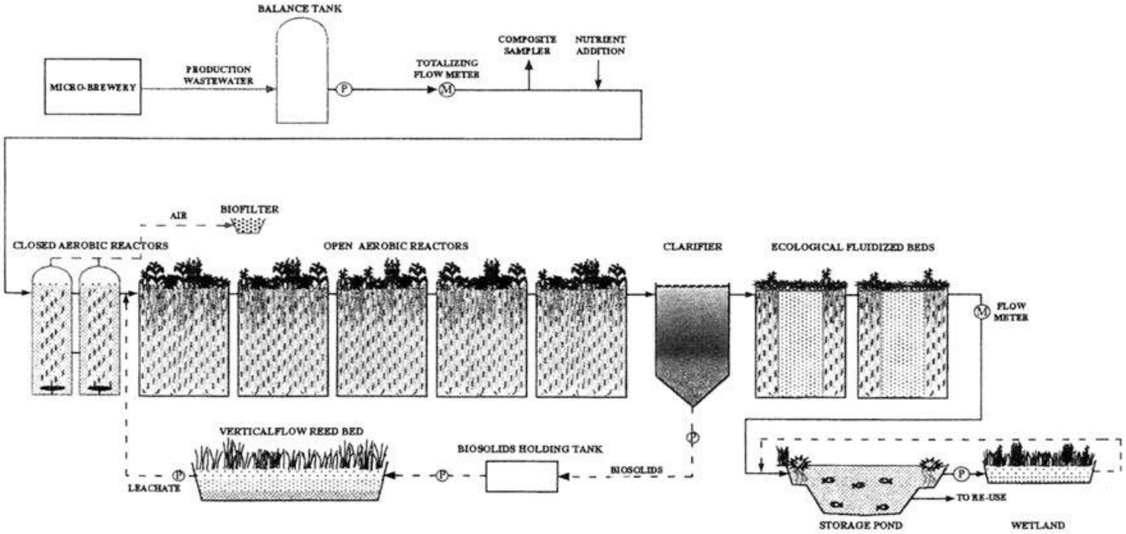


Figure 30. Sonoma Mountain Brewery Eco-Machine System (Todd, Brown, and Wells 2003)

Figure 31. Eco-Machine Planted Tanks (John Todd Ecological Design 2010)

Tidal flow subsurface wetlands (Figure 32) utilize a vertical, tidal flow system where wastewater is cycled vertically through the gravel medium multiple times per day. The tidal flow provides better aeration for plant roots and aerobic microbes in the gravel medium, facilitating faster treatment times that horizontal flow SSF wetlands (Crites, Middlebrooks, and Bastian 2014). Because wastewater is never exposed to the wetland surface, tidal flow wetlands can be easily used as landscape features.

The Living Machine system is a proprietary technology that uses a contained, aboveground tidal flow system to treat wastewater. Primary treatment and flow equalization take place before wastewater is pumped to contained wetland cells filled with a gravel medium and planted with an array of plants. Micro-ecosystems within the gravel medium improve wastewater quality before it passes on to final filtration and disinfection. Living Machine systems have been used as both indoor and outdoor site amenities.

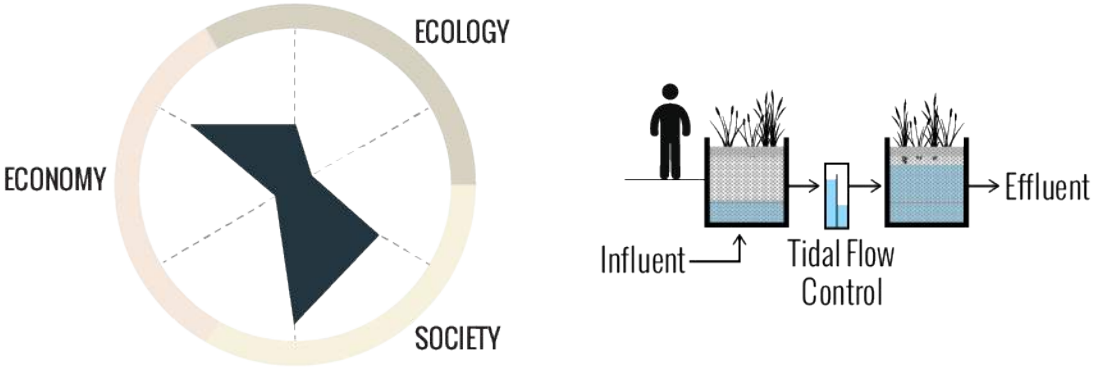


Figure 32. Tidal Flow Wetland (diagram by author)

Economy: Living Machines reclaim little value, but are easily expanded to accommodate larger flows.

Ecology: Outdoor Living Machines can support native plant species, but are not valuable to wildlife besides pollinators. Contained, they have no hydrologic value.

Society: Operating similarly to HF SSF wetlands, Living machines can be easily used as a landscape feature that is highly interactive (Figure 33). Aesthetic value can be high, depending on plant selection.

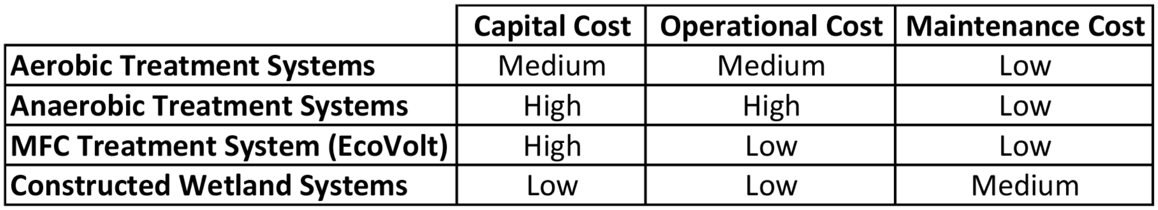
Figure 33. Tidal Wetland Cells as Site Feature (Living Machines 2013)

In 2012, a Tidal Flow Wetland Living Machine was installed at the San Francisco Public Utilities Commission to treat the building's wastewater. As seen in Figure 33, the wetland cell can be easily used as a site amenity. Using indoor and outdoor tidal flow and vertical flow wetland cells, the system reduces water use by over 70 percent, treating over 900,000 gallons for non-potable reuse per year (Living Machines 2013). First, primary treatment significantly reduces wastewater BOD and TSS and is followed by a Living Machine system. Following pretreatment, tidal flow wetland cells reduced BOD from 228.5 to nearly zero (Living Machines 2013). Native plantings were chosen based upon their low light and maintenance requirements.

Cost of Stage 1 and Stage 2 Treatments

While capital, operational, and maintenance costs associated with stage 1 and 2 treatments were not fully considered for this thesis, they are broadly compared to one another in Table 2.

Table 2. Capital, Operational, and Maintenance Costs of Stage 1 and 2 Treatments (diagram by author)



	Capital Cost	Operational Cost	Maintenance Cost
Aerobic Treatment Systems	Medium	Medium	Low
Anaerobic Treatment Systems	High	High	Low
MFC Treatment System (EcoVolt)	High	Low	Low
Constructed Wetland Systems	Low	Low	Medium

Capital costs are highest for anaerobic and MFC systems (Brewers Association 2012b), however, their operational costs are lower due to lesser energy requirements than aerobic systems. MFC operational costs are lower then anaerobic systems because they offset a greater percentage of energy needs by producing a higher-quality biogas. Constructed wetland technologies require low capital and operational investment, but require more frequent maintenance than other systems (Campbell and Ogden 1999). Routine maintenance of all systems is minimal, but occasional large repairs are necessary. These are largely mechanical repairs for aerobic, anaerobic, and MFC systems, while wetland technologies may require replanting or reinstallation of planting or filter mediums (Campbell and Ogden 1999, Crites, Middlebrooks, and Bastian 2014).

Stage 3: Wastewater Reclamation

In this section, options for disposal and reclamation are discussed. Each method is broadly described and is evaluated based on the six criteria presented in the previous chapter. Radar diagrams based on the six evaluation criteria characterize each treatment method’s ability to address each of the criteria.

Land application (Figure 34) is when treated wastewater is applied directly to the landscape via spray or drip irrigation, and disposes of treated water while also watering crops or ornamental vegetation. Small amounts of nutrients, like nitrogen and phosphorus, that remain in the wastewater can serve as a fertilizer for agricultural production (Crites, Middlebrooks, and Bastian 2014). Land application of treated wastewater can also prioritize groundwater recharge by infiltrating water through permeable basins.

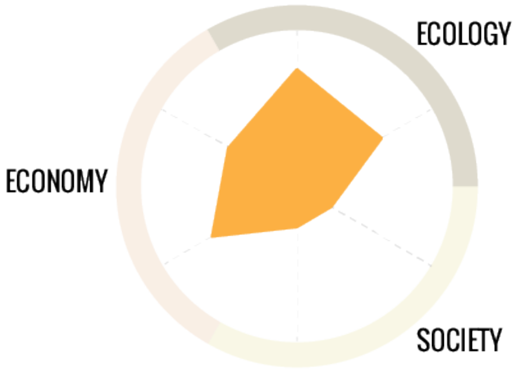


Figure 34. Landscape Application (diagram by author)

Economy: Reusing water for crop or landscape irrigation can offset existing water costs and may also fertilize crops with residual nutrients. Water flows are easily adjusted to respond to increased water flows, but may be limited by the capacity of the landscape to absorb greater amounts of water.

Ecology: Depending on the particular use, water applied to the landscape can increase habitat value by providing a resource for local wildlife. Hydrologic function is addressed through groundwater recharge and evaporation.

Society: While not necessary a visible component of the landscape in itself, land-applied water can benefit ornamental plantings and indirectly educates visitors on water reuse.

Surface release (Figure 35) of treated wastewater to local water bodies is regulated by the NPDES, but has the potential to benefit local ecologies and hydrologic cycles (Ogden 2012, Crites, Middlebrooks, and Bastian 2014). To ensure positive impacts, effluent quality should be constantly monitored and hydrologic system properly assessed.

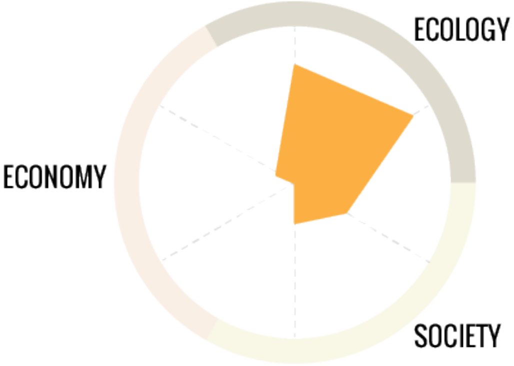


Figure 35. Release to Surface Water (diagram by author)

Economy: Release to surface waters does not reclaim value from the effluent. Adaptability of effluent flow is dependent on the size of the water body and may be limited due to negative impacts on wildlife and the water body itself.

Ecology: Effective release of treated wastewater to surface waters is dependent on site conditions. Discharge can enhance existing riparian wildlife habitats and hydrologic systems, but also has the potential to damage them if water flows are not frequently monitored and controlled.

Society: Discharge to surface waters has the potential to educate visitors on water reuse and may also enhance aesthetics and experience.

Reuse (Figure 36) of treated wastewater for non-potable and potable uses is possible following nanofiltration or reverse osmosis treatment (Simate et al. 2011). Nanofiltration and reverse osmosis differ in their ability to treat wastewater. Reverse osmosis can treat higher-strength wastewater to reuse standards better than nanofiltration, but requires significant operational costs (Simate et al. 2011). While it cannot treat low quality wastewater, nanofiltration is significantly less expensive to operate than reverse osmosis and has been demonstrated to treat brewery effluent following biological treatment to reuse standards (Braeken, Van der Bruggen, and Vandecasteele 2004). Non-potable water is also commonly reused in buildings for toilet flushing and utilities cooling.

Simate et al. (2011) identify two primary applications for the reuse of brewery wastewater within the industrial process. The first is potable water used directly in the production of beer. The second is non-potable water used for cleaning, bottle rinsing, and utilities cooling. While the second use is becoming more common, the first is limited by local and federal regulations and overall public perception. Simate et al. (2011) predict that as perception and regulations change in the future, a beer to water ratio of 1:2 can be achieved, far surpassing the common ratio of 1:7.

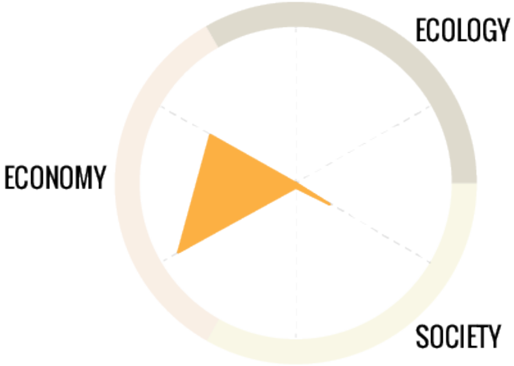


Figure 36. Water Reuse (diagram by author)

Economy: The reuse of treated wastewater within the brewery can greatly reduce water consumption and save money. Water can also be reused for a variety of purposes, both within and outside of the brewery operations.

Ecology: If reused for industrial or building processes, water has no direct ecological value.

Society: The reuse of brewery water has the potential to educate visitors within the brewery, but it has no impact on landscape function and aesthetics.

Reuse in the landscape (Figure 37), such as in a fountain, is another option for wastewater treated via nanofiltration or reverse osmosis. Water reuse as a landscape feature has been demonstrated in many projects, including the Sidwell and Friends School discussed previously (Biohabitats 2014).

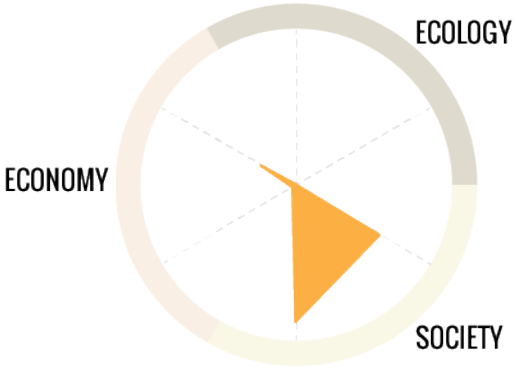


Figure 37. Reuse in Landscape (diagram by author)

Economy: By themselves, landscape features do not reclaim any monetary value, and are assumed to be only slightly adaptable, although this is dependent on the specific use.

Ecology: Use of water for a landscape feature does not directly affect habitat or hydrologic function, but may be used prior to another strategy discussed above.

Society: Landscape features have the potential to engage visitors by facilitating interaction, and can easily serve as an educational tool.

Conclusion

A comparison of all treatment stage evaluations is shown in Figure 39, illustrating the evaluation criteria presented in Figure 38.

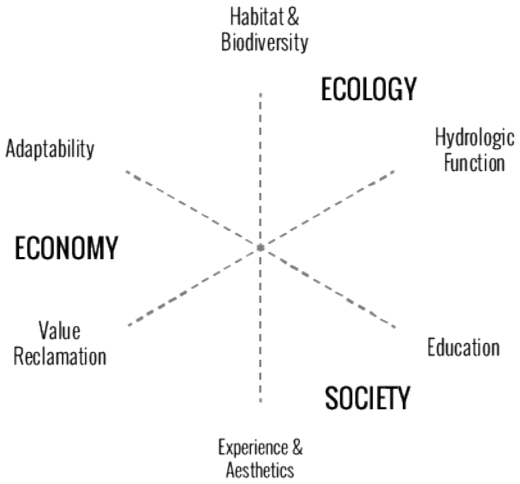


Figure 38. Evaluation Criteria (diagram by author)

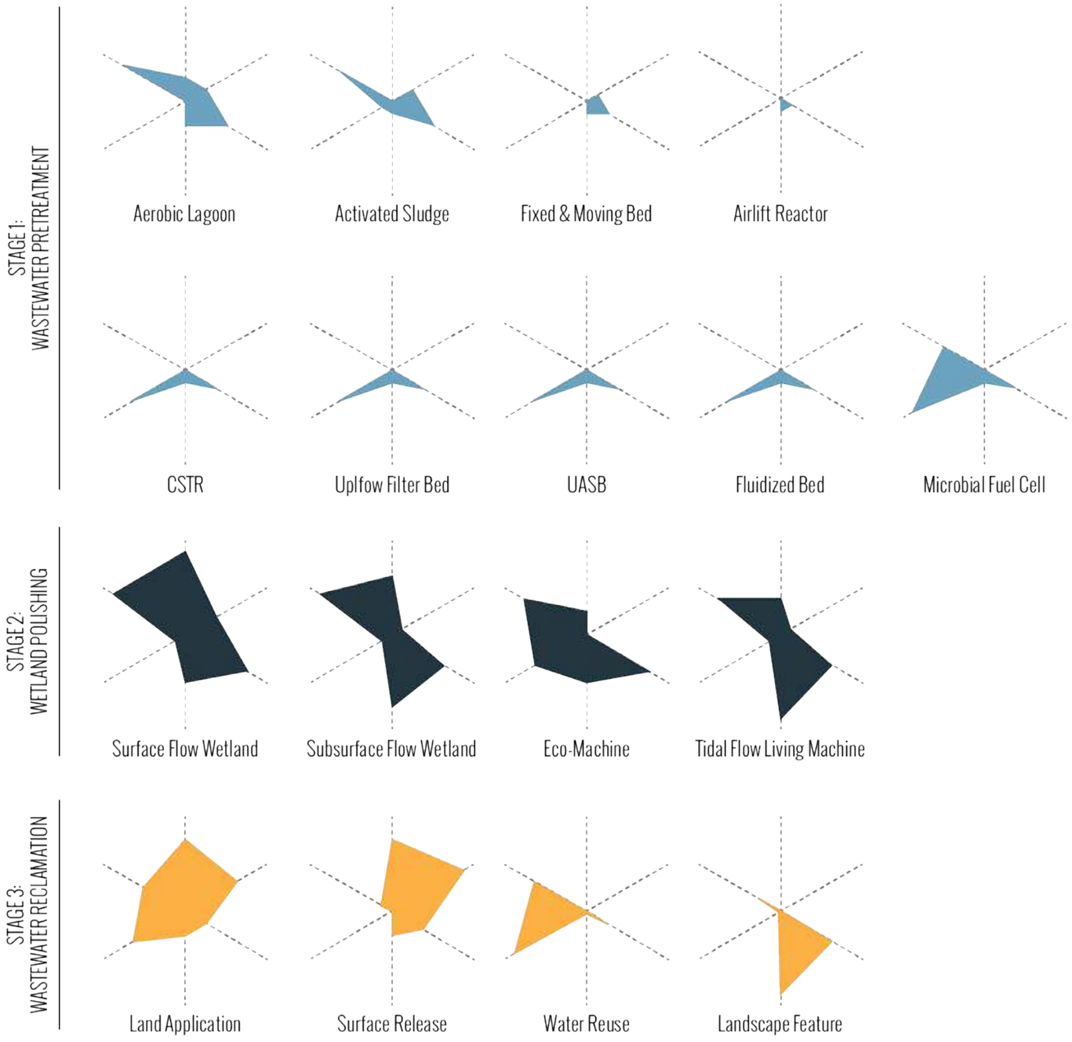


Figure 39. Treatment Stage Comparison (diagram by author)

Wastewater pretreatment technologies have steadily improved over time. Early technologies, like aerobic lagoons and activated sludge systems, require large amounts of land and energy inputs and are quickly being replaced by smaller and less energy-consumptive anaerobic systems (Van Lier 2008). While anaerobic systems hide the treatment process once present in open basins aerobic systems, their added benefits of biogas generation, small footprints, and lower operating costs make them more desirable. However, their inability to adapt to changing wastewater flows can pose problems for a growing industry. New technologies, like the microbial fuel cell, have the added benefit of scalability, along with highly efficient energy production.

Constructed wetland technologies, used here for wastewater polishing, are able to integrate social interaction and ecological function much more easily than pretreatment systems. The four treatment systems evaluated here operate similarly in their ability to treat wastewater, but have tradeoffs in their ability to address social and ecological criteria. Subsurface systems, like typical SSF wetlands and Living Machine systems are much more easily used as a landscape feature and as a result are assumed to improve experience and education. FWS wetlands, while not as conducive to human interaction, have high ecological value. Eco-Machines stand alone in their ability to reclaim significant value from wastewater through a variety of marketable byproducts grown in the treatment cells, although doing so would require more maintenance than the other systems considered here. The use of each of these four treatment methods is highly dependent on site contexts.

Stage 3 reclamation strategies are also highly dependent on site context and may also be used in conjunction with each other. Based on evaluation, water reclamation strategies can be used to address economic, ecological, and/or societal concerns, although they may vary in implementation costs and can be impacted by existing regulations.

CHAPTER 5

PROJECTIVE DESIGN AT TERRAPIN BEER COMPANY

Using earlier evaluations of individual treatment stages and systems, this chapter will develop a set of treatment typologies for Terrapin Beer Company that aim to maximize each of the three evaluation categories: economy, ecology, and society. These typologies are compared to the current best practices for the on-site treatment of brewery effluent and are considered in the development of a proposed treatment system and site design at Terrapin later in this chapter.

Brewery Profile and Wastewater Issues

Terrapin Beer Company is a medium-sized craft brewery located in Athens, Georgia. A burgeoning beer city of 115,000 people, Athens is home to four breweries and brewpubs, two of which have been established since 2014. Established in 2002, Terrapin got its start at the annual Classic City Beer Fest and has grown quickly in the years since. Terrapin is located north of the downtown center and regularly holds public beer tastings and private events at their 40,000 square foot facility. Hosting up to 800 people five days a week, Terrapin boasts an outdoor entertainment area with a large lawn and performance stage, as well as a new indoor tasting room that opened in January 2015.

Figure 40. Terrapin Beer Company - Athens, GA (photo by author)

Since establishment, Terrapin has consistently expanded production and currently sells beer in ten states throughout the Southeast and East Coast. In 2012, the brewery installed a new 100-barrel brewhouse that significantly increased production. Brian Hollinger, Terrapin Beer Co. VP of Operations, projects the brewery will produce 65,000 barrels of beer in 2015, and will continue to expand in the future (personal communication with author, 1/15/2015).

Like most breweries, Terrapin relies on the city for its water and wastewater needs. Shown in Figures 41 and 42, wastewater from Terrapin Beer Co. flows to the municipal sewers and is treated at the North Oconee Water Reclamation Facility (WRF). The North Oconee WRF was built in 2012 and is capable of treating 14 million gallons of wastewater per day, and currently treats around 7 million gallons per day (PUD

Compliance Coordinator David Bloyer, personal communication with author, 1/28/15). While Terrapin's wastewater does not cause problems at the treatment facility, it regularly exceeds quality limits set by the Athens-Clarke County (ACC) Public Utilities Department.

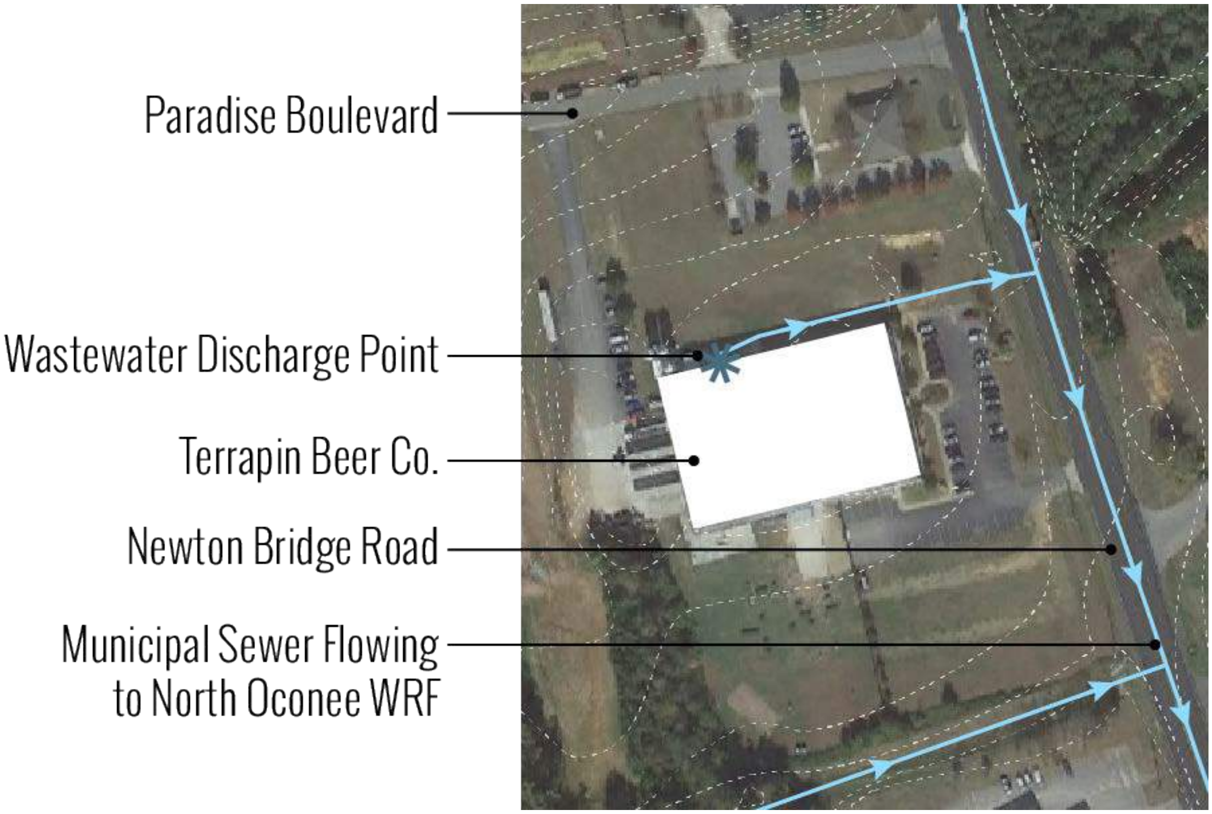


Figure 41. Wastewater Discharge at Terrapin (diagram by author)

Figure 42. North Oconee Watershed and Sewer System (diagram by author)

As Terrapin has expanded, its water consumption and wastewater production have increased. Figure 43 shows monthly water consumption from December 2013 through September 2014. Daily water usage, shown in Figure 44, fluctuates much more widely than monthly water volumes. Some of this incoming water is used in beer, but much of it is used for other applications like cleaning and bottle rinsing. Wastewater leaving Terrapin greatly exceeds wastewater quality requirements set by Athens-Clarke County. Table 3 shows the average quality of Terrapin's wastewater compared to ACC requirements.

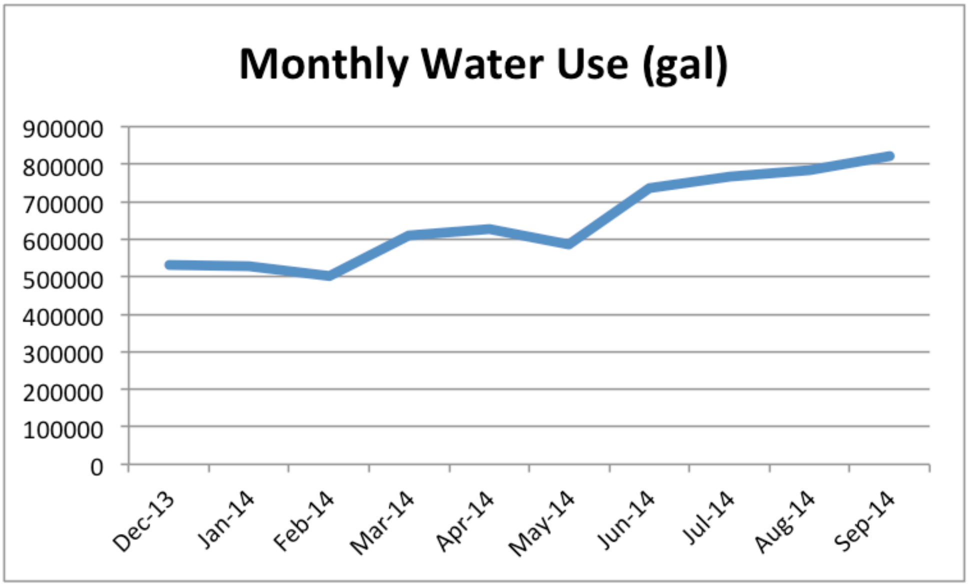


Figure 43. Monthly Water Use at Terrapin Beer Co. from December 2013 through September 2014 (data from Terrapin Beer Co., 2015)

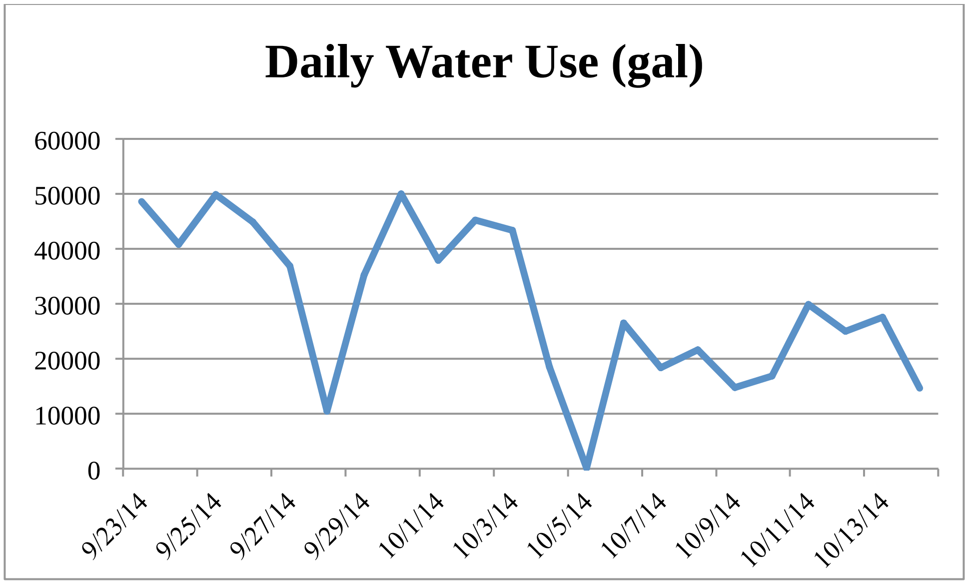


Figure 44. Daily Water Use at Terrapin Beer Co. from Sept 23, 2014 through Oct 13, 2014 (data from Terrapin Beer Co., 2015)

Table 3. Average Wastewater Quality at Terrapin Beer Co. for Nine Sampling Days Between 7/25/2014 and 9/30/2014 (data courtesy Terrapin Beer Co. and David Bloyer, ACC PUD Compliance Coordinator)

	Average	Max	Min	ACC Surcharge Level	ACC Maximum Levels
COD (mg/L)	14108.57	25100	9060	Not Stipulated	Not Stipulated
BOD (mg/L)	7640	13900	5510	250	500
Soluble BOD (mg/L)	7160	13400	5060	Not Stipulated	Not Stipulated
TSS (mg/L)	1886.44	4700	300	250	500
FOG (mg/L)	23.71	40	9	101	200
pH	7.09	10.8	5.12	Not Stipulated	6 to 9
Kjeldahl Nitrogen (mg/L)	148.73	226	78	Not Stipulated	100
Phosphorus (mg/L)	38.24	61.1	20.1	Not Stipulated	15

Using available data, Terrapin's effluent was calculated to have an average BOD of 7,640 mg/L, well above the standard brewery effluent BOD of 1,200-3,600 mg/L (Simate et al. 2011). However, average TSS (1,886.44 mg/L) is well below the standard TSS of brewery effluent (2901-3000 mg/L) (Simate et al. 2011). While internal process improvements could potentially lower high BOD levels, this thesis bases treatment systems and sizing on the data currently available and assumes the continuation of current practices.

Of concern to Athens-Clarke County, are the levels of BOD, TSS, pH, nitrogen, and phosphorus. The ACC Public Utilities Department currently charges $300 per 1,000 pounds ($.30 per pound) of BOD and TSS over 250 milligrams per liter (ACC Public Utilities Department 2014). The Public Utilities Department assumes all water entering the facility exits as wastewater and calculates quality surcharges based upon water usage volume, not wastewater discharge volume (ACC Water Business Office employee, 2/06/2015, personal communication with Author). Since some of the wastewater leaves Terrapin as bottled beer, this billing practice charges Terrapin for wastewater it did not produce. Terrapin's disposal of wastewater to the municipal system currently incurs as much as $20,000 per month in surcharges. Table 4 shows water use and wastewater disposal charges for three months in 2014.

Table 4. Total Water and Wastewater Fees at Terrapin Beer Co. for July, August, and September 2014 (data courtesy Terrapin Beer Co.)

	Jul-14	**Aug-14**	**Sep-14**
Water Usage (Gal)	767230	784580	822730
Water Charges (including fees)	$12,937.20	$13,215.26	$13,889.60
Avg BOD per Day (mg/L)	6555	9250	6975
Surcharged BOD (lb)	40285.22	58805.08	46077.05
Avg TSS per Day (mg/L)	2449	1460	1925
Surcharged TSS (lb)	14050.31	7906.02	11476.44
Surcharge Total (@ $.30/lb)	$16,300.66	$20,013.33	$17,266.05
Total Water and Wastwater Fees	**$29,237.86**	**$33,228.59**	**$31,155.65**

Because wastewater quality regularly exceeds maximum allowable levels, Terrapin will be required to pretreat wastewater on site before sending it to the treatment facility. While capital investments are not considered in this thesis, surcharge fee savings would eventually offset upfront cost of the on-site wastewater treatment system. The typical approach to on-site brewery wastewater treatment is to pretreat wastewater to levels below regulatory requirements and release treated water to the municipal system without surcharges. Described below, New Belgium Brewery's pretreatment facility is considered the brewing industry's current best practice for wastewater pretreatment.

Current Best Practice: New Belgium Brewery

New Belgium Brewery in Fort Collins, Colorado is regarded as one of the most sustainable breweries in the U.S. and is the third largest craft brewery in the country (McWilliams 2014). As a company, New Belgium is committed to sustainable business practices and regularly distributes a sustainability report that highlights the brewery's attempts to improve water use, waste reduction, and on-site energy production (New

Belgium 2014). For the purposes of this thesis, the on-site wastewater treatment system at New Belgium is considered the brewing industry's current best practice, and is a potential option for the treatment of Terrapin's effluent.

New Belgium uses a combined aerobic and anaerobic system to pretreat its wastewater. Biogas from an initial anaerobic digester is sent to a combined heat and power unit, and offsets 15 percent of electricity energy needs (McWilliams 2014). Following initial bulk BOD reduction and biogas production, effluent is sent to an aerobic activated sludge system for polishing. The aerobic system serves to lower BOD to required levels before wastewater is sent to the treatment plant (McWilliams 2014, Brewers Association 2012b). While it is currently sent to the local municipality to be retreated, the highly purified wastewater could be discharged in a nearby stream or further processed for reuse (McWilliams 2014). Similar treatment systems have been widely adopted in the brewing industry (Van Lier 2008). The stages of New Belgium's pretreatment system are shown in Figure 45.

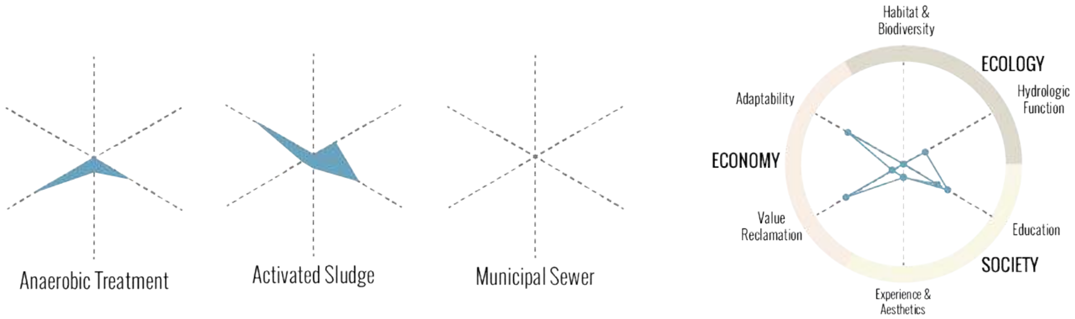


Figure 45. Standard Best Practice for Wastewater Pretreatment (diagram by author)

While New Belgium's treatment system has the potential to address economic and, to some extent, social concerns, it has little ecological value. Additional insights into social impacts can be seen from an aerial view of the New Belgium site shown in Figure

46. The treatment system is located far away from the main production facility that is commonly used for beer tastings and tours (New Belgium 2014). In a phone conversation with the author (3/2/2015), a New Belgium staff member stated that the wastewater treatment facility is not part of the standard brewery tour and can be quite odorous. However, a series of informal bike trails and paths surrounding the facility are periodically used for bike races (New Belgium employee, phone conversation with author, 3/2/2015). While wastewater treatment generates valuable biogas and improves the brewery's image, it diminishes the value of the surrounding social space. It is the opinion of the author that nearby vacant lands could potentially be used for land-based treatment in constructed wetlands that enhance the New Belgium property and serve as a valuable recreational and ecological amenity for several nearby neighborhoods.

Figure 46. New Belgium Brewery Site Plan (diagram by author)

While pretreating wastewater and releasing it to the municipal sewer is one option for Terrapin, this thesis seeks to expand the current model of wastewater treatment in the brewing industry to include on-site water reclamation through treatment systems that serve multiple functions and reclaim value from wastewater.

Feasibility of Stage 1 Treatment Systems

While treatment methods were described and evaluated in Chapter Four, the ability of Stage 1 treatment methods to be incorporated into a wastewater treatment system at Terrapin Beer Co. are limited by two factors: land availability at Terrapin and the ability of constructed wetland systems to effectively polish Terrapin's effluent following Stage 1 of treatment.

Land Availability at Terrapin Beer Co.

Currently, Terrapin Beer Co. leases 5.697 acres for their facility along Newton Bridge Road. Shown in Figure 47, two neighboring parcels are being considered for purchase and could potentially be used for brewery expansion and wastewater treatment (Brian Hollinger, conversation with author, 1/15/2015).

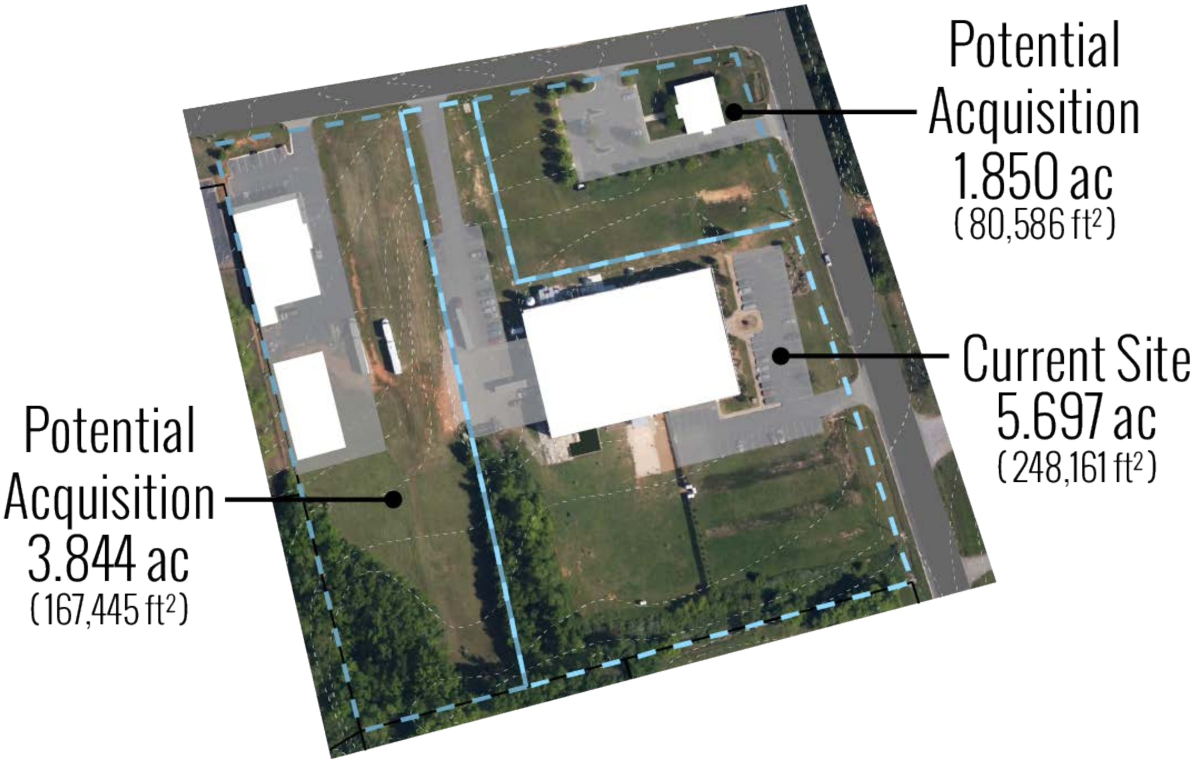


Figure 47. Current Site and Potential Land Acquisitions (diagram by author)

Since land availability around Terrapin is limited, primary treatment options that have small site footprints are preferred. Table 5 shows sizing and land requirements of Stage 1 treatment methods using wastewater metrics from Terrapin. The calculated reactor volume and the on-site condition of the treatment method inform land requirements, which are shown in Table 5. Low land requirements are preferred, while high land requirements are considered unfeasible.

Table 5. Sizing and Land Requirements of Stage 1 Treatment Methods at Terrapin Beer Co. (table by author)

Type of Treatment	Volumetric Loading Rate (lb COD/cubic ft per day)	Volume of Aerobic Reactor (cubic ft)	On-Site Condition	Land Requirement of Treatment Method
Aerobic				
Lagoon	0.01	1,231,398	Open Basin	High
Activated Sludge	.03-.14	49,256-246,280	Open Basin	High
Fixed/Moving Bed	.06-.29	24,628-123,140	Closed or Open Tank	Medium
Airlift-reactor	.29-.57	12,314-24,628	Tank	Low
Anaerobic				
CSTR	.06-.29	24,344-117,661	Tank	Medium
Upflow Filter Bed	.29-.57	12,385-24,344	Tank	Low
UASB	.29-.86	8,209-24,344	Tank	Low
Fluidized Bed	.86-1.72	4,104-8,209	Tank	Low
Microbial Fuel Cell				
EcoVolt	N/A	N/A	Container	Low

Treatment options are sized to treat 30,000 gallons of incoming wastewater per day with an average COD of 14,108 mg per liter. These values were determined using the data from Terrapin Beer Co. shown in Table 3. Thresholds for land requirements considered the low value of the calculated reactor volume. The high threshold is above 49,000 cubic feet, the medium above 24,000 cubic feet but below 49,000, and the low threshold is below 24,000 cubic feet. Sizing of the EcoVolt system is not informed by the volumetric loading rate, but is affected by wastewater composition and flow. As wastewater flows increase and wastewater quality decreases, the EcoVolt system can expand to include more treatment containers (Cambrian Innovation 2014). Expansion does not affect site footprint since containers can be stacked.

While the average wastewater production for Terrapin is 21,000 gallons per day (assuming the industry standard of 70 percent of incoming water discharged as effluent), the value of 30,000 gallons was used to account for an increase in future production. Sizing of treatment options is determined based on volumetric loading rates of the different treatment methods using Equation 1 given by Crites and Tchobanoglous (1998). BOD removal efficiencies are given by Crites and Tchobanoglous (1998). Resulting treatment volumes were then multiplied by a factor of 2 in order to ensure maximum treatment efficiencies, as advised by Crites and Tchobanoglous (1998).

$$V = \frac{CQF}{L_{org}}$$

V = volume of reactor (ft^3)
C = concentration of organic or volatile material in wastewater (mg COD/L)
Q = wastewater flowrate (gal/day)
F = conversion factor 8.34lb/gal(mg/L)
L_{org} = volumetric loading rate (lb COD/ft^3 per day)

Equation 1. Sizing Aerobic and Anaerobic Treatment Systems (Crites and Tchobanoglous 1998)

Stage 1 Treatment and Wetland Function

The effectiveness of wetland technologies described and evaluated in Chapter Four is dependent on the quality of effluent from stage 1 of treatment. Nutrient removal reflects the ability of stage 1 systems to remove Nitrogen and Phosphorus during treatment. While total nutrient removal is typically desirable from these systems, wetland technologies benefit from low amounts of nutrient input (Campbell and Ogden 1999).

Wetland technologies are susceptible to clogging if high levels of solids are present in the wastewater (Crites, Middlebrooks, and Bastian 2014, Campbell and Ogden 1999). Stage 1 treatment options are less preferred if they require removal of solids via external clarification following treatment. Table 6 shows the impact of stage 1 treatment methods on wetland function. BOD (mg/L) remaining following stage 1 of treatment informs the sizing of wetland technologies. The lower the BOD remaining in the effluent, the less land required for stage 2 wastewater polishing.

Table 6. Stage 1 Treatment Methods Inform Wetland Function (table by author)

Type of Treatment	Nutrient Removal	External Clarification Necessary	BOD Removal Efficiency	BOD Remaining in Effluent Following Stage 1
Aerobic				
Lagoon	High	No	.90-.98	153-382
Activated Sludge	High	Yes	.90-.98	153-382
Fixed/Moving Bed	High	No	.90-.98	153-382
Airlift-reactor	High	Yes	.90-.98	153-382
Anaerobic				
CSTR	Medium	Yes	.75-.90	764-1,910
Upflow Filter Bed	Medium	No	.75-.90	764-1,910
UASB	Medium	No	.65-85	1,146-2,674
Fluidized Bed	Medium	No	.80-.95	382-1,528
Microbial Fuel Cell				
EcoVolt	Medium	No	.80-.90	764-1,528

Given these additional criteria, anaerobic (with the exception of the CSTR) and MFC systems are the best options for on-site wastewater treatment at Terrapin Beer Co. Treatment systems that are not feasible are not considered in the development of the following typologies that aim to maximize each of the three evaluation categories: ecology, economy, and society.

Wastewater Treatment Typologies

The following wastewater treatment typologies aim to maximize each of the three evaluation categories: economy, ecology, and society. The purpose of developing a set of typologies is to see how different stages of treatment can be combined to address site-specific concerns in each of the three categories. Treatment and reclamation methods are selected based on their ability to address the category of interest compared to other treatment options within each treatment stage. When treatment and reclamation methods are equal in their ability to address the category of interest, the method that has the most benefit to other categories is used.

Economy Typology

Shown in Figure 48, the Economy Typology maximizes value reclamation and system adaptability. An EcoVolt using MFC technology is first used for initial pretreatment and reclaims value from wastewater in the form of high quality biogas that can be used to heat brewery boilers or can be converted to electricity and heat using a CHP unit. Next, an Eco-Machine polishes wastewater and is capable of producing a range of marketable byproducts. While selected for its potential economic benefit, the Eco-Machine also functions well in education and as a site feature. Finally, wastewater is reused for internal processes after being treated using nanofiltration or reverse osmosis. The added economic benefits are offset energy and water costs, as well as the products from the Eco-Machine system.

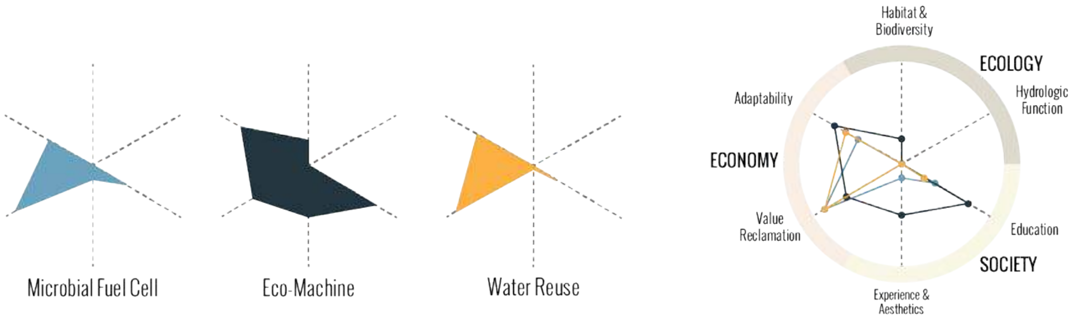


Figure 48. Economy Typology (diagram by author)

Ecology Typology

Shown in Figure 49, the Ecology Typology aims to maximize hydrologic function, as well as habitat and biodiversity. First, microbial fuel cell technology is used to greatly reduce the BOD and TSS in the brewery effluent. While an aerobic lagoon offers the most ecological value of all the first stage treatments, its large land requirement makes it unfeasible for use at Terrapin. Surface flow wetlands polish wastewater and have very high habitat and biodiversity potential. Surface release of treated wastewater, while regulated, contributes to hydrologic function and habitat value. Released water also has the potential to positively impact ecological communities downstream.

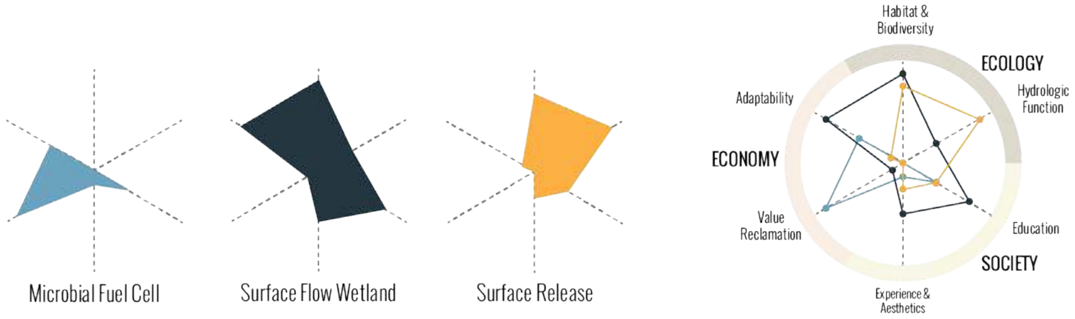


Figure 49. Ecology Typology (diagram by author)

Social Typology

Maximizing education and visitor experience, the Social Typology is shown in Figure 50. Again, microbial fuel cell technology greatly lowers BOD and TSS before wastewater is sent to stage 2 of treatment. The microbial fuel cell offers similar social value to other feasible stage 1 treatment methods, but was chosen based on its additional economic benefits. Stage 2 uses a tidal flow subsurface wetland to polish wastewater. The tidal flow subsurface wetland facilitates greater social interaction than other wetland technologies, and can be easily used as an educational tool. Reusing water in a landscape feature enhances both visitor experience and education. Because use in a landscape feature requires nanofiltration or reverse osmosis, reclaimed water can also be used for internal brewery processes.

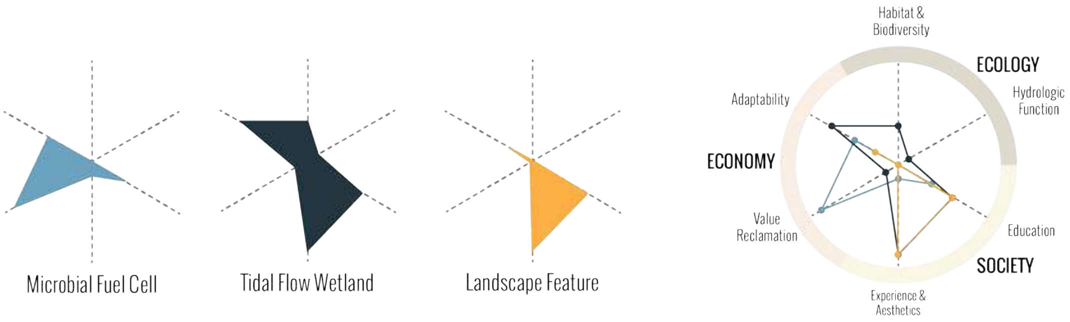


Figure 50. Society Typology (diagram by author)

Typology Comparison

Figure 51 compares the three treatment typologies developed here to the current best practice for on-site treatment of brewery effluent. The typologies developed in this thesis clearly address the categories of ecology and society better than the standard best practice. While best practices address the economic category, the three typologies diversify value reclamation beyond energy production, and are more easily adapted to changing wastewater flows.

When comparing the three typologies to one another, the Ecology Typology best addresses the other two criteria categories, while also maximizing ecological function. This is largely due to the inability of stage 1 treatment methods to address ecological criteria, and as a result, the economic category is supported.

The three typologies developed here expand the current model of on-site wastewater treatment beyond the current focus on energy production to include social and ecological concerns, while also increasing the capability of value reclamation. Next, these typologies are used to inform the development of a proposed wastewater treatment system at Terrapin Beer Co. that responds to existing site conditions and existing economic, ecological, and social opportunities.

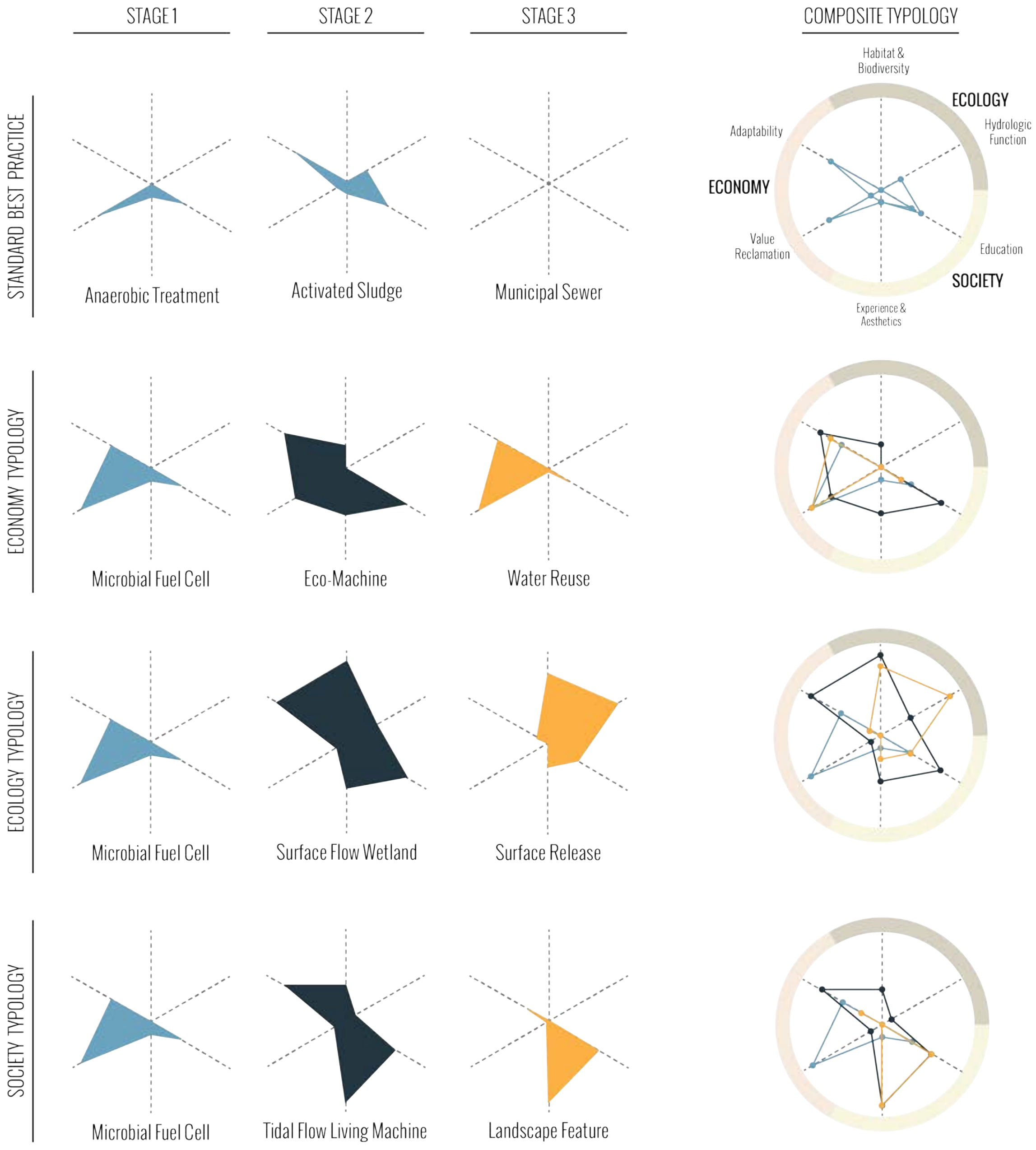


Figure 51. Comparison of Wastewater Treatment Typologies (diagram by author)

Site Considerations

The implementation of an on-site wastewater treatment system requires investigation into site and industry-specific contexts. To better inform how a wastewater treatment system at Terrapin Beer Co. may be implemented, opportunities for economic, ecological, and social interventions are investigated.

Economic Opportunities

Economic opportunities inform the potential for local reuse of reclaimed energy, nutrients, and water from brewery effluent. Reclaimed energy via biogas and/or electricity and heat would most likely be used to offset the brewery's internal energy needs. Reclaimed water could also be used on site to offset non-process water use or for landscape watering. Nutrients in the form of sludge and other solids are more difficult to use on site.

Currently, Terrapin sells its spent grains to local farmers to be used as livestock feed. Shown in Figure 52, semi trailers are loaded with spent grains outside the brewery. There are numerous businesses and industries near Terrapin Beer Co. that may offer the potential for other economic, waste-sharing connections and the creation of industrial ecologies. While not fully investigated in this thesis, it is the opinion of the author that two nearby properties and business operations hold the most potential for water and nutrient reuse. Shown in Figure 53, the Athens Country Club and Athens Land Trust Urban Farm are close to Terrapin and use water for irrigation. Described in Chapter Four, treated wastewater can easily be used for irrigation purposes. The Athens Land Trust Urban Farm is in the early stages of development and contains 49 acres of forest and pasture (Athens Land Trust 2015). Along with water reuse for crop irrigation, nutrients reclaimed from wastewater during stage 1 of treatment could be composted and used as a soil amendment for crop production.

Figure 52. Spent Grain Reuse (photo by author)

Figure 53. Local Economic Connections (diagram by author)

Ecological Opportunities

Ecological opportunities (Figure 54) represent the potential for habitat and biodiversity enhancement, and improvement of hydrologic function at or near Terrapin Beer Co.

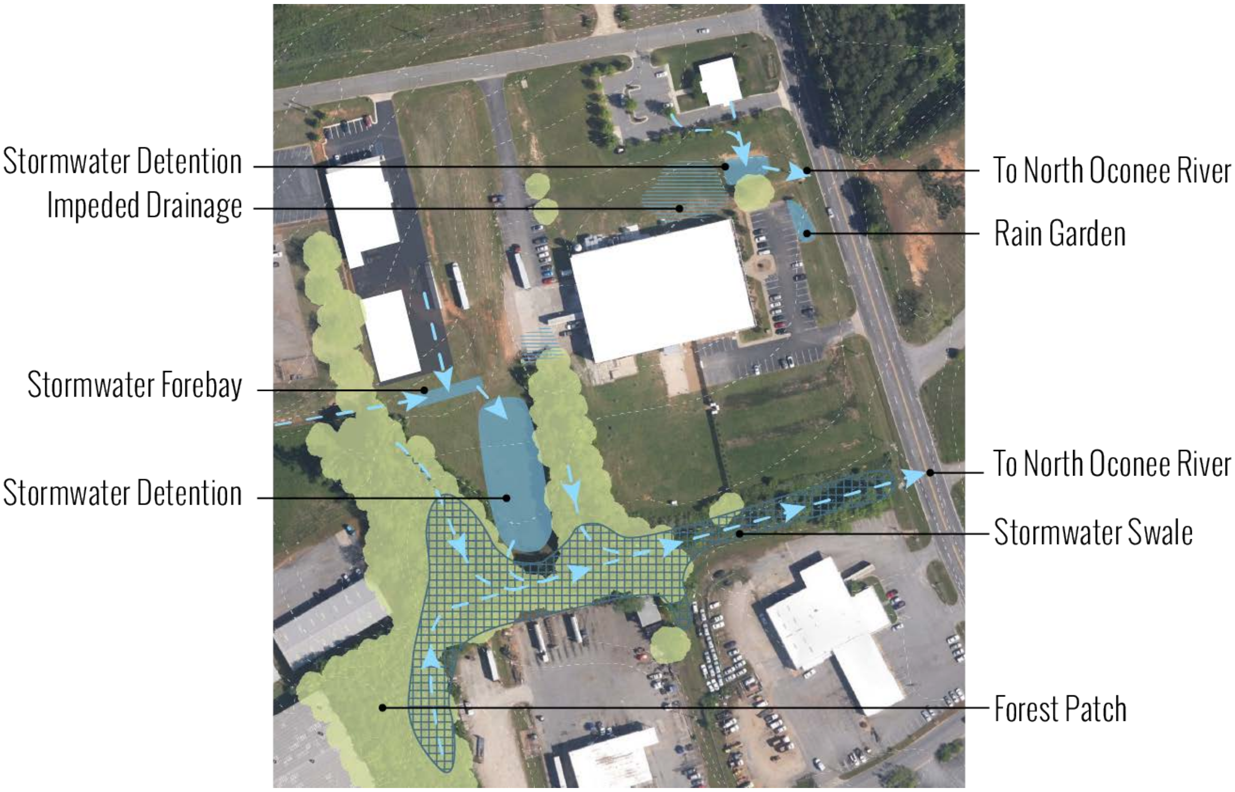


Figure 54. Ecological Opportunities (diagram by author)

There are no permanent water bodies adjacent to Terrapin, but stormwater detention and conveyance features are plentiful. A partially forested stormwater swale borders the south and southwest portion of the current Terrapin property and conveys runoff from Terrapin and adjacent properties toward Newton Bridge Road. This stormwater swale was part of a recent stormwater management project undertaken by Athens-Clarke County to improve the function of the swale (Kathryn Shepard, ACC

Stormwater Coordinator, personal communication with author, 3/12/2015). The swale was cleared of overgrown vegetation bordering Terrapin's property and a small stand of cattails was planted near Newton Bridge road (photo A, Figure 55).

The forested area consists of a mix of early successional and mature trees and can be seen in the background of photos B and D in Figure 55. While the small forest patch likely does not have high habitat value for large species, the author sees potential in expanding and enhancing the edge habitat for use by birds and pollinators. The patch also borders the social space described in the next section and could contribute to aesthetic enhancements.

Figure 55. Site Photos 2/23/2015 - Ecological Opportunities (photos by author)

Stormwater detention basins are present on each of the two adjacent properties being considered for purchase. The basin located in the western property is shown in photo D of Figure 55 and collects runoff from nearby properties. Currently, the basin discharges water to the previously mentioned stormwater swale and offers little habitat value. Converting the basin into a wet detention, or retention pond could improve habitat value by creating a permanent water source for wetland vegetation and associated wildlife species; however, doing so may impact its function for stormwater detention.

The turf detention pond shown in photo C of Figure 55 collects water from the bank parking lot and building to the north. During a site visit on February 23rd, 2015 following a period of heavy rainfall, no water was seen in the basin. However, the basin was impeding the drainage of the large lawn and caused a shallow pool to form against the basin's high side.

Social Opportunities

Social opportunities (Figure 56) consider the educational, experiential, and aesthetic qualities of the Terrapin site.

Figure 56. Social Opportunities (diagram by author)

As stated previously, Terrapin regularly hosts public beer tastings and private events in both indoor and outdoor entertainment areas. The indoor tasting room and gift shop are located at the front of the building and are easily accessible from the nearby parking lot. The outdoor entertainment area is adjacent to visitor parking but is separated by a privacy fence, and can be accessed from both inside and outside the building.

The outdoor patio boasts serving areas for beer tastings and features a stage for live performances (photos C and D of Figure 57). Picnic tables, standing tables, and pallet benches are provided in the lawn area (photos A and B of Figure 57). The forest patch (background of photo A of Figure 57) bordering the west side of the entertainment lawn serves as a visual backdrop for the space, but has little aesthetic value. Outdoor portable toilets detract from the social experience and could potentially be replaced by toilets that utilize recycled wastewater for flushing. While the informality of the space makes it easily adaptable to changing needs, it is the opinion of the author that aesthetic enhancements would make the space more desirable for a wider range of events.

Brewery tours are offered regularly at public beer tastings and serve to educate visitors on the brewing process and sustainable practices such as the reuse of spent grains. A brewery staff member leads visitors through the building and around the production floor while the brewery is in operation. While informative, the tour could be enhanced by wastewater treatment methods that serve educational, functional, and aesthetic purposes.

Figure 57. Site Photos 2/23/2015 - Social Opportunities (photos by author)

Projective Design

Projective design at Terrapin Beer Company was approached as a design experiment, and seeks to maximize all three evaluation categories of economy, ecology, and society, while treating all wastewater to reuse standards. First, a description of wetland sizing methods is described, followed by the site design and descriptions of each treatment stage. Finally, the proposed wastewater treatment system typology for Terrapin is presented.

Sizing of Constructed Wetlands

The wastewater treatment system was designed using available data and wastewater metrics from Terrapin Beer Company and the ACC Public Utilities

Department. Because constructed wetland technologies can be easily expanded to adapt to increasing wastewater flows, constructed wetland technologies are sized to treat the current estimated wastewater volume of 21,000 gallons per day. Land area required for each wetland technology is based on the BOD of effluent from the preceding treatment stage using a standard equation (Equation 2) given by Crites, Middlebrooks, and Bastian (2014) and Campbell and Ogden (Campbell and Ogden 1999).

$$A = \frac{Q(\ln C_0 - \ln C_e)}{K_t * d * n}$$

A = area required for treatment (m^2)
C_0 = influent BOD (mg/L)
C_e = effluent BOD (mg/L)
Q = wastewater flowrate (m^3/day)
K_t = temperature-dependent rate constant
d = depth of gravel bed
n = porosity of gravel or vegetation

Equation 2. Sizing Constructed Wetlands (Crites, Middlebrooks, and Bastian 2014, Campbell and Ogden 1999)

Because tidal flow wetlands are a developing technology, and specific metrics are proprietary information, an experimental (K_t*d*n) value of .605 given by Sun et al (2005) is used. Calculations used depth and porosity values for subsurface and free water surface wetlands recommended by Campbell and Ogden (Campbell and Ogden 1999). SSF wetlands are sized to be 2 feet (.6 meters) deep, with a gravel medium porosity of .4. FWS wetlands are sized to be 18 inches (.45 meters) deep, with a vegetated porosity of .7 (typical range is .65-.75) (Campbell and Ogden 1999).

Wastewater is typically very warm upon exiting the brewery. The temperature-dependent rate constant (K_t) was informed by temperature measurements taken by David Bloyer of the ACC Public Utilities Department. On two separate occasions, Bloyer measured the temperature of Terrapin's effluent to be 93.9 and 78.1 degrees Fahrenheit (email communication with author, 2/5/2015). For the purposes of this thesis, effluent is assumed to have cooled to 68 degrees Fahrenheit (20 degrees Celsius) following stage 1 of treatment, so that values given by Campbell and Ogden (1999) may be used.

Projective Design

This design is approached as a design experiment and attempts on-site treatment of all wastewater from Terrapin to reuse standards. Implementation of the entire system at once is considered unfeasible, so reducing BOD below the regulatory discharge requirement of 250 mg/L is considered the first priority. Ensuing stages of treatment prioritize treating wastewater to reuse standards. The proposed site plan is presented in Figure 58, and is explained in the following sections.

Figure 58. Proposed Site Plan for Wastewater Treatment at Terrapin Beer Co. (diagram by author)

Parcel Acquisition

Shown in Figure 59, the parcel to the north of Terrapin is recommended for purchase to be used for wastewater treatment, as well as future brewery expansion. This parcel is preferred because it is close to the current wastewater output and existing brewery operations. It is also fairly flat near the Terrapin building, making it an ideal location for constructed wetlands. Current stormwater issues, such as impeded drainage from the lawn and the existing stormwater detention basin are addressed in future sections.

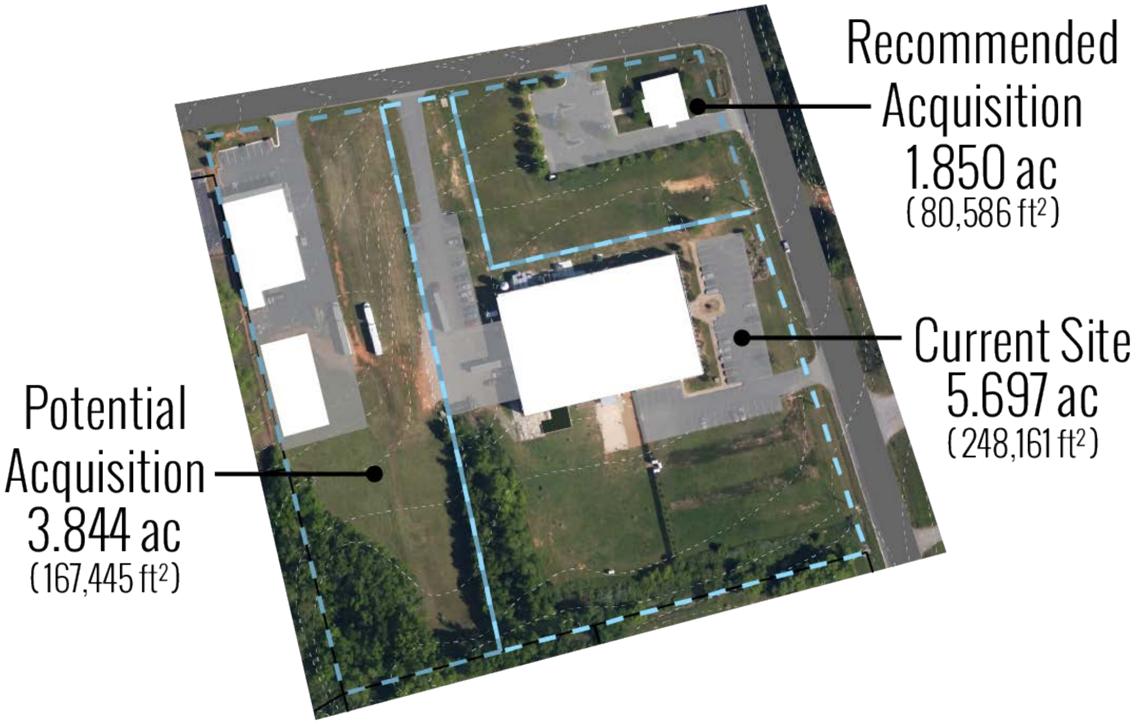


Figure 59. Recommended Land Acquisition (diagram by author)

Stage 1: Wastewater Pretreatment

Upon leaving the brewery, wastewater first passes through a particulate screen to remove large solids. Next, a balancing tank is used for pH adjustment and to equalize wastewater flows before wastewater is sent to an EcoVolt MFC system for bulk BOD and TSS reduction. The EcoVolt generates high-quality renewable biogas that can be used to heat boilers or can be converted into electricity and heat using a CHP Unit. As described earlier in this chapter, the EcoVolt was chosen based on its small footprint and higher-quality biogas production than standard anaerobic treatment options.

Following Stage 1 of treatment, BOD is estimated to be at 764 mg/L. Because this value is above current discharge requirements in Athens Clarke County, additional treatment is necessary to discharge effluent without surcharges (ACC Public Utilities Department 2014). Following Stage 1 of treatment wastewater is split into two equal flows of 10,500 gallons per day. A summary of stage 1 pretreatment is shown in Figure 60.

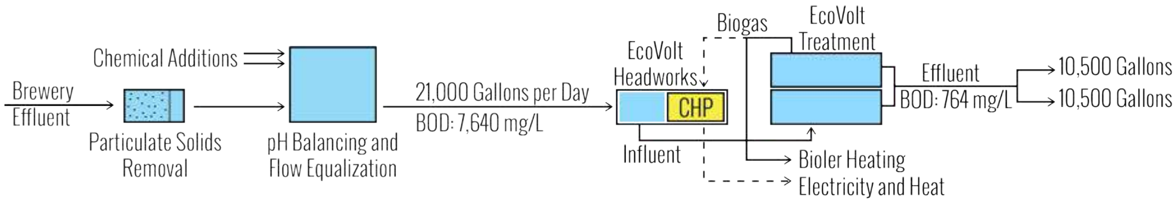


Figure 60. Stage 1: Wastewater Pretreatment (diagram by author)

Stage 2: Wastewater Polishing

Stage 2 of treatment uses a combination of tidal flow wetland cells, subsurface wetlands, and free water surface wetlands to polish wastewater. Following primary treatment, wastewater is split into two equal flows. Each stream, 10,500 gallons per day, is piped to two separate treatment systems on the north and south sides of the building.

South Side Wastewater Polishing

On the south side of the building, wastewater polishing begins with a tidal flow wetland. Tidal flow wetlands are chosen for their use as site features and ability to treat wastewater using a smaller footprint than other wetland technologies. Sized using

Equation 2, the tidal flow system has a surface area of approximately 800 square feet and reduces BOD from 764 to 250 mg/L. Following the tidal flow wetlands, wastewater could be discharged to the municipal sewer system without surcharges. On the south side of the building, tidal flow cells are integrated into the redesigned performance stage and can be used for seating during social functions. After treatment in the tidal flow wetlands, wastewater flows to subsurface constructed wetlands.

The SSF wetlands on the south side of the building border the large event lawn and follow treatment in the tidal flow wetlands. Totaling 5,200 square feet, individual treatment basins are rectangular in shape with small length-to-width ratios to prevent clogging and surface water accumulation, as advised by Crites, Middlebrooks, and Bastian (2014). Sized using Equation 2, the wetlands treat 10,500 gallons of wastewater per day and reduce BOD from 250 mg/L to 10mg/L.

While SSF treatment basins are typically planted with only a few plant species to improve wastewater treatment, a decorative planting shelf surrounds each group of basins and can be planted with a wider range of species to increase habitat and aesthetic values (Campbell and Ogden 1999). Basins are arranged in sequence to allow water to easily flow from one basin to the next. Their arrangement creates smaller social spaces within the large, open entertainment area. In a few locations, low concrete walls are used to contain treatment basins and function as seating for visitors. Wetlands are located at the edges of the entertainment area in order to maintain the lawn as a flexible space with multiple uses. Bordering the forest patch, the western group of wetlands and surrounding planted shelf enhance the habitat value of the forest edge.

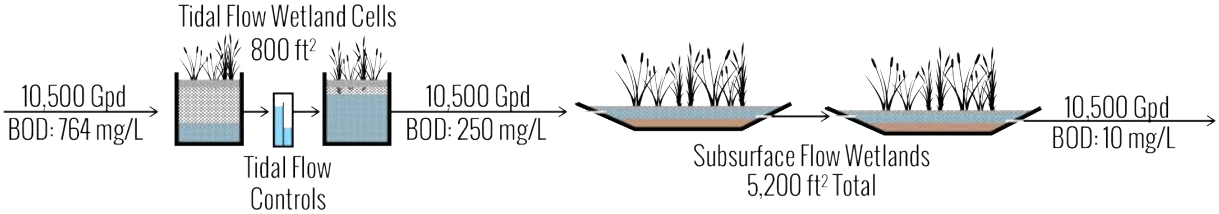


Figure 61. Stage 2: South Side Wastewater Polishing (diagram by author)

North Side Wastewater Polishing

On the north side of the building, tidal flow wetlands are again used to treat a flow of 10,500 gallons per day from 764 to 250 mg/L BOD. Wetland cells can be used as seating and would serve well to educate visitors on wastewater treatment practices during the brewery tours.

Following the tidal flow cells, wastewater travels to nearby subsurface flow wetlands. SSF wetlands on the north side of the building are approximately 2,600 square feet and reduce wastewater BOD from 250 to 50 mg/L. While the north side of the building is not typically used for social gatherings, this space could be a feature of the brewery tour and SSF wetlands would serve an educational purpose.

After BOD is reduced to 50 mg/L in SSF wetlands, wastewater flows to an adjacent free water surface wetland. The FWS wetland requires roughly 7,400 square feet to treat wastewater from 50 to 10 mg/L BOD. The wetland improves local habitat value and is highly visible from Newton Bridge Road.

The addition of a stormwater swale north of the proposed wetlands addresses existing stormwater runoff issues. The swale prevents runoff from entering the wetlands cells and directs it to the existing detention pond.

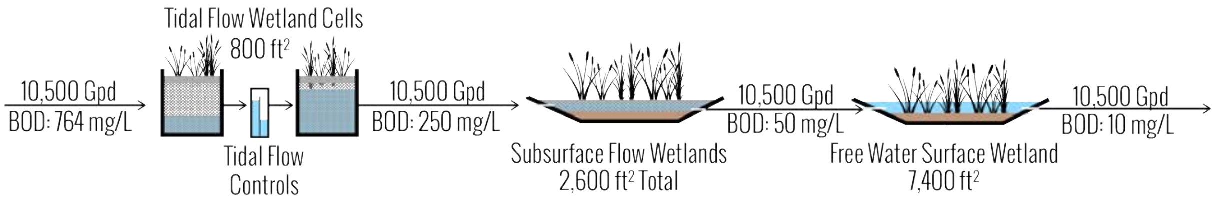


Figure 62. Stage 2: North Side Wastewater Polishing (diagram by author)

Stage 3: Wastewater Reuse and Reclamation

While the proposed stage 1 and 2 treatment systems improve wastewater quality so it is capable of being treated for reuse, stage 3 treatment options are kept flexible due to current regulations on water reclamation and reuse. Both north and south side treatment systems have three options for stage 3 treatment. Figure 63 shows stage 3 treatment options, as well as general wastewater flow through the site. Numbers indicate the three Stage 3 treatment options described below.

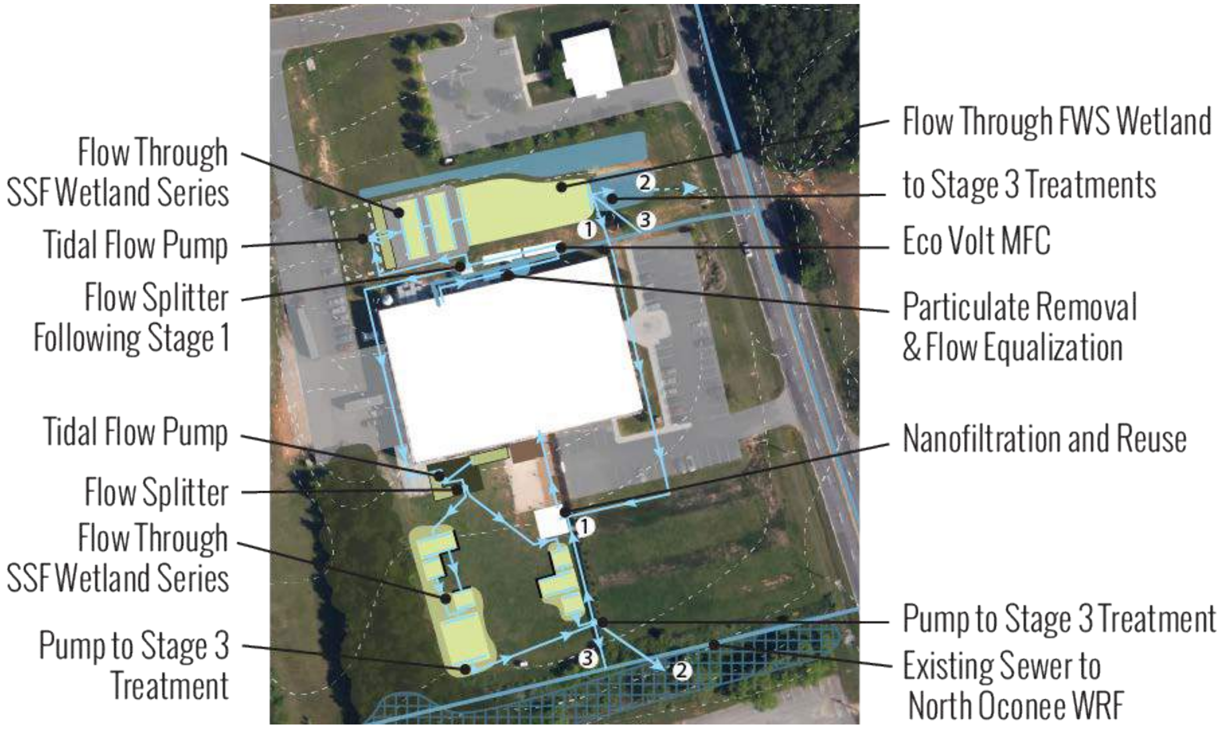


Figure 63. Wastewater Flow and Stage 3 Treatment Options (diagram by author)

Additional treatment and water reuse is the preferred stage 3 treatment option. A new building is proposed near the serving areas and performance stage on the south side of the Terrapin building. This building features a nanofiltration system to treat incoming water to reuse standards and sends treated water into the brewery for reuse in cleaning and cooling applications. It also houses new restroom facilities that can use treated wastewater for toilet flushing. In an ideal system, water will be circulated within a continuous loop from non-process industrial applications, to discharge as wastewater, through the wastewater treatment system, and back again.

The second-preferred stage 3 option is for wastewater to enter the existing stormwater system, bypassing unnecessary, additional treatment at the municipal facility before entering the North Oconee River. On the south side, treated water can enter the recently renovated stormwater swale and would create a stable riparian system for newly established wetland plants. On the north side, the existing detention basin could be converted to a retention basin for both stormwater runoff and treated wastewater. Converting the basin to permanently hold water would not only improve stormwater runoff quality, but would also increase local habitat values and aesthetics.

The third option is to send treated wastewater to the municipal facility via the existing stormwater sewer. While not a preferred option, a connection to the sewer would be necessary when wastewater discharges exceed reuse quality measurements or exceed the brewery’s current need for water. While this design does not propose connections to local businesses like the Athens Country Club or Athens Land Trust urban farm, these connections may be feasible.

Proposed Typology

Figure 64 presents the proposed wastewater treatment typology for Terrapin Beer Company. The typology presents all stage 2 treatment options equally, because their individual contributions to the collective whole were not assessed. Because it is considered the preferred stage 3 treatment, water reuse is presented here and other options excluded. Below, the proposed typology is assessed on the three evaluation categories of economy, ecology, and society.

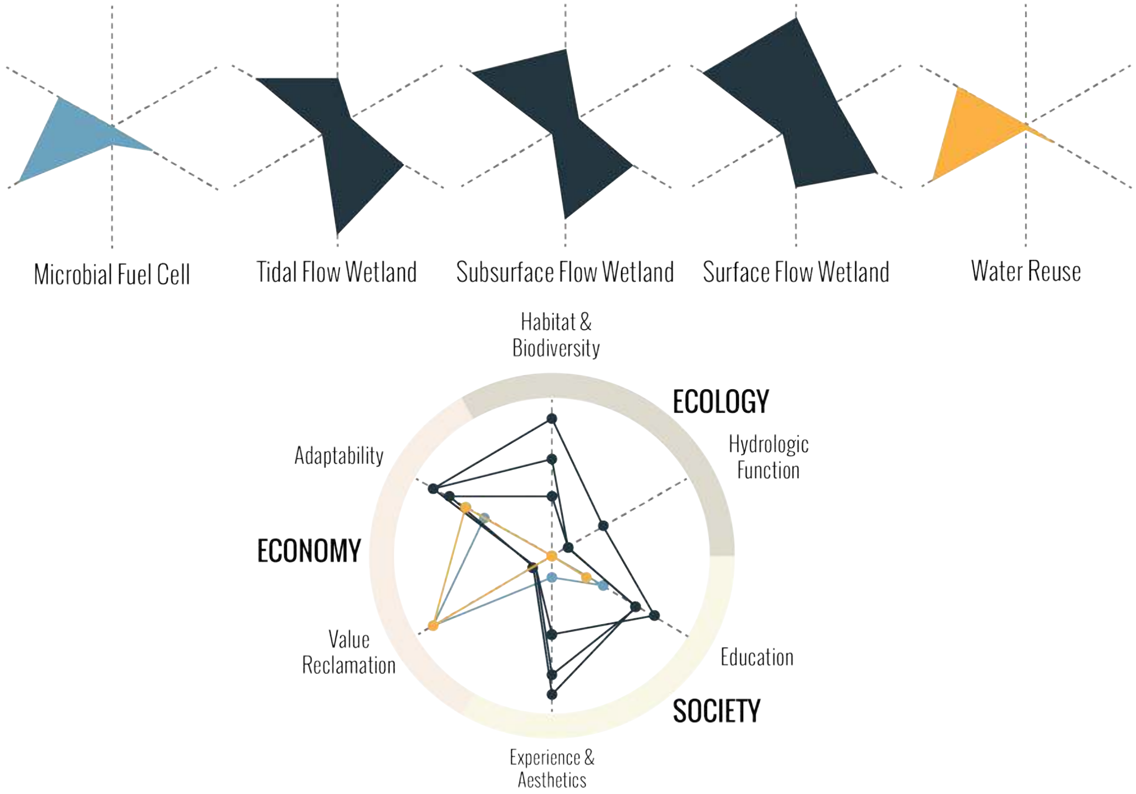


Figure 64. Proposed Typology for Terrapin Beer Company (diagram by author)

Economy: The category of economy is primarily addressed by stages 1 and 3 of treatment. The EcoVolt produces high quality biogas that could be used to offset Terrapin's energy requirements. Water reused for internal brewery processes has the potential to greatly offset non-process water costs and reduce the amount of water purchased from the city.

Ecology: Local habitat and biodiversity value is created using a combination of stage 2 wetland technologies for wastewater polishing. The free water surface wetland contributes most to this category, because water is exposed at the surface. Subsurface wetlands contribute additional habitat and biodiversity value, largely from the wetland shelf planted with a wider range of aquatic plant species. Hydrologic function is the category least addressed by the proposed wastewater system. While discharging treated wastewater to local stormwater systems would increase contribution to this category, the lack of a permanent water body near the Terrapin site is seen as the limiting factor.

Society: Experience and aesthetics are greatly enhanced by wetland technologies, especially within the existing entertainment space on the south side of the Terrapin building. Tidal flow wetlands are easily used as a site feature and aesthetically improve the performance space, while surface flow wetlands frame the large lawn and create spaces for smaller social gathering. The addition of new restroom facilities is also assumed to improve the experience. Education is addressed less than all other criteria, except for hydrologic function; however, it is still considered to have greatly improved. The potential for education is largely dependent on communication, both during the brewery tours and through interpretive signage. The presence of aesthetically pleasing wastewater treatment wetlands in the large gathering space is assumed to contribute the most to education potential.

CHAPTER 6

CONCLUSION: EXPANDING THE SCOPE OF BREWERY WASTEWATER TREATMENT

Redefining Wastewater Infrastructure

As discussed in Chapter 2, traditional wastewater infrastructures are not easily adapted to ever-changing urban conditions and fail to reclaim value from combined urban waste streams that are diverse in composition (Elmer and Leigland 2013, Tjandraatmadja et al. 2005). Decentralizing wastewater management decreases pressure on traditional wastewater systems. Industry, as a source of point-source pollution represents a point of intervention for decentralized wastewater treatment and value reclamation.

Advocating for the transition from centralized waste management to decentralized waste reclamation, this thesis has proposed the craft brewery as an ideal testing ground for localized wastewater treatment and resource recovery. While on-site wastewater treatment and reuse can be accomplished via traditional methods of wastewater treatment (Simate et al. 2011), this thesis has demonstrated that a landscape-based approach has a greater potential to address larger systems of economy, ecology, and society. A social, industrial setting in varying urban and environmental contexts, craft breweries stand to benefit from the adaptability and multiple-use potential of landscape-based wastewater systems.

Moving Forward

While the research presented in this thesis indicates that wetland technologies could be used to polish brewery wastewater following initial pretreatment, their applicability and performance are relatively untested in the treatment of brewery effluent. The use of wetland technologies for on-site treatment requires testing so that decentralized waste reclamation does not become the decentralized pollution of an industrial past. For this reason, it is recommended that small pilot projects first be used to determine more accurate treatment efficiencies and inform large-scale implementation. Because brewery wastewater has a similar composition throughout the industry (Brewers Association 2012b), pilot project results could be used to better predict the industry-wide application of wetland technologies for wastewater treatment.

Accurate collection of wastewater flow and composition data is critical to informing the design and sizing of any on-site treatment practice (Crites, Middlebrooks, and Bastian 2014), especially for breweries that do not already have pretreatment systems. Breweries that plan to install on-site treatment systems should first seek to improve resource use and decrease waste production. While only briefly discussed in this thesis, two manuals published by the Brewers Association (2012a, b) detail a number of ways to improve water use and reduce the production of solid waste and wastewater throughout the brewing process.

Because constructed wetlands and other wetland technologies are best used following initial treatment of wastewater (Crites, Middlebrooks, and Bastian 2014), the author believes that they may be best applied at breweries with existing wastewater pretreatment systems that have well-established performance metrics. Depending on site context, wetland technologies may be used to replace aerobic activated sludge systems currently used for wastewater polishing in the current best practice demonstrated by New Belgium Brewery.

When combined with ever-advancing wastewater treatment technologies, wetland technologies could have impacts far beyond simply treating wastewater. As on-site wastewater treatment and reuse become common practice in the brewing industry (Simate et al. 2011), a landscape-based approach to wastewater treatment and reuse could help redefine the industrial landscape from one that is not only functional and productive, but also ecologically responsible and socially enjoyable.

The Role of the Designer

As discussed in Chapter 2, the design of infrastructural systems has largely been scientific in approach. The field of ecological design has expanded traditional wastewater treatment to include landscape-based technologies; however, the potential multiple-use values of these systems have largely been ignored (Campbell and Ogden 1999). While scientific understanding of wetland technologies is necessary to meet the functional requirements of wastewater systems, the incorporation of creative, artful, and aesthetic design into modern industrial systems is necessary to fully integrate nature and culture (Lister 2006). As a trans-disciplinary profession that has been traditionally concerned with aesthetics and artful design, landscape architecture "stands to gain momentum by widening its sphere of influence to include the operative and logistical aspects of urbanization" (Bélanger 2009, 91).

A continuing challenge for landscape architects will be balancing the technical requirements and performance of landscape-based wastewater treatment with creative design that seeks to expand and strengthen cultural-ecological connections. As argued in this thesis, the craft brewery is an ideal testing ground for a new approach to the design of wastewater infrastructures that engages economic, ecological, and social systems.

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