STORMWATER RUNOFF AND ITS CAPTURE, CLEANSING, AND REUSE

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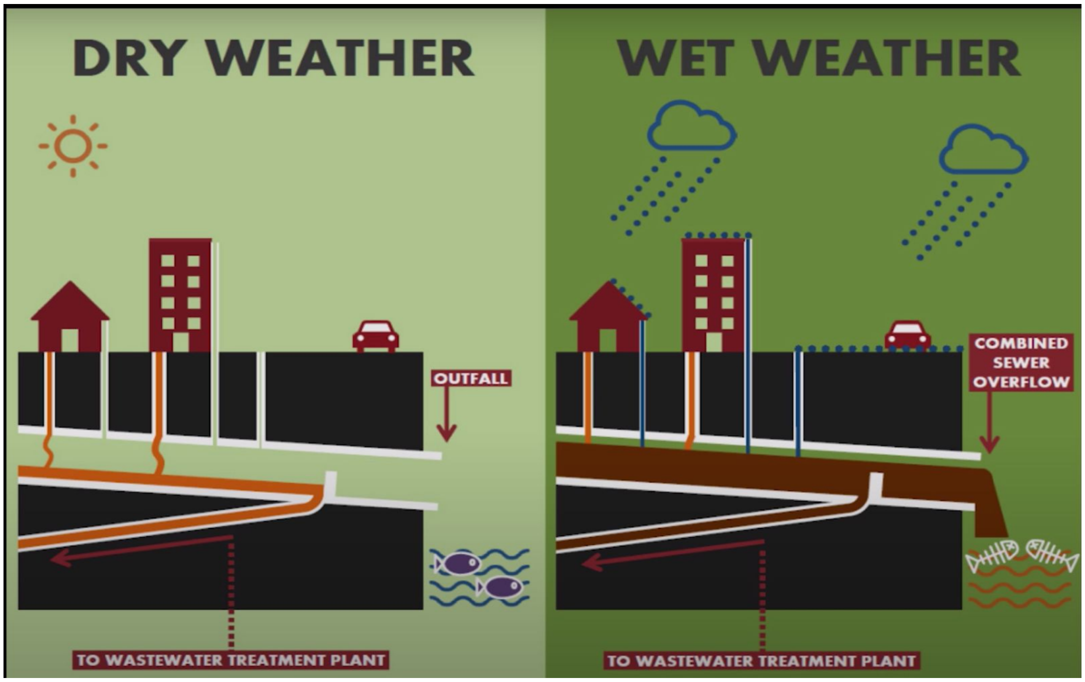
INTRODUCTION TO STORMWATER RUNOFF

Stormwater Runoff is the number one threat to water quality according to the United States Environmental Protection Agency (EPA): a danger not only to public health but to the environment as well. Essentially, Stormwater Runoff can be defined as rainfall which - instead of being absorbed into the ground - lands on an impervious surface, such as concrete or asphalt; this rainfall eventually makes its way through the sewage system into a nearby body of water. Stormwater Runoff is especially harmful due to its potential of carrying various pollutants and contaminants picked up from the ground - including waste, oils, fertilizer, pesticides, and viruses - which also flow into oceans, streams, and lakes in many conditions of rainfall. Overall, stormwater runoff poses a direct threat to the quality of our water, leading to the destruction of marine life and the further pollution of natural water. Stormwater runoff, if left unmanaged, can have severe and long-term economic, social, and environmental impacts.

THE DANGERS OF UNMANAGED STORMWATER RUNOFF

Prior to the urbanization of land and the creation of modern day sewage systems and water treatment facilities, rain would fall exclusively on permeable surfaces, including grass, pastures, plant-life, and soils. A permeable surface has the ability to naturally absorb rainwater into the ground, the ability to filter out any pollutants the rainwater may carry, and the ability to promote growth of plant-life through its supply of water.

However, due to industrialization and urbanization, many of these once natural surfaces have been paved over an impervious surface, such as a roof, pavement, concrete, or asphalt. The essential difference between an impervious surface and a natural surface is that the impervious surface is incapable of absorbing water into the ground. Ultimately, as cities grew, the amount of impervious surfaces did as well, making it increasingly less likely that rainfall would land on a natural surface. In modern cities, a vast majority of area is occupied by impervious surfaces. For example, in Hoboken, New Jersey, 57% of impervious areas are found in rooftops: a total of 45% of the city's area [1].



A diagram depicting how Combined Sewer Overflow can cause pollutants to flow into adjacent bodies of water, creating deadly conditions for marine life [1].

The inability for impervious surfaces to soak rain into the ground called for the inception of the modern day draining system; the system used today was designed to redirect water before the city ended up flooding. Essentially, stormwater which lands on impervious surfaces is redirected into sewer drains where the water eventually arrives at a wastewater treatment plant. At this wastewater treatment plant, the water is cleansed and then reused for household water, tap water, etc. Untreated stormwater is particularly dangerous given its potential to hold contaminants collected during its flow through impervious surfaces. These contaminants include animal/pet waste, viruses, diseases, car oils, fertilizer, pesticides, dirt, and other pollutants.

The capacity of this system, however, is designed for light rainfall; therefore, the amount of water generated during most amounts of rainfall would overwhelm the sewage system: combined sewer overflow. In many American cities and towns, one-tenth of an inch is the threshold needed for water to flow from impervious surfaces. Therefore, in these rainfall conditions, the rainwater in the sewage system will overflow into nearby bodies of water long before it is treated; and with it the rainwater brings along contaminants, leading to an increase in pollution levels.

Stormwater runoff has an extreme negative impact on streams, lakes, rivers, and other bodies of water [2,3]. Ultimately, the natural hydrology is altered, leading to an altered peak flow; channel morphology and in-stream hydraulics are altered; stream temperatures increase due to the heat brought into the water from impervious surfaces as well as an increase in the concentration of pollutants and contaminants, leading to life-threatening conditions for sea life.

The deadly effects of water pollution is not just exclusive to marine life; humans who swim in contaminated oceans, streams, rivers, and lakes are at risk of the following conditions: gastroenterology dysfunction, complications of the ear, nose, and throat, and skin disease.

However, the general public cannot escape the dangers of water pollution by simply only avoiding swimming in the contaminated water. Rather, the effects of mismanaged and untreated stormwater runoff can appear in one's household water. Essentially, 86% of the United States population get their drinking water from sourced surface water [4]. Therefore, keeping contaminants out of oceans, rivers, lakes, streams, aquifers, and other sources of water is an essential step to guaranteeing the public a high standard of water quality.

In many American cities, including Grand Rapids, Michigan, it only takes an average of 15 minutes for stormwater to go from an impervious surface to a body of water. This short period of time shows how it only takes only minutes of rainfall to create combined sewer overflow: the overwhelming of the sewer system's water capacity.

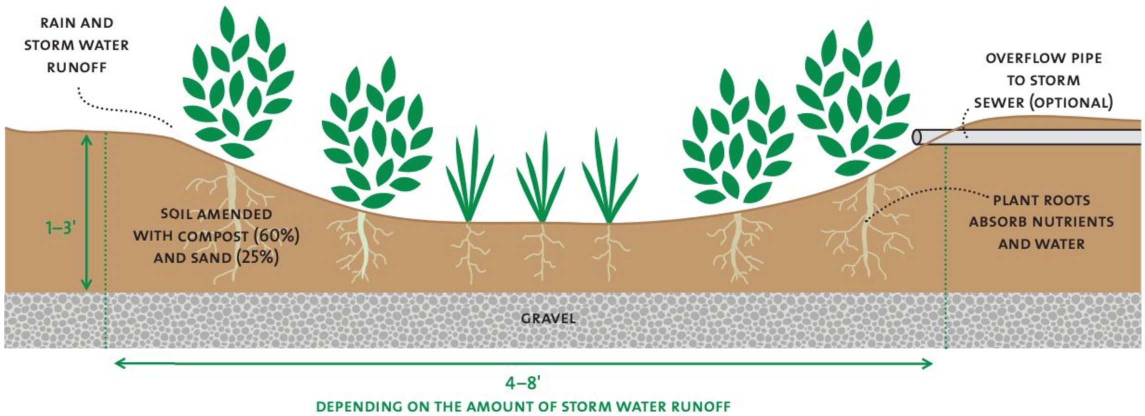
SOLVING STORMWATER RUNOFF: THE BENEFITS OF GREEN INFRASTRUCTURE

The task of solving stormwater runoff is a great and challenging one. The current system of water treatment and disposal is one of many flaws and shortcomings; however, revising the entire system the existing system in every city and town would be fiscally and environmentally irresponsible. Rather, the most effective remedy would be to incorporate sustainable solutions into existing systems. These sustainable solutions, often referred to as green infrastructure, consist of mechanisms designed to capture stormwater and slowly release it over time: a proven way to prevent combined sewer overflow.

Green infrastructure comes in various forms, ranging from bioswales to rain barrels to permeable pavement. In many cases, different methods of green infrastructure can be used interchangeably; however, in other cases, specific methods only fit specific circumstances. Below, the various methods of green infrastructure will be detailed regarding their composition and purpose.

RAIN GARDEN

A rain garden utilizes various techniques of agriculture in order to decrease the water's rate of the filtration. Rain gardens are placed near a building, such as a house; it is the destination for stormwater that falls on an impervious surface, oftentimes a roof. The rain garden consists of a depressed surface (such as a hole) that ranges in size depending on the intended area it is desired to cover.



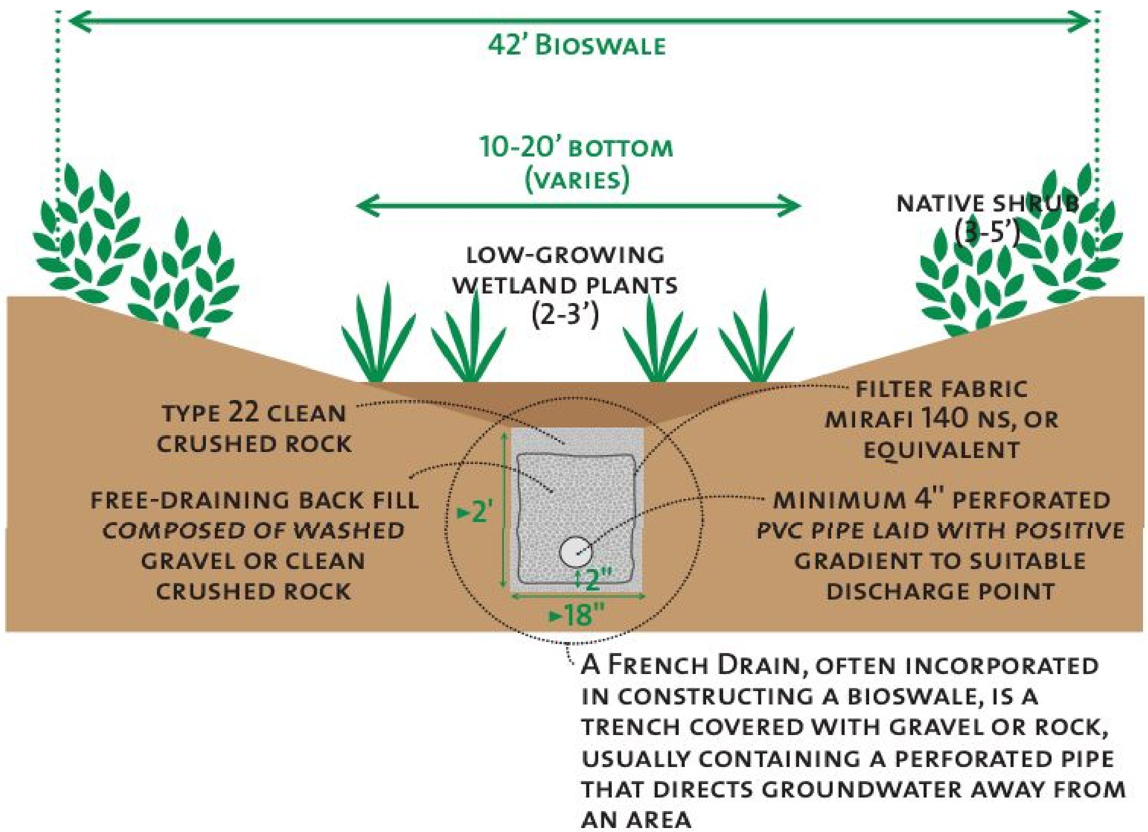
A diagram of the structure of a rain garden [5]

Utilizing a depressed surface is imperative for the rain garden since stormwater is directed downward through the forces of gravity: this is where the stormwater will be absorbed by the roots of the plants and infiltrated into the ground. A gutter is to be led into the depressed area. Native plants are then planted in the depressed area with soil. With the presence of soil, the rain garden can naturally increase its water retention ability and its filtering capacity. Sandy soils have the fastest rate of filtration while clay-like soils have the slowest. It is important to find a healthy balance between those two options - sandy loam soil is considered to be the most ideal; the majority of incoming stormwater should be filtered by the rain garden within 24 hours after initial contact.

Native plants are selected for the rain garden since they are able to handle up to 9 months of wet weather while still being able to survive in extensive dry conditions. In addition to native plants, other plants are often included in the rain garden as well. The New Jersey Rain Garden Manual suggests that the following factors should be considered when selecting the species of plant(s): plant size, seasonal interest, moisture tolerances, sun preferences, plant aggressiveness, salt tolerance, habitat creation. Finally, sections not filled with mulch are covered in gravel; the gravel is used as a method to infiltrate the water in a slow manner and to prevent stormwater runoff. Rain gardens are a solution that prevents pollutants and contaminants from being present in water ways; rain gardens naturally break down pollutants and filter them out without contaminating sewer systems or bodies of water.

BIOSWALES

Bioswales are similar to rain gardens; however, the purpose is served in a more urban environment. In cities especially, rainwater can build up a significant amount of stormwater on impervious surfaces; therefore, the bioswale is constructed in order to handle these conditions of extensive rain: a suitable fit for the urban environment. A bioswale provides an alternate destination for stormwater on the street. Essentially, rainflow is directed into a depressed garden which is absorbed into the soil. Consisting of two layers (a soil layer and a stone layer below), the bioswale is engineered to maximize the amount of held water. New York City, a city that has championed the use of green infrastructure, features bioswales that can hold an average of 2,000 gallons of water [6].



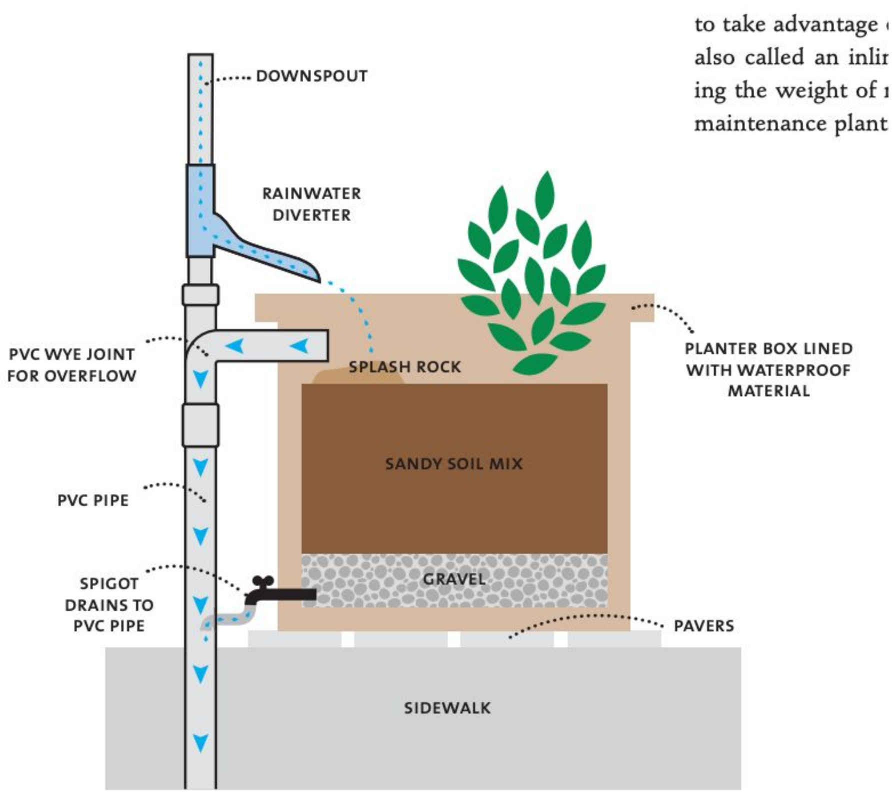
A diagram of the structure of a bioswale [5].

Bioswales include slanted sides, a method used to ensure that the water is brought into the basin by gravity. It is important to understand the slants are very subtle in order to decrease the water's flow rate, thus preventing a potential system overflow. Similar to rain gardens, bioswales include native plants: a proven way for plant life to survive year round. The root systems of the native plants allow for the bioswale's multiple layers to be held together while promoting gradual filtration. In addition to these native plants, dense vegetation is a necessary amendment to the bioswale in order for plants to naturally digest harmful chemicals and pollutants; essentially, the water is naturally treated long before it arrives in the drainage system Bioswales may require an irrigation system to tend to plants during periods of drought: this is largely dependent on the climate. Bioswales are ideally placed adjacent to impervious surfaces on the ground. For stormwater, they provide an alternative destination to sewers.

OTHER FORMS OF GREEN INFRASTRUCTURE

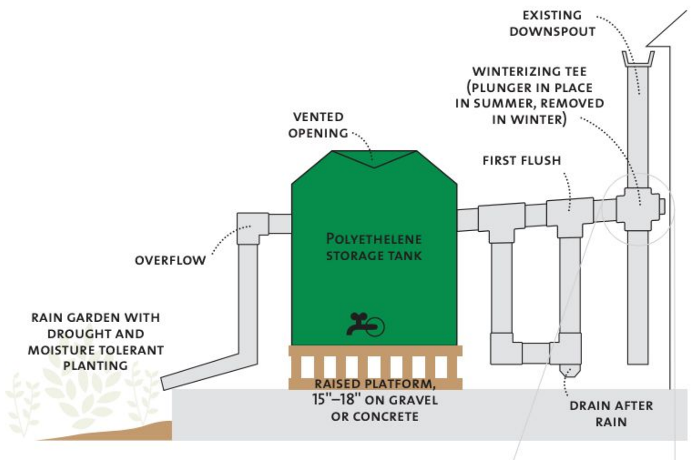
Rain Barrels is a common method of green infrastructure usually typically in suburban impervious surfaces. Essentially, the rainwater is collected in a barrel and over time it slowly escapes in order to prevent combined sewer overflow.

Downspout Planters are similar to rain gardens; however, they are far more present for an urban area. Essentially, stormwater collected from rooftops are led into a miniature garden through a downspout. This garden consists of native plants, a top layer of native soil, and a bottom layer of gravel. In cases of extensive rain, in which the capacity of the garden would be overwhelmed, the excess stormwater is led by a pipe to an area below the cement.



A diagram of the structure of a downspout planter [5]

Rain Water Harvesting is a method in which rainwater from a rooftop is led to a high capacity plastic storage tank through a series of pipes and downspouts. In cases of heavy rainfall, excess rainfall will overflow into another form of green infrastructure, oftentimes a rain garden, that is adjacent to the rain water harvesting site. However, rain water harvesting is discouraged in climates in which precipitation occurs mostly in the winter, yet water is in its highest demand in the summer.



A diagram of the structure of a rainwater harvesting complex [5]

USING STORMWATER CAPTURE TO MITIGATE PUBLIC HEALTH CRISES RELATED TO WATER SUSTAINABILITY

California, along with many other dry climates, are experiencing an increase in the duration and frequency of droughts as an effect of climate change. These droughts have lasting impacts on the water supply of these respective areas. The utilization of a mechanism that efficiently collects stormwater would be vital to the longevity of the water supply.

On a dry day, approximately 100 million gallons of water flow into the ocean throughout Los Angeles County; in Santa Monica that number ranges from 10 million to 25 million gallons daily into the Santa Monica Bay. During the scarce rainstorm in Los Angeles County, one-inch rain can generate approximately 10 billion gallons of stormwater runoff - a vast majority of which flows into the Pacific Ocean [7].

Currently, Central and West Coast groundwater basins of Los Angeles capture and recharge 54,000 acre-feet (approximately 17 billion gallons) of stormwater. Nevertheless, California still imports an annual amount of 10 billion gallons of water in order to satisfy the state’s water supply: an extreme use of energy [7].

By redirecting and reusing stormwater runoff, whether it be through green infrastructure methods or by reharvesting the water, California’s water supply could drastically increase. In Southern California and the San Francisco Bay Area, stormwater capture can increase water supplies within the range of 420,000 to 630,000 acre feet (130 billion to 205 billion gallons) each year: the latter is a rough equivalent to the annual amount of water used by the city of Los Angeles [7].

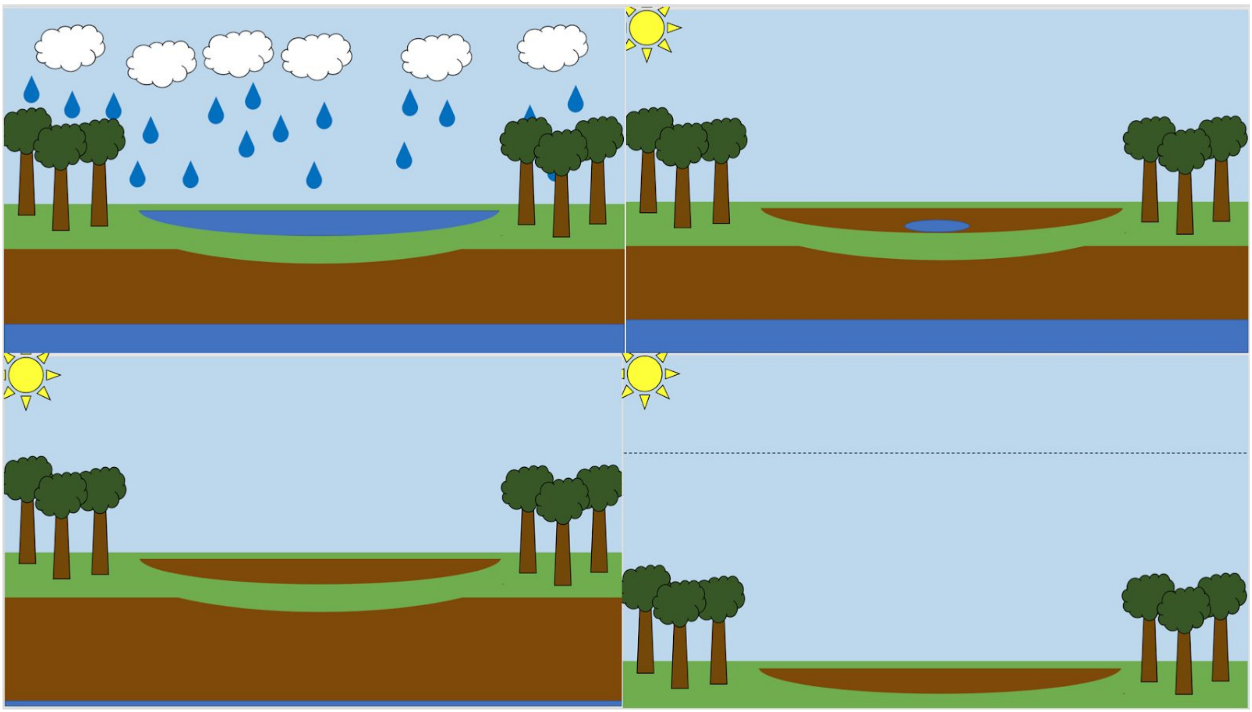
Hundreds of fish in Big Bear Lake in California are found washed up on shore due to depleting water conditions [8].

Not only does a shortage of water lead to direct societal issues - such as widespread thirst and dehydration- it will also lead to indirect effects on agriculture and livestock. Ultimately, without a surplus of water, crops will be unable to grow and livestock will die of either dehydration or starvation. The effects of water shortages in California, an essential supplier of dairy, livestock, and crops, will be felt all around the nation if not the world. The prices of the goods provided by California farmers will increase due to their scarcity.

GROUNDWATER RECHARGE

Due to the prolonged drought in California, most areas of the state were unable to collect stormwater due to the infrequency of rainfall; therefore, they were unable to recycle that stormwater. Ultimately, in these periods of drought, California used water from underground aquifers in order to satisfy the water demands of the state. Essentially, an aquifer is a body of groundwater that is stored beneath the surface of the earth. The Bajaro Valley obtained 85% of its water supply from underground aquifers [9].

Even though the utilization of aquifers for drinking water helped meet the demands of the population, the aquifers of California were being depleted due to the overpumping of groundwater. In cases where more water is extracted than replenished, the supply of groundwater will deplete; and a depletion of groundwater will lead to the collapse of an aquifer, and the water storage and capacity could become forever lost. Additionally, the depletion of an aquifer would cause a collapse, causing the land to sink and above ground infrastructure to face irreparable damage. If these aquifers were to become overly depleted, then California would lose almost all of its ability to become water self-sufficient; therefore, in future times of need, the groundwater aquifers will be unable to maintain the capacity once held. The state would have to rely entirely on the water imported from other states.



Essentially, due to long periods without rain, reservoirs are depleted; this leads to an increased reliance on groundwater in aquifers. Once the groundwater supply is depleted, land will begin to sink overtime, as demonstrated above.

Dr. Jay Famiglietti, a Senior Water Scientist at NASA's Jet Propulsion Lab, describes California's groundwater supply dilemma as an analogy to savings. The rainfall and snowfall are like deposits from income; the above ground reservoirs are like a checkings account; the underground aquifers are like long-term savings. However, since rainfall - or income - is becoming more infrequent, California had to become more reliant on the water supply found in reservoirs. Once the water supply of the reservoirs is depleted, California is becoming completely reliant on the groundwater, or their "long-term savings" [10].

Dr. Andrew Fisher of University of California, Santa Cruz (UCSC) describes California as a state facing a "triple threat" when it comes to water sustainability. The Golden State faces three critical factors that increase the difficulty - but also emphasize the importance - of maintaining water sustainability: increasing demand for water due to an increasing population; urbanization of land, leading to more runoff; more intense and less frequent rainfall due to the effects of climate change. However, Dr. Fisher along with his students are developing projects to replenish the depleted aquifers by recharging them with river water, stormwater runoff, and recycled wastewater: this process is known as Managed Aquifer Recharge (MAR) [11].

Dr. Fisher has found ways to identify the locations of the Bajaro Valley in which annual runoff is the highest; using this method allows for the amount of collected stormwater runoff to be maximized. Essentially, by collecting more stormwater runoff, the rate in which water is pumped back into the aquifer will increase: an extension of the lifespan of the groundwater storage.

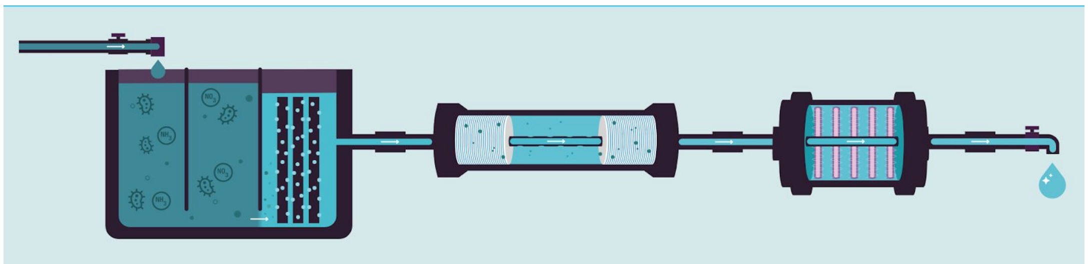
These projects are centered around the idea of capturing water before it enters the ground; once stormwater enters the ground it becomes much more difficult to clean and much easier to diffuse contaminants. These contaminants often feature nitrates: a chemical that has been linked to harmful and biological conditions. Nitrate is quite abundant in California since many plants grown require nitrate-based fertilizers; however, not all nitrate is absorbed as the unused chemicals end up on the ground where they can be picked up by stormwater.

In order to prevent nitrates from polluting the groundwater supply, one of Dr. Fisher's studies at UCSC evaluated the ability for wood chips from redwood trees to absorb and remove nitrate from water. Ultimately, it was found that a redwood tree wood chip layer above native soil is a cost effective and efficient method to filter out harmful nitrate chemicals.

Wood chips from Redwood trees, as shown above, are used to filter out harmful nitrates from entering groundwater [12].

PHYTOREMEDIATION: A SUSTAINABLE REMEDY TO IMPROVE WATER QUALITY

The collection of stormwater often comes with the challenge of cleaning in order to meet the necessary standards of safety. Stormwater is seldom safe to drink following capture; typically, stormwater is treated using various methods. First, the water is treated with membrane bioreactors: a method used to remove ammonia and other nitrogens. Next, the water is treated with reverse osmosis. Finally, UV Light is shined upon the water in order to remove all remaining viruses and bacteria. After the stormwater is treated, it is stored in groundwater basins.



(From Left to Right) Bioreactor, Reverse Osmosis, UV Light. Essentially, a high energy method of cleansing water in order to guarantee safety for public use [13].

Despite the effectiveness of these various processes, they require a lot of energy to operate: this energy is often generated from oil or petroleum, leading to long term consequences for the climate and environment. Ultimately, more sustainable methods of water cleansing exist; most of these methods are linked to a process known as phytoremediation. Essentially, phytoremediation is the practice of using plant-life in order to lower the concentration of contaminants in water and soils.

One common example of phytoremediation is using poplar trees to filter various contaminants out of water. Ultimately, poplar trees are a great resource for recycling urban water while also reducing the carbon concentration in the atmosphere. Poplar trees, specifically *Populus tremula* x *Populus alba*, are effective absorbers of hydrocarbons, nitrogen, phosphorus, and ammonia. Once these various pollutants are ingested by the plant, they are metabolized in various plant tissues and released as a non-harmful gas.

Poplar trees, shown above, are effective removers of various contaminants from water [14].

The water hyacinth, shown above, are effective removers of various contaminants - including heavy metals - from water [15].

In addition to the poplar tree, the *Eichhornia crassipes*, or more commonly known as the Water Hyacinth, was found to be an effective absorber of the following heavy metals: lead, mercury, arsenic, zinc, copper. Studies performed on the species indicated that 50% of metals (Cu, Pb, Zn, Cr, Ni) were removed within the first hour of usage; 26% within 9 hr (Mn, Ba); 10% within 6 hr (Cd); 10% in 24 hr (Fe) [16]. The Water Hyacinth can play an essential role in the process of decontamination; heavy metals are toxic even at low concentrations and pose a serious danger to public health if unremoved from water.

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