Stormwater Management in Quito, Ecuador: Recommended Strategies and Applications of International Precedents

Gestion des eaux pluviales à Quito, Equateur : stratégies recommandées et application des résultats internationaux

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RÉSUMÉ
Quito, en Équateur, est une ville située en haut d'une vallée « Interandean » (élévation ~ 2,830 mètres), au pied du volcan Pichincha. Au-dessus de la ville, les ruisseaux de montagne descendent de haute altitude des prairies des Andes páramos, le long de pentes abruptes via des quebradas (ravins), jusqu’à la rivière Machángara. Une grande partie de la Machángara et de ses affluents a été comblée ou placée dans des ponceaux, modifiant considérablement le drainage naturel. L'urbanisation a conduit à l'expansion de la ville le long de la vallée, à des colonies le long de pentes précaires et les ravins, à la disparition des zones humides et la perte de páramo. Les eaux pluviales, les eaux usées, et les rivières de la ville souffrent de surcharges de polluants, de conduits vieillissants, et de débordements d’égouts. Les gestionnaires de la ville sont en train d’évaluer le low impact development (LID: développement durable) et les méthodes innovantes pour aider à décontaminer les rivières, à atténuer les inondations urbaines, et à promouvoir des systèmes durables de l'eau. Pour faciliter l'évaluation du potentiel de LID à Quito, nous identifions les opportunités et les contraintes, ainsi que des stratégies provenant d’autres villes LID internationales qui peuvent être appliquées dans le cas de Quito avec ses caractéristiques physiques et climatiques, ses pratiques de planification urbaine et ses structures institutionnelles. En mettant en œuvre des stratégies de LID tout en abordant d'autres priorités en matière de gestion de l'eau, Quito fournit une étude de cas unique d'une ville qui pourrait contourner les modèles prohibitifs utilisés dans les pays industrialisés (par exemple les traitements de fin de chaîne), et servir comme modèle pour d’autres villes de l’Amérique latine qui cherchent à résoudre des problèmes de gestion de l'eau similaires.

ABSTRACT
Quito, Ecuador sits high in an Interandean valley (elevation ~2,830 meters) at the foot of Pichincha volcano. Above the city, mountain streams descend from high-altitude Andean páramo grasslands down steep slopes through quebradas (ravines) to the Machángara River. Much of the Machángara and its tributaries have been filled or placed in culverts, dramatically altering natural drainage patterns. Urbanization has led to the city’s expansion along the valley floor, settlements along precarious hillslopes and ravines, disappearance of wetlands, and loss of páramo. The city’s stormwater, wastewater, and surface waters suffer from untreated pollutant loads, aging pipes, and sewer overflows. City leaders are evaluating innovative low impact development (LID) methods to help decontaminate surface waters, mitigate urban flooding, and promote sustainable water systems. To facilitate the evaluation of LID potential in Quito, we identify opportunities and constraints for LID, along with strategies from international LID precedent cities that can be applied in the context of Quito’s unique physical and climatic characteristics, urban planning practices, and institutional structures. By implementing LID strategies while also addressing other water management priorities, Quito provides a unique case study of a city that could bypass prohibitively expensive models used in industrialized countries (e.g., end-of-pipe treatments), and serve as a model for other Latin American cities seeking to resolve similar water management problems.

KEYWORDS
Cangahua soils, Low Impact Development (LID), Páramo ecosystem, Stormwater, urbanization
1 INTRODUCTION AND BACKGROUND

In the face of population growth, urbanization, and climate change challenges, cities around the world are engaging in efforts to preserve, protect, and revitalize urban landscapes and waterways, and questioning the suitability of traditional, centralized water management paradigms (Mitchell 2006; Gupta 2010; Novotny et al. 2010). Innovative stormwater management strategies have emerged over the past few decades in several urban areas of North America, Europe, and Australia, as well as in some developing countries (Carmon and Shamir 2010). Evolving separately and without much communication, such strategies have been termed Low Impact Development (LID) in the United States, Sustainable Urban Drainage Systems (SUDS) in Europe, Water Sensitive Urban Design (WSUD) in Australia, and Low Impact Urban Development and Design (LIUDD) in New Zealand (Carmon and Shamir 2010; Novotny et al. 2010; Morison and Brown 2011). Alternative or commonly associated terms used internationally include “best management practices” (BMPs), “sustainable urban drainage,” “ecological stormwater management,” and “integrated catchment (or watershed) planning” (Stahre 2005).

Exact components and definitions of LID and its international equivalents vary, but generally include the preservation of a site’s natural hydrologic function by preserving as much of the site as possible in an undisturbed condition and, where disturbance is necessary, reducing the impact on surrounding ecosystems (Carmon and Shamir 2010; Novotny et al. 2010). Typical LID strategies include maintenance of pre-development runoff volumes through reduction of impervious surfaces, preservation of existing porous soils, and improving infiltration and storage practices. LID features have multiple environmental benefits including reduction of pollutants in runoff, increased groundwater recharge, habitat improvement, and reduction in frequency and severity of combined sewer overflows (CSOs) (National Research Council 2009; Carmon and Shamir 2010; Novotny et al. 2010). Knowledge and lessons learned from cities that pioneered innovative stormwater management programs can be useful to other cities concerned about water resources sustainability, particularly those cities desiring to introduce stormwater guidance.

Two fundamental challenges exist for managers attempting to transfer LID knowledge to cities in developing countries. The first challenge is that comprehensive guidelines, research on BMP performance, and knowledge from established stormwater management programs can be difficult and time-consuming to apply to a new city. Prior efforts to compile this information, such as those by the US Environmental Protection Agency (EPA) and Center for Watershed Protection (CWP), and the European Commission’s DayWater project have resulted in databases of information geared primarily toward managers with appropriate multidisciplinary knowledge. Implementation thus requires interdisciplinary teams of engineers, planners, landscape architects, hydrologists, and other specialists. The second fundamental challenge is that stormwater solutions need to be customized for each city. Very few cities can simply duplicate or modify a manual from another urbanized area. This problem is compounded for cities in developing countries because they encounter water management problems not typically experienced by the North American, European, and Australian cities that have produced the majority of stormwater guidance manuals.

In Quito, Ecuador, representatives from both the municipality and La Empresa Pública Metropolitana de Agua Potable y Saneamiento (EPMAPS) have expressed interest in learning from other cities’ urban stormwater management experiences and adapting these strategies for Quito’s unique climate, landscape, and urban water challenges. Quito can benefit from a broad assessment of interdisciplinary factors affecting stormwater management, and general recommendations for beginning a comprehensive stormwater program. In this paper, we use information from precedent cities along with a site analysis of Quito to suggest specific strategies that hold the greatest potential for improving Quito’s stormwater management, at least in initial phases. We first identify guiding principles for stormwater management in Quito and then outline specific strategies suitable for its unique physical characteristics and climate, and capable of having large-scale benefits.

2 METHODS

To determine guiding principles and specific structural BMPs suitable for Quito’s stormwater management framework, we examined precedent cities, and reviewed Quito’s physical and climatic characteristics, planning institutions, and water management policies. This analysis consisted of the following steps:
1. We reviewed policies, structural BMPs, and BMP performance data from select cities facing water management problems similar to those encountered by Quito, and highlighted innovative strategies most applicable to Quito. Stormwater strategies from the following cities were reviewed: Emeryville, California (USA); San Francisco Bay Area (USA); Portland, Oregon (USA); Malmö (Sweden); San Francisco, California (USA); Chicago, Illinois (USA); Philadelphia, Pennsylvania (USA); and Chennai, Tamil Nadu (India). These strategies were supplemented with information from watershed research organizations (e.g., CWP and DayWater) and hydrology or site engineering textbooks (Butler and Davies 2004; DeBarry 2004; Strom et al. 2004; CWP 2007; Thévenot 2008; Gupta 2011).

2. To conduct a citywide site analysis and determine natural constraints and opportunities relevant to stormwater management, we researched physical and climatic characteristics of Quito’s municipal administrative district (Figure 1). We also conducted site visits and interviews with representatives from the municipality and EPMAPS in November, 2011 and March, 2012.

3. We briefly traced the historical urban development of Quito from colonial city to its current urban form to understand how land use and demographics could influence the ability of property owners to adopt site-specific stormwater strategies. We also used site visits and interviews to examine the city’s current water management strategies and institutional structures.

3 RESULTS
3.1 Quito’s Guiding Principles
Based on an analysis of site conditions and water management in Quito (Table 1 and Figure 2), the following principles should direct Quito’s stormwater management policies, at least in initial phases.

1. Quito has a variety of distinct neighborhoods with widely varying demographics, land uses, building types, urban form, and precipitation patterns. Compared to Quito, cities that have already produced stormwater management strategies tend to be relatively uniform with respect to these characteristics. To accommodate the variations in Quito’s physical and climatic characteristics, a combination of management techniques from both developed and developing countries should be employed.

2. Because stormwater runoff in Quito is highly polluted and municipal wastewater is untreated, treatment trains and source control of pollutants should be a priority. Even in areas where runoff reduction might be impossible due to watershed physical characteristics or impermeable soils, LID techniques can still be used to filter runoff and reduce pollutants in water bodies.

3. In many cities, the primary impacts of urbanization are caused by an increase in impermeable surfaces leading to reduced stormwater infiltration. In Quito, however, even in the pre-urbanized period, the natural underlying impermeable cangahua hardpan prevented infiltration in many parts of the city. Therefore, Quito’s soils offer less infiltration opportunities than soils in other cities. Quito will be unable to rely heavily on onsite infiltration strategies to manage its stormwater, and will likely instead rely on retention strategies or small open systems with linings and underdrains.

4. Quito has a strong “vertical” (state-local) and “horizontal” (local-local) partnerships between agencies, communities, and their respective watersheds. Quito also has a comprehensive climate change strategy and “Quito verde” identity that can serve as models for other cities. City and community organizations have initiated conferences, created educational materials, encouraged community involvement, and conducted research related to climate change and other water management issues. These strategies can potentially be applied to implement LID pilot projects and modernize stormwater management.

5. Quito essentially already has a Portland-style regional institutional structure in the sense that DMQ has jurisdiction over all watersheds to which Quito’s urban streams drain. DMQ also manages land use and conservation policies for many of these areas. This governance structure lends itself well to integrated watershed management. Additionally, DMQ already has a legal framework (i.e., city ordinances) promoting LID and could simply broaden this framework as new LID ideas and pilot projects arise.

6. Quito has a strong history of international collaboration and support from international aid agencies. EPMAPS could potentially package specific stormwater programs such as rainwater harvesting or native species planting (e.g., in swales and rain gardens) for support from interested agencies.
3.2 Important Observations

Site visits to Quito and interviews with EPMAPS employees reveal several specific features of Quito’s institutional practices and built environment that hold relevance for implementing new stormwater management practices.

3.2.1 Institutional practices

- Quito environmental agencies and EPMAPS have plans to implement green corridors to improve connectivity between the seventeen ecosystems present in DMQ. The five proposed principal corridors will connect fragmented ecosystems located at the peripheral edges of the cities. These green corridors could provide open green spaces to support many LID practices outlined below.

- EPMAPS has experience establishing, funding, and maintaining programs requiring the interdisciplinary knowledge needed for a stormwater management program. In 2002, for example, EPMAPS established its Programa de Saneamiento Ambiental, which provides both community education and ravine management. Based on previous program successes and its interdisciplinary workforce, EPMAPS is the most appropriate agency to implement stormwater guidelines in Quito.

3.2.2 Built environment

- Quito treats 0% of municipal wastewater. The current system of collectors could be modified to better integrate with proposed LID retention or wetland strategies. LID pollutant control methods are unable to substitute as effective source controls for sewage. However, modifying current wastewater basins with LID designs could reduce the overall pollutant load by settling out stormwater derived pollutants.

- Although Quito’s sidewalks vary in width, a common characteristic of all sidewalks is the potential for larger tree wells, rain gardens, planters, and other small biofiltration methods. Current sidewalks feature a series of parking blocks to deter drivers from parking on sidewalks. Replacing parking blocks with green infrastructure would still prevent parking while adding space for onsite water management.

- As a consequence of Quito’s steep topography, high, unsightly retaining walls stabilize slopes to prevent natural disasters in residential areas. Residents could potentially use these spaces for hanging or vertical gardens depending on the suitability of soils and infrastructure at the top of the walls.

- Quito is surrounded by over 30 quebradas, many of which support developments ranging from informal settlements to modern, new apartment buildings, to residential lots with large houses. These neighborhoods have streetscapes unique to Quito, characterized by streets ending at ravine edges. These street ends provide specific landscape elements with minimal traffic, sufficient open space, and direct access to streams, which could be the focus of a stormwater management cornerstone program.

3.3 General Recommendations

General recommendations for Quito include five primary strategies (Table 2). Based on the site analysis, these particular strategies are most likely to be effective given Quito’s unique physical and climatic characteristics, urban form, and institutional structures. These strategies also hold potential to be integrated with Quito’s current and proposed land use and institutional policies.

3.4 Specific Recommended Stormwater Structures

Each general recommendation outlined in Table 2 requires the selection of specific stormwater structures, which can be classified into point structures, linear structures, and local reservoirs (Carmon and Shamir 2010). Point structures refer to specific site management tools, linear structures refer to conveyance tools, and local reservoirs refer to detention or retention basins (typically located downstream of point structures and linear structures). Point structures, linear structures, and local reservoirs also need to be classified as infiltration, detention/retention, or biofiltration structures (Butler and Davies 2004; CWP 2007; Thévenot 2008). Site variables (e.g., soil type, permeability, depth to groundwater and bedrock) can be used for this purpose, and to determine the following characteristics: 1) Filtration potential (total, partial, or flow-through); 2) Type of lining (unlined or lined, type of lining material); and 3) Drainage potential (with or without an underdrain). Based on a review of
stormwater practices and BMP performance data from other cities facing similar water management problems, structures suggested for Quito are listed in Table 3.

4 CONCLUSION

Both developed and developing countries struggle with water supply and demand, stream and groundwater contamination, and impacts of urbanization on the hydrologic cycle (Parkinson and Mark 2005; Novotny 2010; Gupta 2011). For the past two centuries, water and sewer system models in industrialized countries evolved first to quickly convey stormwater to water bodies without treatment. Later models, particularly after the 1972 US Clean Water Act, continued to focus on quick conveyance, but added end-of-pipe treatment to reduce pollutant levels (Novotny 2010). Although these models resulted in the ability of developed countries to treat moderately large quantities of wastewater and provide a reliable water supply, their stormwater treatment models are expensive and not entirely successful. For example, non-point pollution and CSOs continue as critical unresolved issues in the US in spite of the existence of expensive wastewater treatment systems. Thus effective comprehensive stormwater management in developed countries today still remains an exception rather than the rule; even cities with comprehensive LID stormwater plans still struggle with pollution, CSOs, and loss of natural stream flows.

Developing countries often struggle with even more challenging water-related problems. They are often unable to provide basic potable water supply, they do not even have wastewater treatment plants for sanitary sewage, they have solid waste problems, and pollutant loads in their wastewater and stormwater runoff are far greater and often more toxic than in developed countries. Models from developed countries can be inaccessible to developing countries because of high costs and large urban populations. Even if these models were accessible to developing countries, they would simply replicate the overflow pollution challenges experienced by developed countries.

This paper provides a case study of a large capital city in a developing country that has expressed interest in developing stormwater management strategies using modern, innovative LID approaches and integrated watershed management. Specific challenges for Quito and lessons learned include:

- A stormwater management program must be locally developed both at the cityscale and the (building) site scale. Urbanization has affected every city differently and there is no one solution for all cities. Quito’s primary challenges are complex topography, impermeable soils, high groundwater tables, shallow bedrock, and high precipitation amounts in certain parts of the city. Additionally, limited information about soils, groundwater, and bedrock is available at the site scale.

- Some opposition to LID might initially be expected in Quito because so many physical constraints exist. For example, innovative strategies might be dismissed because of limited infiltration potential. Education will be likely be needed to demonstrate other advantages of BMPs, and to convince managers that LID can still be a reality in Quito. Even if complete infiltration of all stormwater is unrealistic, notable pollutant reduction and some quantity control can nevertheless be achieved.

- More source control is needed in Quito. LID strategies can mitigate some non-point source pollutants and direct large quantities of stormwater away from either centralized or decentralized (future) treatment plants. However, pesticides, solid waste, and sewage pollutants can be more effectively reduced through source control strategies such as street sweeping, regulatory enforcement related to illegal discharges, wastewater treatment, and other pollution prevention practices.

- Quito already has an institution (EPMAPS) that could support a stormwater management program. However, structural BMPs require ongoing maintenance, so EPMAPS would need to prepare for a combination of design, education, and ongoing maintenance responsibilities. This is not an unrealistic expectation given their successful experience with other interdisciplinary programs such as PSA.

Quito’s interest in establishing LID strategies parallels their efforts to resolve other management issues such as municipal wastewater treatment, severe urban flooding and landslides, source control, and sewer system deficiencies. By implementing locally-developed LID practices, Quito could begin resolving several problems simultaneously and will have taken a different path to stormwater management by bypassing unsuccessful or prohibitively expensive models used by developed countries. Quito could potentially be a unique example of achieving some aspects of sustainable
environmental management more efficiently than developed countries have achieved it (where and if developed countries have achieved it). In this respect, stormwater management in Quito could be a model not only for other South American cities, but also for cities in developing countries worldwide.
Table 1. Quito site analysis key observations relevant to stormwater management

| Topography | Over 33 major streams and ravines surround the valley of Quito and most of them have been filled or channelized, often with poor quality materials. Often used as sites for landfill or illegal development, filled streambeds can exacerbate flooding, subsidence, soil saturation, and landslides caused by natural springs in the area and stormwater runoff. Streams in both filled and unfilled quebradas can grow suddenly during storms and send runoff to flood low-lying areas of the city (Metzger and Bermúdez 1996). |
| Soils | Pyroclastic “cangahua” impermeable hardpan outcrops are prevalent throughout most of the watershed due to cangahua’s periclinal form. It ranges from one meter to tens of meters thick and consists of silty sands and sandy silts along with pumice and lapilli. Cangahua is the source of impermeable soils in many parts of the city. It is also susceptible to cracks and fails when saturated. |
| Precipitation | Altitude exerts a strong impact on climate in Ecuador, and gives rise to a variety of climates ranging from tropical coastal regions to glaciated Andean volcano peaks. Within DMQ, this variable topography and orography result in highly variable microclimates. In Quito, annual precipitation averages can vary widely over remarkably small distances, ranging from 500 mm/yr in the arid northern parts of the city to over 3,000 mm/yr at higher elevations in the south. |
| Projected climate change impacts | Climate change is expected to exacerbate many of Quito’s water management problems by decreasing precipitation, causing more frequent and intense storms, and reducing the ability of native páramo grassland ecosystems to store water, which will contribute to increases in stormwater runoff. It is likely that the increased frequency in floods, droughts, and landslides experienced over the past decade can also be attributed (in part) to climate change (MDMQ 2009; Zambrano et al. 2011). |
| Demography | The southernmost administrative zone of Quito, Quitumbe, has a high percentage (46%) of “irregular” (i.e., illegal) housing and some of the highest poverty rates in Quito. The area also receives high rainfall, has impermeable soils, and high groundwater tables. Due to this combination of constraints, Quitumbe will have a restricted suite of stormwater BMPs from which to choose. |

Figure 2. Key sources of stormwater pollutants in the Machangara watershed.

A longitudinal profile of Rio Machángara from its headwaters to the Rio San Pedro confluence shows that the sources of non-point pollutants vary according to elevation and land use. Near the headwaters, pollutant sources include agriculture and low density housing, pastures, and small farms. Along the heavily urbanized portion of the river in southern Quito, high-density housing, roads, and industry generate pollutants. Finally, as the river flows eastward toward the lower suburban valleys, pollutant sources consist of debris from quebradas, and runoff from the main highway and low density housing developments in the lower valleys.
Table 2. Five primary suggested strategies

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<th>Detention, Retention and Wetlands</th>
<th>Of the many BMPs available, retention basins (wet ponds) will likely provide the primary mitigation measure for stormwater quality and quantity control in Quito because they are suitable for Quito’s clay soils. Situating basins near Quito’s urban rivers could provide some pollution treatment before runoff enters rivers or other water bodies. Placement near collectors (or modifying collector basins) could provide some treatment at current wastewater discharge points. Retention and detention basins can be combined with other treatment options as part of “treatment trains” to allow for even higher pollutant removal rates.</th>
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<td>Swales</td>
<td>Swales play an important role in transporting runoff through any open drainage system. In impermeable zones, they often have drainage pipes to redirect excess runoff (CWP 2007; SFPUC 2009a). They can be decorative, showcase native Andean grasses and plants, and reduce dependence on curbs, gutters, and storm drains. Their linear nature makes them suitable for use alongside streets to mitigate road runoff pollutants such as pet waste, a major source of stormwater contamination on roads in Quito. The linear nature and conveyance ability make them good options for treatment train elements. In Quito, swales are especially appropriate for the major north-south highways with flat slopes and open space alongside. Swales could also be used as standard features to transport outflow from wet ponds to Machangara tributaries.</td>
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<td>Cornerstone programs</td>
<td>Cornerstone programs modeled on programs like Chicago’s Green Alleys or Portland’s Green Streets could serve as starting points for innovative strategies in Quito. Several land use types (e.g., quebradas, streets, or plazas) could potentially be used for pilot projects in Quito and eventually evolve into cornerstone programs. These programs would consist of integrating aesthetic and recreational elements into the existing built environment or new suburban developments. Cornerstone programs would complement the city’s “Quito verde” identity, as well as the growing interest in public and private gardens, native ecosystems, and traditional Andean ecological principles.</td>
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<td>Rainwater Harvesting and Urban Agriculture</td>
<td>Rainwater harvesting is suitable for Quito’s frequent, short, intense storms and can mitigate some of the impacts of projected climate change water shortages. A rainwater harvesting model can be community-based and decentralized, and requires relatively little coordination with existing infrastructure, or other households. Residents need only minimal income and educational materials to set up harvesting equipment. Solutions are nearly immediate. Urban agriculture in Quito quebradas can be combined with rainwater harvesting and could help reconnect rural and urban communities, promote traditional Andean ecological principles, and contribute to conservation of native species in quebradas. Urban agriculture in Quito could contribute to stormwater management through three mechanisms: (1) soil rehabilitation (leading to runoff reduction) by native plants; (2) crop irrigation as a preferred “use” for harvested rainwater; and (3) agricultural green roofs offering urban dwellers space to grow crops and providing further incentive to reduce runoff from structures.</td>
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<td>Stream Daylighting and Open Drainage Systems</td>
<td>Quito has several hundred kilometers of streams placed in underground conduits. Stream daylighting provides one method to help transform Quito’s current system of underground collectors to a more open drainage system. EPMAPs employees have identified many historical natural stream courses. By combining this information with locations of culverts and pipes in disrepair and locations of low-lying areas subject to frequent flooding, EPMAPs could prioritize areas where stream daylighting would be most valuable. Daylighting would reduce the amount of water entering future planned wastewater treatment facilities by directing stormwater into open channels. Daylighting would also help meet Quito’s objectives of reconnecting people with streams and helping residents understand the value of natural ecosystems.</td>
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Table 3. Examples of specific recommended stormwater structures for Quito
(P.S. denotes point structure, L.R. denotes local reservoir, and L.S. denotes linear structure)

<table>
<thead>
<tr>
<th>PERMEABLE PAVEMENTS (P.S.)</th>
<th>Relevance for Stormwater Management in Quito</th>
<th>Constraints for Stormwater Management in Quito</th>
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<td></td>
<td>High pollutant removal rates for grease, oil, metals, suspended solids. Certain materials are widely available in Quito (e.g., brick, concrete for pervious concrete or pavers, asphalt for porous asphalt)</td>
<td>Low pollutant removal rates for sewage contaminants. Certain materials could be prohibitively expensive for large-scale use in Quito (e.g., natural stone, crushed aggregate or gravel). Permeable pavements should not be used in industrial areas of Quito that lack source control.</td>
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<tr>
<td><strong>GREEN ROOFS (P.S.)</strong></td>
<td>Relevance for Stormwater Management in Quito</td>
<td>Constraints for Stormwater Management in Quito</td>
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<td>Quito has already introduced green roofs and expressed interest in their future potential for water reuse.</td>
<td>Because of exposure to strong equatorial sun and frequent, intense hail storms, plant selection is limited.</td>
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<td>Green roofs for public and commercial buildings have strong top-down support from Quito’s mayor and Environmental Secretary. Many Quito residents express interest in private gardens.</td>
<td>Green roof soil types and depths suitable for Quito are still in experimental phases.</td>
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| **VEGETATED INFILTRATION BASINS (P.S.)** (e.g., rain gardens, curb extensions, planters) | In permeable soils (away from industrial sites) bioretention can be used for groundwater recharge. | Because of limited infiltration potential in Quito, most bioretention basins would need an underdrain leading to the storm system. |
| In areas of Quito with permeable soils (i.e., no need for underdrains), runoff reduction from bioretention systems can exceed 90%. Basins can be customized for available space, incorporate design elements, and support a variety of plants. Bioretention has aesthetic value and high pollutant removal rates. | Bioretention is generally used for relatively small drainage areas. Native plant species can be difficult to find in Quito and prohibitively expensive. Facilities require ongoing maintenance if aesthetic elements are to be maintained. | |

| **RAINWATER HARVESTING (P.S.)** | Prevents relatively clean water from entering stormwater system. Some design elements can be incorporated (e.g., rainwater chains). Rainwater harvesting offers a relatively inexpensive, low-maintenance water conservation method. | Requires some community education prior to installing in residential areas. Rainwater harvesting does not provide water treatment. | |

| **ADDITIONAL SITE-SPECIFIC STRATEGIES (e.g., oil separators, swirl separators, catch basins)** | Can remove pollutants from water using physical differences in pollutants (e.g., trash and oil can float to top of basin). Good for dense urban areas where other strategies do not remove enough pollutants. Good for small businesses in Quito who contribute to clogged sewer problems by discharging grease or other contaminants. | These strategies could be difficult to implement unless Quito provides incentives (e.g., establishes a regulation for grease control). Low removal rates for nutrients and fine sediments. Separators and sumps can be relatively expensive. Size of separator or basin limits water quantity that can be treated. | |

| **CONSTRUCTED OR RESTORED WETLANDS (L.R.)** | Optimal sites include former wetlands (e.g., Carolina park or properties that were drained for cattle ranching). Large wetlands with multiple cells have high pollutant removal rates and could be placed near runoff discharge points. Wetlands have high aesthetic and habitat value. | Adequate surface area is needed for wetlands—they are not typically used for on-site management. Quito might need sediment basins upstream of wetlands to prevent sediment buildup. Wetlands generally need a continuous water source. | |

| **WET PONDS (L.R.)** | Permanent ponding allows for high pollutant removal rates (higher than most other reservoir options). Sealed bottoms allow them to be used in Quito’s impermeable soils. Provide aesthetic and recreational benefits (i.e., a recreational pond). | Sealed bottoms and standing water limits groundwater recharge potential. Large surface areas are needed to accommodate permanent ponds. In some cases, runoff volumes might not be reduced. | |

| **VEGETATED SWALES AND STORMWATER CASCADES (L.S.)** | Linear nature makes them suitable for road runoff or along property. A series of swales or shallow pools ("cascades") separated by weirs can be used for areas in Quito with steep slopes. Swales are well-suited for Quito’s low-density suburb road runoff. In new developments, swales could be standard features. Swales provide aesthetic amenities, add to biodiversity, and have low installation and maintenance costs. | Because of Quito’s impermeable soils and high groundwater tables, underdrains would be required in most places. Pollutant removal rates could be lower during high-velocity flows from Quito’s short, intense storms. Quito’s high-velocity flows could cause erosion. Roads in Quito’s colonial neighborhoods and other ultra-urban locations lack nearby open space for swales. |
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