# Analysis of Best Management Practices for Addressing Urban Stormwater Runoff

Senior Capstone, Sustainable Built Environments

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# Table of Contents

## Introduction

During Tucson rainstorms, many roads and neighborhoods experience high levels of flooding on the city's street networks. This phenomenon creates unsafe road conditions, damage to the road infrastructure, and excessive urban stormwater runoff that is potentially polluted. The vast quantities of impervious surfaces in the urban landscape impede the rainwater's ability to infiltrate the ground, thus resulting in increased volumes of runoff during a rainstorm. Stormwater management is used by municipalities and communities to address the previously mentioned adverse impacts of stormwater runoff. Various techniques and strategies used in stormwater management include, low impact development (LID), green infrastructure, and better site design (BSD) strategies implemented during design stages to reduce stormwater runoff levels. In addition, local governments can establish stormwater utilities and policies in order to help address and better manage the issue of stormwater runoff within urban areas. The primary research questions of this study will include:

- What are the most effective best management practices and techniques to address urban runoff?
- What combination of best management practices and government policies will be the more effective in addressing Tucson's urban runoff problem?

Accordingly, this study will examine a variety of policies and techniques to address stormwater runoff, and then, based on this information, provide a suggestion of the best practices and techniques that may be feasible for implementation in Tucson.

Tucson's current approach to stormwater management is fairly limited and does not provide a meaningful plan to decrease stormwater runoff throughout the city. The City of Tucson has a Stormwater Management Program (SWMP), which includes information on multiple public outreach programs, and information on requirements that primarily address requirements of federal regulations on water pollution. Furthermore, the SWMP states that the city "will continue to evaluate Low Impact Development (LID) practices" to determine their feasibility, but do not make any design standards at this time (Hester, 2014). The SWMP provides a list of "stormwater control measures," that focus on erosion and sediment control measures through slope modification, compaction, and subsurface drainage controls (Hester, 2014). Such stormwater control measures do not necessarily serve to reduce runoff levels; instead those methods alter the site hydrology to guide runoff into the appropriate drainage systems.

Some additional efforts that the City of Tucson has made to manage stormwater runoff include developer education and public education, infrastructure techniques, and the development of some policies. The City of Tucson also has a "Watercourse Preservation Policy" which aims to protect natural water courses and riparian areas (The City of Tucson, 2015). The Watercourse Preservation Policy works to protect riparian areas from impacts of new developments, such as erosion, but it does not address the issue of stormwater runoff generated by the impervious surfaces of developments and infrastructure.

The education and infrastructure techniques include developing a "Water Harvesting Guidance Manual," and providing information on the dangers of flash floods. Tucson Clean & Beautiful is an organization  involved in dispensing information and implementing stormwater management strategies (The City of Tucson, 2015). Of these efforts, the Water Harvesting Guidance Manual is the most direct attempt by the city to reduce the stormwater runoff. The Manual, which is predominately directed towards reducing water consumption of commercial developments, provides a detailed explanation of water harvesting methods that could be implemented during development. As far as policies and regulations, the City of Tucson has implemented the Stormwater Quality Ordinance, and it is developing a set of guidelines for watercourse maintenance (The City of Tucson, 2015). Additional policies pertaining to stormwater management policies are more directed at decreasing external water consumption, and improving runoff quality water in order to comply with the Clean Water Act, rather than reducing runoff as a whole. Although the City of Tucson has begun to implement the aforementioned efforts to improve the city's stormwater management, there is currently a policy gap within the City of Tucson in regards to meaningful stormwater management. The policy gap includes a disparity in stricter development regulations that would reduce alterations to a site's natural hydrology, policies to retroactively install a comprehensive and interconnected green infrastructure network across Tucson, and the requirement for low-impact development techniques to be used in site construction and modifications.

The stormwater management policy gap in Tucson impacts infrastructure maintenance costs, post-storm cleanup costs, and the amount of pollutants carried into the environment by runoff. The adoption of techniques, such as low-impact development strategies and stormwater utilities, could help reduce the environmental impacts of excessive runoff while simultaneously reducing the maintenance costs associated with runoff. Through the use of mixed methods, including qualitative case study review techniques, cost analysis, and an evaluation of Tucson's government structure, current policies and practices pertaining to stormwater management, this study will identify the best management practices (BMPs) and techniques that may be feasible for implementation in Tucson to reduce and better manage its stormwater runoff. Completion of this research will provide the city government with viable solutions to its stormwater management problem. Implementation of such information could ultimately save the city money, and both reduce road hazards and improve the walkability and bikeability of Tucson, during and after a storm. The information gathered by this study can also assist other communities and municipalities, with similar geography and government structure to Tucson, to determine the appropriate combination of practices and policies to better manage stormwater runoff within their location.

## Literary Review

### Sustainability

The built environment and communities function similarly to biological organisms with transit systems acting as a circulatory system, and urban areas functioning like vital organs within the large-scale organism that is our world. The concepts within sustainability provide a framework which allows for the built and social environments to be recognized as a complex organism that acts as an extension of humans. Accordingly, sustainability has a broad and complex scope which extends through multiple scales and attempts to balance the three foundations of our society which are economics, environment, and equity. Within the last few decades, the concept of sustainability has become popular as people, communities, and economies have recognized the need for more holistic practices in order to ensure a prosperous future. The Brundtland Report, which provided the broad framework for the concept of sustainability, identifies that “ecological interactions do not respect the boundaries of individual ownership and political jurisdiction” (Brundtland Commission, 1987). As such, sustainability recognizes how economies, communities, and the environment are all deeply intertwined and how consideration of all three elements is critical to a sustainable solution.

Historically, the three pillars of sustainability have been considered as separate competing entities. However, the separation of these three elements of is inherently flawed because in reality these components are intricately connected with one another. Consequently, to ignore the complex relationships between the environment, economics, and society is unsustainable, and has resulted in the development of communities and policies where these components are competing with one another instead of working together. Implementation of sustainability concepts help to make both the built and natural environments more efficient and equitable for all. Identification of the best practices for developing sustainable solutions can be complex and vary between locations due to the differences in geography, community values, and their economic structure. Sustainable development requires an inter-disciplinary and multi-scale approach that involves the implementation of numerous techniques and policies to address the issues that communities, regions, nations, and the world face in order to continue to meet our present needs, without impeding the needs of future generations (Brundtland Commission, 1987).

In order to develop an effective sustainable community, a multi-scale approach, ranging from the regional level to the individual site, must be taken. The consideration of multiple scales is critical because it helps to address the large-scale, underlying issues that result in the unsustainable conditions we face today. Such unsustainable conditions include poor air and water quality, fragile and competing economies, disconnected natural habitats and urban areas, and inequitable social conditions. Overarching guidelines at the federal, state and regional levels allow for a more comprehensive land-use plan which can help to minimize economic redundancies, disconnection of open space and sprawling developments. The next scale for consideration is the municipality. At the small scale, sustainable communities begin to take shape in the form of medium- to high-density transit-orientated developments (TOD) that are mixed use and incorporate green infrastructure into the overall design. These basic components are vital to forming a community that has a smaller ecological footprint, socially equitable, and economically sound.

Within a municipality, the design of neighborhoods is another vital component to creating a more sustainable community. The layout of traditional suburban neighborhoods is unsustainable because of the internal disconnection and the separation from urban areas which forces people into cars to travel short distances. The sprawl of these neighborhoods also has numerous negative impacts on the environment such as, increased stormwater runoff, destruction of critical habitat, and the encroachment of floodplains and streams. Many of these problems with traditional suburban neighborhoods can be remedied with the use of conservation design techniques and the elimination of cul-de-sacs, placing driveways in the back of the house, introduction of pathways for pedestrians and bicyclists, and the use of open space to delineate neighborhoods. The introduction of such features not only helps to preserve more of the natural environment, but help to craft more vibrant, tight-knit communities by creating more opportunities for the community members to interact with one another. There are also economic benefits for implementing these types of neighborhood design techniques. Not only are people willing to pay more to have these types of features within their community, but often times developers can save money by reducing material quantities, such as pavement or concrete.

Finally, the individual site and building design contribute to the development of a sustainable community. Incorporating sustainable design techniques on the scale of the site and building can further benefit the community economically by creating energy savings, and environmentally by enhancing onsite infiltration, and decreasing the overall footprint. Low-impact development (LID) techniques and green infrastructure, such as green roofs and rain gardens can help improve water quality. Multi-family housing can reduce energy consumption which saves money in the long term while reducing greenhouse gas (GHG) emissions to improve air quality.

**Surface Water Runoff**

Sustainable development encompasses many techniques in order to address a variety of problems that have been created due to historic development patterns. The issue of stormwater runoff generates a number of negative repercussions that impact the sustainability of a community or development, including natural hydrological processes, reduction of aquifer recharge, and pollutants entering the natural environment. Therefore, approaching the issue of stormwater runoff within the context of Tucson requires analyzing the economic, social, and environmental components of multiple case studies, in order to distill relevant elements from those cases and then develop a comprehensive solution to Tucson’s stormwater runoff problem.

Surface water runoff is a naturally occurring process where water does not permeate the ground. In areas with substantial amounts of impervious surfaces and altered landscapes, as seen in urban and agricultural settings, there are three major impacts on the natural hydrological cycle including, a reduction of recharge to the aquifer, increased evaporation, and the transportation of large quantities of sediments and pollutants into the environment (Coyle, 2011). In addition to the disturbances of the natural hydrological cycle, areas with significant levels of impervious surfaces generate high levels of runoff because less water is able to infiltrate the ground. High runoff volumes from agricultural and urban landscapes have been found to contain high “levels of nitrogen and phosphorus” which can result in eutrophication of water bodies (Tong & Chen, 2002). Eutrophication is a process caused by a high concentration of nutrients that promotes algae growth, which then results in the depletion of oxygen as the algae decomposes, causing other aquatic life to suffocate (U.S. Geological Survey, 2015). Areas that experience accelerated eutrophication are referred to as “dead zones” for the morbid repercussions on the ecosystem. Beyond the environmental damage, dead zones can adversely impact economies that rely heavily on fishing and tourism by killing fish stocks, and destroying reef life (Dartmouth, 2012). A large-scale example of a dead zone is the Gulf of Mexico, where surface water runoff, polluted with nitrogen and phosphorous, from agriculture in the Midwest is being transported down the Mississippi River into the Gulf (Dartmouth, 2012). Accordingly, the impacts of poorly managed runoff expand beyond the local environmental implications, and can collectively have large-scale adverse effects on ecosystems.

Within the context of a municipality, the built environment is typically designed to “transport this runoff away from the built environment to the remnant surface flow pathways,” in order to assure that the urban infrastructure can be “utilized in the most severe rainfalls” (Cahill, 2012). However, areas with poor drainage systems often result in potholes and “fatigue cracking,” because water is able to infiltrate from the top or side of the pavement which causes the top surface layer to detach from the bottom layers (Adlinge & Gupta, 2013). High levels of runoff also cause a “rapid increase in the rate and volume of runoff from a developed landscape,” which results in a sudden increase of “stream flow,” also known as flashing flooding, due to the lack of infiltration which generates significant levels of debris and damage to both the built and natural environments (Cahill, 2012). Flash flooding and road deterioration are two prevalent concerns among the Tucson community; therefore, addressing the issue of stormwater runoff is an important step to making the Tucson community more sustainable.

Although there is not a single formula that can be duplicated in various locations to solve the issues associated with stormwater runoff, there is some consensus of basic sustainable development techniques and BMPs that can help alleviate the quantity of stormwater runoff.

Sustainable development techniques to reduce stormwater runoff focus on ways to “reduce the impact of impervious surfaces and sprawling land development patterns;” by producing higher density and mixed use developments that “recognizes the hydrological boundaries of every community” (Cahill, 2012). These sustainable development techniques are associated with Non-Structural and Structural BMPs, which are the two categories of BMPs that are considered to address stormwater runoff. Non-Structural BMPs focus on pollution prevention of stormwater runoff by preserving natural landscapes, reducing impervious cover and sprawl, and street maintenance (GreenTreks Network, 2006). Structural BMPs focus primarily on the mitigation of stormwater runoff impacts through mechanisms that increase infiltration, reduce runoff volumes, and improve the quality of runoff (GreenTreks Network, 2006). Such mechanisms include bioswales, green roofs, and retention basins.

**Stormwater Management Solutions**

Source control stormwater management solutions look to address urban runoff at the site where the runoff is being generated (Karvonen, 2011). An example of a source control is Low Impact Development (LID), which aims to reduce stormwater volumes and pollution levels through “site design, infiltration, and treatment strategies” (Karvonen, 2011). The main goal of LID is to maintain the natural hydrology of the site, which reduces the environmental impact of developments on the watershed as a whole. Proponents for source control solutions value the use of these techniques because they are small-scale, replicate natural drainage process, and are more economical than constructing infrastructure to manage and clean the runoff. LID techniques are considered to provide cost savings for communities and developers by offering an alternative to the costly large-scale engineering solutions that have been used historically. LID techniques can create a cost savings for communities through “pollution prevention benefits and avoided treatment costs," among other environmental benefits not achievable in traditional management practices (Myles, 2014).

Another stormwater management option is to establish a stormwater utility. A stormwater utility is a service entity within a municipality or county government that plans, constructs, and maintains stormwater management techniques. Stormwater utilities are typically funded by either flat fees, or fees based on the "demand" that a property places on the utility's drainage system (Brisman, 2002). The flat fee rate structure is advantageous because of its simplicity; however, it does not encourage a change in the individual site design as a tool to reduce runoff. In contrast, a fee system based on the property's demand for the stormwater management system encourages, property owners and developers to modify their property to reduce runoff levels. Municipalities can base the fees on a number of site attributes, including "impervious surface area, soil type, runoff rate," property size, etc. (Brisman, 2002). The establishment of stormwater utilities has been controversial in some municipalities, in part because residents and companies are resistant to paying an additional fee. Accordingly, it is important for municipalities to conduct a public education campaign to inform the public why a stormwater utility is necessary and its benefits.

## Methodology

It is rare to find a one-size fits all solution for the political and infrastructural issues that municipalities face. Accordingly, various techniques and policies can be implemented and customized to meet the unique needs of a particular area. A pragmatic paradigm is ideal when attempting to identify these solutions, because it looks at the effectiveness of the results "with respect to the specific problem that the researcher" seeks to resolve (Mertens, 2010). Furthermore, pragmatism attempts to identify what will work in a defined situation, which can then be used to initiate a real-world project that can be accomplished. In regards to Tucson's stormwater management, a pragmatic approach will allow for the analysis and rating of techniques from case studies that Tucson could use as framework in the advancement of their stormwater management approach. Pragmatism also provides the framework for mixed method research in which both qualitative and quantitative data is collected. Collection of both qualitative and quantitative data will be beneficial to the project because it will allow for a closer look at both the costs and the benefits of implementing certain stormwater techniques in Tucson.

Within the framework of a pragmatic paradigm, a series of case studies will be analyzed as the primary form of data collection to select the best management techniques for Tucson to implement. The case studies selected for the study include local and national examples of municipalities that have implemented various stormwater management solutions, in order to develop an understanding of the possible techniques that have been successfully implemented. While analyzing these case studies, the primary questions are the following: what BMPs and techniques were used to reduce urban runoff? What are the levels of accountability to implement and adhere to the BMPs and techniques? What is the quality of the BMPs and techniques used to reduce runoff? A focus on these set of questions will help to acquire the best management practices and techniques that were the more effective in reducing runoff and the most beneficial for the community overall.

## Case Studies:

To determine the best course of action for managing the City of Tucson's stormwater runoff, three case studies are analyzed – Oro Valley, Arizona, Los Angeles, California, and Kirkland, Washington. The Town of Oro Valley was selected as a case for a municipality that established a stormwater utility. The City of Los Angeles is a case were specific policies require the use of low-impact development to reduce runoff. Finally, the City of Kirkland provides a case where requirements for the use of low-impact development techniques and a stormwater utility have been established.

**Oro Valley, Arizona – Stormwater Utility**

A local example of a municipality implementing a stormwater utility to more effectively manage their stormwater runoff is the Town of Oro Valley. Oro Valley is a community of about 40,000 people that is located approximately six miles north of Tucson, Arizona, between the Tortolita and Catalina mountains. Oro Valley's climate is fairly similar to Tucson's, and the average rainfall is about 12 inches annually (Weather DB, 2015). In 2001, Oro Valley created its Stormwater Utility (SWU) and Stormwater Utility Commission (SWUC) in response to the federal government's National Pollution Discharge Elimination System (NPDES) (Town of Oro Valley, 2010). The mission of the SWU is to promote safety, protect water quality, and Oro Valley's "working and natural environments before, during and after" storm events (Town of Oro Valley, 2010). The SWU operated without a fee until 2008 when the Town Council approved a quarterly flat rate fee of "$2.90 for residential properties, and $2.90 per 5,000 square feet of impervious surface for commercial, business and non-profit properties" (Stormwater Utility Commission, 2008). The stormwater utility fee covers about half of the SWU's funding, the other half is made up of "funds from Local, State and Federal agencies," volunteer groups and the Pima County Regional Flood Control District (Town of Oro Valley, 2010).

In compliance with Arizona Department of Environmental Quality (ADEQ), the Town of Oro Valley has created "Stormwater Management Plan Annual Report" since 2009. The report includes background information on the Town's stormwater program, and information on performance measures and monitoring. However, the monitoring section of the plan simply states that there are provisions for stormwater monitoring since none of the town's washes fit the criteria provided by the ADEQ permit (Town of Oro Valley, 2015). The performance measures outlined include, inspection results, public education and public outreach information, investigated illicit spills, street sweeping costs, and the number of pollutant sources and problem drainage areas mitigated (Town of Oro Valley, 2015).

Oro Valley's public education approach includes the provision of brochures and fact sheets distributed through utility bills, at public events and locations, as well as their website, and responding to public inquiries (Town of Oro Valley, 2015). The information provided describes the purpose for stormwater management, as well as basic actions that residents and businesses can take to improve stormwater runoff quality. The suggested actions include, limited use of pesticides and fertilizers, proper disposal of chemicals and pet waste, and "environmentally friendly landscaping techniques" (Town of Oro Valley, 2016). Another community program that Oro Valley has created is the "Adopt-a-Wash" program, where community groups or members can elect to maintain and clean certain washes with support and education provided by the town (Town of Oro Valley, 2016). Besides the basic information outlined in the stormwater management plan and the frequently asked questions page, there is minimal information provided on the best management practices (BMPs) that can be incorporated in a development.

**Los Angeles, California – Low Impact Development Techniques**

Los Angeles is a city of just under four million people that is located along the Pacific coast of southern California. Los Angeles is considered a Mediterranean climate that receives about 15 inches of rainfall annually (Climate-Data, 2015). In 2002, the City of Los Angeles created the "Standard Urban Stormwater Mitigation Plan" (SUSMP) in an attempt to better manage stormwater runoff from developments (City of Los Angeles, 2011). In addition to the SUSMP, Los Angeles collaborates with the greater Los Angeles region to develop specific watershed management plans which provide a detailed description of the region's approach, including the integration of LID (City of Los Angeles, 2015). In 2011, Los Angeles passed a Low Impact Development ordinance, which expanded upon SUSMP to include LID BMPs in all developments and redevelopments. Specifically, the LID ordinance requires developments and redevelopments to capture, infiltrate or use, "rainwater from a three-quarter inch rainstorm" with the techniques delineated in the City's LID Handbook (City of Los Angeles, 2011).

The LID Handbook provides developers a comprehensive guide for to the LID ordinance requirements and processes, as well as detailed information and design criteria for the prescribed BMPs. The LID ordinance requires a LID Plan, to be submitted and approved prior to the issuance of building or grading permits. The LID Handbook outlines the performance measures and practices that must be included in the LID plan, which include, peak stormwater runoff discharge rates, conservation of natural areas, slope and channel protection, and drain location identification (City of Los Angeles, 2011). For small-scale residential developments, the LID Handbook identifies techniques such as, rain barrels, permeable pavements, and rain gardens to be implemented to comply with the LID ordinance (City of Los Angeles, 2011). For all other developments, the LID Handbook prioritizes the BMPs to be incorporated with the development plan as follows (City of Los Angeles, 2011);

1. Infiltration Systems – Basins, bioretention, infiltration galleries, etc.
2. Stormwater Capture and Use – Rain barrels, cisterns, irrigation systems, etc.
3. High Efficiency Biofiltration/Bioretention Systems – Planter boxes, filter strips, vegetated swales, etc.

Along with the list of BMPs, the LID Handbook also provides developers and residents with information on how to construct, operate and maintain the techniques. The handbook includes information on size requirements and infiltration rate calculations, as well as soil and vegetation requirements (City of Los Angeles, 2011). The LID ordinance also considers the feasibility for a development to achieve the outlined requirements. Accordingly, if a development is unable to meet the ordinance requirements onsite, an offsite mitigation project must be completed, that achieves "at least the same level of water quality protection" as if it were retain on the original site (City of Los Angeles, 2011).

Beyond the LID Handbook and stormwater management plans, the City of Los Angeles provides citizens with an extensive amount of information on their website which addresses proper disposal of potential pollutants, volunteer clean-up events, classroom and event materials, and additional information how to install a rainwater harvesting system (City of Los Angeles, 2015). Los Angeles also promotes various clean-up events and provides information on stormwater management through social media outlets, including Facebook, YouTube, Twitter, and a blog (City of Los Angeles, 2015). The website also includes a "library" of various documents and reports produced by the City, along with additional external resources pertaining to stormwater management and LID.

**Kirkland, Washington – Stormwater Utility and Low Impact Development Techniques**

The City of Kirkland is a community of about 85,000 residents, located east of Seattle along the coast of Lake Washington. The area is considered an oceanic climate which averages 35 inches of rain annually (City-Data, 2015). Kirkland's stormwater utility was formed in 1998, and uses a similar fee structure to the Town of Oro Valley. In Kirkland, single-family properties pay a flat rate of $217.62 annually, which breaks down to $16.87 a month plus a 7.5% utility tax

(City of Kirkland, 2016). Commercial and multi-family properties are charged $16.87 per "equivalent service units" (ESU), which is a measurement of the amount of impervious surface on their property, plus the 7.5% utility tax (City of Kirkland, 2016). Commercial properties can reduce their annual stormwater utility fee by 10% if they implement a "permissive rainwater harvesting system" that collects and uses 95% of annual runoff volumes (City of Kirkland, 2015).

In addition to Kirkland's stormwater utility, the City adopted the "2009 King County Surface Water Design Manual" (KCSWDM), which required developments to "evaluate the feasibility of LID facilities and install at least one element" to mitigate runoff onsite (City of Kirkland, 2015). The requirements for the scale of the LID BMPs are based on the lot size and the amount of impervious area. For example, for lots 11,000 square feet, runoff from at least 10% of the impervious surfaces must be mitigated through a LID technique (City of Kirkland, 2015). Kirkland justified the adoption of this requirement as a tool to mitigate the impacts of development in congruency with the stormwater utility, which is intended to "reduce the impacts" (City of Kirkland, 2014). The scale of the LID technique is dependent on the size of the development and the feasibility based on site features (City of Kirkland, 2015). If the LID BMPs are not feasible on a particular site, a "Stormwater Adjustment Form" must be completed to bypass the requirement (City of Kirkland, 2015). Smaller developments are encouraged, but not required, to incorporate a LID feature. The following are some of the preferred techniques outlined in the KCSWDM (King County, 2009):

1. Dispersion – minimization of the area disturbed by development through "devices that disperse runoff" and native vegetation.
2. Infiltration – Runoff must "fully and reliably" infiltrate the ground for most storm events.

3. Rainwater Harvesting – The collection and storage of runoff for household or irrigation purposes.
4. Reduced Impervious Surface Credit – Impervious surface reduction through “restricted footprint, wheel strip driveways, open grid decking, etc.”
5. Native Growth Retention Credit – A credit for 1 square foot of impervious surface can be considered mitigated by 3.5 square feet of native vegetation area preserved.

The City of Kirkland has also developed both a Surface Water Master Plan and Stormwater Management Program Plan. The Surface Water Master Plan provides recommendations for the community’s priorities and projects to address flooding, water quality and stormwater infrastructure maintenance (City of Kirkland, 2016). The surface water plan provides some details on LID and LID maintenance, however, most design guidelines and information is provided by the KCSWDM. The Stormwater Management Program Plan directly addresses the techniques and approaches of the city to comply with the NPDES permit program, such as public education, illicit discharge mitigation, maintenance and monitoring (City of Kirkland, 2015). The Stormwater Management Program Plan provides the various programs and activities the City has created to inform the public on the implications of stormwater runoff. In particular, the plan identifies the use of social media, brochures, public workshops, volunteer clean-up programs, and other programs that specifically target residents and businesses (City of Kirkland, 2015). Kirkland’s website also provides a variety of resources for residents to take action to manage drainage and flooding, and resources for developers on LID and erosion control (City of Kirkland, 2016).

## Data

The point-based rating system, depicted in Table 1, will be used to compare the effectiveness of each study's respective technique. The sum of the points earned by each study is then used to determine the rating awarded to that management system. Table 2 provides the breakdown of points awarded to each rating level. The comparison the studies with this rating system will help to determine which stormwater management approach yielded the best results. The rating system was developed using considerations from the Environmental Protection Agency (EPA), the EPA's National Pollutant Discharge Elimination System (NPDES), and the Community Rating System (CRS) created by the Federal Emergency Management Agency (FEMA) to determine a flood insurance credit based on stormwater management. In particular, a requirement of NPDES is the implementation of a public education program that informs on the impacts of stormwater runoff and ways to reduce pollutants in runoff (EPA, 2016). Accordingly, the rating system developed in this study looks at the whether a public education program exists, as well as the extent of the program. A public education program is an important component to stormwater management, because it helps to inform people of the impacts of their individual behaviors, which can collectively have a significant impact on stormwater runoff quantities and quality.

The topic of "resources" in the rating system is founded in both the NPDES program and in the criteria for the CRS credit. The subsections addressing the availability and quality of strategies or guides builds on the educational components of the NPDES program, but the existence of a Stormwater Management Master Plan is a feature of both the NPDES program and the CRS credit. The resource topic builds on the public education feature by providing, in greater detail, the specific techniques and actions that residents and developers can implement on their properties to mitigate or reduce stormwater runoff. The Stormwater Management Master Plan is an important feature because it serves as a guiding document that outlines the priorities and actions of the community.

The third topic, “management techniques,” analyzes the specific management techniques that a jurisdiction implements to manage their stormwater runoff. The management techniques section is weighted with the most points since it looks at the effectiveness of what jurisdictions are actually doing to manage their stormwater. The quality of techniques implemented and the level of accountability are the two sections with the most points since these features help to determine the overall strength of the jurisdiction’s management approach. The quality of the techniques is aimed at identifying whether the quality and quantity of stormwater runoff is being addressed, and if there are alternatives if certain sites are not conducive to the management techniques. Implementation accountability is intended to rate the intentions and enforcement level of the management techniques, in order to determine if the jurisdiction is simply “checking a box” to meet federal requirements or if there are attempts to proactively address the jurisdiction’s stormwater management issues. All of the components in the rating system that has been developed, help to determine the effectiveness and the utility of a jurisdiction’s stormwater management approach.

| Topic | Considerations | Points | |
|---|---|---|---|
| **Public Education** | | **10** | |
| Information on the issue | Information on environmental, safety, infrastructure impacts of runoff; information on how stormwater runoff is generated. | | 5 |
| Information on solutions | Information on individual behavior changes; description of LID, green infrastructure, etc. | | 5 |
| **Resources** | | **20** | |
| Availability of mitigation strategies/guides | Are strategies/guides provided? | | 5 |
| Quality of mitigation strategies/guides | Are a broad range of techniques offered? Are design examples provided? Are construction instructions provided? Are maintenance instructions provided? | | 10 |
| Stormwater Management Master Plan | Is there a stormwater management master plan? | | 5 |
| **Management Techniques** | | **60** | |
| Quantity of techniques | Are multiple regulatory or policies approaches being made? | | 10 |
| Quality of techniques | Do techniques aim to improve runoff quality and reduce runoff volumes? Are there feasibility considerations? Are there alternative options? | | 25 |
| Implementation Accountability | Are the techniques mandatory or encouraged? Are they applied to all developments? Are the intentions to meet or exceed federal regulations? | | 20 |
| Extras | Are incentives to reduce impervious cover or exceed requirements offered? Are there any especially unique or creative strategies? | | 5 |
| | | **Total** | **90** |

*Table 1: Stormwater Management Rating System*

| Rating System | Points Awarded |
|---|---|
| Outstanding | 76 - 90 |
| Above Satisfactory | 60 - 75 |
| Satisfactory | 43 - 59 |
| Below Satisfactory | 26 - 42 |
| Unsatisfactory | 0 - 25 |

*Table 2: Rating System Point Classification*

| **Topic** | **Points Possible** | **Points Awarded** |
|---|---|---|
| **Public Education** | **10** | **10** |
| Information on the issue | 5 | 5 |
| Information on solutions | 5 | 5 |
| **Resources** | **20** | **13** |
| Availability of mitigation strategies/guides | 5 | 5 |
| Quality of mitigation strategies/guides | 10 | 3 |
| Stormwater Management Master Plan | 5 | 5 |
| **Management Techniques** | **60** | **35** |
| Quantity of techniques | 10 | 10 |
| Quality of techniques | 25 | 10 |
| Implementation Accountability | 20 | 15 |
| Extras | 5 | 0 |
| **Total** | **90** | **58** |

*Table 3: Evaluation of Oro Valley's Stormwater Management System*

| **Topic** | **Points Possible** | **Points Awarded** |
|---|---|---|
| **Public Education** | **10** | **10** |
| Information on the issue | 5 | 5 |
| Information on solutions | 5 | 5 |
| **Resources** | **20** | **20** |
| Availability of mitigation strategies/guides | 5 | 5 |
| Quality of mitigation strategies/guides | 10 | 10 |
| Stormwater Management Master Plan | 5 | 5 |
| **Management Techniques** | **60** | **50** |
| Quantity of techniques | 10 | 10 |
| Quality of techniques | 25 | 25 |
| Implementation Accountability | 20 | 15 |
| Extras | 5 | 0 |
| **Total** | **90** | **80** |

*Table 4: Evaluation of Los Angeles' Stormwater Management System*

| Topic | Points Possible | Points Awarded |
|---|---|---|
| **Public Education** | **10** | **10** |
| Information on the issue | 5 | 5 |
| Information on solutions | 5 | 5 |
| **Resources** | **20** | **17** |
| Availability of mitigation strategies/guides | 5 | 5 |
| Quality of mitigation strategies/guides | 10 | 7 |
| Stormwater Management Master Plan | 5 | 5 |
| **Management Techniques** | **60** | **50** |
| Quantity of techniques | 10 | 10 |
| Quality of techniques | 25 | 22 |
| Implementation Accountability | 20 | 13 |
| Extras | 5 | 5 |
| **Total** | **90** | **77** |

*Table 5: Evaluation of Kirkland's Stormwater Management System*

## Discussion and Results

### Rating System Results – Town of Oro Valley

Applying the proposed rating system to the Town of Oro Valley's stormwater management approach, based on the information gathered, the town received a "Satisfactory" rating with a score of 58. Table 3 illustrates how points were awarded for Oro Valley. In the "Public Education" section, Oro Valley received the full amount of points in each section because the town does provide information on the impacts of stormwater runoff, and briefly discusses potential strategies that individuals can use to reduce their runoff and pollutants entering the environment.

Under the "Resources" section, Oro Valley was awarded 13 points out of 20. The town received full points for offering mitigation strategies and for having a stormwater management master plan, but Oro Valley lost points in this section due to the quality of the mitigation strategies/guides provided. The rating system determines the quality of the strategies/guides provided by the range of techniques offered, design and construction examples, and maintenance instructions. From those considerations, Oro Valley only provides a variety of techniques that are included in their public education resources, but there is no detailed information provided on how to actually implement those techniques.

Finally, under the “Management Techniques” section, Oro Valley received 35 points out of 60. Under the quantity of techniques, Oro Valley received all of the eligible points because it uses a stormwater utility and fee, as well as the stormwater and pollutant management requirements outlined in their development code to comply with the Clean Water Act. However, the quality of the town’s techniques only received 10 out of 25 points because the performance measures outlined in their stormwater management plan only aim to improve runoff quality. Oro Valley provides minimal information on ways to reduce runoff volumes, besides the fee stormwater utility fee for commercial developments, which is based on the amount of impervious surface. Although this fee system could encourage commercial developments to reduce their impervious surface coverage, there is little financial incentive for developments to alter their behavior due to the small amount of the fee, $2.90 per 5,000 square feet of impervious surface. Furthermore, there are no alternative or feasibility considerations offered to developments or residents besides the stormwater utility fee. For the “implementation accountability” subsection, Oro Valley received 15 out of 20 points since the stormwater utility fee is mandatory for all residents and developments. The town lost points in this section since the stormwater utility and management plan only aims to meet state and federal regulations, instead of taking additional steps to mitigate stormwater runoff. Finally, the town does not provide any unique or creative strategies to manage their stormwater runoff, so they did not receive those additional points.

Oro Valley's flat rate fee of $2.90 per quarter, or $11.60 annually, does not provide residents with an incentive to reduce runoff levels from their properties. Likewise, for commercial properties, which are charged $2.90 per 5,000 square feet of impervious surface, the financial burden is minimal. Furthermore, the revenue from Oro Valley's stormwater utility fees only finances about half of the utility's budget, indicating that there may be a discrepancy in the services provided by the utility and what is being charged for those services. Accordingly, the current system in Oro Valley does not support the literature's idea of a stormwater utility, which is to charge properties' based on the demand they place on the utility's system. Therefore, the current structure of Oro Valley's stormwater management approach does not seem to be the best system for the City of Tucson to model since it predominately addresses the quality of runoff, instead of both the quality and quantity. Quality of runoff is mostly addressed by Oro Valley's stormwater utility through the educational information that focuses on ways to reduce pollutant levels, rather than actual runoff volumes.

**Rating System Results – City of Los Angeles**

The City of Los Angeles received an "outstanding" score, based on the proposed rating system, for its stormwater management practices. As seen in Table 4, Los Angeles received a score of 80 out of 90. In the "public education" section, Los Angeles received all the points possible due to the comprehensive information provided through their website, social media, and "library" of resources. Within this information, Los Angeles details the impacts of runoff, how it is generated, as well as information on ways to change individual behaviors and a thorough description on LID techniques.

In the "Resources" section, Los Angeles also received all the possible points because of their comprehensive LID guide and stormwater management master plans. Los Angeles' LID

Handbook provides residents and developers with both construction and maintenance instructions for a broad range of LID techniques. In addition, Los Angeles has its SUSMP and specific stormwater management plans for particular watersheds to help guide and provide a comprehensive approach to stormwater management in the Los Angeles region.

Finally, in the “management techniques” section, Los Angeles scored 50 points out of 60 points. Los Angeles received full points in the quantity of techniques due to the use of multiple approaches, including the LID ordinance and the stormwater management and drainage requirements outlined in their city code. Los Angeles also received full points in the quality of techniques section with the use of the LID ordinance as the main tool for stormwater management. The LID ordinance helps to reduce both the quantity and the quality of stormwater runoff through the inherent ability of these techniques and the more specific requirement that “rainwater from a three-quarter inch rainstorm” must be captured or infiltrated. The city also earned full points in this section due to the feasibility considerations and alternative options provided in the LID ordinance. The prime example, which allows the city to meet the considerations, is the requirement for developments to establish an offsite mitigation project if installation of LID techniques on the development site is unfeasible. Los Angeles received 20 out of 25 points in the implementation accountability section since the main goal of the city’s management strategy is to meet state and federal regulations. However, the city earned points in this section for making the LID ordinance mandatory for all developments and redevelopments, including smaller-scale residential developments. Finally, Los Angeles was not awarded any points for including additional incentives for residents or developers to exceed the outlined requirements.

**Rating System Results – City of Kirkland**

Based on the proposed rating system, the City of Kirkland received an “Outstanding” rating with a score of 77 out of 90. In the first sections of “Public Education,” Kirkland received full points due to the variety of resources and information the city provides on the topic of stormwater management. Kirkland’s Stormwater Management Program Plan identifies the programs and activities available that are intended to inform the public of the implications of stormwater runoff, including the use of social media and volunteer clean-up programs. Kirkland’s website also has a series of webpages on the topic of stormwater management, including LID, and a list of resources for people to learn more about stormwater management and runoff.

In the “Resources” section, Kirkland scored 17 points out of 20. Kirkland received full points for providing both a Stormwater Management Master Plan and strategies and a guide to mitigate stormwater runoff. The city received seven points in the section evaluating the quality of the mitigation strategies and guides for the provision of thorough guides, but lost three points because the guides are combined with other water-related issues and lack clarity in their presentation of techniques. The lack of clarity and accessibility makes it more difficult for developers and residents to easily acquire the necessary information on how to design, construct, and maintain the LID features.

Finally, in the “Management Techniques” section, Kirkland scored 50 points out of 60. The city received full points for the quantity of their techniques since they have a LID ordinance, a stormwater utility, and additional provisions regarding runoff in their zoning code. Kirkland scored 22 out of 25 points in the quality of techniques sections since their stormwater utility and LID ordinance aims to reduce the volume of runoff while improving the quality of it. The stormwater utility fee provides an incentive for commercial developments to reduce their impervious surface cover to lower their fee rate, which contributes to a reduction in runoff volumes. The LID ordinance also helps reduce impervious surfaces, while incorporating strategies that reduce runoff volumes while improving the quality of runoff. Kirkland also earned points for considering the site-specific feasibility of implementing the required LID techniques. However, they lost three points for not providing alternative options when the implementation of LID techniques is unfeasible. Instead, developers can complete an application to waive the requirement. The ability to waive the LID requirements if it is unfeasible for the specific site also caused Kirkland to lose two points in the implementation accountability section. Although the LID requirement is considered mandatory for developments, the waiver provides an option for developers to bypass the requirement, if the site is eligible. Kirkland lost five points in this section for intending to meet state and federal regulations, instead of trying to exceed the standards. Finally, Kirkland was awarded full points in the extras section for providing a financial incentive through a commercial property's stormwater utility fee if they install a rainwater harvesting system that captures 95% of the site's annual runoff.

Kirkland's stormwater utility is structured similarly to Oro Valley's, but the actual fee rate is a fair amount higher with residential properties paying $217.62 annually, and commercial properties paying $16.87 per ESU, plus a 7.5% utility tax. The higher rates established by Kirkland create more of an incentive for properties to reduce their impervious surfaces. Kirkland's intention to use the stormwater utility fee to help reduce runoff quantities is more apparent than Oro Valley's, since Kirkland provides an incentive to reduce a commercial property's stormwater utility fee if they reduce their runoff volumes by 95%. Accordingly, Kirkland's stormwater utility provides a stronger model to help manage and reduce stormwater runoff than Oro Valley's. However, the accountability of Kirkland's stormwater management approaches are less comprehensive in comparison to Los Angeles', resulting in Kirkland's slightly lower score.

## Conclusion

The focus of this study is to identify the most effective BMPs, techniques and government policies to address urban runoff. Based on the information gathered and using the rating system for stormwater management approaches, the most effective approach is through a strong LID ordinance. The rating system created for the purpose of this study helped to evaluate three case studies that represented three different stormwater management techniques. The rating system considered public education on stormwater runoff, availability of resources relating to stormwater management, and the effectiveness of the actual management techniques. Of the three sections, the effectiveness of the management techniques is the most heavily weighted, especially in the quality of the techniques and their level of accountability for implementation.

The City of Los Angeles received the highest score with the implementation of their LID ordinance. Los Angeles narrowly outscored the City of Kirkland due to the greater clarity and accessibility of Los Angeles' guide, and their stronger accountability that requires a comparable LID mitigation project offsite, if LID techniques onsite are unfeasible. Both Los Angeles and Kirkland outscored Oro Valley, due to the town's poor quality of the execution of their techniques through the inexpensive stormwater utility fee and the minimal resources provided.

Both Oro Valley and Kirkland utilized a hybrid fee structure for their stormwater utilities; meaning that each of the municipalities provided a flat-fee rate structure for residential properties, but imposed a fee structure for commercial properties that was dependent on the impervious surface area of the development. As discussed in the Literature Review, the advantage of a fee system based on site features is that it can encourage residents and developments to reduce the impervious surface quantities onsite, in order to reduce their fee. However, this concept is only effective if there is a meaningful financial incentive to do so, and if alternative mitigation techniques and resources on those techniques are made available.

The results of this study contradict the natural assumption that a municipality with a stormwater utility and a LID ordinance would have a stronger stormwater management system, since multiple approaches could be considered better than one. That said, the results indicate that the quality and the strength of a stormwater management approach is more effective than the quantity. However, it important to note that Kirkland only scored three fewer points than Los Angeles, and both cities scored an “Outstanding” for their stormwater management approaches. The narrow point difference between Kirkland and Los Angeles also indicates that further comparison and analysis of their two approaches may need to be conducted, in order to make an informed decision about which approach is truly more effective.

Of the three case studies analyzed, the two studies that had ordinances requiring the use of LID techniques received “Outstanding” scores on the proposed stormwater management rating system. The effectiveness of ordinances that required LID techniques performed well in the proposed rating system because these techniques address both the quality and quantity of runoff. Stormwater utilities may have been less effective in this rating system since a major feature of stormwater utilities is to supply the funding to maintain and install stormwater management techniques. Therefore, an ordinance requiring the use of LID techniques can have a more direct impact on runoff quantity and quality by establishing explicit requirements that the jurisdiction and all developments must achieve. Whereas a stormwater utility as a management technique focuses more on the jurisdiction's infrastructure, and has a less direct impact on the actions of private developments.

Based on the results of the study, it is recommended that the City of Tucson develop a LID ordinance that is modeled after the City of Los Angeles' ordinance. In particular, Tucson should attempt to replicate both the degree of accountability and the clarity of materials that Los Angeles' stormwater management approach demonstrates. The clarity of Los Angeles' LID guide is important to consider in the development of a LID ordinance, because it provides developers and residents a clear understanding of the expectations and the strategies to meet those expectations. Such clarity can reduce development costs because all the necessary information is readily available, and it can help provide a unified design guide for the community. Tucson should also consider Los Angeles' approach to address feasibility concerns for sites that are unsuitable for the implementation of the LID techniques outlined. This component of Los Angeles' ordinance is highly effective at ensuring that stormwater runoff will be mitigated to a greater extent than if the requirement was simply waived for unsuitable conditions. Los Angeles' LID ordinance provides a strong framework for the City of Tucson to build from to meet Tucson's current needs.

**Limitations**

The stormwater management techniques used in the cases analyzed have been implemented relatively recently, therefore, the impacts of their effectiveness may not be fully realized yet. In addition, the economic and social impacts of these management techniques may not be entirely recognized. Furthermore, the study did not analyze hard data on the improvement of runoff quality, changes in maintenance costs or changes in runoff volumes in any of the studies. This data was not analyzed because the municipalities did not have the information accessible, and because of the time limitations for this study. Finally, each of the municipalities reviewed were different population sizes and land areas. These variations between the cases are a limitation because the resources and conditions between each municipality also vary, so what's feasible for Los Angeles may not be feasible for Oro Valley. That said, the aim of this study is to identify the BMPs and techniques for stormwater management, which has been accomplished by looking at the comprehensive nature of each stormwater management approach.

**Future Studies**

Since there was limited data available from the municipalities on the changes in runoff quality, maintenance costs and runoff volumes after either a stormwater utility or LID ordinance has been implemented, a future study could be to collect that information to further guide the analysis of the BMPs. Other studies could look at the economic and social impacts of either a stormwater utility or LID ordinances. In particular, a study could consider the impacts of stormwater utility pricing on low-income families, or conduct a cost-benefit analysis for developments in places that have implemented these types of stormwater management strategies. Another study could evaluate the effectiveness of stormwater utility fees in reducing the amount of impervious surface on a property.

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