Spring 5-16-2014

Watershed Protection as the Primary Tool to Achieve High Quality Drinking Water

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This Master's Project:

Watershed Protection as the Primary Tool to Achieve High Quality Drinking Water

by

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is submitted in partial fulfillment of the requirements
for the degree of:

Master of Science
in
ENVIRONMENTAL MANAGEMENT

at the

UNIVERSITY OF SAN FRANCISCO

Submitted:		Received:	
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SUMMARY

Watershed protection and the use of green infrastructure have often been thought of as complimentary additions to water quality protection and that the use of human engineered drinking water filtration was a necessity. However, the largest city in the U.S., New York City, as well as multiple other cities, consistently meets drinking water quality standards through the implementation of watershed protection programs and without the use of human engineered filtration technology. For many cities, watershed protection is no longer just one component of a multi-barrier approach to protect water quality, but is now the main strategy. Drivers for watershed protection include, increasing impaired water quality in lakes and rivers, increasing regulations, and new market tools, such as the ability to define and value ecosystem services.

Increasing contaminants in waterbodies such as heavy metals, pharmaceuticals, pathogens, and chemicals, many of which are not monitored, signify a need to preserve a secure upstream source of water (Ernst et al., 2004). In the U.S., watershed protection efforts peaked in the eighteen and nineteen hundreds during the early development of large cities; however, the necessity to preserve surface waters has led to a revival of watershed protection in the U.S. as well as many growing cities throughout the world (Postel & Thompson, 2005).

This research examines the cost-effectiveness of watershed protection (green infrastructure), versus human engineered treatment (gray infrastructure) by comparing cities that have utilized either gray or green infrastructure (Ch. 5). Using turbidity and *E. coli* as indicators of effectiveness, the results of this analysis determined that human engineered infrastructure is more effective at reducing turbidity levels; however, both methods (human engineered and watershed protection) met all water quality standards. Additionally, watershed protection achieved water quality objectives often times at a fraction of the cost of human engineered treatment and is capable of supporting a larger populations than gray infrastructure (Table 3).

Multiple examples of cities ranging from New York City, USA to Bogota, Columbia are discussed to show how watershed protection can reduce the associated costs and risks

stemming from impaired water and usually eliminate the need for human engineered treatment (U.S. EPA, 2011; Ernst et al., 2004; Gartner et al., 2013; Appleton, 2002). One of the most surprising results from this research is that some of the largest cities in the U.S. rely solely upon watershed protection as the primary method to achieve water quality standards (Ch. 5, Table 3). Protection strategies implemented by cities range from complete protection through conservation easements, land acquisitions, and designations to management strategies, such as the implementation of agricultural and forestry management practices (Ch. 7). While traditional protection approaches such as land acquisition may be the most foolproof at controlling contaminants from entering surface waters; other strategies including forestry and agricultural management practices can still be effective.

Within the past decade or so, additional strategies have emerged in the field of environmental economics that consider the value of hydrological services provided by watersheds. Chapter 7 discusses an economic tool (Payments for Environmental Services) that applies a non-traditional watershed protection strategy to unite already existing land uses, such as farming, with conservation.

Key Terms

Green Infrastructure: Ecosystems within a watershed that provide water filtration/purification services. These may include forests, riparian/buffer zones, grasslands, wetlands, and floodplains.

Gray or Human Engineered Infrastructure: Human built infrastructure designed for the purpose of drinking water filtration. Infrastructure ranges from simple sand filtration to advanced membrane filtration treatment.

Source Water: Includes the pathway of water from a headwater area into a reservoir, lake, river or other end route. It is the first and most important phase in water distribution in terms of risks for contamination (Ernst et al., 2004).

Watershed Protection: Typically, 100 percent of land areas within a watershed cannot be protected due to existing land uses; however, there are some instances where entire watersheds are protected. Watershed protection, for purposes of this research, mainly refers to the protection of any or all <u>upstream</u> aboveground ecosystems within a watershed beginning from the headwaters to riparian zones, wetlands, and other areas (see Figure 1). "Upstream" is emphasized because the importance is to protect water before it reaches the intake of a drinking water system. There is a range of protection strategies including, protection of green infrastructure/upstream ecosystems to limiting the amount of contaminants entering the system; protection and management strategies are discussed in Ch. 7.

Watershed: Drainage basin for precipitation that flows into a larger water body, such as an ocean. This area is defined by topography and the gravitational course of water.

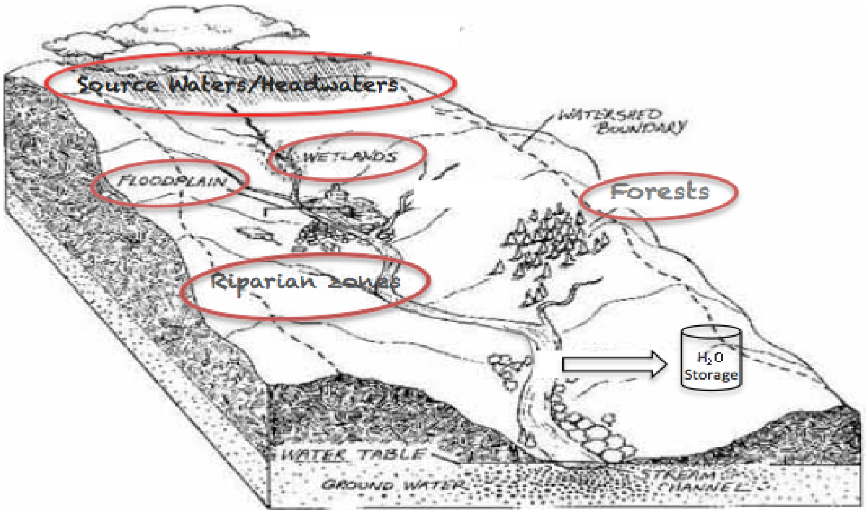

Figure 1. Watershed Protection Representation
Protection may refer to the protection of the entire watershed area within a defined boundary, or protection of a combination of ecosystems. Note that all protected areas are located upstream of the drinking water intake. (Figure adapted from Placer County Resource Conservation District (2014))

1.0 INTRODUCTION

Water availability and the quality of available water are becoming two of the biggest challenges of the 21st century. High-quality water is essential for human consumption, aquatic life, and other beneficial uses and is threatened globally. In the U.S., 80 percent of all water usage (or 270,000 million gallons/day) is supplied by surface water sources (Kenny, et al., 2009). Efforts to preserve surface water quality are primarily driven by regulations and water treatment technologies; however, due to increasing municipal water treatment costs, and a decline in the overall quality of surface water, alternative ways to achieve high water quality are being sought. Watershed protection as an option to protect water resources is becoming an increasingly sensible option for many growing cities throughout the world (Postel & Thompson, 2003). Watershed protection should be the first (and possibly the most important) step in a multi- barrier approach to protecting downstream water quality as it provides a long-term solution in the face of increasing nonpoint sources of pollution and increasing treatment costs.

1.1 Importance of Clean Water

Each year approximately 2.2 million people die as a result of lack of access to clean water (Dudley & Stolton, 2003). The probability of water contamination is particularly pronounced in urban settings. Cities are home to nearly half of the world's population (Dudley & Stolton, 2003). Among urban inhabitants, particularly in developing countries, approximately one third live without access to clean water (Dudley & Stolton, 2003). The probability of water contamination in urban settings is higher due to the lack of watershed and surface water protection. In urban areas, especially in developing regions, raw sewage and animal waste, and the introduction of chemicals from industrial, and accidental occurrences is high (Davies & Mazumder, 2003). Acute or sudden health problems are usually associated with microorganism contamination from human or animal waste (Davies & Mazumder, 2003). Microorganisms however, are not the only contaminants that may cause acute health issues; there are also a handful of chemicals with the potential to cause acute health effects even in small concentrations. More likely though, is the exposure to small amounts of constituents such as, metals, pesticides, and nutrients over a long period, leading to long-term or chronic health implications.

Health risks posed by contaminated drinking water can be estimated by multiplying the likelihood of a contamination event occurring by the associated health effect (Davies & Mazumder, 2003). Specific health effects are varied depending on contaminant and range from carcinogenic effects to endocrine disruption that may lead to reproductive and developmental issues. Human health impacts associated with poor drinking water quality such as infant mortality and reduced worker productivity, are an unnecessary cost that can be reduced with the protection of surface drinking water sources (Dudley & Stolton, 2003).

1.2 Threats to Water Quality

Water quality is determined by the presence of contaminants, as well as aesthetic characteristics such as, odor and clarity (National Research Council, 2000). Indicators of lowered water quality include the presence of chemicals, pathogens, nutrients, salts, and sediments in surface or groundwater (Brauman et al., 2007). Constituents of concern (or threats) will vary somewhat within each watershed, however, there is likely to be considerable overlap especially within watersheds with similar land use, e.g., agriculture, recreation. Common indicators of acceptable water quality are: 1) the absence of microbes or disease causing organisms, and 2) acceptable ranges of potentially harmful chemicals, radioactive compounds, and physical analytes (e.g., dissolved oxygen, pH) (Davies & Mazumder, 2003).

In the 1970s during the implementation of the Clean Water Act, point source pollution, including factories and sewage treatment plants were heavily targeted as being the main source of surface water pollution (Aron et al., 2013). Currently however, nonpoint source pollution such as agriculture, septic leaching and storm water runoff is now the primary source of surface water pollution (Thompson, 2003). Even though billions of dollars have been spent on the Clean Water Act, the original goals (e.g., fishable, swimmable waters) of the CWA have largely not been accomplished due to nonpoint source pollution (National Research Council, 2001; U.S. EPA, 1996). An increasing number of chemicals and chemical loads in waterways, combined with urban sprawl and development, are elevating the risk for contaminants entering drinking water (Ernst et al., 2004). Sprawl and development contribute to habitat loss and fragmentation including a loss of natural watershed areas such as forests and floodplains, which are essential for the protection of water supplies. The U.S. Forest Service predicts that by 2050 a further 23 million acres of forests will be lost to development (CWP & U.S. Forest Service, 2008).

1.2.1 Emerging Contaminants

The production of synthetic organic pesticides tripled from 400 million pounds in 1950 to 1.4 billion pounds in 1980 (Trautmann et al., 2012). As the number of chemicals (pesticides or others) manufactured increases yearly, so does the number and variety of chemicals reaching waterways. Monitoring and testing for new chemicals is not up to date and it is extremely costly; therefore, many of the new chemicals are going undetected in waterways and the number will likely continue to increase (Ernst, 2004). In a U.S. study looking at 140 streams from across the county, 80 percent of the streams tested contained steroids and nonprescription drugs (Ernst, 2004). Furthermore, in a 2001 USGS study, herbicide concentrations were present in 99 percent of urban stream samples collected (as cited in Postel & Thompson, 2005). A study identifying contaminants found in household tap water across U.S. states found over 300 different contaminants, of which 200 were not under current regulation (CWP & U.S. Forest Service, 2008).

During water filtration, pesticides and pharmaceuticals are some of the most difficult constituents to remove. Furthermore, because little is known about these new chemicals, even less is known about the way they interact with common disinfection chemicals and their ability to form potentially harmful byproducts. The best option to protect water quality is to prevent pharmaceuticals and pesticides from entering surface waterways by eliminating the transport of these chemicals into waterways where they could potentially affect public health (Ernst, 2004).

1.2.2 Microbial Contamination

The most common risks attributed to drinking water are posed by infections from bacteria such as *Escherichia coli,* protozoa such as *Giardia*, and viruses such as Hepatitis A (Davies & Mazumder, 2003). Half of the population of developing countries is affected by microbial diseases, dependent upon water supply and sanitation (Davies & Mazumder, 2003). Yet, developing countries are not the only the only places where human health is affected by poor water quality. Every year in the U.S., even where human engineered filtration systems are widely used, microbial outbreaks and chemical contamination occurs (Davies & Mazumder, 2003). Recently, the protozoa *Cryptosporidium* was present in drinking water supplies which caused numerous illnesses and deaths in Nevada (in 1994) as well as Milwaukee (in 1993), even though these cities use filtration and chlorination techniques (Davies & Mazumder, 2003). Clearly human engineered drinking water treatment methods are not entirely foolproof and are also costly (Postel & Thompson, 2005; Dearmont et al., 1998) and in some places of the world impractical. Davies & Mazumder (2003) note that "many drinking water disease outbreaks have resulted from breaches in treatment facilities, therefore, even with greater treatment intensity poor source water quality intrinsically has greater associated health risks". In the early 2000s, the risk to communities was further evidenced in a study by Livernois (2002) (as cited by Davies & Mazumder, 2003) who reported a $64 million economic loss in the city of Walkerton, Ontario due to an *E.coli* outbreak that killed seven people and caused 2000 people to become infected.

1.2.3 Disinfection By-products

Disinfection by-products are becoming an increasing health concern as more and more chemicals are required to treat heavily degraded water. Disinfection by-products are most commonly associated with halogenated chemicals such as chlorine. Chlorine has been used in the U.S. since the early 1900s and today is used by 98 percent of water treatment facilities to deactivate potentially deadly microorganisms (Calomiris, 1998). Trihalomethanes, such as chloroform, and haloacetic acids are some of the most common disinfection by-products (WHO, 2004). The formation of trihalomethanes is higher within surface water supplies (as compared with groundwater supplies) due to the presence of organic material (e.g., leaves, algae, wood) (Madabhushi, 1999). The United States Environmental Protection Agency (USEPA) current standard for the total concentration of trihalomethanes (TTHMs) present in surface water is 0.08 mg/L; current concentrations of TTHMs detected in surface waters range from 0.03 to 0.15 mg/L (Madabhushi, 1999).

The efficacy of chlorine to degrade constituents ranging from microorganisms to pesticides has been recognized (Ormad et al., 2008), however, so has the formation of potentially harmful byproducts. The formation of trihalomethanes which are produced when organic matter attaches to chlorine, has indicated carcinogenic as well as mutagenic properties in lab studies (WHO, 2004). A study conducted in California comparing women who ingested higher levels of TTHM (0.075 mg/L) resulted in a 60 percent increase in the rate of miscarriages than women who ingested lower concentrations (Madabhushi, 1999). Trihalomethanes have also been linked to damage of the heart, lung, kidney and nervous system.

1.2.4 DEVELOPMENT-RELATED WATER QUALITY IMPAIRMENTS

Within watersheds throughout the world, development, including the conversion of land to agriculture, urban, or industrial land use is prolific (Postel & Thompson, 2005). When considering 100 of the world's largest watersheds, half of the land area within one third of these watersheds is undergoing intensive land use practices. Nearly all the vegetation (90 percent) within 13 watersheds in Europe and China's Yangtze and Yellow River watersheds has been deforested (Postel & Thompson, 2005).

Since 1954, the percentage of urbanized land has quadrupled (Ernst et al., 2004). Development within watershed areas is resulting in an increasing number and presence of impurities that end up in drinking water. Developed land limits infiltration and causes water to move at a much faster rate than would otherwise occur. Because the infiltration rate is decreased, groundwater flows into streams and rivers are decreased, which leads to higher concentrations of contaminants in waterways. A common indicator of development is increased turbidity, which is a direct result of development, mismanaged forestry practices or other destructive land uses (Ernst et al., 2004). Suspended sediment, or turbidity is often used as an indicator of water quality due to the ability of agricultural or industrial metals and other constituents to attach to it (Dearmont et al., 1998). A higher level of planning and watershed protection measures is necessary in developing areas prior to the construction of roads, utility corridors, and rural settlements. Construction-related activities require close monitoring, as construction is commonly associated with increased erosion, sedimentation, and an overall degradation of water quality (Dudley & Stolton, 2003).

Additional nutrient inputs related to agricultural or recreational activities cause a rise in primary production, leading to a higher level of organic matter and a greater need for disinfection and therefore associated treatment costs (Davies & Mazumder, 2003). In comparison to the long-term costs of maintaining human engineered or gray infrastructure (water filtration systems) for growing populations, watershed protection is becoming increasingly known as a low cost, long-term solution [as exemplified in the case below] (Ernst et al., 2004).

In the early 2000s, the state of New Jersey was faced with a decision: to allow development within the Sterling Forest Watershed, or to invest in protection. At the time, the Sterling Forest, which provided water for more than two million residents, was privately owned (Lerner & Poole, 2006). Developers sought to convert the 16,000-acre Sterling Forest into housing communities, golf courses, and hundreds of acres of commercial and industrial development. Studies on the effects of development within the Sterling Forest Watershed indicated that pollution as a result of development would require the infrastructure of a $160 million filtration treatment plant. Land conservation organizations (The Trust for Public Land and the Open Space Institute) and New Jersey representatives offered a combined $65 million to the private landowners to preserve 150,000 acres, or 90 percent of the forest. The offer was accepted and development plans were terminated (Lerner & Poole, 2006). Conservation of this forest helped to avoid millions of dollars in potential treatment costs.

1.3 RESEARCH SUMMARY

This chapter discussed the importance of clean water and threats to water quality including emerging contaminants, microbial contamination, disinfection byproducts and development-related water quality impairments. An overview of watershed ecology (Chapter 2) and development of water quality policies (Chapter 3) and human engineered water treatment (Chapter 4) are also presented.

The goal of this research is to investigate the cost effectiveness of human engineered treatment methods compared to green infrastructure (source water and watershed protection) to achieve drinking water quality standards. This goal is achieved by performing a cost effectiveness analysis comparing municipalities reliant upon human engineered water treatment methods and municipalities that have implemented source water protection programs in lieu of human engineered filtration systems (Chapter 5).

Three examples of municipalities that have implemented watershed protection and management programs are discussed to provide a range of examples (Chapter 5). These examples may be of interest to water providers, such as governments or cities considering watershed protection as a tool to solve water supply and quality problems. Chapter six reviews specific strategies for implementation of watershed protection that range from traditional land acquisitions to the implementation of Best Management Practices including sustainable forestry and agricultural practices. Further protection strategies are emerging within the field of environmental economics, more specifically the application of payments for hydrological services; this strategy is occurring predominately in developing countries (Chapter 7). Lastly, a review of research conclusions and final recommendations are presented in Chapter 8.

2.0 WATERSHED ECOLOGY

In order to understand why watersheds are so valuable for water resources, it is first important to define what is meant by the term. The simplest definition of a watershed is a drainage area. Water begins its course in the headwater reaches (or source waters) and drains into lower elevation areas and eventually connects to a river, bay, ocean or other waterbody- this location is otherwise known as the *pour point* (Merrill, 2013). Headwaters on top of mountains distribute a majority of the earth's precipitation and therefore are of special concern relative to water quality. Watersheds are also nested (Merrill, 2013), meaning they can represent a larger watershed system consisting of many different rivers (on the scale of hundreds of miles) or a subset of the larger watershed (a few miles or less), which contain a few tributaries and possibly just one river. Watersheds contain various ecosystems important for water quality protection, including forests, riparian areas, wetlands and floodplains. As exemplified by a GIS analysis conducted by the city of Charlotte, North Carolina, no one ecosystem is necessarily more important than another in terms of protecting water quality (Ernst, 2004). The city of Charlotte determined that tributaries and streams within the upper part of the Mountain Island Lake Watershed were just as significant for water quality as the floodplain region. For a watershed to provide adequate protection it should: provide adequate infiltration, buffer peak flows, recharge groundwater supplies, reduce erosional processes and sedimentation, filter pollutants, and retain adequate water chemistry (Dudley & Stolton, 2003).

2.1 HYDROLOGICAL SERVICES OF WATERSHEDS AND THE VALUE OF WATER QUALITY

Hydrological services provided by watershed are almost always undervalued (Dudley & Stolton, 2003). For example, China's forests are often valued for extractive purposes-the value of wood in China's forests is $2.5 million. On the other hand, a likely lesser-known value is the value of water storage in China's forest which is three times this amount (Dudley & Stolton, 2003). Watersheds are extremely important areas and have the ability to regulate water flows, reduce erosional processes and contaminant loads, and provide important habitat (Postel & Thompson, 2005). Aside from the many other important hydrological services just mentioned, water filtration/purification may be one of the most important hydrological services that watersheds provide. Biophysical characteristics such as soil composition, precipitation patterns, slope, the presence, age, and type of vegetation are all characteristics that influence the functionality of watersheds to act as filtration systems (Dudley & Stolton, 2003).

Buffer zones can be any form of vegetation which impedes sediment or filters pollutants from a water body (Brauman et al., 2007). Buffer zones include ecosystems like wetlands and riparian areas. Buffer zones have been shown to reduce contaminant loads (Correll, 1997; Sullivan et al., 2007) which may enter into adjacent or downstream water bodies. Breakdown of contaminants in waterways is encouraged by buffer zones, as these habitats help maintain the natural configuration as well as regulate the temperature of a waterway (Brauman et al., 2007). In one example, farmers in California noted that implementing vegetation buffers outweighed the costs of lost crop production. The net benefit was due to improved water quality and minimal soil erosion (Brauman et al., 2007).

Sullivan et al., (2007) conducted a study on the effectiveness of vegetated buffers to filter and reduce fecal coliform bacteria counts. The study was conducted in Oregon using rainfall events to collect water samples at a) upstream manure application sites and b) sites downstream of vegetated buffers. Sullivan et al., (2007) noted a 99 percent reduction in fecal coliform bacteria in water samples collected after water had filtered through a vegetated buffer compared to upstream sites where cow manure was applied and coliform counts were high.

There are multiple methods used to determine the value of improved water quality, one common method is determining an individual's Willingness To Pay (WTP). Leggett & Bockstael (1998) used hedonic pricing, one form of WTP, to determine the value of increased water quality along an estuary. The authors concluded that improved water quality, specifically lowered fecal coliform counts, has a positive effect on property values. They estimated that if fecal coliform counts were improved by one count (the current count range is 0.04mL to 23mL) there would be a $5,000 property value increase displayed by parcels located along the estuary. As with many environmental services, the importance of hydrologic services, such as the provision of water and the quality of water provided, is often undervalued (Dudley & Stolton, 2003).

2.1.1 Role of Vegetation in Water Quality

Nearly 3,000 cities rely on catchments within national forests for municipal water supply (Dissmeyer, 2000). Similar to the quantity of pollution and number of contaminants reaching waterways, the importance of forested areas is increasing. Sixty million people obtain water collected by grasslands and forests (Dissmeyer, 2000). Vegetation is important in reducing contaminant loads; vegetation can reduce or degrade common contaminants, such as nitrate, metals, and pesticides. As raw water is filtered and the quality of water improves, treatment costs decrease (Ernst, 2004).

The preservation of forests and vegetated areas upstream reduce erosion and therefore sediment concentrations within the water column. Vegetation also reduces the amount of sediment transported into waterways by stabilizing the soil and filtering suspended sediment particles (Thompson, 2003; Brauman et al., 2007). Furthermore, leaf litter acts as a barrier against what would otherwise be scouring rain events leading to erosion of the surface and transport of sediment into waterways (Dudley & Stolton, 2003). Forest or riparian buffers can absorb up to eighty percent of sediment contained in runoff from forestry roads (Gartner et al., 2013). On a large scale, erosional processes, such as landslides, are prevented within forested areas due to soil stabilization provided by root networks (Dudley & Stolton, 2003).

Vegetation within forests degrades contaminants and filters and absorbs sediment. Plants remove contaminants usually through uptake via roots but also reduce contaminant loads through indirect processes such as, the addition of organic matter to the soil profile as plants decay (Dosskey et al., 2010). In one example Brauman et al., (2007) noted that reforesting less than 10 percent of the Mississipii floodplain could decrease nitrogen inputs into the Gulf of Mexico by ~30 percent.

Ernst et al. (2004) emphasizes the importance of forested areas in particular, as a cost effective solution to provide high quality municipal drinking water. Ernst et al. (2004) noted a direct relationship between the ratio of forest cover in watershed areas and the cost of water treatment. The percentage of forest cover in watershed areas may determine roughly 50 percent of the variability in treatment costs. More specifically, treatment costs decreased by 20 percent for every 10 percent increase in forested areas; costs did however stop declining after 60 percent cover. When comparing watersheds with 60 percent forest cover to watersheds containing 10 percent forest cover, the maximum benefit that could be achieved would lead to a $78 decrease per million gallons (Ernst et al., 2004)(Table 1). When considering a typical treatment plant operating at 22 million gallons a day, a watershed with 10 percent forested cover would require $2,530 in treatment costs; comparatively, a watershed containing 60 percent forested cover would only require $814 in treatment costs (Ernst et al., 2004) (Table 1).

Table 1. Forest Cover Impacts on Treatment Costs

% of Watershed Forested	Treatment and Chemical Costs *per mil gal*	% Change in Costs	Average Treatment Costs *per day at 22 mil gal*
10%	$115	19%	$2,530
20%	$93	20%	$2,046
30%	$73	21%	$1,606
40%	$58	21%	$1,276
50%	$46	21%	$1,012
60%	$37	19%	$814

Source: (Ernst et al., 2004)

Undisturbed ecosystems, such as wetlands and floodplains are especially valuable to improve water quality; however, alternative land use practices, such as farming may occur in conjunction with a protected area. Alternative land uses are acceptable as long as ecosystem functioning is not compromised (Ernst et al., 2004).

2.1.2 Role of Soils in Water Quality

Many contaminants have an affinity for and bind to sediment which causes these constituents to become immobile and not impact downstream water bodies (Dosskey et al., 2010). Furthermore, soils have a variety of microbiological communities that can degrade nitrate, pesticides, bacteria and viruses, and other contaminants (Brauman et al., 2007). Wetlands are oftentimes incorporated into treatment plants because of the ability of microbial communities within wetlands to break down these constituents (Brauman et al., 2007). Sheoran & Sheoran (2006) describe the potential of soils within wetlands to mitigate heavy metals within severely impaired acid mine drainage areas. Similar to the processes within a traditional water filtration plant, metals from acid mine drainage bind to the organic matter present in wetlands and the particulate matter settles to the bottom where it becomes integrated into the geochemical cycle (Sheoran & Sheoran, 2006)

3.0 Development of Water Quality Policies in the U.S.

The U.S. Environmental Protection Agency (US EPA) approach to solve water quality problems has historically revolved around remediation and reducing contaminant levels in identified waterbodies (U.S. EPA, 2011). The two largest policies relative to water quality within the U.S. have been the Clean Water Act (CWA) (1972) and the Safe Drinking Water Act (SDWA) (1974). The goals of the CWA are to achieve the restoration and maintenance of the chemical, physical and biological integrity of the Nation's waters (CWA, section 101 (a) objective) (U.S. EPA, 2011). These goals have been primarily accomplished through regulating point source and Nonpoint source (NPS) pollution in surface waters.

While the CWA addresses problems arising in the beginning of the life cycle of water distribution-contamination within sources, the SDWA addresses contaminants specifically within drinking water, or water at the end of its distribution life cycle. The SDWA defines Maximum Contaminant Levels (MCLs) and MCL Goals of constituents within drinking water that have negative health effects. Public water providers are required to comply with U.S. EPA and state defined contaminant levels (U.S. EPA, 1997). The first amendment to the SDWA was in 1986 and required the EPA to list and regulate 25 new contaminants every three years, however, this was repealed in the 1996 amendment and substituted for a risk-based approach (U.S. EPA, 1997).

The EPA's approach to ensuring water quality prior to the 1990's was based on regulating contaminants after they had entered a body of water. During the 1996 CWA amendments, recognition was given to source water areas and their ability to achieve water quality standards. During the most recent amendment, the EPA began integrating protection and prevention into their clean water strategy. Section 1453 of the 1996 amendments required each state to conduct a source water assessment which included: 1) delineating the source water protection areas, 2) inventorying the contaminant sources within the area, and 3) determining the susceptibility of these contaminants (U.S. EPA, 1997). Funding was allocated to states through Drinking Water State Revolving Funds, which paid for assessment and protection programs (Ernst, 2004).

In a 2011 EPA report, "Coming Together for Clean Water: EPA's Strategy to Protect America's Waters", the EPA proposed that expanding the number of healthy watersheds was a necessary component of solving water quality issues. Furthermore, the EPA acknowledged that source water (watershed) protection should be considered as one of the main approaches to achieve a healthy watershed (U.S. EPA, 2011). The "Healthy Watersheds Initiative" was developed by the EPA to more clearly define their plan to protect watersheds and is defined as follows…

> "The HWI is intended to preserve and maintain natural ecosystems by protecting our remaining healthy watersheds, preventing them from becoming impaired, and accelerating our restoration successes. It is based on an integrated, systems based approach to watershed protection, supported by the latest science that views watersheds as dynamic systems that include surface water (instream flow in rivers and lake levels) and subsurface groundwater quantity variability, water quality, biological resources and their habitat, and other key processes (e.g., geo-morphic) that support healthy aquatic resources" (U.S. EPA, 2011).

The EPA's goal was to have 50 percent of publicly supplied water under source water protection programs by 2005 (U.S. EPA, 1997). U.S. Congress has taken a step in the right direction by recently budgeting for watershed protection accomplished by land purchases from the federal clean water funds (Lerner & Poole, 2006). However, currently, the U.S. is still reliant upon human engineered treatment methods or, after-the-fact remediation techniques to repair already impaired water (Davies & Mazumder, 2003). Under the 1989 Surface Water Treatment Rule (part of the SDWA), filtration of surface water is required by water providers unless providers can prove that surface water meets drinking water standards including: turbidity requirements, coliform bacteria requirements, protozoan and viral disinfection standards, and a watershed management program (Davies & Mazumder, 2003). If a water provider, such as a municipality or utility, can prove that surface waters meet drinking water standards, the EPA can grant a Filtration Avoidance Determination (FAD) to the provider (Pires, 2004). An avoidance determination allows these cities to avoid the construction of human engineered filtration infrastructure. That being said, some form of water treatment (chlorination or ozonation) for microbial contaminants is required for all cities.

Predictions in the early 1900s from city planners stated that a reliance on chlorination and treatment would become known as an end-all solution to water purification (National Research Council, 2000). And indeed, that is what's occurring today; a the current reliance upon treatment, such as chlorination and advanced filtration methods, is leading to a decrease in the protection of important source water areas and buffer zones within watersheds (Ernst et al., 2004).

3.1 Revival of Watershed Protection to preserve Water Quality

It is evident that current water quality strategies are failing; new waterbodies are being listed for water quality impairments much faster than waterbodies are being removed (U.S. EPA, 2011). In the U.S., approximately 30 million residents rely on water sources which are impaired and do not comply with EPA water quality standards (Lerner & Poole, 2006). The EPA has determined that $140 billion is necessary to improve water quality and lower the number of impaired sources (Lerner & Poole, 2006). The EPA (2011) states that, "there is a direct relationship between land cover, hydrology and key watershed processes and the condition of aquatic ecosystems". The preservation of intact, healthy watersheds is necessary for the restoration of degraded waterbodies; furthermore, preservation of healthy watersheds now will eliminate the much higher cost of having to restore waterbodies that become degraded in the future. Communities and planning agencies currently recognize that investment **now** in a clean water source is far less expensive than after-the-fact remediation.

While the EPA only recently began to seriously integrate watershed protection measures into their policies, this is not a novel idea. The growth of cities is linked to the availability and safety of water supplies (U.S. EPA, 1997). As early as the 1800s, prior to modern treatment technologies, large cities including, San Francisco, Seattle, Boston, and New York City were securing a safe source of water for their growing populations by protecting headwater areas (Ernst et al., 2004; Alcott et al., 2013). Land preservation, such as the protection of headwaters and buffer zones is the first step in protecting and improving downstream drinking water quality. Watershed protection plans are designed to improve water quality through natural filtration (green infrastructure) and/or to protect water quality by limiting the amount of pollutants entering the system (Brauman et al., 2007). The preservation of watershed areas: 1) eliminates major sources of contamination that may arise from development, and 2) buffers from existing nonpoint sources of pollution (B. Thompson, 2003).

As aforementioned, the protection of watershed areas, including source areas, was at its height in the eighteen and nineteen hundreds when large cities were developing within the U.S. Today, there is a mix of current water quality management techniques used across the country ranging from cities that have eliminated the necessity of filtration technology and are entirely reliant upon green infrastructure, i.e. soil and vegetation filtration, to cities that are entirely reliant upon human engineered treatment methods. Ideally, a watershed protection plan would include the preservation of all or a majority of the upstream watershed, including source water areas, forests, riparian zones, and etc. However, it is more likely in current day situations that a combination of these areas will be protected due to different land uses and ownership occurring within a watershed. Alternative management strategies such as, managed forests or farmland (while not the best option) still create an opportunity for increased water quality through certain protection measures. Landscape use patterns will continue to change as time progresses however, development and encroachment on natural areas is almost certain to increase. As the amount of undeveloped available land dwindles, so does the chance for water providers and utilities to secure the opportunity to decrease treatment costs as well as increase the quality of water to consumers long-term. For this reason, growing cities should be particularly interested in using land protection as a tool to solving water quality problems.

Consumers want the best product: high quality water, at the lowest cost. Therefore, water utilities need to strongly weigh protection options between “green” infrastructure (watershed protection) and “gray” (human engineered) and select water quality management decisions that will provide the most cost effective results (Alcott et al., 2013). Important considerations for water utilities are costs, including future operation and maintenance, or land acquisition; predicted land use changes in upstream areas; population trends; potential land management partners; and other water quality improvement techniques such as, Best Management Practices (BMPs).

Watershed protection is popular among many interest groups including, regulators, voters, landowners, and water (and hydroelectric) providers. As aforementioned, the EPA has integrated source water assessments and watershed protection as a component of the CWA; voters support watershed protection as they recognize the importance of clean water as essential; landowners support source protection as they are typically fairly compensated for the protection of their land along streams or rivers; and water and electric providers recognize the ability of watershed protection to lower production costs.

Multiple agencies and water providers are recognizing the ability of watershed protection to lower common contaminant concentrations within surface and ground water supplies (Ernst, 2004). There is an increased cognizance that high quality raw water provided by watershed protection 1) lowers treatment costs, 2) lowers public health risks. In 2002, the Trust for Public Land and the American Water Works Association reviewed nearly thirty drinking water suppliers and found that there was a negative correlation in the amount of forested area compared to treatment costs, that is, the more forest cover that was present, the less treatment costs were (as cited by Ernst et al., 2004). Health risks are known to be lower in a protected watershed because the introduction of chemicals, sediment, nutrients, sewage and other contaminants is decreased or eliminated (Davies & Mazumder, 2003). Clean source water requires less treatment and lowers the risk of water borne illnesses (Davies & Mazumder, 2003).

3.2 Effectiveness & Avoided Costs of Watershed Protection

While human engineered treatment such as filtration or purification is usually effective, the conservation of watershed areas is less costly than downstream after-the-fact treatment and remediation (J. Quinn, 2005). Or, in other words: "It is much easier and less costly to protect water quality than it is to restore water quality" (Peckenham et al., 2005). In fact, water providers spend 19 times more on chemicals to treat polluted waters than government spends on protection and pollution prevention efforts (CWP, U.S. Forest Service 2008). The EPA has recently acknowledged healthy watersheds and watershed protection as a necessary and cost-effective component of their clean water strategy (U.S. EPA, 2011). Furthermore, the American Water Works Research Foundation noted that land ownership was the most effective strategy to ensure long-term protection of water resources (Lerner & Poole, 2006).

The choice to protect watersheds as a preventative measure, rather than performing remedial methods at a later point in time, is becoming an increasingly favored method for securing clean drinking water supplies (U.S. EPA, 2011; Davies & Mazumder, 2003). In fact, protected areas already supply drinking water for nearly one third of the world's biggest cities and provide clean, reliable sources of water (Dudley & Stolton, 2003). Some of the best drinking water in the world is a result of watershed protection programs that were implemented in cities like Bogota, Columbia (discussed below), New York City (Ch. 5), and Melbourne, Australia (Ch. 6) (Appleton, 2002; Dudley & Stolton, 2003). Smaller examples of cities that have invested in watershed protection and as a result have avoided filtration technologies include Auburn, Maine, Gastonia, North Carolina, and Bogota, Columbia.

Auburn has a population of approximately 17,000 people and receives its water from Lake Auburn (Auburn Water & Sewerage Districts, 2013). The estimated cost to provide a filtration treatment system to the city of Auburn was $30 million with $750,000/yr in operating costs (Ernst, 2004). Instead the city purchased 434 acres surrounding Lake Auburn for a one-time fee of $570,000. Water quality results from Lake Auburn consistently meet standards; water quality results, including turbidity and *E. coli* levels from 2012 from Lake Auburn were within acceptable range of EPA health criteria (Auburn Water & Sewerage Districts, 2013).

In another example, the Gastonia, North Carolina changed its drinking water source from a lake surrounded by development and rising Non Point Source (NPS) pollution to a protected lake and saved $250,000 in treatment costs annually (Lerner & Poole, 2006). So far Gastonia together with Charlotte, NC, have preserved more than 4,000 acres of watershed habitat to protect 70 percent of lakeshore area and another 20 percent of upland streams in the Mountain Island Lake watershed (Ernst, 2004). The land was paid for through a land-banking bond; so far more than $30 million has been spent to preserve these areas (Ernst, 2004).

The city of Bogota, Columbia is one of a handful of cities around the world noted for having excellent water quality as residents receive drinking water from a protected national park (the Chingaza) within the Andes (Postel & Thompson, 2005). Water is filtered through the páramo, a high elevation wetland within the Chingaza National Park and is of such high quality that even during heavy rainfall periods, filtration through sand filters at the utility's treatment plant is rarely used. The páramo wetland filters and supplies nearly 8 million people with a dependable source of pure drinking water at the rate of 28 m^3 per second (Postel & Thompson, 2005). The only treatment necessary for this water source is chlorine.

Within the U.S. there are multiple examples of cities that have implemented watershed protection programs and avoided the costly implementation of filtration plants (Table 2). New York City is the most famous example; this city has saved (and continues to save) billions of dollars and furthermore, has excellent water quality (explained in greater depth in Chapter 5). New York City saved approximately $6 billion dollars through the protection of headwaters within the Catskills mountain range which eliminated the need to build a filtration plant (Brauman et al., 2007; Lerner & Poole, 2006; National Research Council, 2000).

Table 2. U.S. Cities Utilizing Watershed Protection and Avoiding Filtration Treatment

Metropolitan area	Population	Avoided costs through watershed protection
	(thousands)	
New York City[a]	9,000	$1.5 billion spent on watershed protection over 10 years to avoid at least $6 billion in capital costs and $300 million in annual operating costs.
Boston, Massachusetts[b]	2,300	$180 million (gross) avoided cost.
Seattle, Washington[c]	1,300	$150–200 million (gross) avoided cost.
Portland, Oregon[d]	825	$920,000 spent annually to protect watershed is avoiding a $200 million capital cost.
Portland, Maine[d]	160	$729,000 spent annually to protect watershed has avoided $25 million in capital costs and $725,000 in operating costs.
Syracuse, New York[e]	150	$10 million watershed plan is avoiding $45–60 million in capital costs.
Auburn, Maine[f]	23	$570,000 spent to acquire watershed land is avoiding $30 million capital cost and $750,000 in annual operating costs.

Source: (Postel & Thompson, 2005)

3.3 Other Benefits of Watershed Protection

An important aspect of land conservation is its applicability as an economic tool within developing countries. Dissimilar to the U.S., Australia, and other developed nations, many rural areas lack regulatory control over water quality. Within rural landscapes, landowners and farmers are being paid for the protection and conservation of upstream areas through payments from downstream consumers; this payment scheme is considered Payments for Environmental (or in this case specifically hydrological) Services and discussed more in Chapter 7.

There are multiple obvious other benefits gained from the protection of watershed areas such as, the creation of recreational/green spaces, flood buffering capacity, carbon capture, and the preservation of biodiversity including species of special concern. Additional benefits provide further evidence for watershed protection; however, these benefits are not discussed within this paper as this research focuses on watershed protection and it's ability to improve water quality.

4.0 HUMAN ENGINEERED WATER TREATMENT

Three phases exists in the transport of drinking water to the consumer: 1) the source phase, 2) the treatment phase and 3) the distribution and delivery phase (Davies & Mazumder, 2003). The first and most important phase in terms of risks for contamination is the source phase (Ernst et al., 2004), which includes the pathway of water from a headwater area into a reservoir, lake, river or other end route. Concern for contamination is highest in the source phase as drinking water may come into contact with a variety of pollutants that are draining into a similar end route. Next, water is transported to a treatment system where multiple stages exist for purification and disinfection (described below) (Ernst et al., 2004). Treated water then flows into holding areas, wells, pipes, and eventually to the tap.

Typical water purification involves: 1) filtering larger materials, including vegetation, large soil particles, 2) treatment using disinfectants, the most common being chlorine 3) additional filtration via a carbon, sand or gravel filter to remove smaller particles, and 4) application of a lasting disinfectant while water is being distributed (San Diego Water Authority, 2014). Disinfection is required by **all** drinking water providers due to the presence of microorganisms such as coliforms. Similarly, cities reliant upon human engineered infrastructure or watershed protection may use chemical treatments. Chemical treatment usually occurs for aesthetic characteristics of drinking water such as taste, color, or odor or to reduce corrosion.

There are three main chemicals used to treat municipal drinking water, these include: coagulants, disinfectants, and pH adjusters. Coagulants bind to impurities so that larger particles settle to the bottom or are able to be filtered. Disinfectants kill microorganisms, including bacteria. The most widely used disinfectant is chlorine. Chlorine is effective because of its ability to destroy the cell structure and chemical bonds within microorganisms. Adjusters for pH buffer the acidity from coagulants (Dearmont et al., 1998). Further chemicals used in municipal water treatment vary, dependent upon localized sources of contamination such as pesticides or naturally occurring elements. For example, activated carbon is recommended for treatment of pesticides and ferric sulfate is suggested to treat for elevated arsenic (Dearmont et al., 1998).

4.1 Effectiveness of Human Engineered Treatment

A 1998 study of chemical costs considering 12 treatment plants in Texas found that the average treatment cost per million gallons was $74 (Dearmont et al., 1998). Raw water was collected from the Red, Brazos, Colorado, and Rio Grande river systems and turbidity was used as the independent variable. Water quality results and costs from four years showed no exceedances of the Maximum Contaminant Level (MCL) for turbidity or other required MCLs, however, it was indicated that many of the treatment plants had installed costly treatment systems, such as ones using activated carbon filtration (Dearmont et al., 1998). Nonetheless, these plants were capable of treating large amounts of water, approximately 222 million gallons, per month.

In another study, Ormand et al. (2008) reviewed the effectiveness of common treatment methods (preoxidation by chlorine or ozone, chemical precipitation with aluminum sulfate and activated carbon adsorption) to degrade pesticides in drinking water. Ormand et al. also found that 60 percent of pesticides were removed using oxidation via chlorine and 70 percent were degraded using oxidation via ozone. The most effective treatment for removing pesticides from drinking water supplies was a combination of oxidation via ozone and activated carbon filtration; however, the combination of this method also produced the unwanted byproduct of trihalomethanes (Ormad et al., 2008).

4.2 Increasing Treatment Costs

When considering watershed protection, there are no costs involved in "running" an ecosystem. Comparatively, human engineered treatment costs typically include: infrastructure, chemicals, energy, and maintenance (California Department of Water Resources, 2009). Furthermore, a combination of more stringent regulations, rising energy and material costs, and an increasing complexity of chemicals present in waterways is increasing the costs of human engineered treatment. Increasing pollution leads to additional time and resources used to treat water and remove or degrade contaminants (Davies & Mazumder, 2003).

Since 1965, there has been a 30 percent increase in the amount of chlorine (as well as associated treatment costs) added to drinking waters due to contaminated source waters (Lerner & Poole, 2006). In Cincinnati, an increase in pesticide concentrations in waterways have led to a 10 percent increase in consumers' water bills, specifically due to the use of carbon filtration technologies for pesticides (Lerner & Poole, 2006). In Milwaukee, $54 million has been spent to prevent outbreaks of Cryptosporidium bacteria after an initial outbreak in 1993 killed 103 people (Lerner & Poole, 2006).

Water treatment costs fluctuate according to regional variations including land use, soils, rainfall patterns, and temperature (Dearmont et al., 1998). A majority of chemical costs are spent on pH adjusters, coagulants, and disinfectants. A pattern present across most of the world is development within watershed or aquifer recharge areas, resulting in an increased variety and presence of chemicals and therefore, increased treatment costs. Dearmont et al. (1998) reviewed water quality results and costs of 12 water treatment plants in Texas for three years. They found a $95 increase per million gallons of water treated when raw water contamination was present. Scaling up this figure to a Texas state-wide estimate, considering 30 percent of the cities who depend on surface water supplies have chemical contamination, reveals a $13 million annual increase in treatment costs (Dearmont et al., 1998).

Water treatment during the rainy season is noted as being especially problematic and costly as turbidity and sediment concentrations in waterways increase (Dudley & Stolton, 2003). Filtration to remove sediment and particulate matter is an expensive process. According to Ernst et al. (2004) and Dearmont et al. (1998), every 4 percent increase in raw water turbidity can increase treatment costs by 1 percent. An analysis by Dearmont et al., (1998) of water treatment costs for 12 plants in Texas revealed that even a 1 percent decrease in turbidity [provided by vegetation and soils] would decrease chemical costs by approximately $70,000 per year.

The Guandu water treatment facility in Rio de Janeiro notes large variations in the concentrations of chemicals necessary between the dry and rainy season. Deforested hillsides within Rio de Janeiro cause increased erosional processes, resulting in increased suspended sediment concentrations within waterways. Chlorine consumption increased by 32 percent in five years within the Guandu River (Dudley & Stolton, 2003). Increased chlorine concentrations can be linked to a decline in water quality as higher concentrations of chlorine indicate the presence of increased microorganisms. The Guandu water treatment facility noted that as much as 80 percent of their treatment costs are chemicals, such as chlorine (Dudley & Stolton, 2003).

Additional nutrient inputs can also increase treatment costs as a rise in primary productivity usually leads to higher levels of organic matter and a greater need for disinfection (Davies & Mazumder, 2003). Concentrations of Total Suspended Solids and nitrates can often be minimized by protection of headwater and streamside ecosystems. Cleaner raw water inputs provided by intact upstream areas which require minimal or sometimes no treatment will lower treatment costs (Davies & Mazumder, 2003; Ernst et al., 2004).

5.0 Cost Effectiveness Analysis: Human Engineered treatment vs. Watershed Protection

This chapter presents a cost effectiveness analysis on human engineered filtration and treatment (gray infrastructure) versus watershed protection (green infrastructure) by first providing an overview of the research (5.1), followed by the presentation of three case studies for human engineered treatement (5.2) and three case studies for watershed protection (5.3), followed by a summary of results pertaining specifically to costs and effectiveness (5.4, Table 3), and lastly, a summary comparison of human engineered infrastructure versus watershed protection (5.5). Two summary tables are provided in this chapter; Table 3 provides a summary of the costs and effectiveness of the six case studies and Table 4 provides a summary comparison of human engineered infrastructure versus watershed protection.

5.1 Research Introduction

The costs of human engineered infrastructure versus watershed protection have been cited in previous sections (Ernst et al., 2004; Postel & Thompson, 2005; Peckenham et al., 2005); however, a comparison which considers the effectiveness of human engineered infrastructure (gray infrastructure) versus the ability of protected watersheds (green infrastructure) to filter or protect from pollutants entering water bodies is lacking. Water utility providers note that economic analyses which provide evidence of the effectiveness and cost-savings of watershed protection are often times non-existent or perceived as too costly to conduct (Gartner et al., 2013). In other words, utility providers want to see evidence that watershed protection is effective before investing in land conservation or watershed protection measures in place of human engineered infrastructure.

In order to provide this evidence, a green-gray analysis was performed as part of this research; green-gray analyses are an increasingly used tool for performing economic comparisons considering the efficacy and functioning of natural or green ecosystems compared to gray or human-built infrastructure that uses steel, concrete, and etc. (Gartner et al., 2013). The goal of this research was to investigate the cost effectiveness of human engineered infrastructure, specifically water filtration systems, compared to green infrastructure (watershed protection) to achieve drinking water quality standards. This goal is achieved by performing a cost effectiveness analysis that compares three municipalities reliant upon human engineered water filtration and three municipalities that have implemented watershed protection programs in lieu of human engineered infrastructure. There are seven municipalities in the U.S. that have obtained a waiver by the U.S. EPA (FAD) to avoid filtration of their water because their source is so well protected (Table 2); three of these cities were chosen for analysis (NYC, NY; Seattle, WA; Portland, ME). These examples may be of interest to water providers, such as cities or water utilities considering watershed protection as a tool to solve water supply and quality problems.

For the purposes of this research, *effectiveness* is defined as: the ability of infrastructure (human engineered (gray), or watershed protection (green)) to remove common contaminants, such as sediments and microorganisms from raw water.
A cost effectiveness analysis is presented below which describes the ability of human engineered (gray infrastructure) versus watershed protection (green infrastructure) to safeguard drinking water from two common water quality indicators: 1) *E. coli* and 2) turbidity.

Escherichia coli (E. coli) is a bacterium commonly used as a surrogate to estimate microbial contamination such as, bacteria, viruses and protozoa which can enter the water through mammalian waste (Sullivan et al., 2007). *E. coli* is measured by the Most Probable Number (MPN) of colony forming units. According to the EPA Maximum Contaminant Level (MCL), no more than 5 % of samples collected per month may test positive for *E. coli* concentrations/colonies (U.S. EPA, 2013); this standard is true regardless of the infrastructure method (human engineered of watershed protection).

The second water quality indicator chosen was turbidity; turbidity was chosen as an indicator because changes in turbidity levels have the ability to reflect sudden land use changes within a watershed (Gartner et al., 2013). Turbidity is not a direct measure of total or suspended solids but rather how particles, which may be metals, nutrients, sediment or bacteria, interfere with light. High turbidity levels indicate higher suspended and dissolved solids. There are two MCLs for turbidity assigned to for surface water providers: one level applies to cities that rely upon human engineered filtration and the other applies to cities that have obtained Filtration Avoidance Determinations. The federal Environmental Protection Agency's MCL for turbidity within systems that use human engineered treatment is 1.0 nephelometric turbidity units (NTUs) per each sample collected (U.S. EPA, 2013). The U.S. EPA's MCL is 5.0 NTUs per sample for municipalities that have acquired a Filtration Avoidance Determination (FAD) (U.S. EPA, 2013).

In the following analysis, three examples of cities that rely on human engineered treatment (gray infrastructure) are presented, followed by three cities that have implemented watershed protection programs (green infrastructure) and have obtained a Filtration Avoidance Determination. This analysis includes two pieces: costs and effectiveness; costs include: 1) the costs of human engineered infrastructure including, the construction of the filtration system, maintenance, chemicals, energy and other associated costs or, 2) the costs of implementing a watershed protection program including, acquisition of land, program implementation. The second part of this analysis determines the effectiveness of the current water quality achievement method. Effectiveness is measured by reviewing 2012 water quality monitoring results for *E. coli* and turbidity from three human engineered examples and three watershed protection examples. Federal EPA drinking water guidelines (MCLs) as described previously will be used as the standard of comparison for effectiveness. Total cost estimates are difficult to determine for each example provided as some watershed programs are extensive and cover hundreds of different costs- as in the case of NYC. To prevent over or under estimating costs between examples provided, avoided costs were used as a simplification for the cost analysis. Avoided costs represent the potential cost of human engineered infrastructure that cities were facing prior to the implementation of watershed protection programs.

Table 3 presented at the end of this chapter provides a summary of the costs and effectiveness (water quality results). The following sections discuss individual case studies, or "examples", used for the cost effectiveness analysis of human engineered treatment versus watershed protection.

5.2 Human Engineered Infrastructure Case Studies

The following section contains three examples of cities that rely upon human engineered filtration to meet water quality standards. The examples presented range from a highly advanced membrane filtration system (San Diego), to more basic sand filtration systems (Salem, OR, and Maynard, MA).

5.2.1. Case Study 1- Twin Oaks Valley Treatment Facility San Diego, CA

The city of San Diego receives a majority of its water (60 percent) from the Delta region of northern California, and the remainder of its water (40 percent) from the Colorado River (California Department of Water Resources, 2009). To meet San Diego's growing population, the Twin Oaks Valley membrane filtration plant was constructed in 2008. The treatment facility is noted for being a state of the art facility; the facility is able to treat 100 million gallons of water per day and supply 880,000 people, or 220,000 four-person households (San Diego Water Authority, 2014). The cost to construct the filtration plant was $157 million with annual operation costs of $7.5 million, including $6.5 million for materials and chemicals, and another $1 million for energy costs (California Department of Water Resources, 2009).

The membrane filtration plant functions by pumping water through "hollow strands of membrane material" which pull water molecules through their center and leave behind contaminants (San Diego Water Authority, 2014). The membranes filter out contaminants ranging from dust to bacteria and out-compete traditional water treatment technologies that use flocculation and sedimentation techniques (San Diego Water Authority, 2014). The Twin Oaks Valley treatment plant also produces 80 percent less chemical byproducts as chemical coagulants used in traditional treatment processes are no longer necessary with membrane technology (San Diego Water Authority, 2014). If there are any traces of contaminants, Twin Oaks, similar to all other treatment facilities (and cities possessing FADs), disinfects water prior to distribution (San Diego Water Authority, 2014).

While the cost of the Twin Oaks Valley membrane filtration plant was high ($157 million), the filtration plant is very effective at removing contaminants and particulates (San Diego Water Authority, 2014). The average turbidity value of water from the Twin Oaks Valley treatment facility was 0.02 NTUs, well within the EPA drinking water guidelines of <1.0 NTU (Olivenhain Municipal Water District, 2013). Even more impressive, the **highest** recorded 2012 turbidity value at the Twin Oaks facility (0.04 NTUs) is lower than any of the gray or green infrastructure turbidity results that were identified in this analysis (Table 3) (Olivenhain Municipal Water District, 2013).

Furthermore, as expected from a high-end filtration system, no concentrations of *E. coli* were detected in any samples collected (Table 3).

In summary, the Twin Oaks Valley filtration plant was the most costly infrastructure among all six case studies; however, this infrastructure also provided the highest water quality results when assessing turbidity and *E. coli* results.

5.2.2 Case Study 2 - Geren Island Treatment Facility Salem, Oregon

Even though Salem, Oregon has a watershed management program, the city still relies upon filtration treatment to achieve water quality standards. This city has taken advantage of using slow sand filtration-a mostly cost-effective filtration method. Slow sand filtration is noted for being very effective under normal to low flow conditions; however, as the city discovered in the 1990s, increased turbidity severely limits the functioning of the systems (Ernst, 2004).

The City of Salem receives its drinking water from the North Santiam River that begins in the foothills of the Cascades. Surface water from the Santiam river is diverted into the Geren Island Water Treatment Facility, which had up until recently relied upon slow sand filtration as the primary treatment method (City of Salem Public Works Department, 2013). Slow sand filtration does not actually employ sand in the process of filtration. Instead, the sand forms a substrate for a layer of floating biological matter, known as *schmutzdecke,* that contains beneficial bacteria and fungi that ingest dissolved organic material (Huisman & Wood, 1974). Slow sand filtration systems are not recommended for cities with large populations (>100,000) (USGAO, 1998). Nonetheless, it is utilized in Salem and provides 9,500 million gallons of water to 170,000 people (T. Sherman, 2014).

Eighty percent of land in the Salem watershed is forested and managed by a combination of the U.S. Forest Service, the Oregon Dept. of Forestry, or the Bureau of Land Management (Ernst, 2004). Timber extraction occurs in much of the managed portions of the forest and is tied to a large flood event that occurred in 1996. Aside from filtering and trapping sediment, vegetation and tree root systems also stabilize sediment; therefore, when large regions of forests are extracted, the support system holding sediment in place is also removed. Highly increased turbidity levels were observed after a large rain event occurred in 1996 and is directly linked to the harvesting of trees in the North Santiam River watershed.

A case in point for Salem is to note the result that mismanaged forestry practices had on their entire watershed, especially because the treatment system Salem was relying upon was not built to handle such abrupt changes. Forestry management, often combined with extractive use is sometimes seen as a middle of the road alternative to protection; however, as observed through changes in Salem's water quality, these practices drastically change the outcome of water quality.

As aforementioned, Salem's sand filtration system was noted for being previously very effective; however, high levels of turbidity (> 8 NTUs) observed in the 1996 flood clogged filters and stopped water production (Ernst, 2004). The city's water supply was halted due to the filtration system being inoperable and the city was forced to spend $200,000 on potable water as a short-term solution. As a long-term solution, a permanent $1 million chemical pre-treatment system was constructed to treat raw water prior to it reaching the sand filters (Ernst, 2004). Annual operation costs for the current pretreatment system and sand filtration are estimated at $1.15 million, which includes $500,000 for staff costs, $250,000 for chemicals, $250,000 for energy, and $150,000 in maintenance costs (T. Sherman, 2014). For a city that previously spent $27 per million gallons of water treated, one million dollars in new infrastructure is a substantial cost (U.S. General Accounting Office, 1998). Furthermore, Salem city officials still note the possibility of turbidity levels exceeding the drinking water standard if fine particulate matter levels are increased during heavy storm events (U.S. General Accounting Office, 1998).

A source water assessment in 2003, indicated roadways, septic systems, pastures, and forest operations as sources of contaminants (City of Salem Public Works Department, 2013). Increased sedimentation, microbiological organisms, and nutrients in local water supplies may result from these sources. The new pretreatment chemical facility (Geren Island facility), which uses chemicals to cause precipitation of sediment from the water column, seems to be helping to manage turbidity. Water quality results for turbidity from the Geren Island facility during 2012 ranged from 0.05 to 0.25 NTUs (City of Salem Public Works Department, 2013). As shown in Table 3, the average turbidity result during 2012 was 0.09 NTUs (City of Salem Public Works Department, 2013), within the EPA drinking water standards. Nonetheless, Salem city officials still indicate concern over the potential for rare flooding and rain events leading to excess suspended sediment concentrations and turbidity (U.S. General Accounting Office, 1998). Aside from turbidity factors, slow sand filtration which is still utilized by the city of Salem is noted for providing almost 100 percent removal of bacteria and viruses (City of Salem Public Works Department, 2013). Zero percent of samples collected to test for the presence of *E. coli* contained any traces of the coliform bacteria.

5.2.3. Case Study 3- Maynard, MA.

Maynard, Massachusetts is located outside of Boston, and similar to other neighboring towns, is experiencing a growing population due to its proximity to a large metropolitan area (Ernst, 2004). Maynard receives its drinking water from a combination of three wells sites and associated treatment facilities (Woodard & Curran Assoc., 2011). Recently, consumers in the town of Maynard, Massachusetts noticed discoloration in their drinking water due to the presence of iron and manganese within groundwater used for drinking water supplies. The elevated concentrations were a result of urban influences, such as runoff. While iron and manganese are not public health concerns, the town nonetheless was still concerned about the aesthetic quality of their drinking water and investigated the implementation of treatment systems. The town considered greensand, also known as glauconite, which is commonly used to treat iron and manganese (Rader, n.d.). Greensand is coated with manganese oxide which is able to oxidize iron and manganese present in raw water (Rader, n.d.). Eventually, the town voted to approve the construction of a $4.6 million greensand filtration plant for the treatment of iron and manganese (Ernst, 2004).

Unfortunately, Maynard's water resource concerns did not stop when the greensand filtration facility was constructed. In 2011, the new focus of concern became water supply and availability. The town of Maynard conducted a water resources assessment in 2011 and determined that a backup source of water filtration was necessary. This determination was made based on the risk of current groundwater wells having a mechanical failure and becoming inoperable (Woodard & Curran Assoc., 2011). An engineering firm (Woodward & Curran) assessed the feasibility and cost of switching to the White Pond surface water source that was previously used. Prior to the Surface Water Treatment Rule (SWTR) of 1989, White Pond provided drinking water to the town however, the SWTR required filtration and a filtration plant was never constructed. Woodward & Curran Assoc. (2011) estimated the total present cost for constructing a filtration system for White Pond to be $14 million with annual operating and maintenance costs of $250,000 (Table 3).

As of 2014, the town of Maynard is still reliant upon greensand filtration and chemical treatment to control the aesthetic factors of drinking water relative to the presence of metals; water quality results are reported based upon these methods. Cost estimates listed in Table 3 are based on the implementation of future surface water filtration infrastructure from White Pond given by Woodward & Curran Assoc. (2011). Water quality results from the current greensand filtration system were used, as the new White Pond filtration system is not constructed. Water quality results will most likely improve with the implementation of the new surface water filtration system.

The 2013 water quality report (reports 2012 results) for the town of Maynard lists only detected contaminants or contaminants above the EPA's Maximum Contaminant Levels (MCL). In 2012, over one hundred potential contaminants were tested. No turbidity results *or E. coli* concentrations were listed therefore, this research assumes that the MCL for turbidity (>1.0 NTU) was not violated and samples collected for *E. coli* did not contain any detections of the coliform (Table 3). The most common detections within Maynard's public water supply were chlorination by-products including, trihalomethanes and haloacetic acids, however, none of these constituents exceeded the federal EPA's MCLs (Town of Maynard Dept. of Public Works, 2012).

5.3 WATERSHED PROTECTION CASE STUDIES

The following section presents three case studies of municipalities that have used watershed protection in place of human engineered infrastructure. The three examples provided (NYC, Seattle, and Portland, ME) are three of seven cities in the U.S. that have obtained Filtration Avoidance Determination from the U.S. EPA (Postel & Thompson, 2005).

5.3.1 Case Study 1- Cat-Del Watershed

Catskills, NY

New York City has implemented one of the largest watershed protection programs in the world, supplying water to 9 million residents without the use of a human engineered infrastructure (Appleton, 2002). NYC's water supply comes from nearly 2,000 square miles of watershed area north and west of the city (NYCDEP, 2012). The NYC watershed protection program exemplifies that water quality meeting or exceeding drinking water quality standards can be achieved at a fraction of the cost through a successful watershed protection program. The estimated cost of funding the Catskill, Delaware watershed protection program over the course of the next ten years is estimated to be $1 to $1.5 billion, [or $150 million/yr.] (Dudley & Stolton, 2003). This figure sounds hefty, however, when considering the alternative: $6 billion on a filtration system (U.S. EPA, 2011), it becomes reasonable.

Ninety percent of the drinking water in NYC is supplied by the Catskill and Delaware (also known as the Cat-Del) watersheds (Appleton, 2002). The Croton watershed, which supplies the remaining 10 percent, is currently required to receive filtration (Appleton, 2002). The distinction between the Croton watershed and the Cat-Del watersheds is a significant case in point as it exemplifies the potential fate (and costs) that may be incurred to the city if the Cat-Del watersheds are not protected and managed adequately.

In the 1980's and 90's, residents and regulators became concerned about the quality of water from the Croton watershed. Water quality impairments at this time were a result of increasing development and Nonpoint source (NPS) pollution emanating from a rising number of vacation homes and roadways that were being built in the 1980's and 90's. During the 1990's, in response to the Surface Water Treatment Rule (SWTR), regulators were forced to seriously consider filtration infrastructure options to filter water from the Croton watershed. Construction began in the 1990's on a $2.8 billion filtration system, and as of 2013, the Croton filtration plant was almost complete (NYCDEP, 2012).

While installing a filtration plant is often times an easier solution, or unfortunately sometimes the only solution, it is certainly not the most cost effective option if protection measures can be implemented. In the 1980's and 1990's, pressures from development were occurring within the Cat-Del watersheds. The area had an increasing number of vacation homes and NPS pollution occurring (Pires, 2004). Estimates to install a filtration treatment plant for the Catskill, Delaware watersheds were estimated to cost $6 billion and another $250 million annually in operation costs (Table 3) (Gartner et al., 2013). The commissioner of the NYCDEP in the 1990's had a strong desire to maintain the strategy of watershed protection and management to provide drinking water (Appleton, 2002). The more recent success story that evolved within the past twenty years or so as a result of the persistence and vision of the NYCDEP is revisited later in this section. First, the history of water supply management before it was addressed by the NYCDEP is considered.

Present day water quality from the Cat-Del watersheds is for the most part outstanding in the city (it was even imported to England for tea tasting at one point). However, water quality during the seventeenth and eighteenth centuries was poor. Events including, cholera outbreaks and large fires plagued the city during its initial development (Pires, 2004). During this timeframe, the NYC Board of Water Supply was responsible for the city's water supply and management. The Board of Water Supply exercised the state's powers of eminent domain to acquire upstream areas within the Cat-Del watershed that were necessary for the city's growing population in the eighteenth century (Pires, 2004). This traditional command and control approach which forced landowners and farmers to relinquish their properties, and essentially their livelihoods to the city created a large rift between the upstream landowners and downstream consumers and regulators (Appleton, 2002; Pires, 2004). The New York City Department of Environmental Protection (NCDEP) is the present day water regulator for NYC. In the 1990s, under increasing pressures to implement a treatment plant or severely rework the current watershed protection program, the NYCDEP proposed a Memorandum of Agreement (MOA), which outlined strategies for controlling NPS pollution, development, land acquisitions, and future management strategies. This was a defining moment in the potential long-term success of NYC's watershed protection program (Appleton, 2002).

As aforementioned, a large rift had historically been created between upstream landowners and downstream regulators who were perceived as outsiders due to the powers of eminent domain that regulators had previously exercised. Controlling NPS pollution from farms was a large component of the proposed MOA. When negotiations were initiated in the 90's concerning the MOA, landowners and farmers were extremely resistant to cooperate because of historical conflicts (Appleton, 2002). However, in time, after mutual education between regulators and farmers, a system known as "Whole Farm Planning" evolved which was surprisingly developed not by the NYDEP, but by the farming community. Whole Farm Planning was designed to consider individual farm and business needs and then recommend management practices to benefit water quality and save farmers time and money. The NYCDEP agreed to allow the farmers to design the program and to not take a traditional regulatory approach if more than 85 percent of farmers and landowners participated in the program (Appleton, 2002). Since the initiation of this program, 93 percent of farmers within the Cat-Del watershed have joined the program and the program has been deemed a huge success.

Another large component of the MOA was the acquisition of sensitive watershed areas; land was acquired through two methods: simple fee acquisition and conservation easements (Pires, 2004). The NYCDEP was required to approach landowners in the upper watershed areas who held a total of 143,000 acres of targeted lands to inquire about acquisition and possible land management alternatives. Approximately $260 million was set aside for land conservation purposes. Within the final 1997 MOA, the city agreed to pay market value price for the land (this method is known as simple fee acquisition). Landowners who were not interested in selling but who wanted to protect their property in perpetuity from long-term development had the option of applying a conservation easement onto their property. This alternative compensates landowners for the acceptance to protect and therefore, maintain water quality into the future.

So far, ~1.26 million acres have been conserved within the Cat-Del watersheds (Gartner et al., 2013). The NYC watershed protection program has been funded through a tax on resident's water utility bills, trust funds, and bonds (Dudley & Stolton, 2003). Negotiations revolving around the proposed MOA took years but what resulted has catalyzed the forward thinking needed by regulators and water utilities to recognize the potential of watershed protection and management.

It is noteworthy to mention that the lure of watershed protection does not just emanate from lowered costs. Water quality results for NYC consistently meet state and federal water quality criteria (NYCDEP, 2012). Water quality results from 2012 collected from the Cat-Del distribution system show that both *E. coli* concentrations and turbidity levels met the required EPA health standards (Table 3). In 2012, the Department of Environmental Protection collected 30,000 samples from NYC's distribution system; in addition, 20,000 samples were collected from the upstate reservoir to meet FAD requirements (NYCDEP, 2012).

Water samples collected from the distribution system during 2012 monitoring resulted in an average turbidity level of 1.0 NTU and zero percent positive samples collected to test for the presence *E. coli* (Table 3; NYCDEP, 2012). While the average turbidity concentration of 1.0 NTU for 2012 is well within EPA guidelines (<5.0 NTUs), the average turbidity level may be somewhat elevated due to unusually high rainfall amounts and winds caused by Hurricane Sandy in October 2012.

In addition to the large watershed protection program, NYC's drinking water still undergoes common disinfection required of all water providers. Disinfection is accomplished by treating the water with chlorine, ultraviolet light. Utilities in NYC additionally treat water with food grade phosphoric acid and sodium hydroxide to lower the corrosivity of pipes (NYCDEP, 2012).

5.3.2 Case study 2-Cedar River Watershed Seattle, WA.

The present day rate of municipal water to Seattle residents is less than one half of one percent/day for what has been called one of the cleanest, best sources of drinking in the world (Seattle Public Utilities, 2012). The protected Cedar River Watershed supports approximately one million people within the Seattle region (Postel & Thomspon, 2005). Furthermore, the Cedar River Watershed is also known as the best remaining habitat for salmon within the county (FCRW, 2014). The CRW also provides water to Seattle's residents, is the only publically owned municipal watershed in the U.S. Ninety-nine percent of the Cedar River watershed is owned by the public (Seattle Public Utilities, 2012).

In the 1800's, residents of Seattle voted for a publicly owned water supply system after a fire burned a large portion of Seattle's private water supply system (Seattle Public Utilities, 2012). The headwaters of the Cedar River were chosen to serve as a future source for the public water supply. Source waters supplying the city of Seattle begin where rainfall collects in the headwaters of the Cascade mountains and flows either as surface or groundwater flows eventually into the Chester Morse Lake (FCRW, 2014). A large portion of the rainfall enters a porous glacial moraine layer that creates a network of springs that flow into the Cedar River. The moraine layer and old growth forests are extremely important within the watershed as they provide such a high level of natural filtration, there is no need for further human engineered filtration downstream (FCRW, 2014). Aside from the Cedar River watershed, there are only seven other cities in the U.S. that require no human engineered filtration systems for providing municipal drinking water (Postel & Thompson, 2005). Seattle has saved $150-200 million in avoided costs of human engineered infrastructure (Postel & Thompson, 2005).

Strategies for watershed protection within the Cedar River Watershed include land acquisition, strict land use regulations, and education. Historically logging took place in the watershed; therefore, a majority of the forest which is present in the upper Cedar River watershed is second growth forest (Seattle Public Utilities, 2012). Seattle Public Utilities began exchanging land with the U.S. Forest Service in 1962 to preserve remaining critical areas of the upper Cedar River Watershed. Land exchanges specifically with the U.S. Forest Service to protect watershed areas were valued at $8 million dollars (U.S. EPA, 1999).

The upper Cedar River Municipal Watershed is a protected area, meaning no recreational, industrial or agricultural activities are permitted within its 143 square mile boundary. Because industrial, agricultural and recreational land uses are not permitted within the Cedar River Watershed, common contaminants, such as pesticides or chemicals are not a significant concern within the watershed (Seattle Public Utilities, 2012). Furthermore, public access is strictly controlled within the watershed to prevent the spread of human borne illnesses, such as cholera (FCRW, 2014).

Education is also a key strategy in the city's watershed protection program. In 2001, the $7 million Cedar River Watershed Education Center was built through funding from the City of Seattle and Friends of the Cedar River Watershed- a non-profit organization (Seattle Public Utilities, 2012). Yearly, 10,000 students are educated on the Cedar River Watershed (U.S. EPA, 1999). Furthermore, approximately $250,000 are spent annually on education-related costs (U.S. EPA, 1999).

One million residents within King County are supplied with water (over one hundred million gallons/day) from this 90,000 acre area (FCRW, 2014). Water quality samples from the Cedar River consistently meet the EPA Maximum Contaminant Levels for water quality parameters including, coliform and turbidity, as well as nitrate, metals, radioactive particles, and others. Although municipal water is not filtered, before water reaches the consumer's tap, it is: 1) screened to remove debris, 2) chlorinated for microbes 3) ozonated for taste improvements, and 4) adjusted for pH to control corrosion. In 2012, Seattle Public Utilities tested for 211 potential contaminants, 201 of these contaminants were not detected because the concentration was too low or they were not present in the water. Water quality results from 2012 showed average turbidity concentrations of 0.3 NTUs, which ranged from 0.2-2.3 NTUs (Table 3) (Seattle Public Utilities, 2012). In 2012, zero percent of samples collected resulted in a detection of *E. coli*. Further water quality treatment applied by the city of Seattle includes, disinfection of Seattle's drinking water provided by chlorine and chemical treatments (calcium oxide, sodium carbonate) to control corrosion of pipes (Cedar River Water & Sewer District, 2012).

5.3.3 Case Study 3 - Crooked River Watershed Portland, ME.

Portland, Maine, a city with approximately 200,000 residents, relies upon Lake Sebago and the Crooked River Watershed for the provision of their drinking water. The city has achieved a Filtration Avoidance Determination (FAD) largely due to their previous land conservation efforts (Gartner et al., 2013). Currently, development, including an expanding city population and NPS pollution is threatening the status of the FAD. Other threats that were identified by the Portland Water District (2013) included boating, ice fishing, and shoreline development. In an effort to maintain the FAD and avoid costs of building a necessary membrane filtration treatment plant (est. $118 to $155 million), the city of Portland reviewed future options for expanding their watershed protection area (Gartner et al., 2013).

Approximately 80 percent of the land use within the Crooked River Watershed is forested area; the remaining land use is a mix of residential, timber, and agricultural areas (Portland Water District, 2013). Current green infrastructure in the watershed includes

2,500 acres of privately owned and protected watershed areas achieved through conservation easements and occurring mainly in the lower watershed areas. Additional watershed protection measures include a 3,000-foot no trespassing zone surrounding water intakes (Portland Water District, 2013).

Portland is unique as the city has also declared a “no regrets” approach to watershed protection; the city will continue to invest in watershed protection even if developmental pressures eventually force the city to build gray infrastructure to meet water quality standards (Gartner et al., 2013). The main objective of Portland’s watershed protection plan is not to meet the Filtration Avoidance Determination every five years; instead, the city realizes that investing in the protection of the lake now will reduce current and future treatment costs.

One million dollars is currently spent annually on the Crooked River Watershed protection program through a combination of land management, surveillance, education, and water quality monitoring activities. The program’s largest component is land management with a focus on land acquisition but the land management strategy also includes routine property and septic system inspections and permitting. One to two percent of annual revenues from the Portland Water District are spent on conservation fees (Gartner et al., 2013). While the city could enforce the power of eminent domain to obtain necessary watershed areas, so far they have paid full market value for land (Portland Water District, 2013).

In 2009, a conservation grant from the US Dept. of Agriculture and National Resources Conservation Service (Northern Forests Conservation Innovation Grant) was awarded to the city of Portland to explore necessary expansion of their watershed protection program (Gartner et al., 2013). The World Resources Institute was hired by the city of Portland to conduct a cost benefit analysis on investing in green infrastructure (land conservation, reforesting, and etc.) compared with installing a membrane filtration treatment system (Gartner et al., 2013). The analysis looked at five green infrastructure strategies to maintain the status of the FAD and water quality for the next twenty years. The green infrastructure strategies included: reforestation, riparian buffers, conservation easements, culverts, and forest certification. Under the baseline scenario, the cost to implement the necessary green infrastructure was estimated to be $106 million (Figure 1,

Table 3) (Gartner et al., 2013). Comparatively, the baseline estimate for the implementation of a membrane filtration treatment system was $118 million (Gartner et al., 2013).

As of 2013, the Portland Water District agreed to fund up to 25 percent of conservation expenses to expand the number of protected acres in their watershed (Gartner et al., 2013). The green infrastructure option is predicted to save the city $12 million over the next 20 years under baseline conditions, and as much as $110 million over the next twenty years under the optimistic scenario (high-end cost of a membrane filtration plant and low conservation easement fees) (Gartner et al., 2013).

During the 2012 monitoring year, the city of Portland met every EPA health standard. Over 15,000 samples were tested by the Portland Water District, including synthetic inorganic, organic chemicals, and disinfection-by-products and most remained at undetectable levels (Portland Water District, 2013). The average end-of-tap turbidity level was 0.2 NTUs, ranging from 0.14 to 0.43 (the lowest turbidity levels of the three watershed protection examples within this analysis) (Table 3). *E. coli* concentrations were not reported in the 2012 results as only detected contaminants were published; *E. coli* concentrations collected in samples are assumed to be zero.

Even though additional watershed protection is not necessary for Portland at this moment in time (2012 water quality results were within EPA water quality criteria), the city is taking proactive measures to prevent possible future degradation of water supplies from increasing development occurring within the watershed. In addition to additional watershed protection measures, Portland recently upgraded their ozone disinfection system, which is specifically aimed at treating microbiological contaminants (Portland Water District, 2013). Chemical treatments applied to Portland's water include, chlorine for disinfection, sodium hydroxide for pH adjustments, and zinc orthophosphate to control pipe corrosion. Cities and water utilities would benefit from adapting Portland Maine's "no regrets" approach to watershed protection; even if a city is required to filter raw water, an investment in watershed protection is ultimately an investment in water quality.

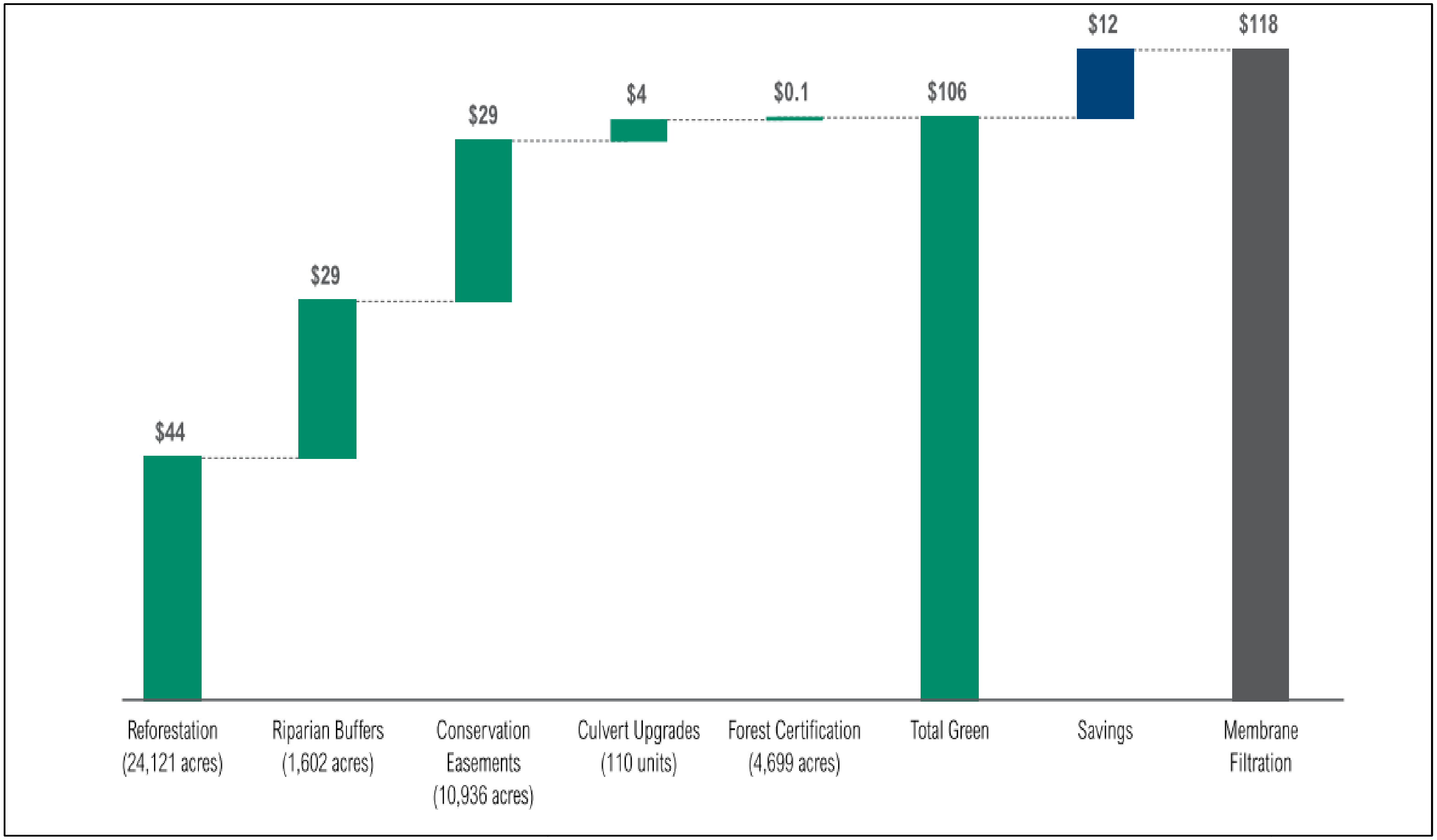

Figure 2. Cost Savings of Watershed Protection for Portland, Me. Source: (Gartner et al., 2013)
Twelve million dollars are noted as the conservative or baseline cost savings of implementing watershed protection in lieu of gray infrastructure; optimistic estimates for cost savings are valued at $110 million (Gartner et al., 2013).

Table 3. Results: Cost Effectiveness of Human Engineered (Gray) Infrastructure vs. Watershed Protection (Green) Infrastructure

Location	Population Served	Method of Water Quality Protection	Costs			2012 Water Quality Effectiveness	
			Infrastructure *or* Land Acquisition	Annual Operation Costs [a]	Cost Savings/ Avoided Cost [h]	Turbidity [b] < 1.0 NTUs *or* <5.0 NTUs [d]	*E. coli* [b,c] (≤5% samples positive)
Human Engineered/Gray Infrastructure							
San Diego, CA	~900,000[1]	**Twin Oaks Valley** Dual membrane filtration[1]	$157 mil[2]	$7.5 mil[2]	None	0.02[1]	0%[1]
Salem, OR	170,000[3]	**Geren Island** Slow sand filtration[3]	$42 mil[3]	$1.15 mil[3]	None	0.09[4]	0%[4]
Maynard, MA[h]	10,000[h]	Future Infrastructure Membrane filtration[h]	$14 mil [h]	$250,000 [h]	None	<1.0[5]	0%[5]
Watershed Protection/Green Infrastructure							
NYC, NY	9,000,000[6]	**Catskill-Delaware River Watershed** ~1,260,000 acres [14]	**$1.5 billion total** ($150 mil over 10 years) [7]		$6 billion[8,14]	1.0[9]	0%[9]
Seattle, WA	1,400,000[13]	**Cedar R. Watershed** 90,000[10]	$8 mil[11]	$7 mil[e,13]	$150-200 mil[12]	0.3[13]	0%[13]
Portland, ME[f]	200,000[14]	**Crooked R. Watershed** 2,500[15]	$106 mil[g, 14]	$1mil[14]	$118 mil[14]	0.2 [15]	0% [15]

[a] Operation Costs include personnel, materials, chemicals, energy costs.

[b] Results are taken from the 2012 distribution water quality results

[c] Water quality based on *E. coli* is dependent upon the presence of absence of E. coli within samples. No more than 5 % of samples collected per month may contain *E. coli* concentrations. The Maximum Contaminant Level Goal proposed by the EPA is 0 %.

[d] The EPA drinking water standard for Turbidity for systems that use direct filtration <1.0 NTUs. The EPA standard for municipalities which rely on source water protection and have acquired a filtration avoidance determination is <5.0 NTUs in each sample collected.

[e] Education-related costs only

[f] Preliminary study of the cost effectiveness of future investments in green versus gray infrastructure in Portland by Gartner et al. (2013)

[g] Watershed acres based on preliminary study by Gartner et al. and includes reforestation, riparian and conseration easements acerages

[h] Preliminary water resources assessment by Woodard & Curran (Woodard & Curran Assoc. (2011). *Assessment of Water Resources, Town of Maynard, MA*. Maynard, Ma. Retrieved from http://www.townofmaynard-ma.gov/documents/water-resources-report-20110830.pdf). Costs provided for future water treatment infrastructure for White Pond surface water. Water quality results are given using the current treatment system-greensand filtration, chemical treatment.

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5.4 Summary of Cost Effectiveness Analysis

The objectives of this research were to examine the effectiveness of watershed protection at meeting water quality standards and also to compare the costs that would have otherwise been incurred by human engineered infrastructure. This research was accomplished by comparing recent water quality results from human engineered filtration versus water quality results from water providers that have obtained FADs through watershed protection. The second step was to compare the costs each city had incurred to safeguard their water quality. It was determined that all the three cities reliant upon watershed protection (NYC, Seattle, and Portland) met required water quality health criteria; furthermore, avoided treatment costs for these three cities were in the millions and sometimes billions of dollars (Table 3). Another important conclusion from this analysis that watershed protection supports large populations, oftentimes in the millions, while a single water treatment plan can only supply a population in the thousands (Table 3). For example, the largest human engineered treatment system studied (Twin Oaks Valley) can only supply one tenth as many people as the Cat-Del Watershed (Table 3). A summary presenting a full-range of considerations between infrastructure types is presented in the next section (Table 4) after a discussion of the costs and effectiveness results of the six case studies.

5.4.1 Costs

To perform a cost comparison, it would be inaccurate to simply compare the costs of land acquisitions to the cost of gray infrastructure; sustaining gray infrastructure requires additional annual and replacement costs whereas the majority of transactions for land acquisitions and protection (green infrastructure) are one-time fees and last in perpetuity. Avoided costs are often used to assess the value of green infrastructure (Gartner et al., 2013); this method is oftentimes the most straightforward way to determine costs of infrastructure when performing a green-gray analysis. The avoided costs of human engineered infrastructure for cities with watershed protection ranged from six billion dollars for NYC to $118 million for Portland, Maine. If you subtract the total estimated costs for the implementation of the Cat-Del watershed protection program by the proposed cost to build a filtration plant to supply NYC, the city saved approximately four billion dollars (Table 3). In comparison, all cities that implemented gray infrastructure paid the maximum cost for water quality protection; these cities have no avoided costs and additionally they pay annual and replacement costs. Further considerations pertaining to the values provided by both infrastructure types are discussed below in section 5.5 and Table 4.

5.4.2 EFFECTIVENESS

To determine the effectiveness of each infrastructure type, 2012 water quality results for turbidity and *E. coli.* were compared to U.S. EPA drinking water health criteria. Water quality health standards were met for all six of the case studies reviewed; however, there were differences in turbidity levels among human engineered treatment, and even larger differences when comparing turbidity results from human engineered infrastructure to watershed protection infrastructure.

As anticipated when considering human engineered infrastructure, water quality results were higher within more advanced filtration systems (dual membrane filtration) and the cost of infrastructure reflected this. Results from the analysis found that the Twin Oaks Valley membrane filtration plant was the most costly infrastructure among the three human engineered examples; however, this infrastructure was also the most effective at lowering turbidity levels. The Twin Oaks Valley membrane filtration system resulted in the lowest average turbidity results (0.02 NTUs) among all six case studies. The Geren Island slow sand filtration facility had the second lowest average turbidity results (0.09) and Maynard's current greensand filtration system reported turbidity levels as <1.0 NTU's.

Turbidity results were higher (but still meeting EPA criteria) among cities relying solely upon watershed protection. The highest average turbidity level (1.0 NTU) was observed within drinking water from New York City's Catskill-Delaware Watershed. While 1.0 NTUs is consistently higher than the average turbidity levels within the human engineered examples, it is still within 4 NTUs of the EPA health criterion. New York City also has the highest costs associated with infrastructure ($1.5 billion over ten years) but the protected Cat-Del Watershed also supplies the largest population of any of the six examples presented.

Conclusions that can be drawn from assessing the results of turbidity within the three watershed protection examples include a possible correlation between watershed size and turbidity levels; turbidity levels may be easier to manage in smaller watersheds. Portland, Maine's watershed includes 300,000 total acres (U.S. EPA, 1999) and resulted in the lowest turbidity levels within the protected watershed examples while NYC's watershed includes over one million acres (Gartner et al., 2013) and had the highest turbidity levels. Reasons for this result likely stem from the fact that a larger watershed is more difficult to manage; multiple land uses occur and enforcement of protective regulations becomes more cumbersome the larger the land area.

When assessing the effectiveness of infrastructure to prevent microorganism contamination, water quality monitoring results from all six case studies met microorganism *(E. coli)* health criteria. Zero percent of samples tested positive within any of the six cases examined. Future effectiveness analyses may want to consider including other coliform species or more years of data in analyses as this may lend more definitive results. Significant rainfall and storm events can have an influence on the outcome of water quality results, especially within protected watershed areas. Considering multiple years of data may decrease the variability observed in turbidity results caused by factors such as more intense weather events. Furthermore, to obtain more definitive microbial water quality results, total coliform results chould be considered as an additional microbial indicator.

5.5 Summary Comparison of Human Engineered Infrastructure vs. Watershed Protection

One of the most surprising results from this research is that some of the largest cities in the U.S. rely solely upon watershed protection as the primary method to achieve water quality standards. Millions of people are supported by the protection of upstream areas that supply clean water; in comparison, the largest water filtration plant reviewed only supported 900,000 people (Table 3). Other important considerations include the fact that human engineered treatment systems have a limited life span (30 years or so) (Gartner et al., 2013), comparatively; investment in watershed protection is typically in perpetuity as green infrastructure is permanent. Along the same lines, human engineered treatment has associated annual maintenance, energy, and chemical costs which are all currently increasing (Davies & Mazumder, 2003). When considering green infrastructure, oftentimes the acquisition of land is a one-time expense. This is not to say that other watershed protection program costs do not exist; costs outside of land conservation activities include things like, personnel, education and outreach, and water quality monitoring. However, watershed protection has been shown to avoid millions of dollars in potential gray infrastructure (Table 3).

Investment in green infrastructure is wise as the value of land will increase over time (Table 4). As ecosystems reach climax state, especially ecosystems such as wetlands and forests, the ability of ecosystems to provide the full benefit of hydrological services (water filtration, purification) will be attained. Additionally, if cities want to add to their green infrastructure portfolio as the city's population increases, they can do so by acquiring more land. Green infrastructure has a higher investment potential than gray infrastructure as gray infrastructure depreciates over time. Gray infrastructure is devalued as equipment, infrastructure degrades and the need to install more current technologies to meet regulations increases.

The reliability of green or gray infrastructure to withstand changes in weather patterns and susceptibility to natural disasters is also a large factor in determining the value of each type. As mentioned previously when discussing the 1996 flood in Salem, Oregon as well as when Hurricane Sandy hit New York, large storm events impact the ability of infrastructure to filter sediment and also contaminants which may be bound to sediment. Overall human engineered infrastructure has a slightly better ability to handle abrupt changes in weather patterns, especially specific systems designed to handle an influx in the amount of sediment and large amounts of storm water; however, as discussed in the case study of Salem, small, basic filtration systems such as, sand filters can lead to malfunctions or worse, cause system to become inoperable. Following a storm event, a vegetated, undeveloped watershed will have less turbid raw water than an unprotected watershed, however, the raw water will still likely have elevated concentrations of sediment due to natural erosional processes and the transport of sediment.

When considering the risk posed to infrastructure from natural disasters, human engineered infrastructure is at a much higher risk than watershed protection. When considering events such as, earthquakes, floods, and fires, gray infrastructure may collapse and fail to adequately distribute safe water. On the other hand, watershed protection not only provides a less risky scenario for distributing water, but protection of ecosystems such as, forests, wetlands, and riparian areas helps to minimize the severity of some natural disasters, such as fires and floods.

Table 4. Summary of Findings: Human Engineered Infrastructure vs. Watershed Protection

	Human Engineered	**Watershed Protection**
Population Served	Hundreds to thousands	Thousands to millions
Lifespan	Temporary; ~30 yrs.	Permanent
Investment Value	Low; depreciates over time	High; can always "add" to infrastructure; Value of land may > with climax communities
Costs:		
Infrastructure Costs	High	Lower (in comparison)
Annual Costs	High; maintenance, chemicals, energy, labor	Lower; watershed protection program costs, education
Effectiveness: Met EPA water quality health guidelines?		
Turbidity	Yes; lowest turbidity values observed	Yes
E. coli	Yes	Yes
Reliability:		
Extreme Weather Event	Lower risk, depends on type of filtration system	Higher risk, especially relative to turbidity
Natural Disaster	High risk	Lower risk
Ancillary Benefits?	No	Yes

6.0 WATERSHED PROTECTION & MANAGEMENT OPTIONS

A variety of watershed protection management options exist, ranging from complete protection through land conservation and designation of watersheds as protected areas, such as national parks, to implementing Best Management Practices (BMPS), such as reducing or eliminating the use of pesticides within a watershed (Figure 3). Two broad strategies can be discerned: land conservation strategies and implementation of management practices. Strategies will vary within every municipality depending on historical and current factors, such as previous and current land uses, stakeholders, population growth trends, and funding. Management practices present an alternative set of strategies to cities that do not have an abundance of available land, such as due to existing development, or do not have the funding to acquire available land. Contrarily, more traditional methods of protection, such as land acquisition, apply to cities that have access to funding and available, undeveloped land.

The steps below outline suggested actions to implement a watershed protection plan:

1) Perform a watershed assessment and identify sources of point source and Nonpoint source (NPS) pollution
2) Conduct a green-gray analysis to determine what role green infrastructure will play in protection (Gartner et al., 2013) (i.e. will it just be a complimentary strategy to existing or gray infrastructure or will it be the primary infrastructure?)
3) Prioritize the most valuable land in terms of water quality preservation (Gartner et al., 2013)
4) Partner with stakeholders such as, landowners, and conservation agencies (Gartner et al., 2013)
5) Develop funding (Gartner et al., 2013)
6) Define a watershed protection and management strategy
7) Carry out protection strategy through land conservation, easements, and management activities

6.1 Watershed Protection Options

Three general categories of land conservation measures exist which are described below; they include: land acquisitions, conservation easements, and land designations. First, however, an overview of land conservation strategies is presented.

6.1.1 Land Conservation Strategies

The two most common forms of land conservation that are utilized within watershed protection scenarios are land acquisition and conservation easements. Both of these strategies are useful but factors specific to each watershed, such as stakeholders, funding, and level of protection determine which strategy is most appropriate. Prior to contacting landowners concerning conservation measures, prioritization on the most valuable parcels should be considered. Prioritizing parcels is of particular importance to government and conservation agencies so that conservation efforts and funding are effective at protecting water resources. Gartner et al., (2013) note that the proximity of land areas to lakes and streams, or other source water areas are of obvious significance. Also of importance are prioritizing parcels with existing forests or wetlands, or parcels with a particular soil type, slope, or proximity to roadways to buffer from existing sources of pollution (Gartner et al., 2013).

6.1.1.1 Land Acquisition

Acquisition, for the purposes of watershed protection, is the purchase (or sometimes lawful take) of land areas that are necessary for the protection of water resources. New York City, New York and Portland, Maine, as previously described, are two cities that heavily relied upon this protection strategy. During 2012 alone, New York City purchased over 5,000 acres for protection purposes (NYCDEP, 2012). Two thirds of domestic forest areas (areas that exclude government owned land) are owned by private landowners (Gartner, 2010). Half of these owners are non-industrial private landowners. Historically, the power of eminent domain was often exercised by cities to acquire necessary watershed areas (Pires, 2004). Currently, it not uncommon for cities to pay full market value of land to keep tensions low between the public and regulatory agencies. That being said, land acquisition is also the most costly form of conservation strategy; for this reason, agencies also rely upon conservation easements and payments to landowners for the implementation of Best Management Practices (Gartner et al., 2013).

6.1.1.2 Conservation Easements

Landowners oftentimes choose conservation easements over land acquisition when approached by a land trust or government agency interested in purchasing their property. Conservation easements can also be more attractive to agencies and stakeholders interested in protection as they are less costly than direct land acquisitions (Gartner et al., 2013). A conservation easement is an agreement between a land trust or government agency that ensures the land will remain protected in perpetuity. “Protected” in this case generally means no form of development including, residential, commercial, or industrial. Landowners who have entered into conservation easements still hold the rights to their property but they have agreed to designate the land for conservation purposes only.

6.1.1.3 Designation

Oftentimes, protected watersheds fall under the category of national parks or reserves because of legal protection measures that can be established (Postel & Thompson, 2005). Multiple “designations” of land conservation areas exist; examples include national parks, state forests, nature reserves, and game reserves. In many areas, such as the Drakensberg World Heritage Site (supplying Durban, South Africa) all of these designations coexist. Among the most populated cities within the U.S., Europe, Asia and Africa, approximately thirty percent depend upon legally protected lands for their water supplies (Postel & Thompson, 2005). For example, 40 percent of the water in the country of Honduras comes from La Tigra National Park; the cost of protection of this land area is a fraction (5 percent) of the cost of alternative sources (Postel & Thompson, 2005).

Melbourne, Australia is another example of a region that relies upon legally designated areas for their water supply; furthermore, Melbourne’s drinking water is noted as being the highest quality water in Australia (Dudley & Stolton, 2003). This purity is likely due to Melbourne having one of the best-protected watershed areas worldwide

(Dudley & Stolton, 2003). Melbourne receives ninety percent of its water from land areas under legal designations; fifty percent of Melbourne's upstream watersheds fall within National Parks, with the remaining areas under State Forest designation. Melbourne Water, the jurisdictional entity responsible for the protection and supply of Melbourne's water, and the Department of Sustainability and Environment and Parks Victoria, have designated some of these watersheds specifically for the protection of water resources (Dudley & Stolton, 2003). For example, 80 percent of the Yarra Ranges National Park (Victoria's ninth largest park) is designated solely for the protection of water resources (Dudley & Stolton, 2003). The International Union for Conservation Nature (IUCN) has also helped to secure some protected watershed areas. The focus of the IUCN's protected areas is the conservation of biodiversity, but nonetheless, watershed protection is still achieved.

Designating land areas as a national forest is a widely used land conservation strategy. Many national forests within the U.S. were originally created specifically to protect water supplies (Dudley & Stolton, 2003). In fact, half of California's water runoff is captured within national forests, which comprise only 20 percent of the land area (Dudley & Stolton, 2003). Historically, Los Angeles incorporated forest protection into their water supply plan; this approach paid off as the city now relies upon the 900,000 acre Eastern Sierra Watershed within the Angeles National Forest as a source of water supply (Dudley & Stolton, 2003). The Los Angeles National Forest is mainly comprised of protected areas with accepted recreational land uses (e.g., hiking, biking) yet, some portions of the watershed are heavily restricted from public use, such as the San Dimas Experimental Forest.

6.2 Complimentary Strategies

In areas where conservation clashes with socioeconomic factors, a combination of management strategies exists to maintain a higher level of water quality than would otherwise be achieved. Complimentary strategies that may be implemented, especially by cities that do not have adequate funding or a large amount of undeveloped land, include additional green infrastructure or complimentary management strategies.

6.2.1 ADDITIONAL GREEN INFRASTRUCTURE

In a perfect scenario, all or a majority of necessary watershed areas would be protected; however, this is not feasible for a large portion of the world. The level of human disturbance is not the determining factor in the provision of high quality water instead; it is the functionality of the ecosystems present within the watershed (Dudley & Stolton, 2003). Land use planning can be used to design landscape mosaics, which plan for the preservation of some intact vegetated areas, as well as consider current land uses, such as farming, timber harvesting, or small residential developments. "Landscape mosaics" can still provide adequate ecosystem services such as water filtration (Dudley & Stolton, 2003). Vegetated corridors are especially useful where land space is limited. Buffer zones and filter strips can be established to slow and filter polluted runoff from agriculture or industrial processes. Furthermore, grass buffers can act as both a buffer zone and a cattle-grazing area (Dudley & Stolton, 2003).

Buffer zones are a common watershed protection technique as they serve as the closest barrier to source water areas. In Sydney, Australia, the Sydney Catchment Authority utilizes "special areas" or buffer zones adjacent to dams or reservoirs to trap and filter contaminants in the New South Wales Watershed (Postel & Thompson, 2005). Buffer zones have been implemented across 25 percent of the 3 million acre watershed of New South Wales and supplies more than four million people in Sydney (Postel & Thompson, 2005).

6.2.2 AGRICULTURAL MANAGEMENT PRACTICES

Agricultural management practices, such as the implementation of Best Management Practices (BMPs) are a common strategy included in watershed management and protection strategies. In this scenario management practices are designed to control stormwater and irrigation run off which has the ability to transport sediment and pesticides to downstream waterways and impair water quality. Practices are usually suggested by government agencies. Within irrigated lands, farmers can choose from a variety of BMPs including,

- Reduction in the use of pesticides,
- Alternative pesticide use, including less toxic or less persistent pesticides and

- Controlling or capturing irrigation runoff such as,
  - -installing micro-irrigation
  - -installing vegetated buffers or
  - -installing retention holding ponds.

6.2.3 Forestry Management Practices

Forests are likely the most important ecosystem within watersheds due to the extensive hydrological services provided by vegetation and soils (Ch. 2). Management of forests within watershed areas is highly important. Timber extraction or heavy-use recreational activities, such as the use of ATVs, often occur within designated forest areas within watersheds. A large portion of management issues occurring within forests revolves around controlling the quantity of sediment contained in runoff. Forestry roads account for more than 90 percent of the sediment runoff from forested areas (Gartner et al., 2013). Forestry management practices are usually suggested by government agencies on a state-by-state basis and revolve around maintenance of forestry roads, restoration of riparian areas, identifying unstable soil surfaces within timber extraction areas, and managing the application of herbicides (Gartner et al., 2013). Some common forestry management practices include:

- Maintenance of forestry roads including,
  - -installation of temporary bridges to avoid skid roads
  - -resurfacing
- Installation of culverts
- Restoration, re-vegetation activities
- Managing timber harvesting
- Development of a water quality monitoring program.

Indicators of declining water quality in forests include obvious factors such as increasing turbidity and less common indicators such as fish die-offs which have been linked to presence of toxic pesticides used in large illegal cannabis growing operations (M. Gabriel, 2013). Illegal cannabis operations are an emerging problem, especially recently within the state of California. These operations are having specific detrimental impacts on the quality of water within rural streams and rivers due to large nitrogen inputs from fertilizers and harmful pesticides which have long since been banned in the U.S. (e.g., DDT) (Gabriel et al., 2012). Illegal cannabis operations are increasingly prevalent in national forests due to the sheer size of forests and the absence of forest rangers or law enforcement.

While sustainable management of in-tact and old-growth forests are extremely important as they provide advanced filtration, purification services, restoration activities are also important especially in areas that don't have an abundance of remaining forested areas. A theme, which repeats throughout this paper, is that investment now will save money in the future, and the same is true for restoration activities. Investment in reforestation activities <u>now</u> will provide forests that support downstream consumers with high water quality in the future.

6.2.3.1 SUSTAINABLE FORESTRY CASE STUDY: STOCKHOLM, SWEDEN

In Stockholm, Sweden, sustainable forestry efforts have been balanced with water quality goals to produce water that is comparable to other local water sources that receive treatment (Dudley & Stolton, 2003). Stockholm is home to nearly two million residents and is recognized to have consistently good water quality (Dudley & Stolton, 2003). Stockholm Vatten Company is Stockholm's main water supplier. The company controls approximately 12,000 acres of land area surrounding Lake Bornsjon, (the backup water source to Lake Malaren-the city's main supply); Lake Bornsjon does not require filtration due to cognizant forestry management efforts that have achieved Swedish Forest Stewardship Council (FSC) certification (Dudley & Stolton, 2003). Spruce, birch and pine are extracted from the area surrounding Lake Bornsjon, yet large surface water protection measures have been implemented, such as reducing and eliminating the use of heavy machinery, soil erosion control practices, and selective harvesting (Dudley & Stolton, 2003).

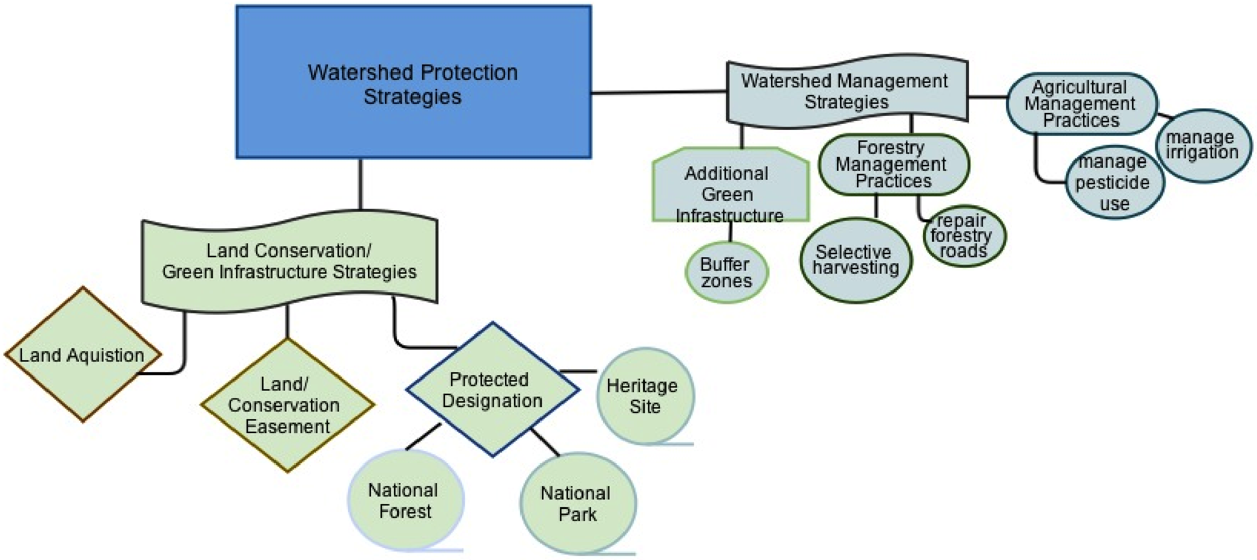

Figure 3. Overview of Watershed Protection Strategies

7.0 ACHIEVING WATERSHED PROTECTION IN A DEVELOPING WORLD: MARKET-BASED TOOLS TO ACHIEVE WATERSHED PROTECTION

Even though a land area may be designated as a national park, forest or world heritage reserve, local inhabitants may use protected areas for alternative land uses including cattle grazing, agricultural operations, or fuelwood provision. Oftentimes these activities occur in developing countries and result in the degradation of water quality, especially for downstream consumers. While there are land use disagreements between upstream inhabitants and downstream consumers, this research does not address the socioeconomic issues at hand. Instead, an increasingly used conservation technique (PES) is discussed which, may help relieve tensions between upstream inhabitants and downstream consumers.

7.1 PROVIDING INCENTIVES: PAYMENT FOR ENVIRONMENTAL SERVICES

Payments for Environmental Services (PES) aims to recognize the economic value of ecosystem services through monetary transactions. Payment for Environmental Services (PES) programs compensate rural landowners for protected or better managed upstream land areas (Postel & Thompson, 2005). Most PES programs related to water resources are within Central and South America (Dudley & Stolton, 2003; Southgate & Wunder, 2009). Deforestation and conversion of upstream ecosystems to agricultural, industrial, or other land uses results in lowered water quality downstream. Nevertheless, water quality improvements can result if landowners upstream protect these areas. First, however, incentive has to be provided to landowners to preserve these habitats. These incentives (or payments) must exceed the value of the alternative land use that would otherwise be implemented, e.g., agriculture.

Placing a water fee on consumers who receive the benefits of clean water generates payments. Payments to landowners/providers should occur on a continuous basis and avoid one-time fees as incentive to protect land areas must be reinforced. Landowners who receive their payment through a one-time fee early on may disregard conservation or management agreements later on (Dudley & Stolton, 2003). Payments collected are usually placed into a fund, in this scenario known specifically as a *waterfund,* for the protection of upstream forests, wetlands, riparian, or other ecosystems and carried out by landowners or conservation agencies.

7.1.1 WATERFUNDS

Waterfunds reward “water producers”, such as farmers, for the conservation of upstream habitat. Cities that have adapted waterfunds to secure municipal water sources include, Bogota, Columbia, the country of Mexico, and others (Goldman et al., 2010). Mexico and Ecuador have implemented waterfund programs targeted to preserve headwaters and riparian areas and improve water quality and avoid increased water quality treatment or the installation of a treatment plant all-together.

7.1.1.1 CASE STUDY: QUITO, ECUADOR

Eighty percent of the drinking water supplying 1.5 million people in Quito comes from two ecological reserves: the Antisana and the Cayambe Coca (Postel & Thompson, 2005). Within these reserves are over one million acres of cloud forests and grasslands (Postel & Thompson, 2005). Nearly thirty thousand people live in or adjacent to these reserves and graze cattle and/or harvest timber (Postel & Thompson, 2005). In response to these land uses, which sometimes result in impaired downstream water quality, Quito established a water trust fund (Fondo del Agua or FONAG) to implement a watershed protection strategy. Quito’s watershed protection strategy includes the implementation of agricultural management strategies, fencing around important source water areas, and the acquisition of valuable land parcels.

Funding has been collected from downstream stakeholders with an interest in water quality or water quantity issues within the reserves; some of the stakeholders include commercial flower growers, hydroelectric companies, farms, and a water utility (Postel & Thompson, 2005). Stakeholders, such as Quito’s water utility and hydroelectric companies also saw the potential to lower present and future treatment costs. In 2007, EMAAP-Q, the utility provider for Quito, was mandated to increase their contributions to the waterfund from one percent of their yearly revenues to four percent (Southgate &

Wunder, 2009). The balance of the FONAG fund in 2007 was expected to be approaching $ 5 million (Southgate & Wunder, 2009).

7.1.1.2 CASE STUDY: MEXICO

Mexico represents another country that has significantly developed compensation for ecological or, more specifically, hydrological services. Drivers for Mexico's program include dwindling water resources and high levels of deforestation occurring in Mexico's forests; the program focuses on the protection of vulnerable forests (Southgate & Wunder, 2009). Prioritization is given to forests that are known to recharge aquifers and protect source waters. Protection has occurred through the creation of a voluntary program known as the National Program for Hydrological Environmental Services, which, similar to Ecuador, pays landowners to maintain their forest. So far, the program has protected approximately 800,000 acres and paid $8 million to water producers (landowners) for protection of these areas (Pagiola et al., 2002).

Dependent upon the forest type, landowners are paid the opportunity cost of the land which ranges from $24, to $38 per hectare for cloud forest types (Pagiola et al., 2002). Cloud forests create and capture large quantities of water; because of this, cloud forests are some of the most economically and environmentally valuable ecosystems in Central and South America. Water producers are paid annually once adequate compliance with the program's guidelines has been met. Landowners are not allowed to deforest any portion of their land under the guidelines; if deforestation does occur, payments are stopped and the contract is voided (Southgate & Wunder, 2009). Compliance is enforced through observation of changes in forest patterns using aerial imagery and random field visits (Southgate & Wunder, 2009).

Even though the program is currently voluntary, it is expected that within a few years, as the value of hydrological services is recognized, interested private stakeholders will begin to make payments (Pagiola et al., 2002). Landowners have shown strong interest in the National Program for Hydrological Environmental Services; in 2003 the program received applications for over one million acres even though the current budget only allows for 200,000 acres (Southgate & Wunder, 2009). As of 2004, the revenue generated by downstream water consumers was $30 million (Southgate & Wunder, 2009).

8.0 CONCLUSIONS & RECOMMENDATIONS

8.1 CONCLUSIONS

A pristine watershed is not necessary to implement a watershed protection program; the success of a protection program more so relies on adequate foresight and planning. This paper has identified a mix protection programs ranging from public (Seattle, WA), private (Portland, ME), rural (Quito, Ecuador) and developing watersheds (Portland, ME). As explained above, multiple factors such as regulations, stakeholder interests, and costs interact to shape water quality management within particular watersheds. Consequently, there is no cookbook recipe to achieve high water quality. Some regions have water quality issues that are somewhat straightforward and have somewhat easy solutions, while others may be much more complex. For example, in some regions watershed protection is not feasible due to a conflict with existing land use or a lack of funding. In these scenarios, other management strategies exist, such as agricultural, forestry, storm water management practices, that can be implemented on small or large scales. As the amount of undeveloped land decreases, a combination of strategies involving land conservation techniques in unison with management strategies are likely to evolve.

As for developed countries seeking to meet water quality regulations, avoiding filtration should not be seen as the only goal of watershed protection; protection through green infrastructure results in reduced public health risks, lowered filtration and treatment costs, and a long list of external benefits to cities that were not discussed (e.g., recreational opportunities, carbon sequestration). As seen in Ch. 5, individual cities have saved millions and in some cases even billions of dollars in filtration and treatment costs. These values do not even touch upon the ancillary benefits that these cities received; if these benefits were taken into account, the value of watershed protection rises even higher.

As presented in Ch. 5, watershed protection achieves high water quality that meets U.S. EPA drinking water criteria. Results from the cost effectiveness analysis showed that advanced human engineered infrastructure, such as the Twin Oaks Valley filtration plant can minimize turbidity to very low levels; nonetheless, all three watershed protection examples met turbidity standards and did so at a fraction of the implementation costs.

The difference in costs and investment values were significant between green and gray infrastructure types. Investments in human engineered infrastructure are short-lived because gray infrastructure depreciates over time. Furthermore, the cost to invest in more advanced infrastructure as raw water quality degrades may be a losing battle. Water quality degradation in the future will continue to decline if the source of the water is not protected. Eventually, there may be a tipping point in the near future when water quality becomes too degraded and treatment costs become too high to effectively filter and treat degraded water. Development is inevitable in many watersheds but cities who have integrated land protection and management options into future plans will be able to safeguard water quality and water resources more effectively. Land conservation measures can adapt to growing city populations; as a city's population grows oftentimes, so can the amount of acquired land to meet protection requirements. On the other hand, cities that neglect to protect surface water resources and use adequate land use planning strategies will likely face high filtration, treatment costs and may place downstream populations at risk for drinking water contamination.

8.2 RECOMMENDATIONS

8.2.1 DESIGN A MONITORING PROGRAM AND ADAPTIVELY MANAGE

A water quality monitoring program should be implemented to determine the effectiveness of a protection plan. Water quality monitoring is critical within the first few years to measure the initial success of a program and to subsequently manage and amend the plan as necessary. Adjustments will likely have to be made according to specific management practices or protection efforts that are the most effective at improving water quality. Water quality monitoring should occur throughout the watershed, ranging from upstream to downstream areas prior to raw water reaching the drinking water intake. For example, NYC has a stringent monitoring program including the collection of 20,000 water samples/yr. within upstream areas of the Cat-Del Watershed and 30,000 samples after distribution (NYCDEP, 2012). Water quality monitoring can also be useful to cities that have not implemented protection programs. A monitoring program can track the rate of declining quality within cities that are experiencing high rates of development and deforestation. Water quality trends can be directly compared to treatment costs to track the rate of increase.

8.2.2 Balance Existing Land Uses, Protection Measures

Identifying the correct balance between existing land uses and watershed protection efforts is key to the current and future success of watershed protection programs. For example, even though New York City's strategy to protect the Cat-Del watershed took years, what emerged was a strategy that balanced the needs of both upstream landowners and farmers (existing land uses) and downstream consumers (watershed protection efforts). Similar successful strategies apply the same approach, waterfunds, which utilize Payments for Environmental Services, generate funds for upstream landowners to implement conservation and protection measures without compromising the livelihoods of inhabitants. In these examples, the existence of farming, selective logging (existing land uses) are not in opposition with water protection measures because education and incentives (payments) have been provided to landowners who are applying specific conservation or management practices to their operations. Incentives directed specifically at landowner participation can include, tax relief, trading markets, including water quality and carbon trading, and payments for conservation and management activities (PES). PES schemes also provide a long-term continuous supply of funding, which is imperative for a program to be successful.

8.2.3 Identify Funding

Funding for a watershed protection program is likely one of the biggest hurdles cities face. Therefore, it is recommended that cities interested in developing watershed protection programs identify funding sources as early as possible. Funds for financing programs can be collected through water utility taxes and surcharges, bonds, trusts, voluntary contributions, government grants and programs, and local, private stakeholders. Government funding is a common way to support protection programs and is utilized by a lot of U.S. cities (Proposition 84, Clean Water State Revolving Fund); however, grants and programs may not provide a long-term renewable funding source to support the ongoing support of a protection program. Local sources and stakeholders oftentimes have a higher capacity to support watershed protection programs in the long-term. Stakeholders, such as water utilities, hydroelectric providers, developers, community organizations, and downstream consumers are important local revenue sources. Education and outreach activities concerning the importance of water quality, protection, and watershed management strategies should be directed at these potential benefactors.

8.2.4 Utilize Economic Analyses

Considering the U.S., great strides in land conservation efforts were made through the protection of national forests and parks in the 1900s; however, populations and cities are still expanding. Therefore, an expansion in the number of protected forests and upstream areas is still necessary to support these growing populations. As exemplified with Portland, ME, the economic backing provided by green-gray analyses can support the decision to invest green infrastructure and protect these areas. Economic analyses open the door to funding and support from local sources such as, landowners, organizations, stakeholders, and citizens. Currently, green-gray analyses are under-utilized (Gartner et al., 2013); providing economic evidence to stakeholders that green infrastructure is cost effective will be a large driver for conservation and implementation of protection programs. Therefore, it is recommended that municipalities utilize economic tools such as green-gray, cost effectiveness, or cost benefit analyses to consider future drinking water protection decisions.

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