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Perceived Benefits of Constructed Wetlands in a Southern California Water District

THESIS

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MASTER OF ARTS

in Urban and Regional Planning

by

Noemi Carmen Wyss

Thesis Committee:
Professor David L. Feldman, Chair
Associate Professor Doug Houston
Assistant Professor Nicola Ulibarri

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DEDICATION

This research is dedicated to

Newsha and my time at Water in the West at the Woods Institute at Stanford

for getting me excited about water and green infrastructure.

And to

My parents, Christina and Tony, Livia, Lucas, Emma and James

for listening to me talk about constructed wetlands for the last two years.

I couldn't have done it without your support and pep talks

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ABSTRACT OF THE THESIS

Perceived Benefits of Constructed Wetlands in
A Southern California Water District

By
Noemi Carmen Wyss
Master of Arts in Social Ecology
University of California, Irvine, 2017
Professor David L. Feldman, Chair

To deal with urban runoff and stormwater polluting our waterways, cities across California are implementing low-impact development (LID). This research will look at a specific solution: natural treatment system (NTS) or constructed wetlands in Southern California. These systems vary in size, maintenance level, ability to filter pollutants, aesthetics, and others. This research works with Irvine Ranch Water District to evaluate the benefits, challenges and future of these types of systems. The research included observations of visitors to the sites, in depth interviews with nine experts, and an extensive literature review of benefits of constructed wetlands. By studying perception we are interested in how different people value these sites and how that can be used to create places community-members care about. While most find NTS sites beneficial and overall positive use of urban land, there are still disconnects between the community members and their understanding of these complex engineered systems. The future of these systems is unclear, as the benefits are battling with high costs, both for land and operation and maintenance, and what some interviewees called “messy” land uses.

1 Introduction

With current upward trends in population and a recovering economy, we are again seeing growth in development in urban and suburban settings. While this has many benefits for the housing crisis, it can be more problematic for water and the natural environment. Hydrologic models show that urbanizing areas have larger increases in runoff, with the runoff volume increasing linearly with impervious surface area (Brun and Band, 2000). Long-term stream flow monitoring has shown development leads to higher flood peaks and increases annual runoff volumes two to four times the previous levels for suburban areas and 15 times the previous for highly urbanized areas (Gaffield, Goo, Richards, & Jackson, 2003). As urban areas become more dense and built out, the amount of runoff will increase and the resulting natural waterways become more polluted.

In urban areas in the developed world we have largely used end-of-pipe solutions to manage stormwater runoff. The goal for urban water managers and decision-makers has been to channel and push the water out of the development as quickly as possible. This reliance on engineered grey infrastructure is costly, inefficient and unsustainable (Ahiablame, Engel, & Chaubey, 2012). To avert polluted waterways we must search for other solutions. Green infrastructure or low-impact development (LID) are two of the many methods implemented to treat water at the source in a cleaner, more natural way. There are increasing examples of cities implementing green infrastructure to replace tunnels and storm drains with huge benefits. New York City emphasized stream buffer restoration, green roofs, and bioswales with a cost saving of more than $1.5 billion (Talberth and Hanson, 2012).

While green infrastructure is not a replacement for end-of-pipe water management, it can be a supplemental portion. The current centralized system of treating runoff does not attenuate pollution well, protect or create habitat, manage flood flows, provide sufficient groundwater recharge, or provide possible surface water storage (Quesnel, Ajami, & Wyss, 2016; Feldman, 2017; Hering, Waite, Luthy, Drewes, & Sedlak, 2013). Having a treatment system that can grow and adapt with its environment, is key to sustainability and resilience

In the past, stormwater management focused on the reduction of peak discharge rates from runoff by removing water quickly from developed areas to reduce flooding (CEI, 2003). This approach did not aim to reduce runoff volume nor improve water quality, and instead focused on collecting and routing to the nearest centralized municipal facility or waterway (Ahiablame et al., 2012). For most of the 20th century, the primary goal for urban waterway management was flood control and public health. While these are still first priorities, these traditional approaches to management have been at the expense of other goals such as public amenity and ecosystem health. New water sensitive design approaches have shown potential for achieving public safety, amenity goals, and improved ecological condition simultaneously (Walsh et al., 2005).

However, for these natural water treatment systems to work efficiently, there must be more public investment and engagement of the residents that live and work near these engineered natural systems.

1.1 Definitions

1.1.1 Low Impact Development (LID)

Low-impact development (LID) is a land management strategy that controls stormwater at the source with decentralized, micro-scale, control measures (Ahiablame et al., 2012). LID aims to more closely mimic pre-development hydrologic conditions than traditional infrastructure shows the effect the built environment can have on the hydrologic cycle. These technologies and practices can also offer cross-sectorial benefits such as reducing greenhouse gas (GHG) emissions and providing green space for communities (Figure 2) (The Johnson Foundation, 2012). LID refers to “systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration, or use of stormwater in order to protect water quality and associated aquatic habitat” (US EPA, 2016).

This land development approach was pioneered in the early 1990s. The goal of LID is only related to stormwater, whereas green infrastructure is more broadly defined (Figure 1).

LID includes a variety of technologies such as bioretention, infiltration wells, stormwater wetlands, wet ponds, level spreaders, permeable pavements, swales, green rooms, vegetated strips, sand filters, and water harvesting systems to name a few (Ahiablame et al., 2012). However, LID can also apply to nonstructural practices including minimization of site disturbance, preservation of natural site features, reduction and disconnection of impervious surfaces, strategic grading, native vegetation utilization, soil amendment and aerification, and minimization of grass lawns (Ahiablame et al., 2012). All of these techniques and technologies are part of the decentralization of stormwater management. The goal of LID practices are to keep water onsite as long as possible and water quality protected through natural vegetation (Ahiablame et al., 2012).

The term LID/low impact planning is used in the United States and Canada, whereas similar practices are called Water Sensitive Urban Design in Australia and Sustainable Drainage Systems in the United Kingdom (Ahiablame et al., 2012; Wong & Brown, 2009). These will be covered in more detail in 2.2-Water Sensitive Urban Design/ Planning.

1.1.2 Green Infrastructure

Most urban stormwater flows over impervious surfaces, such as buildings or roads, and is sent directly into nearby surface water bodies (National Research Council, 2008). This not only degrades the natural environment as stormwater picks up pollutants and debris during overland flow, but also wastes water that could potentially be captured for treatment and reuse or for recharging groundwater (Thurston et al., 2003). One way to more sustainably handle stormwater is to use green infrastructure. Green infrastructure uses natural processes such as infiltration or evapotranspiration to capture stormwater or runoff onsite and reuse (U.S. EPA, 2014a). For example, instead of rainwater flowing into storm drains directly, precipitation infiltrates the ground through permeable pavement or is captured in barrels for reuse. Green infrastructure can be used at the household- to watershed-scale and aids in the principles of low-impact development (LID) (U.S. EPA, 2014b). While LID is the goal, green infrastructure are the specific technologies that allow for the urban environment to revert back to its original hydrologic state.

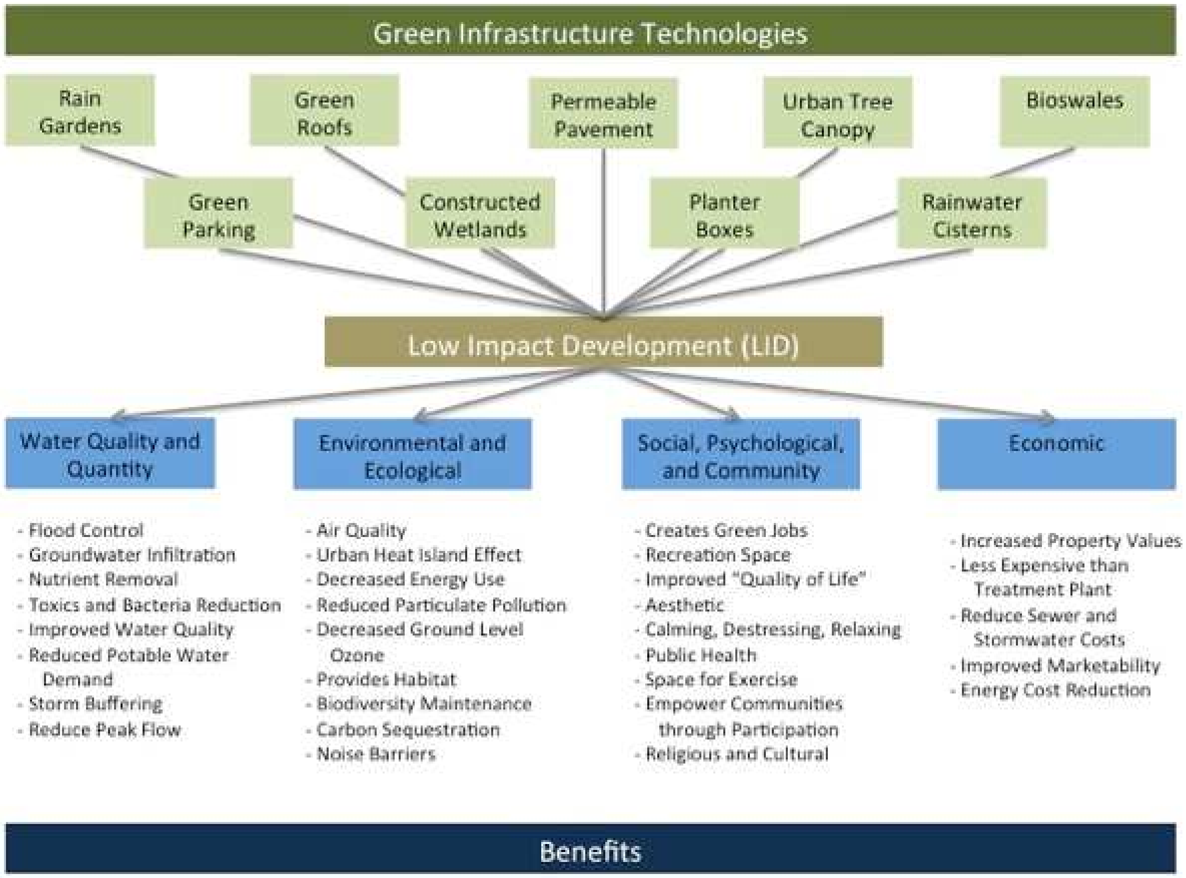

Figure 1. Types of Green Infrastructure and Benefits

LID technologies and practices can take pollutants out of water, but also offer cross-sectorial benefits such as reducing greenhouse gas (GHG) emissions and providing green space for communities (Figure 1). Green infrastructure has water quality and quantity benefits, as well as environmental, social, psychological, community and economic. Green infrastructure can provide benefits to humans such as the connection between urban sprawl and green spaces and how they have to be connected to development principles and not in contradiction (Benedict and McMahon, N.D.; Tzoulas et al. 2007). Green infrastructure is included in the growing field of sustainable planning (Ahern, 2007). These benefits will be discussed more thoroughly in 2.3-Benefits of LID.

1.1.3 Constructed Wetlands

Natural Treatment Systems, or NTS sites for this research, will be used interchangeably with constructed wetlands and retention basins. These ponds are a type of green infrastructure that support the concept of LID. These engineered systems are designed to promote a natural process to purify runoff from nearby land uses and natural precipitation. The water in these ponds can contain many pollutants and contaminants: lead, cadmium, total nitrogen, ortho-phosphorous, selenium, bacteria and viruses, oil and grease, and mercury to name a few (Winans et al., 2012). A retention basin will allow many of these contaminants to filter into the soil and ground, instead of continuing on into the stream or bay. A natural “constructed” wetland provides many benefits at relatively low cost (Winans et al., 2012). These systems are designed to be environmentally friendly, aesthetically pleasing, and effective at reducing pollutants. These systems generate value and have a positive water energy nexus, meaning low energy for high water productivity (Mukheibir et al., 2014).

Water quality treatment wetlands are categorized into three general configurations[1]:

- Wetlands that are adjacent to existing stream channels (off-line) (Figure 2)
- Wetlands established within existing stream channels (in-line) (Figure 3)
- Wetlands that are incorporated within existing and planned flood control retarding basins (Figure 4)

[1] San Diego Creek NTS Master Plan, June 2005 prepared by Geosyntec.

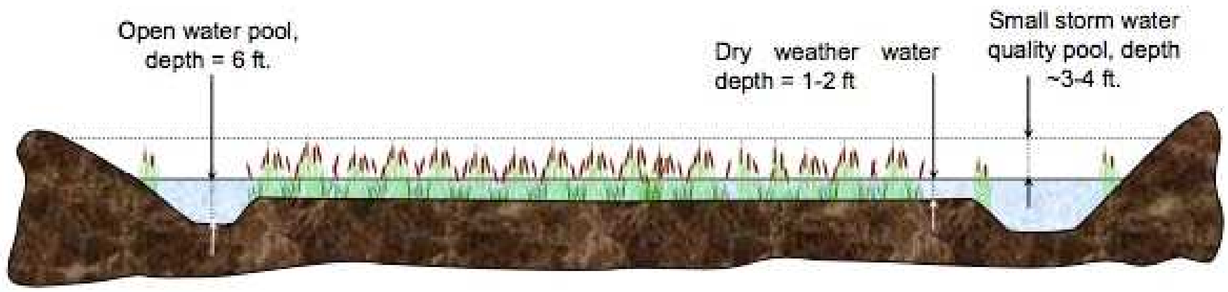

Figure 2. Type I Off-Line Water Quality Treatment Wetland

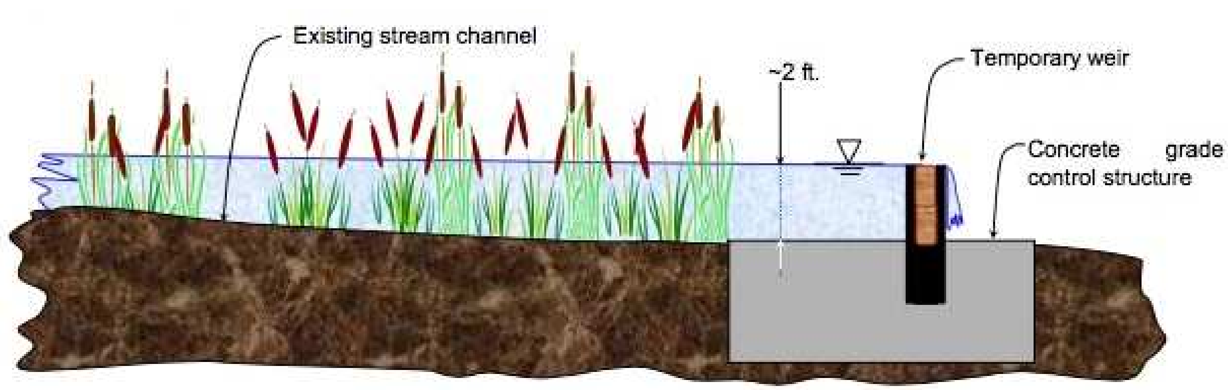

Figure 3. Type II Off-Line Water Quality Treatment Wetland

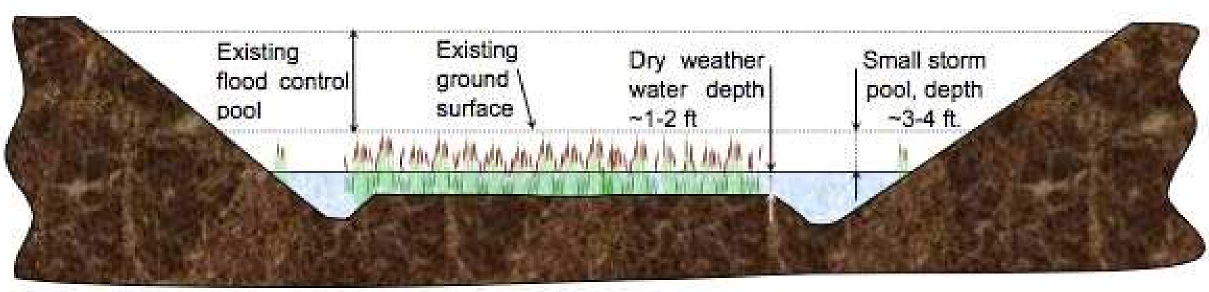

Figure 4. Type III Water Quality Treatment Wetland within Flood Control Basin

Constructed wetlands must be integrated with hydrologic, hydraulic, and botanic designs to achieve the most successful outcomes. In Australia, these systems frequently include compartmentalization of wetlands to enable different processes for by-pass of high flows, testing of particle size distribution of suspended solids to determine required detention time, use of hydrologic effectiveness curves for selecting appropriate detention storage volume, use of hydrodynamic conditions such as hydraulic efficiency to relate to wetland and pond shapes, bathymetry, and vegetation layout, and finally the active engagement of landscape designers to achieve a balance between aesthetic objectives and stormwater quality (Wong, 2006a).

1.2 Problem

Our current built environment, especially in urban areas, is segregated from the natural environment, with channels and pipes that move water from one area to another. Additionally, we have constructed our treatment systems to treat water at the end of the pipe rather than during the process. In conventional development water is routed offsite as quickly as possible through structural stormwater conveyance systems (Ahiablame et al., 2012). While stormwater management is a problem, this research addresses the ability to evaluate benefits and challenges of LID and whether there is a desire for the continuation of these types of engineered systems. Stormwater runoff has been treated as a resource with no value or aesthetic, recreation or educational benefits to the urban environment (Wong, 2006a). This has created a challenge for those tasked with regulation of water quality in urban areas. If we do not know how the public perceives or understands these systems, their benefit capabilities may be hindered.

If we return to pre-development landscaping and allow more natural environments, we will also see secondary benefits such as air quality, water quality and quantity, lower cost, aesthetics, heat island effect and others. The negative impacts of the current grey infrastructure system have led to more intelligent and smarter planning methods such as smart growth, water sensitive urban design, low impact development planning, and other alternatives to reduce impacts of urbanization on natural resources (Coffman, 2002).

These problems of increased urban contaminants, an outdated grey infrastructure system that treats end-pipe water, and the increasing changes in the global environment have led to a need for innovative solutions in urban water policy (Hering et al., 2013). However, if we are placing these technologically advanced systems within communities that do not appreciate and understand them there may be a gap in ultimate benefits achieved.

1.3 Research Question

To deal with stormwater pollution of our surface waters, many water districts, cities and developers are looking at innovative ways to capture and filter urban runoff before it enters our natural waterways. Across California different low-impact development (LID) techniques are being constructed to protect our precious natural water systems. This research will look at a specific solution: constructed wetlands. These systems vary in size, maintenance level, and ability to filter pollutants, aesthetics, and much more. One Southern California water district, Irvine Ranch Water District (IRWD), has implemented 29 of these "Natural Treatment System" sites across its service area. While studying the engineered performance of these constructed systems is worthwhile, this research will focus on the perception stakeholders have, both experts and community-members, about these water sensitive urban design systems. Are these constructed wetlands perceived as beneficial urban land uses by community members and stakeholders?

This question targets the idea that everyone has a different background, experience, and perceptions that shape how they see the world. This research is less interested in specifics-how well these systems actually perform in carrying out their intended functions, as important as that issue is, or with the correct answer to "fix" the problem. Instead the research explores the importance of communication and education about constructed wetlands with residents living near the sites and having public engagement. Without public acceptance, both residents and experts, the NTS sites will have more difficulty in the future becoming a foundation of stormwater management in urban areas. Understanding perceptions, particularly about challenges, can help us tailor policies to allow these decentralized systems to become much more widely used.

2 Background of Low Impact Development

2.1 Urban Stream Syndrome

In most places, precipitation falls and drains into creeks or rivers and eventually into larger bodies of water. While in a drought, more chemicals and pollutants stay as dust on surfaces, and in the case of rainfall get swept into streams and bays and create high levels of contamination. This runoff water, called urban streams, will collect chemicals, oils, bacteria and other pollutants before emptying into a nearby stream or bay. There are many drivers of this effect such as the imperviousness of the built environment, the formal drainage systems, modifications of rivers and streams in urban settings and increase of imported water can alter the water flow system (Askarizadeh et al., 2015). Urban Stream Syndrome's symptoms include elevated concentrations of nutrients and contaminants, altered channel morphology, and reduced biotic richness, with increased dominance of tolerant species (Walsh et al., 2005). A major problem with urban stream syndrome is the amount of nutrient uptake is reduced. Because of hydrologic changes, urban streams tend to be more "flashy," meaning more frequent, larger flow events. This is the result of increased areas of impervious surfaces and more efficient, channelized systems to transport the water through piped stormwater drainage systems (Walsh et al., 2005). These symptoms are driven predominantly from urban stormwater runoff, which in most urban areas is managed for flood control by direct piped connection between impervious surfaces and streams.

Differences in the permeability of pervious areas of the catchment and differences in management practices for land cover and drainage of impervious parts has an effect on urban streams (Booth, 2005; Walsh et al., 2005)

2.2 Water Sensitive Urban Design/ Planning

Ecological Sustainable Development is a movement that seeks to create development that goes beyond protection of the environment from pollution, to protecting and conserving natural resources (Wong, 2006b). For urban development this means no long term adverse effects on greenhouse gas levels, material resources, biodiversity, and ambient water environments (Wong, 2006a). These land developments should be able to endure indefinitely as they neither deplete resources not degrade environmental quality. From this sustainable development grew Water Sensitive Urban Design (WSUD) that evolved to focus on stormwater management and creating a more holistic management of the urban water cycle and its integration into urban design (Wong, 2006b). These designs can be at the local, precinct, or regional level and initiatives can focus on planning, water conservation, stormwater quality, or stormwater detention (Wong, 2006b). For instance, a local area can implement porous pavement in a project but only at the precinct or regional level can constructed wetlands be implemented for stormwater quality.

The goals of WSUD are to increase the quantity of water that infiltrates the ground to eventually reach the groundwater table, and to reduce pollution of surface runoff which ends up recharging the aquifer (Carmon, Shamir, & Meiron-Pistiner, 1997).

WSUD has four essential elements for effective adoption: regulatory framework, assessment and costing, community acceptance, and technology and design (Wong, 2006a). The current regulatory process has fragmented roles and responsibilities in urban water management. To improve this there must be better implementation of innovative technologies, equitable performance standards, and more efficient methods for demonstration compliance to standards (Wong, 2006a). Assessment and costing relates to costs of initiatives and external benefits that occur. The third essential element is community acceptance and governance describes the political support, implementation rates, and industry's technological capacity that is required for these complex systems (Wong, 2006a). The public has become significantly more involved in redefining the WSUD problem and strategies and informing local policy development (Wong, 2006a). Technology and design of WSUD elements has evolved with the new collaborations with architects and other stakeholders.

Another example of water sensitive urban design is China's funding to experiment with ways urban areas can act like sponges to absorb precipitation through LID technologies such as permeable pavements, rain gardens, wetlands, or reuse water locally for irrigation of vegetation (Shepard, 2016). While the term "Sponge City" might be unique to China, it follows the principles of LID and green infrastructure. These types of sustainable practices surrounding water are increasing around the world.

2.3 Benefits of LID

Low impact development and green space have many benefits according to the literature. Countless studies from across the world have shown how parks and open space have improved quality of life (Carleton et al., 2000). LID practices have been successfully used to manage stormwater runoff, improve water quality, and protect the environment (Ahiablame et al., 2012). In this section we will analyze the direct and indirect benefits of urban green space related to water quality, psychological benefits, environmental, social, public health, and economics.

Wetlands are defined by structures, characteristics, processes, and functions (Turner et al., 2000). Characteristics are the basic site-specific features such as the biological, chemical and physical features which include species present, substrate properties, hydrology, size and shape (Lambert, 2003). Structures include biotic and abiotic characteristics such as vegetation and soil types. Processes refer to transformation of matter or energy in the system, such as wetland hydrology, geomorphology, saturated soil and vegetation (Lambert, 2003; Turner et al., 2000). Functions are the relationships between characteristics, structure, and processes. This includes flood water control, nutrient retention and food web support (Turner et al., 2000). Turner et al. also describes nine groups of stakeholders influenced by wetlands. The first are *direct extensive users* who directly harvest goods from wetlands in a sustainable way. *Direct intensive users* harvest more extensively, and therefore have a higher risk that yield exceeds primary production. *Direct exploiters* harvest sediments in the wetlands, mineral resources, and clay without concern for the health of the system. *Agricultural producers* drain and convert agricultural land because of its fertility and high nutrient value and *water abstractors* use wetlands as a source for drinking water, flow augmentation, or agricultural irrigation. *Human settlements close to wetlands* value water as an amenity that needs to be protected, and *indirect users* benefit from wetland services such as storm abatement, flood mitigation, hydrological stabilization, and water purification to individuals and communities in large catchment areas. *Nature conservation and amenity groups* value nature conservation objectives and recreational usage values. Lastly are *nonusers,* who do not value wetlands, potentially because of their recognition of intrinsic value to wetlands (Turner et al., 2000). These can be visualized in Figure 5. Of these nine types of values for wetlands, most likely only three to four are relevant to our stakeholders.

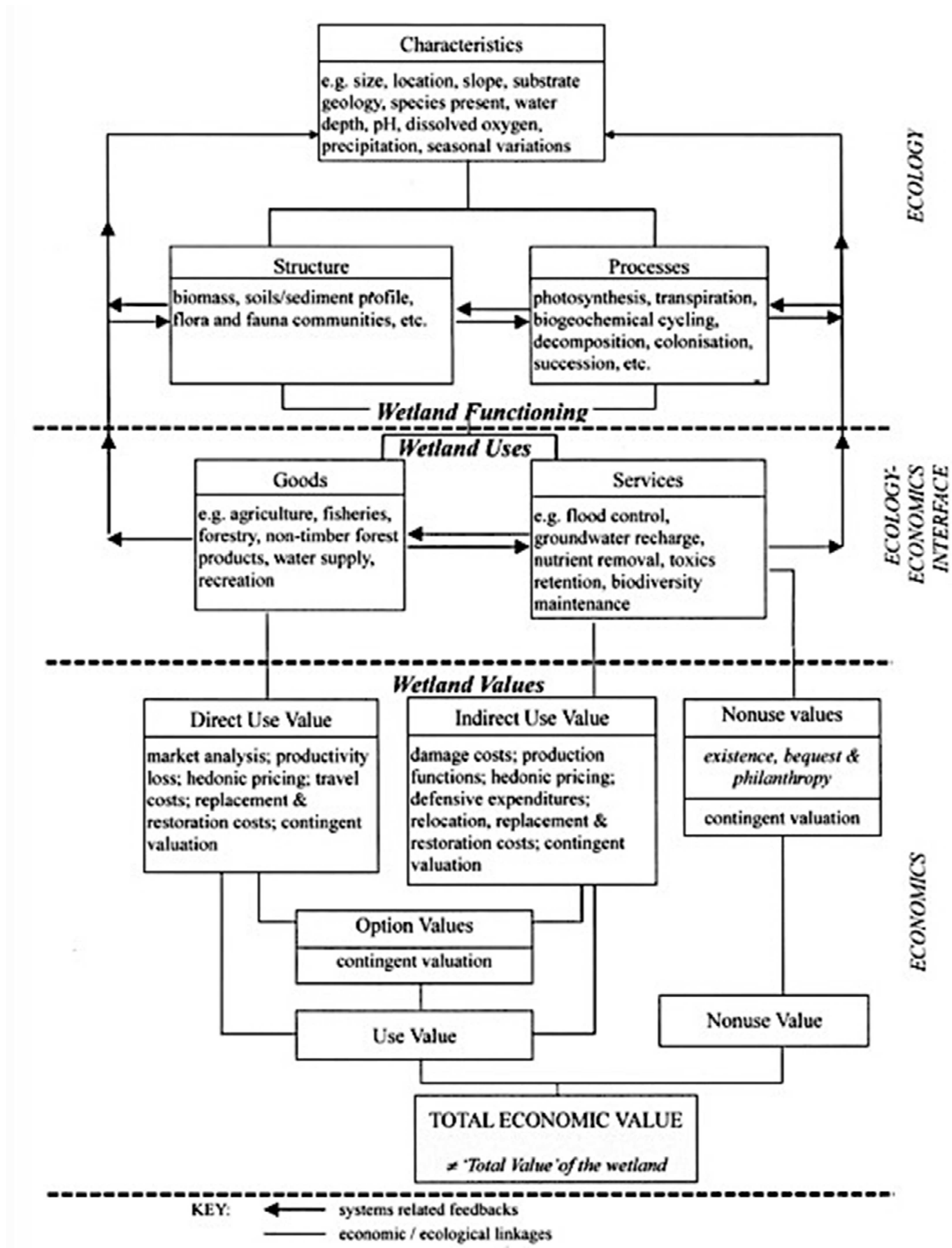

Figure 5 Connections Among Wetland Functions, Uses and Values

Source: (Turner et al., 2000)

In this section, we are evaluating the benefits of constructed wetlands, a form of LID, however besides water quality and economic benefits, very little review of these systems has been done. Therefore, we will focus on literature related to green infrastructure, open space, and wetlands.

2.3.1 Water Quality

Water related benefits of LID are improved water quality, maintenance of predevelopment runoff volume, maintenance of predevelopment runoff discharge rate, groundwater recharge and discharge, reduced potable water and energy demand, recycling and beneficial reuse, retention and removal of nutrients, and flood control and storm buffering (Debusk, Asce, Wynn, Ph, & Asce, 2011; The Low Impact Development Center Inc., 2010; Woodward & Wui, 2001). We will discuss these further in this section by looking at specific studies and examples.

LID principles related to water quality include integrating stormwater management strategies in the early stage of site planning and design, managing stormwater as close to the source as possible with distributed micro-scale practices, promote natural water features and natural hydrologic functions to create a hydrologic multifunctional landscape, and focusing on prevention rather than mitigation and remediation (Ahiablame et al., 2012). To evaluate the performance of a BMP, such as constructed wetlands, the real interest lies ultimately in the long-term effects on total pollutant mass flux (Carleton et al., 2000).

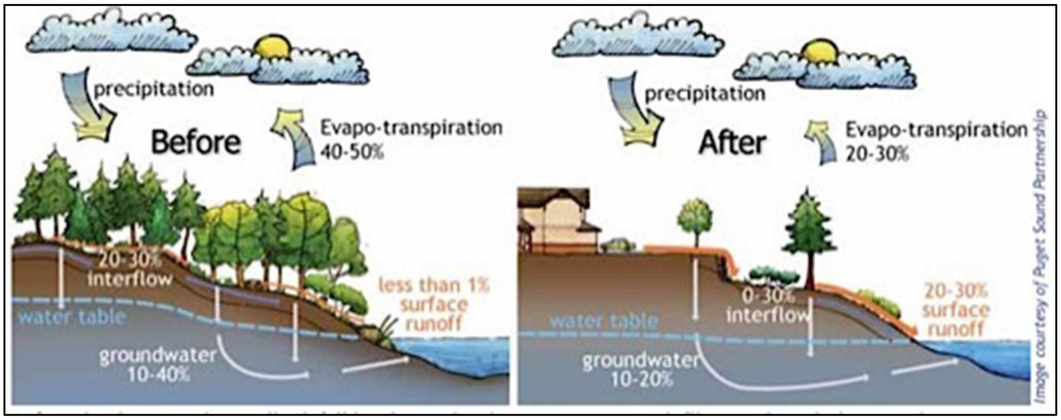

Figure 6. Effects of Development on Hydrologic Cycle

Before the development of land, during rainfall, twenty to thirty percent of the rain would flow into the soil (Figure 6). With the paving of much of the natural landscape, anywhere from zero to thirty percent is allowed to percolate into the groundwater. This change in water flowing into aquifers can deplete the amount of available groundwater and therefore harm water users relying on this supply of water. Many Americans rely on groundwater as their primary water source. “Before development almost all rainfall is taken up by plants, evaporates of infiltrates through the ground. After conventional development, surface runoff increases significantly while evaporation and infiltration into the ground decrease” (Hinman, 2012) (Figure 5). In urban settings, these chemicals and toxins come from fertilizers, oil from cars, bacteria, soaps, tobacco spit, paint, chemicals and litter (Nelson, 2015). Changes of natural hydrological systems in urban areas generally increase the runoff rate and volume, decrease infiltration, decrease groundwater recharge and base flow, and deteriorate the water quality in streams, rivers and shallow groundwater (Harbor, 1994) (Ahiablame et al., 2012).

Urban water quality is a complex issue. The problem arises because of the extreme build up of pervious surfaces. “A manmade surface will generate 2-6 times more stormwater runoff than natural surface” (Wolf, 2004). Sprawl and personal vehicles has led to an expansion of roads and buildings across most open spaces in urban areas. This leaves little room for the natural hydrologic cycle, which has been disrupted. These roads, parking lots, and sidewalks are covered in bacteria, grease, oil, chemicals and fertilizers that get swept into the nearest storm drain and onwards to the nearest river, lake, bay or ocean (American Rivers, 2014). This research tackles just one solution to the massive urban water issue: low impact development. By carefully investigating natural treatment sites and their benefits and challenges we can turn our concrete lands into something that benefits both the environment and people.

Implementing LID leads to a shift towards volume-based hydrology (VBH) that focuses on reducing stormwater volume to solve related problems such as pollutant loading, water velocity, peak flow rate, erosion, and sedimentation (Ahiablame et al., 2012).

Reducing flows

Bioretention cells behave similarly to wetlands in that they can be used to capture runoff, promote infiltration and evapotranspiration, recharge groundwater, protect stream channels, reduce peak flow, and reduce pollutant loads through native and perennial vegetation (Ahiablame et al., 2012). In North Carolina and Maryland, these systems have been found to reduce average peak flows by at least 45 percent during a series of rainfall events. In another case, DeBusk and Wynn were able to reduce flow volumes and rates from a parking lot by 97 and 99 percent respectively (Debusk et al., 2011).

Others have shown that 48 to 74 percent of runoff that flows through a bioretention system escapes as infiltration and evaporation, and 20 to 50 percent through exfiltration and evapotranspiration (Li et al., 2009, (Ahiablame et al., 2012).

Sediment, nutrient, and bacteria reduction

Multiple studies have shown that bioretention cells are one of the most effect LID systems and capable of reducing up to 99 percent of sediment and nutrient losses, in some cases (Debusk et al., 2011). Luell et al found 84 and 50 percent of TN and TSS, respectively, were retained in their bioretention cells over a 13-month period (2011). Frequently analyzed, through composite samples, are total nitrogen (TN), total phosphorus (TP), and suspended sediment concentration (SSC) (Debusk et al., 2011). The limits of detection for the methods used were 0.5 mg/L for TN, 0.02 mg/L for TP with the Hach methods 10071 and 8190 respectively and 1 mg/L for SSC with the ASTM Method D 3977-97 (Debusk et al., 2011). For the Debusk et al study in Blacksburg Virginia the median mass removal rates for suspended sediment, total nitrogen, and total phosphorus were all greater than 99 percent. Both TN and TP mass removal rates were negatively correlated to inflow volume (ρ ¼ 0:53, p ¼ 0:006 for both TN and TP), rather than inflow pollutant concentration or mass (Debusk et al., 2011). For their bioretention cell, the system was very efficient in reducing flows, suspended sediment, total nitrogen, and total phosphorus.

Other studies have shown that bioretention facilities have the ability to reduce TSS up to 76 percent, between 70 and 85 percent of phosphorus (P), and 55 to 65 percent of total Kjeldahl nitrogen (TKN) (Davis et al., 2006, (Ahiablame et al., 2012). The findings of the Davis' research were that including vegetation in a bioretention system would allow for better management and control of the nutrients. Metals such as Copper, Lead and Zinc are effectively removed at 95 percent for most bioretention cases (Dietz, 2007).

Common water quality parameters when assessing water quality for LID technologies are nutrients, metals, pH, dissolved oxygen, and temperature. Stormwater runoff can contain a wide variety of pathogens including bacteria, fungi, viruses, and protozoans such as Cryptosporidium and Giardia (US EPA, 2016). These pathogens can easily affect public health and wildlife health (Ahiablame et al., 2012). Pollutants are removed primarily though plant uptake, which depends on the bioavailability of pollutants in the water column.

Dissolved oxygen if more abundant in rapid versus stagnant waters. Temperature and pH have impacts on downstream habitats. As water temperatures increase, dissolved oxygen decreased due to rapid saturation, causing microbial uptake of some pollutants to decrease (Ahiablame et al., 2012). PH is an important indicator to study because it determines the solubility or ability of things to be dissolved in the water, and biological availability of nutrients and heavy metals (USGS, 2016). For instance metals in the water are more toxic at lower pH because they are more soluble.

Table 1 Summary of Percent Runoff Reduction and Pollutant Removal by Bioretention Systems

Study	Location	Runoff	TSS	P/TP	NO_3–N	NH_4–N	TKN	TN	Cu	Pb	Zn	FC[a]	O/G[b]
Davis et al. (2001)	Lab experiment, USA	–	–	60–80	24	60–80	60–80	–	>90	>90	>90	–	–
Davis et al. (2003)	Lab experiment, USA	–	–	>65	>15	–	>52	>49	>43	>70	>64	–	–
Hsieh and Davis (2005)	Lab experiment, USA	–	–	4–99	1–43	2–49	–	–	–	66–98	–	–	>96
Glass and Bissouma (2005)	Washington, DC, USA	–	98	−3	–	−65	–	–	75	71	80	–	–
Sun and Davis (2007)	Lab experiment, USA	–	–	–	–	–	–	–	88–97	88–97	88–97	–	–
Davis et al. (2006)	Maryland, USA	–	–	70–85	<20	–	55–65	–	–	–	–	–	–
Dietz and Clausen (2006)	Connecticut, USA	–	–	–	67	82	26	51	–	–	–	–	–
Hong et al. (2006)	Lab experiment, USA	–	–	–	–	–	–	–	–	–	–	–	83–97
Hunt et al. (2006)	North Carolina, USA	–	–	–	13–75	–	–	–	99	81	98	–	–
Roseen et al. (2006)	New Hampshire, USA	–	96	–	27	–	–	–	–	–	99	–	–
Davis (2007)	Maryland, USA	–	47	76	83	–	–	–	57	83	62	–	–
Rusciano and Obropta (2007)	Lab experiment, USA	–	92	–	–	–	–	–	–	–	–	92	–
Hunt et al. (2008)	North Carolina, USA	–	60	31	–	73	44	32	54	31	77	71	–
Zhang et al. (2010)	Lab experiment, USA	–	–	–	–	–	–	–	–	–	–	>82	–
Chapman and Horner (2010)	Washington, USA	48–74	87–93	67–83	63–82	–	–	–	80–90	86–93	80–90	–	92–96
DeBusk and Wynn (2011)	Virginia, USA	97	99	99	–	–	–	99	–	–	–	–	–
Zhang et al. (2011)	Lab experiment, USA	–	–	–	–	–	–	–	–	–	–	72–97	–

[a] *FC* fecal coliform including *E. coli*

[b] *O/G* oil/grease

Source: (Ahiablame et al., 2012)

Dietz and Clausen found that having a saturated zone in a bioretention system can dramatically improve the retention of nitrogen (2006). They had a facility that was capable of storing 2.54 cm of runoff and demonstrated efficient removal of NO_2-N+NO_3-N, NH_4+-N, and TN (Dietz and Clausen, 2005). Others have found benefits in denitrification with the use of sulfur, wood chips, or charcoal (Ergas et al., 2010; Halaburka, LeFevre, & Luthy, 2016).

Metal reduction for bioretention systems varies between 30 and 99 percent Table 1. For instance various sites saw nearly 100 percent reduction of lead, copper and zinc. Bacteria retention ranged from 70 to 99 percent through the levels of E. coli.

Construction of wetlands designed specifically as best management practices (BMPs), according to the literature, have concluded that constructed wetlands typically performed slightly better and with less variability than natural wetlands at removing various constituents (Carleton et al., 2000). These types of wetlands have become established methods of secondary wastewater treatment, but their applicability for treatment of stormwater runoff has been less extensively studied (Carleton et al., 2000).

2.3.2 Environmental and Ecological

Environmental benefits of wetlands include reduction of heat, carbon sequestration, nesting for birds, reduction in urban heat island effect, improved air quality, habitat for insects and frogs, space for natural vegetation. The environmental benefits include: water and air quality, soil erosion, noise barriers, wildlife habitat and habitat connectivity, and stabilization of sediment, biomass production (Woodward & Wui, 2001).

Storage and recycling of nutrients and organic waste, groundwater recharge and discharge, natural flood control and flow regulation, erosion control, salinity control, water treatment, climatic stabilization, maintenance of migration and nursery habitats, maintenance of ecosystem stability, maintenance of integrity of other ecosystems, and maintenance of biological and genetic diversity (Marti, 2011).

2.3.3 Social- Psychological- Community Benefits

Assessment of low impact development effectiveness is usually based on achieving water quality, maintenance, public health, and social benefits. Acquiring and maintaining public support for LID technologies requires demonstrating that they are effective at minimizing flood risk and the negative impacts of urbanization on human and ecosystem health (Poff and Zimmerman, 2010).

The key to these innovative systems' acceptability and likeliness of being adopted includes changes public confidence and perceived competence in those responsible for managing these NTS sites through public education to gain trust (Po et al., 2005). Having an uneducated public leads to difficulties in operating and maintenance as well as building future sites. In effect, cities of the future must undergo a "paradigm shift" to overcome bureaucratic nightmares, developer concerns with returns-on-investment, tendencies toward fragmented urban planning, and resistance to public–private partnerships in water governance decisions (Saha and Paterson, 2008; Van de Meene et al., 2011). Second, policy, particularly regulatory, change also will be needed to establish scientifically supportable risk-criteria; enhance public confidence in water reuse; and eliminate concerns about inconsistent standards between different jurisdictions

(Nellor and Larson, 2010). Third, these innovations are designed to be at the neighborhood-level, or "add-ons" to existing water infrastructure and not replacements. This makes them more practical and adaptive in their implementation because they are not being marketed as replacements for traditional infrastructure, which has the confidence of the public due to its proven reliability.

A study in the United Kingdom surveyed visitors to a marine environment and found perceived benefits of visiting the ocean were "calming activities such as sunbathing and relaxing, and others exciting such as rock pooling" (Wyles, Pahl, & Thompson, 2014). Studies have shown that natural environments can improve moods and increase abilities to perform cognitive tasks (Wyles et al., 2014). One study showed that recovering post-surgical patients that overlooked trees instead of brick walls recovered more rapidly and required less pain relief (Ulrich, 1984). Interestingly, it has been found that "blue" environments relating to water are preferred over forests and greener areas. These blue areas are associated with more positive mood and relaxation (White et. al 2013). These spaces are important for public education surrounding environment and water. Research has shown that living near the coast has increased awareness of the marine (Steel 2005). It also provides a more aesthetically pleasing environment instead of pure concrete or asphalt fields. Bioswales and other mechanisms implemented as curb extensions, edge islands, and medians can be used to slow motor vehicles (NACTO, 2014). Under psychological benefits are the studies relating green spaces to reduction in stress (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007).

Urban areas include more impervious surfaces such as roofs, roads, and parking lots that collect pathogens, metals, sediment and chemical pollutants that quickly flow into waterways during storm events (Gaffield et al., 2003). This leads to chronic and acute illnesses through drinking water, seafood, and contact recreation. Impervious surfaces can lead to ponds forming which are potential breeding areas for mosquitoes that can carry dengue hemorrhagic fever, West Nile virus, and other infectious diseases (Gaffield et al., 2003). Reducing stormwater runoff and non-point source pollution is a valuable component of a strategy to protect public health. Approximately 99 million Americans have acute gastrointestinal illnesses annually and 6-40 percent of these may be caused by contaminated drinking water (Gaffield et al., 2003).

Increased runoff volumes lead to greater pollutant loads as the larger water volumes collects more contaminants. An urban watershed near Indianapolis, Indiana between 1973 and 1991 saw an average runoff volume increase by 80 percent and average annual loads for lead, copper, and zing increased by more than 50 percent (Gaffield et al., 2003).

Public health benefits that can be improved through wetlands and green spaces are asthma and space for exercise. Green spaces have also been linked to areas with reduced crime and lower blood pressure, cholesterol and stress levels (Kondo, Low, Henning, & Branas, 2015). Additionally these constructed wetlands improve the aesthetic value of an area, can provide "green job" opportunities, educational opportunities and empower communities for environmental protection through public education and participation (The Low Impact Development Center Inc., 2010). Some people see wetlands as having religious or cultural benefits (Marti, 2011).

2.3.4 Economic Benefits and Costs

Attempting to give wetlands an economic value is difficult, and frequently studies assign monetary values to the services and functions that are provided (Marti, 2011). Wetland services are evaluated economically to estimate ecosystem benefits to people and allow financial experts to perform cost-benefit analysis. These cost-benefit analysis compare the benefits and costs to society of policies, programs, and actions to protect or restore an ecosystem (Lambert, 2003). Other reasons include education to the public through objective evidence. Economic valuation depends on human preferences and their perception (positive or negative) of the impact of wetlands on their well-being (Lambert, 2003). This is frequently measured as willingness-to-pay (WTP), but because a payment is not actually made it is an estimation of what people may pay to receive some benefit. Most indirect users of wetlands are not paying the externalities or cost associated with their actions. For instance, a resident living near a constructed wetland is not paying the cost of water treatment needed to take out the excess nitrates he used in his fertilizer. Or a resident that is excessively watering his lawn or driving is not paying for the erosion and pollution damage that is being caused. Utility payers in the water district then pay these costs.

Discovering the value of wetlands has two benefits: ability to place a precise value on a particular resource to provide information that assists the process of building support for implemented projects or estimating the values to predict aggregate values of similar systems nationally or internationally (Woodward & Wui, 2001).

The methods described in 0-**Appendix A: Methods of Economic Analysis** are valuable; they are not exhaustive and should be used as a portion of the decision-making process and not the absolute answer.

Table 2. Comparison of Costs of Options for Addressing Waterborne Illness

Option	Estimate	Cost, in Billions of 2002 Dollars	Source
Continue to manage waterborne illnesses	Annual cost of waterborne gastrointestinal illnesses	\$2.1-13.8[a]	Estimate of total cost of endemic gastrointestinal illnesses in 1985 and range of these illnesses attributed to drinking water
Improve drinking water treatment	20-year capital needs to meet current and proposed drinking water standards	\$33.0[a]	1999 Drinking Water Infrastructure Needs Survey; "regulatory needs" for compliance with current and future regulations
Improve stormwater management	20-year capital needs for runoff control	\$9.3[a]	1996 Clean Water Needs Survey; categories VI (stormwater) and VIID (urban runoff)
[a] adjusted for inflation			

Source: (Gaffield et al., 2003)

Stormwater management infrastructure discussed above can also reduce sewer costs and minimize basement flooding (NACTO, 2014). For instance New York City has chosen to spend \$1.4 billion over ten years to protect its Catskill-Delaware water supply by purchasing land as a buffer against development, instead of a new \$6 billion filtration plant with an annual operating cost of \$300 million (Gaffield et al., 2003). Green infrastructure also saves building energy (Foster, Lowe, & Winkelman, 2011). Other economic benefits of LID include reduced construction and maintenance costs, improved marketability, and energy cost reduction and water conservation (The Low Impact Development Center Inc., 2010).

According to Table 2, there are three options for addressing waterborne illnesses and their related costs. Improving stormwater management, potentially through constructed wetlands, can be the cheapest cost and is significantly cheaper than upgrading the grey infrastructure. A leading goal of LID is to reduce costs for the construction and maintenance of stormwater infrastructure (Ahiablame et al., 2012). These engineered systems have costs associated with construction, maintenance and operation.

2.4 Perception Theory and LID

Perception is the "awareness of the elements of environment through physical sensation" or "physical sensation interpreted in the light of experience".[2] According to these definitions, perception relies on our individual senses and experiences in the world around us. From this grew the study of environmental and urban perception. For instance, the way one person perceives a single park or landmark can be entirely unique, or the same, as another individual. The fascinating thing about perception is that it is tied to reality, but at the same time separate. William Ittelson studied environment perception and the urban experience and tried to understand the nature of environmental perception (1978). He found that environmental values, preferences, and aesthetics represent an approach to environmental perception that combines cultural, historical, recreational and valuation form (Ittelson, 1978).

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[2] Merriam-Webster. "Definition of Perception". https://www.merriam-webster.com/dictionary/perception. *Accessed April 7, 2017.*

Perception studies try to distinguish the differences between what experts and those in decision-making positions know, and the knowledge of a regular community-member. This section focuses more on values and benefits that those living near constructed wetlands or other LID technologies believe. While scientists and those in the field have long understood the benefits of wetlands, the general public has been less educated. Understanding the perception of the public will dictate preferences and future behaviors (Kim & Petrolia, 2013).

Kim and Petrolia conducted a study on the disappearing coastal wetlands in Louisiana (Kim & Petrolia, 2013). The main purpose of the study was to evaluate the knowledge the general public had on the benefits of wetland restoration. They conducted a survey of Louisiana residents to analyze: (i) the perceived impacts of major wetland loss, (ii) whether Louisiana citizens believe that wetland restoration can reduce tropical hurricane impacts, (iii) if so, how likely and to what extent do they believe it, and (iv) whether Louisiana citizens are willing to support financially wetland restoration projects to mitigate the negative (Kim & Petrolia, 2013).

Wetlands, in the United States, had long been perceived with a negative connotation as “sinister and forbidding, and as having little value” (Marti, 2011) and the US Supreme Court decision in *Leovy vs. United States* (1990) described them as a “fact which may be supposed to be known by everybody… that swamps and stagnant waters are the cause of malarial and malignant fevers, and that police power is never more legitimately exercised than in removing such nuisances” (USSC 177 U.S. 621, 1900). These perceptions and ideas have led to vast losses of wetlands nationwide, with an estimated 53 percent of original wetland area in two hundred years (Marti, 2011). The Federal Clean Water Act Section 404 enacted in 1972 and President

Carter’s Executive Order 11990 in 1977 began the public perceptions shift on wetlands. Carter’s statement along with the executive order was:

> “The Nation's coastal and inland wetlands are vital natural resources of critical importance to the people of this country. Wetlands are areas of great natural productivity, hydrological utility, and environmental diversity, providing natural flood control, improved water quality, recharge of aquifers, flow stabilization of streams and rivers, and habitat for fish and wildlife resources. Wetlands contribute to the production of agricultural products and timber, and provide recreational, scientific, and aesthetic resources of national interest. The unwise use and development of wetlands will destroy many of their special qualities and important natural functions…[The] alteration and destruction of wetlands through draining, dredging, filling, and other means has had an adverse cumulative impact on our natural resources and on the quality of human life” (Carter, 1977).

As science becomes better and more effective in its application we find socio-political factors, particularly how people think about the environment, play a larger role in environmental outcomes (Ives & Kendal, 2014). Ives and Kendal argue this is primarily becomes environmental managers are trained in natural sciences, while social scientists are underrepresented (2014).

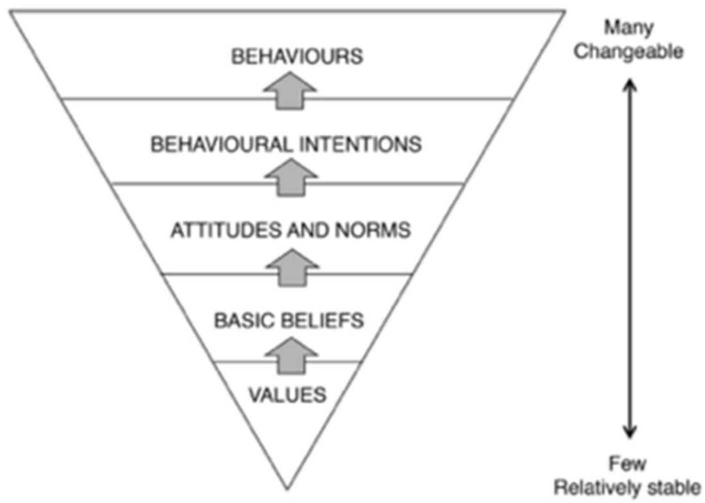


Figure 7. Visual Representation of Cognitive Hierarchy

Source: (Ives & Kendal, 2014)

Environmental values are labeled as Biospheric (nature centered), Social Altruistic (human centered), and Egoistic (self-centered), all of which can predict pro-environment behaviors and attitudes (Ives & Kendal, 2014). The way each individual perceives the environment and his resulting behavior is unique. While some see certain benefits or challenges, others may see completely different ones. Understanding these varying views and values can help policy-makers and decision-makers improve the urban and natural environment.

2.5 Irvine Ranch Water District

The San Diego Creek Watershed is located in Orange County, California. It covers approximately 118 square miles including all of Irvine and Tustin, portions of Lake Forest, Laguna Hills, Newport Beach, Orange, Santa Ana, and unincorporated Orange County (Geosyntec, 2005). San Diego Creek flows into Upper Newport Bay (UNB) and drains almost 80 percent of the total area tributary to Newport Bay. The western and central portions of the San Diego Creek Watershed are flat alluvial plain, bordered by Santiago Hills to the northeast and the San Joaquin Hills to the south. Majority of the soils in the hills have low infiltration capacity (silty-loam soils interbedded with fine textured soils, and clayey soils with a high swelling potential). These types of soils are also found in the El Modena-Irvine Channel, Lower Peters Canyon Wash, and lower San Diego Creek (Geosyntec, 2005).

After World War II the San Diego Creek Watershed experienced rapid growth and land-use development (Geosyntec, 2005). Over fifty percent of the watershed has been urbanized, with majority of the recent developments concentrated on the western portion of the watershed. Approximately 15 percent of the watershed is used for agricultural purposes and 35 percent as open space (Geosyntec, 2005). Orange County Water District (OCWD) manages the groundwater resources in the County of Orange. The groundwater flows in a westerly direction following the topographic relief formed by the San Joaquin and Santiago Hills (Geosyntec, 2005). Groundwater in the Irvine sub-basin are shared by IRWD and The Irvine Company, and used primarily for agricultural irrigation (OCWD, 1999).

San Diego Creek Watershed is under the jurisdiction of the Santa Ana RWQCB (Region 8). The San Diego Creek Channel flows into the Upper and Lower Newport Bays, both of which are listed in the 303(d) List of Water Quality Limited Segments for bacteria and viruses, metals, pesticides, and organic compounds (RBF Consulting, 2012). The San Diego Creek is considered an Environmentally Sensitive Area (ESAs) meaning existing riparian areas along the Creek have been preserved and are protected with buffer zones.

Irvine has an average of 12.14 inches of rain between 1976 and 2016. The highest amount of rain was 29.11 inches in the 1997-1998 rain year and the lowest 2.03 inches between 2006-2007.[3] The City of Irvine has 37 Planning Areas.

The San Diego Creek Natural Treatment System Master Plan is a voluntary initiative developed by the Irvine Ranch Water District (IRWD) to address regional water quality treatment needs in the San Diego Creek watershed, in particular implementing regional treatment control BMPs that assist the County and City efforts to comply with loading restrictions (TMDLs) in the watershed and Upper Newport Bay (IRWD, 2003). However, in the long run it will save money as communities avoid expenses of building new sewer infrastructure or retrofitting existing systems to handle urban runoff.

The NTS facilities are all inspected and maintained by IRWD according to the NTS Master Plan. The inspections include weekly site visits to ensure the facility is operating properly, record observations, and initiate any maintenance activities that may be required. BMP maintenance activities can be trash/debris removal, vegetation removal/thinning, sediment removal, integrated pest/plant management, and vector control (Templeton Planning Group, 2008).

The benefits of water quality treatment, in the form of constructed wetlands, are more than just stormwater detention facilities because NTS facilities can treat dry-weather runoff and are

[3] OC Watersheds, 2017. Real-Time Rainfall Totals http://www.ocwatersheds.com/rainrecords/rainfalldata/stormdata/

more effective at stormwater treatment through the inclusion of permanent pool and vegetation (Geosyntec, 2007).

Water quality pollutants modeled are total suspended solids (sediment), total phosphorus, nitrate-nitrogen, nitrite-nitrogen, total Kjeldahl nitrogen (TKN), dissolved copper, total lead, and dissolved zinc. Other pollutants of concern include turbidity, cadmium, pesticides, selenium, PCBs, pathogens, petroleum hydrocarbons, and trash and debris.

According to the Master Plan the two main objectives of the NTS facilities are:

- To improve water quality within the San Diego Creek watershed and other watersheds that lie within IRWD boundaries; and
- To reduce Total Maximum Daily Loads (TMDLs) of various constituents discharged to Upper Newport Bay

The definition of the NTS Operation and Maintenance (O&M) requirements will include

- Periodic inspections;
- Water quality monitoring and reporting;
- Trash;
- Debris and sediment removal;
- Erosion control and slope stability;
- Vegetation control, removal and replacement;
- Weed abatement;
- Rodent and vector control;
- Structural maintenance;
- Landscape and irrigation repair; and
- Maintenance and identification of the entities responsible for the required O&M activities.

2.5.1.1 Constraints: regulations

The Orange County Watershed Program manages the San Diego Creek Watershed manages the San Diego Creek Watershed as well as other watersheds in the County. The NTS Master Plan helps with regulations for wildlife protection, habitat preservation and restoration, and control of discharges to navigable waters (Geosyntec, 2005).

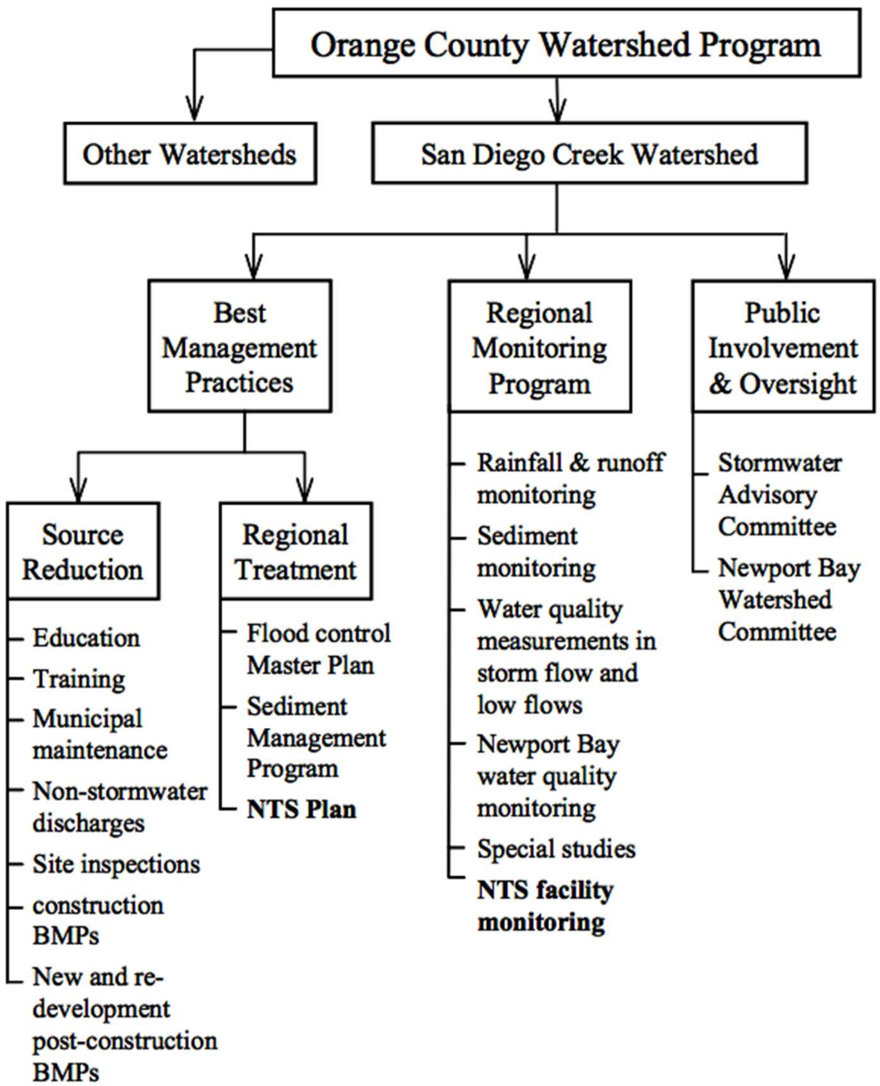


Figure 8. Orange County Watershed Program

According to the NTS Design Guidelines: "Urban runoff will be routed to each bioretention area via surface flow from impervious and landscaped areas" (IRWD, 2012).

According to the NTS Master Plan includes eight TMDL constituents and their respective target and water quality objectives. Additionally the table shows what the NTS Plan is estimated to achieve and how it is estimated to contribute to TMDL compliance for the region. Peters Canyon Channel is on the 2006 CWA Section 303(d) List of Water Quality Limited Segments, TMDLs including DDT and Toxaphene.

Table 3. TMDL Summary and Estimated Annual Contribution of the NTS Plan

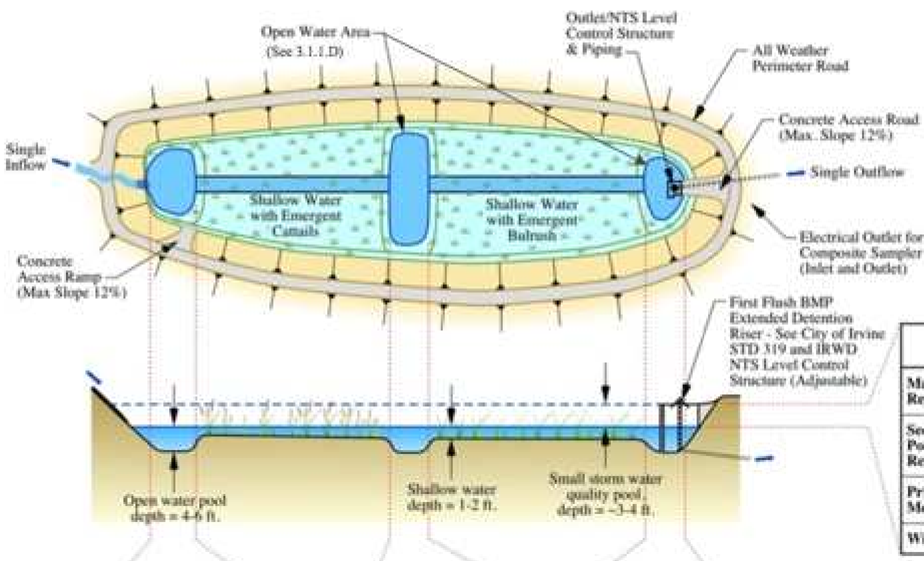
TMDL Constituent	TMDL target and water quality objective[1]	What the NTS Plan is estimated to achieve	Estimated contribution of the NTS Plan to TMDL compliance
Nitrogen	TMDL for TN Load to Upper Newport Bay (UNB): Dry season = 153,861 lbs; Wet season = 144,364 lbs.	Dry Season: Ave TN removed = 127,300 lbs Load to UNB = 70,500 lbs Wet Season: Ave TN removed = 103,500 lbs Load to UNB = 129,200 lbs	Both dry and wet season TMDL objectives are met.
Sediment	TMDL for sediment: 62,500 tons/year to UNB; 62,500 tons/year to watershed (trapped in sediment basins).	Annual sediment loads are variable, strongly associated on rainfall. Estimated removal in NTS facilities is about 800 tons/year from urban and open land sources for average rainfall year conditions.	Estimated sediment loads from urban and open land areas are below the TMDL allocation for these sources. The NTS Plan is not intended to address in-stream sediment sources (channel scour), which is the source of the vast majority of sediments in storm runoff.
Phosphorous	TMDL for TP (Load to UNB): 62,080 lbs/year	TP loads are strongly associated with sediment loads. Estimated removal is 4,300 lbs/year from urban and open land sources for average rainfall year conditions.	Estimated TP loads from urban and open land areas are below the TMDL limit in all years except extreme rainfall years. The NTS plan does not address in- stream sources of TP.
Pathogens	TMDL for fecal coliform in flows to UNB: Maximum = 400 MPN per 100 mL (with 10% exceedance in 30-days) 30-day average = 200 MPN per 100 mL	Fecal coliform concentration is variable, associated with rainfall. Average maximum fecal coliform concentrations are reduced by roughly 30 percent in dry weather low flows, and about 10 percent in storm flows.	TMDL would be met for most, but not all dry and wet season low flows. TMDL is not met for storm flows.
Diazinon and Chlorpyrifos	Concentration limits in San Diego Creek (ng/L): **Diazinon** 80 (acute) 50 (chronic)	Removals were not quantified. Characteristics of chlorpyrifos and diazinon suggest that removal will occur in NTS facilities, primarily by adsorption to wetland sediments and	Undetermined. Some reduction is expected from NTS facilities.

	Chlorpyrifos 20 (acute) 14 (chronic)	biodegradation.	
Organochlorine compounds	Annual load limits to Newport Bay (g/yr) Chlordane = 314.7 Dieldrin = 262 DDT = 432.6 PCBs = 282 Toxaphene = 8.9	Removals were not quantified due to lack of monitoring data and undetermined sources. These legacy compounds are strongly associated with sediments. Sediment removal in NTS facilities could provide minimal treatment of these compounds.	Undetermined. Reduction by NTS facilities is expected to be small.
Selenium	Annual total load target = 891.4 lbs. Loads are partitioned into four flow tiers	Estimated annual removal at site 67 is about 200 lbs, or about 20 to 50 percent of the low flow selenium load. All surface flow NTS facilities may have incidental removals of selenium from base flows.	NTS facilities will remove significant quantities of selenium from low flows; however, TMDL compliance at the low flow tier is undetermined. NTS facilities are not intended for treatment of selenium in storm runoff.
Heavy metals	Concentration based TMDLs expressed at four flow tiers. Concentrations are based on the CTR objectives using average hardness values of the associated flow tier.	Annual loads are variable, depending on rainfall. Total metal loads in storm runoff from urban and open land sources are reduced by about 13 percent for copper, 10 percent for lead, and 12 percent for zinc. Cadmium was not modeled. Removal from low flows was not quantified.	TMDL objectives are met on average for the highest flow tier (large flows), assuming in-stream sources are controlled. Exceedances of the CTR criteria would still be expected. Data from the San Joaquin Marsh indicates that NTS facilities will contribute to metal reductions during dry weather low flows.

[1] TMDL target are subject to periodic review and revision. Toxics TMDLs issued by the USEPA are subject to review and adoption by the RWQCB.

2.5.2 Design Parameters for NTS Sites

According to the NTS Guidelines there are specific design objectives and elements that must be achieved to ensure a functioning and effective system (IRWD, 2012). Each wetland can be tailored to local conditions and constraints. The nine design elements are shown below and described in more detail (Figure 9).



	Extended Detention
Main Pollutant Removed	Sediment
Secondary Pollutant Removed	Oil and Grease, Phosphorus, Metals, Organics
Primary Removal Mechanisms	Sedimentation
Wildlife	None

	Inlet Pool	Cattail Stand	Open Water Pool	Bulrush Stand	Outlet Pool
Main Pollutant Removed	Sediment, Pathogens	Nitrate, Phosphorus, Metals, Pathogens	Pathogens, Organic Transformation	Organics, Pesticides	Pathogens
Secondary Pollutant Removed	Phosphorus, Metals, Organics	Organics	Sediment	Nitrate, Phosphorus, Metals	Organics
Primary Removal Mechanisms	Sedimentation, UV Solar Radiation	Nitrification, Plant Uptake, Filtration, Sedimentation	UV Solar Radiation, Volatilization	Nitrification, Plant Uptake, Sedimentation	UV Solar Radiation
Wildlife	Mosquito Fish, Birds	Birds, Insect Larvae e.g., Dragonflies, Mosquito Fish	Ducks, Mosquito Fish	Birds, Insect Larvae e.g., Dragonflies, Mosquito Fish	Ducks, Mosquito Fish

Figure 9. Typical NTS Site Components and Design

- **Inlet Structure**: are designed to dissipate energy at the inflow, which will reduce the potential for erosion and damage to wetland plants. They also spread the water and are usually limited to one per site to make water quality monitoring more efficient. The inlet should be a minimum of one foot above the basin to prevent blockage of the storm drain by sediment build up.
- **Inlet Pool**: is designed to trap the majority of coarse sediments from the inflow waters. Vector control may be achieved through the use of Mosquito fish and the pool should promote easy desilting and trash removal.
- **Shallow Water with Emergent Cattails**: The water here is one to two feet in depth and supports emergent plants such as cattails, which provide frictional resistance to slow the velocity of the inlet waters, promote sedimentation and increase the time for pollutant removal. Cattails are aggressive emergent plants that are effective in facilitating microbially mediated removal of nitrate and immobilization of heavy metals and metalloids such as selenium. Cattails also provide a good physical substrate for filtering bacteria, and some removal of soluble phosphate and are frequently selected for planting in upstream areas near the inlets because they are not an attractive food source for native fish and birds.
- **Open Water Areas**: These areas are approximately four to six feet deep and provide favorable environments for mosquito fish and sites for ultraviolet degradation of complex organics and pathogens. Open water areas also provide access areas for mosquito control measures.
- **Shallow Water with Emergent Bulrush**: Bulrushes also help to slow the velocity of inlet flows, promoting sedimentation and increasing retention time for pollutant removal. Bulrushes provide a good long-lasting six peat source for anoxic degradation of organic pollutants such as pesticides and petroleum products.
- **Outlet Structures**: Outlet structures control the hydraulic regime of the wetlands through precise level control. A trash rack on the outlet will prevent plugging with debris and provide safety to the public.
- **Riparian and Upland Vegetation**: Vegetation in the riparian area adjacent to the

wetlands can serve important habitat functions, including producing detritus, a critical foundation of the wetland food chain, and shade, as well as providing a transition between the wetlands and the surrounding habitat. Upland vegetation will serve as a buffer between the natural treatment system wetlands and the surrounding urban uses. Figure 10 is a cross-section of a typical natural treatment system showing the transitions between the riparian and upland areas with trees and bike paths.

- **Plug-Flow Configuration:** The natural treatment systems are designed to be a linear channel-like configuration in order to promote "plug flow". Plug flow refers to the concept that water entering the wetlands moves as a unit from the inlet to outlet, promoting uniform flow, which improves treatment effectiveness.
- **Monitoring Equipment**: Monitoring devices for automatic flow measurement and water quality sampling will be installed near the inlets and outlets to measure influent and effluent pollutant concentrations.

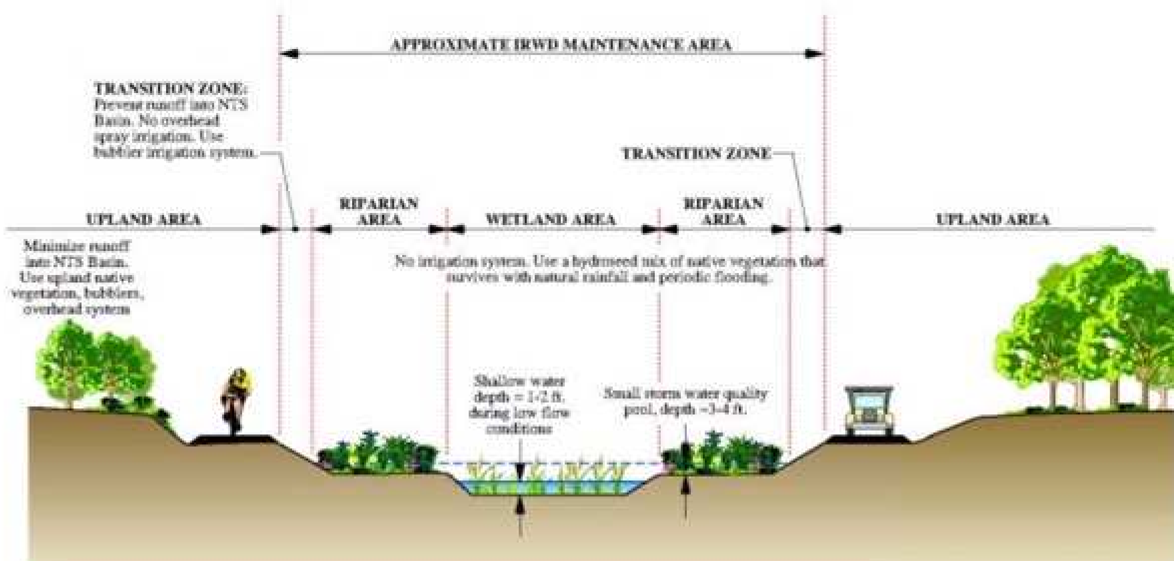


Figure 10. Typical Cross-Section of an NTS Site

Other design considerations that may vary depending on the location are depth of water, detention time (optimal is 10-14 days), high runoff flows, trash and sediments, and channel banks (IRWD, 2012).

2.5.3 Vegetation

As described above, vegetation is an integral part of the NTS sites. Plants can help achieve pollutant treatment and provide wildlife habitat, as well as withstand stresses from insect and diseases, drought, temperature, wind and sun exposure (IRWD, 2012). The Design Guide says the planting arrangement should be in a random “natural plant layout” but include distinct and diverse layers of overstory trees, understory trees, shrubs and herbaceous materials (IRWD, 2012). Overstory species include: California Sycamore, Coast Live Oak, Fremont Cottonwood, Black Willow, Red Willow, and Arroyo Willow. Understory vegetation should transition from the cattail and bulrush habitat through shallower water wetlands into the wooded overstory habitat. Shrub vegetation includes California sagebrush, California buckwheat, Toyon, giant wild-rye, monkeyflower, and California rose. The groundcover vegetation is seen in the Seed Mix (Table 4). The Seed Mix includes native plants found in local freshwater marsh community and seeds are collected within a ten-mile radius of the project site. A complete list of weed species is included as Appendix 10.1 (IRWD, 2012).

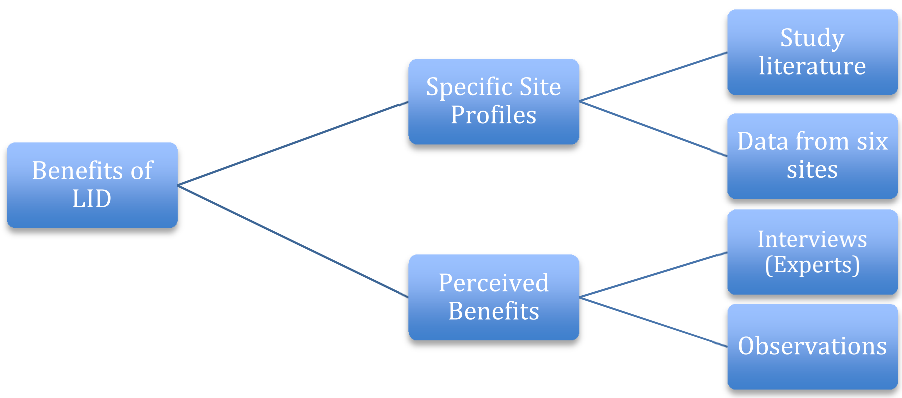
Table 4. IRWD NTS Basins Seed Mix

Species	Common Name	Lbs/acre
Ambrosia psilostachya	western ragweed	10.0
Anemopsis californica	yerba mansa	0.5
Artemisia douglasiana	California mugwort	1.7
Bromus carinatus	California brome	4.4
Eleocharis macrostachya	common spike-rush	0.3
Elymus glaucus ssp. glaucus	blue wildrye	1.7
Epilobium ciliatum ssp. ciliatum	green willow-herb	1.3
Frankenia salinia	alkali heath	0.7
Heliotropum curassavicum	salt heliotrope	0.2
Hordeum brachyantherum	meadow barley	4.3
Lasthenia californica	California goldfields	2.0
Leymus condensatus	giant wildrye	1.8
Leymus triticoides	beardless wildrye	4.8
Lupinus bicolor	miniature lupine	4.0
Lupinus succulentus	arroyo lupine	7.0
Muhlenbergia rigens	California deergrass	0.1
Nassella lepida	foothill needlegrass	0.4
Nassella pulchra	purple needlegrass	3.8
Phacelia ramosissima	branching phacelia	1.0
Pluchea odorata	marsh-fleabane	0.1
Rumex salicifolius	willow dock	0.4
Scirpus maritimus	alkali bulrush	4.0
Urtica dioica ssp. holosericea	hoary nettle	0.3
Verbena lasiostachys	western verbena	0.9
Total (per acre)		**56.3**

Source: (IRWD, 2012)

3 Research Methodology

This research on the perception stakeholders have toward water sensitive urban design systems was tested through two methods. First, I used a quantitative approach to analyze six different constructed wetlands. In the second portion, using interviews and observations, I delved further into "perception" or how individuals see these systems as beneficial. The research design pathway is:



There is an overall question of low-impact development benefits and the perception of these systems. To narrow down the study we look only at Irvine Ranch Water District and the stakeholders involved.

3.1 Part I: Quantitative Approach

The purpose of this research portion is to evaluate constructed wetlands in one water district in Southern California. By choosing sites with a variety of locations, drainage sizes, vegetation levels, ages, and inlet systems we can get a snapshot of the benefits and challenges of these LID technologies. In this section we will also look at surrounding land uses, irrigation types, zoning and densities and how that can affect the water quality in the different sites. For each site, there will be a background to describe the reasons or expectations in the Master Plan for the particular site's construction. We also looked at land use and density surrounding the sites, as well as "purple pipe" access, and impervious versus pervious areas.

3.1.1 Case selection

IRWD currently has nearly 29 sites that are in use and being monitored and evaluated weekly by staff. Of these basins the Natural Resource Manager assisted me in selecting sites that are particularly interesting from an urban planning perspective and have sufficient water quality data to evaluate. This meant either surrounded by a different type of land use, varying densities, located near expansive road networks or spatially unique. We chose three sites that have been online for almost ten years and three newer sites, to see if there are any temporal differences in the benefits of the basin.

The wetlands that were selected are Cypress Meadows A, El Modena, Los Olivos, Quail Springs, and Trabuco. Water Quality Treatment (WQT) wetlands are categorized into three general configurations based on their location in relation to stream channels and detention basins (Geosyntec, 2005). The sites selected are a combination of Wetland types I and III, as described earlier in the definitions section (1.1.3.-Constructed Wetlands).

NTS Site	#	Location	Type of Wetland	Year online	Facility Status
Cypress A	73A	Irvine	I	2013	New
El Modena	56	Orange	I	2008	Retrofit to existing
Los Olivos	69A	Irvine	I	2014	New
Quail Springs	31	Irvine	III	2006	New
Trabuco	16	Irvine	III	2008	Retrofit to existing

3.1.2 Data Collection

This portion of the research draws on water quality data and records previously collected by IRWD, City of Irvine land use and zoning data, and SCAG land use data. Most of the sites have been collecting weekly water quality samples for almost ten years. For each of the sites I focused on, I show graphs of lead, bacteria (either enterococcus or e-coli depending on availability), total nitrogen, coliform, and flows. These are frequent indicators in the literature of water quality health.

Additionally, I constructed maps using Geographic Information System (GIS) software for each of the sites that are being studied. For the four sites located in Irvine, I obtained land use and zoning files from the City. For El Modena, located in Orange, I had access to SCAG land use shape files. The Irvine data is from 2014 and SCAG 2012. These maps will show how surrounding land uses affect the health of these constructed systems.

3.1.3 Validity Issues

The main validity issues for this portion of the research revolve around the accuracy of data collected. Water quality data can vary tremendously depending on most recent rain event or who collected the samples and where they collected them from. Additionally if bacteria samples were not tested quickly enough after being collected it could ruin the sample. Nonetheless I used the data that exists, and understand the variety of challenges that can occur with water quality sampling.

The City of Irvine land use data is from 2014, meaning the data is three years old. While I modified known changes in development near the NTS sites, there may be inaccuracies.

3.2 Part II: Qualitative Approach

In the second portion of the research, the previously found and tested benefits of constructed wetlands will be discussed with stakeholders. These individuals are a variety of stakeholders including developers, designers, engineers, city officials, water district officials, County public works, and environmental/advocacy groups. These individuals are involved in the process of designing, maintaining, operating, studying, or living near the studied sites. These unique experiences with the wetlands will shape their perceptions of the benefits of the system and their opinions on future construction. From the interviews I gathered what these different stakeholders consider an efficient system and how they perceive NTS sites in general.

Through my interview guide I was able to gain their perceptions about low-impact development and distinguish what they consider an appropriate indicator for labeling an infiltration basin a beneficial site. By talking to a variety of people I saw a wide perspective of thoughts on the issue. By discovering how these various groups label or define an effective wetland system, I was able to see how this leads them to make different choices for their respective agencies or organizations.

Additionally, I observed 59 individuals at three sites and their level of activity, engagement and time with the site and basic demographic information. I originally planned to conduct five-minute surveys with individuals to gain a better sense of the frequency of site visits, benefits and reasons for visiting the site, and overall value the specific site has to them, but I was unsuccessful in getting participants interested. An example of the survey is attached as Appendix D.

3.2.1 Data Collection

The data collection for this portion will consist of half to one hour-long interviews with stakeholders and observations of users of the sites.

There are two interview guides, one for the experts and a shorter survey for community members. In the expert interview guide it begins with background of the interviewee, questions about water, constructed wetlands, LID, and governance. The survey is much shorter and only has nine quick questions. The observations will be passive engagement with participants and are noted when I visited the sites.

Table 5. Stakeholders

Expert Interview		Community-Member	
Public Agencies	Private	Surveys	Observations
IRWD, county public works, city officials, city public works, city engineers, public utilities, environmental advocates	Developer, engineers, landscape designers	- 2 sites - 30 people - Benefits, reasons for visiting - Value	- 2 sites - Up to 100 - Activity at site - Active or passive engagement - Basic demographics

Table 5 shows the Expert and Community-Member sampling strategy and the professions of the expert interviews.

3.2.2 Sampling: Experts

The participants were identified and selected by reviewing conference proceedings, participation in related policy and education workshops, and by recommendations from experts in the field and stakeholders. Recruitment occurred through email and contact information was collected from conference proceeds, workshop publicity, networking contact with experts or stakeholders, and from publically available information on the websites of professional and public government organizations. There were 18 emails sent to experts and nine responded, two with no interest in interviewing and seven agreed. There were nine expert interviews completed from city and county officials, engineers, designers, and environmental advocacy individuals.

3.2.3 Sampling: Community- Members

The community-member survey was designed to focus primarily on knowledge about water and behaviors related to water and the environment. The community-member interview guide was a short survey that was asked to the visitors of the site. The goals of the interviews were to discover background of individual, level of environmental consciousness, knowledge about general water and urban water systems, and perceived benefits of NTS sites. The surveys were designed to be at three of the sites: Cypress A, Los Olivos, and El Modena. After multiple efforts there was no success in conducting surveys. Visitors replied, “not interested” when asked to complete a quick survey, were biking/running, said they did not understand English, or were distracted with young children or pets.

The observations took place at three of the sites frequented by users: Cypress A, Los Olivos, and El Modena. The observations consisted of the researcher noting the activity and demographics. The demographic information was compared to the census data to understand which members of the surrounding area are using the site. Other demographic information collected was in broad categories of age, gender, and race. The purpose of these observations is to gain a better understanding of the types of users of the sites and how they are using the public facilities.

The observations and surveys occurred on random days of the weeks and times. There were a variety of weekday and weekend mornings and afternoons. There were 50 observations completed at three sites in a two-month period.

Methods

The surveys were based on a study of people's perception about the importance of forests in Borneo (Meijaard et al., 2013). In the research, study surveys included questions about respondent's age, sex, ethnic group, years of residence in the village, as well as frequency with which they entered the forest and reasons for entering the forest. For our survey, we will ask about the vicinity site instead of the forest and instead of "logging, hunting, artisanal mining, collecting non-timber forest products, other" we will ask about the benefits discussed in the literature review (Meijaard et al., 2013). The Borneo forest research survey asked respondents about the economic, spiritual, and cultural benefits of the forest. The survey was not used, but a copy is included as Appendix D.

3.2.4 Unit of Analysis

The unit of analysis for this research was perceptions, primarily through definitions of effectiveness and low impact development. The research will discover, through observations and interviews, the fluidity of peoples' perceptions and definitions based on their past experiences. For instance those with an engineering background will have different ideas about what makes a system beneficial compared to a developer or city official.

3.2.5 Data Analysis

The interviews were recorded, transcribed and coded for patterns of benefits of the systems. The interview questions will reveal the interviewees position, level of education about water, environmental consciousness as background information. After understanding what the interviewee perceives as benefits, challenges, and the future of the systems, we will combine the information and codes to note the wide variability of perceptions about a single topic.

3.2.6 Validity and Reliability

As with any qualitative data the validity issues are based on the interviewees' knowledge of the situation or the interviewer interpreting or coding incorrectly. I do not anticipate significant personal bias in influencing the findings as the topic is not personal. However, there will be bias in sampling and the techniques will be discussed.

As the sample size was only nine people, there are issues with reliability related to diversity and generalizability. I understand that the interviewees have unique perspectives and therefore not every view may have been heard. However, given the small group I was able to hear a wide range of perceptions about constructed wetlands and still think it shows an interesting view. While there may also be bias with the intensity to which some interviewees responded to my questions, I analyzed them a few days or weeks after the interview and therefore was able to achieve distance and a more objective view from the situation.

While the interviewees were relatively small in number, with the data that was collected I have made connections and shown similarities and differences. While this research does not represent all perspectives or potentially skewed values, I have made policy implications and recommendations based on the data collected.

4 Site Profiles

IRWD has 29 existing NTS sites and nine that will come online in the next few years (Figure 11).

Those with labels are the five sites that are further studied in this research.

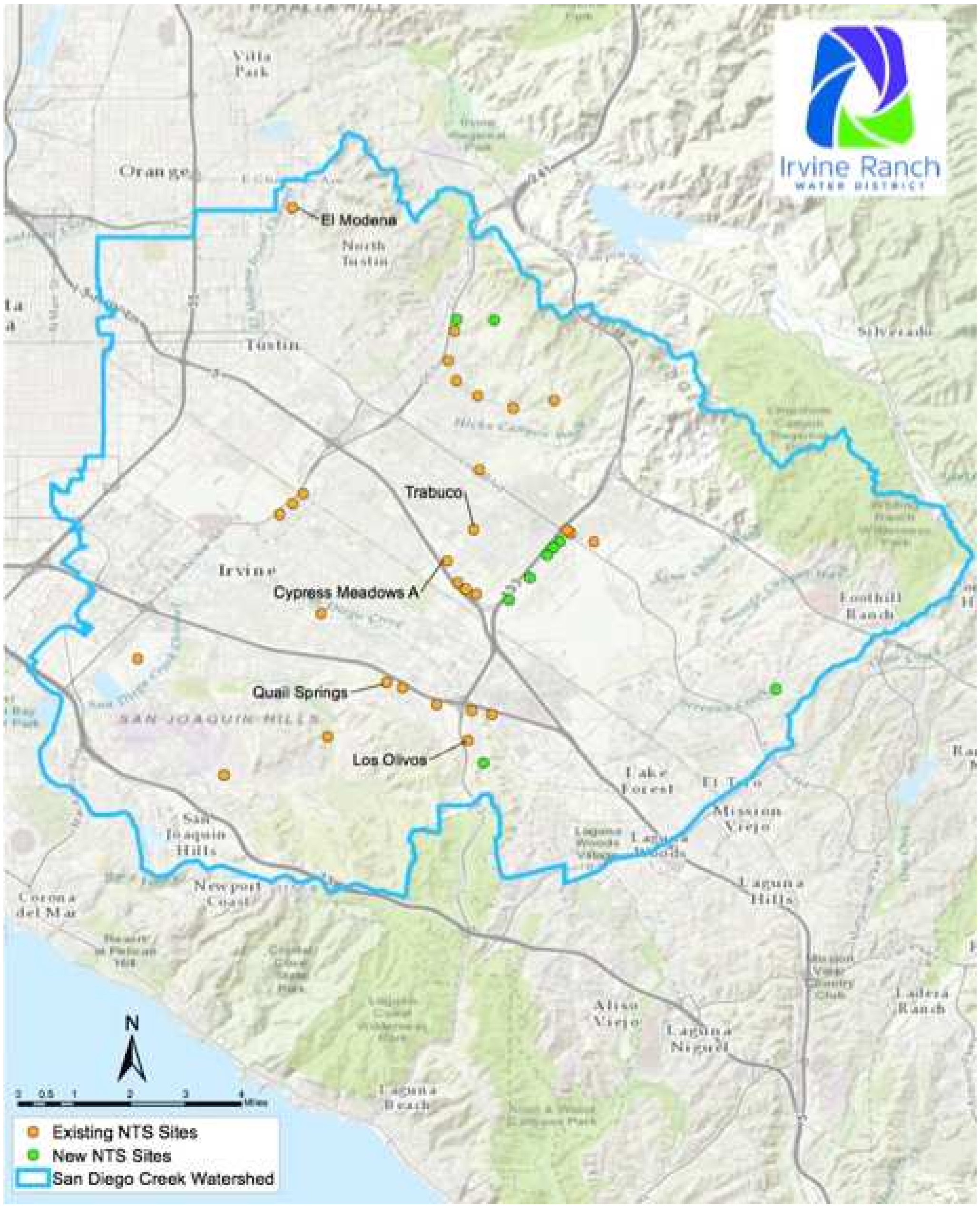


Figure 11. IRWD Active and New NTS Sites

4.1 Cypress Meadows A

Figure 12. Cypress Meadows A Watershed

Figure 13. Cypress Meadows A Zoning

Figure 14. Cypress Meadows A Land Use

4.1.1 Background

Table 6. Cypress Meadows A Profile

Location	Drainage size (acres)	Type of Wetland	Year online	Inlet (land use)	Outlet	Facility Status
Irvine	275.13	I	2013	Residential, parks, sports fields, commercial	Caltrans Channel	New

Land Use

Cypress Meadows A is located in Irvine's Planning Area 40 (PA 40). PA 40 is 571 acres and divided into two major watersheds: East and West. The two combined drain from Trabuco road in the North, Jeffrey Road in the West, I-5 in the South, and SR-133 Toll Road in the East. PA 40 was originally agricultural land, but was converted to a mixture of single-family residential, multi-family residential, schools, parks, and commercial uses (Figure 13,Figure 14 Templeton Planning Group, 2008). This means the site went from almost 0 percent impervious to 70 percent impervious with full build-out of Planning Area 40. Both Cypress Meadows A and Trabuco Retarding Basin, discussed later, are located within PA 40 West Watershed. These two systems drain to the Caltrans Channel ("Freeway Drain") and ultimately to Peters Canyon Wash.

The zoning density of the surrounding area is primarily Medium-High Density Residential and Medium-Density Residential. The area draining into the NTS site is a mixture of rentals and owner occupied. The drainage basin also includes an elementary school, middle school, parks, and sports fields.

The total acreage of the drainage basin is 275.13 acres with 54.78 acres as park and green spaces according to the City of Irvine General Plan Land Use Map (City of Irvine, 2016). This is approximately 19.91 percent of the catchment basin for the area. The residential condominiums, apartments, and high-density residential are 105.83 acres of the total area that drains into Cypress Meadows A site. Of the residential portion, 67.38 percent is apartment rentals and the remaining 32.62 percent are medium to high density condominiums or townhomes (Figure 15).

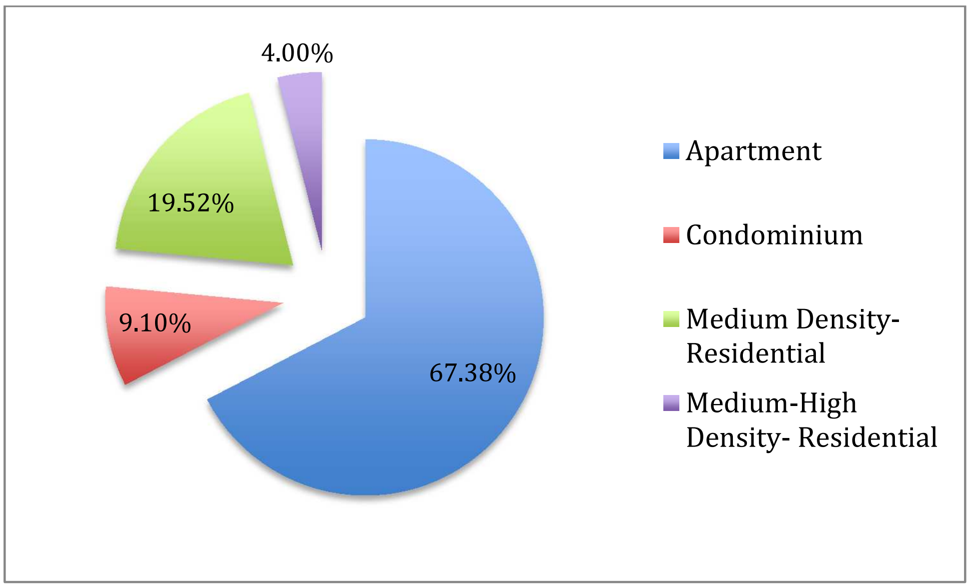


Figure 15. Cypress Meadows A Housing

Characteristics

This site is part of the Cypresses, which include Cypress Meadow A, Cypress Meadow B, Cypress Meadow C, and Cypress Meadow D. The largest of the four, Cypress A, has a drainage area of 275.13 acres. This area covers an almost square shape from the I-5 to Jeffery Road to Trabuco

Road to future development on Tulip Road. The site is located in Planning Area 40 in the City of Irvine and the Natural Treatment System (NTS) was proposed for the entire planning area.

The site lies in the northern portion of the Tustin Plain and has quaternary-age alluvium deposits at depths of over 100 feet. According to the Orange County Hydrology Manual Soil Map, the soil is classified as Group B (Geosyntec, 2007). These soil groups have moderate infiltration rates when wet, and consist of moderately deep to deep, moderately well to well drained sandy-loam soils with moderately fine to moderately coarse textures.

In 2010, this site was identified as a BMP that would be used on-site to control predicable pollutant runoff. According to Murano Apartment's WQMP the basin would accept dry weather flows and low storm water flows form the larger developments and discharge treated runoff to the Caltrans Channel Drain (Fuscoe Engineering, 2010). Cypress A is a Type 1 facility, meaning off-line. The site has three inlets, 100, 101, and 102, and one outlet pipe.

Water Quality Metrics

Between January 2014 and August 2016, Cypress A has approximately 170 gpm coming in from Inlet 100, 408.5 gpm from 101, and 430 gpm from 102 for a total of 984.6 gpm from the three inlets. The site's outlet pipe had a flow rate of 820.9 over the two-and-a-half year period. As seen in Appendix E, the flows fluctuate throughout the year with slightly higher rates during the summer months. According to the WQMP for Cypress Meadows A the existing concentration of Total Nitrogen was around 21 mg/L which is still approximately the amount in the combined three inlet calculations, however the amount at the outlet has effectively brought the contaminant down to near zero.

4.2 El Modena

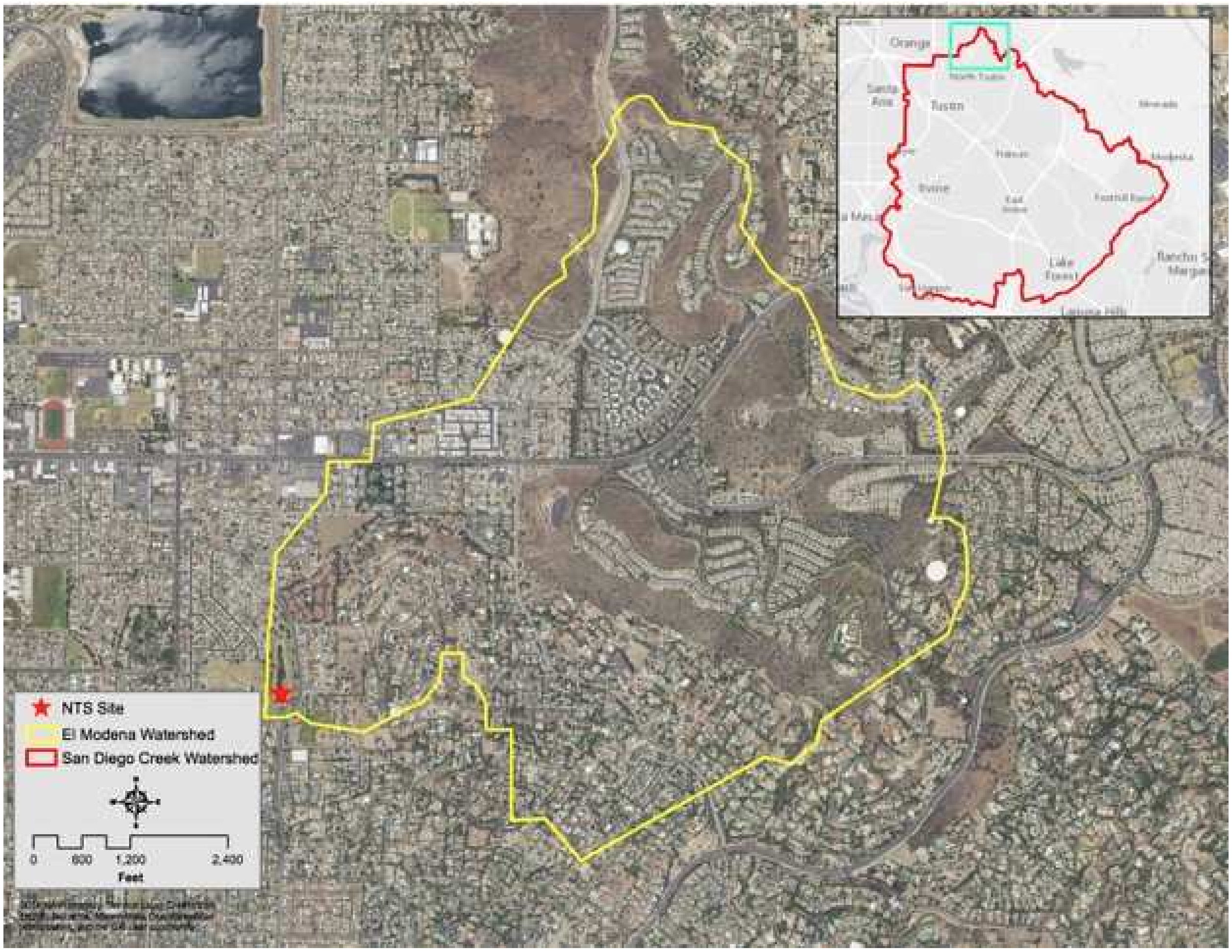


Figure 16. El Modena Watershed

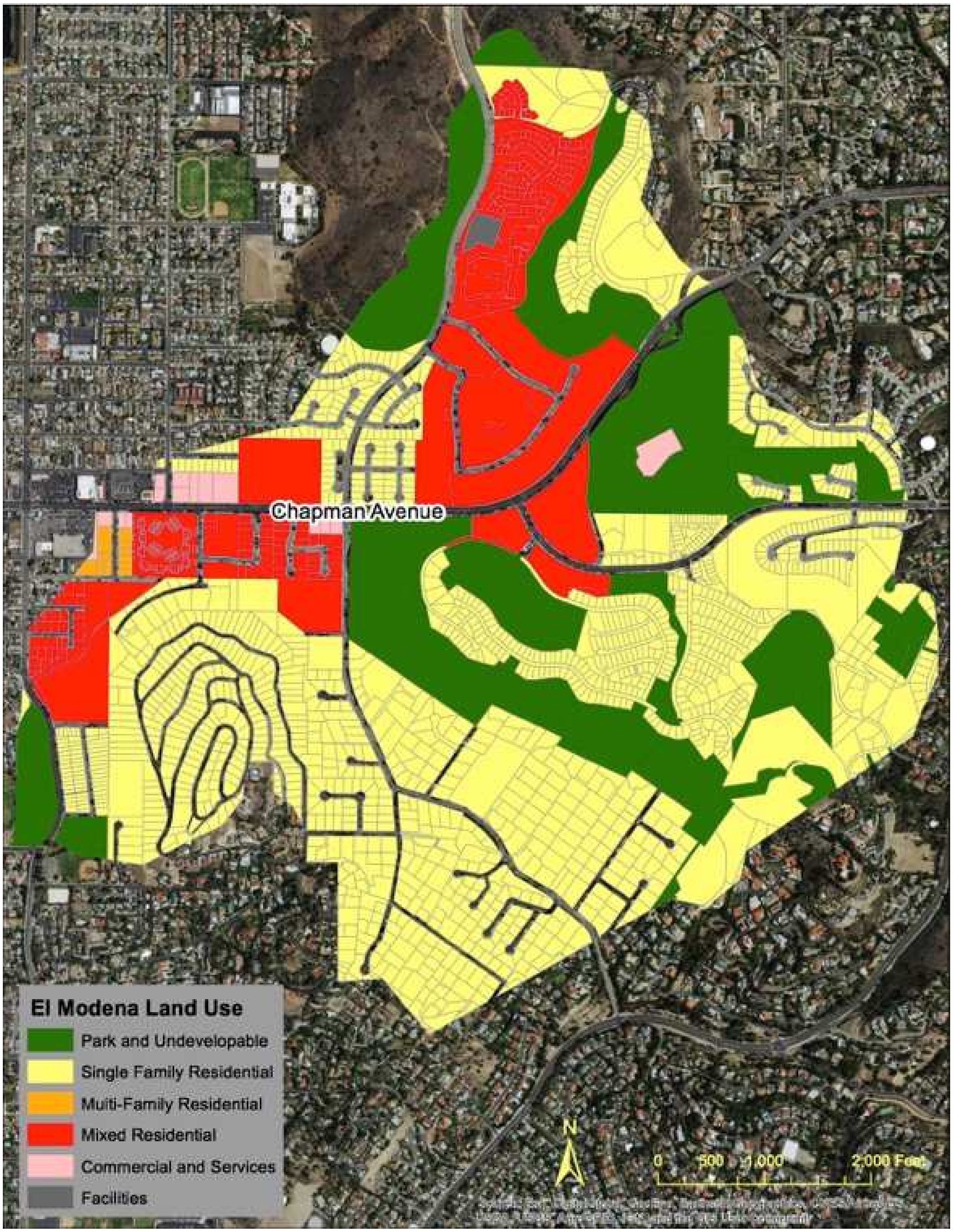


Figure 17. El Modena Land Use

4.2.1 Background

Table 7. El Modena Profile

Location	Drainage size (acres)	Type of Wetland	Year online	Inlet	Outlet	Facility Status
Orange	1125.37	I	2008	El Modena-Irvine Channel	El Modena-Irvine Channel	Retrofit to existing

Land Use

El Modena Detention Basin (El Modena) is located in El Modena Park in the City of Orange. The park is approximately 9.5-acres and is bordered by El Modena-Irvine (EMI) Channel, two parcels of land owned by Orange County School District, and by Hewes and Jordan Avenues on the east and south sides respectively (Figure 16). The drainage area is approximately 1125 acres of residential and foothill areas northeast of the public park. The NTS was originally designed and constructed in the early 1970s as a retarding basin for peak flows from the EMI Channel during large storm events (VA Consulting, 2008).

The basin is approximately 1.5 acres, with the emergent plant marsh area 0.6 acres and the open water 0.9 acres. The NTS site has an open water storage volume of 6.3 acre feet, for an average water depth of six feet (VA Consulting, 2008).

El Modena is considered a Type I- within existing facility. The Basin is owned and operated by the Orange County Flood Control District (OCFCD) and is primarily designed to reduce peak flows in the El Modena Channel north of the site.

El Modena NTS site is primarily surrounded by single-family residential, except for an elementary school on the western portion (Figure 17). The drainage area is primarily residential housing with single-family almost 77 percent of the housing makeup (Figure 18).

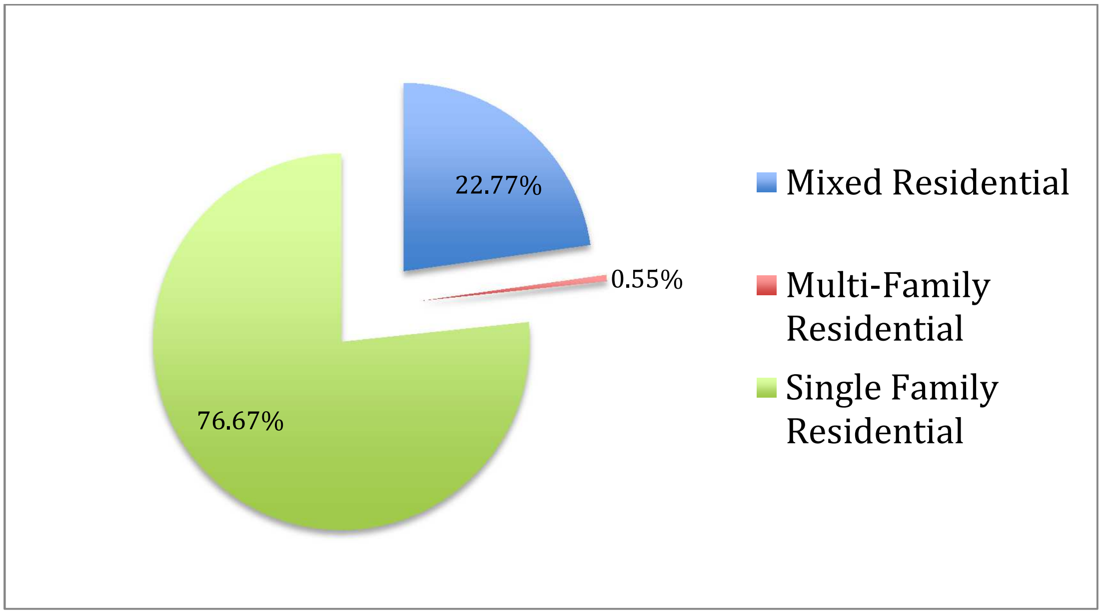


Figure 18. El Modena Housing

Characteristics

El Modena NTS site is designed to have a total footprint of 2.6 acres. The average dry inflow is approximately 100 gpm and wet season inflow is also 100 gpm. The residence time in dry flow is between 10-12 days, and refill time is approximately 43 hours. The site has one inlet on the north side of the site, an outlet on the south side, and an emergency spillway approximately ten feet above the base of the outlet structure. The outlet and emergency spillway send water back to the EMI flood control channel. El Modena is unique in that it does not automatically flow out of the site, instead it waits till water reaches a certain level and the lift station's pumps start.

The surrounding park area has been covered with Marathon II grass, Sycamore trees, picnic tables, benches, and an informational sign about the NTS site. The construction of El Modena in the early 1970s had a production construction cost total of $563,875 with operation and maintenance estimated to be $35,090 annually.

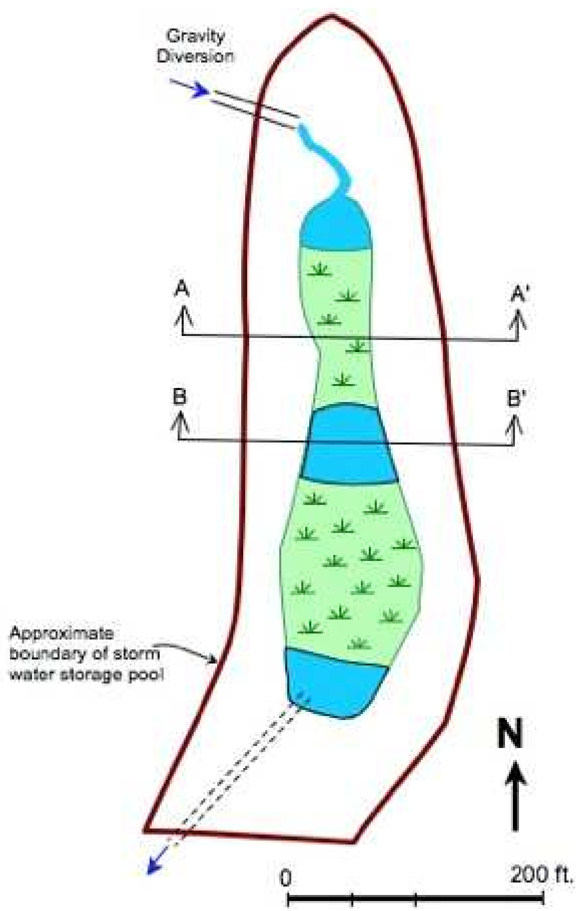


Figure 19. Design of El Modena

4.3 Los Olivos

Figure 20. Los Olivos Watershed

Figure 21. Los Olivos Land Use

Figure 22. Los Olivos Zoning

4.3.1 Background

Table 8. Los Olivos Profile

Location	Drainage Area (acres)	Type of Wetland	Year online	Inlet	Outlet	Facility Status
Irvine	110.36	I	2014	Residentia l	San Diego Creek	New

Land Use

Los Olivos NTS site is located off Irvine Center Drive and I-405 in Planning Area 39 in south Irvine near the Irvine Spectrum (Figure 20). PA 39 is approximately 352 acres and is split into Phase 1, 191-acres, which has been constructed, and Phase 2, 161-acres (RBF Consulting, 2012). The NTS site is located at the most northern portion of Phase 1 next to the San Diego Creek and I-405. Phase 1 has approximately 110 acres of the 191-acre property developed, 58 percent, with medium high-density multi-family residential, commercial center, trails and parks (Figure 21, Figure 22). Phase 2 plans for 73 percent developed but will include a second NTS site (RBF Consulting, 2012). Phase 2 also includes medium-high density residential, park and a school. The two phases combined are approximately 3,700 homes. The NTS site was constructed in 2012 and operational in 2014.

To the west of the properties are canyons and hillsides of Laguna Hills. Phase 1 of PA 39 was 100 percent vegetated area before development, and currently is approximately 25 percent landscaped area. Adjacent to the NTS site is the San Diego Creek, which is a protected riparian and wetland area. San Diego Creek Trail provides bike and walking trails along the creek.

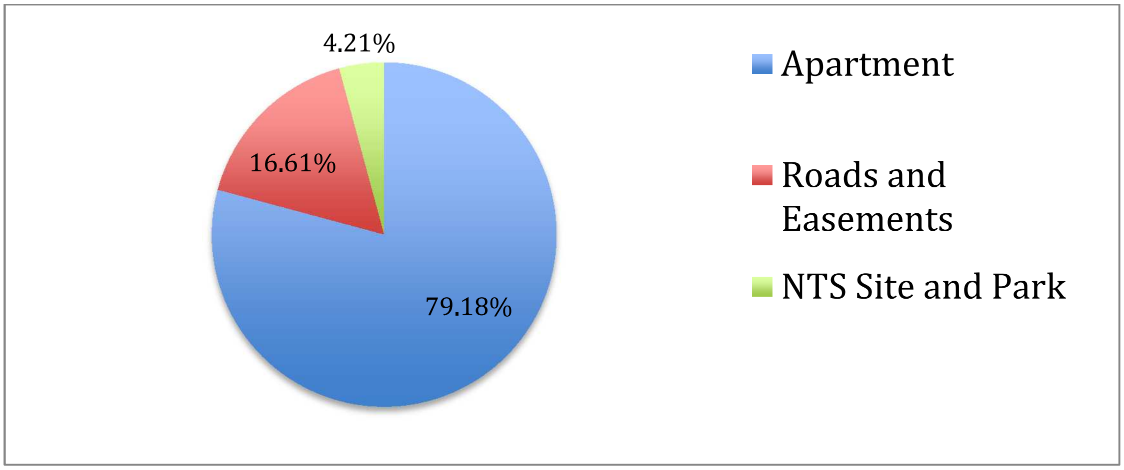


Figure 23. Los Olivos Land Use Percentages

Characteristics

Los Olivos NTS basin is intended to treat small storm and first flush runoff, and dry and wet weather season low flow. The basin and shallow water channel is lined with a geotextile filter fabric, gravel bedding, and riprap gradation. The NTS site receives drainage from roof drains associated with buildings in the area and surface flow from paved areas through main line storm drains using manhole diversion type structures. The NTS site flows to San Diego Creek Channel, Reach 1, and into the Upper and Lower Newport Bays. According to the O&M manual for the site, the open water wetland is expected to receive sufficient flows to sustain wetland plants (RBF Consulting, 2012).

According to the O&M Manual created for the site, Los Olivos NTS has an anticipated dry season flow of 2.43 gpm and a residence time ranging from 11.6 days to 29.1 days depending on the weirboard heights (1 foot to 2 foot respectively) (RBF Consulting, 2012). The marsh area with emergent plants is around 1.4 acres and the surface water area is 0.23 acres.

The WQMP for the site includes eight educational materials ranging from guidelines for pest control, car wash fundraisers, using concrete and mortar, and paint; proper maintenance practices for businesses, sewage spill responsibilities for private homeowners, and better landscape and gardening practices to prevent ocean pollution (Stantec, 2008).

The NTS site has two inlets one on the south site of the basin and the other on the north near the I-405 freeway. The inlets lead to a channel that flows into a basin on the north side of the site. Los Olivos has one outlet located on the west side near the bike path that continues under the I-405 freeway.

Wildlife and Vegetation

The vegetation for the site is divided into three locations: wetland vegetation, shallow water vegetation, and vegetation between shallow water and high water line. The wetland vegetation includes cattails and bulrush. In the landscape plan, there were plans for 60 trees surrounding the basin: 26 California Sycamores, 18 Fremont Cottonwood, and 16 Coast Live Oak.

In PA 39 biologists found nesting birds Passerine and Raptors, which require a 50-foot buffer and no construction during nesting season, respectively. The NTS site itself has bird-nesting boxes for Tree Swallows, House Wrens, and Bluebirds that are monitored during nesting season by IRWD staff.

Water Quality Metrics

As Phase 1 of PA 39 is more than 10 residential units it requires analysis of pollutants of concern. According to the Los Olivos WQMP it found heavy metals, nutrients, pesticides, organic compounds, sediments, trash and debris, and oil and grease to be anticipated and bacteria/virus, nutrients, pesticides, and oxygen-demanding substances to be potential. Appendix E has additional information.

4.4 Quail Springs

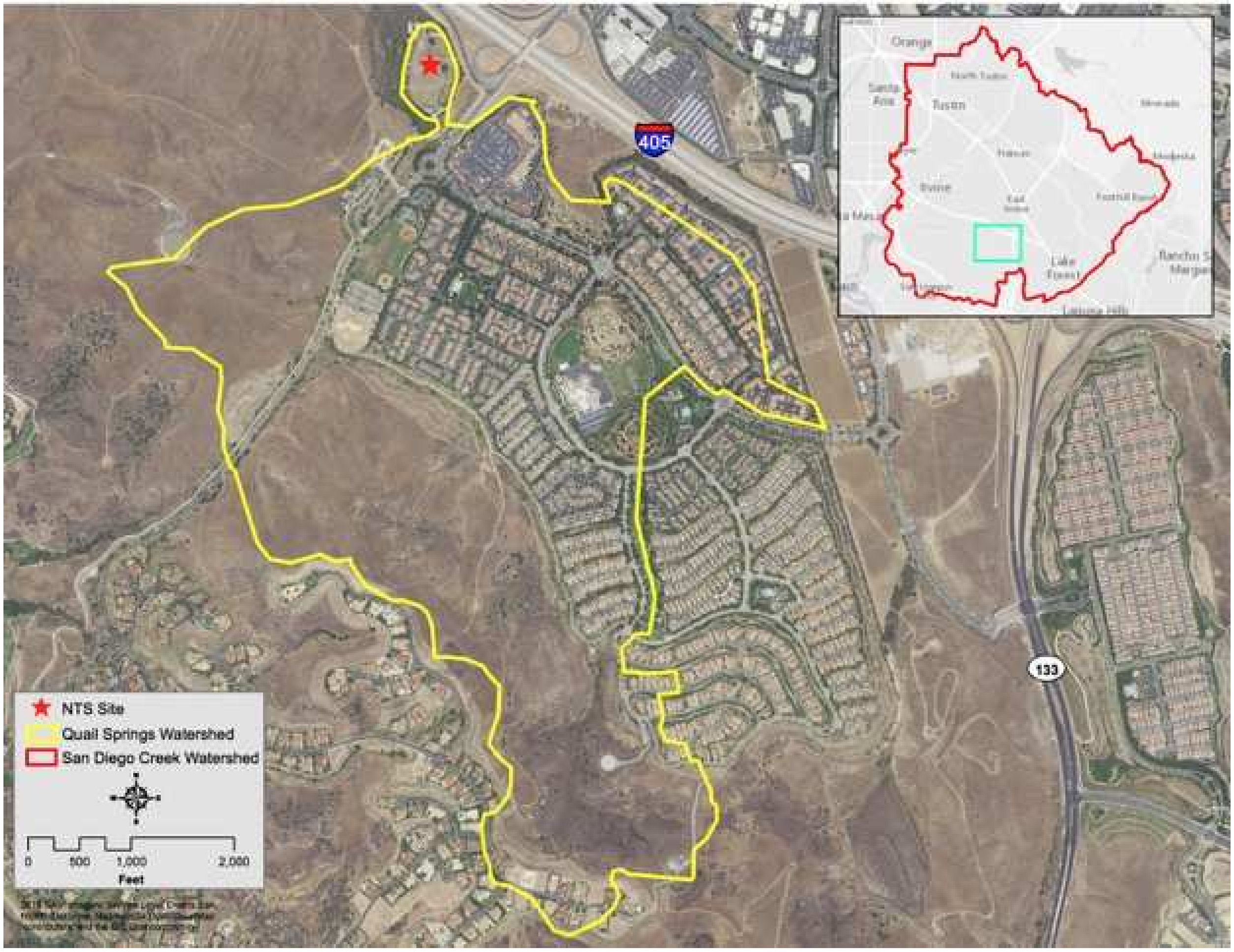


Figure 24. Quail Springs Watershed

Figure 25. Quail Springs Land Use

Figure 26. Quail Springs Zoning

4.4.1 Background

Table 9. Quail Springs Profile

Location	Drainage size	Type of Wetland	Year online	Inlet	Outlet	Facility Status
Irvine	543	I	2006	Residential, commercial, open space from Quail Hill development area	San Joaquin Channel	New

Land Use

Quail Springs NTS site is located in Irvine's Planning Area 17 in Quail Hill. PA 17 has three NTS sites: West Basin (Quail Springs), P10 Basin (Quail Meadow) and East Basin (Old Laguna). The site focused on in this section is Quail Springs because of its unique location in City of Irvine open space. Quail Springs is between the I-405 freeway, Shady Canyon Avenue and Quail Hill trail area (Figure 24). The watershed area is primarily multi-family residential, commercial, and open space (Figure 25,Figure 26).

Characteristics

The watershed area is approximately 543 acres but during low flows approximately 48 percent of the area, 262 acres, are diverted to an existing wetland facility located west and adjacent to Quail Springs NTS site and the remaining 281 acres (51 percent) flow through the site.

Quail Springs is designed as a flow-through type facility meaning it is intended to manage flood flows and treat both wet season low flows and dry season flows. The West Basin spillway flows into the existing wetlands, then to the San Joaquin Channel, Orange County Flood Control District open channel Facility No. F-14, then the Pacific Ocean via the San Diego Creek.

The site has one inlet with a gabion structure to slow down heavy inlet flows, one outlet, and an emergency spillway. After the inlet there are two separate channels that each have two basins that meet at the outlet structure.

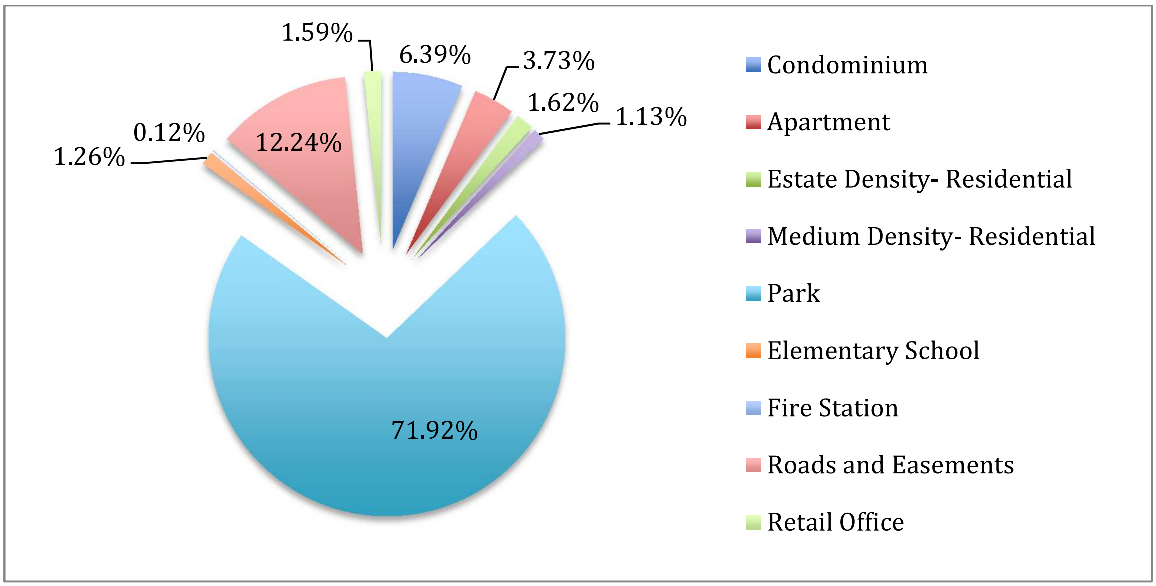


Figure 27. Quail Springs Land Use Percentages

Wildlife and Vegetation

The plants included in the landscape plans are Rose Gum, Manna Gum, Wite Ironbark, Aleppo Pine, Afghan Pine, California Sycamore, Lodon Plan Tree, Western Cottonwood, and Brisbane box. Shrubs and groundcover vegetation includes Toyon, Lemonade Berry, Gooding's Willow, Arroyo Willow, and Mexican Elderberry. The site has 17 bird boxes for nesting house wrens, tree swallows, and bluebirds.

Water Quality Metrics

The average dry season inflow for Quail Springs is around 4.49 gpm and in the wet season this will increase to 22.44 gpm. The average residence time for the site is 10 days. The wetland area with emergent plants is 0.48 acres and the open water 0.12 acres. The site has an open water storage volume of 0.72 acre-feet with an average depth of six feet. For a storm event, the site has available storage volume of 49.3 acre-feet with a depth of 4 to 11 feet. Appendix E provides more detailed graphs.

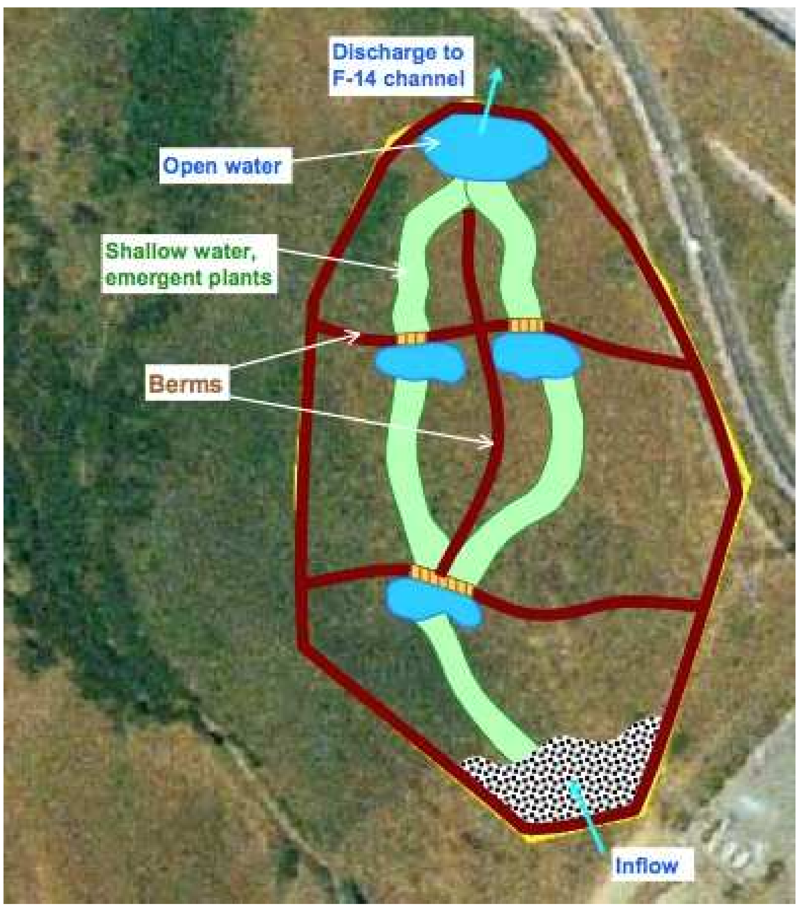


Figure 28. Aerial Photograph and Conceptual Layout

4.5 Trabuco Retarding Basin

Figure 29. Trabuco Watershed

Figure 30. Trabuco Land Use

Figure 31. Trabuco Zoning

4.5.1 Background

Table 10. Trabuco Retarding Basin Profile

Location	Drainage size (acres)	Type of Wetland	Year online	Inlet	Outlet	Facility Status
Irvine	19,621	III	2008	Residential, parks, commercial	Central-Irvine Channel (Trabuco Road Channel to Peters Canyon	Retrofit to Existing

Land Use

Like Cypress Meadows A, Trabuco is located within Planning Area 40 and receives waters from apartments, condominiums, variety of residential, parks, commercial centers, and schools (Figure 30,Figure 31). Trabuco Retarding Basin (Trabuco) is located off Trabuco Avenue and Jeffery Avenue in central Irvine (Figure 29). The entire watershed is 19,621 acres. A majority, 77.4 percent, is housing.

Table 11. Trabuco Land Use Percentages

Land Use	Acres	Percentage
Park	2804.423832	14.29%
Roads and Easements	1528.637885	7.79%
Apartment	156.9655609	1.34%
Condominium	263.3931599	1.34%
Estate Density- Residential	8.53932064	0.04%
Low Density- Residential	287.5307815	1.47%
Medium Density- Residential	14469.95466	73.75%
Medium-High Density- Residential	3.38485938	0.02%
Retail Office	44.24436859	0.23%
Community Commercial	7.74890652	0.04%
Private School	16.5408742	0.08%
Elementary School	30.16619796	0.15%
Total	19621.53041	

Characteristics

Trabuco is a Type III-Within Existing Facility and currently operated and maintained by the Orange County Flood Control District (OCFD) as a regional flood control facility (RBF Consulting, 2010). The site includes three inlets that have been designed to collect the 100-year runoff from tributary areas (RBF Consulting, 2010). The constructed wetland treating dry weather low flows would be integrated into the basin according to preliminary designs. Like El Modena, Trabuco is also a retrofit to existing instead of new construction. All modifications of Trabuco require approval from the California State Division of Safety of Dams and the OCFCD prior to construction.

Trabuco has three inlets at the north, south, and east corners, one outlet in the west corner that drains to the Caltrans Channel under the I-5 freeway, and an emergency spillway (RBF Consulting, 2010). According to Planning Area 40 Environmental Impact Report a portion of the existing drainage area from the area will be routed to Trabuco as PDF-SH-1 (Templeton, 2008). This existing trunk storm drain pipe system located in Trabuco Road is designed and built to convey the proposed discharges from a portion of PA 40. The Basin was modified to attenuate the flow from increased drainage areas and land use changes, to provide additional water quality benefits to the watershed. These changes mean the drainage area tributary to the existing Caltrans Channel will be less than the current flows into the Caltrans Channel, thus reducing the impact of the developed flow rates to the channel.

Wildlife and Vegetation

Trabuco is intended as a recreation area along the rim as it connects to nearby parks and other trails. The preliminary site design includes a conceptual habitat enhancement plan, which would "encourage use by and increase the long-term conservation values for the tricolored blackbird" (Appendix B of San Diego Creek NTS Master Plan, June 2004). The tricolored blackbird (*Agelaius tricolor*) is non-migratory bird that lives in freshwater marshes among dense stands of cattails or bulrushes.[4] These birds are considered climate threatened, and have declined in numbers in recent decades because of loss of habitat primarily because the tricolored blackbird nests in dense colonies, which makes it more vulnerable. This nomadic species forages in grasslands and scrub habitat adjacent and up to five kilometers from their nesting and breeding areas (Appendix B of San Diego Creek NTS Master Plan, June 2004). This means the conceptual habitat enhancement plan for Trabuco includes annual grassland/scrub with native and non-native annual grass species with coastal sage scrub species typically found in the area, grassland element with native and non-native annual grasses, and woodland/scrub with Mexican Elderberry, Coast Live Oak, Sagebrush, Coast Goldenbush, and Buckwheat as well as others (Appendix B of San Diego Creek NTS Master Plan, June 2004). Figure 32 shows the preliminary Conceptual Layout and Habitat Enhancement Plan for Trabuco.

Cost

The construction of Trabuco Retarding Basin had a construction cost total of $1,557,468 with operation and maintenance estimated to be $34,944 annually (Geosyntec, 2004- Appendix C).

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[4] Audubon, "Guide to North American Birds: Tricolored Blackbird." http://www.audubon.org/field-guide/bird/tricolored-blackbird

According to the San Diego Creek NTS Master Plan Appendix B, maintenance includes sediment and trash removal near inlet, vegetation removal near inlets and outlets, replanting during wetland establishment, removal of invasive plant species (2004).

Water Quality Metrics

The average dry season inflow is around 35.46 gpm and average wet season around 80.79 gpm. The wetland residence time is 10 days. The Basin flood volume is 390 acre-feet, water quality storage volume 81 acre-feet, and storage area of 24.2 acres at the crest. Water quality treatment volume provided by Trabuco basin approximately 6.9 acre-feet including a 10 percent sediment allowance and the expected runoff is closer to 4.2 acre-feet for the North Drainage Area (RBF Consulting, 2010).

Trabuco is estimated to infiltrate and/or evapotranspire 15 percent of the inflow to extended detention basins and 20 percent of inflow to biofilters. The site is designed to have a permanent pool during wet seasons and extended detention storage above the permanent pool. Trabuco includes bypass flows for when heavy flows need to allow bypass of the facilities.

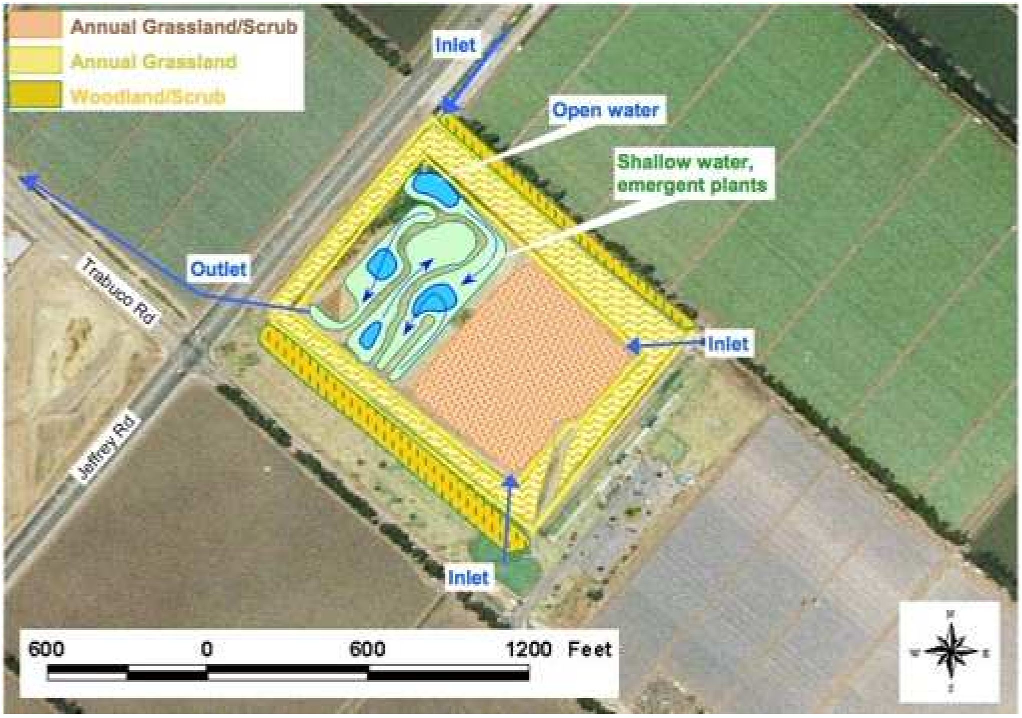

Figure 32. Aerial and Conceptual Layout of Trabuco

5 Comparison of Site Characteristics

The five sites examined in this research provide an interesting snapshot of the variety of locations, functions, neighboring land uses and types of community engagement than can exist. Looking at

Table 12 we see that Quail Springs is the only site that has a majority of the land use draining into is as Park and Open Space, the other four sites are primarily housing or other, which consists of roads and easements.

Table 12. NTS Sites and Land Use

Site	Drainage Size	Park	% Pervious	Housing	% Housing	Other	% Other
Cypress A	275.13	54.78	19.9%	105.83	38.47%	113.86	41.38%
El Modena	1125.37	388.01	34.5%	708.11	62.92%	29.26	2.60%
Los Olivos	110.36	4.64	4.2%	87.39	79.19%	18.33	16.61%
Quail Springs	1047.23	753.18	71.9%	134.83	12.87%	159.21	15.20%
Trabuco	19,621.53	2804.42	14.3%	15189.77	77.41%	98.70	0.50%

The four Irvine sites, Cypress A, Los Olivos, Quail Springs and Trabuco, all have medium-high and high density residential surrounding the NTS sites. El Modena, located in Orange, has significantly more single-family housing compared to higher density housing.

From the water quality data in Appendix E, we see that all the sites are performing well in the main indicators examined. We looked at flows, both monthly and annual averages, total nitrogen, lead, fecal coliform, and pH at all the sites. While there were exceptions, El Modena in the last few months having higher lead concentration in the outlet compared to the inlet.

From a design standpoint, El Modena is the only NTS site studied that is designed as a park with a constructed wetland as an additional benefit. The other four sites located in Irvine have a fence separating the site from the public or are a green feature alongside a bike or running trail. The access to the site creates a different type of facility that allows for more engagement and involvement by the public. A constructed wetland designed like El Modena with park benches, barbecue pits, and picnic tables allow visitors to spend more time at the basin and therefore appreciate it more.

Table 13. Observations at Three NTS Sites

NTS Site	Location	Number of visitors	Race			Gender		Age		Activity					Talk with me
			White	Asian	Hispanic	M	F	0-40	40+	Walk	Bike	Run	Sit	Other	
Cypress A	Irvine	18	5	5	2	7	10	11	7	5	12	1			1
El Modena	Orange	15	7		8	8	7	3	12	7			6	1	6
Los Olivos	Irvine	26	17	9		19	7	20	6	10	9	7			1

For the observations, only three sites were chosen: Cypress Meadows A, El Modena and Los Olivos. All three have more active parks and trails, and therefore see more activity. Table 13 shows the results of the observations conducted on 4-5 separate occasions at each of the sites. They were conducted on various days and times, usually as an IRWD employee. While the number of participants observed is relatively small, it still provides an interesting analysis. At the two sites with trails connecting to larger City bike trails, we see active movement with joggers, cyclists, and those walking with strollers or dogs. Cypress A and Los Olivos do not have picnic tables in the vicinity of the site or benches, which inhibits visitors from sitting and engaging with the site. El Modena on the other hand has six picnic tables and multiple benches that visitors can sit at and enjoy the park. This difference in location relative to the surrounding community is the primary reason for the different types of activity at the sites. I also noticed at Cypress A and Los

Olivos there were significantly more children and young adults commuting to work on bicycles. El Modena had primarily older adults with dogs.

El Modena, is located in an Orange County city with lower median incomes, however we see the most engagement with the site compared to the other two sites located in Irvine. Neighbors at El Modena actively engage with the site by calling in to complain, talking to IRWD employees when completing weekly monitoring, and feeding and taking care of the wildlife. While there were lower numbers of visitors at El Modena, they stayed longer and were more connected to the site. At the other two sites, I was approached twice for clarification on the purpose of various parts of the site or for species of birds that are frequently visiting the wetland.

While the observations were limited in number, they show a glimpse of the type of people and activity types that are happening at three very different constructed wetland sites in IRWD's service area.

6 Interview Analysis

The purpose of the interviews were to have discussions with those implementing, designing, and engaging with the constructed wetlands. The interviews lasted between 30-60 minutes. They were focused primarily on what the interviewee thought were benefits, challenges, future of the sites, and how the public viewed the sites. Through these interviews I was able to hear various perspectives from individuals with different backgrounds.

I completed nine interviews: three private sector, five public sector, and one environmental advocate. Within the public sector there were those working at city or county agencies. The individuals came from a variety of backgrounds in research, engineering, geology, law, architecture, and hydrology.

Seven of the interviewees were moderate intensity, with levelheaded answers and academic toned. Two interviewees had more of a lecturing or educating tone, with raised voiced at times and profanities. Six of the nine interviewed were male and all in moderate to higher-level positions at their respective agencies.

Challenges in Water in California

When asked about the major challenges in water in California, answers that came up multiple times were: challenges in regulatory requirements from the state, drought, cost of regulations, mismanagement, supply, over-pumping of aquifers. Less common answers were the lack of water, transparency for water agencies, pricing water, and inappropriate farming of alfalfa in the desert. One individual answered the greatest challenge was “ensuring reliability at reasonable cost," because all of the low hanging fruit is gone and water is still being used relatively carelessly.

Multiple experts brought up the past of grey infrastructure and how water was treated as a nuisance and how we wanted to move water quickly away from people through stormdrains to the ocean. As one interviewee said: "How do we come back from bad planning and design in the 1960s and 70s, due to a lack of understanding, and how do we mitigate that problem". This idea of poor water infrastructure planning is related to the broader problem of stormwater management.

According to the nine interviewees the biggest challenges to water in California are regulations and supply.

Droughts impact on water sensitive urban design

Three respondents said the drought brought attention to water and made people more accepting of water sensitive design. Four interviewees brought up drought tolerant landscaping and having demonstration gardens to begin conversations and teach neighbors about water. However, since the drought ended, one interviewee commented that people are overwatering again.

While the drought brought attention to water, the trend had been going in the direction of more low impact development in cities. According to three interviewees, how the permits were written and the water quality management requirements for new development had been around since 2009. These new requirements were already pushing for more LID.

Benefits of Constructed Wetlands

While all interviewees brought up water quality and pollutant removal as a benefit of constructed wetlands, not all mentioned it first. Other water benefits mentioned included water supply (specifically for groundwater recharge), flood control, infiltration, cheaper to clean the water, and trash removal.

Other benefits not related to water were aesthetic, public resource for walking and trails, habitat for wildlife, and economic benefits. Three interviewees mentioned social behavior, and were less focused on the functionality of the NTS site at mitigating runoff but more interested in the other benefits. Two mentioned the comfort and enjoyment people feel in green spaces or the increase in land value surrounding natural environments (five mentioned).

One interviewee said there were no benefits that an engineered proprietary system could not achieve. He mentioned modular wetlands and Filtera, which for a few ten thousand dollars can "plop right in and does all the same water quality benefits without the messiness." When asked what was considered "messy" he mentioned the vegetation and wildlife that must be constantly maintained and monitored.

While one interviewee saw little benefits to constructed wetlands, another summed it up nicely: "you're building on this triple bottom line: the economic benefits, environmental benefits, and the social benefits. Because everyone can take something from this." This concept of sustainability and a space that can have multiple benefits is one of the major draws to this type of larger-scale green infrastructure.

Challenges of Constructed Wetlands

Every respondent mentioned operation and maintenance as the biggest challenge that constructed wetlands face. Some elaborated and added the difficulty with who maintains the sites and if they are educated on proper maintenance. Related to operation and maintenance was cost, especially land cost. Other challenges that were mentioned were vector control, such as mosquitos and rodents, invasive plant species, and the smell if there is no aeration. Two of the interviewees mentioned the MS4 permit, which leads to more regulations and therefore costs.

One interviewee summarized: time, space and money were the challenges. This includes getting them back to where they need to be, finding land, and funding.

Future of Constructed Wetlands

In general most interviewees felt positively about constructed wetlands and that they would continue to be built in the future. However, they did acknowledge the challenges such as land, soils ability to filter, and developer’s willingness to build. Some interviewees said we were becoming more interactive with our water space and are able to see changes in how water is handled. Constructed wetlands are living machines that can help us treat the water we use. They are going to stay but we will use them differently, to create biophilia or a sense of connection with nature through walkways, bridges and places to sit.

But the majority of interviewees were positive about the future of green infrastructure and said "now that requirements and money is committed, that's going to drive new solutions." As was mentioned a few times, regulation requires these types of systems to be constructed to mitigate runoff and therefore they will continue to be built.

Three of the respondents said there was no need to build many more: that proprietary systems can be used instead and be placed under a plaza or street and the water quality benefits remain or that there are sufficient constructed wetlands currently built to handle the runoff in Irvine.

How do you think public views sites?

When I posed this question, majority of my interviewees hesitated and answered that they did no know what the public felt or thought but could make assumptions. However, some answered with more force than others.

The consensus was that the public perceives these sites as a net positive and that they appreciate open space. However, four interviewees also emphasized that the public most likely does not understand the primary purpose of these sites and only is aware of the secondary benefits. As most of the interviewees live in Irvine, they have seen the NTS sites and remarked on the relatively good signage and pathways, which also serves as a tool for education. Social interactions with sites are important for people to see them as benefits. "They love them and like to experience them, but they do not understand them as a treatment system. Instead they see them as a feature and that is probably a big loss because if people understood what they are doing they would probably act differently." Overall, the sites are seen as creating more natural environment in the urban landscape, and less cookie cutter development.

One expert said: "you'd be surprised that the public doesn't know that stormwater is not treated. That when it rains that water is hitting the pavement and its going tot the nearest body of water." Another said he wished the public knew that the cities are looking out to protect the surface waters and these are their attempts in fulfilling regulatory requirements. One public agency spends $0.5 million every year for public education on water conservation and nutrient fertilizer and pesticide management. It becomes apparent that these public agencies and city officials all perceive their residents as having little knowledge about water and water infrastructure.

Who drives local water policy?

Every interviewee said the State was the main driver of urban water policy.

While some interviewees mentioned in individual pockets city governments may drive local water policy, typically mandates are made by the state and city officials have to figure out how to implement it. The State has the option to give more flexibility to local governments, but we are seeing again and again that stormwater discharge permits are getting more prescriptive. This creates tensions between the federal and state regulations and governments. The tension can be good because it can instigate change, yet it is also challenging. Every four to five years there is a revision to the stormwater permit, and depending on what is in there it can definitely drive our policies.

However, half of the interviewees remarked on the role of developers and how “money can make a lot of things happen”. Majority also mentioned that IRWD was unique in that they were set up well financially and therefore could afford to be more innovative in solutions. Three interviewees said it was a really good agency and well respected.

Conclusion

Multiple interviewees said the purpose of constructed wetlands was to return an area to its previous water state. One interviewee mentioned a case in Owen’s Valley where a wetland vanished and came back with native plants and animals. Another said it was either previously waterways being replenished with soil and plant life to come back as a natural occurring water source or an area that did not previously have water but is being developed in a water space for animal and plant life to flourish. While these examples are not specifically constructed wetlands, the experts’ perception of this is important for future development.

Many of the conversations focused on sustainability and being resilient for the future: “we live in a large area and when they [Los Angeles] are resilient we are resilient. So building resilience globally is important.”

7 Why Findings Important

As cities become more innovative with water sensitive urban designs, we need to evaluate not only effectiveness of the LID technologies but what residents and stakeholders perceive of these constructed wetlands. In continuing to build LID we must understand how the public engages and understands the engineered systems. Through this added knowledge we can design differently and create policies to allow these sites to be more successful and educational. These sites have many benefits, but also challenges. The construction and operation is costly, and the sites must constantly be cleaned and monitored. By understanding how people view these LID technologies we can better evaluate if these are a beneficial use of valuable urban land.

As one interviewee pointed out, there are three approaches to managing water quality: regulatory, science, and technology, NTS sites are at the center of all three. By following cities MS4 permits, using engineered systems and understanding water quality parameters we can create more effective systems. In conducting this research, people asked my why we should care about public perception about constructed wetlands as they can function effectively without the public's knowledge. Understanding public perception is important because the decision-makers and city officials must have public acceptance to continue implementing and constructed these systems. Any project, with the public's approval will have a significantly easier time becoming reality.

8 Recommendations

Constructed wetlands are a LID technology being implemented at 35 locations in IRWD's service area in the next half-decade. While these systems are effective in attenuating flows and trapping contaminants, pollutants and trash as they are designed to do in their Master Plan, they also have many other benefits discovered through observations, expert interviews, and literature review. By combining the primary water quality benefits with the multitude of secondary benefits there is little doubt that these systems are effective. However, by meeting with experts and observing residents engaging with the sites we see that there are gaps in knowledge and potential of these systems.

8.1 Communication and Public Education

While IRWD has begun the process, there must be signage explaining the problems the constructed wetlands are addressing and the processes in which is functions. Additionally, there should be flyers or information sheets distributed to residents living in drainage basins of these NTS sites and events held at the sites in which employees of IRWD can be available to answer questions and present about the benefits. Other possibilities are visible charts on reduction of certain metals or contaminants, much like cities across California kept track of water usage during the drought. By making the primary purpose of the NTS site more obvious, community-members will feel more connected and responsible for its wellbeing.

As the major challenge, according to the interviewees, was operation and maintenance, I would recommend hiring volunteers or local students to assist with planting and monitoring of invasive plants and trash removal. Especially as a few of the sites have schools located in the vicinity, field trips can easily become both a learning experience for young students and easy clean up for IRWD. By having the community more involved with the local water districts and schools these systems become neighborhood assets instead of water district facilities.

Additionally, IRWD should share its experiences about constructed wetlands with other water districts and cities to start a conversation about these types of green infrastructure. By openly discussing the challenges, benefits and lessons learned other agencies will more readily adapt the new technology.

8.2 Design Recommendations

I would encourage the NTS sites in Irvine to create a greater sense of biophilia by creating more places to engage with the site through picnic tables and benches. As mentioned earlier, the major difference between the sites studied were El Modena provided places to sit and engage with the site and experience biophilia. The other sites were focused on trails and movement to allow visitors quicker paths while commuting or exercising. The majority of sites are not accessible to the public or have little activities for visitors besides passing through.

8.3 Policy Recommendations

Using the preliminary study in this research it becomes apparent that there must be increasing collaboration between groups to promote the continued construction of constructed wetlands. I propose a water district, or lead agency, includes developers and park and recreation departments earlier in the process to ensure the sites are not solely water quality treatment basins but also parks that enhance community spaces. Many of the interviewees noted the difficulty with getting developers involved, but if all parties can openly discuss challenges and more evenly distribute the burdens these systems could become more widely used.

A policy recommendation would be that cities create a “Green Infrastructure Implementation Team” that works with developers, designers, water districts, engineers, and community members to create guidelines for a city on how green infrastructure should be implemented and designed. This team would also assist developers in finding capital to finance the projects, answer questions, and do site inspections to ensure compliance. The Parks and Recreation Department of a city would be included to assist in the design of a constructed wetland to allow maximum public benefit.

8.4 Future Research

The findings can be expanded upon and improved through additional research in the future. Additionally, the work at Irvine Ranch Water District on the NTS sites should be evaluated more closely to transfer the knowledge and functionality to other water districts throughout California and the Country. While Southern California has a semi-arid climate, the possibility of using constructed wetlands in more wet urban landscapes would add valuable information to the growing literature available on these types of green infrastructure. Other aspects to investigate are constructed wetlands potential implementation in various hydrologic regions, soil types, political climates, and regulatory barriers that exist for these sites. Additionally, it would be interesting to see how perceptions of other green infrastructure systems compares to constructed wetlands which have a more visible aesthetic benefit than some of the other systems mentioned in Figure 1.

This is still a preliminary study and therefore more research on the perceptions of residents should be completed. Throughout this research, the interviewees or myself, made assumptions on what we thought the public knew and valued about constructed wetlands. Future research should include the public opinions and knowledge through surveys and interviews. By understanding what the public knows and thinks about constructed wetlands we can more easily create sites that communities take care of on their own.

By focusing on these four areas, we can have better successes with implementation of these engineered systems in urban areas. This would become a greater public benefit for all.

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10 Appendices

Appendix A: Methods of Economic Analysis

Method	Applicable to	Description and Importance	Constraints and Limitations
Market Price Method	*Direct use values,* especially wetland products	The value is estimated from the price in commercial markets (law of supply and demand)	Market imperfections (subsidies, lack of transparency) and policy distort the market price
Damage Cost Avoided, Replacement Cost or substitute cost	*Indirect use values,* coastal protection, avoided erosion, pollution control, water retention…	The value of organic pollutant or any other pollutant's removal can be estimated from the cost of building and running a water treatment plant (substitute cost). The value of flood control can be estimated from the damage if flooding would occur (damage cost avoided). Other examples include stabilization of sediment, habitat for species, removal of nutrients, water quality control groundwater recharge/discharge	It is assumed that the cost of avoided damage or substitutes matches the original benefit. But many external circumstances may change the value of the original expected benefit and the method may therefore lead to under- or over- estimates. Insurance companies are very interested in this method.

Travel Cost Method	Recreation and Tourism	The recreational value of a site is estimated from the amount of money that people spend on reaching the site.	This method only gives an estimate. Over- estimates are easily made as the site may not be the only reason for traveling to that area. This method also requires a lot of quantitative data.
Hedonic Pricing Method	Some aspects of Indirect Use, Future Use and Non-Use Values	This method is used when wetland values influence the price of marketed goods. Clean air, large surface of water or aesthetic views will increase the price of houses or land (overall environment).	This method only gives an estimate. Over- estimates are easily made as the site may not be the only reason for traveling to that area. This method also requires a lot of quantitative data. This method only captures people's willingness to pay for perceived benefits. If people are not aware of the link between the environment attribute and the benefits to themselves, the value will not be reflected in the price. This method is very data intensive.

Contingent Valuation Method	Tourism and Non-use values	This method asks people directly how much they would be willing to pay for specific environmental services. It is often the only way to estimate the Non-Use values. It is also referred to as a “stated preference method”	There are various sources of possible bias in the interview techniques. There is also controversy over whether people would actually pay the amounts stated in the interviews. It is the most controversial of the non-market valuation methods but is one of the only ways to assign monetary values to non-use values of ecosystems that do not involve market purchases.
Contingent Choice Method	For all wetland goods and services	Estimate values based on asking people to make tradeoffs among sets of ecosystem or environmental services	Does not directly ask for willingness to pay as this is inferred from tradeoffs that include cost attribute. This is a very good method to help decision makers to rank policy options.
Benefit Transfer Method	For ecosystem services in general and recreational uses in particular	Estimates economic values by transferring existing benefit estimates from studies already completed for another location or context.	Often used when it is too expensive to conduct a new full economic valuation for a specific site. Can only be as accurate as the initial study. Extrapolation can only be done for sites with the same gross characteristics.

Productivity Method	For specific wetland goods and services: water, soils, humidity	Estimates the economic values for wetland products or services that contribute to the production of commercially marketed goods	The methodology is straightforward and data requirements are limited but the method only works for some goods or services.

Source: (Lambert, 2003);(Woodward & Wui, 2001)

Appendix B: Weed Species

- Mustard (Hirschfeldia spp.and Brassica spp.)
- Pampus grass (Cortaderia selloana)
- Bermuda grass (Cynodon dactylon)
- Hottentot-fig (Carpobrotus edulis)
- Garland chrysanthemum (Chrysanthemum coronarium)
- French broom (Genista monspessulana)
- Scotch broom (Cytisus scoparius)
- Eucalyptus (Eucalyptus spp.)
- Bermuda buttercup (Oxalis pes-caprae)
- Radish (Raphanus spp.)
- Castor bean (Ricinus communis)
- Germin ivy (Senecio mikanioides)
- Pink periwinkle (Vinca major)
- Gorse (Ulex europaea)
- Cardoon (Cynara cardunculus)
- Tamarisk (Tamarix ramosissima)
- Myoporum (Myoporum spp.)
- Tocalote (Centaurea melitensis)
- Yellow star-thistle (Centaurea solstitialis)
- Poison hemlock (Conium maculatum)
- Sweet fennel (Foeniculum vulgare)
- Giant reed (Arundo donax)
- Tree tobacco (Nicotiana glauca)
- Pepper tree (Schinus spp.)
- Ice plant (Mesembryanthemum spp.)
- Australian saltbush (Atriplex semibaccata)

- Spanish sunflower (Pulicaria paludosa)
- White sweet clover (Melilotus alba)
- Artichoke thistle (Cynara cardunculus)
- Oleandor (Nerium oleandor)
- Cocklebur (Xanthium spinosum and X. strumarium)
- Palms (Washingtonia and Phoenix spp.)
- Y ucca spp.
- Jimson weed (Datura spp.)
- Johnsongrass (Sorghum spp.)
- Russian thistle (Salsola tragus)
- Milk thistle (Silybum spp.)
- Bull thistle (Cirsium vulgare)
- Scotch thistle (Onopordum spp.)
- Mallow (Malua parviflora)
- Nettle (Urtica spp.)
- Curly dock (Rumex spp.)
- Dodder (Cuscuta indecora)
- Burclover (Medicago polymorpha)
- Nutsedge (Cyperus esculentus L.)
- Alkali sida (Maluella spp.)
- Gourd (Cucurbita spp.)
- Morningglory (Ipomoea spp.)
- Waterhyacinth (Eichornia spp.)
- Waterprimrose (Ludwigia spp.)
- Prickly lettuce (Lactuca serriola)
- Foxtail chess (Bromus madritensis ssp. rubens)
- Crabgrass (Digitaria sanguinalis)
- Largeseed Dodder (Cuscuta indecora)

- Waterhyssop (Bacopa eisenii)
- Smartweed (Polygonum lapathifolium)
- Rabbitfoot (Polypogon monspeliensis)
- Pepperweed (Lepidium latifolium)
- Morningglory (Ipomoea spp.)
- Lesser watercress (Coronopus didymus)
- Barnyard grass (Echinochloa crus-galli)
- Scarlet pimpernel (Anagallis arvensis)
- Bristly ox-tongue (Picris echioides)
- Mexican tea (Chenopodium ambrosioides)
- Lamb's quarters (Chenopodium album)
- Whitetop (Cardaria spp.)
- Water speedwell (Veronica anagallis-aquatica)
- Mexican primrose (Oenethera speciosa)
- Sweet pea (Lathyrus odorata)
- Kikuyu grass (Pennisetum clandestinum)
- Brassbuttons (Cotula coronopifolia)
- Filaree (Erodium spp.)
- Sow-thistle (Sonchus asper)
- Pokeweed (Phytolacca americana)
- Celery (Apium graveolens)
- Conyza (Conyza bonariensis)

Appendix C: Interview Guide-Experts

Background information

1. ***What do you do for a living?/ How did you get to where you are today? /Did you always see yourself in ________ field?***

Water

2. ***Now my thesis is primarily about water, so I'll start asking some questions about that. What would you say is the biggest issue in water in California?***
3. ***Have you always been interested in water issues?***

Wetland

4. ***What does "constructed wetland" mean to you?***
5. ***What are the benefits of these systems in urban environments?***
6. ***How has the drought impacted this water sensitive urban design?***
7. ***What can be done to make these systems more beneficial?***
8. ***Do you think these are beneficial uses of urban lands?***
9. ***Where do you see the future of these specific wetlands or the entire system in five years?***
    a. ***Will they continue to be constructed or are we moving away from these kinds of low impact development?***

10. What are the challenges of these sites?

11. How do you think the public views these sites?

Conclusion

12. Who would you say drives local water policy when it comes to something like low impact development: cities, state officials, water districts, and developers?

Appendix D: Survey Guide

Survey- Community Members

Age (general): _______________ Date: ______________________

Sex: ______________ Day of Week: _______________

Ethnic group: _________________ Time: _____________________

Background Questions:

Years of residence in the area: ______________________________

Occupation: ______________________________

Did you move here because of this site?

____

____

Site Specific

Frequency with which you visit the site?

- 0-1 per month
- 1-2 per month
- 1-2 per week
- 4+ per week
- Other: _______________

Reasons for visit/ type of activity:

____

____

How would you rate the park/ open space? 1-10 (poor-excellent)

____

____

Why do you give it this rating?

> Ex: Aesthetic/scenery, well maintained/clean, great walk/park, secluded/peaceful, wildlife viewing/birding

____

____

How much do you value this site [1-10 (no value-great value)]

____

____

What improvement would make your visit more enjoyable?

____

____

____

Do you know what this site is?

____

____

What do you think the primary purpose of this site is?

____

____

Any other comments?

____

____

____

Reference

Boulder County Parks and Open Space "5- Year Visitor Study 2010" http://www.bouldercounty.org/os/culture/posresearch/2010posfiveyear.pdf

Northwest Ohio Wetlands Survey https://www.utoledo.edu/nsm/lec/pdfs/Wetlands_Survey_2007q1.pdf

Appendix E: Water Quality Graphs

Cypress Meadows A

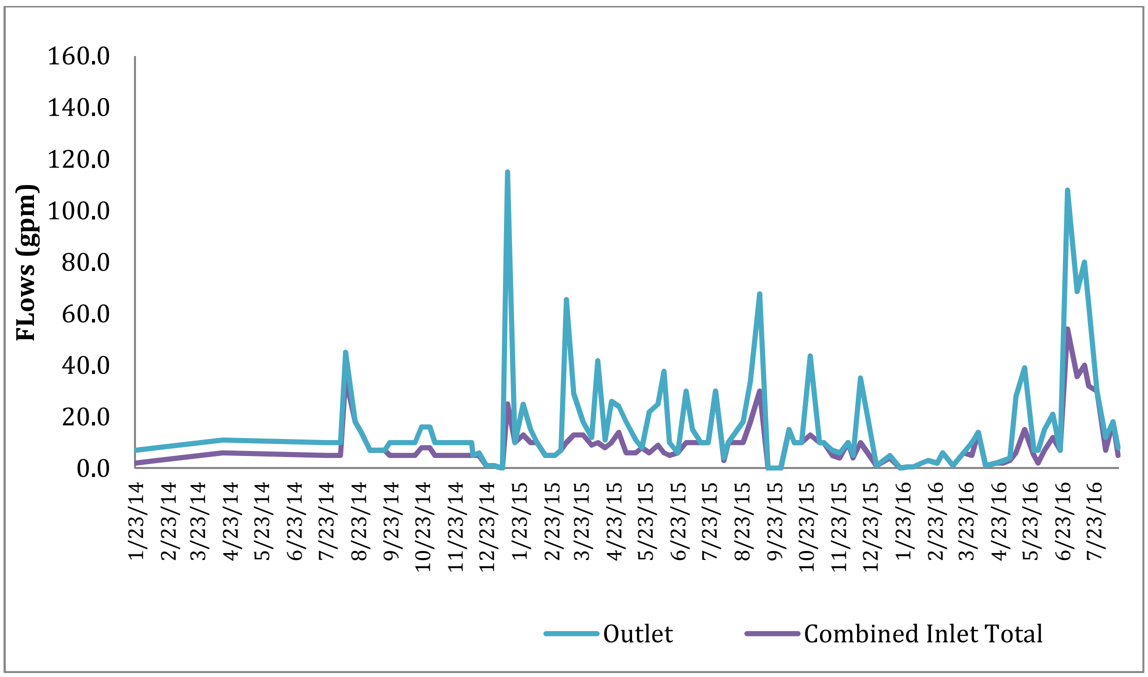

Figure A. Cypress Meadows A Flows

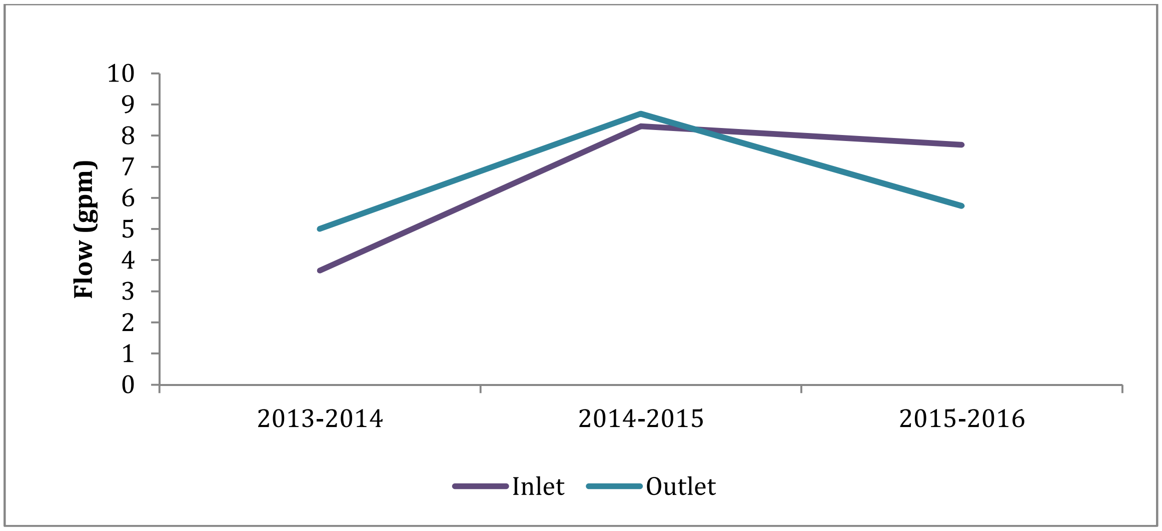

Figure B. Cypress Meadows A Annual Flows

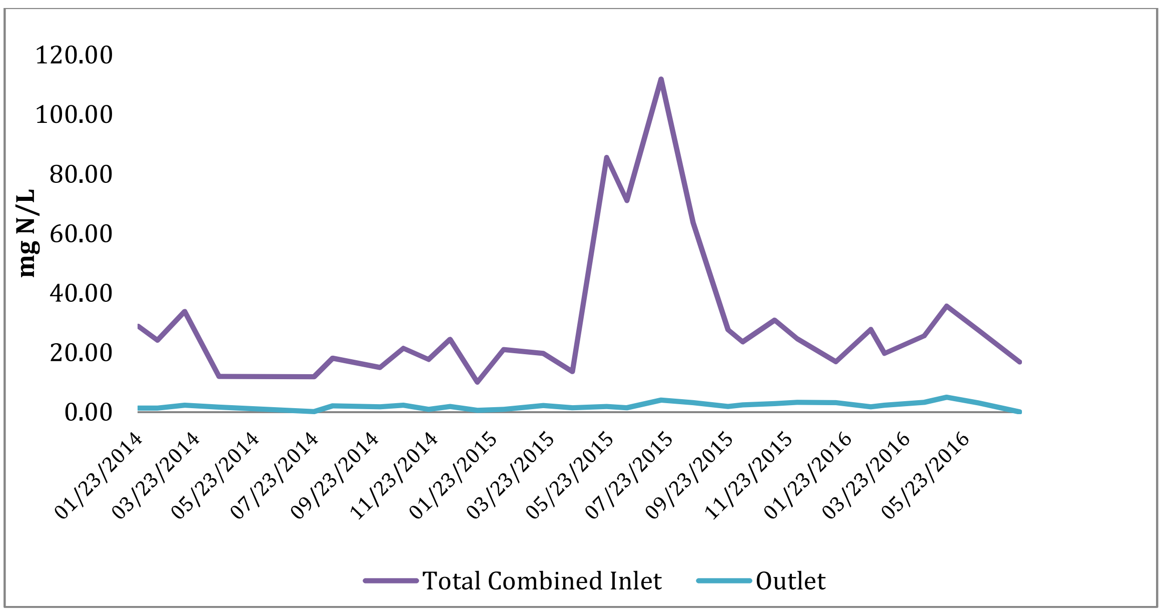

Figure C. Cypress Meadows A Total Nitrogen

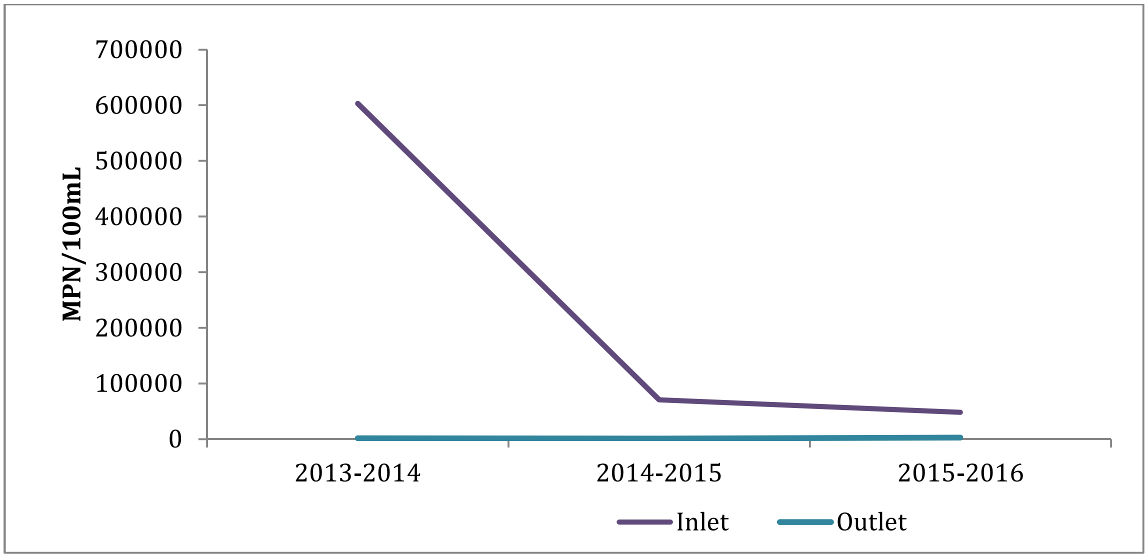

Figure D. Cypress Meadows A Total Coliform Levels

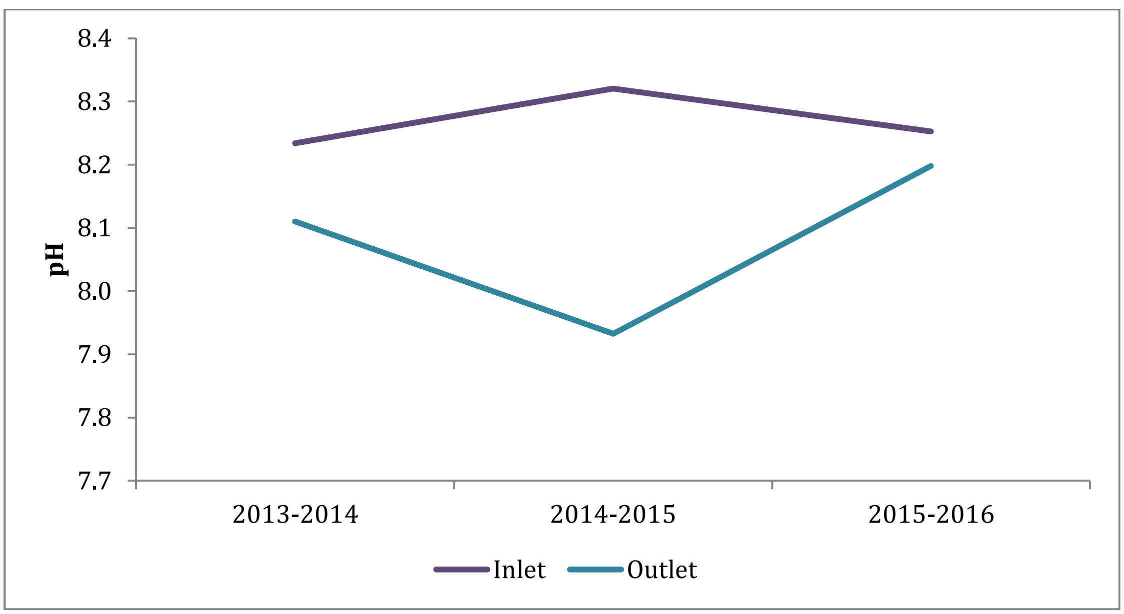

Figure E. Cypress Meadows A Annual pH

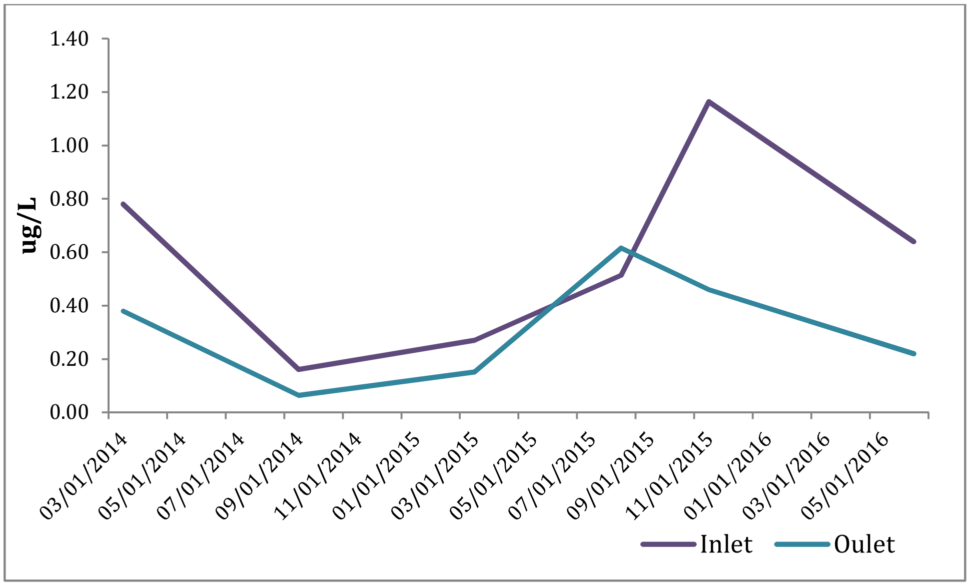

Figure F. Cypress Meadows A Lead

Los Olivos

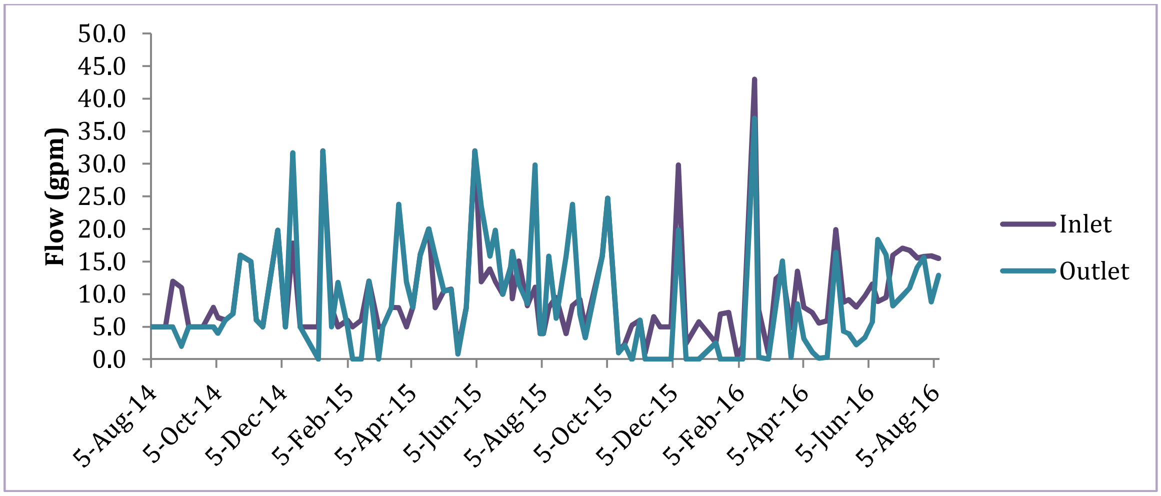

Figure G. Los Olivos Monthly Flows

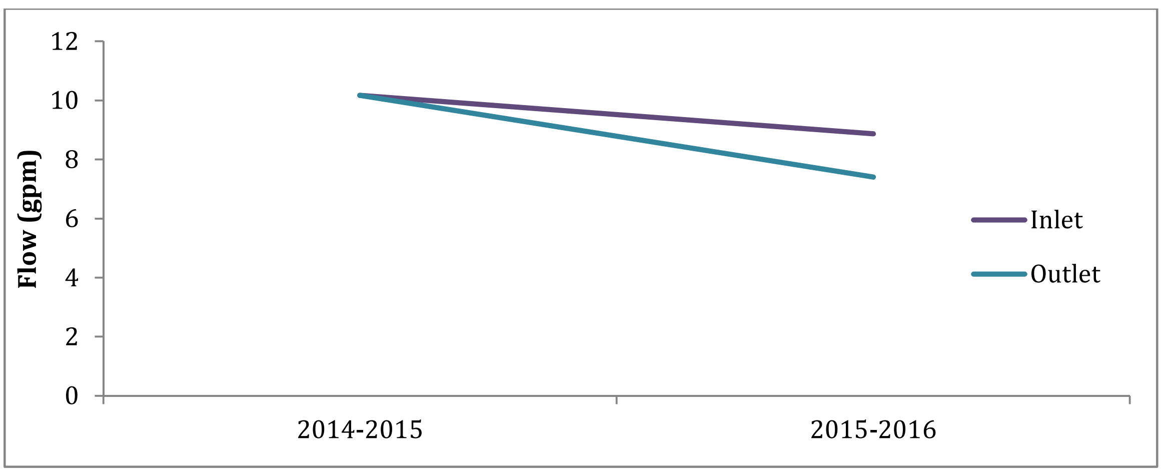

Figure H. Los Olivos Annual Flow

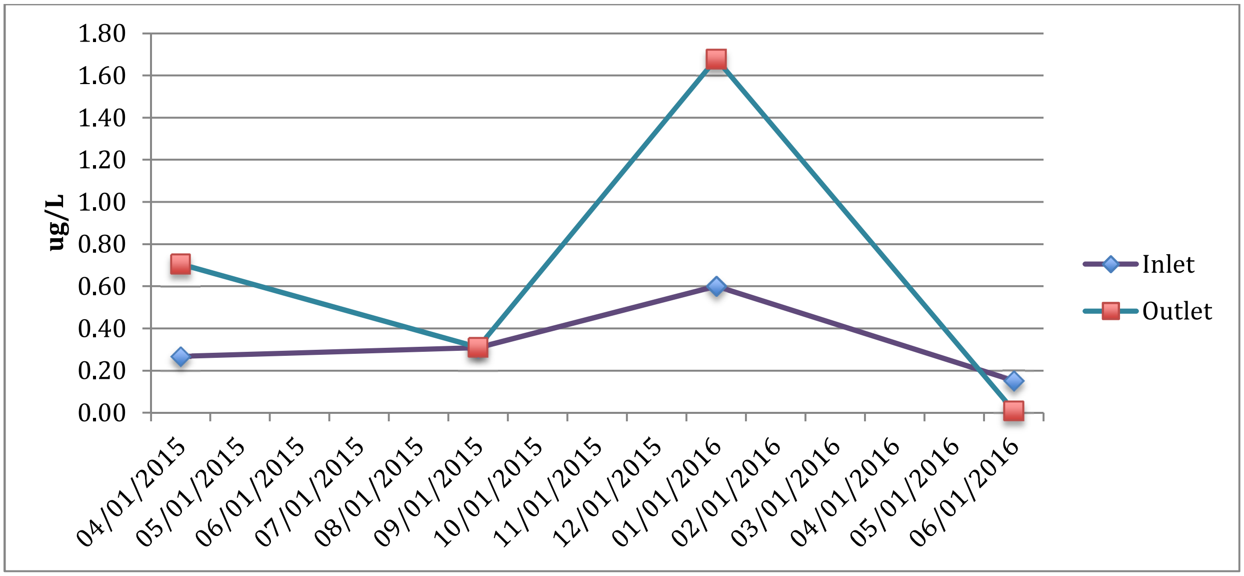

Figure I. Los Olivos Lead

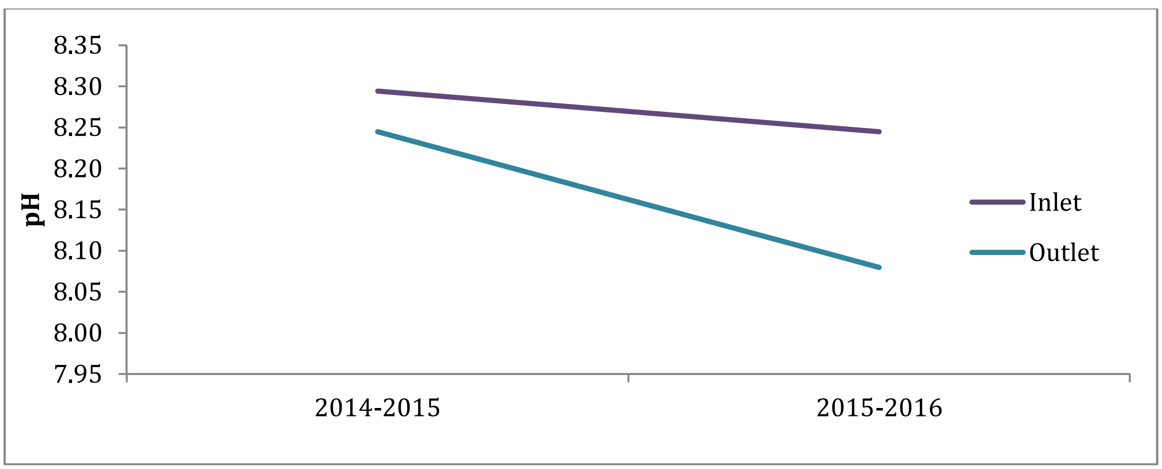

Figure J. Los Olivos Annual pH

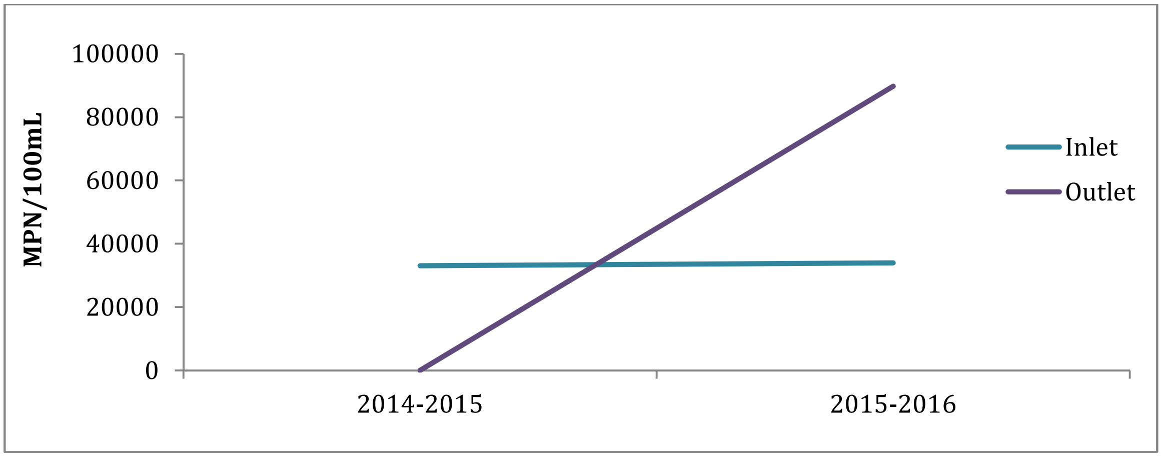

Figure K. Los Olivos Total Coliform Levels

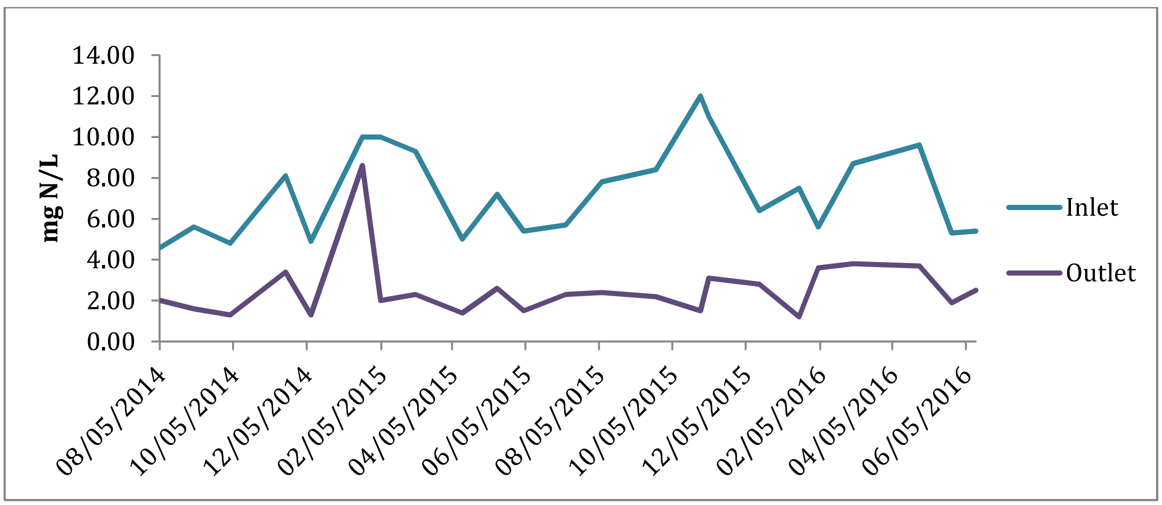

Figure L. Los Olivos Total Nitrogen

El Modena

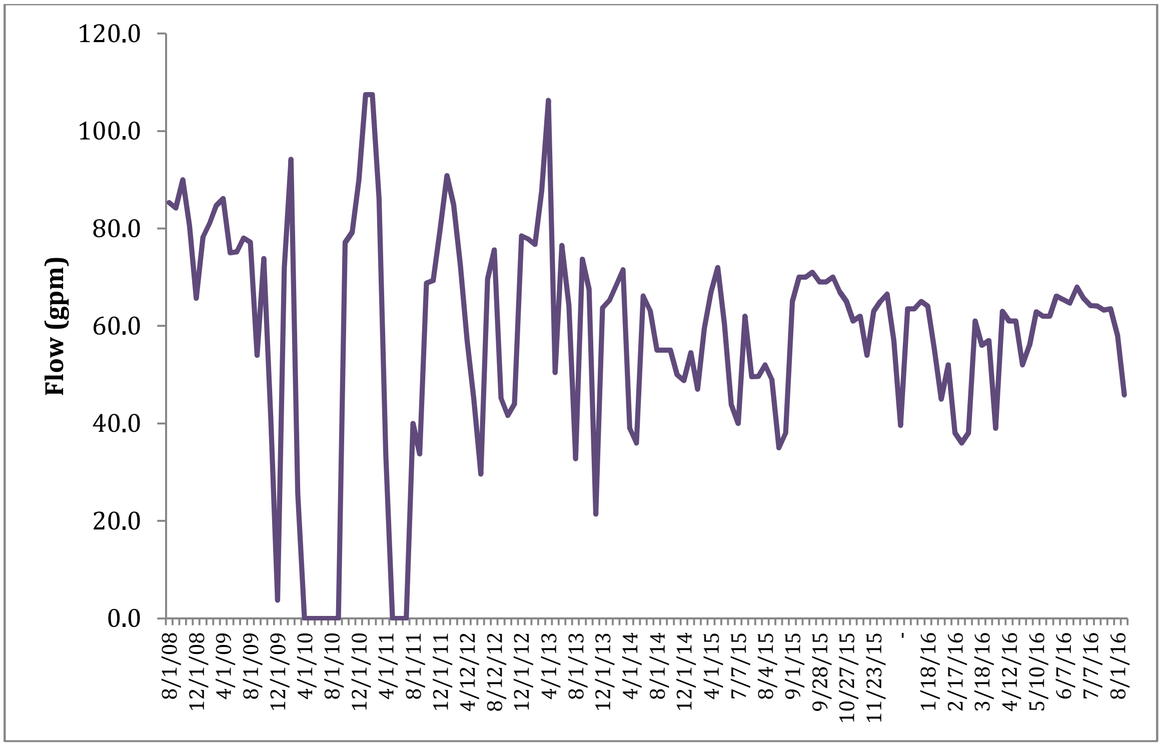

Figure M. El Modena Inlet Flows Monthly

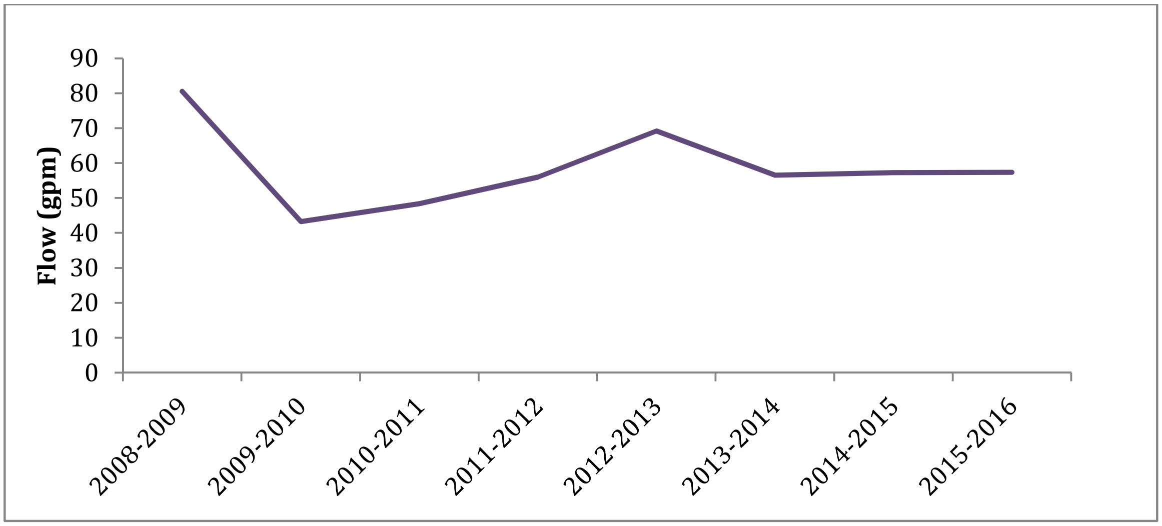

Figure N. El Modena Annual Flows

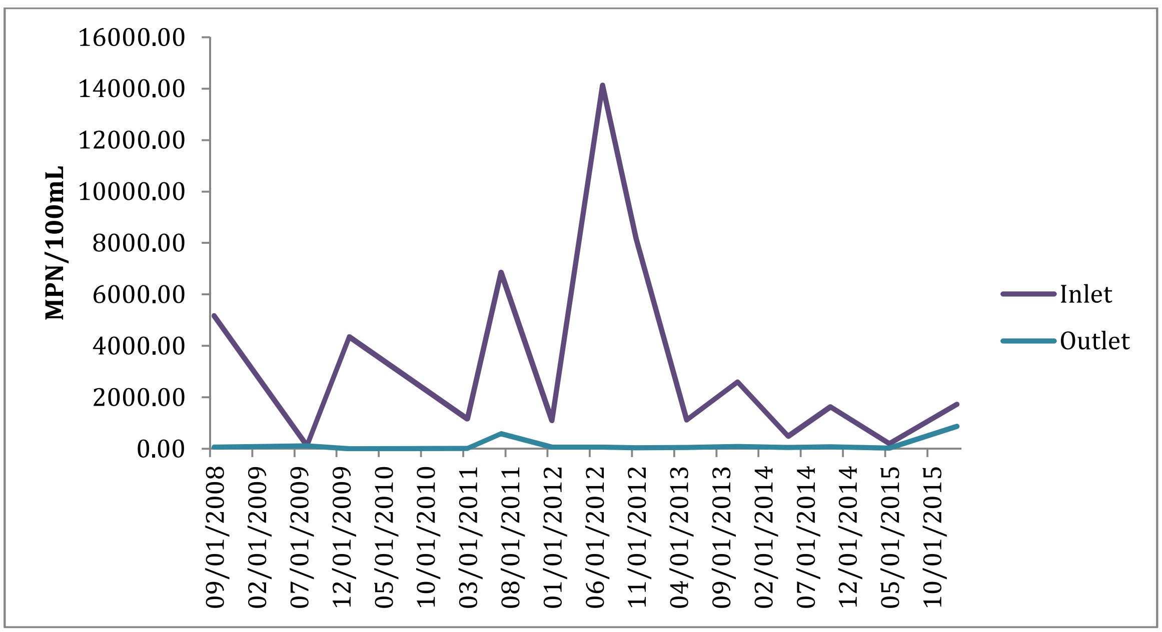

Figure O. El Modena Enterococcus

Table A. El Modena Enterococcus

Date	Percent Reduction of Enterococcus
09/10/2008	98.86
08/12/2009	3.15
01/13/2010	99.98
03/08/2011	98.84
07/26/2011	91.56
01/10/2012	94.77
07/09/2012	99.58
11/12/2012	99.59
05/20/2013	95.92
11/04/2013	96.70
05/19/2014	90.03
10/27/2014	95.41
05/11/2015	87.64
1/18/2016	49.77

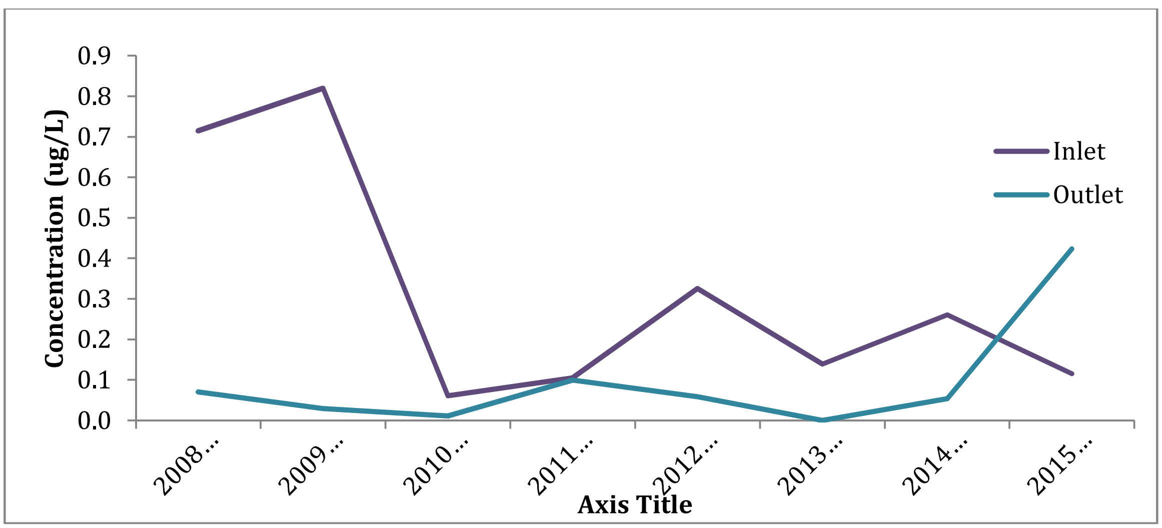

Figure P. El Modena Lead

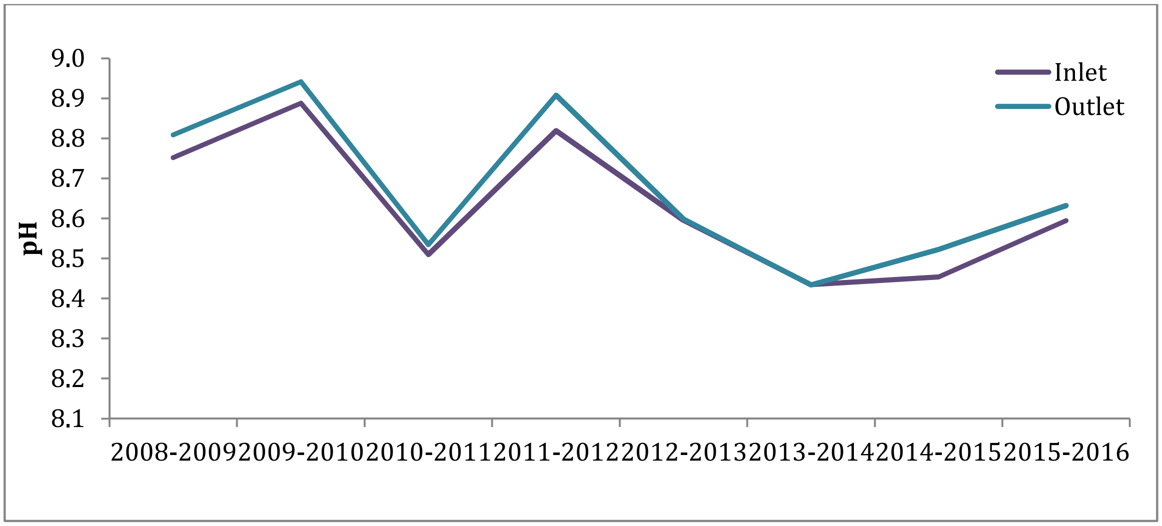

Figure Q. El Modena Annual pH

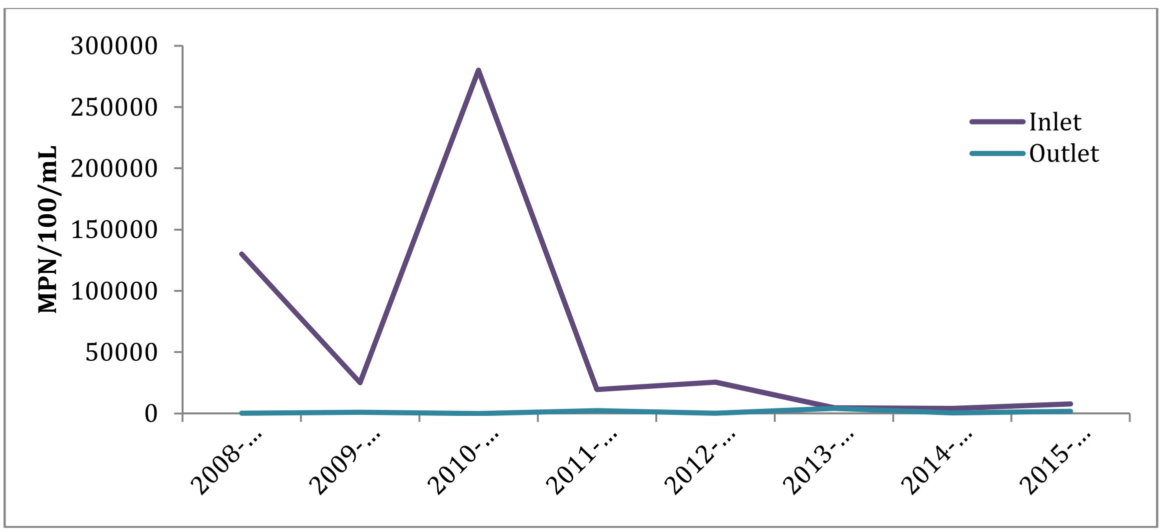

Figure R. El Modena Total Coliform Levels

Quail Springs

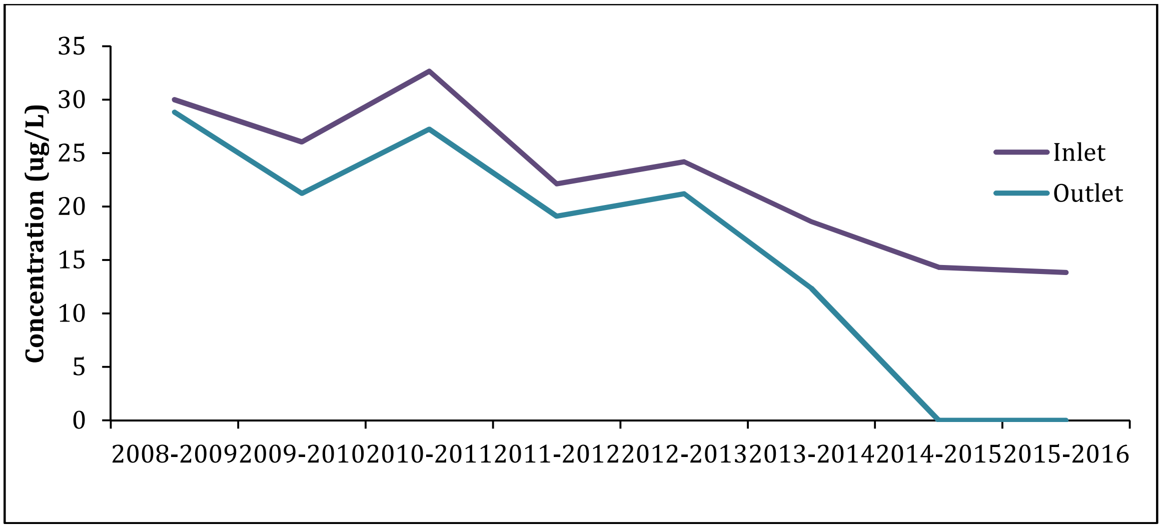

Figure S. Quail Springs Annual Flow

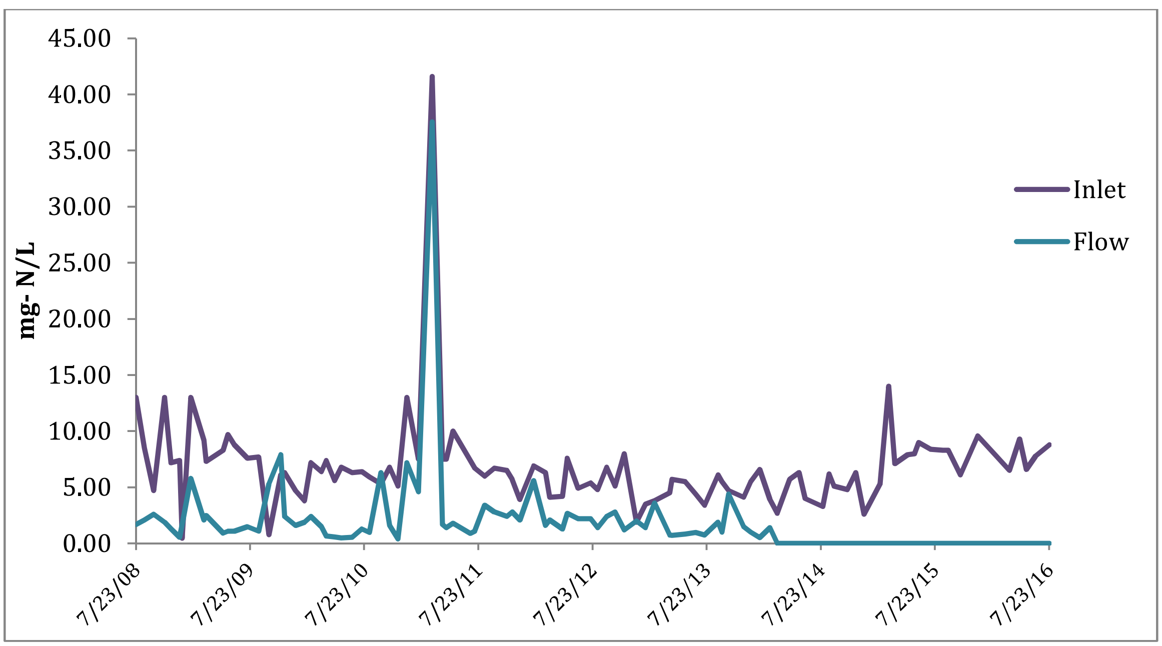

Figure T. Quail Springs Total Nitrogen Monthly

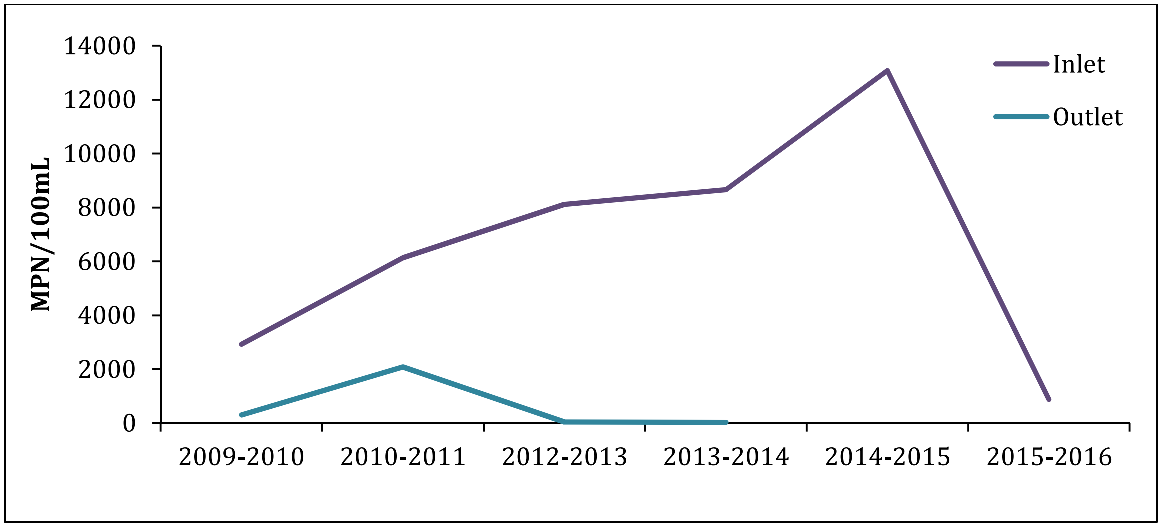

Figure U. Quail Springs Enterococcus Levels

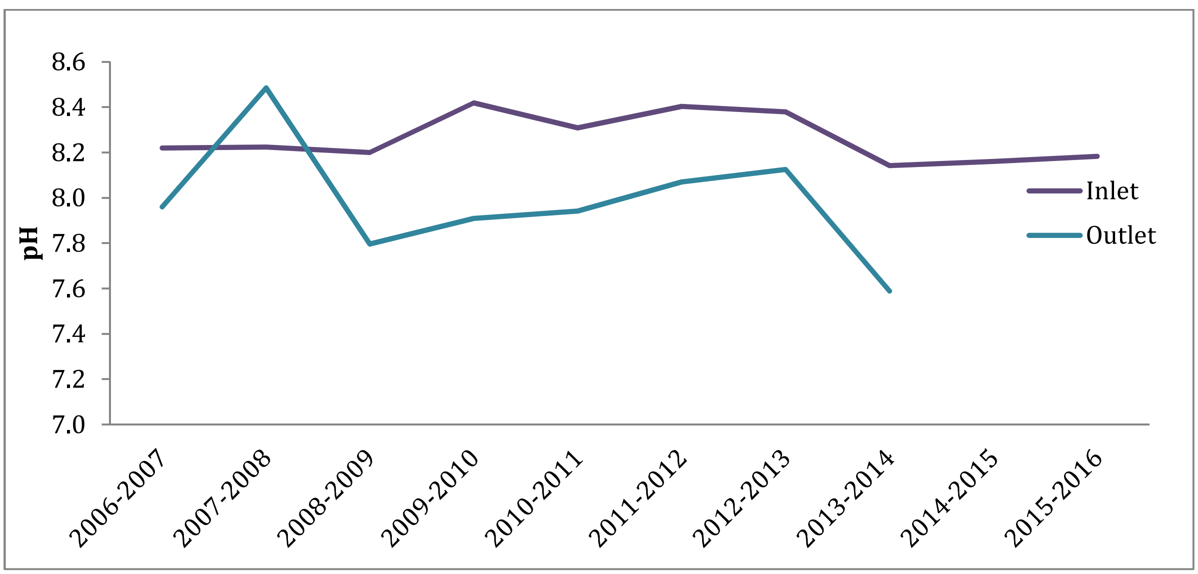

Figure V. Quail Springs Annual pH

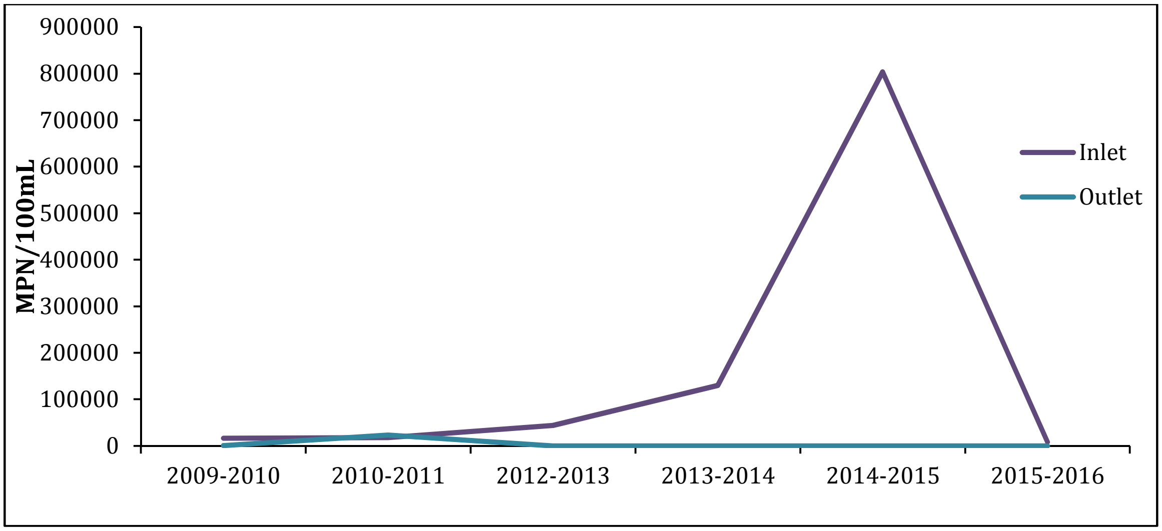

Figure W Quail Springs Total Coliform Levels

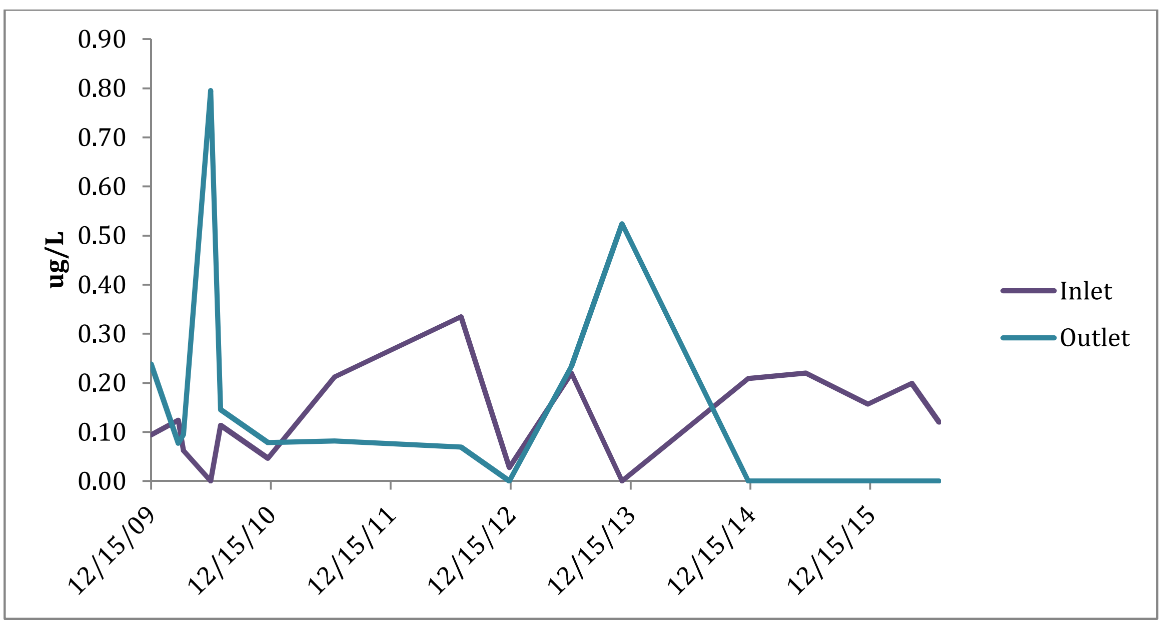

Figure X. Quail Springs Lead Monthly

Trabuco

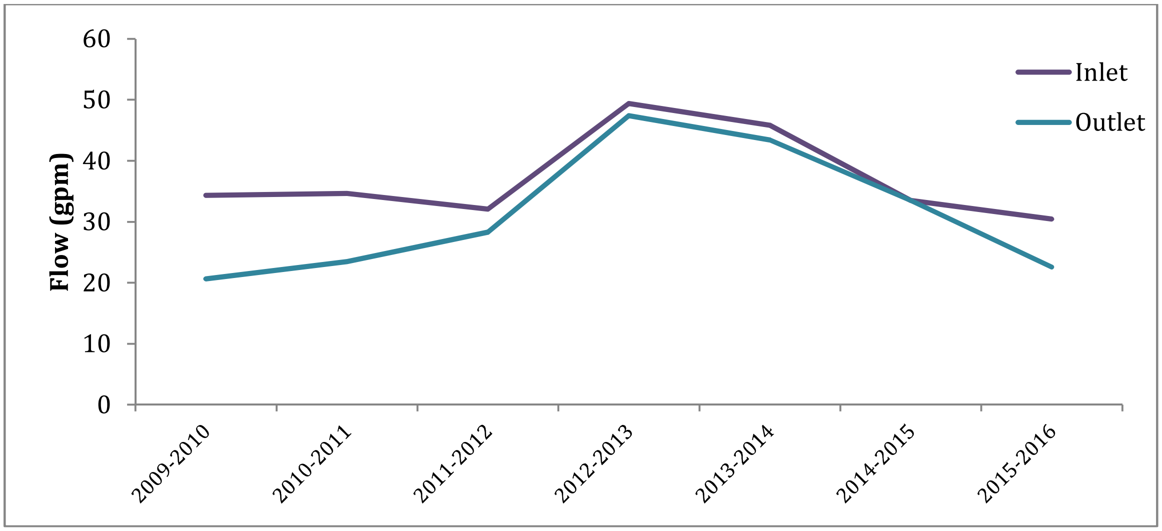

Figure Y. Trabuco Annual Flows

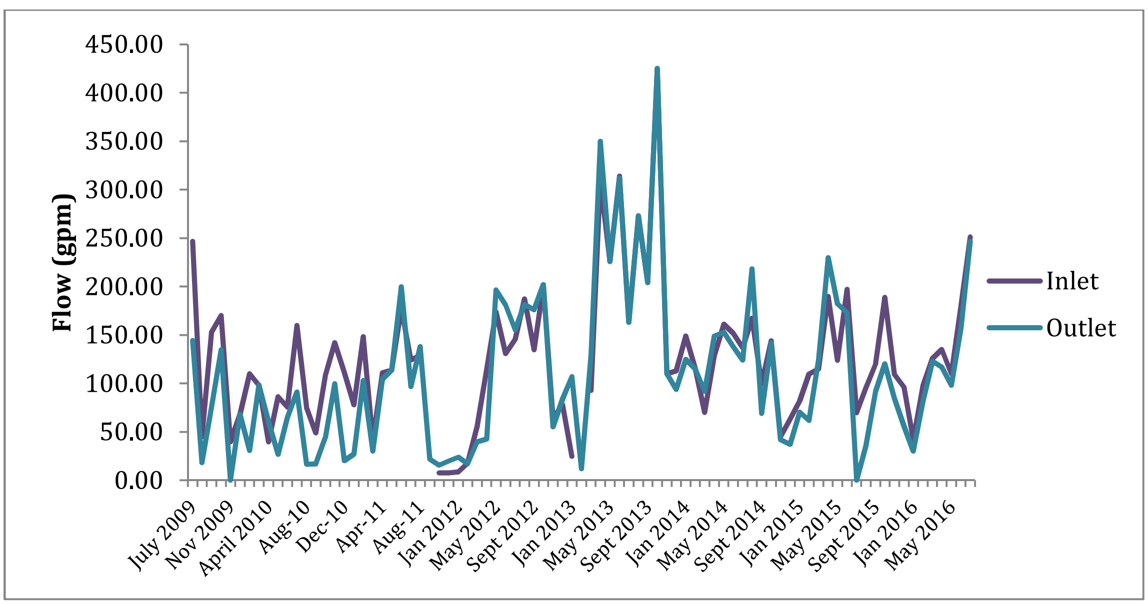

Figure Z. Trabuco Monthly Flows

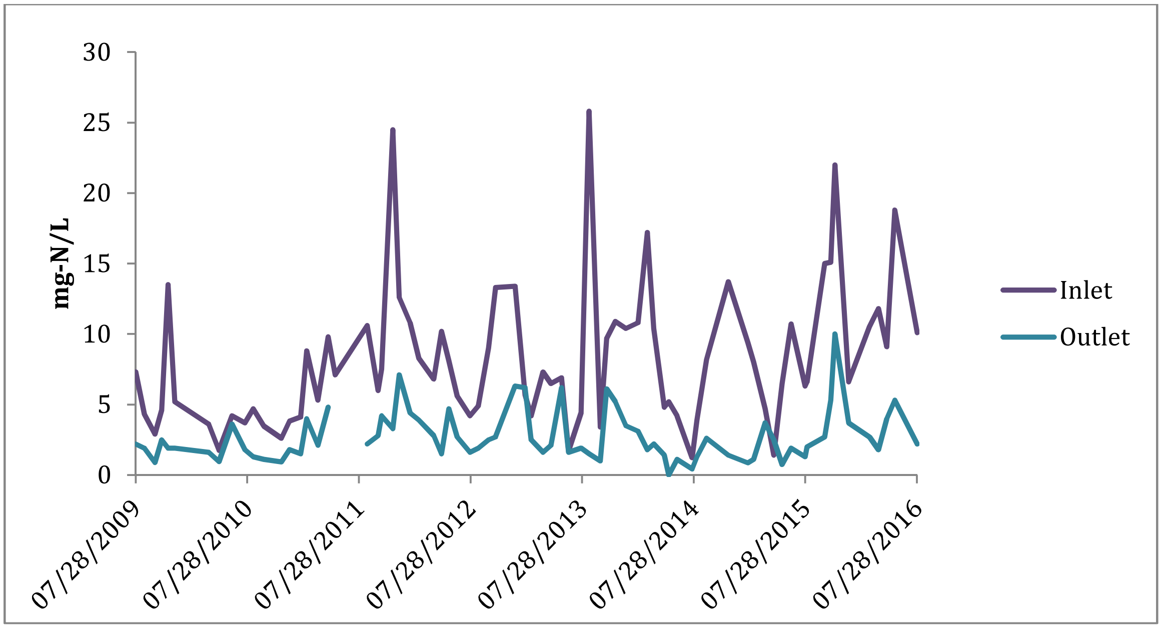

Figure AA. Trabuco Total Nitrogen

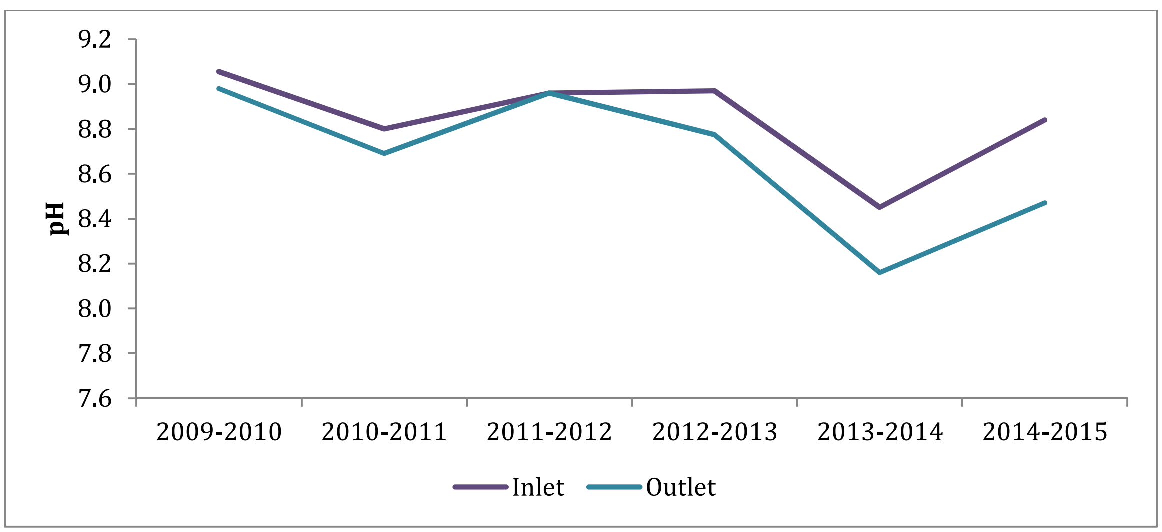

Figure BB. Trabuco Annual pH

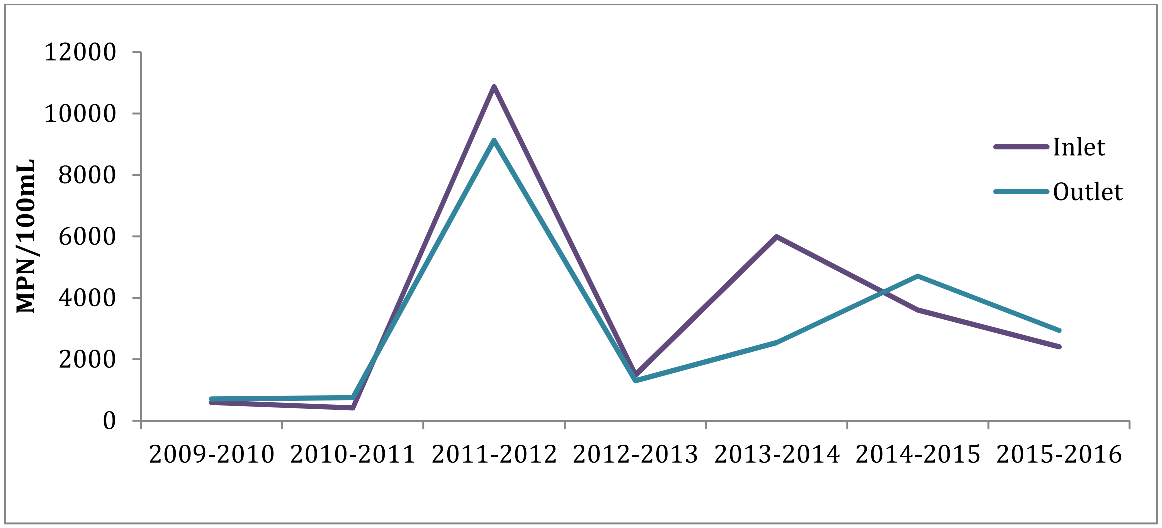

Figure CC. Trabuco Total Coliform Levels

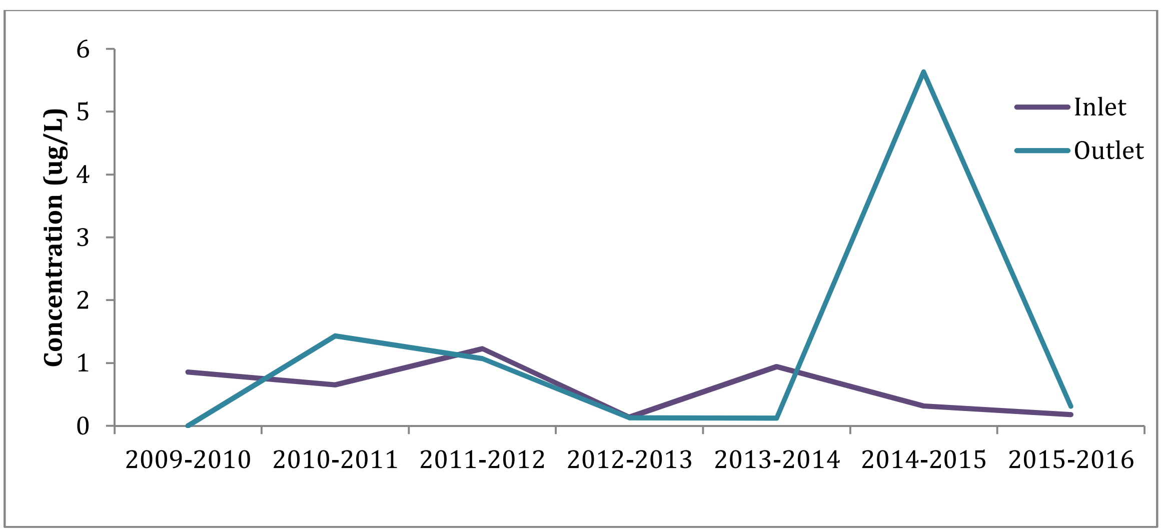

Figure DD. Trabuco Lead