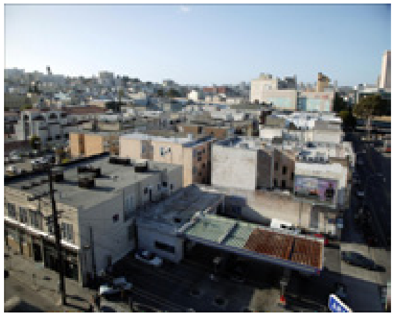
Designing Stormwater with Green Roofs in San Francisco

375 Alabama Street



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ABSTRACT

Across America many cities have suffered from the ever increasing demand of the growing population due to urbanization. Strolling through a downtown metropolitan area, many miles of impervious pavements cover streetscapes and as a result lead to sewage backups and flooded streets. All this is due to poor stormwater management practices. The Mission District in San Francisco fits this category. I particularly chose this site because its location is just filled with impervious surfaces and as a remedy to the problem, green roofs will be measured to mitigate the stormwater issue, on the ground plane level and rooftop. The intent of this project is to evaluate effectiveness of using green roofs/rooftop gardens as infrastructures to minimizing stormwater runoff in urban cities. The vicinity of the project will be within the San Francisco bay area. I will be designing a green roof for the building on 375 Alabama St., San Francisco, CA.

Acknowledgements

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DEDICATION

Special thanks to my family who have supported me throughout my entire college career with unconditional love

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INTRODUCTION

As the population in America increases (tenfold through each decade), the demand for more land occupancy within the metropolitan cities occurs. With more land subjected to development to meet the needs of a growing population, more of the taxpayer dollars are being put to work to expand and retrofit the existing stormwater infrastructure to lessen the stress on the sewer systems during the rainy months. Rather than making modifications on the ground level and constantly breaking ground, why not move upwards toward the rooftop of buildings and start making changes there by building green roofs?

FIGURE 1 CITY OF SAN FRANCISCO

For centuries, green roofs have existed and have been heavily implemented throughout Europe and it is through these past decades that the baton has been passed over to North America. "Green roofs are simply roofs bearing vegetation that may take many different forms" (Cantor

2008). The green roof technology, although not new, has become a trend in the sustainability movement. There are 3 types of green roofs which are: intensive, extensive and semi-extensive, which will be later discussed in the paper.

As the effectiveness of green roofs is recognized, municipalities across North America, like Portland, are creating incentive programs for property owners to build green roofs. It would make sense for other large municipalities, like the City of San Francisco, to follow in their footsteps in promoting green roofs (Fig. 1). By implementing green roofs in San Francisco on a large scale, not only would it bring greenery to the buildings and raise environmental awareness but it would also show that the Bay Area is at the forefront of innovation. The large scale green roof system will become part of the city's urban landscape, creating a connection between the parks, the environment, and open spaces.

This project will demonstrate the effectiveness of green roofs. The green roof that will be proposed is located in the Mission District of San Francisco, on Alabama Street. The building the proposed green roof design is for is a commercial property and is privately owned. This particular building was chosen due to its two tiered rooftop and also for its ease of accessibility for this project. This Mission District location has a unique land profile where it creates microclimates, making it warmer than the rest of the city. Not to mention, San Francisco has frequent sewage system backups during the rainy seasons.

In the course of this paper, the benefits and disadvantages of the implementation of green roofs will be addressed. The benefits include: aesthetic improvements, air pollution reduction, reduction of urban heat island effect, energy efficiency, increase of roof life expectancy, and ecological restoration. More emphasis is placed on the effectiveness of green roofs and the benefits if used as a mitigation tool with stormwater. The effects of stormwater on the receiving ends of the San Francisco watersheds and what role green roofs will play will be addressed. Furthermore, cost estimates on implementing a green roof for a single building to a city wide scale will be examined for the City of San Francisco. With the aim of designing a successful green roof, a series of case studies were conducted at several sites in San Francisco and out of state: California Academy of Sciences, Yerba Buena Gardens, and ASLA headquarters in Washington D.C. Due to drawbacks, thorough evaluation of these built projects was not accomplished; however, the successes and failures of the program elements found at these sites are addressed and incorporated into the proposed design for the building on Alabama Street.

The goal of this research project is to educate individuals on green roofs and what role they play in the stormwater infrastructure system. The project also aims to inform individuals of the reason the City of San Francisco would be a great municipality to lead the way for a city wide green roof implementation.

Information from the case studies and a literature review will be used in the proposed green roof design for the building on Alabama Street. Schematic plans will be produced along with which plants are to be used in each scenario. A compilation of stormwater calculations and cost estimates will be part of the final product. On top of that, a city wide scenario simulation will be produced to compare and contrast the effects of a single building to a large scale implementation of green roofs.

HISTORY OF GREEN ROOFS

The birth of green roofs wasn't a 21st century innovation rather one that dated back to the ancient civilizations. By examining the history of green roofs, it will show how the ancient idea has evolved through the centuries, initially for aesthetic purposes to one that is practiced today for mitigating the environmental issues plaguing the built environments. These issues will be further discussed in later chapters.

It was during the 7th century when the idea of roof gardens was developed, such famous example is the Hanging Gardens of Babylon, although there is lack of evidence that the place existed (Fig. 2). Other historical references to roof gardens were the great stepped pyramidal towers of Mesopotamia, known as ziggurats, which were built during 4th B.C – 600 B.C. The landings and flat terraces of these towers had vegetation growing on them to alleviate the heat exposure and to soften the climb for users (Osmundson 1999). One of the ziggurats that can still be seen today is the ziggurat of Nanna in Iraq. Shifting over to Europe, for centuries countries such as Kurdistan and Scandinavia

FIGURE 2 HANGING GARDENS OF BABYLON

have traditionally employed the combination of using both mud and grass for their rooftops for insulation during the winter and summer months (Dunnett, 2008). These types of grass rooftops had the most influence on structure of the contemporary green roofs seen today and would be considered to be extensive roofs (Fig. 3). Similar sod roofs were built by European settlers during the western expansion of America. It wasn't until events such as the World Exhibition of 1868 in Paris that brought the popularity of extensive roofs into the mainstream where the showcase of a concrete 'nature roof' was displayed (Dunnett, 2008).

Following the exhibition, various types of roof gardens were built throughout North America.

FIGURE 3 SOD ROOFS

With new advancements in better building materials, sturdier buildings were developed which directly influenced green roofs. During the 20th century, the development of building materials and more sophisticated construction techniques in Europe and America lead to the construction of more elaborate rooftop gardens (Dunnett, 2008). As a result of the technological advancements in building materials, a famous intensive roof garden built around this time period was the Rockefeller Cenvter.

The popularity of contemporary green roofs is credited to Germany for spearheading the green roof movement through their concerns with the environment and ecological degradation during the 1950s. It is these principles along with ones from countries such as Scandinavia that we build green roofs today. Through the years of research, the realization of the benefits of green roofs provided to the building and users alike can't be without and are a triumph to improvement of the environment.

COMPONENTS OF GREEN ROOFS

Putting together a green roof isn't as simple as setting down a roll of grass on a rooftop. Rather green roofs are comprised of multiple layers, similar to a sandwich with different condiments stacked on top of each other. Each of the different types of green roofs, extensive, intensive, or semi-intensive, all have these layers. The following layers of the green roofs will be discussed and are ranked from the top to bottom are: vegetation, growing medium, filter fabric, drainage, root protection, waterproof membrane, and the roof deck. Although there are three different types of green roofs, these layers are commonly found in each one. A general overview of each layers function with the green roof will be discussed.

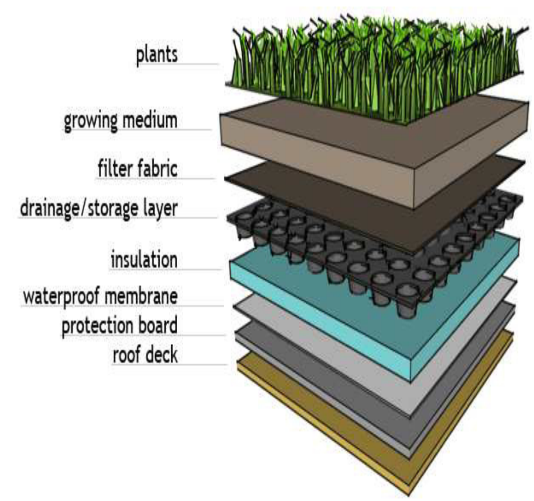


FIGURE 4 LAYERS OF A GREEN ROOF

Vegetation

The vegetation layer is the visible layer where the user of the green roof will see the different types of plants growing. Like the plants on the ground level, these plants are subjected to the exposure of the sun and different climates on the rooftop. The plants ability to survive through harsh climatic changes and various environmental factors is determined by its adaptability to its suitable climate zone. Each of the three different types of green roofs has this layer; however, the types of vegetation planted on them vary on the rooting depth of each plant. Out of the three green roofs, the lighter weight extensive roof system has shallower growing vegetation, such as drought tolerant succulents and mixtures of herbs. Going up a level, the heavier weighing intensive green roof system can hold deeper rooting vegetation, such as sedums, perennial grasses, to shrubs and small trees (Cantor 23). The third system, semi-intensive roof, has both the shallow and deep rooting vegetation with only portion of the roof dedicated to the deep rooting vegetation. For the vegetation to thrive on a green roof the right types of plants should be chosen to suit the weight of the roof and the depth of the system can sustain.

Growing medium

Following the vegetation layer is the growing medium that upholds the vegetation. Unlike the growing medium found in ground level plants, the growing medium for green roofs need to be light weight so that the structural load on the roof will not be heavy and lead to costly retrofits to the rooftop. When choosing a growing medium, "soils with high percentage of organic content may have disadvantages for green roofs, whether extensive or intensive. Over time, the organic components decompose and the surface level of soil recedes." (Cantor 23) In addition, high organic content growing mediums can lead to the blockage of both the filter fabric and the drainage layer. However, it is not to say, organic content in the medium can't be mixed in with overall medium, but just minimal amount. Thus, inorganic growing medium is the more suitable choice. These inorganic mediums are the following but not limited to: shale, pumice, lava, and expanded brick (Cantor 24). The fineness of the growing medium also needs to be taken into account on the survival of the vegetation since it regulates the amount of water retained and drained within the growing medium layer.

Filter Fabric

Subsequently, after the growing medium layer comes the filter fabric. The role of the filter fabric is to prevent the clogging of the drainage layer from the particles of the growing medium. If the drainage layer were to be clogged due to the failure of the filter fabric, water would not be distributed throughout the green roof system. Additionally, the water would not drain properly and cause stress to the plants (Cantor 26).

Drainage

Below the filter fabric is the drainage layer. The drainage layer similar to the growing medium absorbs water but on a larger scale. "This layer usually composed of synthetic or high permeable granular mineral material is used to collect the excess water not absorbed by the plants and growing medium" (Cantor 26). These granular materials are but not limited to: gravel, stone chips, lava rocks, and pumice. The water collected is diverted to the drainage channels within the green roof system. "If drainage is inadequate on a flat green roof, then damage to the roof membrane may ensue because of continuous contact with water or wet soil." To create a successful green roof, a good drainage layer is vital its overall health.

Root protection

Underneath the drainage layer comes the root protection layer. The function of the root layer is to stop the roots from causing leaks by penetrating into the waterproofing layer. The root layer material is made of either PVC material, copper foils, and or the use of root-retardant chemicals (Cantor 27).

Waterproofing

The waterproofing layer is the first layer that is applied to the roof. The intent of the application is to make the rooftop leak proof from the excess water. The materials used for waterproofing but not limited to are: PVC, EPDM rubber, and applied polyurethane. In addition, some of the materials used for waterproofing have extra protection for root penetration prevention.

Roof Deck

The roof deck is the main structure the green roof will be assembled on. Typically, the types of decks commonly found in green roofs are ones with reinforced concrete, precast concrete planks, steel, and steel concrete composites (Cantor 27). Depending on the type of green roof being assembled, structural modifications of the roof deck may be necessary.

TYPES OF GREEN ROOFS

Intensive

Intensive roofs are similar to the gardens on the ground level where it's expected that people will use the space like a conventional garden (Dunnett 4). Built to be aesthetically pleasing and support human foot traffic and accessibility, these types of green roofs require regular maintenance (Fig. 5). Intensive roofs

FIGURE 5 WEST ONE APARTMENTS IN UK

have deep soil depths and can go from more than a foot deep with a saturated weight of 70+ lbs/sq. ft (Green Roof Types). The deep soil depths allow intensive green roofs to support a diversity of plants which include but not limited to: trees, shrubs, lawns, and herbaceous plantings. By having deeper soil depths than the other types of roofs, the added weight of the saturated/unsaturated soils and vegetation creates the need for stronger structural support. With more advantages, the intensive roofs cost more than the extensive roofs.

Extensive

Extensive roofs are not intended for regular use by humans, and are deemed inaccessible. However though, there is the possibility for pathways and small gathering areas near the rooftops building structures. From a maintenance standpoint, extensive roofs are low maintenance (Fig. 6). The soil depth of the extensive roof is shallower than that of the intensive roof, where it ranges from 3" – 6" deep with a saturated weight of 15-30 lbs/sq. ft, leading to lighter weight materials and structural support (Green Roof Types). Unlike intensive roofs, the vegetation on extensive roofs is not as diverse, where the selection of plants is shallow rooting and drought tolerant which includes but not limited to: succulents, mosses, and grasses. With the usage of drought tolerant plants, irrigation is optional. The role of the extensive roof is more of an ecological approach where less material is used to build it, resulting in a more cost efficient green roof.

FIGURE 6 EXTENSIVE ROOF AT BALITMORE HILTON

Semi-Intensive

The combination of both the intensive and extensive roof elements leads to the semi-extensive roof. "Semi-extensive roofs have the same low or no-input philosophy as the extensive roof and use similarly lightweight substrates and modern green-roof construction technologies…" (Dunnett 7). The depth of the semi-intensive roof ranges from 6"-12" deep and has a saturated weight of 30-50 lbs (Green Roof Types). Similar to intensive roofs, semi-extensive roofs can harbor diverse plant materials, which include but not limited to: shrubs, grasses, herbs, and perennials. By being a hybrid of the two other green roof types, the semi-extensive roofs are intended for human use and require regular maintenance (Fig. 7). Semi-extensive roofs cost slightly more than the extensive roofs but less than the intensive roofs.

FIGURE 7 SEMI-INTENSIVE ROOF ABOVE CALHOUN BUILDING

BENEFITS OF GREEN ROOFS

Transforming barren roofs into green roofs has many benefits associated with it. Green roofs can be costly retrofits to the building it's being assembled on however, looking at the bigger picture; the services provided by the green roofs surmount the economical costs. Individuals, the building owner, the surrounding community, the environment and even wildlife directly benefit from the implementation of green roofs. The following benefits will be discussed: stormwater runoff, improved water quality, mitigate urban heat island effect, energy conservation, wildlife habitat creation, and air pollution.

Stormwater runoff

Storm events cause large amounts of stormwater runoff from impervious paving and barren roofs to go into sewer systems and watersheds. Municipalities and communities are often times affected by stormwater runoff during peak heights of storms. The impact of stormwater can cause floods, create runoff from industrial chemicals, promote erosion, and even habitat destruction. Wastewater treatment plants and the sewer systems often times overload in heavy storm events creating excess discharge into the watersheds. The impervious paved surfaces most of the time have contaminants such as oils, particulates, pesticides, and other heavy metals (Dunnett 55). If these contaminants were to be washed away from a storm event, the receiving ends of watersheds will be polluted. Green roofs mitigate the stormwater runoff predicament by retaining and detaining the stormwater within the vegetation and growing medium layers. The absorption of stormwater within the layers of the green roof reduces runoff into the streets and lessening the impact on the stormwater infrastructure system, minimizing risk of flood and water pollution (Fig. 8). "Studies have shown that extensive roofs will typically capture between 50 and nearly 100 percent of incoming rain, depending on the amount of growing medium used, the density of vegetation, the intensity of an individual rainstorm, and the frequency of local rain events. An intensive green roof, with thicker layers of growing medium, will capture more rainfall under comparable conditions than an extensive roof" (U.S EPA, P.8).

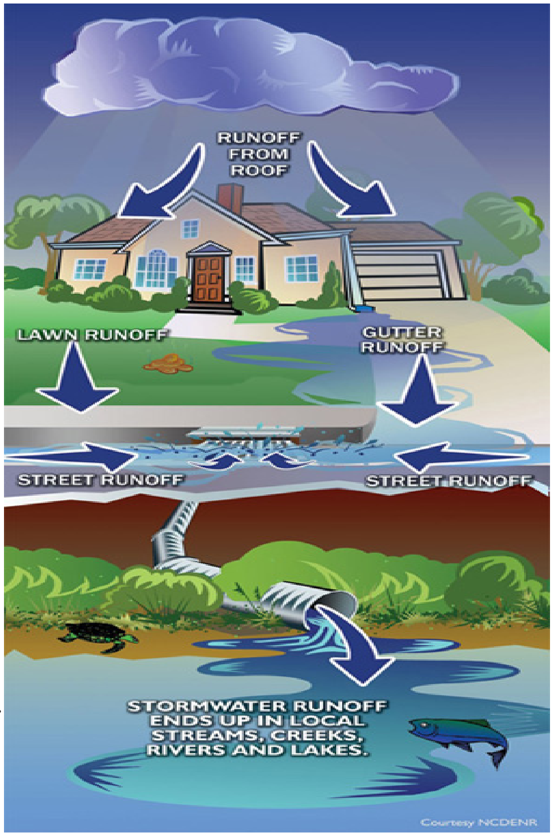


FIGURE 8 STORMWATER PROCESS

Regardless the type of green roof assembled on buildings, they can be used as stormwater management tools.

Improve water quality

Green roofs not only slow stormwater down but act as filters for the stormwater. "Findings from various studies demonstrate the ability of green roofs to remove pollutants and highlight the need to select growing media carefully to avoid elevated levels of certain pollutants, which may initially leach from organic materials" (U.S EPA, P.9). Certain municipalities that have combined server systems, during storm events the runoff stormwater can alter the sanitary treated wastewater, decreasing the effectiveness of the treatment plants (Whole Building Design). With the slowing down of the stormwater, the efforts from the treatment plants will not be put to waste.

Mitigate urban heat island effect

The urban heat island effect is when the temperature is higher in built areas than the rural areas (U.S EPA). With more buildings being built in cities and more land subjected to development, the growing concern of urban heat island effect is spot on. Paved surfaces and dark colored building materials absorb the heat during the day and release at night due to the lack of vegetation mitigating the absorption of heat (Cantor

2008, P.30). Green roofs provide buildings with a layer of protection from the heat absorption. "The processes of evaporation from green roofs and transpiration by plants release water, and cool the ambient temperature of the building." (Cantor 2008, P.30) With a network of green roofs built on a large scale, the urban heat island effect can be potentially mitigated (Fig. 9).

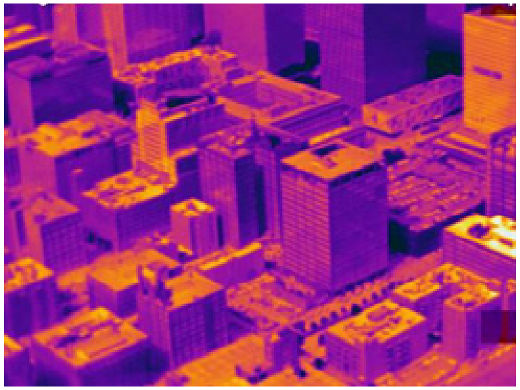


FIGURE 9 URBAN HEAT ISLAND EFFECT

Energy conservation

Green roofs can impact a buildings usage of energy. With the ability to reduce temperature, buildings will use less energy to cool down the building compared to a building with a bare roof. The green roofs provides a layer of insulation for the building repelling heat during warm months and keep heat in during the cold months. By conserving energy year round, the green roof cuts the cost of energy for the users of the building.

Wildlife habitat creation

With more land being developed, wildlife habitat destruction is inevitable. Green roofs can replace the developed land by creating habitat ecosystems for the wildlife. The vegetations chosen for a green roof have the potential to replicate natural habitats and attract wildlife depending on the design. "Plants that provide nectar and pollen resources are especially important, and in many cases plant species support specific invertebrate species." (Ecoschemes 2003, P. 30) Due to the lack of disturbance by humans and accessibility, extensive green roofs have higher habitat value than the intensive roofs. These green roofs serve as links to open spaces for wildlife.

Air pollution

Air pollution is contributed by the growing population of humans and the rapid expansion of development (Fig. 10). The vegetation on the green roof has the ability to absorb the pollutants in the air. Through the decrease energy consumption during the warm seasons, it will decrease the emissions of green-

FIGURE 10 AIR POLLUTION

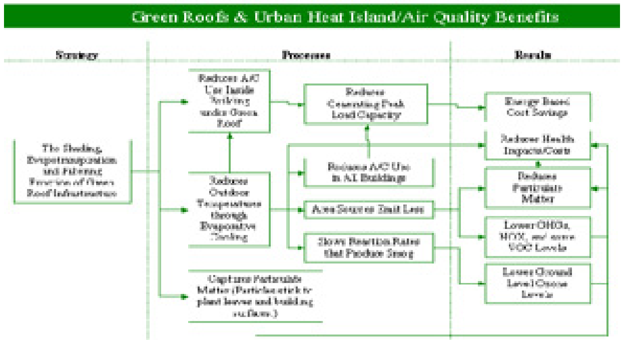


FIGURE 11 GREEN ROOFS & AIR AND HEAT ISLAND EFFECT QUALITY BENEFITS

house gases and burning of fossil fuels since they're directly associated with energy production (Fig. 11). Plant materials require the intake of carbon dioxide from the air for the process of respiration. Through the intake of carbon dioxide, the plants are reducing the heat trapping gas that contributes to global warming (Trees and Vegetation).

Although green roofs economically cost a lot to build in the U.S. compared to the conventional roof, they are assets to the environment and to people. In the long run, the green roof will pay itself off for the building owner and provide ecological services to the environment. Green roofs turn the grey rooftops to thriving spaces. The quality of life is better for humans with green roofs because it provides a green space for individuals to go to when stress needs to be relieved or just simply a place to relax. Wildlife biodiversity benefit from the creation of green roofs because they have a makeshift habitat away from their natural environment in times of need. Watersheds are not impacted as much with green roofs mitigating stormwater. Green roofs even increase the L.E.E.D points for a project.

Disadvantages

The initial investment of green roofs can cost the building owner a substantial amount. Extensive roofs can cost from $5 - $25 sq/ft. and intensive roofs go from $25 - $40+ sq/ft. (U.S EPA, P.10) Also, If green roofs were installed incorrectly, it can lead to structural damages caused by water leaking into the building. No matter the size of the damage caused by the leaking roof, it is a significant value for the building owner.

TRADITIONAL STORMWATER INFRASTRUCTURE

Besides the green roof technology, there are various types of ground level stormwater infrastructures used by municipalities to alleviate the stormwater runoff issues. These ground level infrastructures work great as a team with green roofs because they have the ability to capture debris's and pollutants green roofs can't due to location differences.

Bioswales

FIGURE 12 BIOSWALE IN PARKING LOT

Bioswales are slightly sloped ditches with vegetation growing in them (Fig. 12). The role of bioswales is to slow down the runoff of stormwater by detaining and improving the quality through the filtration in the vegetation and engineered soils. Through the reduction of runoff, it directly reduces the chances of erosion elsewhere and has the potential to create habitat depending on vegetation selection. Bioswales have the ability to reduce more than 80% of pollutants and sediments from runoff. The cost of the bioswale is about $0.50 sq/ft.

(Grass Swales) Bioswales are relatively inexpensive compared to green roofs and depending on the size, it can cleanse significant amounts of pollutants from stormwater.

Catch Basin

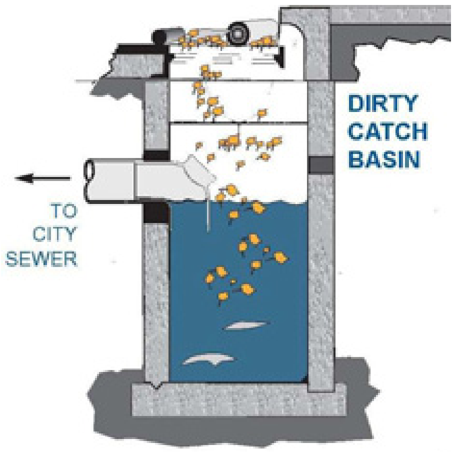


FIGURE 13 CATCH BASINS

"Catch basins are inlets connected to the storm drain systems that typically include a grate or curb inlet and a sump to capture sediments, debris, and associated pollutants" (Catch Basins, Fig. 13). These catch basins serve as a filter for the other stormwater management practices because they have the ability to trap the large sediments and pollutants. Catch basins can be upgraded by adding an insert so that substances such oils and greases can be captured during storm events. These inserts can be either plastic trays or filter fabrics that can be added to the catch basins. The efficiency of a catch basin depends on the size of the sump and typically, catch basins can capture sediments up to 60% of the sumps capacity (Catch Basins). These additions to storm drain systems cost about $3000 per unit which is inexpensive, but the equipment used to clean out these catch basins can be fifty times the amount of a single unit, along with routine maintenance. Comparing catch basins with green roofs, catch basins cost a fraction of green roofs, but the services it provides to the environment is minimal. Plus, if catch basins are not cleaned out periodically, pollutants will be re-suspended and serve as a harbor for pollutants and the soluble pollutants can even slip through the inserts. Yet, catch basins can be supplements to the bigger stormwater infrastructure.

Rain garden


FIGURE 14 RAIN GARDEN

Rain gardens similar to green roofs capture stormwater during the rainy reason from impervious pavements. Rain gardens are counterparts to regular gardens but what draws the line is that they are depressions within the ground and are engineered to capture water and retain water periodically through the proper selection of vegetation and growing medium. The role of the rain gardens is that they can filter out sediments and certain elements, such as phosphorus and nitrogen, cleaning the stormwater before returning back into the system (Rain Gardens, Fig. 14). Like green roofs, there are several types of rain gardens, under-drained and self-contained. The under-drained rain garden is a fast draining system where the rainwater will drain within 4 hours time span, whereas the self-contained rain garden, the water stays longer in the garden and doesn't infiltrate as fast. The cost of a rain garden can cost $10 - $20 sq/ft. (BMP Guide). If rain gardens are not engineered properly, it can pose as a breeding ground for mosquitoes. Rain gardens are less expensive than green roofs and have similar functions to bioswales.

These ground level stormwater infrastructures all share a common purpose which is to deter runoff from overwhelming the existing stormwater systems. Whether it is a bioswale, catch basin, or rain garden, there services contribute improving the environment collectively. Comparing them to green roofs, these additional systems require ground breaking whereas green roofs are built on existing structures that already have building footprints. There are tradeoffs with each system and regardless of the infrastructure used to mitigate stormwater, they will reduce significant amounts.

San Francisco Stormwater Infrastructure Status

The cities of across America have different types of stormwater infrastructure systems. The city of San Francisco is one of the few municipalities with combined sewer systems. Combined sewer systems are sewers that collect both stormwater and sewage under one network of pipes (Fig. 16). On an average day, the sewer system collects about 80 million gallons of wastewater, however, during storm events the system is heavily impacted and takes in 500 million gallons of both wastewater and stormwater combined, six times the original amount (Water Pollution Prevention). Although both the stormwater and wastewater are treated at the treatment plants, the impact on the stormwater infrastructure system can be minimized through the efforts of implementing green roofs across the city. San Francisco has about 25,000 street drains scattered across the city to capture stormwater and during severe storm events, these drains connected to the larger system get backed up and flood the streets (Stormwater Management, Fig 15). Of the 25,000 drains, 8% are connected directly to the local

FIGURE 15 FLOODED STREET IN SAN FRANCISCO

watersheds that surround the San Francisco region which means the non-pollutant free stormwater is not treated at the treatment plant and have detrimental effects on the watershed ecosystems. Currently, the Public Utilities Commission is in charge of the stormwater infrastructure system and based on an interview with them, their annual budget for the treatment plants, pump stations, and collection systems is around $150 million dollars. Separately, the commission has about $4 billion dollars to fix the sewers, treatment plants, and to implement new green solutions to mitigate stormwater issues. A fraction of the allocated amount for green solutions will receive about $70 million to jump start the program, such as the implementation of bioswales and other stormwater mitigation projects. With regard to policy, the implementation of new policies such as the future of both existing and new developments will have to retain 90% of the stormwater on the site. In relation to green roofs, the city of San Francisco currently does not have an incentive program for the onsite detention and retention of water. The potential of green roofs will be realized by building owners as incentive programs are created in San Francisco, similar to the City of Portland where there is a grant incentive based program. Institutions such as the California Academy of Sciences have put into practice the green roof approach and have shown the general public the nuts and bolts of a green roof.

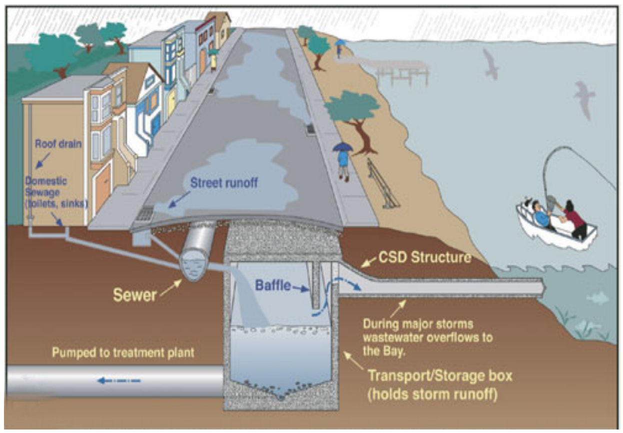


FIGURE 16 COMBINED SEWER SYSTEMS

Case Study: ASLA Headquarters

FIGURE 17 ASLA HEADQUARTERS GREEN ROOF

The green roof at the ASLA headquarters is located in the heart of Washington D.C., one block away from the Mount Vernon Historic District and a mile away from the White House. The green roof covers the entire rooftop of the building and is surrounded by infill development and various businesses in the downtown vicinity on I-Street NW (Fig. 17).

The building was acquired by ASLA in 1997 as the new headquarters for the organization. In 2005, the organization made the decision to transform the barren rooftop equipped with HVAC equipment into an experiential and environmental friendly green roof. The entire green roof project took one year to execute and successfully build. The intent of the project was not to create an ordinary green roof but rather one that surpasses the environmental aspects. The program of the design incorporated cultural, aesthetics, and experiential elements where it turned the barren rooftop into an outdoor user friendly space.

Site & User Analysis

Surrounded by infill development, the ASLA headquarters green roof gives the user an engaging experience. As users set foot on the rooftop, the two artificial waves creates a sense of privacy and directs the users view over the horizon. The users of the ASLA green roof are the individuals at the headquarters, students, and the general public. During the course of a rainy season, the ASLA green roof can capture up to 70% percent of the rainfall, which is around 17,800 of 25,500 gallons of water, considering the rooftop has a surface area of only 2,900 square feet.

General Features

As an experiential green roof, users will find themselves surrounded by artificial topography on both ends of the roof that represents waves, respectively facing North and South. These artificial structures create a shelter from the wind, hide the mechanical units, and block out the unwanted views for the users (Fig. 18). The perennials, grasses, and succulents that sit on top of the waves give the user a feeling of looking over the horizon.


FIGURE 18 ASLA ROOFTOP AERIAL VIEW

The walking surface on the rooftop is different from the traditional green roof where it is usually paved. The designers of the rooftop wanted to give users more surface area to move about and also more green surface area. As a result, grating was used as an element for the walking surface with vegetation growing below it, allowing the user to see the vegetation as they move around the rooftop. The elevated grating covers about 60% of the rooftop and also increases the total green surface area by 30%. Traditionally, if the rooftop was just covered in pavement, there wouldn't have been a 30% increase in green surface area. Applying the elements from the ASLA green roof to the building on Alabama Street in San Francisco, it would draw out the busy individuals to the rooftop and provide them with an educational and experiential experience. Other lessons learned that can also be applied are the relocation of the existing HAVC systems and hide them from hind sight as they can be an eyesore and decrease the green surface area. In addition, creating a structure to block wind since the rooftop at Alabama street can get quite windy. Comparing the access to the rooftop from the ASLA rooftop to the one on Alabama Street, they are similar, but the Alabama Street building has multiple rooftop points of entry and the constraint would be successfully connecting one point of entry to the other.

Plant List

Vegetation at the ASLA headquarters green roof varied from grasses, perennials, trees, to succulents.

South Wave

Optunia humifusa – Prickly pear cactus

Phlox subulata – Moss phlox

Sedum spp. – Sedums

Silene caroliniana – Wild pink

North Wave

Achillea millefolium - Yarrow

Allium schoenoprasum – Chive

Allium cernuum – Nodding onion

Artemisia ludoviciana – Silver king

Asclepias tuberose – Butterfly milkweed

Bouteloua gracilis – Blue grama grass

Eragrostis spectabilis – Purple lovegrass

Sedum spp. – Sedums

Grates

Delosperma nubigenum “Basutoland” – Ice plant

Sedum spp. - Sedum

Talinum calycinum – Fameflower

Stair Tower

Ceonanthus americanus – New Jersey tea

Comptonia peregrine – Sweet fern

Rhus aromatica – Fragrant sumac

Rosa Carolina - Pasture rose

Case Study:
California Academy of Scienc-es

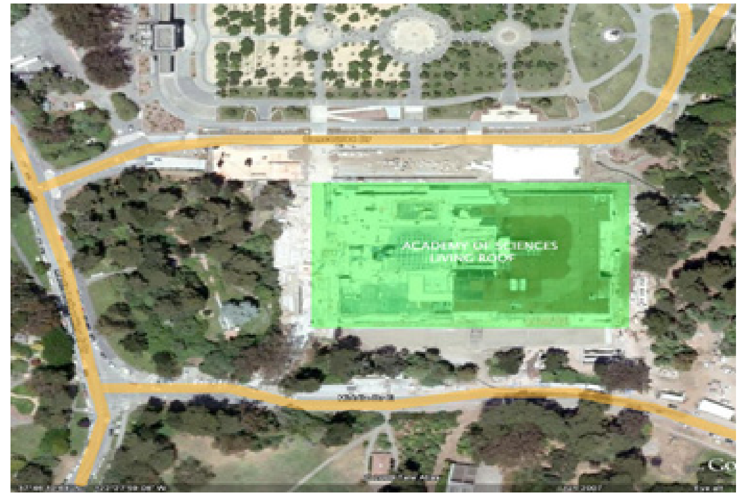


FIGURE 19 CALIFORNIA ACADEMY OF SCIENCES LIVING ROOF

The new Academy of Sciences is a LEED certified green building which employs sustainable practices. Known for a leading institution for researching and preserving the natural environment since 1853, the newly built museum is leading by example through the practices of environmental principles from ground up (Fig. 19).

<u>Site & User Analysis</u>

The Academy of Sciences building, a large public space, sits in the center of Golden Park surrounded by open space. The accessibility to the rooftop is only through the building, either by going up a three story stairway or by taking the elevator (Fig. 20). At the rooftop, users will find themselves on a platform that only allows them to maneuver within a fenced off area of 2,900 square-foot out of the 197,000 square-foot rooftop. There are other pathways on the roof-top however; they are off limits to use since they're only for emergency evacuations. The other 194,100 square feet of roof space is covered with carpets of vegetation. With a large surface area of vegetation the living roof has the ability to retain 70% of the rainwater that hits the roof, which is about 2 million gallons of water (Living Roof). The stormwater that does runoff the rooftop is captured and reused for irrigation of the rooftop vegetation through an underground cistern.

FIGURE 20 CAS ROOFTOP ACCESS

General Features

The elements of the living roof on the Academy of Sciences is similar to the ASLA green roof where it allows the user to experience what a green roof is and educate them through the usage of informational placards on different aspects of the green roof. At the rooftop, users will see dome structures covered in vegetation which symbolize the seven hills within the San Francisco region (Fig. 21). Native plants were used for the carpets of vegetation to create wildlife habitat which in turn indirectly creates a corridor with the open space of Golden Park. Solar panels are lined up across the edge of the roof overhang which does its job by lowering energy consumption, along with the insulation layers from the living roof. Borrowing elements from the Academy of Sciences living roof and applying it to the proposed design for the Alabama street building would make a more energy efficient building, such as the usage of solar panels and creating wildlife habitat.

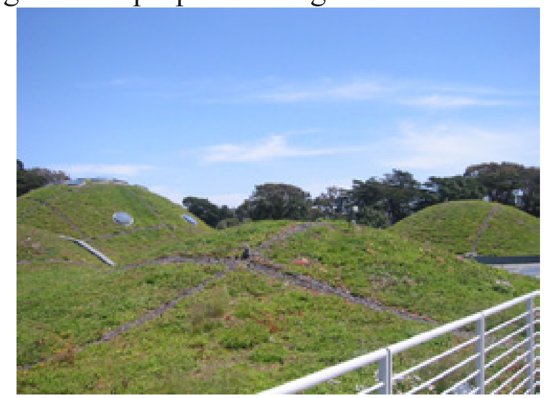


FIGURE 21 LIVING ROOF DOMES

Planting List

Four Perennial Plants

Strawberry — Fragaria chiloensis

Self Heal — Prunella vulgaris

Sea Pink — Armeria maritima ssp. californica

Stonecrop — Sedum spathulifolium

Five Annual Wildflowers

Tidy Tips — Layia platyglossa

Goldfield — Lasthenia californica

Miniature Lupine — Lupinus nanus

California Poppy — Eschscholzia californica

California Plantain — Plantago erecta

Case Study: Hamilton West Apartments

Case Study:
Hamilton West Apartments

FIGURE 22 HAMILTON WEST APARTMENTS EXTENSIVE ROOF

The Hamilton West Apartments building is located on Southwest Clay Street in Portland, Oregon, a block away from Hwy 405 (Fig. 22). The ecoroof installed on the building's rooftop was a joint project between the Housing Authority of Portland, City of Portland of Environmental Services, and the Portland Development Commission. The intent of the project was to measure the efficiency of green roofs and to determine the amount of stormwater captured and the quality of the water. This built project is one of many successful low impact development projects implemented by the city of Portland. Similar to the city of San Francisco, Portland has a combined sewer overflow problem, so in order to tackle this issue, ecoroofs such as the one found on

Hamilton West Apartments was installed and continually monitored.

Site and User Analysis

Similar to the ASLA headquarters, the Hamilton West apartment building is surrounded by infill development. The rooftop is accessible through the usage of an elevator. On the rooftop, there is a 1,000 square foot concrete patio fenced off and can be only accessed from the rooftops penthouse. On sunny days, the tenants of the building use the rooftop patio amenity. However, the circulation for the tenants are only limited to the edge of the patio that borders the west and east sides of the ecoroof. The vegetation of the ecoroof covers about 5,140 square foot of the rooftop. There is one drain on each side of the roof where all the stormwater drains too. The east side has 2,620 square feet of vegetation with a depth of 3 inches for the substrate and the west side has 2,520 square feet of vegetation with a depth of 5 inches for the substrate.

General Features

Similar to the Academy of Sciences living roof, the ecoroof on the Hamilton West Apartment building is one that allows the tenants of the building to experience the rooftop in a narrow space. The patio the tenants have access to have tables and seating for them to enjoy the vegetated rooftop. The lesson learned from this private rooftop that can be used on the Alabama street building rooftop is having an open space for the tenants of the building to use where congregations can take place.

Planting List

West Side

Blue Fescue (Festuca glauca)

Cascade stonecrop (Sedum divergens)

Iceplant (Delosperma cooperii)

Spanish stonecrop (Sedum hispanicum)

Common thyme (Thymus vulgaris)

Dragon’s blood (Sedum spurium)

East Side

Spanish stonecrop (Sedum hispanicum)

Kirin-so (Sedum kamtschaticum)

Iceplant (Delosperma cooperii)

Redstem filaree (Erodium cicutarium)

Dragon’s blood (Sedum spurium)

Oregon stonecrop (Sedum oreganum)

Case Study:
Ballard Library

FIGURE 23 SEATTLE BALLARD LIBRARY EXTENSIVE ROOF

The Ballard Branch of the Seattle Public Library is located in Seattle, Washington, in between NW 57th street and NW 56th street, intersecting, 22nd Ave NW (Fig. 23). As a public institution to the community, the Ballard Branch library's approach to build the eco-roof is to educate the public on green building design and demonstrate the services eco-roofs provide. The eco-roof was placed on top of the library to reduce energy costs for the building, along with reducing stormwater runoff and provide ecological restoration.

<u>Site and User Analysis</u>

The eco-roof on top of the library is not accessible to the public, only to maintenance personnel. However, though, similar to the Academy of Sciences, there is an observation deck on the rooftop that allows users to view the green roof. The eco-roof covers about 20,500 square feet of the rooftop and has a depth of 6 inches.

General Features

The eco-roof is not your ordinary flat roof; rather it is curved, which creates multiple micro-climates on the rooftop. With the curved roof, it creates low and high points for maximum water retention (Fig. 24).

FIGURE 24 SEATTLE BALLARD LIBRARY

The choice of vegetation on the rooftop was based on low maintenance and it ranged from indigenous grasses to various sedums. A row of solar panels are lined up across the north end of the rooftop, providing solar energy to the library. The eco-roof cost $20 sq/ft. which equates to around a little over $400,000. The elements that can be borrowed from this green roof project are the usage of solar panels and deck for users to experience the eco-roof.

Plant list:

Achillea tomentosa -Woolly yarrow

Armeria maritime- Sea pink, sea thrift

Carex inops (pensylvanica) -Long-stoloned sedge

Eriphyllum lanatum -Oregon sunshine

Festuca rubra -Red creeping fescue

Festuca idahoensis- Idaho fescue

Phlox subulata -Creeping phlox

Saxifrage cespitosa -Tufted saxifrage

Sedum oreganum- Oregon stonecrop

Sedum album -White stonecrop

Sedum spurium -Two-row stonecrop

Sisyrinchium idahoensis -Blue-eyed grass

Thymus serphyllum -Thyme

Triteleia hyacintha -Fool’s onion

Case Study:
Yerba Buena Gardens

FIGURE 25 YERBA BUENA GARDEN

Yerba Buena Gardens is located in San Francisco, between Folsom Street and Howard Street, intersecting 3th and 4th street (Fig. 25). The 5 ½ acres property took 30 years in the making covering about 2 blocks within San Francisco, surrounded by high rise buildings (Osmundson 2008, P. 89). Yerba Buena gardens which has multiple outdoor spaces, sit on top of the George Mason Moscone Center. The 130,000 square foot of outdoor spaces found at Yerba Buena Gardens include large open lawn, children's play area, amphitheater, and water features with seating areas. The large open lawn with slopes is created with artificial blocks of Styrofoam, with 2 feet of soil on top of the blocks so weight is reduced (Osmundson 2008, P.89). Additional structures such as ramps, walkways, and plazas also sit on top of Styrofoam fill. The usage of artificial material to make the slopes in the lawn and to reduce weight structurally is similar to the ASLA headquarters artificial waves which are also made of artificial Styrofoam.

Site and User analysis

Sitting in a metropolitan setting, Yerba Buena Gardens is open to the general public. The property itself is accessible from each corner along the streets it's surrounded by. The accessibility to the roof garden at Yerba Buena Gardens is accessible from the South and North end of the property from a flight of stairs (Fig. 26). Surrounded by high rises in an urban environment, the roof garden gives users an intimate setting to relax in. The openness of the outdoor spaces gives the users a sense of safety and the small pocket provides privacy to individuals. The users of the site are very diverse, from tourists, nearby office workers, children to the native residents of San Francisco. With majority of the children occupying the playground area in the Southern part of the property on the roof garden, the Northern part of the property, known as the Esplanade, is filled with adults of all ages where they spend time in the open lawn area and or enjoy the intimate pocket spaces near the water features (Fig. 27).

FIGURE 26 YERBA BUENA ROOFTOP GARDEN

General Features

The outdoor spaces found throughout Yerba Buena Gardens are utilized by the general public. The ground level spaces and rooftop gardens allow the users of the site to experience the site from different elevations.

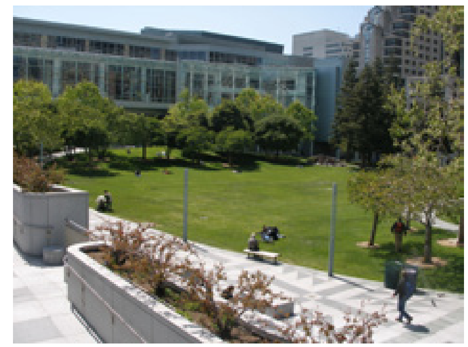


FIGURE 27 YERBA BUENA ESPLANADE

The general features such as roof garden, amphitheater, and open spaces are a success because they are utilized by the users of the site. The elements that can be used on the Alabama site are the private intimate spaces and the using of light weight materials for design applications for structural weight reduction.

Plant List

Agapanthus spp. – Lily of the Nile

Alstroemeria spp. – Peruvian Lily

Cistus ladanifer – Crimson Spot Rockrose

Digitalis purpurea - Foxglove

Lagerstroemia indica – Crape Myrtle

Leptospermum spp. – New Zealand Tea Plant

Liriope muscari – Liriope

Loropetalum chinese – Chinese Fringe Bush

Nandina domestica – Heavenly Bamboo

Pelargonium spp. – Geranium

Pittosporum spp. – Pittosporum

Prunus cerasifera – Purple Cherry Plum Tree

Rhaphiolepis indica – Indian Hawthorn

Rosmarinus offinalis - Rosemary

Rhododendron spp. – Azalea

Site Analysis:
375 Alabama Street Building

FIGURE 28 ALABAMA STREET BUILDING

Location

The site of the proposed green roof is located between 16th and 17th Street, right along Alabama street. The building on 375 Alabama street is a commercial building, similarly like the ASLA headquarters, it is encircled by infill development, with the nearest park about a quarter of a mile away (Fig 28).

Rooftop Access

At the Alabama Street building, there are multiple entry points to the two tier leveled rooftop. Access to both levels is easy. The upper rooftop is accessible from the west side of the building from a flight stairs. Upon arrival to the door that leads to the rooftop, there is a 3 foot drop of stairs one has to walk down to get to the base of the upper rooftop. The upper level has a surface area of about 19,300 sq. ft. As for the lower level, there are 2 points of entry one can take. One point of entry is from the southwest side where the only way is to walk through a company's office suite on the fourth floor to get access to the door that leads to the rooftop. As for the other point of entry, that is through the east side of the building where one can easily gain access to through a flight of stairs and or going through the fourth floor. The users of the lower rooftop will find themselves surrounded by a chain link fence that separates them from the southwest portion of the rooftop. The lower level rooftop has a surface area of about 14,400 sq. ft. (See Site Analysis)

User Analysis

The users of the rooftop are primarily the individuals that work inside the building. The lower level rooftop where the fenced off Eastern patio area is located, is used by individuals from the 1st – 4th floor. Users of the Eastern patio never went beyond the fenced off area. As for the Southwest patio area on the same level, it is only used by the individuals who work at the company on the 4th floor. The area that is between the Eastern and Southwest patios is a void space where no one uses it. Going up to the rooftop randomly throughout different times of the day, I observed that people went up to the rooftop to catch a short break from work. There activities ranged from smoking and or talking on the mobile phone.

Structural Components

Stepping foot on the rooftop, one will notice that the surface is made of concrete. On both the upper and lower levels of the roofs, the barriers that go along the edge of the rooftop are 6 foot high walls that block the panoramic views of the city. Throughout the upper level of the rooftop, there are A/C units and antennas, specifically in the southwest corner and the northwest corners. Going down to the lower level of the rooftop, there are A/C units lined along the southern border. In the lower level rooftop, one will find erected triangular shaped structures with single sided windows that capture natural sunlight into building.

Sunlight and Wind Exposure

At the upper and lower level, full sunlight is received throughout the day, however though there are areas that are slightly shaded throughout the day. Standing on the rooftop, a southern wind runs through and even though there is a six foot wall, the wind breeze can still be felt.

Rooftop and street level storm drains

There are drains on all four corners of the rooftop, both on the upper and lower levels. During the rainy season, one will notice that there is standing water on parts of the rooftop after a rain event. The existing drains on the rooftop are not effectively placed for the discharge of the stormwater. Looking at the ground level, there are storm drains on both the west and east sides of the building, where majority of the stormwater from the nearby streets flow to.

RAINFALL

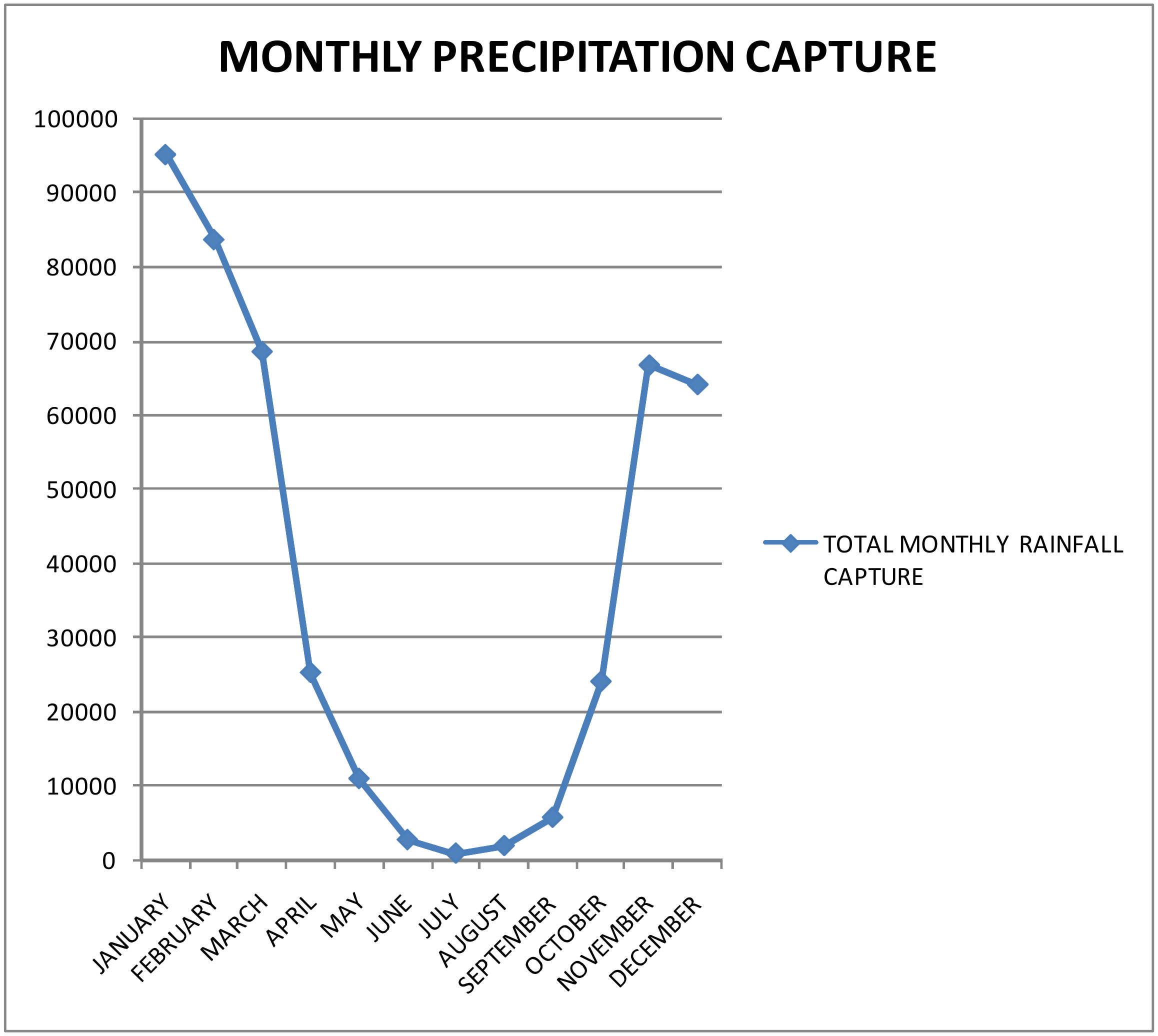


FIGURE 29 SAN FRANCISCO MONTHLY AVERAGE RAINFALL

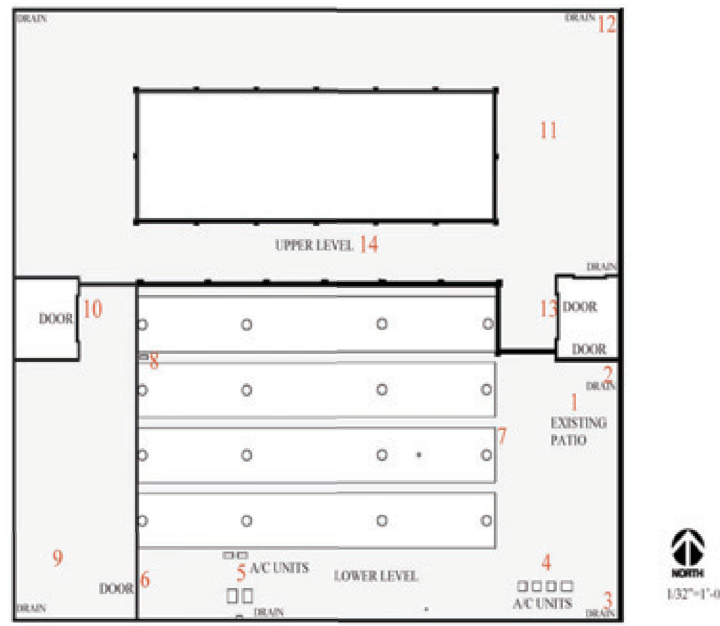
MONTHLY avg.	INCHES	GALLONS
JANUARY	4.72	95,155
FEBRUARY	4.15	83,664
MARCH	3.4	68,544
APRIL	1.25	25,200
MAY	0.54	10,886
JUNE	0.13	2,620
JULY	0.04	806
AUGUST	0.09	1,814
SEPTEMBER	0.28	5,644
OCTOBER	1.19	23,990
NOVEMBER	3.31	66,729
DECEMBER	3.18	64,108
TOTAL	22.28	449,160

375 ALABAMA STREET ROOFTOP

SITE ANALYSIS

375 ALABAMA STREET ROOFTOP

SITE ANALYSIS



375 ALABAMA STREET   ROOFTOP

The Green Roof Design

Addressing the Obstacles and the Program

The proposed design of the Alabama street building is based on the research about the different types of green roofs, the five case studies, site analysis, and the answers received during the interviews taken from the individuals that work in the building. An illustrative plan will incorporate the strong elements from each of the case studies and general information about green roofs. With the creation of the illustrative design, it will demonstrate why a green roof will be most appropriate for the building and also a comparison of the existing rooftop can be made. A general cost of the green roof will be provided, along with the amount of stormwater the rooftop can potentially deter from running off. In addition, a layout of a large scale assessment of green roof implementation for the Mission District will be addressed and the City of San Francisco as a whole.

Existing Rooftop Conditions

Being able to access the rooftop of the Alabama Street building allowed for thorough inspection of the components that made up the rooftop. By pinpointing the location of the HVAC structures and storm drains on the rooftop, the necessary changes were incorporated into the illustrative plan for a well-rounded design. The fate of the HVAC units was that they were moved accordingly due to purposes of obstruction of view and also to widen the new pathway for circulation for users. The storm drains were moved because of their failure in disposing of standing water on the rooftop during rain events.

Rooftop Hazards

From an interview with the building manager, the individuals who work at the building are advised not to go up to the upper level rooftop because of radiation exposure from the radio towers and other hazards such as electrical conduits that can cause tripping.

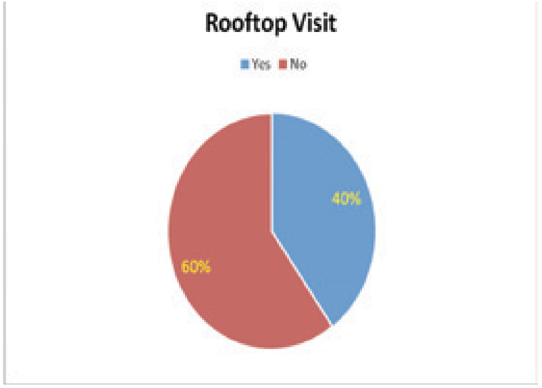
User Analysis

After making observations of what activities people did on the rooftop, a more thorough analysis was conducted through interviewing individuals from each floor of the building with a set of basic questions. The series of questions asked were the following:

1. Do you go up to the rooftop?
   - •More than once a day
   - •Once every few days
   - •Not at all
2. What do you do up there? List.
3. Do you know what a green roof is? Yes or No
4. If there were a green roof on top of this building, would you go up there more often? Yes or No

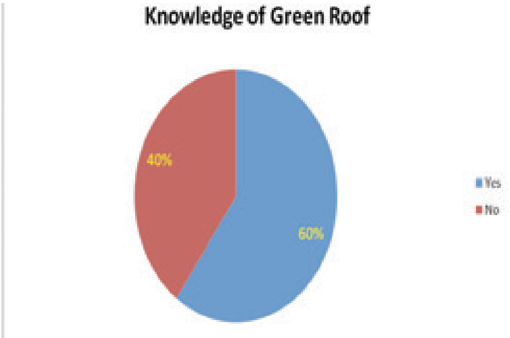
Findings from the interviews:

1. Currently about 40% of the individuals who work in the building visiting the rooftop at least once a day or couple times throughout the week.

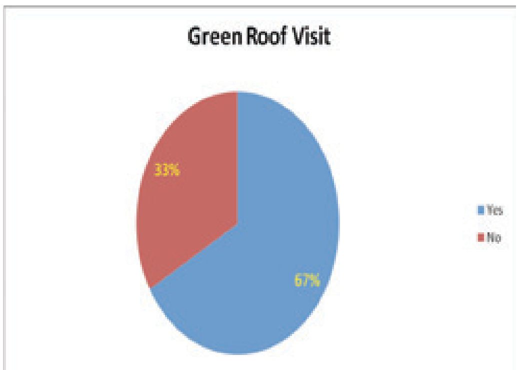


2. Respondents gave several reasons for going up to the rooftop:
   - •Smoke
   - •Talk on phone
   - •Eat lunch
   - •Drink a beer

3. About 60% of the tenants in the building know what green roofs are.



4. If there were a green roof on the rooftop, 66% of the individuals who work in the working will go up more often.



Vegetation

The vegetation chosen for both the rooftops are drought tolerant and are California natives. The range of different colors and heights creates a field of colors for the users to enjoy while on the green roof. The variety of plants chosen creates habitat and attracts insects/ pollinators.

Plant list

Carex pansa – California Meadow Sedge

Eschscholzia californica – California poppy

Fragaria chiloensis - Strawberry

Lupinus nanus – Sky Lupine

Sedum spp. - Sedum

Sisyrinchium bellum – Blue Eyed grass

Rooftop Design

Upper Rooftop (extensive roof system)

From the interview with the building manager, it was apparent that the upper roof was not approved for access by the individuals who worked in the building. By going up there for the site analysis, there were no signs of the upper rooftop being used at all. Through that observation, an extensive roof system is most appropriate for the upper rooftop. The selection of plant materials that suits the upper rooftop for the extensive roof system is succulents such as sedums and native grasses. A full list of plant names can be seen on the illustrative plan.

Lower Rooftop (semi-extensive roof system)

Compared to the upper rooftop, the lower rooftop is accessed by individuals who work in the building. From the site analysis, the lower rooftop is segregated into two different patio areas by two different groups of users. To link the two groups together, the chain link fence was taken down and the makeshift patio was removed. As a result, a central patio area was created where it is accessible by both groups of users through using an elevated metal grate to walk on top of the carpet of vegetation. By allowing the users of the rooftop to walk on top of a metal grate, they can experience the green roof below them. The perspective pictures create a clearer image of the centralized patio area. The HVAC units were moved from their original locations and placed along the side of the pyramidal structures due to availability of space. In relation to space, rows of solar panels are placed on the opposite side of the windows on the pyramidal structures because of its location facing south. The solar panels serve as an energy producer for the building while the green roof reciprocates the effect by saving the building energy usage. The Alabama street building being in the Mission District would be a great model for why green roofs should be built in the area and within the City of San Francisco.

Connecting the Green roof to the users

During the course of the interviews with the individuals, the impression that was received was that everyone was consumed by their work and were stressed. Looking at the interview results, 40% of the users use the roof and about 60% know what green roofs are. When asking the individuals if they would go up to the rooftop if a green roof were implemented, 66% said they would, roughly 24% increase in rooftop usage. Part of the 24% of the individuals who would go up to the rooftop were the individuals who currently don't use the rooftop.

The proposed semi-extensive roof design draws the people from within the building to the top of the rooftop where they can temporarily escape the everyday stress they face at work and experience the hidden theraputic amenity of a rooftop garden. At the same time, it serves as an educational experience because green roofs aren't just rooftops with vegetation but they provide beneficial environmental services to the environment. The voided space between both the patios will serve as the bridge that connects the southwest and eastern parts of the building together, where once separated, is now reunited. The new patio area will transform a grey space into a green space where collaboration amongst individuals will take place and the birth of new ideas.

Stormwater and the green roof

With the green roof on top of the Alabama Street building, throughout the year it will mitigate about 450,000 gallons of rain water from going into the stormwater infrastructure system (Fig. 29). Looking at the historic rainfall averages within a 10 year period, the most rainfall San Francisco has received in a given day was roughly about 3.61 inches. Under heavy storm conditions, the Alabama Street building will be able to mitigate the 3.61 inches of rain, which is equivalent to 73,000 gallons of stormwater. With the mitigation of stormwater from entering the combined sewer system, the receiving ends of watersheds will not be impacted by the high fluctuations of water levels and be affected by the pollutants in the stormwater. The Alabama Street building sewer system is connected to Islais Creek watershed and historically this was a creek used for irrigating the crop fields (Islais Creek). Through the years of heavy usage and as dump site for the earthquake debris of 1906, the life of the creek has deteriorated and transformed into a culvert that carries the stormwater and wastewaters into the San Francisco Bay. The green roof on top of the Alabama Street building will decrease the environmental impacts on Islais Creek.

FIGURE ISLAIS CREEK

Cost Estimate

The Alabama Street rooftop has about 33,600 square feet. With the implementation of both the semi-extensive and extensive green roof system, it will cost about $20 per square foot which includes the minor retrofits to the roof, such as relocation of the HVAC units and the layers that make up the green roof. With 33,600 square feet of roof and $20 per square foot, the cost estimate is about $672,000, which will pay itself off through the years from lower energy bill and from stormwater incentives.

ILLUSTRATIVE

Scale 1"= 20'-0"

PLANT LIST

Carex pansa - California Meadow Sedge

Eschscholzia californica - California poppy

Fragaria chiloensis - Strawberry

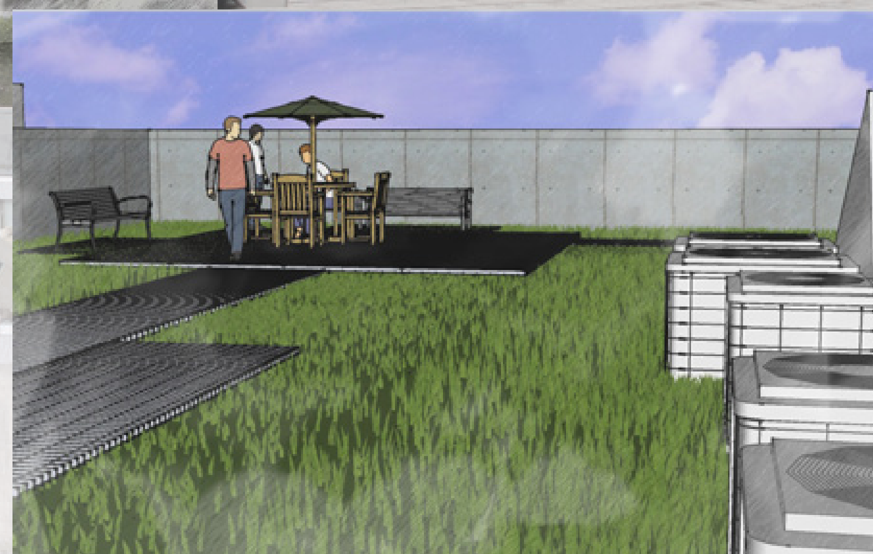
Lupinus nanus - Sky Lupine

Sedum spp. - Sedum

Sisyrinchium bellum - Blue Eyed grass

375 ALABAMA STREET ROOFTOP

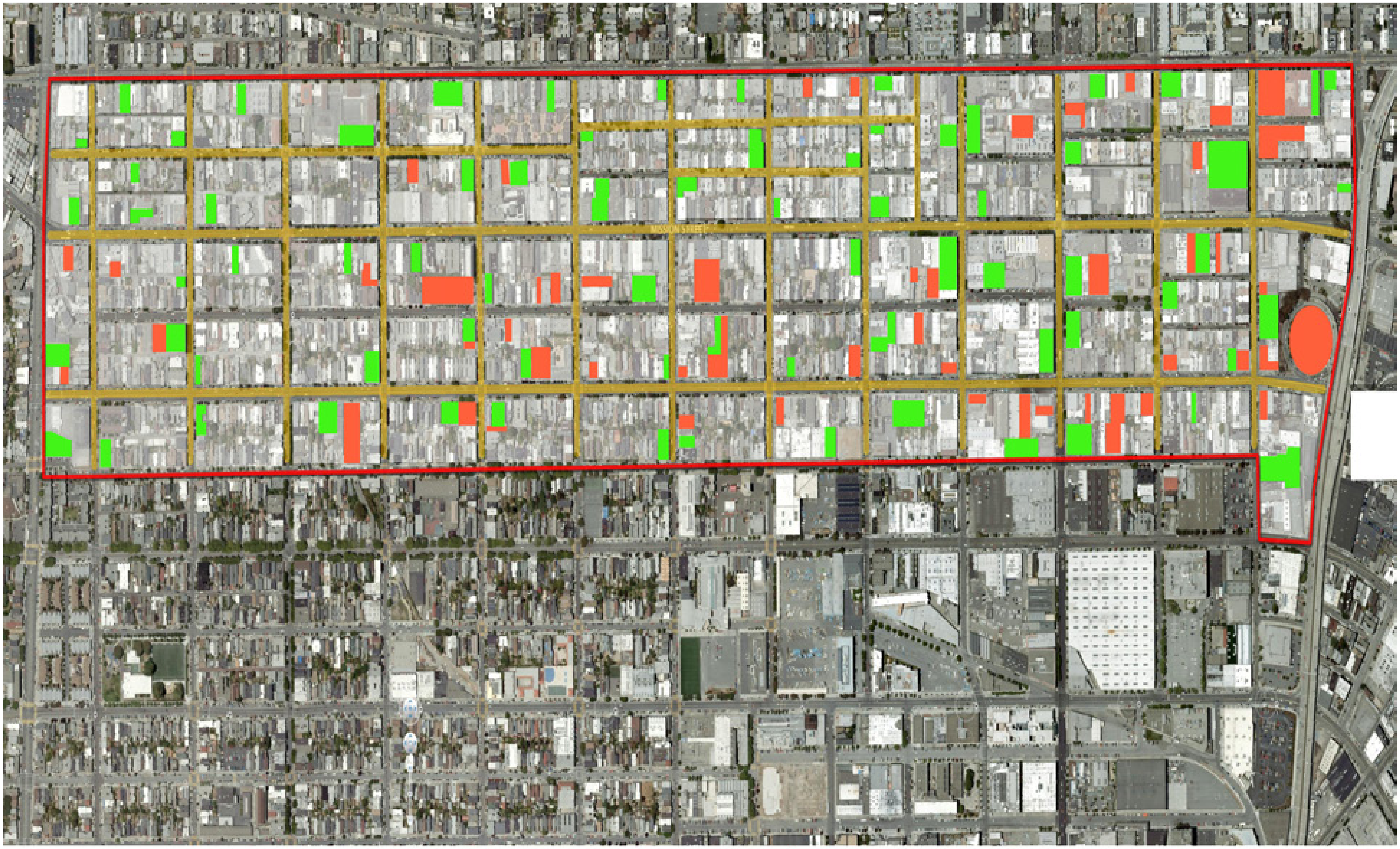
PERSPECTIVES



375 ALABAMA STREET   ROOFTOP

PERSPECTIVES

375 ALABAMA STREET ROOFTOP



GREEN ROOFS

10 YEAR HISTORIC 1-DAY PEAK RAINFALL: 3.61 INCHES
YEARLY RAINFALL AVERAGE: 22.28 INCHES
TOTAL SQUARE FT: 730,680
HISTORIC 1-DAY PEAK RAINFALL CAPTURE:1,582,652 GAL.
POTENTIAL RUNOFF CAPTURE: 9,767,730 GAL. PER YEAR

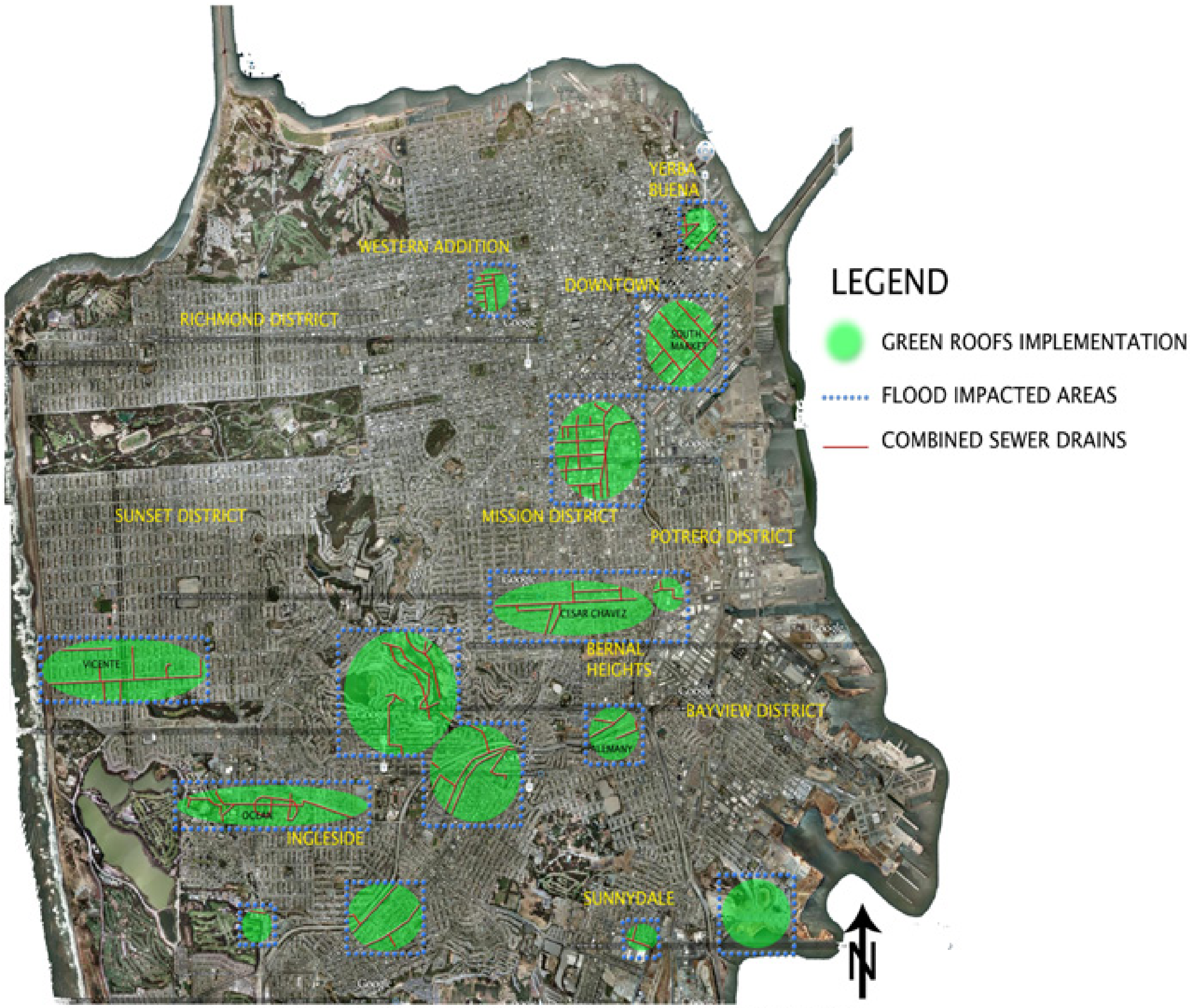
PARKING LOTS

TOTAL SQUARE FT: 503,715
HISTORIC 1-DAY PEAK RAINFALL RUNOFF: 1,091,064 GAL.
IMPERVIOUS PAVING RUNOFF: 6,733,662 GAL. PER YEAR

IMPERVIOUS SURFACE

TOTAL SQAURE FT: 12,067,081
GREEN ROOF AREA: 6%

MISSION DISTRICT
GREEN ROOF SIMULATION



CITY-WIDE ASSESSMENT INDICATES THE FOLLOWING REGIONS CIRCLED IN BLUE ARE SUBJECTED TO FLOOD EVENTS DURING THE STORM SEASON. THESE REGIONS HAVE COMBINED SEWER DRAINS IN PLACE, BUT DUE TO HIGH DENSITY, FLOOD EVENTS OCCUR. THE IMPLEMENTATION OF GREEN ROOFS IN THESE FLOOD PRONE REGIONS WILL MITIGATE THE IMPACT ON THE STORMWATER INFRASTRUCTURE SYSTEM.

STORMWATER HOTSPOTS
IN SAN FRANCISCO

CONCLUSION

The main goal of this research is to educate and promote the implementation of green roofs in municipalities. From small scale to a several street blocks to a city wide implementation, the positive effect of green roofs on mitigating stormwater from runoff into the stormwater infrastructure system is apparent. Green roofs combined with the traditional stormwater infrastructures will serve as complements to each other. Both people and the environment benefit from the implementation of green roofs, especially in a city like San Francisco. Although the initial monetary costs may be high, the long term value of the green roof only appreciates.

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