•Ballona Creek Watershed•

Drainage in Los Angeles

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Environmental and Water Resources Engineering

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Introduction

The inspiration for this project came from my personal experience living in Los Angeles, California. From the 4 years I spent living there as an undergraduate University of Southern California student and the one summer I spent interning in the water division at their municipal utility company, I became fascinated by the intricate water infrastructures of Los Angeles. After a good discussion about this with Dr. Maidment, we developed a refined project idea; tell a story of how water moves through these infrastructures. In other words, how does water drain through a large urbanized city, such as Los Angeles?

From working on GIS CE 394K ArcGIS Pro exercises, the students became familiarized with stream characteristics and drainage patterns of natural watersheds that are not heavily influenced by anthropogenic activities. The follow-up question is then:

When natural drainage becomes compromised by urbanization, how do engineers compensate and design improved drainage systems to sustain highly populated cities?

Project Scope

The scope of this project will investigate the Ballona Creek watershed. It encompasses the greater Los Angeles area in Southern California, and it includes well-known landmarks such as Beverly Hills and West Hollywood. Los Angeles is the second largest urbanized city in the United States, which makes it an appropriate urban extreme to examine.

Objectives

1. Understand drainage patterns within a highly urbanized environment.
2. Simulate the ArcGIS Pro skills developed from the class exercises and apply them towards the artificial environment of the Ballona Creek Watershed.
3. Compare and contrast the drainage patterns of a natural watershed to that of an urbanized one.
4. Suggest future research directions to better analysis drainage in urban systems.

Watershed Background

Watershed Overview

Ballona Creek watershed covers approximately 130 square miles of highly urbanized area within the Los Angeles basin of Southern California. Figure 1 displays this watershed and defines the boundaries.

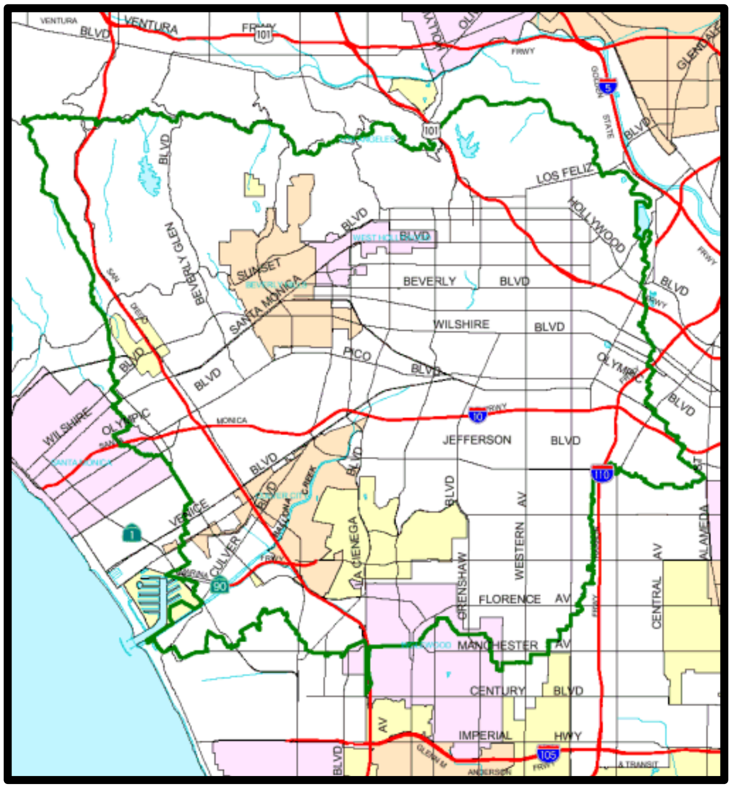

Figure 1. Ballona Creek Watershed Street Map View from LADPW

This watershed extends north into the Santa Monica Mountains where the headwaters are located, west into Beverly Hills and Culver City, east into downtown Los Angeles, and south to the Baldwin Hills. This watershed drains out through a nine mile long channel into the Santa Monica bay, shown on the southwest corner of the map adjacent to Marina Del Ray.

Urbanization Impacts

Of course, Ballona Creek watershed was not always highly urbanized. Prior to the 1850s, it was a natural terrain, characterized by complex drainage network of intermittent and perennial streams that flowed into wetlands and springs. Figure 2 shows the land transformation from 1977-present.

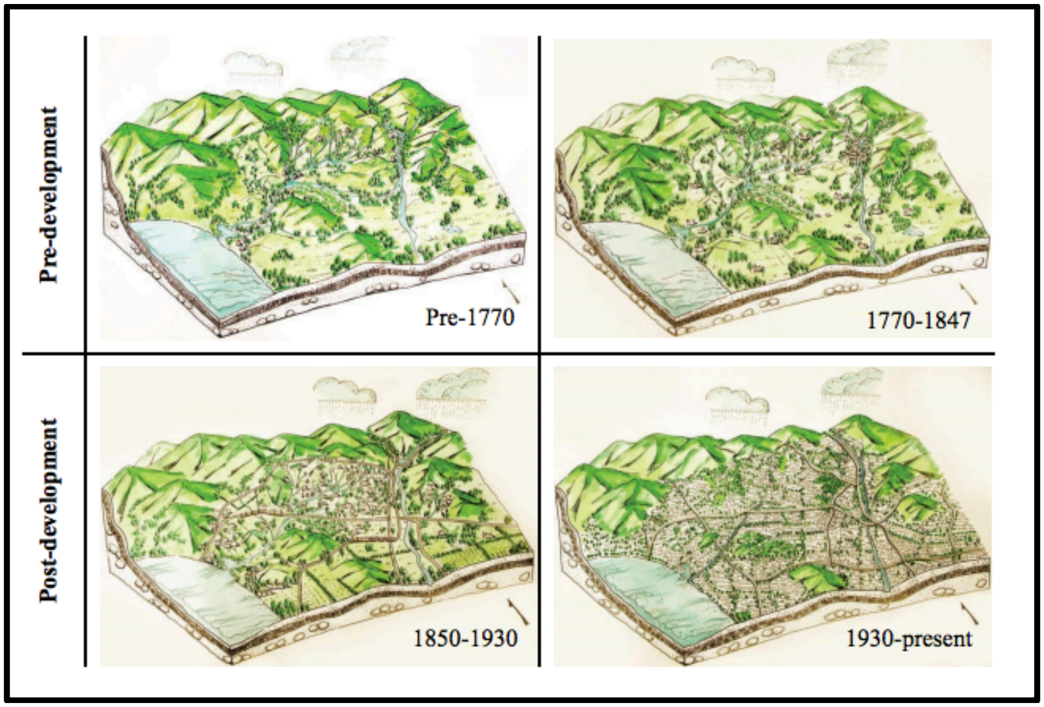

Figure 2. Pre-Development and Post-Development of Ballona Creek watershed (Braa et al., 2001)

The transformation of the land to agricultural use during early settlements into the watershed began to disrupt the hydrologic cycle. Population density continued to exponentially rise, and around 1850s, the rapid construction of homes, skyscrapers, and paved roads began to raise the percentage of impervious surfaces. Consequentially, this urbanization further disrupted the hydrologic cycle and altered runoff rates. By early 1900s, natural water supplies alone could no longer sufficiently meet the high water demands of the city, and as a result, water had to be imported. These hydrologic disruptions and the introduction of imported water imbalanced the water balance. Figure 3 is a generalized schematic of the water balance, and it shows the inputs and outputs of a pre or post-developed watershed.

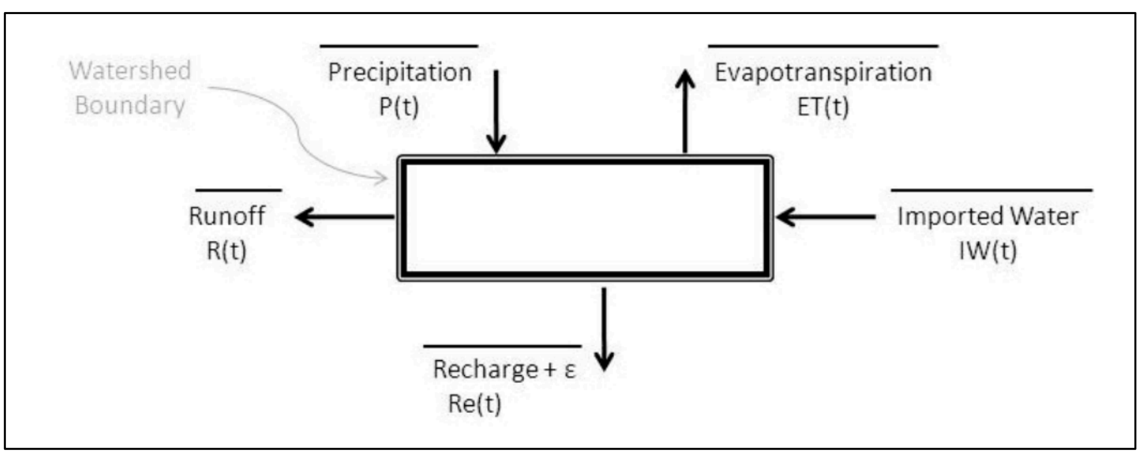

Figure 3. Conceptual water balance applicable to pre and post development of a given watershed

According to this water balance, significant rise in non-native imported water raises the water input, which increases the net water output. Furthermore, the increase in impervious surfaces decreases recharge water output because water cannot percolate through the ground soil. This means if no alternations are made on existing drainage systems to facilitate higher runoff R(t) or recharge Re(t), water would accumulate and flood the urban city. Thus, from 1935-1939, the United States Army Corps of Engineers channelized Ballona Creek as shown in Figure 4 to mitigate flood risks, and its tributaries became channelized as well in the 1950s.

Figure 4. Ballona Creek Channel from Aerial View

The walls of this open channel are lined with concrete, and the bottom is paved with stones. The channel itself is trapezoidal in shape, with the bottom widths varying from 80 to 200 feet and depths varying from 19 to 23 feet from the top of the levee according to the Environmental Protection Agency. In addition to channelizing Ballona Creek during 1930-1940s, storm drains were also built underground to prevent flooding and facilitate the drainage of excess water from rain. ArcGIS Pro will be used to map this constructed drainage system.

Methodology

Table 1 outlines the data acquisition for this project. It also outlines the function of the datasets for examining water drainage characteristics in the Ballona Creek watershed.

Dataset Source	Use
United States Geological Survey (USGS)	1. Delineate the watershed using the provided stream gage of Ballona Creek near Culver City, CA and the Watershed tool from hydro ArcGIS server. 2. Collect historical daily discharge data (cfs) from 1928-1978.
Landscape ArcGIS Server	1. Examine landcover from USA_NCLD_2006. 2. Examine flowlines and the best estimate of the actual mean annual flow (cfs) from USA_NHDPlusV2_1_Flat. 3. Examine flowline types, particularly streams and artificial paths, from USA_NHDHighRes.
Los Angeles County GIS Data Portal	1. Examine underground gravity mains from Los Angeles County storm drain system. 2. Examine direction of water flow from Direction of Flow within Sub Watersheds. This will overlay on top of the results from Flow Direction Geoprocessing tool and the DEM extracted from elevation ArcGIS Server.
U.S. Climate Data	1. Examine precipitation in Los Angeles during December 1977.

Table 1. Dataset sources and its corresponding data uses

The watershed shapefile will then be uploaded to hydroshare.org and then imported to the National Water Model Forecast viewer to examine the drainage and velocity output.

Results and Analysis

The nature of drainage systems is dependent on the landform. Table 1 summarizes the percentages of various landform types within Los Angeles from the year 2006. Los Angeles is the second largest urbanized city in the United States, with vegetation drastically reduced within a span of 80 years as shown in Figure 2. Thus, as expected, the landform is majority development at 88.41%.

Landform	Sum_Count	Area (km^2)	Percentage (%)
Development	313995	282.60	88.41
Forest	4473	4.03	1.26
Open Water	1229	1.11	0.35
Shrub Scrub Grass	35440	31.90	9.98
Wetland	39	0.04	0.01

Table 2. Landform area (km^2) and percentage (%) of Ballona Creek watershed

The diagram in Figure 5 show that from the 88.41% of development, 52% of the land use is residential, while 12% is commercial and public. The water that is discharged into Ballona Creek channel is not just from storm water; outdoor water usage from residential homes, such as from sprinklers, and restaurants washing the front steps of their store, also drain out to the channel.

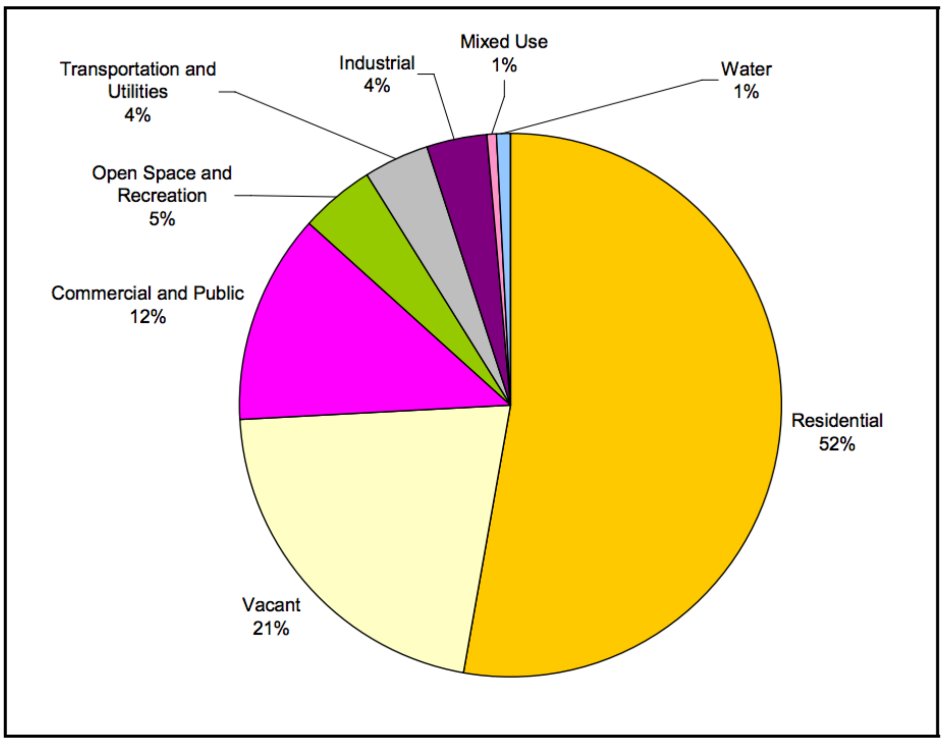

Figure 5. Land use distribution in Ballona Creeek watershed

The next largest landform is 9.98% shrub scrub grass, and most of this natural landform is located near the San Macros Mountains as shown in Figure 6.

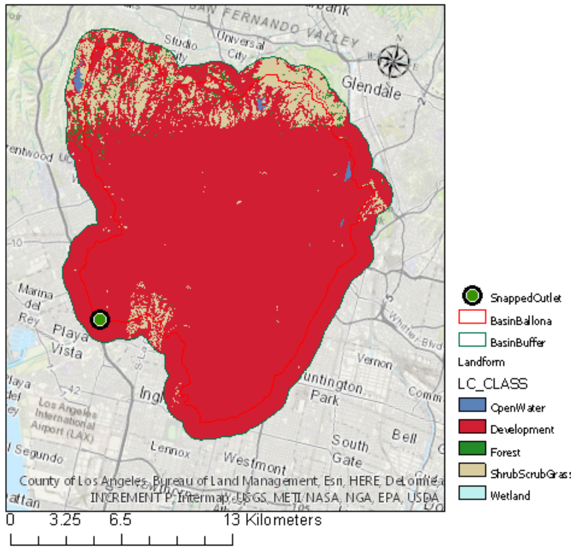

Figure 6. ArcGis Pro Ballona Creek Watershed map of landcover

It can be concluded from Figure 6 that there is reduced interception due to lack of vegetation to capture what little precipitation there is in Los before it reaches the ground surface. According to the Los Angeles Department of Public Works, this watershed is approximately 40% impervious. This high imperviousness percentage and reduced interception allows for higher volume of precipitation or urban runoff to accumulate on the ground. Therefore, this watershed must rely on an artificial manmade drainage system rather than the existing landform for discharging water.

Figure 7 indicates one main flowline from the National Hydrography Dataset (NHD), or NHDPlusV2, which is the Ballona Creek channel with an actual mean annual flow of approximately 10.96 cfs.

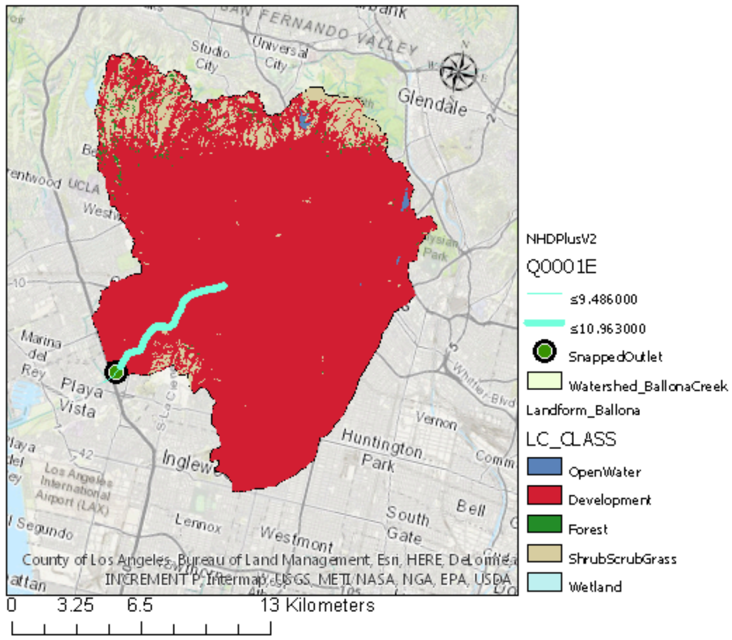

Figure 7. ArcGis Pro Ballona Creek Watershed Map of Landcover and NHDPlusV2

It is important to note there is limitation on the NHDPlusV2 flowlines; it does not map the channelized tributaries in the watershed, such as the Sepulveda channel. The map in Figure 8 below illustrate the flowlines of the tributaries missing from the National Hydrography Dataset.

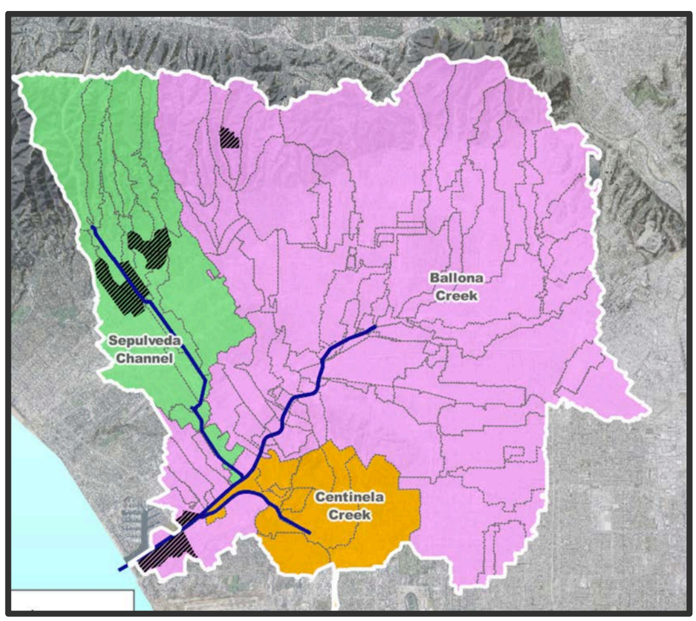

Figure 8. Ballona Creek Watershed map with channelized tributaries from CA Waterboards

Figure 9 illustrates the flowline types within the Ballona Creek watershed using the high resolution National Hydrography dataset (NHDHighResolution). Streams and rivers, indicated by the light blue lines, are located north of the watershed near the San Marcos Mountains. This coincides with the natural shrub scrub grass landform, which indicates that the northern region of the watershed near the mountains is not heavily impacted by development and urbanization. The mountains are not an ideal region to develop roads and skyscrapers, and therefore, few natural drainage streams still exists there.

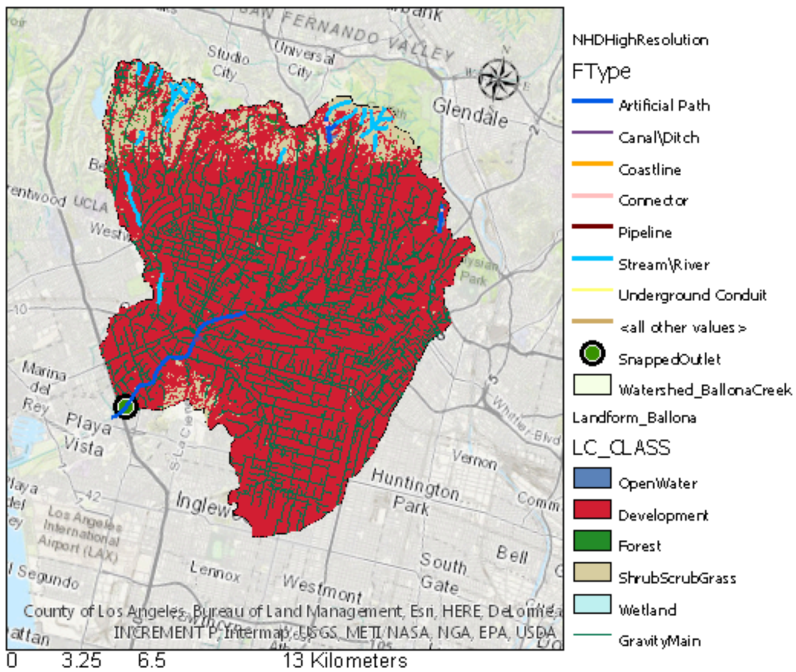

Figure 9. ArcGIS Pro Ballona Creek watershed map of the gravity main lines, landform, and flowline types

The map also illustrates the intricate network of gravity main lines that spread all across the watershed underground and below the highly urbanized city. This complex drainage network to the south of the mountainous region and within the developed landscape replaces the natural drainage network that once existed in the 1700s and early 1800s. Figure 10 shows a zoomed in look at the underground gravity main lines.

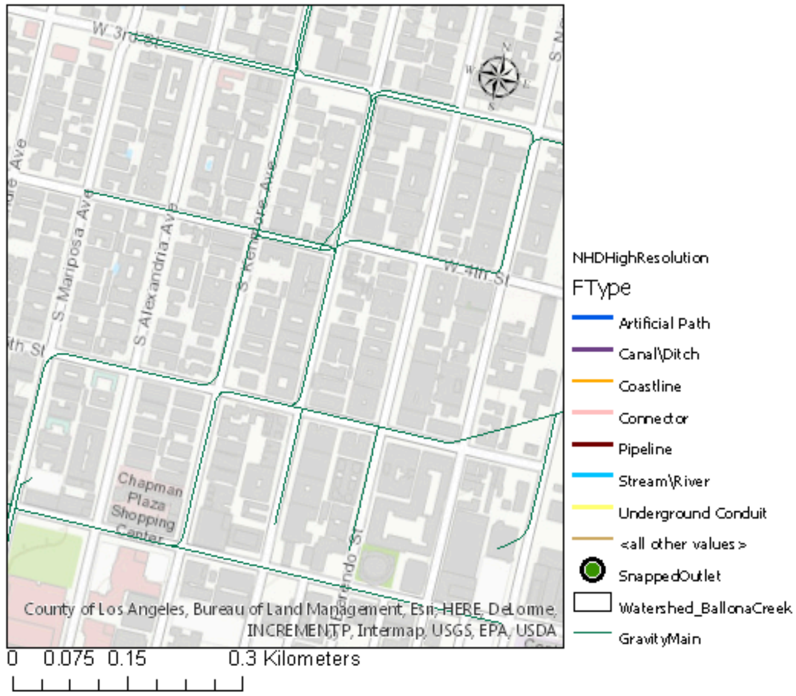

Figure 10. ArcGIS map of gravity main lines at a zoomed scale

These lines run through major city streets of Los Angeles and through residential blocks (depicted as an agglomeration of gray rectangles on the map) to drain storm water and other outdoor water outputs. Note that sewer and indoor water does not drain into these gravity main lines. These types of water have separate sewer lines that get treated at wastewater treatment plants and are not directly discharged into the ocean.

Although this underground drainage network is artificial, it reflects the behavior of above ground natural drainage network in several ways. To demonstrate this point, the drainage of the Ballona Creek watershed is compared to that of the San Marcos Basin from class exercises. The flowline map of the San Marcos Basin is shown in Figure 11 below as reference.

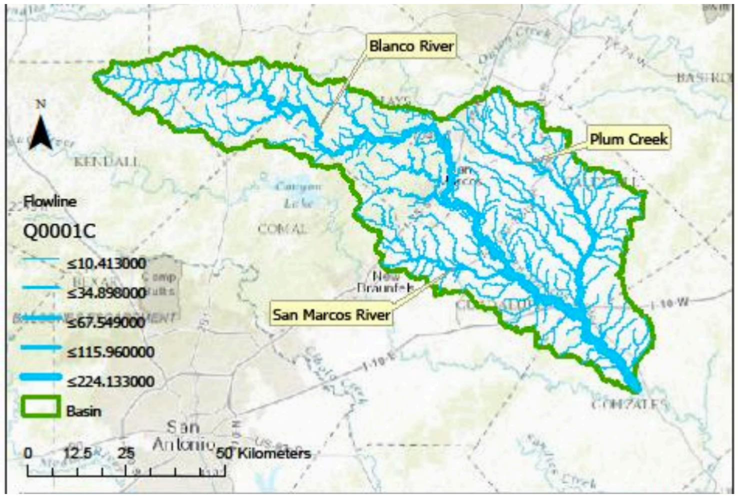

Figure 11. ArcGIS San Marcos Basin Flowline map

First, as the name suggests, the gravity main lines also operate by using the force of gravity to drain the water. Next, the spaghetti-like gravity main lines correspond to the small spaghetti-like stream branches, or tributaries. These spaghetti-like branches both flow into one main stream that then discharges out of the watershed. In the case of the Ballona Creek watershed, this main stream is the Ballona Creek channel. Figure 12 illustrates this drainage pattern. The channel is indicated as an artificial path by the dark blue line.

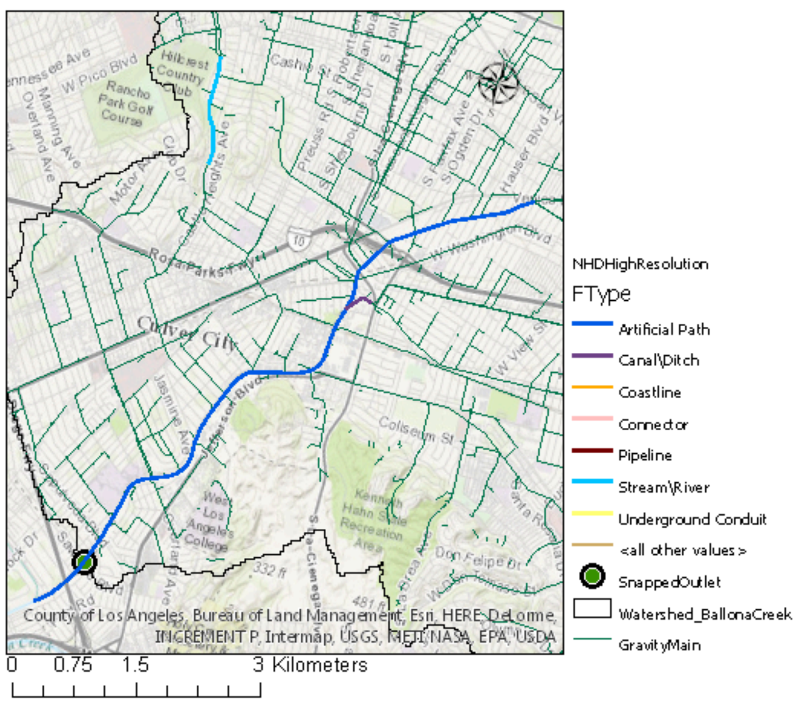

Figure 12. ArcGis Ballona Creek watershed zoomed map of artificial channel and gravity main lines

The gravity main lines thus correspond to natural streams within a natural watershed. This parallel allows for the theoretical calculation of drainage density, or total stream length divided by drainage area for an urbanized watershed. This value is an important indicator of how well or how poorly a watershed is being drained. However, because channelized tributaries are missing from the maps, the drainage density cannot be accurately calculated in this project due to missing data.

Lastly, Figure 13 and Figure 14 both reinforce the concept of gravity flow into a main channel by taking a look at flow direction and elevation.

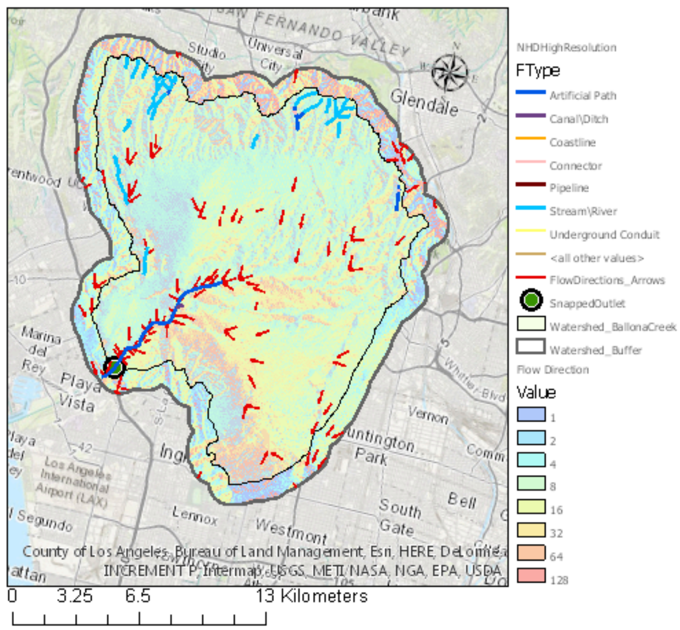

Figure 13. ArcGis Pro Ballona Creek Watershed map of flow direction

The arrows clearly point the direction of water flow towards the Ballona Creek channel and follows the main Sepulveda Channel and Centinela Creek tributary lines.

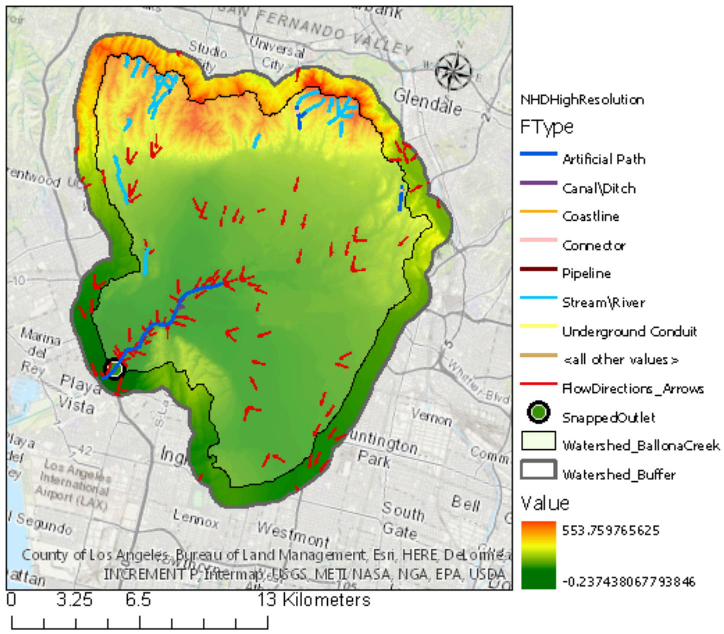

Figure 14. ArcGis Pro Map of flow direction arrows and DEM elevation (m)

This DEM illustrates the higher elevation mountainous region to the north of the watershed with warm colors of red and yellow. It makes sense then that water flows by gravity from this higher elevation down to the lower elevation at Ballona Creek channel, and therefore, a portion of the drainage discharge is from natural streams and rivers near the mountains.

National Water Model Forecast

It is useful for Los Angeles urban planners, engineers, and environmentalists to observe forecasted water discharge and flow velocity from the Ballona Creek channel. This prediction is important for making flood risk prevention decisions. Ballona Creek was channelized for this purpose; the large and growing Los Angeles residential population wants their driveways clear of water immediately for practical transportation and damage mitigation reasons. Thus, is it imperative for urban decision makers and designers to ensure the drainage system remains efficient and sustainable, especially to combat against foreseeable drastic changes in water discharge and velocity. An example of this would be from an approaching heavy storm.

The National Water Model (NWM) is capable of producing these forecasts; it is a public hydrologic model tool that simulates forecast streamflow over the entire continential United States. To create these drainage output forecasts, the Ballona Creek Watershed shapefile was uploaded to hydroshare.org and then imported to the NWM Forecast Viewer. The medium range configuration was selected to see the forecasts out to 10 days. Figure 15 below shows the forecasted discharge flow to be approximately 13.5-14.0 cfs from November 28-December 9, 2016.

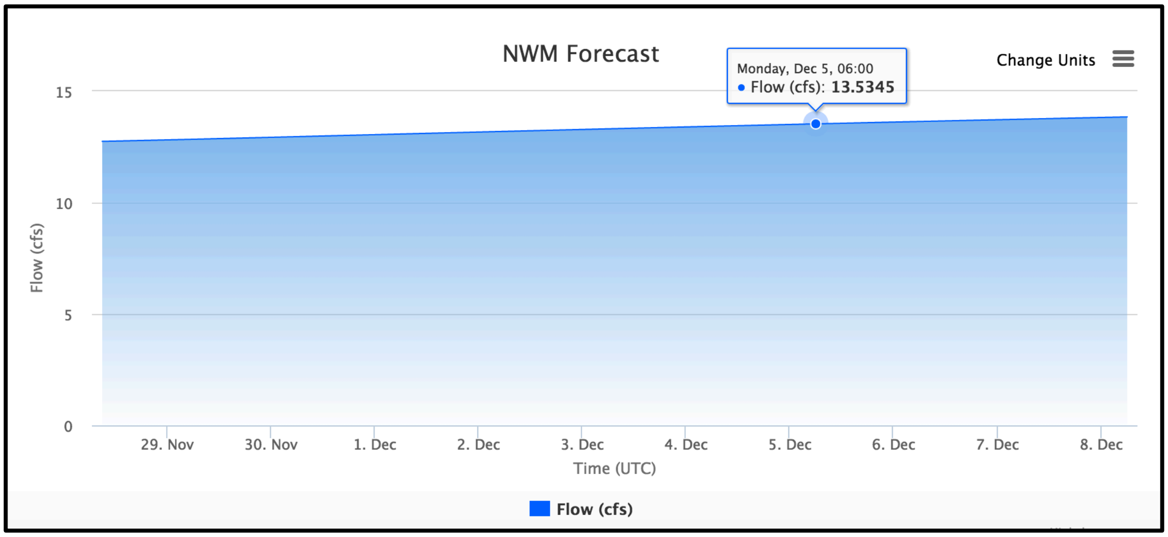

Figure 15. National Water Model Forecast for discharge flow at Ballona Creek watershed

The question is whether or not this predicted forecast is reasonable. Quantitatively, this forecast is slightly higher than the best estimate mean average flow of 10.96 cfs from Figure 7. This forecast is also slightly higher in comparison to historical median daily discharge of approximately 9 cfs as shown from Figure 16 below.

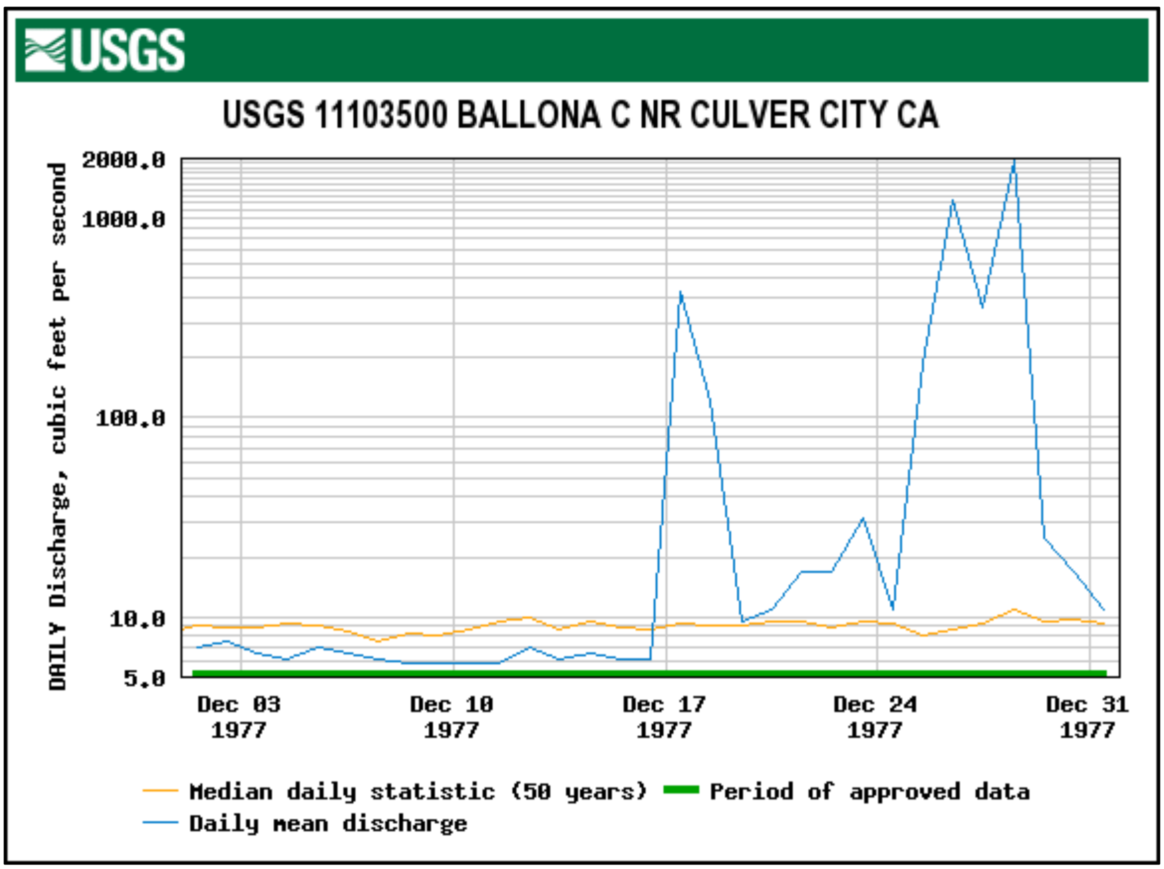

Figure 16. Historical daily discharge data in December 1977 from USGS

Note that the available historical daily discharge data was limited from March of Year 1928 to September of Year 1978, which is why the comparison was made to real data from December 1977. This timeframe coincides with the beginning of development in the Ballona Creek Watershed. It can be concluded that this approximate 1-2 cfs overall rise in average daily discharge is due to urbanization over the span of 88 years. Notice the drastic peaks in the daily discharge even up to as high as ~2000 cfs. An overlap of precipitation and discharge trends in December illustrates the direct correlation of the two in Figure 17.

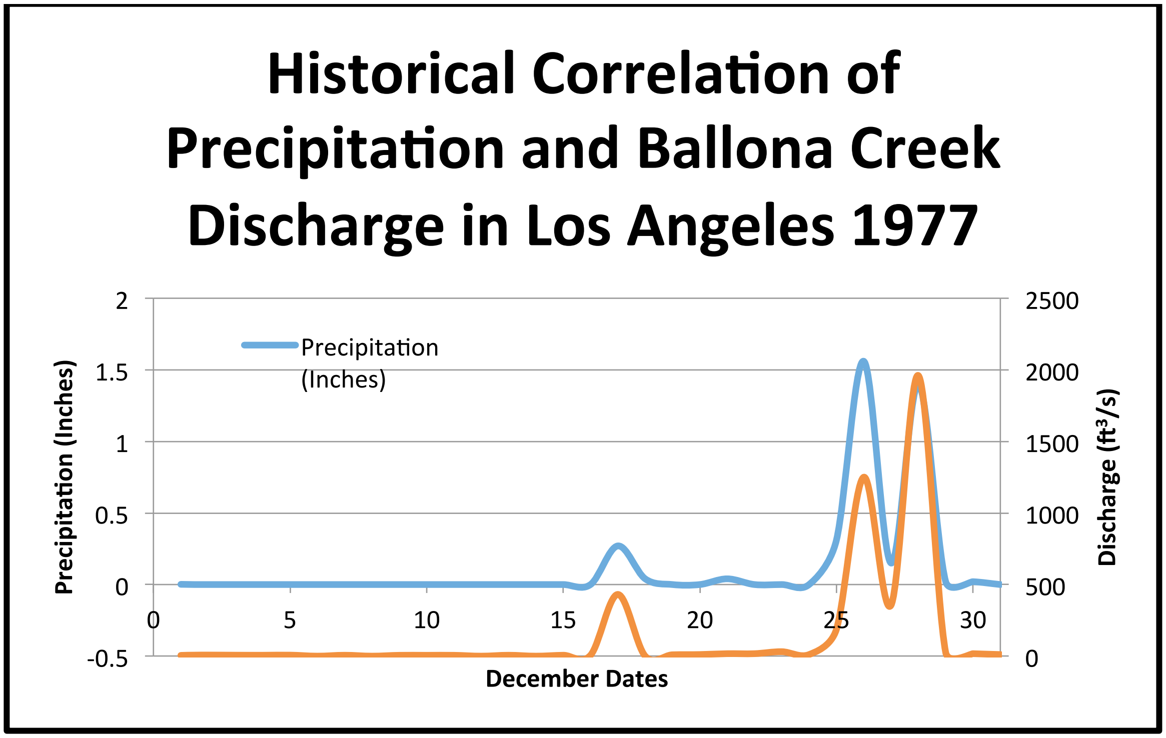

Figure 17. Historical correlation of precipitation and Ballona Creek discharge in Los Angeles 1977

Precipitation is the cause of drastic rises in discharge flow rates. It can also be concluded that the forecasted 13.5-14.0 cfs discharge reflects water discharge primarily from residential and commercial use, or water drained from the mountains. This makes sense as the upcoming weather forecast for December 1-December 8 reveal no precipitation.

From Figure 18, the forecast predicts the flow velocity to be fairly consistent around 0.1 ft/s. This raises discussion on the accuracy of the NWM on the Ballona Creek channel, because the speed is very slow for an open channel.

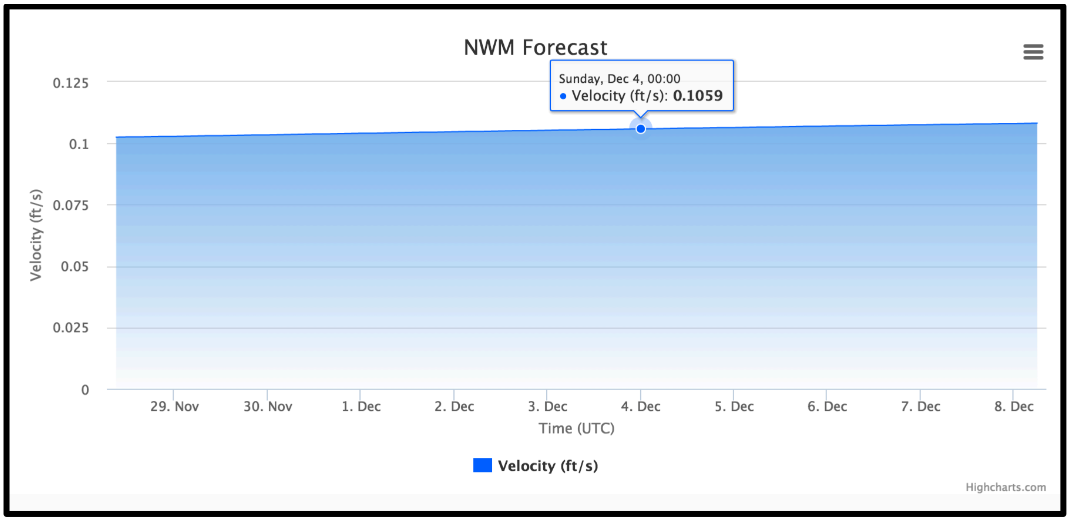

Figure 18. National Water Model Forecast for velocity at Ballona Creek watershed

Indeed, there are limitations on the NWM; it is difficult to generalize a mathematical model for hydrologic cycles across the entire nation. Furthermore, the majority of the 2.7 million streams that the model reaches are natural water bodies. This becomes a problem for channelized streams, because the model does not account for its manmade material and artificial shape. In the case of Ballona Creek channel, it is lined with concrete and trapezoidal in shape. The forecast possibly could be underestimating the actual velocity or discharge. Further hands on research can be conducted to better understand the hydrologic cycle within an urbanized environment to prove or disprove this hypothesis. This knowledge could enhance and refine the accuracy of the National Water Model for cities with high impervious percentages. It could also potentially increase more points of reach across the United States, where not only are natural rivers represented, but also major streets and channels.

The Manning's Equation is a common equation that governs Open Channel Flow, which correlates channel velocity, flow area, and channel slope. It can be used to theoretically calculate the discharge flow rate (Q) and velocity (v) of a given open channel. It is a reliable estimate as it specifically accounts for the material, slope, and dimensions of the channel.

$$Q = VA = \left(\frac{1.486}{n}\right) * A * R^{\frac{2}{3}} * \sqrt{S}$$

Equation 1. Manning's Equation

Where:

Q = Flow Rate, (ft^3/s)

v = Velocity, (ft/s)

A = Flow Area, (ft^2)

n = Manning's Roughness Coefficient

R = Hydraulic Radius, (ft)

S = Channel Slope, (ft/ft)

As mentioned previously, the Ballona Creek channel is a trapezoidal open channel; Equations 2-4 are relevant equations to calculate the physical characteristics of the channel.

$$A = \left(\frac{y}{2}\right) * (b + T)$$

Equation 2. Area of trapezoid

Where:

y =depth, (ft)

b = bottom length, (ft)

T = top length, (ft)

A = Area of trapezoid, (ft^2)

$$P = b + y * 2 * (\sqrt{1 + z_1^2}$$

Equation 3. Wetted perimeter equation

Where:

Z_1 =side slope, (ft)

P = wetted perimeter, (ft)

$$R = \frac{A}{P}$$

Equation 4. Hydraulic Radius Equation

To calculate the slope:

$$S = -\frac{dz}{dx}$$

Equation 5. Channel Slope Equation

Where S is the slope, dz is the change in elevation, and dx is the length of the channel. The slope of the Ballona Creek channel was estimated by arbitrarily selecting choosing two points on the map. The elevations at these two points were identified, and the length between the two points was measured. The slope was calculated to be 0.008 ft/ft.

According to Los Angeles Department of Public Works (LADPW), the Ballona Creek channel above Sawtelle Blvd is 95 feet wide as the upper width and 23 feet tall in depth, with the assumption of the side slope as 1.5:1. The bottom length was not given but was assumed by LADPW to be 23 feet. This contradicts the bottom width estimate of 80-200 ft previously mentioned by the Environmental Protection Agency, but the bottom width of 23 feet was selected for consistency in sources. Manning's roughness coefficient n is 0.013 because the channel is lined with concrete.

Table 3 summarizes the parameter values for Manning's Equation to calculate for maximum velocity and discharge flow rate.

Parameter	Value
y (ft)	23
T (ft)	95
b (ft)	23
n	0.013
S (ft/ft)	0.008
Z_1 (ft/ft)	1.5
A (ft^2)	1357
P (ft)	105.93
R (ft)	12.81

Table 3. Parameter values for Manning's Equation applied to Ballona Creek channel

Combining Equations 1-5, the maximum velocity is calculated to be 56.02 ft/s and the maximum discharge flow rate at 76,023.83 cfs. This seems roughly reasonable, as Ballona Creek channel is designed to discharge 71,400 cfs from a 50-year frequency storm event.

To validate the discharge and velocity forecasted by the NWM, the specific depth of the water in the channel, as well as the top and bottom width at that given point in time, needs to be collected. Those explicit data has not yet been found publicly.

Conclusion

Urbanization and the growing population density of Los Angeles disrupt the natural hydrologic cycle and compromise the natural drainage system of the Ballona Creek watershed. Using ArcGIS Pro, this project was able to showcase the artificial drainage system designed by engineers and city planners to combat flood risk due to increased impervious surfaces and water input. The capacity and capability of the Ballona Creek channel is fascinating; one large nine-mile long channel can discharge all the storm water and urban runoff from the watershed of 130 square miles. The complex network of underground drainage pipes is absolutely crucial to maintain the water balance, because the small natural drainage remaining up north near the San Marcos Mountains cannot ensure proper water discharge. Overall, this design parallels natural drainage systems, but discharge flow rates and velocity differ. There are limited datasets available to study an urbanized watershed, but future research and studies can help engineers and city planners better understand water movement through urbanized environment and make informed decisions.

Future Work

This semester-long exercise can serve as a springboard to more extensive research for the future.

1. **National Water Model Enhanced Water Prediction Capability:** Hyper-Resolution Modeling for zoomed urban hydrologic processes.

   It is evident from this simple exercise that there are limited data available for urban hydrology. As our country continues to become more urbanized, it becomes increasingly relevant to study how water moves say, through a major street down Austin, Texas. Understanding the behavior of water on impervious surfaces can help add channelized flowlines to national datasets and create more accurate forecast predictions on the National Water Model.

2. **Water Quality Assessment:** Impact of urban runoff as non-point source pollution on wetlands and marine life downstream.

   As water drains through the urbanized streets of Los Angeles to the Ballona Creek channel, it becomes contaminated with motor oil, trash, bacteria, pesticides, and other pollutants. Unfortunately, due to the massive daily discharge volume (tens of millions of gallons of water), the storm water and urban runoff that drains from the channel are not treated. Wildlife in the wetlands downstream of the channel becomes dangerously vulnerable to the toxicity of the contaminated water. Not only is it important to ensure proper watershed drainage to meet human needs, it is also important to protect what little natural environment remains within the highly urbanized Ballona Creek watershed.

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