Restoring and Preserving the Incan Cultural Wonder of Saqsaywaman

A Thesis
Presented to
The Faculty and Staff of Engineering and Applied Science
University of Virginia

In Partial Fulfillment
of the requirement for the Degree
Masters of Science

by
Kenneth Scott Lohr
May
2014

Approval Sheet

The thesis

is submitted in partial fulfillment of the requirement

for the degree of

Master of Science in Civil Engineering

Kenneth Lohr

Author

This thesis has been read and approved by the examining Committee

Richard W. Miksad

Advisor

Jonathan L. Goodall

George L. Cahen

Accepted for the School of Engineering and Applied Science:

Dean, School of Engineering and Applied Science

May

2014

Acknowledgments

Thanks to all the member of the 2013 research trip to Peru

Richard W. Miksad, University of Virginia

Joseph Torp, Civil Engineering student, University of Virginia

Olivia Jeffers, Civil Engineering graduate, University of Virginia

Paul Ruess, Civil Engineering student, University of Virginia

Tosh Bance, Engineer, Microsoft Inc.

A special thanks to all the others without whom this report would not have been possible

Kenneth Wright, Wright Water Engineering

Alexei Vranich, UCLA Cotsen Instute of Archeology

Kelley Frank, Civil Engineering student, University of Virginia

The University of Virginia

Luke Wildfire and the other members of the 2010 research study from UVA

Dr. Daniel Ugaz Sanchez-Moreno, Asesor del DM Relaciones Institucionales, Ministerio de Cultura, Lima - Peru

Dra. Ana María Hoyle (DG-DGPC/MC), Director General de herencia cultural de Ministerio de Cultura, Lima - Peru

Congresista Julia Teves Quispe, , Congreso de la República, Perú

Sr. Fermin Diaz Angulo, office of Arq. Roberto Zegarra Alfaro, Gobiuerno Regional Cusco

Dr. Arminda Gibaja Oviedo, Chief Archaeologist, the National Institute of Culture at Cuzco

Lic. Mario Fernando Caller Salas, Director, Oficina Central de Cultura UNI, Lima - Peru

Ing. Jose Antonio Reynoso Palma, Parque de Saqsaywaman

Ing. Edith Quirquihuaña Zavala, Parque de Saqsaywama

Oscar Montufar, Jefe de Parque de Saqsaywama

Very special thanks to Professor Richard Miksad who was my advisor and my mentor in conducting research and writing this report.

Table of Contents

List of Figures

Map of Figure Locations

List of Tables

I. Introduction

I.1. Abstract

The study of Saqsaywaman started by looking at the collapsed terrace walls then expanded to the drainage basin that flow to the terrace walls, and finally expanded to the water flow over the entire site of Saqsaywaman. The topographical survey conducted at Saqsaywaman, Peru in July of 2013 reveals several key factors that affect the current wall collapse crisis. Over 4,000 survey points were collected using a total station. Those points were then used in order to create a three-dimensional model of the site of Saqsaywaman. This model was used to analyze the topography and runoff patterns on the site. The rational method was first used to estimate the water runoff for the site based off the 27 drainage basins and sub-basins. The runoff is estimated as a percentage of the total rainfall that lands on the site. Through a ground cover analysis the percentage of runoff to rainfall was found to be 37 percent. The maximum total runoff for a storm with a rainfall intensity of 0.2 meters per hour is 7500 cubic meters per hour.

Many of drainage ports at Saqsaywaman are not currently performing any hydraulic function because the water inlets are not located at ground level. Some of the inlets are buried while others are floating above the current ground surface. It is hypothesized, that all of the port inlets were once at ground level only there can serve any hydraulic purpose. The hydraulic flow rates of the ports have been analyzed and the average maximum volumetric flow rate for an average port is around 6500 cubic centimeters per second.

The current drainage channels recently constructed are not uniformly designed and have several problem areas that are over capacity during large rainstorms. This has caused large amount of water to overflow the channels in several locations, concentrating the damage to the walls. The other attempts to help fix the problem are at best preventative steps to help prevent further damage but all fail to correct the source of the problem.

The real source of the problem is the excessive amount of runoff and the northward flow. The amount of runoff has increased over the years due to ground cover changes as more impervious surfaces have been put in place. The current topography causes the water runoff to flow north towards the main terrace walls that were never designed to receive water runoff. This is causing the walls to collapse, taking with it the historical beauty of this cultural heritage site.

A new analysis, based off evidence of terraces above the walls at Saqsaywaman, shows that the flow patterns would change dramatically if the site was terraced. The flow patterns would direct all the water to the south, east, and west instead of to the north as seen with the current topography. There are some remnants of these terraces in the form of topographical clues, stone rubble piles, and old maps that suggest these terraces once existed.

Based on this study it is recommended that the drainage channels be upgraded to meet storm water runoff needs in order to prevent further damage to the site in the short term. In the long term, it is recommended that the topography of the site be returned to its original form which should help to alleviate water runoff problems.

II. Background Information

II.1. Saqsaywaman Background

Saqsaywaman is a World Cultural Heritage site that is located located to the north west of the city of Cusco, Peru. Together, Saqsaywaman and the ancient city of Cusco make up the shape of a puma (figure 1). Saqsaywaman makes up the head of the puma and Cusco makes up the body. The construction of this site was started by Packakuteq, the ninth Inca, somewhere around 1438. Construction continued for around 50 years and was completed under the rule of Wayna Qhapaq (MacQuarrie, 2008). Saqsaywaman consists of 5 major sectors as shown in figure 2. It is famous for its 3 massive zigzagging walls that run in the Baluartes sector shown in figure 3.

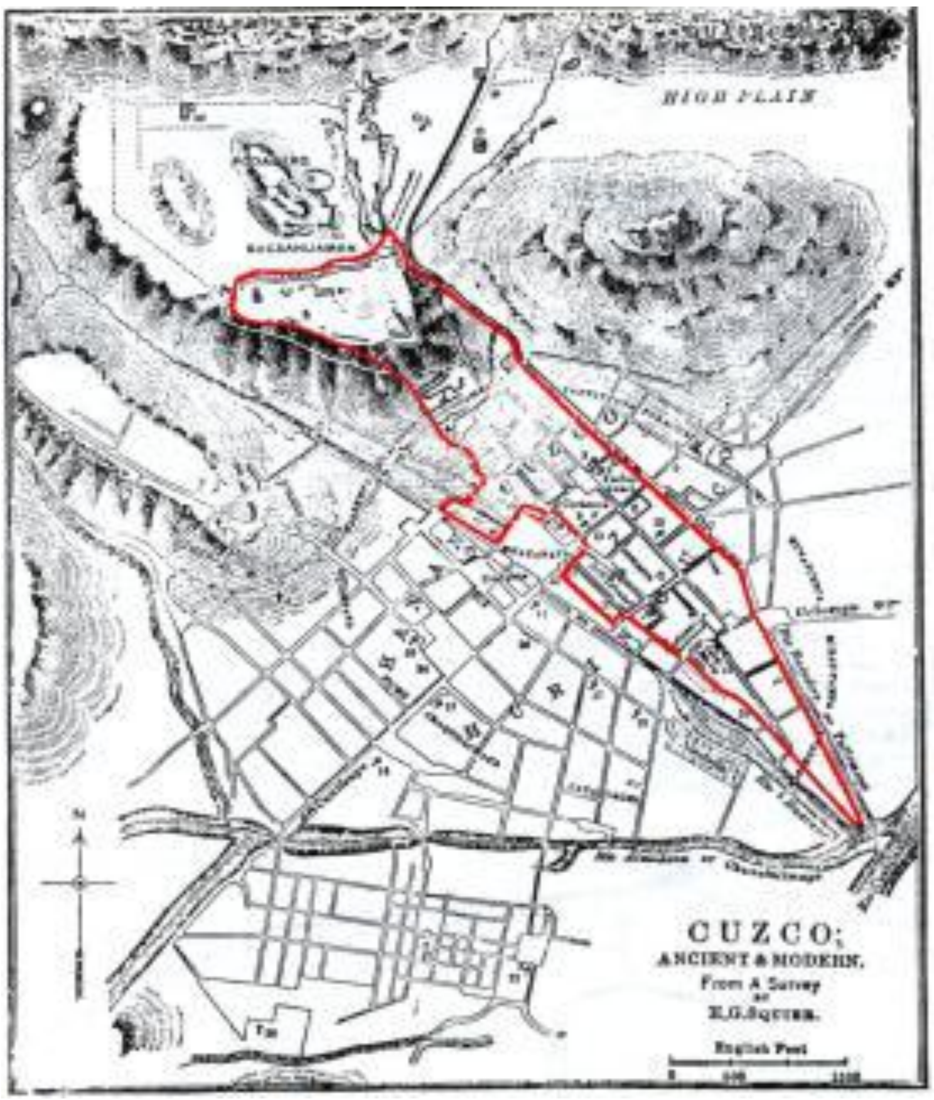

Figure 1. Cusco and Saqsaywaman Puma (El Cusco tiene forma de Puma 2008)

Figure 2. Five Major Sectors of Saqsaywaman (Google, 2014)

Figure 3. Frontal View of Plaza and the Three Walls (Mystic, 2010)

The site looks very different today than it looked in 1930 which was still different from original appearance. Dismantling of the site started not long after it was completed.

> *"What we see today of the Fortress of Saqsa Waman is but a shadow of the splendor that it once held.....the dismantling of the fortress started in 1537 only five years after the first Spaniards reached Cusco….and the fortress continued to serve as a quarry until the beginning of our (20th) century" (Protzen, 1993).*

Saqsaywaman was used as a stone quarry for many years so most of the walls now currently stop at the beginning of the terrace above it. The bottom of the walls remain because the stones were too large (some weighing in excess of 150 metric tons) to be easily carried down the hill to Cusco. Squier describes the walls as they could have been seen in 1877:

"Each wall supports a terrace or platform…. The summit of each wall rose originally from six to eight feet above the level of the terrace, forming a parapet with an interior step that defenders could mount to discharge their missiles against assailants"

"The first or outer wall has an average height of 27 feet; the second wall is 35 feet within it, and is 18 feet high; the third wall is 18 feet within the second, and s, in its highest part, 14 feet in elevation. The total elevation of the works is therefore 59 feet" (Protzen J, 1993).

In 1930 there was very little evidence of any stonework above the walls in the tower sector (figure 4). Archeologists began excavation in 1933 to bring the site back what is seen today.

Figure 4. Unexcavated Photo of Saqsaywman in 1930 (Bauer, 2004)

A photo by Reinhard (figure 5) shows a view of Saqsaywaman prior to recent large scale excavation work. The topography shown in this picture is very different from the current topography and very little of the ruins can be seen above the main terrace walls. The ground cover has also changed dramatically over the years as Saqsaywaman has become a major tourist attraction. The large amount of tourist foot traffic has since worn down the grass causing much of the site to become compacted dirt.

Figure 5. Old Photo of Unexcavated Saqsaywaman (Reinhard, 2011)

II.2. Site Layout

The basic layout of Saqsaywaman is shown by Gasparirni and Margolies (1980) in the map (figure 6). For the purpose of our research, I will be focusing on the Baluartes and Tower sectors of the site. There are several major landmarks (figure 7) that will be referenced in order to give perspective of locations on the site. The first landmark is the 3 main walls which are separated by terraces in the Baluartes sector. These walls have made Saqsaywaman famous. There are also more walls that are located on the east side of the site known as the east terraces. These walls run perpendicular to the main terrace walls and include an entrance gate to the site. Cruz Moq'o is another set of three terraces that are on the south end of the site. There are currently large wooden crosses set up on the top of these terraces which can be accessed by a walking path from the east side. There are remnants of two major ceremonial towers that are located in the tower sector. The most prominent tower is Mayuqmarka, which is a round tower located on the west side of the tower sector. A rectangular tower known as Sallaqmarka is located near the center of the tower sector. There have been references to a third tower Pacuarmarka but currently no remains of this tower can be seen. There is a main entrance gate and a stairway that climbs the main terraces. This entrance is located near the center of Chukipanpa, a large field that separates Sawsaywaman from El Rodadero. At the top of the main entrance is a tourist walkway that leads to a lookout point which is a popular tourist destination for photographs. From the lookout point, the city of Cusco (figure 8) can be seen. The final landmark that will be reference is the 2009 excavation sector. This is an area located just above the third wall in the tower sector that has been recently covered in a cementicious clay covering, which will be discussed further later in the report.

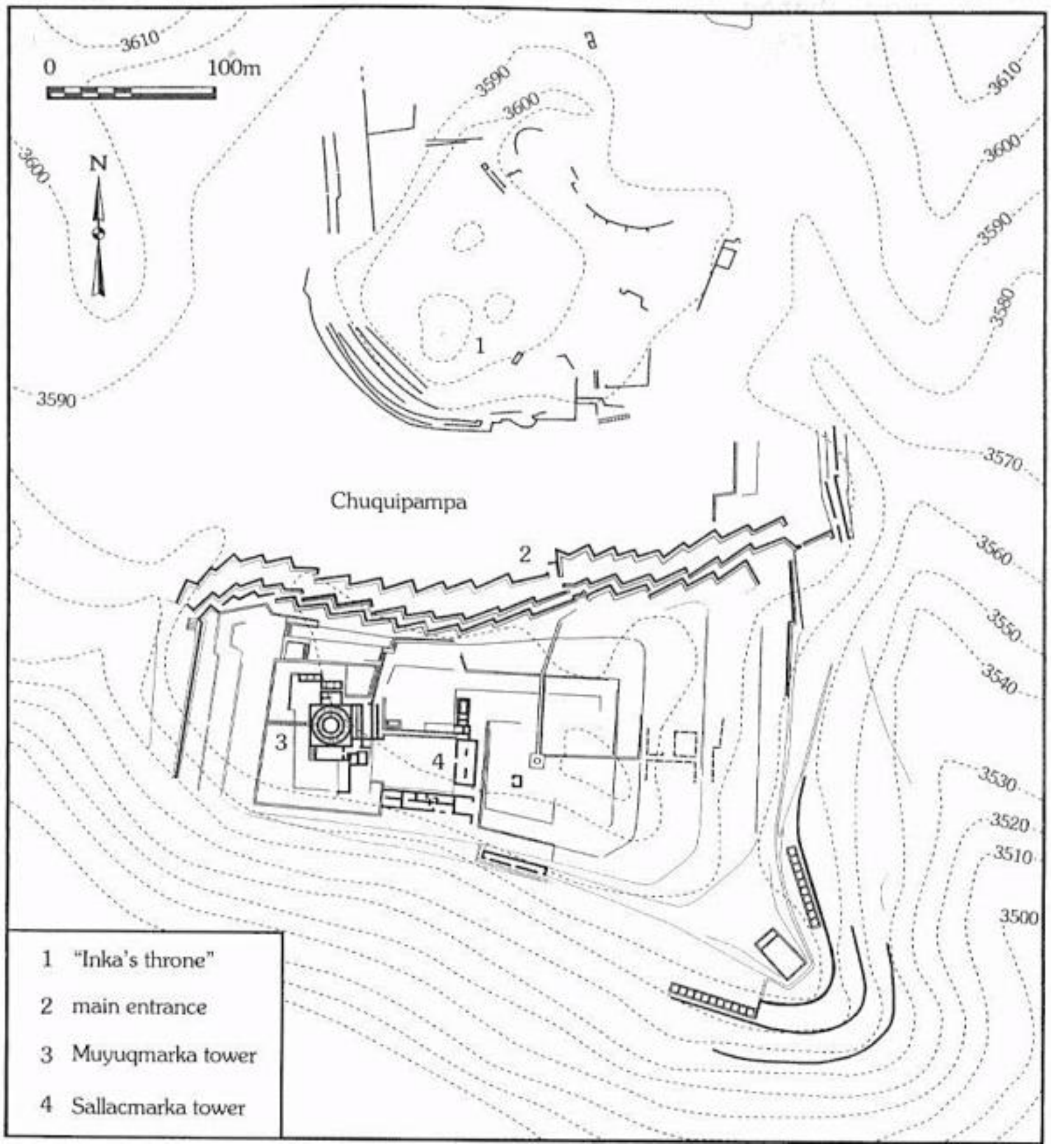

Figure 6. Map of Saqsaywaman (Gasparirni and Margolies, 1980)

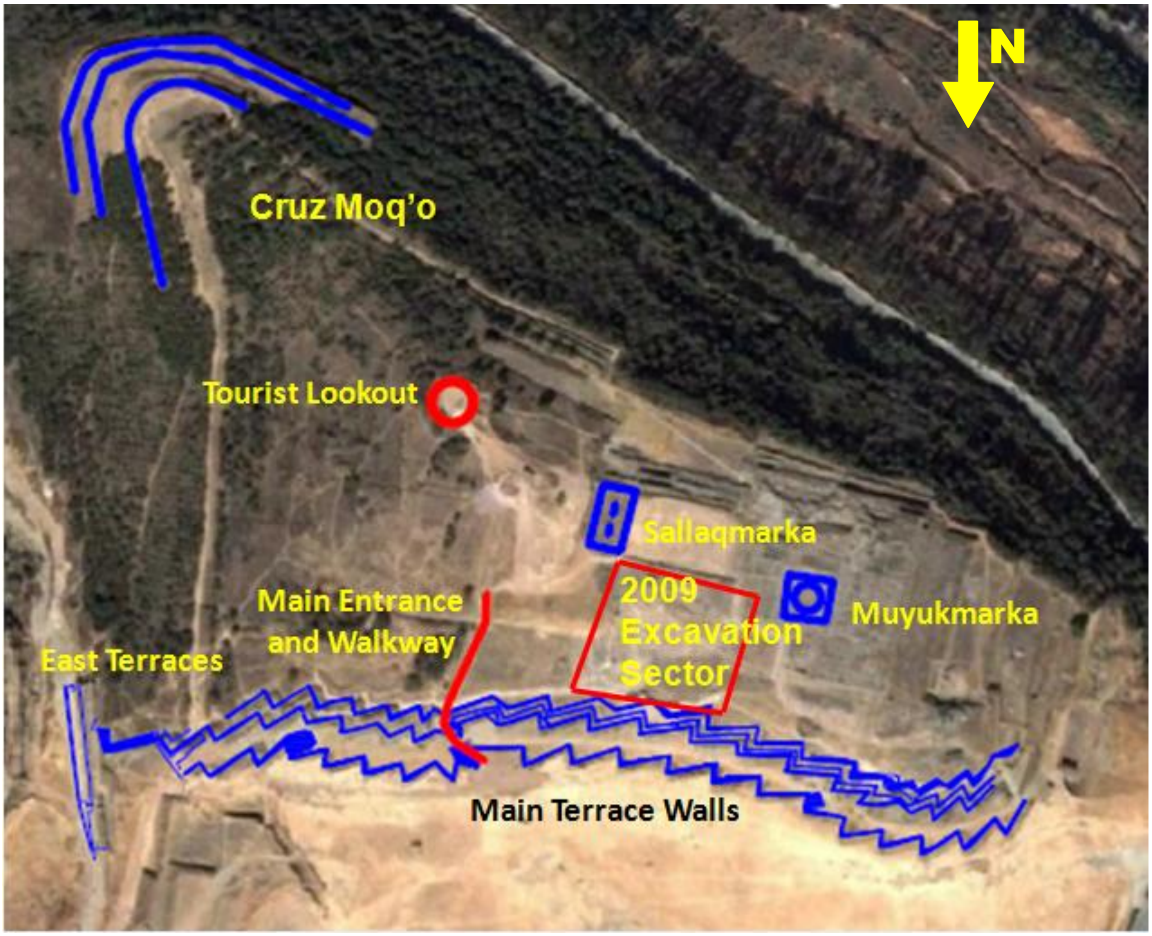

Figure 7. Major landmarks (Google, 2014)

Figure 8. View from Saqsaywaman of Plaza de Armas (Lohr, 2013)

II.3. Rendering the Original Beauty

Two representations of what Saqsaywaman may have looked like when it was completed were modeled by Mar (2014). His three-dimensional representation of Saqsaywaman is shown in figure 9. Upon looking at the tower sector close up (figure 10) the former buildings on top of Sawsaywaman, which only remain as stone remnants today, can be seen.

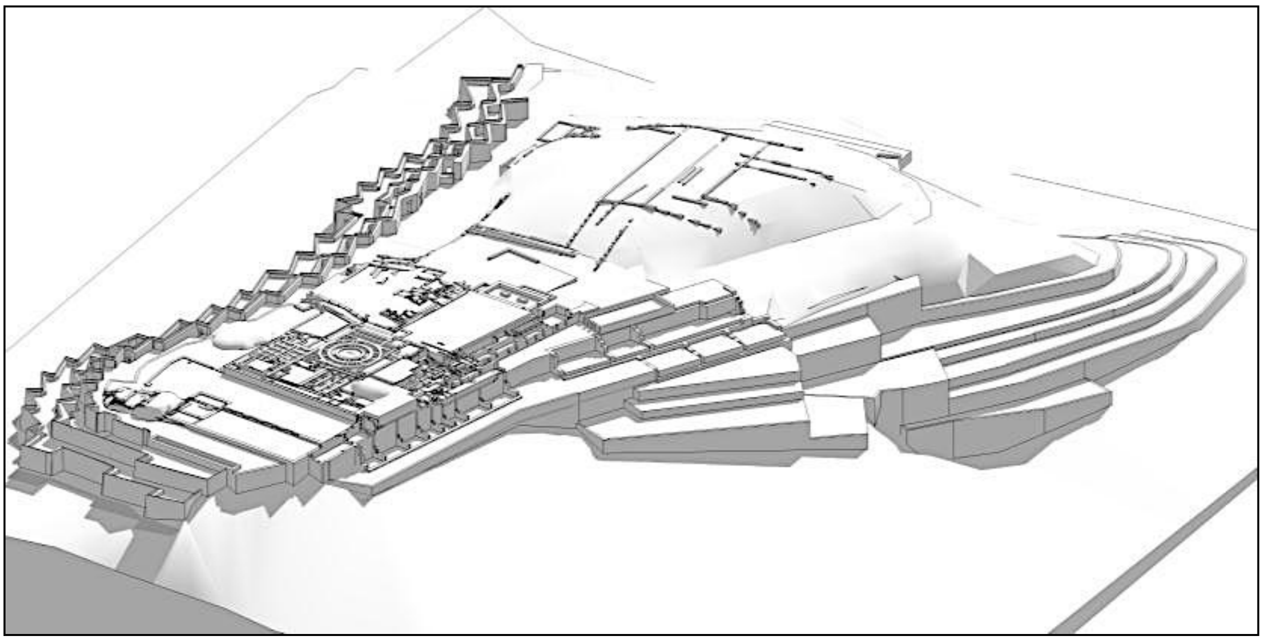

Figure 9. Representation of Saqsaywaman just after Completion (Mar, 2014)

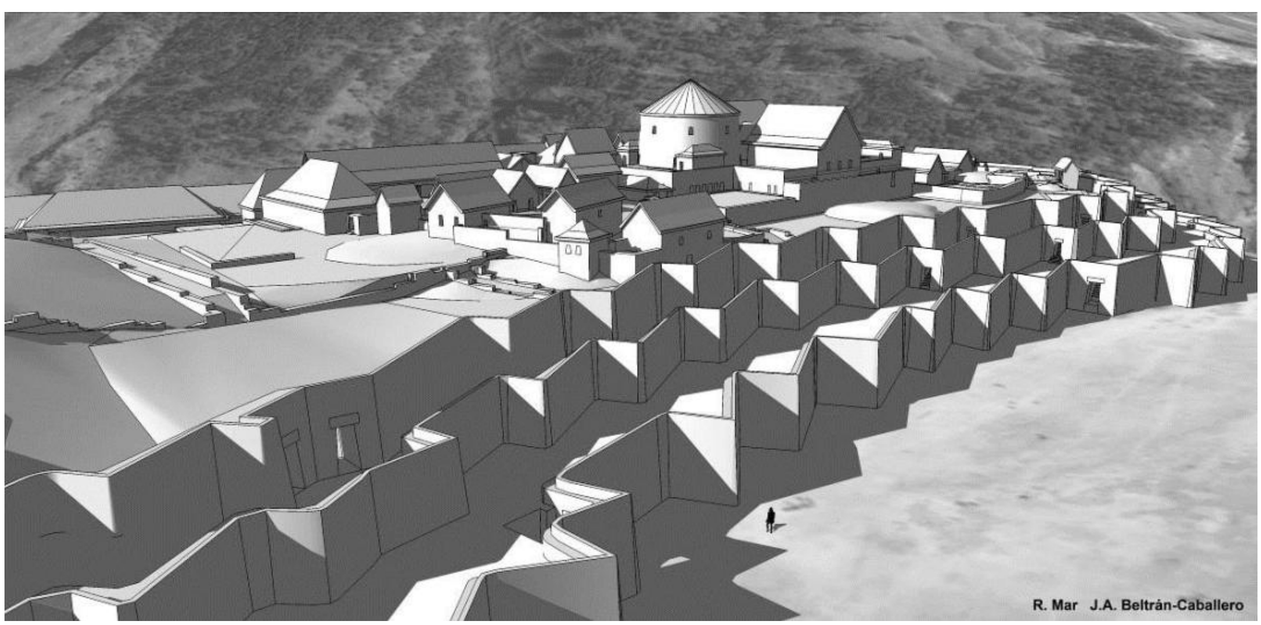

Figure 10. Model of tower Sector by Ricardo (Mar, 2014)

III. Problem Outline

III.1. The Problem

There is now a major problem occurring at Saqsaywaman. The walls are beginning to collapse destroying the beautiful stonework that has lasted over 500 years and it is taking with it the rich cultural heritage of the Incas who built this amazing masterpiece. A research study conducted by Miksad and Wildfire (2011) determined the main cause of the problem to be excessive water runoff caused by the introduction of a cementicious clay ground cover. The clay drastically reduces water infiltration into the ground, so instead it becomes surface runoff. The current topography of the ground surface causes the water to flow directly to the third wall. This water causes a rise in the hydrostatic pressure behind the wall which then bulges the wall out and eventually collapses sections of the wall.

This cementicious clay was added in 2009 and visible damage could be seen by 2010. The damage started off as a change in batter of the walls. Inca walls are normally built at around a 10 percent batter which means that they lean back into themselves which makes them more stable. This batter has been reduced and when it nears 0 percent the walls become very unstable and can fail. Other types of damage that can be seen are wall bulges where stones are being pushed out of the wall from the increase in hydrostatic pressure behind the wall caused by excess water buildup. The stones are also starting to shear and separate in some places there are large cracks where the rocks once fit perfectly together.

A large rainstorm collapsed a large portion of the wall in 2010. This collapsed portion can be seen in figure 11. The rocks from the wall have been completely pushed out of the wall. The damage is only getting worse as shown in figure 12, taken in 2013, at the same location of figure 11. The damage is now extending along longer portions of the third wall.

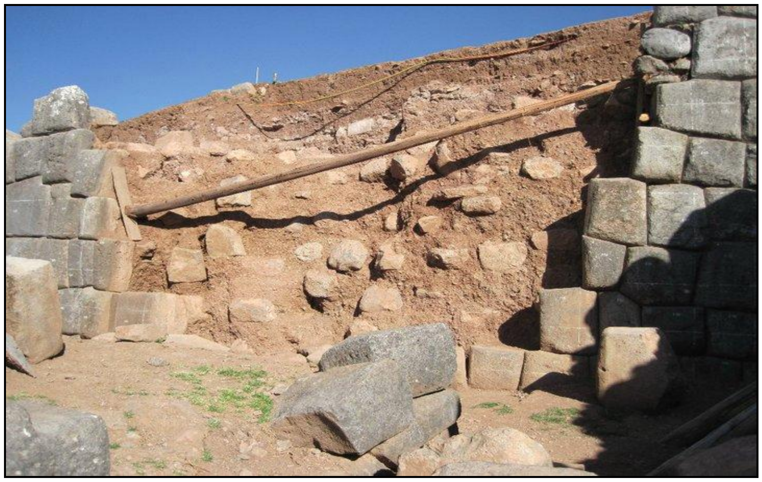

Figure 11. Major Collapsed Section of Third Wall (Wildfire, 2011)

Figure 12. Completely Collapsed Portion of the Third Wall (Lohr, 2013)

III.2. The Cause

The cementicious clay ground cover is believed to be the major cause of the recent collapses. The clay was placed on the ground in order to preserve ruins that were at the top of the complex, but without realizing this they created extra runoff and a smooth surface for the water. This clay covers approximately 2,000 square meters of the site as seen in red in figure 13. It is located in what will be referred to as the 2009 excavation sector. In figure 14, it can easily see the clay mounds which work to funnel the water to the bottom of the hill and towards the third wall. This concentrates the runoff to a very small area and causes the water to gain high velocities which help it to overflow the drainage channels and reach the third wall.

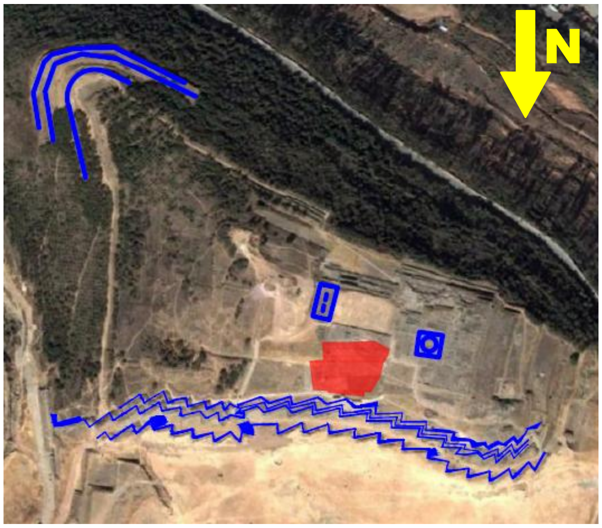

Figure 13. The 2009 Clay Area Location and Size (Google, 2014)

Figure 14. The Cementicious Clay Ground Cover (Lohr, 2013)

During the rainy season (January) of 2013, dye trace experiments were conducted using environmentally friendly Bright Dyes water tracer. During these tests it became apparent that the cementicious clay, along with the smooth channels, creates a "water slide" effect that collects all the water and allows it to flow very quickly down towards the third wall. This water is in such a large quantity and has such a great speed that it flows over the sides of the ad hoc drainage channel and to the third wall. This is cause of the major collapsed section just across from the 2009 excavation sector. Images from these dye trace experiments are shown below in figure 15.

Figure 15. Dye Trace Flows in 2009 Excavation Sector Highlighted Conducted in January of 2013 (Miksad, 2013)

III.3. Attempts to Correct the Problem

There have been several attempts to help fix the problem and prevent future damage, but for the most part these have been unsuccessful and have on occasion actually made the problem worse. There are three major types of damage control that have been implemented; the first of which is clay channels

A. Ad-Hoc Clay Drainage Channels

Clay channels, which will be referred to as ad-hoc drainage channels, have been constructed in order to try to catch the water flowing from the top of the hill and carry it safely off to the side into the ravine in order to protect the third wall. These channels however were not well designed. They vary widely in width, depth, and slope, which causes the carrying capacity of the channels to fluctuate about their length. Some areas of the channel are very large and can easily carry all of the water that flows into it, while other areas are too small and cannot come close to carrying the water that it receives during a large rainstorm. This causes these channels to overflow in several locations. This acts to concentrate the water and make it flow to the third wall at several locations where large quantities of water will flow over the wall. One of the key areas of this concentration is the area of original and still the largest collapse. The locations of these channels are shown below in figure 16. An in depth analysis of these channels will be shown later in the report which will show the carrying capacity of the different sections of the channels and the locations of major problems.

Figure 16. Location of Major Ad-hoc Drainage Channels

These ad-hoc channels have been constructed in several different ways. The largest and most important of these channels is the one that lies just above the third wall. A portion of this channel can be seen below in figure 17. The channels at this location have changed several times over the past years in an attempt to increase the carrying capacity so that the channel can meet the peak water runoff demand. This particular channel is constructed from a cementicious material with a trapezoidal base along with a clay wing on either side. The major purpose of this channel is to collect any water that is running north towards the third wall and carry to safely to either the east or west side of the complex where it can harmlessly flow into one of the ravines.

Figure 17. Ad-hoc Drainage Channel near Main Collapses Site (Lohr, 2013)

Another set of channels are located along the second terrace. These channels are considerably smaller than the ones on top of the third wall and while most are made of clay some are simply channels dug into the dirt. A portion of this channel is shown in figure 18. These channels are much shorter in length than the major channel on top of the wall and many collect water and direct it into one of the many drainage ports that are located along the second terrace.

Figure 18. Ad-hoc Drainage Channel along Second Terrace (Lohr, 2013)

There are also channels that run along the first terrace; one of these can be seen below in figure 19. These channels are all clay and consist of a small channel with a larger mound at the north side to prevent water from running over top of the channel. This channel is larger than the one running along the second terrace but smaller than the one running along the top of the third wall. This is likely because this channel mainly receives its water from the rainfall that lands on the first terrace which is larger than the second terrace but not nearly as large as the water that lands above the third wall which flows into the drainage channel above the third wall.

Figure 19. Ad-hoc Drainage Channel Running along the First Terrace (Lohr, 2013)

There is also a relatively new drainage channel that has been constructed on the west side of the complex. This channel is unique in that it has been constructed to look more like an Inca constructed drainage channel. This can be seen below in figure 20, showing the new channel on the left and a channel constructed by the Incas, atop Mayuqmarka, on the right.

Figure 20. New Inca Type Drainage Channel (left) and Original Inca Drainage Channel (right) near Mayuqmarka (Lohr, 2013)

Some of the channels have small basins which are assumed to be sediment basins with the purpose of causing turbulence in the water which allows sediment in the water to settle out to the bottom of the basin rather than flowing with the water. This allows the sediment basins to be cleaned occasionally rather than having large amounts of sediments being deposited where the water is finally absorbed into the ground. The largest of the sedimentary basins can be found on the drainage channel located just above the third wall while smaller ones can be found along the second terrace channels just before the water flows into a drainage port. Both of these types of sediment basins can be seen below in figure 21.

Figure 21. Sediment Basin along Major Ad-hoc Channel (left) and along Second Terrace (right) (Lohr, 2013)

B. Shed Roof Structures

Another attempt to help fix the problem was the construction of roof structures to help protect the collapsed sections of the wall from receiving direct rainfall. The largest of the sheds is shown below in figure 22a. It covers the original and largest collapsed section of wall that started in 2010 and has been in steady decline since. These sheds are made from wooden poles that hold up a corrugated metal material that acts as a roof on a normal house would and carries the water to the end of the roof where it flows off. The metal is then covered in a grass/thatch material in order to prevent it from standing out to the many tourists who tour the site every day. There are three of these roof areas the locations of which are shown below in figure 22b.

Figure 22a. Shed Roof Covering Major Three Collapsed Area (Lohr, 2013)

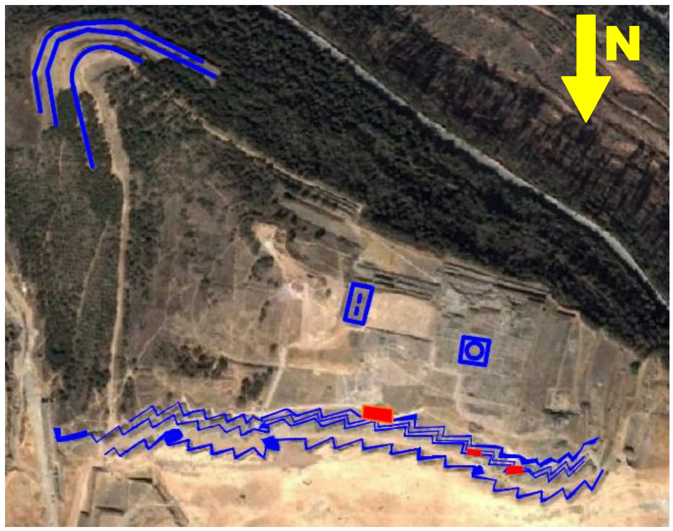

Figure 22b. Map Showing Locations of Roof Coverings

C. Wall Braces

Braces were put in place, not to fix the problem, but merely to prevent/delay further collapse of the walls. These braces are made of large wooden poles and boards which are mounted into the ground and angled to lay flat against the large walls as shown in figure 23. This keeps pressure on the stones in hope of counteracting the hydrostatic pressure that is pushing on the opposite side of the wall. In theory, these braces should help prevent the batter of the walls from deteriorating as well as preventing bulges of large stones which can compromise the structural integrity of the wall, but they fail to fix the source of the problem.

Figure 23. Large Wooden Brace Used to Support Wall (Lohr, 2012)

IV. Data Collection

IV.1. Research Trips

There have been multiple research trips to Saqsaywaman sponsored by the University of Virginia in order to collect the necessary data for analyzing the site. The first of these trips was in July of 2010. The purpose of this first trip was to survey the extent of the damage and determine the cause of the damage. This initial trip focused solely on the walls and the runoff that led to them. The second trip was conducted in January of 2013 for basic relations to set up the research trip that would take place the following July. The most recent research trip was conducted in July of 2013. The main goal of this trip was to collect enough data to construct a three-dimensional model that could be used to analyze the topography and flow patterns for the site. Another team is preparing to continue the study in July of 2014 with the purpose of continuing with the three-dimensional model as well as analyzing the possible topographical changes that have taken place over time since Saqsaywaman was constructed.

IV.2. Surveying

For this study I used a TopCon GTS-230W series electronic total station paired with a Carlson data collector to take point measurements around the park. A tape measure, plumb bob, tripod, Leica laser distance finder, and prism were also used. The prism, total station, tripod, and data collector are shown below in figure 24.

Figure 24. Surveying Equipment (Lohr, 2013)

The first thing that must be done before surveying can start is to locate two benchmark points that have known location data (Northing, Easting, and Elevation). Once these are found, set up the total station somewhere that has a clear view of the area to be surveyed as well as the two benchmark points. At this point, a permanent benchmark point in the ground was set up that could be used for future surveys and reference. The permanent benchmark point was created by placing a brass pin in concrete atop El Rodadero and labeled UVA 2013 as shown in figure 25. The next step is to shoot backsights to the benchmark points in order to get a known location and direction/orientation of the total station. Three different setup points were used during the survey completed in the July of 2013. The major one (UVA 2013) located atop El Rodadero, a second point on the East side located in the field (Chukipampa), and a final one located on the East hillside near Christo Blanko. The locations of these three setup points as well as the benchmark points are shown in figure 26.

Figure 25. El Rodadero (left) where New Permanent Benchmark Point (right) is Located (Lohr, 2013)

Figure 26. Locations of Setup and Benchmark Points (Google, 2014)

Once the total station has a known location and orientation, surveying of new points can begin. Points were taken along the entire fortress complex. A total of around 4,000 survey points were taken with the total station over a nine day span. These data points were then used in order to create a three-dimensional model of the site using AutoCad computer modeling software.

IV.3. Other Data

Other data was also needed for this study. This data was in the form of old maps, aerial photographs, drawings, and journals which were used to help determine what the Saqsaywaman looked like from when it was built up until present day. New aerial photos were collected from Google Earth in order to determine the ground cover for the site. Rainfall data was also collected from the Saqsaywaman Park engineers were used in order to create a design storm for the runoff analysis.

Historical images from recent years were collected from Google Earth to show how the ground cover has changed in recent years. Rainfall data was collected from the Saqsaywaman Park engineers Jose Antonio Reynoso Palma and Edith Quirquihuaña Zavala. This data can be seen in the appendix at the end of this report. Passages from Squier's book "PERU, Incidents of Travel and Exploration in the Land of the Incas" (1877) was used for verbal descriptions of Saqsaywaman in the 1800's. Graziano Gasparini & Luise Margolies piece, "Inca Architecture"

(1980) was used for mapped drawings of the layout of Saqsaywaman. Reconstruction images by Ricardo Mar were used to show what Saqsaywaman likely looked like when it was completed. Passes of Garcilasco de la Vega, El Inca, *"Royal Commentaries of the Incas and a General History of Peru*" (1966) were used for basic background information on Saqsaywaman and the Incas. An old aerial photo from American Library of museum of natural history was also used to show how the site looked in its unexcavated form in 1930.

V. Modeling

One of the major goals of this research trip was to build a three-dimensional model that could be used to help analyze the current runoff conditions of the site. AutoCad 2013 was used for the construction of this model.

The first step of the model is to import all the data points that were collected with the total station. Once the points are imported a surface can be created that will interpolate elevation data for everywhere within the boundaries of the site chosen. After the surface is created it can be smoothed and simplified in order to fix slight errors due to construction an entire surface of data from discrete data points. With the surface created the walls were then outlines and are shown below in figure 27. An isometric view of the completed model is shown below in figure 28.

Figure 27. Map of Three Walls on the Site

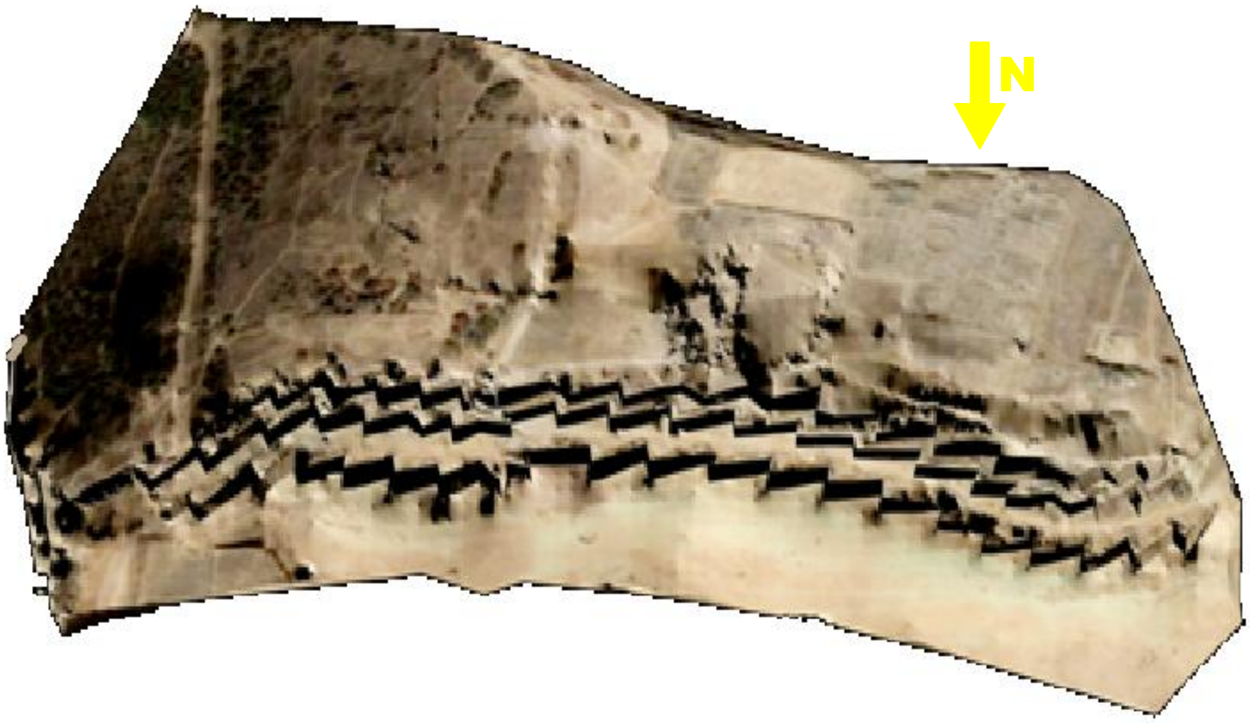

Figure 28. Isometric View of Modeled Site

VI. Runoff Analysis

A water runoff analysis of the complex has been conducted. This analysis consists of dividing the watershed into drainage basins and sub-basins and calculating the runoff for each basin. Then, an in-depth study of the water flow through the drainage ports on the site was completed. Finally, a study of the flow capacities of the ad-hoc drainage channels was completed in order to see where the major problem areas are located.

VI.1. Rational Method Runoff Calculation

The rational method is used in order to conduct a runoff study to determine the maximum quantity of water runoff during a design storm. There are several steps to using the rational method. The first step is to divide the area into drainage basins and sub-basins and then compute a C-value for each basin which is a factor of the land cover types. A design storm must be created and from that, a rainfall intensity is found which is used to calculate the total amount of runoff for each drainage basin. For this design storm, a rainfall intensity of 0.2 meter per hour is used. The flow of water over the site can then be shown as it flows through each drainage basin and finally exits the site.

The rational method approximates the maximum runoff seen during a storm, which is the peak flow seen on a hydrograph figure 29. The rainfall starts then there is a short lag time as all of the water is absorbed. Then, the flow starts to increase as some of the water starts to become surface runoff. The flow peaks as the maximum amount of rainfall becomes surface runoff, this is what we are calculating using the rational method. Finally, the flow starts to decrease again as the all of the water from the storm is converted to runoff or losses (Mays 2011).

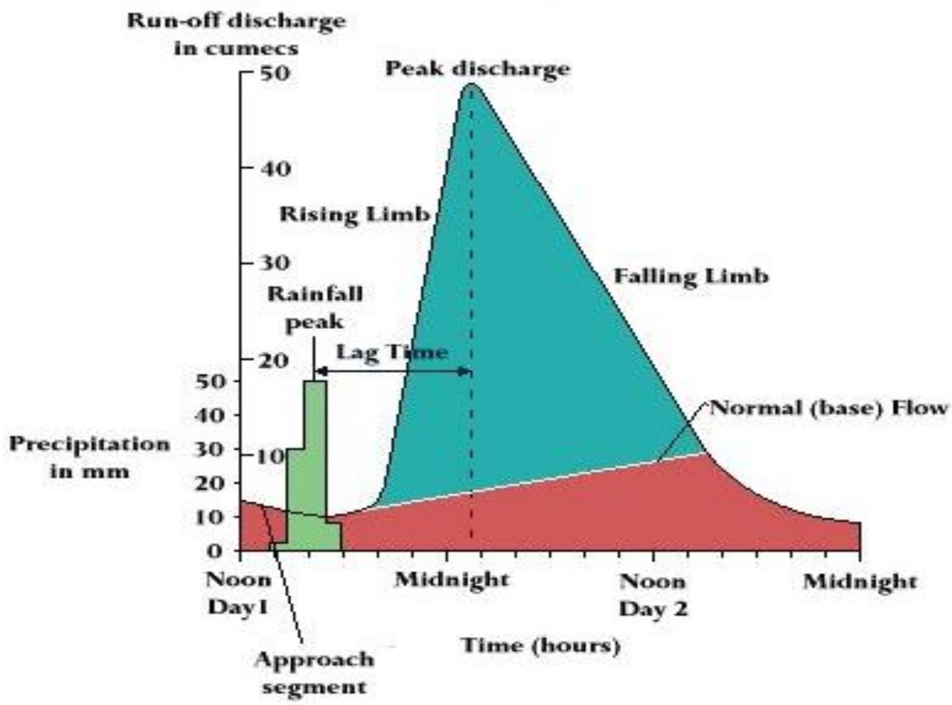

Figure 29. Example Hydrograph (Shah 2000)

A. Drainage Basin Delineation

The drainage basins and sub-basins are determined from the elevations of the ground. A drainage basin or catchment area is simply the area where the precipitation that falls onto the ground flows to a single or a set of streams (Encyclopedia Britannica, 2008). A watershed can be found using computer analysis or by hand using a simple topographical map. It is found by mapping out the edge of the area that will drainage to a single point so the drainage basin edge will run along high points of elevation or ridges that will separate drainage basins by causing water to flow in two different directions. By computer analysis, the site consists of five major drainage basins that are shown below in figure 30.

Figure 30. The Five Major Drainage Basins

These five major drainage basins can be further split up into a total of 27 sub-basins. Basins 1 and 2 are divided into four sub-basins as shown in figures 31 and 32, while basin 4 is divided into twelve sub-basins (figure 33). Finally basin 5 is split into five sub-basins (figure 34). These sub-

basins all flow into the major basins but they are separated because the flow patterns between the different sub-basins vary from each other.

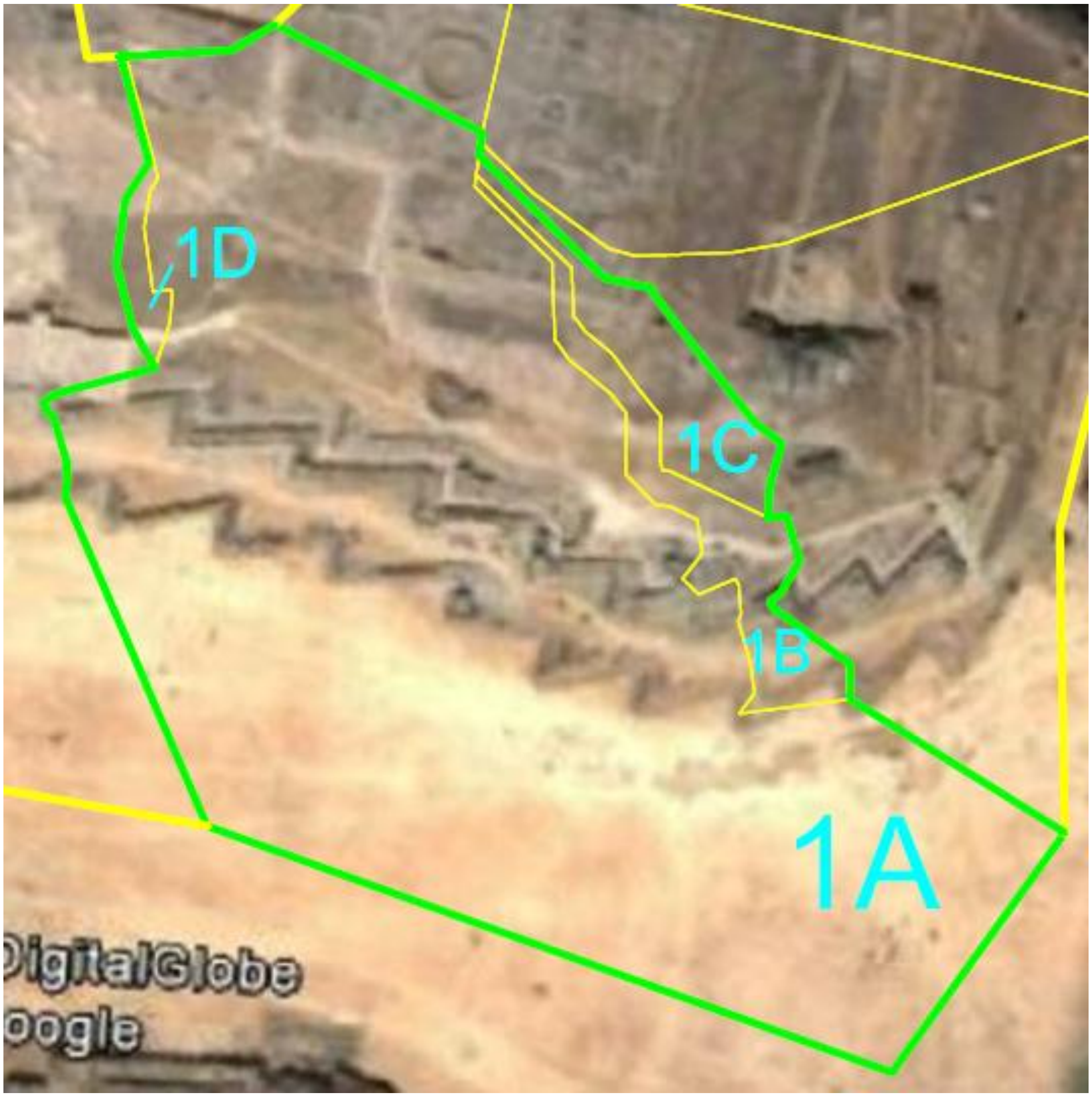

Figure 31. Basin 1 Sub-basins

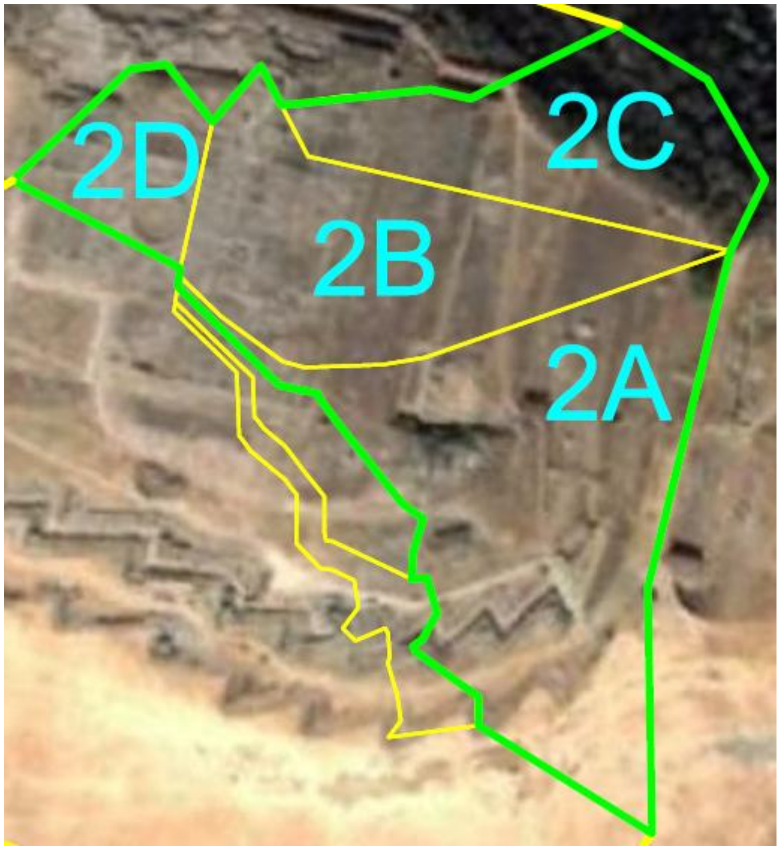

Figure 32. Basin 2 Sub-basins

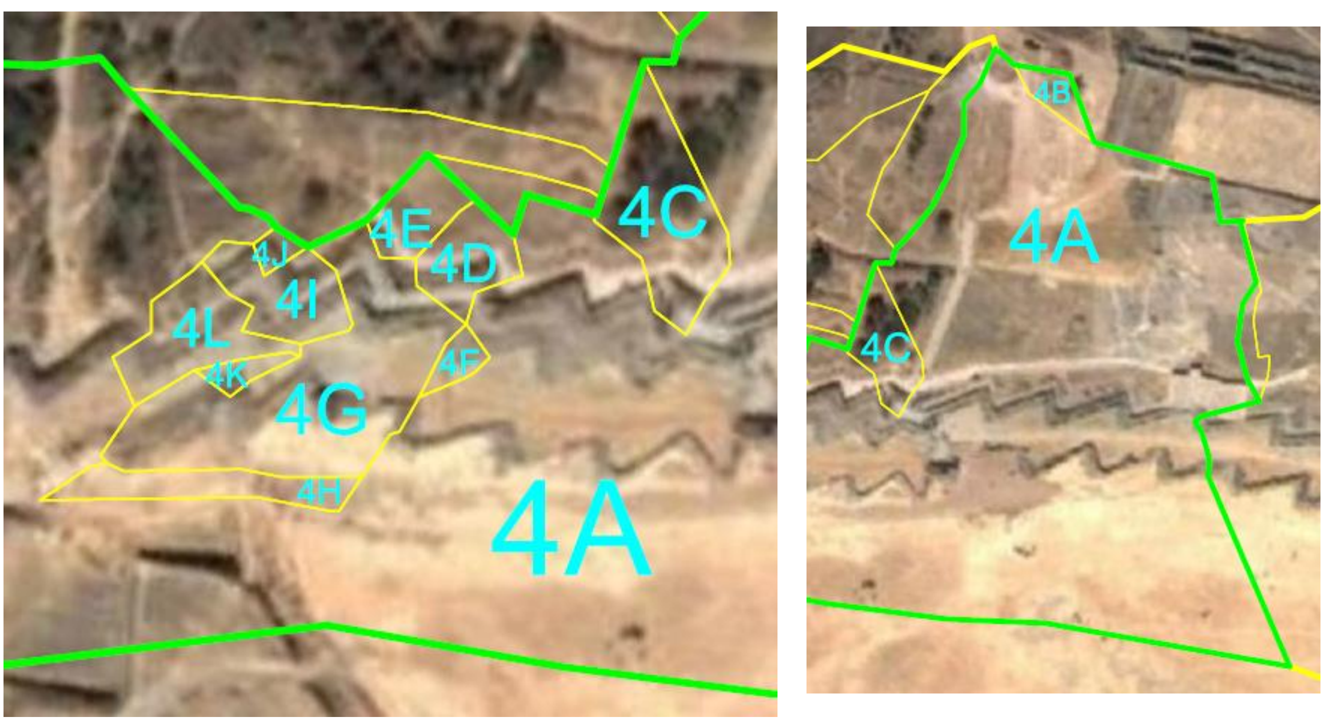

Figure 33. Basin 4 Sub-basins (East Side on Left West side on Right)

Figure 34. Basin 5 Sub-basins

B. Composite C Calculation

The next step in using the rational method is to determine the composite C-value for each of the drainage basins. The C-value is an approximation of the percentage of precipitation that will become storm runoff compared to the total amount of precipitation that will fall to the ground. A C-value of 90 means that 90 percent of the rainfall that hits the ground will be converted to runoff and the other 10 percent will be losses. The major types of losses can transpiration, evaporation, and infiltration. Transpiration is where the water is given off by plants and vegetation, evaporation is water that converts to water vapor, and infiltration is water that is absorbed into the ground. The C-value is a factor of the ground cover for each drainage basin and is calculated by taking the weighted average of the C-value for each type of ground cover scaled by the area of that particular ground cover in the drainage basin. The specific C-value for each different type of ground cover is shown below in table 1. The C-values vary from 0.95 where nearly all the precipitation is converted to runoff to as low as 0.10 where nearly all the water is losses and very little becomes runoff.

Table 1. Specific C-value for Each Ground Cover Type
(Design and Construction of Sanitary and Storm Sewers, 1969)

Rational Method Runoff Coefficients

Type of Development		Runoff Coefficients
Business		
Downtown		0.70 to 0.95
Neighborhood		0.50 to 0.70
Residential		
Single family		0.30 to 0.50
Multi-units (detached)		0.40 to 0.60
Multi-units (attached)		0.60 to 0.75
Residential (suburban)		0.25 to 0.40
Apartment		0.50 to 0.70
Industrial		
Light		0.50 to 0.80
Heavy		0.60 to 0.90
Park, Cemeteries		0.10 to 0.25
Playgrounds		0.20 to 0.35
Railroad Yard		0.20 to 0.35
Unimproved		0.10 to 0.30
Character of Surface		
Pavement		
Asphalt and Concrete		0.70 to 0.95
Brick		0.70 to 0.85
Roofs		0.75 to 0.95
Lawns, Sandy Soil		
Flat	2%	0.05 to 0.10
Average	2% to 7%	0.10 to 0.15
Steep	7%	0.15 to 0.20
Lawns, Heavy Soil		
Flat	2%	0.13 to 0.17
Average	2% to 7%	0.18 to 0.22
Steep	7%	0.25 to 0.35

For this analysis I chose to use six different types of ground cover classifications to represent the ground cover of the site. The different types of ground cover and their respective colors and C-values are: Small Trees: Royal Blue (0.2), Tall Grasses 3-4”: Red (0.3), Short Grasses: Orange (0.4), Compacted Dirt: Green (0.55), Impermeable Clay: Yellow (0.9), and Stone: Pink (0.95). Examples of the different ground cover types are shown below in figure 35.

Figure 35. Different Ground Cover Types Used for Rational Method Composite C Calculation Small Trees: Royal Blue (0.2), Tall Grasses 3-4”: Red (0.3), Short Grasses: Orange (0.4), Compacted Dirt: Green (0.55), Impermeable Clay: Yellow (0.9), and Stone: Pink (0.95) (Lohr, 2013)

A Google Earth image from September of 2013 was used as an overlay in order to determine the ground cover for the different areas of the site. The ground cover of each portion of the site can be seen below in figure 36. Each transparent color overlay represents a different ground cover type. The royal blue represents trees, pink: stone, orange: short grasses, green: compacted dirt, gray: clay, and red: tall grasses, and light blue represents a 10 percent to 90 percent mixture of stone and short grasses respectively.

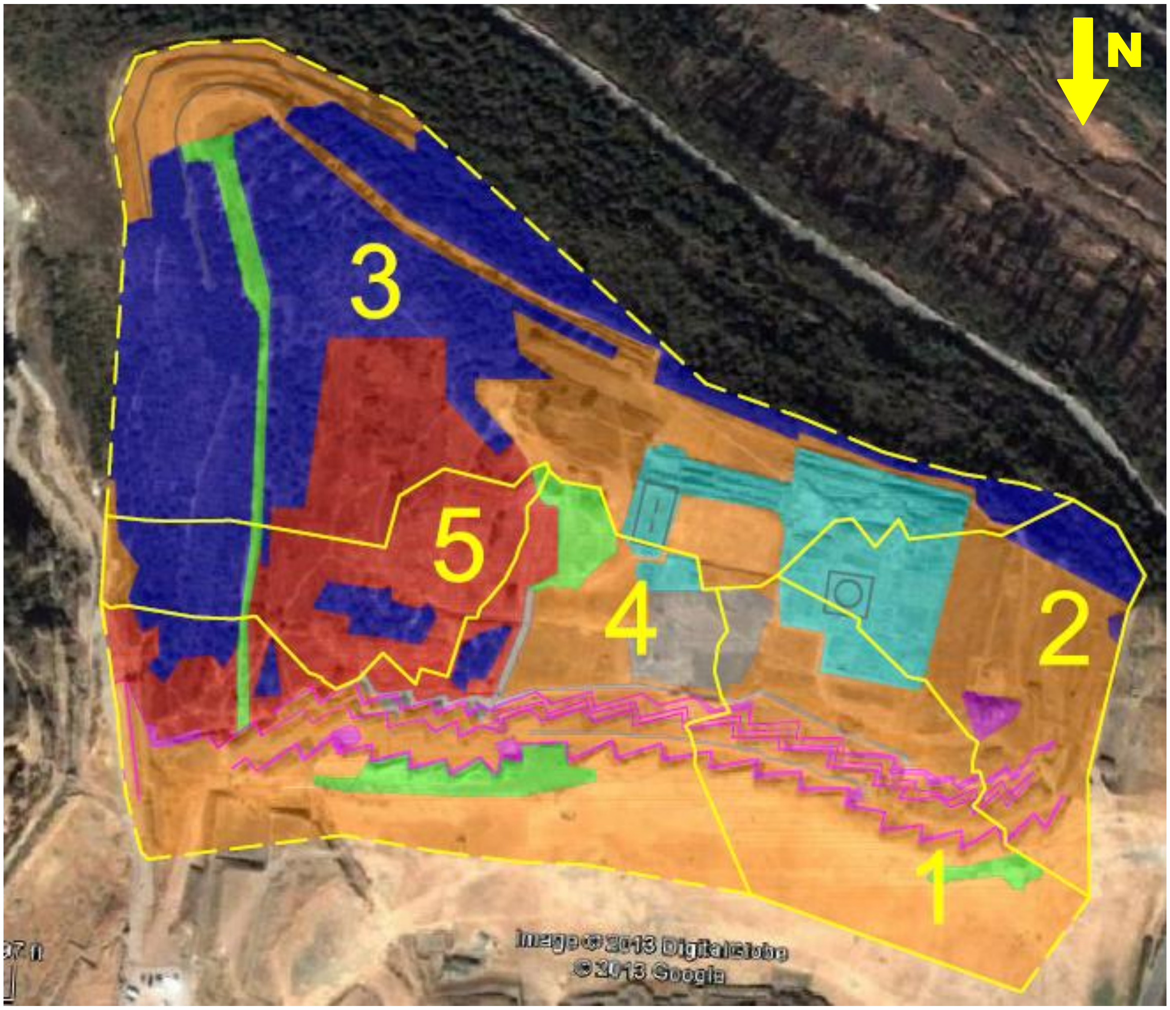

Figure 36. Current Ground Cover: Trees (Royal Blue); Stone (Pink); Short Grasses (Orange); Compacted Dirt (Green); Clay (Gray); Tall Grasses (Red); 10% Stone and 90% Short Grasses (Light Blue)

The majority of the south eastern side of the site is small trees seen in royal blue, while the majority of the west side of the site is short grasses (orange). There is a section of tall grass in the center east portion of the site. The major contributor to the total clay area (gray) is the 2009 excavation sector but there are also some clay drainage channels scattered about. The stone (pink) is represented by the terrace walls as well as some of the ruins near Mayuqmarka. There is some compacted dirt (green) in several highly trafficked portions of the site where grass no longer grows.

After all of the information from the ground cover is collected and combined with the drainage basins. A composite C-value was calculated for each drainage basin. Table 2 shows the drainage basins along with their respective areas, ground cover distributions, and final composite C-value.

Drainage basin 1 has the highest Composite C-value at 0.46. This is mainly due to the large percentage of impermeable surfaces such as stone and clay. Basin 4 is the next highest at 0.45. It has more clay and stone than basin 1, but this is balanced out by the large area of short grasses that make up most of the basin. Basin 2 is located in the middle with a composite C-value of 0.41. Basin 2 is 6 percent stone that is located near Mayuqmarka which helps to raise its C-value. Drainage Basin 3 is next to the lowest at 0.30 because it is mainly made up of trees and tall grasses as well as some compacted dirt. Basin 5 has the lowest C-value at 0.28 because nearly the entire basin is made up of tall grasses and small trees. Overall the Composite C-value for the entire site comes out to be 0.37. This means that 37 percent of the rainfall received at the site will turn into water runoff. The most notable sub-basin is 1D which is almost all clay leading to the highest C-value of 0.79.

Table 2. Composite C Calculation for Drainage Basins and Sub-basins

Composite C calculation								
Drainge Basin	Area (m^2)	Small Trees	Short Grass	Compacted dirt	Stone	Clay	Tall Grass	composite C
1	**15000**	**0**	**13000**	**340**	**620**	**880**	**0**	**0.46**
1A	14000		12000	340	540	760		0.45
1B	690		620		64			0.45
1C	610		600		12			0.41
1D	160		34		3	120		0.79
2	**11000**	**1300**	**9300**	**0**	**680**	**0**	**0**	**0.41**
2A	5000	67	4500		420			0.44
2B	3000		2900		140			0.42
2C	2300	1187	1100		22			0.30
2D	910		820		91			0.46
3	**41000**	**21000**	**14000**	**1200**	**330**		**4600**	**0.30**
4	**26000**	**1200**	**15000**	**2500**	**900**	**1900**	**3900**	**0.45**
4A	23000	978	14000	2258	680	1700	3500	0.44
4B	180			180				0.55
4C	460	210			4	90	150	0.38
4D	190				10	99	77	0.65
4E	150					34	120	0.43
4F	55		54		1			0.41
4G	1000		840		170			0.49
4H	210		140	73				0.45
4I	230		220		18			0.44
4J	34						34	0.30
4K	47		47					0.40
4L	280		260		21			0.44
5	**8800**	**2700**	**670**	**200**	**0**	**6**	**5500**	**0.28**
5A	790			48			740	0.32
5B	6100	2700	370	160			2900	0.27
5C	910						910	0.30
5D	120						120	0.30
5E	850					6	850	0.30
Total	**100000**	**26000**	**53000**	**4200**	**2500**	**2800**	**14000**	**0.37**

C. Runoff Calculation

After the composite C-values have been found, the next step is to compute the amount of runoff for the site for a specified design storm. For this calculation, a design storm with a rainfall intensity of 0.2 meters per hour was selected. The equation for calculating the runoff with the rational method is shown below (equation 1). The runoff is then calculated for each drainage basin and sub-basin. The complete results from the calculation are shown below in table 3.

$$Q=CiA \qquad \text{(Equation 1)}$$

Where:
Q = the total runoff in cubic meters per hour
C = the composite C-value
i = the rainfall intensity in meters per hour
A = the area in square meters

Drainage basin 3 has the most total runoff (2439 cubic meters per hour) but this is only slightly larger than drainage basin 4 (2297.6 m^3/hr) even though basin 3 has nearly twice the area of 4. Together these two drainage basins account for 63 percent of the total runoff for the site. Drainage basin 5 (490.3 m^3/hr) contributes only 6.5 percent of the total runoff because of its small size and low C-value. Drainage Basins 1 and 2 account for the other 30 percent of the total runoff having runoff rate of 1351 and 923 m^3/hr respectively. The total runoff for the site turns out to be 7500 cubic meters per hour for this design storm. This equates to 7.4 cm per hour per square meter of land area.

Table 3. Rational Method Runoff Calculation Results

Drainage Basin Analysis			
Drainage Basin	Area	C value	Runoff
	(m^2)		(m^3/hr)
1	15000	0.46	1400
1A	14000	0.45	1300
1B	690	0.45	62
1C	610	0.41	50
1D	160	0.79	25
2	11000	0.41	920.0
2A	5000	0.44	440.0
2B	3000	0.42	250.0
2C	2300	0.30	140.0
2D	910	0.46	83.0
3	41000	0.30	2400
4	26000	0.45	2300
4A	23000	0.44	2000
4B	180	0.55	20
4C	460	0.38	35
4D	190	0.65	25
4E	150	0.43	13
4F	55	0.41	4.6
4G	1000	0.49	98
4H	210	0.45	19
4I	230	0.44	20
4J	34	0.30	2.0
4K	47	0.40	3.8
4L	280	0.44	25
5	9000	0.28	504
5A	790	0.32	50
5B	6100	0.27	330
5C	910	0.30	55
5D	120	0.30	7.2
5E	850	0.30	52
Total	100000	0.37	7500

The water runoff flow can also be shown in graphical form as shown below in figure 37. The blue lines represent reference object and the blue circle are depression areas where water pooling occurs. The yellow lines show the location and direction of the water runoff and their size is proportional to the volume of runoff. This figure shows that most of the water from the northern half of the site eventually makes its way to the walls. The locations of most of the collapsed sections of wall are located in the middle of the map on the third wall. This correlated with the majority of the water flow reaching the walls.

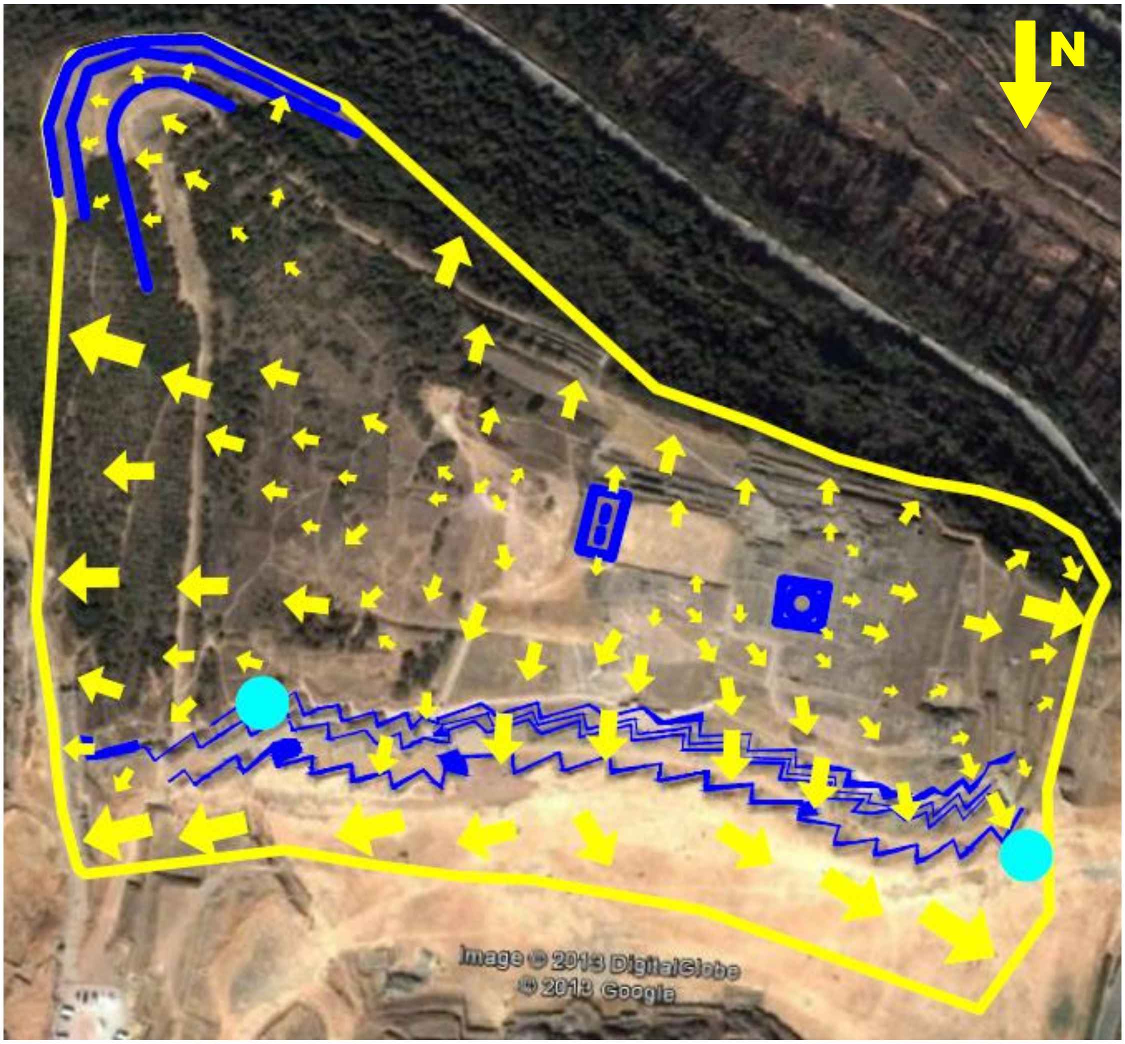

Figure 37. Graphical Representation of Rational Method Runoff Flow

D. Rational Method Limitations

The rational method has several limitations. It does not take into account anything but the ground cover when determining how much precipitation will become runoff. The soil type, moisture content, and climate can also have a large impact on this value. Different types of soil will absorb different amounts of water. The more moisture that is already in the soil the less moisture it can hold when the precipitation begins. Hotter and dryer climate will usually have a higher evaporation rates which would lead to less runoff. The rational method also assumes that the runoff rate will remain constant if the precipitation rate is constant. This is not true as during the initial part of the storm more water can be stored in the dry soil but once the soil becomes saturated less water infiltrated causing more runoff. It also assumes the precipitation rate remains constant throughout the entire duration of the storm and is uniform over the entire site. On site storage, such as ponds or lakes, is also not taken into account when using the rational method (Marek, 2011)

Because of these assumptions and limitations it is recommended that the rational method only be used when estimated the runoff for sites that are less than 810,000 square meters (Marek, 2011). The site under investigation in this study is only 100,000 square meters so this is well below this threshold. The rational method is being used to calculate the peak flow on a hydrograph on the site assuming that all the runoff occurs as surface flow.

VI.2. Drainage Ports

A. Drainage Port Design

There are many small water intakes that are located along the second terrace. These intakes are created from carved channels in the stone wall that go all the way through the wall and have an outlet on the front of the second wall. These are referred to as drainage ports. They carry water through the second wall where it discharges onto the first terrace. Figure 38 shows how the drainage ports are designed.

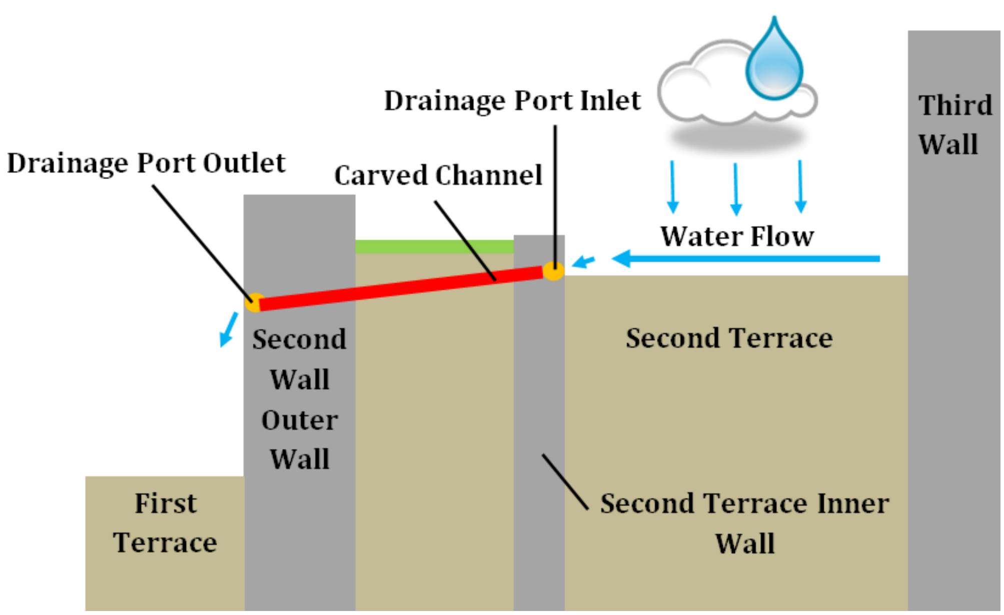

Figure 38. Drainage Port Design

The drainage ports are designed to collect the water that lands on the second terrace during precipitation and carry the water safely through the second wall and onto the first terrace. The inlets and outlets of a drainage port can be seen below in figure 39. Outlet locations vary from being around 4 meters above the terrace below to half a meter below.

Figure 39. Drainage Port Inlet (left) and Outlet (right) (Miksad, 2010)

There are 45 drainage ports located at the site. These drainage ports are mainly located along the second terrace but there are several on the first terrace. There are also remains of drainage ports in the form of carved channels that are currently located at the third terrace wall. Most of these channels are not currently located within the wall itself so their original location is unknown. It is possible that these were functioning drainage ports at one time, but since the walls have deteriorated and many of the stone have been taken from the walls and used in the city to construct buildings, they are no longer functioning. Figure 40 shows the location of all of the drainage ports at the site while figure 41 shows one of the channel stones found near the third wall.

Figure 40. Map of Drainage Port Locations

Figure 41. Drainage Port Stones at Third Wall (Jeffers, 2013)

Many of the ports are not functioning today as the water inlet is not located at ground level. Some of the port inlets are buried beneath the ground while other are floating above ground level (figure 42), neither of which allows water to enter and flow through them. From an engineering standpoint, it is our belief that the port inlets were constructed to be at ground level where they could best function hydraulically. Later, I will analyze a case where I assume that the ground level along the second terrace matches the drainage port intake heights and compare this to the current topographical situation.

Figure 42. Left: Buried Drainage Port (Miksad, 2010) Middle: Ideal Port Inlet Location at Ground Level (Miksad, 2010) Right: Elevated Drainage Port Inlet (Luke, 2010)

18 of the ports were buried during July of 2013 (ports D-1, D-3, D-4, D-5, D-6, D-12, D-13, D-18, D-21, D-34, D-35.2, D-36, D-37, D-39, D-40, D-41, D-42, and D-44). Most of these inlets were kindly uncovered by staff of Saqsaywaman so that measurements could be taken, but 2 port inlets could not be unburied (D7 and D22) for various reasons.

B. Drainage Port Flow

I analyzed the flow through the drainage ports using manning's equation for open channel flow (equation 2). I analyzed the flow at varying percentages of max capacity as well as what is considered to be the best hydraulic cross-section. The "best" hydraulic cross section for flow in a rectangular shaped channel is where the flow height is half of the flow depth. This provides the most efficient flow because the surface area is at a minimum relative to the flow area.

$$Q = \frac{k}{n} A R_h^{\frac{2}{3}} * S_0^{\frac{1}{2}} \qquad \text{(Equation 2)}$$

Where:
Q = Volumetric Flow Rate (m^3/s)
k = 1.0
n = Manning's Coefficient=0.035 for smooth rock surface
A = Cross-sectional Flow Area (m^2)
R_h = Hydraulic Radius (m)
S_0 = Slope (m/m)
(Crowe 2010)

The ports were also analyzed using the Woodburn equation (equation 3) in order to determine how far the water would land from the wall when the water jets out from the drainage port outlet. The Woodburn equation is merely a derivation of Newton's second law of Motion. In order to use this equation the drop height and water velocity must be known in order to calculate the horizontal distance (x) that the water travels before it lands on the ground. A simple diagram is shown in figure 43 to explain the Woodburn equation.

$$x = \sqrt{\frac{2v^2}{g}\Delta y} \qquad \text{(Equation 3)}$$

Where:
v = water velocity (m/s)
g = gravitational constant (9.81 m/s^s)
Δy = vertical drop (m)
x = horizontal jet distance (m)

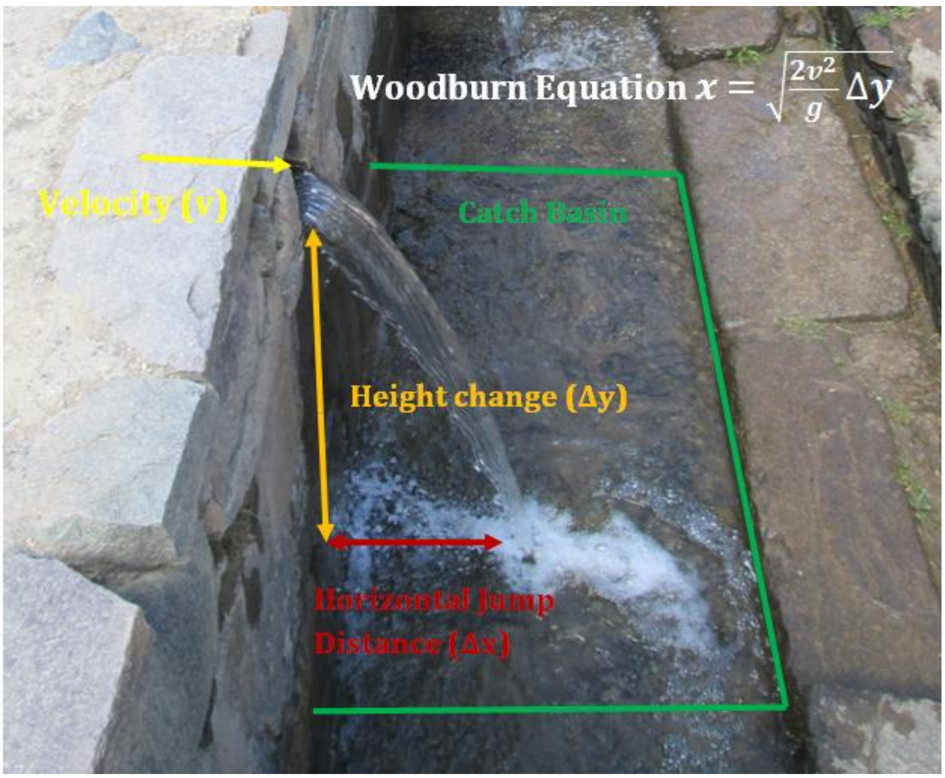

Figure 43. Woodburn Equation Diagram (Lohr, 2012)

An in-depth analysis of drainage port D16 is shown graphically in figure 44 and numerically in table 4. The volumetric flow rate is shown in blue while the jet distance is shown in red. The volumetric flow rate increase slowly at first, but then is near linear after it reaches 30 percent capacity. This is because the flow is directly proportional to the area and hydraulic radius to the two-thirds power. The jet distance for the Woodburn equation grows very rapidly at first but then flattens out asymptotically. This is well represented by a square root function due to the fact that the velocity increases by less with each increase in flow rate because of the greater area.

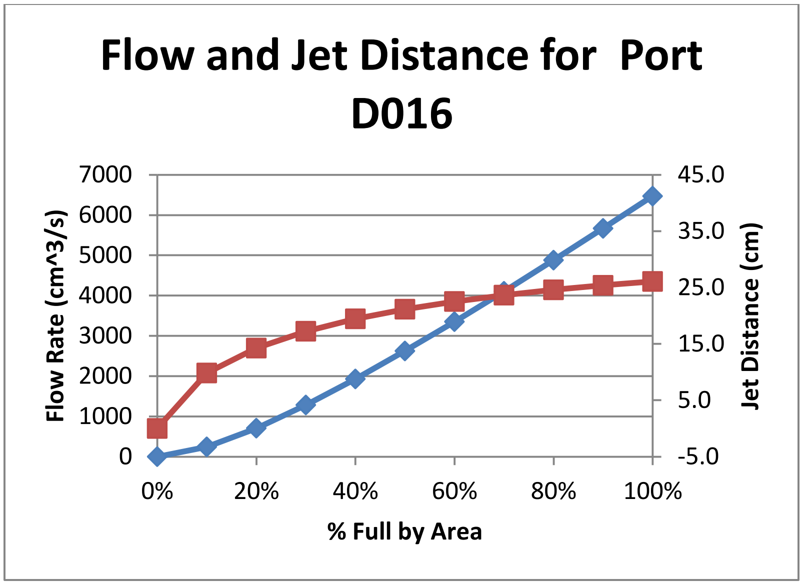

Figure 44. Graphical Representation of Drainage Port D16 flow (Torp, 2014) Volumetric Flow (Blue) Jet Distance (Red)

Table 4. Numerical Representation of Flow through Drainage Port D16 (Torp, 2014)

Dimensions			
Base (cm)	Height (cm)	Fall Height (cm)	Full Area (cm^2)
14	12	225	168

Drainage Port Flow Analysis			
% Full	Q (cm^3/s)	Jet Distance (cm)	Velocity (m/s)
0%	0.0	0.0	0.0
10%	240	9.8	0.15
20%	710	14	0.21
30%	1300	17	0.25
40%	1900	19	0.29
50%	2600	21	0.31
60%	3400	23	0.33
70%	4100	24	0.35
80%	4900	25	0.36
90%	5700	25	0.37
100%	6500	26	0.39

The results of the calculations for all of the ports are shown in table 5. This table shows the parameters of the drainage ports operating at 100 percent capacity.

Table 5. Drainage Port Flow Analysis Results (Torp, 2014)

Flow Analysis	Dimensions			Area	Hydraulic	Wetted	Slope	Volumetric	Port Velocity	Woodburn
Drainage Port	Base (cm)	Height (cm)	Fall Height (cm)	(cm^2)	Radius (cm)	Perimeter (cm)	(m/m)	Flow (cm^3/s)	(cm/s)	Distance (cm)
D01	13	17	260	220	4	40	0.10	6200	35	26
D02	10	12	210	120	3	29	0.05	2100	21	14
D03	14	17	110	240	5	41	0.13	8100	42	20
D04	14	17	280	240	5	41	0.13	8100	42	37
D05	12	10	400	120	3	28	0.13	3300	35	31
D06	11	7	400	77	3	22	0.13	1900	30	27
D07	13	5	MISSING	65	2	21	0.13	1500	28	#VALUE!
D08	16	12	150	190	4	35	0.39	11000	70	39
D09	12	13	150	260	4	33	0.43	8300	67	38
D10	14	13	200	180	4	35	0.13	5700	39	25
D11	14	15	210	210	4	38	0.12	6600	39	26
D12	11	10	210	110	3	27	0.16	3300	38	25
D13	10	12	240	120	3	29	0.04	1800	19	13
D14	13	10	240	130	4	29	0.17	4200	41	28
D15	10	10	240	100	3	26	0.04	1500	19	13
D16	14	12	230	170	4	33	0.11	4900	36	25
D17	13	12	170	160	4	32	0.69	11000	87	51
D18	14	15	210	210	4	38	0.16	7600	45	30
D19	15	11	250	170	4	33	0.17	5800	44	24
D20	15	14	200	210	4	37	0.13	7000	42	27
D21	15	14	110	210	4	37	0.12	6700	40	19
D22	13	14	MISSING	180	4	35	0.13	5700	39	#VALUE!
D23	14	13	260	180	4	35	0.10	5100	35	20
D24	13	15	200	200	4	37	0.10	5300	34	21
D25	14	13	77	180	4	35	0.13	5800	40	16
D26	16	13	170	210	5	37	0.09	5800	35	21
D27	12.7	8	210	100	3	26	0.16	3000	37	24
D28	13	10	220	130	4	29	0.07	2700	26	17
D29	14	13	200	180	4	35	0.03	2800	19	12
D30	15	8	220	120	3	28	0.04	1800	19	12
D31	15	15	200	230	5	39	0.07	5500	30	19
D32	15	18	170	270	5	44	0.06	6200	29	17
D33	13	8	190	100	3	26	0.08	2200	27	16
D34	10	10	240	100	3	26	0.09	2100	27	19
D35.1	15	17	300	260	5	42	0.08	7000	34	27
D35.2	16	14	280	220	5	38	0.12	7400	41	31
D36	13	18	280	230	4	42	0.05	5000	27	20
D37	12	15	280	180	4	36	0.09	4600	32	24
D38	11	6	290	66	3	21	0.14	1600	29	22
D39	11	7	320	77	3	22	0.13	1900	30	24
D40	13	13	240	170	4	34	0.11	4700	35	24
D41	11	13	190	140	4	32	0.17	4700	41	26
D42	14	16	350	220	5	40	0.21	9600	53	45
D43	16	33	51	530	6	69	-0.06	14000	34	11
D44	8	8	74	64	2	21	0.03	710	14	5

Eleven of the ports have recently been installed with liners to prevent seepage of water into the stone walls. Some of these liners are made of plastic while others are wood. The ports that now have these liners are 19, 20, 23, 24, 26, 27, 28, 30, 31, 32, and 33. An example of one of these liners can be seen below in figure 45. These pipes change the flow rates of the ports and the new maximum flow rates can be seen below in table 6. On average the flow through the ports increased by 150 percent with the introduction of the liners. The main cause of this is a drastic reduction in the manning's roughness coefficient.

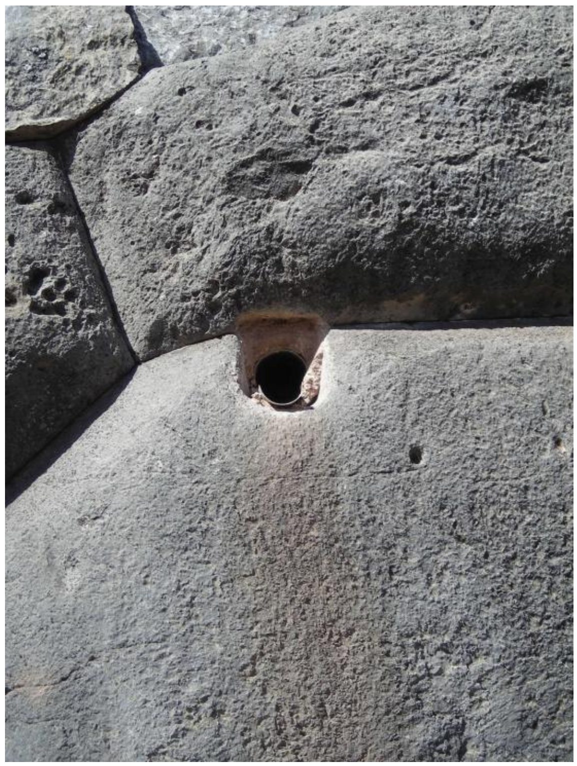

Figure 45. Drainage Port with PVC Liner (Lohr, 2012)

Table 6. Drainage Port Flow Rates with PVC Liners (Torp, 2014)

	Pipe Diameter (cm)	Area (m^2)	Wp (m)	Rh (m)	So (cm/cm)	Flow (cm^3/s)	Velocity (m/s)	Pipe Material	Flow Increase
D19	8.5	0.01	0.27	0.021	0.17	20000	3.5	PLASTIC	160%
D20	11	0.01	0.35	0.028	0.13	35095	3.7	PLASTIC	280%
D23	7.5	0.00	0.24	0.019	0.10	8200	1.9	WOOD	23%
D24	9.0	0.01	0.28	0.023	0.10	13000	2.1	WOOD	87%
D26	7.5	0.00	0.24	0.019	0.092	7800	1.8	WOOD	2%
D27	7.5	0.00	0.24	0.019	0.16	11000	2.4	WOOD	160%
D28	7.5	0.00	0.24	0.019	0.069	6800	1.5	WOOD	90%
D30	11	0.01	0.35	0.028	0.038	19000	2.0	PLASTIC	670%
D31	8.0	0.01	0.25	0.020	0.067	8000	1.6	WOOD	11%
D32	7.5	0.00	0.24	0.019	0.056	6100	1.4	WOOD	-25%
D33	7.5	0.00	0.24	0.019	0.083	7500	1.7	WOOD	150%

C. El Grande Port

One drainage port in particular stands out from the rest. Drainage port D43 is much larger than the rest of the drainage ports and it slopes in the opposite direction. Instead of carrying water from the second terrace through the second terrace wall to the first terrace this port carries water from the first terrace to the second terrace. This port has since been named “El Grande” and can be seen below in figure 46. It is located in the second terrace wall on the eastern side of the complex. El Grande has dimensions that are 16 cm in width and 22 cm in height giving it a total area of 528 square centimeters which is nearly twice as large as the next biggest port.

Figure 46. El Grande Port Outlet (Miksad, 2010)

One possible purpose for this large port is to collect runoff from the first terrace and safely carry it through the second wall so it can safely by directed down into the nearby ravine. This would prevent large amounts of water from flowing down the end of the first terrace towards the secondary entrance that is located on the east terraces. The port however is not large enough to carry all of the water from the east half of the first terrace during a normal storm event.

VI.3. Drainage Channels

The ad hoc drainage channels that are around the site carry large amounts of water. I wanted to determine just how much water they could safely carry and then compare this to the amount of water they would need to carry during a large storm event. Figure 47 below shows the current drainage canal systems. The canal sections are color coded by their max flow capacities in cubic centimeters per second as follows: Red: 0-100, Orange: 100-250, Yellow: 250-500, Magenta: 500-1000, Green: greater than 1000, and Cyan: not enough data.

Figure 47. Current Drainage Channel Flow Capacities (Red: 0-100, Orange: 100-250, Yellow: 250-500, Magenta: 500-1000, Green: greater than 1000, Cyan: not enough data)

The drainage channels were then analyzed based on the amount of water that they would receive during a large storm event. Based on this analysis the problem areas of the drainage channels were identified. These areas are highlighted in figure 48. The red areas are areas of suspected problems while the yellow areas are areas where possible problems could occur.

Figure 48. Drainage Channel Problem Areas (red: problem area, yellow: possible problem area, green: no problems)

VI.4. Gravel Drain

Recent excavations at Saqsaywaman have uncovered a gravel drain that is located just above the third wall. The exact location of the excavation is shown in figure 49. The excavation took place just above the third wall to the west of the main staircase that leads up to the tourist lookout.

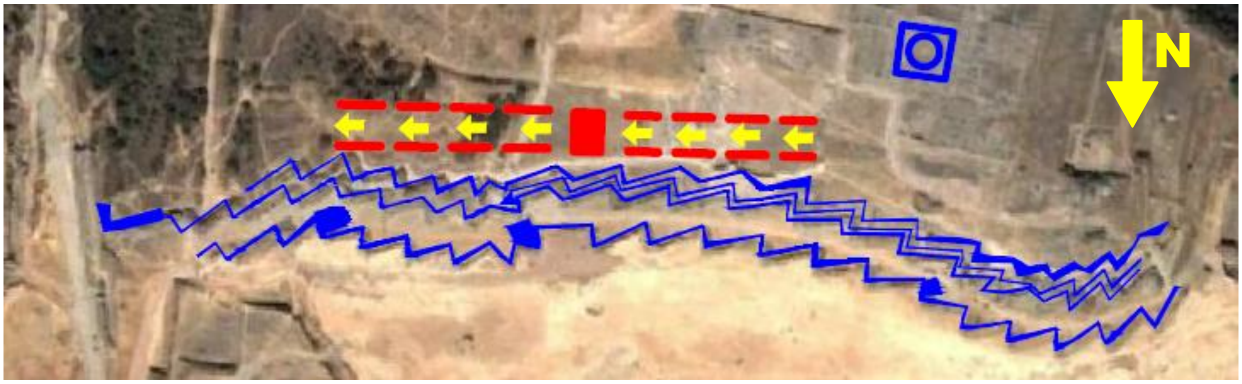

Figure 49. Location and Flow Direction of the Recently Discovered Gravel Drain

Figure 50 shows the actual excavation of the gravel drain. It is believed that this gravel drainage system was designed to function similarly to a modern French drain. The water would percolate into the gravel where it would then follow the gravel channel to carry the water to the desired location where the channel would end. This drain was probably used to capture any water that was heading towards the third wall and was designed to carry the water to the east where it could harmlessly flow into the ravine. Figure 51 shows the location of the gravel drain relative to the rest of the site and shows where it is perceived to travel.

Figure 50: Actual Excavation of the Gravel Drain Located above the Third Wall (Palma, 2013)

Figure 51. Newly Excavated Gravel Drain Used to Divert Runoff Away from the Third Wall (Miksad, 2013)

VI.5. Master Drainage System

It is highly probable that the Incas used multiple water control methods together in harmony to create a master drainage system. This system would have been made up of the drainage ports, drainage channels, lateral drainage systems, terraces, and recently discovered gravel drainage systems. It is likely that this system would have functioned to control the water runoff during average storm events and would have prevented water from deteriorating the walls as is occurring today. If this master drainage system was still functioning today, these current drainage issues would not be occurring.

VII. Topographic Study

VII.1. Current Topography

The current topography of the site is represented in the contour map below (figure 52). Starting from the north end of the site the topography is fairly flat along Chukipanpa. The topography makes several large jumps as it works its way up the terraces which are representative of the walls themselves. The ground level on the terraces themselves however is fairly flat. The center portion above the third wall where the two towers are located is relatively flat until the far south end of the site where it starts to slope down quickly to the road. At the west end of the site past

Mayuqmarka there are once again terraces that are fairly flat but which make large jumps down at the terrace walls. The east side of the site is slightly more complex. Just above the main stairway through the third wall there is a tourist walkway that climbs up to a lookout point which is a popular site for tourists to take picture of Cusco. To the left side of this walkway the land slope off slightly to the east, but then the slope gets much more dramatic. The land starts to slope off steeply down towards the ravine on the east side. The steep slope is halted for a pedestrian walkway which travels out to Cruz Moq'o and then continues again.

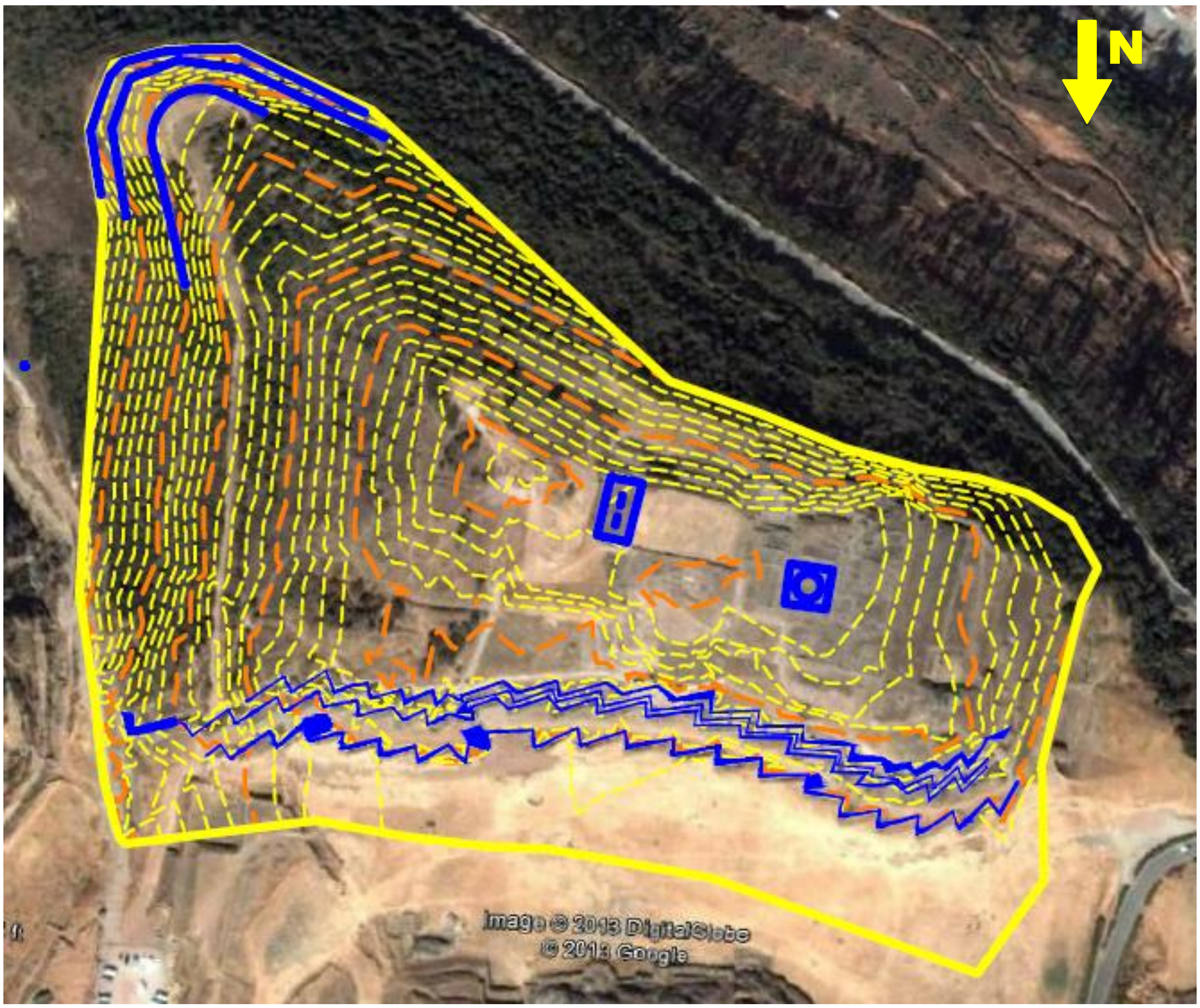

Figure 52. Contour Map of Saqsaywaman
Major Contours (Orange) 10 Meter Intervals, Minor Contours (Yellow) 2 Meter Intervals

Figure 53 shows the slope directions of the site. The red portions slope to the east (left) while the purple portions slope to the west (left). For the most part the east side of the side slopes to the east and the west side of the site slopes to the west ignoring the convoluted areas near the walls. The dividing point where the slope changes from east to west will be called the drainage divide line. This line has been dashed in on figure 53 in green. This was designed on purpose by the Incas in order to have lateral drainage into the ravines on the east and west of the site. This prevents water from running longitudinally (north and south) where it may run over the walls and pool in the flat areas. The yellow arrows represent the flow directions on the site with the size of the arrow indicating the amount of runoff.

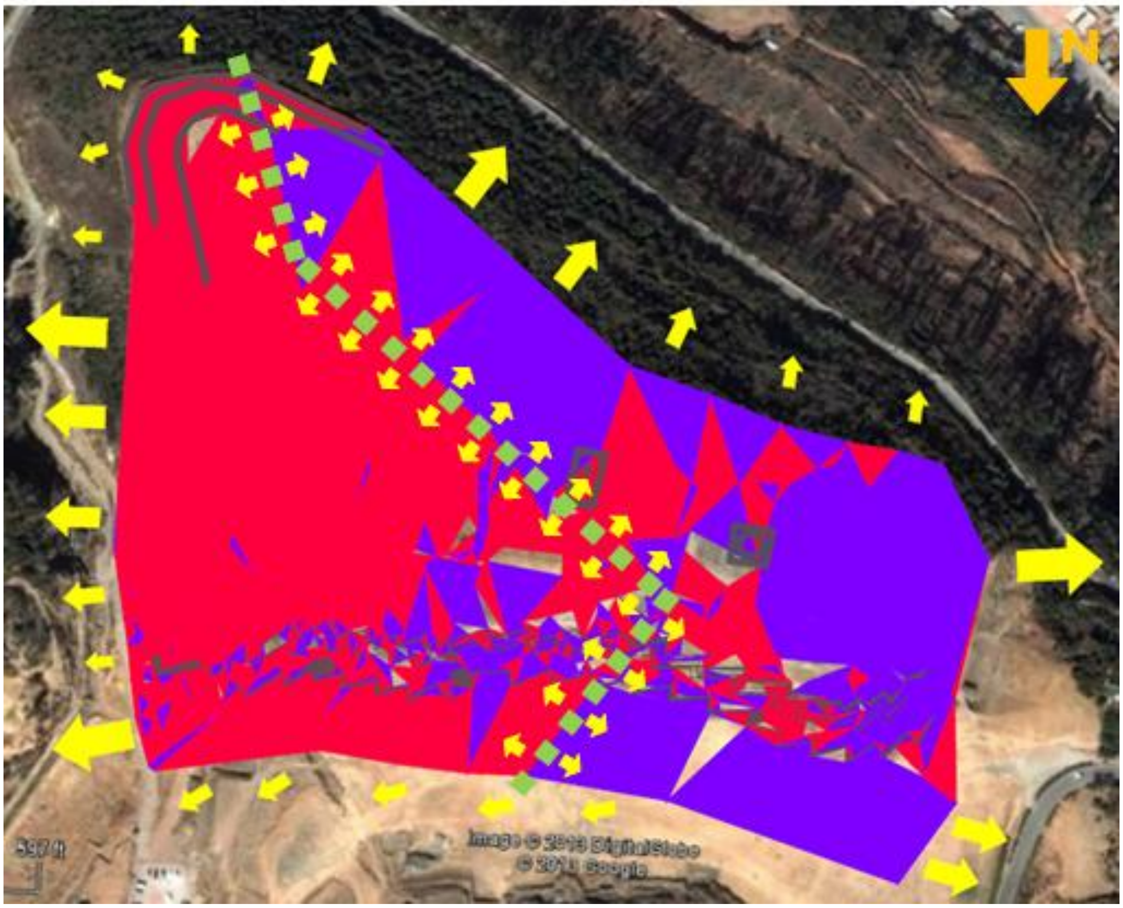

Figure 53. Slope Direction Map (red: flow to the left [East], Purple: flow to the right [West])

There is also a slope magnitude map (figure 54). This breaks down the slopes on the site into different categories and represents them as colors. The slope range in rainbow order as the slopes increase as shown in table 7. The lower slopes are found on the terraces and in Chukipanpa. The steepest of slopes are found on the east side of the site as the ground quickly slopes off towards the east ravine.

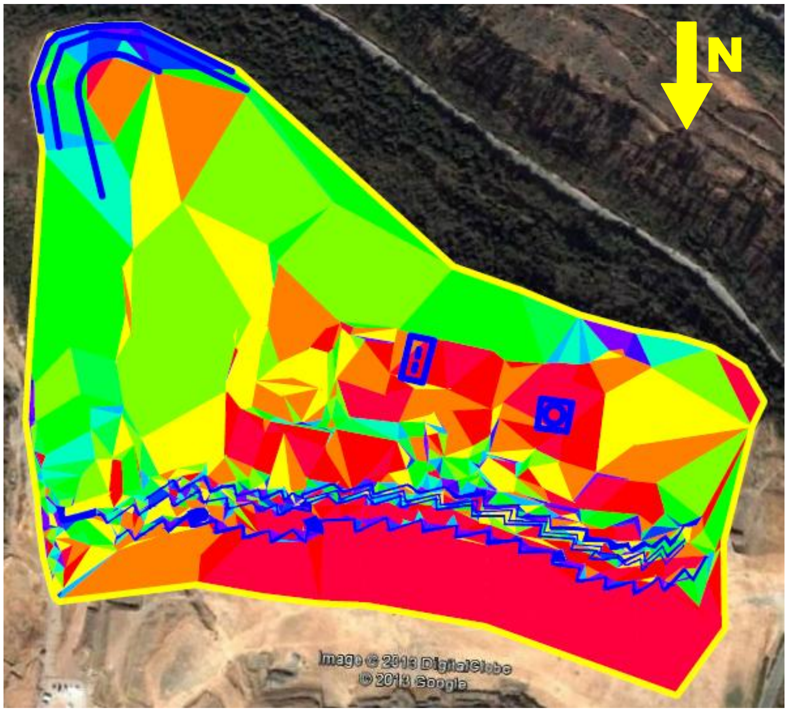

Figure 54. Slope Map

Table 7. Slope Map Legend

	0%-5%
	5%-10%
	10%-20%
	20%-30%
	30%-40%
	40%-50%
	50%-60%
	60%-70%
	70%-80%
	80%-90%
	90%-100%
	100%-15650%

VII.2. Drainage Port Defined Terrace Elevations

One proposal that has been investigated is that the ground level along the second terrace must have been located at the port inlet height. This is the only thing that makes sense hydraulically in order for the drainage ports to function as any piece of a master drainage system. Water cannot jump upwards or go through the ground to get into the port inlet so the inlet must be located at ground level where the water can easily flow into the port and then discharge on the other side.

Based on this proposal I mapped out the current ground level of the second terrace and compared it to the inlet elevation of the drainage ports (figure 55). Here the current ground level on the second terrace is shown in purple and the proposed ground level based off the port inlet elevations is dashed in red. It appears that the current elevation does not align very well with the elevation defined by the drainage port inlets. Many of the drainage ports are above the current ground level and there are also some below it. The drainage port defined elevation is not perfectly smooth in all areas. There are several spikes and valleys mainly located on the east side. These would be used in order to funnel the water into drainage ports so there would be less total runoff along the terrace that could cause erosion.

The same analysis was then completed for the first terrace only the profile from the second terrace drainage port elevations was used because there are very few drainage ports on the first terrace. This map is shown in figure 55 where the cyan line is the current ground level of the first terrace and the red dashed line is the drainage port defined ground level transposed onto the first terrace. The existing ground level on the first terrace is much smoother than the existing ground level of the second terrace. Figure 55 shows that the terraces are relatively evenly spaces with an average of around 3 meters separating them in elevation. The red circles represent the drainage ports locations along the second terrace.

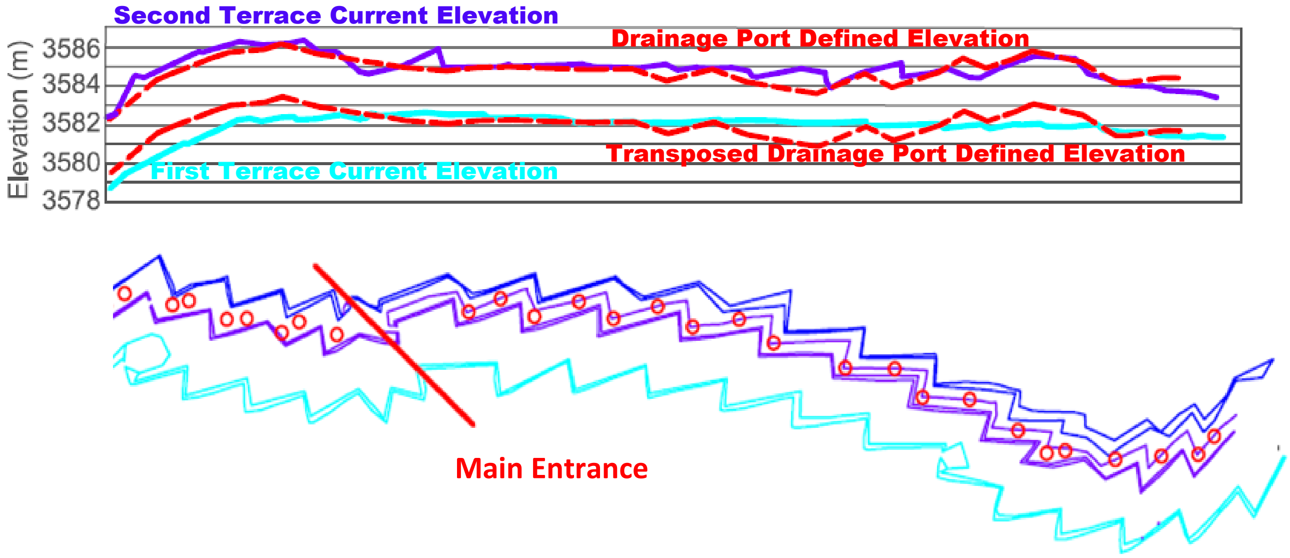

Figure 55. Proposed Terraces Elevation View (Current First Terrace Elevation in Cyan, Current Second Terrace Elevation in Purple, Drainage Port Defined Elevation Dashed in Red)

VII.3. Proposed Terraces

There is evidence to support that there may once have been terraces along the entire tower sector of Saqsaywaman. The first evidence is in the form of old drawing and maps of Saqsaywaman. One of those maps is drawn my Gasparirni and Margolies (1980) and is shown below in figure 56. This map shows terraces along the top side of Saqsaywaman. Those terraces run concentrically around the site getting steadily higher in elevation with each terrace. These terraces would make sense looking at other Inca sites. The Incas used terraces for a variety of purposes such as to control water flow, increase stability, and for farming.

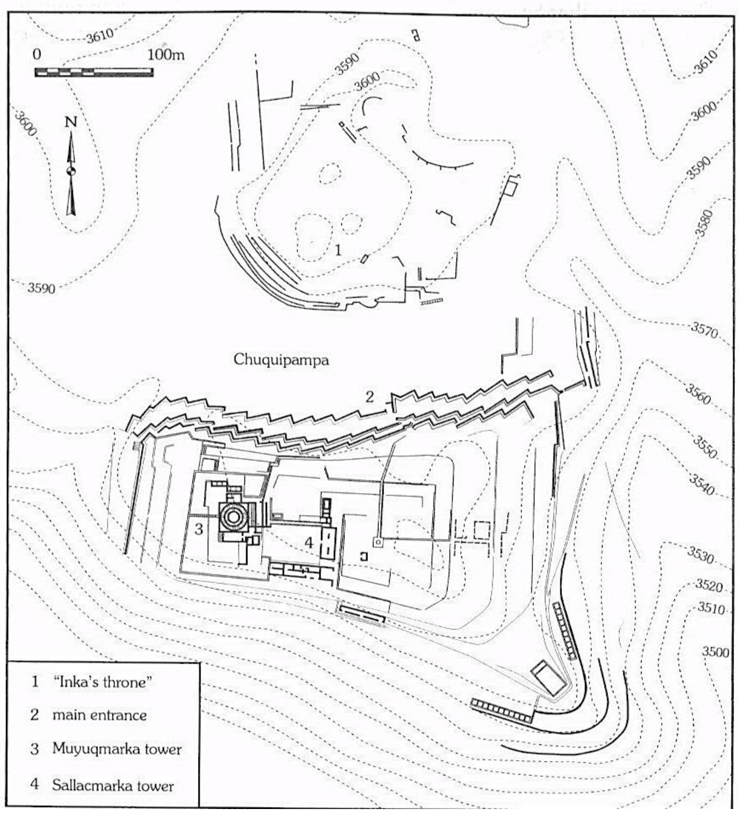

Figure 56. Map of Saqsaywaman (Gasparirni and Margolies, 1980)

If there were terraces at Saqsaywaman like the ones shown by Gasparirni and Margolies, then the water flow patterns above the walls would be much different than as seen today. Figure 57 shows a representation of the terraces in Gasparini's map drawn onto the new model. The dashed orange lines represent possible locations of terraces. The new flow directions based off this terraces layout are represented in figure 58. The vary drastically from the current flow patterns because now most of the water is shed laterally to the east and west and a little water flows off the back of the site to the south but no water is directed towards the wall. This flow pattern makes much more sense hydraulically from an engineering standpoint and agrees with the layout of most other Inca sites such as Tipon and Machu Picchu.

Figure 57. Gasparini & Margolies Terraces Represented in 3-D Model

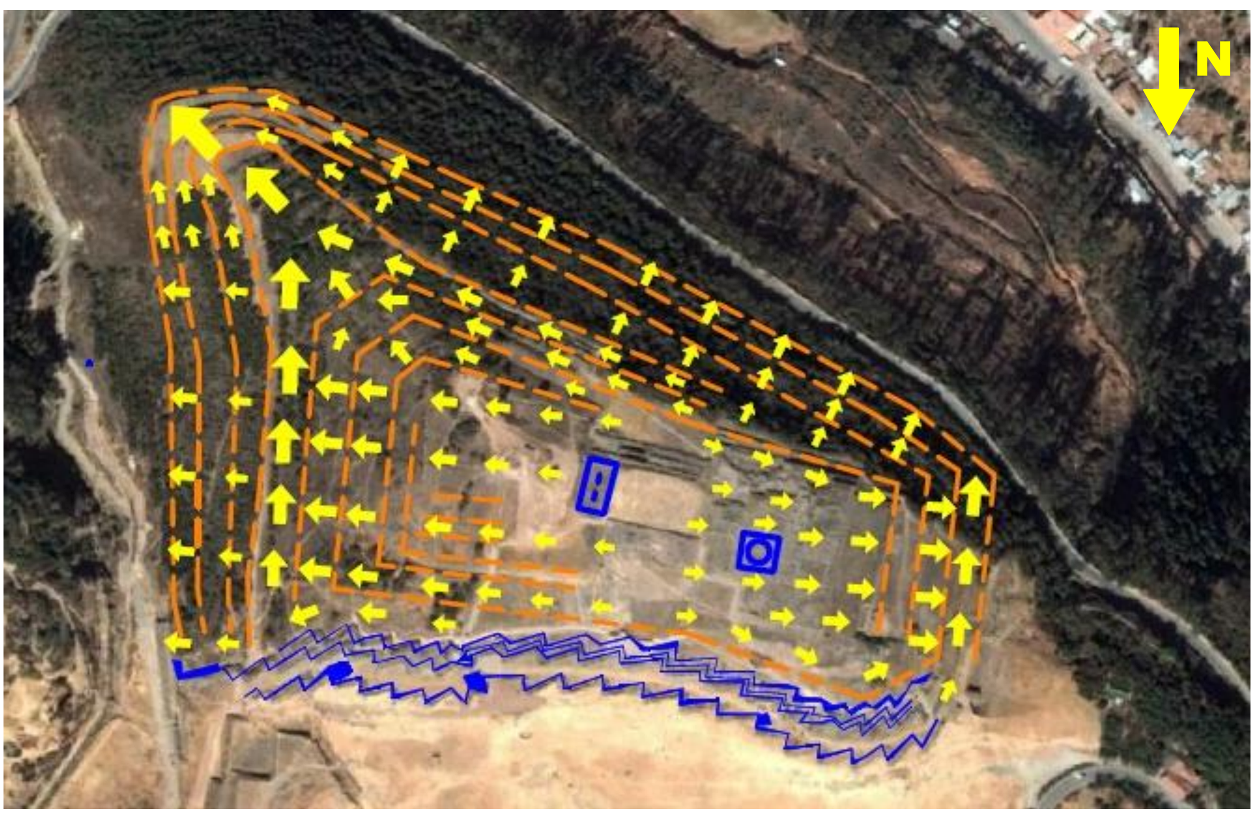

Figure 58. New Runoff Patterns with Terraces Layout

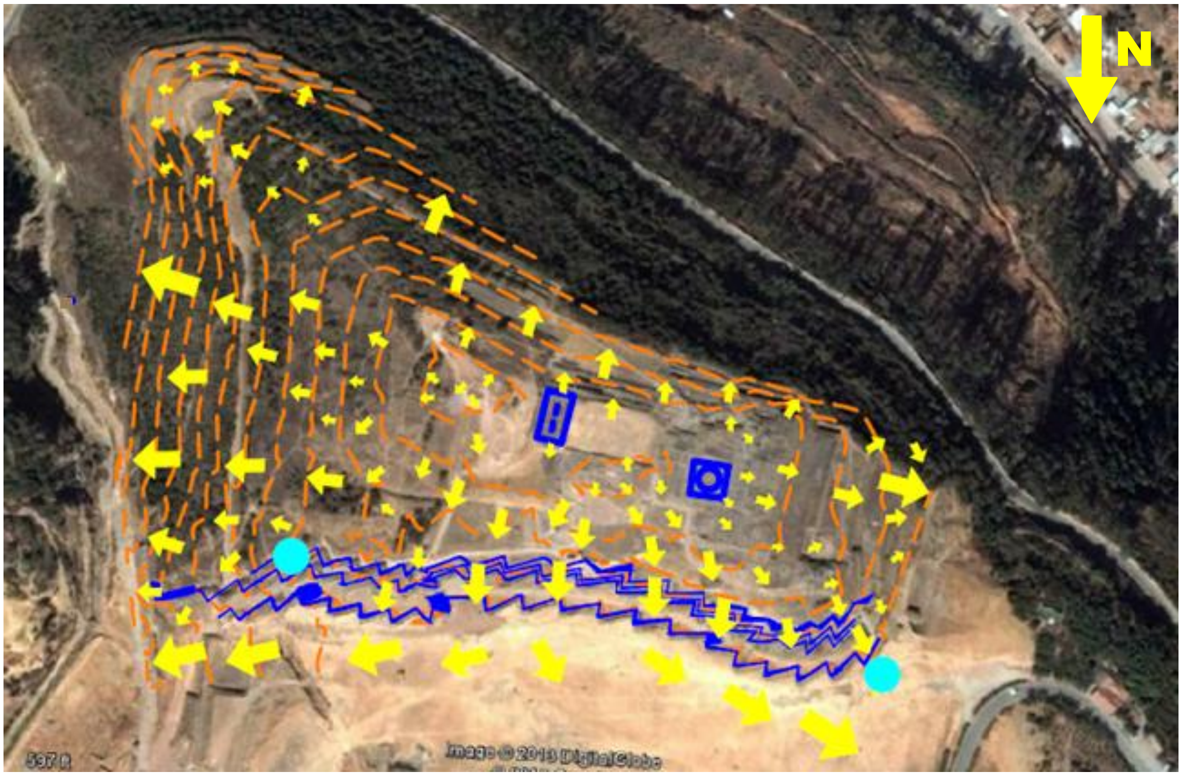

Figure 59. Current Topography and Flow Patterns

Comparing the flow patterns from figure 58 and 59 above reveals some very interesting points. The first major difference is irregularity of the flow in the current runoff patterns. The water flows in all directions throughout the site. It is much like a mountain where there is one high point and the flow pattern looks like concentric circles. The proposed terrace layout has a much more uniform flow pattern. Most of the water flows to the East, West, or North along defined sheets of flow. The second major difference is that the current flow pattern causes water to flow to the south over the main terrace walls, while in the terraces layout the water all flows to the east and west and none of the water flows to the south, thus avoiding the terrace walls. This would avoid the current problem of water buildup behind the third wall.

There is also other evidence that these terraces once existed. There are piles of stone rubble that could easily be the remnants of old terrace walls located just to the east of the new pedestrian walkway. There are also steps in the side wall of the old walkway that goes to the top of the lookout. These steps are shown in figure 60 and could be remnants of the sides of the old terraces. The current topography shows slight signs of terracing along the slope up to the lookout. There are several small flat areas located along the hillside to the left of the old walkway. These flat portions align with the piles of stones and the drops in the walkway which all suggest that there were once terraces located on this hillside (figure 61). The opposite flow direction of the El Grande port aligns with the new flow pattern as well where the port would carry water to the south through the second terrace wall.

Figure 60. Step Down in Walls of Old Walkway to Top of Tower Sector (Miksad, 2013)

Figure 61. Signs of Possible Inca Terraces in Current Topography (Lohr, 2013)

VIII. Conclusions

There are three main conclusions that can be made from this research study. First, elements have been found that suggest the Incas may have used a master drainage system in order to control the water runoff at Saqsaywaman. This is supported by the use of such systems at other Inca sites built around the same time period and the fact that multiple components of said system still exist today, most are just no longer functioning properly.

Secondly, the topography of the terraces was very different during the completion of Saqsaywaman. This is supported by the fact that many of the drainage ports are not currently located at ground level. This means that they serve no hydraulic function. The drainage port inlets must have been located at ground level in order for the water to enter them. A sample terraced flow projection shows how the topography could have been used to help control water runoff.

Finally, there were originally terraces located above the third wall. The extent of this terrace system in still unknown, but due to evidence in the form of better hydraulic flow, terrace wall remnants, and topographical clues, I concluded that there were terraces of some sort. These terraces would drastically change the runoff flow above the third wall and cause the water to be shed laterally instead of flowing towards the third wall. This would have prevented the damage that is currently being seen at the third wall today.

IX. Recommendations

There are two major recommendations for preserving and restoring Saqsaywaman:

The first recommendation is a short term solution. In order to prevent further damage to the walls, the drainage channels should be modified so they can carry the runoff load during a major storm event. The main problem areas were highlighted earlier in this report. At these problem areas, the channels can be enlarged so that they can handle the water runoff loads during larger storm events.

The second recommendation is to help restore Saqsaywaman in the long term. It is imperative that the functionality of the master Inca drainage system be restored. In order to do this, further investigation into the original topography should be completed. Once the original topography is restored, the drainage ports once again begin to function as intended and major water flow will be shunted laterally away from the walls. This should help to alleviate all water runoff problems as well as restore the site to its original cultural status and preserve the heritage of the Inca people.

X. References

Bauer, B. (2004). *Ancient cusco heartland of the inca*. (1st ed.). USA: University of Texas Press.

Crowe, C. T., Elger, D. F., Roberson, J. A., & Williams, B. C. (2010). *Engineering fluid mechanics*. (Ninth ed.). Jefferson City: Wiley.

Design and Construction of Sanitary and Storm Sewers, American Society of Civil Engineers and the Water Pollution Control Federation, 1969.

El Cusco tiene forma de Puma. (2008, February 20). *Cusco Vivo*. April 20, 2014, from http://cuscovivo.wordpress.com/2008/02/20/puma/

Encyclopedia Britannica. (2008). Drainage basin. In S. Singh & J. Rafferty (Eds.), *Encyclopedia Britannica*. http://www.britannica.com/EBchecked/topic/170868/drainage-basin

Garcilasco de la Vega, El Inca, *"Royal Commentaries of the Incas and a General History of Peru"*, (translated by Haropld Livermore), University of Texas Press, 1966.

Google. (Designer). (2014). [Web Graphic]. http://www.google.com/earth/

Gasparini, G. & Margolies, L., *"Inca Architecture"* (translated by Paricia j. Lyon), Indiana University Press, 1980.

Jeffers, O. (Photographer) (2013). [Digital].

MacQuarrie, K. (2008). *The last days of the incas*. Simon & Schuster.

Mar, Ricardo y Beltran, Alejandro – Caballero, *"El Conjunto Arquelogogico de Saqsaywaman (Cusco) Una Aproximcion a su Arquitectura"*, Revista Espannola de Antropologia Americana, 2014

Marek, M. (2011, Oct 01). *Hydraulic design manual*. http://onlinemanuals.txdot.gov/txdotmanuals/hyd/rational_method.htm

Mays, L. W. (2010). *Water resources engineering* (2^{nd} ed.). New York: Wiley.

Miksad, R. (Photographer) (2013). [Digital].

Mystic places: sacsayhuaman. (2010). http://www.worldmysteries.com/mpl_9.htm

Palma, JAR. (Photographer) (2013). [Digital].

Protzen, J. (1993). *Inca architecture and construction*. New York, NY: Oxford University Press.

Reinhard, J. (2011). J. Bartle (Ed.), *Peru in image* http://www.amazon.com/Peru-Images-en-Imagenes/dp/9972904539

Shah, R. (2000, January 1). Pupil Vision - Year Eleven/Rivers/hydrographs. *Pupil Vision - Year Eleven/Rivers/hydrographs*. April 20, 2014, from http://www.pupilvision.com/yeareleven/hydrograph.htm

Squier, G.E. "*PERU, Incidents of Travel and Exploration in the Land of the Incas",* Harper and Brothers, Publishers, New York, 1877.

Torp, J. (Designer). (2014, March). Draiage Port Runoff Analysis [Web Graphic].

Wildfire, L. (Photographer) (2010). [Digital].

Wildfire, L., Miksad, R.W., Perez, A., Culotti, A., Beckman, E., Vranich, A., & Wright, K.L. (2011). A paleo-hydrologic analysis of rainfall-runoff and drainage of the incan ruins of saqsaywaman, cusco, peru.

XI. Appendices

XI.1. Permits

PERU | Ministerio de Cultura

"Año de la Inversión para el Desarrollo Rural y la Seguridad Alimentaria"

El que suscribe: **DIRECTOR REGIONAL DE CULTURA CUSCO – MINISTERIO DE CULTURA.**

AUTORIZA

Al Sr. **FERMIN G. DIAZ ANGULO** en su condición de miembro del Equipo de la Universidad de Virginia, Facultad de Ingeniería y Ciencias Aplicadas, para que siete (07) personas ingresen con el objetivo de complementar estudios de **ANALISIS PALEO-HIDROLOGICO DE LLUVIAS ESCORRENTIAS Y DRENAJES DE SACSAYHUAMAN** según detalle siguiente:

- Parque Arqueológico de Sacsayhuaman: del 04 al 17 de Agosto del 2013

Para la realización de los estudios complementarios se autoriza a las siguientes personas:

- DR. RICHERD WALTER MIKSAD
- SR. KENNETH SCOTT LOHR
- SR. PAUL RUESS
- SR. JOSEPH R.T. TORP
- SRTA. OLIVIA JEFFERS
- SR. TOSH BANCE
- SR. FERMIN G. DIAZ ANGULO

Se responsabilizara al solicitante y a las personas que ingresaran, por cualquier infracción o daño que pudiera producirse durante los estudios complementarios en vista de que dicho estudio se encuentra dentro del Parque Arqueológico de Sacsayhuaman, siéndoles aplicable las sanciones civiles, penales y administrativas correspondientes. Asimismo, es responsabilidad del solicitante y de las personas que ingresan, cualquier accidente personal que pudiera ocurrir en dicha ceremonia, debiendo de tomar en cuenta las recomendaciones contenidas en el Informe Técnico Nº 049-2013-DRC-C-DPAS/PMPAS-JPD/MC y Memorándum Nº 144-2013-DPAS/DRC-C/MC. Se adjunta copia de los documentos. La actividad deberá estar acompañado y monitoreado por personal profesional del Plan Maestro del PAS durante el tiempo solicitado, entregar a la Dirección Regional de Cultura Cusco el estudio complementario a realizar.

El presente documento se otorga en atención a la Hoja de Tramite Nº 201304560 e Informe Técnico Nº 049-2013-DRC-C-DPAS/PMPAS-JPD/MC y Memorándum Nº 144-2013-DPAS/DRC-C/MC.

MINISTERIO DE CULTURA
CUSCO

MINISTERIO DE CULTURA

DAVID UGARTE VEGA CENTENO
DIRECTOR

PERÚ | Ministerio de Cultura | Dirección Regional de Cultura Cusco | Dirección del Parque Arqueológico de Saqsaywaman

"Año de la Inversión para el Desarrollo Rural y la Seguridad Alimentaria"

INFORME N° 021-2013-DRC-C-DPAS/PMPAS/PN-SKA/MC

A : **Sr. Pedro Taca Chunga**
Director del Parque Arqueológico de Saqsaywaman

DE : **Blgo. Samuel Kjuro Arenas.**
Responsable del Programa Patrimonio Natural

ASUNTO : **Informe Técnico.**

REFERENCIA: HOJA DE TRAMITE N° 201304560

FECHA : **Saqsaywaman, 16 de mayo 2013.**

MINISTERIO DE CULTURA
DIRECCIÓN REGIONAL DE CULTURA CUSCO
DIRECCIÓN PARQUE ARQUEOLÓGICO DE SAQSAYWAMAN
RECIBIDO
16 MAYO 2013
Registro N°:
Hora: 15:27 Firma:

Previo un cordial saludo tengo a bien dirigirme a Usted, con la finalidad de alcanzar opinión en referencia a la HOJA DE TRAMITE N° 201304560; donde el señor Fermín G. Díaz Angulo, a nombre del grupo de 06 personas de la Universidad de Virginia, Facultad de Ingeniería y Ciencias Aplicadas, solicita autorización y permiso para ingresar a Monitorear y Complementar Estudios sobre los Drenajes en el Parque Arqueológico de Saqsaywaman (Baluartes) en las fechas señaladas del 04 al 17 de agosto del 2013 del presente año.

Antecedentes:

- Habiendo entregado el resultado preliminar de Análisis Paleo-Hidrológico de Lluvias, Escorrentías y Drenajes de Sacsayhuaman, a la Dirección Regional de Cultura Cusco, como referencia del trabajo preliminar realizado en los Baluartes del PAS.

Opinión:

- Dar viabilidad a la solicitud de permiso a los miembros de la Universidad de Virginia.

Dr. Richard Walter Miksad	Pasaporte USA N° 0171540044	72 años
Sr. Kenneth Scott Lohr	Pasaporte USA N° 429693031	22 años
Sr. Paul Ruess	Estudiante	
Sr. Joseph R. T. Torp.	Estudiante	
Srta. Olivia Jeffers	Estudiante	
Sr. Tosh Bance	Ingeniero	

Sr. Fermín G. Díaz Angulo, ciudadano peruano.

Siempre y cuando cumplan las sugerencias siguientes:

Sugerencias:

- Ceñirse a las recomendaciones dispuestas por la Dirección Regional de Cultura Cusco, conforme establece la Ley del Patrimonio Cultural de la Nación.
- Deberán estar acompañados y monitoreados por personal profesional del Plan Maestro del PAS, durante el tiempo solicitado.
- Entregar a la Dirección Regional de Cultura Cusco, el estudio complementario a realizar de Análisis Paleo-Hidrológico de Lluvias, Escorrentías y Drenajes de Saqsaywaman.

Es todo cuanto informo a Usted para su conocimiento y fines correspondientes.

Atentamente,

Samuel Kjuro Arenas
BIÓLOGO
C B P 7507

Cc. /Arch

MINISTERIO DE CULTURA
Dirección Regional de Cultura Cusco
Dirección Parque Arqueológico de Saqsaywaman
Folio N° -3-

PERÚ | Ministerio de Cultura | Dirección Regional de Cultura Cusco | Dirección del Parque Arqueológico de Saqsaywaman

"Año de la Inversión para el Desarrollo Rural y la Seguridad Alimentaria"

MINISTERIO DE CULTURA DIRECCIÓN REGIONAL DE CULTURA CUSCO DIRECCIÓN PARQUE ARQUEOLÓGICO DE SAQSAYWAMAN
RECIBIDO
04 JUN. 2013
Registro Nº 1840 Hora

INFORME Nº 049-2013 - DRC-C-DPAS/PMPAS-JPD/MC

A : **Sr. PEDRO TACA CHUNGA**
DIRECTOR DEL PARQUE ARQUEOLÓGICO DE SAQSAYWAMAN

DE : Arqlgo. José Pilares Daza
ARQUEOLOGO DEL PARQUE ARQUEOLOGICO DE SAQSAYWAMAN

ASUNTO : **SOLICITA AUTORIZACIÓN DE INGRESO PARA MONITOREO DE ESTUDIO**

REFERENCIA : Hoja de Tramite 201304560.

FECHA : Saqsaywaman, 04 de Junio del 2013.

Previo cordial saludo me dirijo a Ud. con la finalidad de informar que en atención a la Hoja de Tramite Nº 201304560, mediante el cual Sr. Fermín G. Díaz Angulo, solicita autorización de ingreso para Monitoreo y complementación de estudio de drenajes del Parque Arqueológico de Saqsaywaman, en representación del grupo de 06 personas de la Universidad de Virginia, facultad de Ingeniería y ciencias aplicadas; para los días del 04 al 17 de agosto del presente año, al respecto le manifiesto lo siguiente:

Antecedentes:

- Habiendo entregado el resultado preliminar de Análisis Paleo-Hidrológico de Lluvias, Escorrentías y Drenajes de Saqsaywaman, a la Dirección Regional de Cultura Cusco, como referencia del trabajo preliminar realizado en los Baluartes del PAS.

OPINION.

- Respecto a los puntos indicados en el documento **OPINO PROCEDENTE LA PETICION,** al grupo de 06 personas de la Universidad de Virginia, facultad de Ingeniería y ciencias aplicadas Sres.

Dr. Richard Walter Miksad	Pasaporte USA Nº 0171540044	72 años
Sr. Kenneth Scott Lohr	Pasaporte USA Nº 429693031	22 años
Sr. Paul Ruess	Estudiante	
Sr. Joseph R. T. Torp.	Estudiante	
Srta. Olivia Jeffers	Estudiante	
Sr. Tosh Bance	Ingeniero	
Sr. Fermín G. Díaz Angulo, ciudadano peruano.		

Siempre y cuando cumplan las sugerencias siguientes:

Sugerencias:

- Ceñirse a las recomendaciones dispuestas por la Dirección Regional de Cultura Cusco, conforme establece la Ley del Patrimonio Cultural de la Nación.
- Deberán estar acompañados y monitoreados por personal profesional del Plan Maestro del PAS, durante el tiempo solicitado.
- Entregar a la Dirección Regional de Cultura Cusco, el estudio complementario a realizar de Análisis Paleo-Hidrológico de Lluvias, Escorrentías y Drenajes de Saqsaywaman.

Es cuanto cumplo en informar a su despacho para los fines consecuentes. Se adjunta el Expediente de referencia.

Atentamente.

Lic. José Pilares Daza
ARQUEOLOGO
R.N.A. Nº CP. 0773

cc. Archivo
Dirección PAS

MINISTERIO DE CULTURA
Dirección Regional de Cultura Cusco
Dirección Parque Arqueológico de Saqsaywaman
Folio Nº -4-

XI.2. Surveying and Modeling Instructions

Guide to Surveying Using a Total Station

This section will describe how to use a Top Com GTS-230W total station and a Carlson data collector running SurvCE software to complete a point survey and then use that data to create a surface in AutoCad Civil 3-D 2013.

Field Work

The materials that needed for the field portion of surveying include: total station, tripod, data collector (optional but highlight recommended), hand level (optional), plumb bob, measuring tape, and a prism.

Tripod Set up

The first step is to decide where you will set up your total station. You must set up the total station on a point of known location and be able to see another point of known location to use as a backsight as well as be able to see the area that you are looking to survey. Alternatively, you can set up the total station at any point and then take two backsight points. Once you have determined a location set up the tripod at this location. The legs of the tripod can be adjusted in height by loosening the screw located near the bottom of the leg and then retightening the screw to re-secure the leg. The top of the tripod should be approximately at chest height that way to make it easy and comfortable to see through the total station once it is set up. Try to get the top of the tripod approximately level using the hand level if desired. At this point take the cover off of the top of the tripod by loosening the hand screw underneath the top platform. Attach the plumb bob to the tripod by screwing the end of the plumb bob into the bottom of the hand screw. Then use the plumb bob to make sure that the center of the tripod is close to the benchmark point you are setting up on. The total station has a little leeway in this area about an inch or so in any direction. Remove the plumb bob from the tripod.

Total Station Set up

Once the tripod is correctly in place, carefully take the total station out of it case and attach it to the tripod using the hand screw coming up from the center of the tripod. Now use the 3 leveling screws and the bubble level to level the total station. Then turn on the laser plummet which will shoot a laser dot on the ground to determine the exact location of the total station. If the total station is not aligned directly with the benchmark point you are setting up on, loosed the hand screw and carefully slide the total station over until the laser is on your desired location. If the total station is too far from the desired location take the total station off of the tripod and move the tripod to be better centered over the point and then repeat the basic leveling process. Make sure to turn off the laser plummet to not run down the battery on the total station. Then, you must use the 3 leveling screws and the bar level in order to more finely level the total station. In order to most easily accomplish this align the bar level between two leveling screws and adjust those screws until level. The turn the total station where the bar level is between the third screw and one of the previous screws. Now adjust only the third screw in order to level the unit. Turn the total station to align the bar level between the third screw and the other screw not used in step two and check to make sure that it is level.

Data Collector Setup

Take out your data collector and turn it on. Open the SurvCE software file. Go to

Surveying

With all of the equipment ready to go, move the prism to where you would like your first point to be.

Data Importing

Take the data collector and export the data from it. It will be in text file format which you can import into Microsoft Excel if you like or which can be directly imported into AutoCad. In AutoCad, go to the insert ribbon and then data from file.

Surface Creation

Go to surface creation tools and select create surface from points. Select the points that you uploaded in the previous step and click ok. This should create a surface using the points that you collected.

XI.3. Rainfall Data

CORPAC S.A.
ÁREA DE METEOROLOGÍA AERONÁUTICA
EQUIPO DE PRONÓSTICOS Y CLIMATOLOGÍA

AEROPUERTO DE CUSCO
PRECIPITACIÓN MÁXIMA EN 24 HORAS (MILÍMETROS)
PERÍODO: Ene/1990 - Oct/2011

Latitud: 13° 32' S **Longitud: 71° 56' W** **Altura: 3248 m**

AÑO	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DIC
1990	20.2	20.2	14.0	29.0	3.7	6.5	0.0	4.2	18.0	20.0	16.0	18.0
1991	12.4	25.7	21.5	18.7	3.5	2.2	2.6	0.0	9.9	19.2	20.0	21.0
1992	12.0	25.7	21.5	10.0	0.0	0.0	0.0	6.3	9.0	23.6	19.9	45.6
1993	23.0	17.0	16.0	3.0	10.0	0.2	0.0	5.0	3.0	15.0	15.0	30.0
1994	40.0	30.5	29.0	13.0	6.0	0.0	0.0	0.0	7.0	15.0	14.0	22.1
1995	25.0	18.0	17.8	4.0	0.0	0.0	0.0	0.0	9.0	11.0	10.0	17.0
1996	25.0	13.0	15.6	6.0	9.0	0.0	0.0	3.0	10.0	5.0	14.0	17.0
1997	28.0	20.0	25.0	15.0	4.0	1.0	0.5	4.0	7.0	9.0	22.4	29.0
1998	40.1	22.2	12.0	10.0	5.0	2.0	0.0	2.0	1.0	12.0	9.0	20.7
1999	17.0	13.6	21.0	19.0	7.2	3.3	0.7	0.0	11.0	3.0	9.2	25.0
2000	18.0	15.3	18.0	2.0	2.6	5.0	1.0	2.0	5.0	18.0	21.0	14.0
2001	40.0	45.9	27.0	8.5	3.9	0.0	15.0	5.0	4.0	14.0	17.0	20.0
2002	23.0	30.4	19.4	6.4	5.0	1.6	9.0	2.2	5.4	20.2	18.6	22.6
2003	35.2	24.8	23.6	35.4	2.2	5.4	0.2	12.0	2.6	7.8	7.8	16.0
2004	23.4	21.2	12.8	11.8	1.2	12.8	6.0	5.1	6.8	20.0	12.0	25.6
2005	18.6	17.2	26.8	9.4	1.8	0.2	1.8	1.0	2.4	5.6	11.6	12.6
2006	33.2	16.0	17.8	30.0	0.0	3.4	TRZ	4.8	5.0	18.6	9.6	25.4
2007	14.4	17.4	29.0	27.8	4.2	0.0	2.2	TRZ	1.0	15.6	24.0	12.0
2008	27.6	42.8	19.0	6.6	6.2	1.2	1.6	3.4	17.2	12.2	16.0	44.2
2009	18.6	32.6	23.4	9.2	0.8	0.0	1.8	3.8	9.4	10.6	28.6	11.8
2010	31.6	27.8	26.2	5.6	1.6	0.2	1.2	1.2	2.6	17.2	13.6	28.0
2011	29.6	29.0	21.8	15.0	0.4	TRZ	4.8	TRZ	7.4	15.6		

Nota:
- La cantidad total de precipitación de las últimas 24 horas es medida a las 07:00 a.m.
- El indicativo TRZ significa Trazas de precipitación y es equivalente a una cantidad menor a 0.1 m.m.

LNM/ MCB.
Nov-2011

Pág. 2/6

Rainfall data for Cusco Area Received from engineers at Saqsaywaman Park 2013

XI.4. Historical Images

1956

August 2002 (Google, 2014)

March 2008 (Google, 2014)

May 2011 (Google, 2014)

August 2012 (Google, 2014)

April 2013 (Google, 2014)