A Comprehensive Hydraulic Analysis of the 500-year-old Ancient Incan Water System at Saksaywaman, Peru

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ABSTRACT

The following thesis is a comprehensive hydraulic analysis of the 500-year-old ancient Incan water system at Saksaywaman, Peru. This water system, called the Muyuqmarka, was once used for ceremonial and agricultural purposes for the Inca elite. What remains of the Muyuqmarka water system results from natural wear and European colonization. This thesis analyzes and reassesses the Muyuqmarka stone channel segments from a hydraulic engineering perspective in order to support archeologists and other research in verifying the previous reconstruction of an original Incan structure. The analysis is achieved through hydraulic engineering theories and equations, detailed inventory of channel segments, and an in-the-field ArcGIS surveyed map of channel locations. The three takeaways from this investigation are as follows: the current condition of the Muyuqmarka water passages have channel segments that are visibly and hydraulically misplaced, compared to other sets of hydraulic data the half-full water channel calculations were the most efficient equations used to accurately analyze the data, and finally, the limestone and andesite stones had similar hydraulic radii possibly leading to the conclusion that the Incans may have mixed their stone channels. Through the data presented in this thesis it is evident that the current condition of the Muyuqmarka erroneously represents the original Incan structure. Not only can this data be used to prove the inaccuracy of its current reconstructed form, but it can also be used in support of restoring the channels to their original design.

I. INTRODUCTION

A. THE MUYUQMARKA AT SAQSAYWAMAN INCA SITE

Saqsaywaman is located at the northern end of Cusco, Peru and is approximately 170,000 square meters in area. The Muyuqmarka, the hydraulic structure on the western side of Saqsaywaman, is composed of a 22.5 meter long rectangular outer base containing three concentric rings with three stone (water) channels leading out of it, as seen in Figure 2. During Inca times, this structure was seen as a sacred building that was most likely used for ceremonial purposes and agricultural rituals for the Inca elite in the city of Saqsaywaman. Sara Morrisset, a former master's student from St. Johns College (Cambridge, England), emphasized in her dissertation that the Muyuqmarka "served as [a] venue[s] for rituals and other ceremonies" (Morrisset 47). Along with ceremonial rituals, agricultural rituals would have taken place as the channels' flow would cascade from terrace to terrace watering the ground.

Figure 1*: Saqsaywaman Site (Saksaywaman)*

To add, although it is not explicitly stated whether the Muyuqmarka was a water tower or a cistern in the ancient Inca city of Saqsaywaman, the Spanish historian, Garcilaso de la Vega, gave his accounts of his travels to the city in his book *Royal Commentaries of the Inca*s in 1617.

De la Vega describes a water source in the city called the "Moyoc Marca." This source was fortified with three walls encircling it and it brought a "copious supply of excellent water" (De la Vega 468). How this water got to the Muyuqmarka is still a mystery, however, hypotheses include springs that fed directly into the system or laborers carrying gallons of water in vessels to the system by ways of underground passages. Today all that remains of this ancient water system are the foundation and channel ruins left behind from Spanish conquistadors.

B. RESEARCH OBJECTIVE

Since unburied and rediscovered in the 1930s, the Muyuqmarka has seen changes to its original stone foundation layout. This is evident when one walks around the channels and see channel segments side by side that don't appear to match in stone type, stone color, and channel shape. This research is a comprehensive hydraulic analysis of the 500-yr old ancient Inca water system at Saqsaywaman, Peru. The objective is to analyze and reassess the Muyuqmarka stone channel segments from an engineering perspective in order to support archeologists and others in verifying the previous reconstruction of a 500-yr old Inca structure. This is achieved through hydraulic engineering investigation, detailed inventory of channel segments, and surveyed map of channel locations.

Figure 2 shows the Muyuqmarka with its three stone channels.

Figure 2*: Circular tower remains of the Muyuqmarka (Sacsayhuamán)*

C. PERSONAL CONTRIBUTION

The research on the Muyuqmarka began in the fall of 2016 for an undergraduate research course headed by the University of Virginia Civil Engineering Department with Dr. Richard Miksad. Dr. Miksad was first invited to Cusco, Peru in 2010 to conduct a hydraulic analysis on Saqsaywaman's 500-year-old collapsing megalithic wall system. Since 2010, teams of University of Virginia engineering students have collected and conducted hydraulic and structural analysis on site. From the fall of 2016 to the spring of 2017 the research team, consisting of Kyle Mavity, Helena Nicholakos, Zoë Schmitt, and Erica Mutschler, each studied a separate aspect of the Inca site Saqsaywaman. The team members focused on modeling the Great Walls of the site to uncovering the buried walls on the site's eastern hillslope. Using previous hydraulic dimensions taken from the Muyuqmarka in 2014, personal contribution throughout the year consisted of obtaining and assessing forensic, hydraulic-engineering analysis to determine how the Inca stored and supplied water to the network of ceremonial channels at the Muyuqmarka. Moving forward into the summer of 2017, field research on site was conducted at the Muyuqmarka and further dimensioned 141 channel segments and geospatially mapped 170 channel segments. This thesis is a compilation of knowledge built upon data taken from 2014 to 2017. Unless otherwise noted, all the hydraulic calculations, tables, and assumptions are taken from the 141 dimensioned channel segments during the summer of 2017. Each channel's stone dimension as well as details such as stone type, location, and unique carved features are catalogued. This data was taken to manipulate the channel segments and apply the principles of hydraulic engineering to investigate the Muyuqmarka's water system.

D. ORGANIZATION

Following the introduction and research objective, this thesis is organized as follows: historical and contextual background, methods, results, conclusion, future work, and recommendations. Chapter 2 talks about the past and current state of the Inca site of Saqsaywaman and the ruins left behind by the Spaniards. Chapter 2 also reviews previous work that has been done on-site with the Muyuqmarka. Chapter 3 outlines the foundational hydraulic theories behind the Muyuqmarka research as well as the data collected, tools used for interpretation, and work processes completed to analyze the research. Chapter 4 examines the Muyuqmarka results from the data and work processes addressed in Chapter 3. Chapter 4 also presents the final catalogued channel products and investigates the ongoing conflict of the National Institute of Culture of Peru's (INC) reconstruction work done to the Muyuqmarka. Chapter 5 consists of the thesis conclusion and future work that can be done to the Muyuqmarka and recommendations for the National Institute of Culture of Peru. Chapter 5 concludes with the greater significance of this research and the corrective steps to be taken to restore the current state of the Muyuqmarka.

II. HISTORICAL AND CONTEXTUAL BACKGROUND

A. HISTORICAL BACKGROUND

The extensive Inca Empire once occupied 2,500 miles of South American coastline, arid Andean mountains, and dense tropical jungle along the western side of modern day Ecuador down through Chile before being conquered by the Spaniards in 1532. In its heyday, the empire stood as the largest empire in the Americas as well as the largest empire in the world (Cartwright). Not until its last 100 years had the Inca Empire risen to such power by conquering and building upon neighboring ethnic groups. The great Inca leader, Pachacuti Inca Yupanqui, quickly conquered and expanded the empire while constructing marvels such as Machu Picchu and miles of roadway systems (Cartwright).

When the Spanish conquistadors arrived in the mid-16th century, they quickly discovered the opportunity to prosper by plundering the empire's abundant riches and resources. In order to build their own Spanish city in the Inca's capital, Cusco, in 1559 the conquistadors dismantled the surrounding Inca buildings to build their own site. Saqsaywaman, which conveniently towered above Cusco on a hill, was one major site torn down for their use (Morrisset 35). For this reason, the ancient Inca site of Saqsaywaman is missing several stones and only bears the foundation of a complex system of structures. It no longer stands in its original glory and the natural effects of wear that four hundred plus years would have on infrastructure yielded the ruins of what once loomed over Cusco. The monumental zig-zag walls that face north of Saksaywaman (depicted below in Figure 3) stand smaller than they did in Inca times. All that remains of the Muyuqmarka's circular tower is its foundation and groundwork of complex channels that spread out from it.

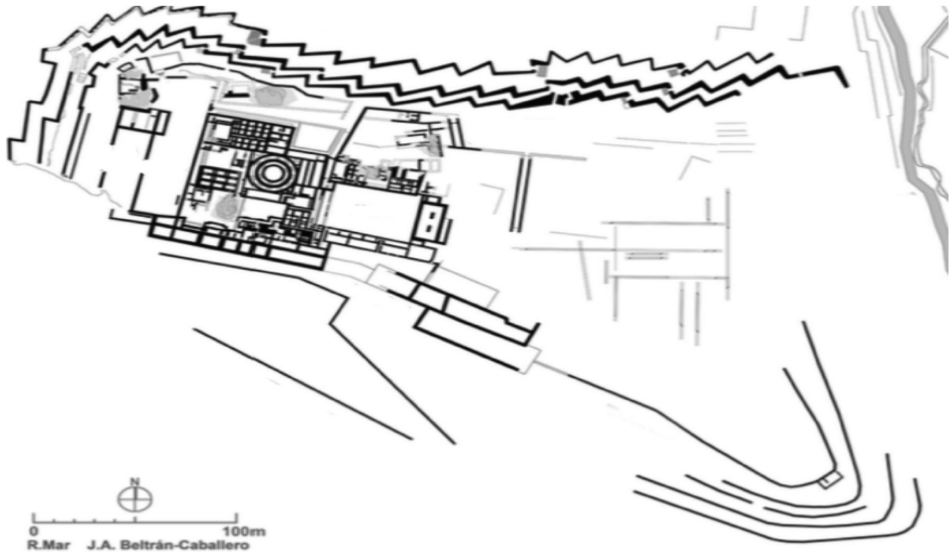


***Figure 3**: Saqsaywaman (Morrisset 2016)*

Unfortunately, Inca history is scarce since the civilization did not have a written language. What is known today about the culture is drawn from an accumulation of Spanish writings from the 17th century, archeological discoveries, and engineering analysis. With these missing gaps of history, archaeologist and engineers must speculate in order to build an understanding of the formation of the Inca Empire. When the Muyuqmarka was rediscovered and reconstructed in 1934 by Luis E. Valcárcel, the drains, circular footing, and foundation were all that remained in place (Morrisset 23). However, Valcárcel took it upon himself to reconstruct the channels with little to no hydraulic engineering knowledge. This led to hydraulically mismatched stone channel segments that misrepresented the original design of the Inca. Figure 4 is an example of a reconstructed channel by Valcárcel and Figure 5 is an example of a questionable channel reconstruction where the three channel segments lead to nowhere.

***Figure 4**: Reconstructed channels on-site (Photo by Author)*

***Figure 5**: Questionable channel reconstruction (Photo by Author)*

B. PREVIOUS ENGINEERING ANALYSIS WORK

During the summer of 2014, a University of Virginia student, Gina O'Neil, mapped, calculated, and catalogued the hydraulic radii of the three stone channels that led away from the Muyuqmarka. Her research concluded with the summary that there were misplaced stones and mismatched channel segments. O'Neil, along with the help of the Peruvian anthropologist Ivan Montesinos Garrido, traced on cardboard cut-outs the channels' dimensions and then mapped where those cut-outs could be found around the Muyuqmarka (O'Neil). Figure 6 shows O'Neil and Garrido on-site at the Muyuqmarka tracing the cardboard cut-out A1. Figure 7 is a map drawn to scale by Garrido that represents the Muyuqmarka tower foundation and consequent visible channel remains. The solid channel lines are the enacted remains and the dotted channel lines represent hypothetical missing channel segments.

Figure 6*: Example of cardboard tracings (O'Neil 2014)*

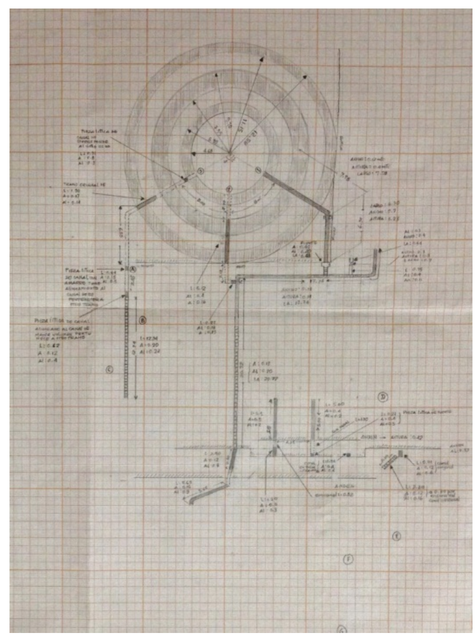


Figure 7*: Map of channel tracings (O'Neil 2014)*

O'Neil then took the card-board tracings and catalogued their dimensions and hydraulic radii into an excel document. When calculating the hydraulic radius, it was assumed that the Inca did not fill their channels completely, thus only using about 50 percent of the holding capacity. By color-coding the hydraulic radii, O'Neil was able to categorize and arrange similar hydraulic radii. The color arrangement helped present the incorrect channel segments along the three channels. It was concluded by looking at the tracings and excel document, "[the] majority of excavated stone segments were incorrectly connected, leading to a great misrepresentation of the tower sector in Inca times" (O'Neil).

Taking from O'Neil's idea of using the hydraulic radius to analyze the Muyuqmarka channel segments, the work presented in this thesis concerning the segments is unique in that it expands upon the quantitative understanding as well as the qualitative understanding. In O'Neil's work, 46 stones were hand-mapped and their hydraulic radii were found. In this thesis, 141 stones were located and mapped in Esri ArcMap. Additionally, not only were the 141 stones' hydraulic radii calculated, but their best hydraulic section for uniform flow in an open channel was found and inputted into the Chezy-Manning equation. Along with the 141 stones, 146 cross-sections were made, with five accounting for stones where extra cross-sections were taken. More details concerning each stones' dimension, stone type, stone color and any other small details were also catalogued and used as criteria for comparison. Furthermore, the stone channel dimensions' were used for the Chezy-Manning calculation. This determined how much water could have flowed out of the Muyuqmarka structure itself and through the three channels that spread out from its inner circle. O'Neil's work was a hydraulic stepping stone to a bigger analyzation of the Muyuqmarka. This thesis is a full engineering analysis, both quantitatively and qualitatively, of the Muyuqmarka hydraulic Inca complex.

III. METHODS

A. HYDRAULIC THEORIES AND EQUATIONS

To hydraulically examine the collected 146 channel cross-sections, five segments had two cross-sections taken, the stone segments follow the laws of open-channel fluid dynamics. Meaning the channel's upper surface is exposed to the atmosphere. For the purpose of this research, and taking information from previous Inca water systems, the open channels are assumed to abide by uniform flow. Uniform flow is when the velocity is constant along a streamline, meaning the cross-section and depth are constant throughout the length of the channel segment (Elger 558). Moving forward, the assumptions are as follows: steady uniform flow with constant cross-section shapes along each of the Muyuqmarka's three main channels.

Using open-channel fluid dynamics, the following calculations were used to analyze the data: hydraulic radius (R_h), best hydraulic section for uniform flow, and Chezy-Manning. Each of the equations used are explained below.

The hydraulic radius equation is given as:

Equation 1

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

Equation 1 takes the channel's cross-sectional area and divides by the channel's wetted perimeter (Elger 556). This equation is used to calculate the uniformity as well as compare each of the 141 channel segments. For example in channel 1 from the Muyuqmarka, in order for the stone segments to be hydraulically compatible, each of the segments should have similar hydraulic radii. If the hydraulic radius of one segment varies vastly, then that channel segment is misplaced within the channel and is not hydraulically compatible with the other stone segments.

The next fluid mechanic equation used to analyze the channel segments is the best hydraulic section for uniform flow. The best hydraulic section for an open channel with uniform flow occurs when the channel maximizes its hydraulic radius, or in turn minimizes its wetted perimeter (Cengel 17). It takes into account the channel's geometry (cross-sectional area and perimeter) that would give the maximum discharge (Elger 563). A geometry with a minimum wetted perimeter provides the maximum discharge. In other words, a minimum wetted perimeter minimizes energy loss due to friction, allowing for maximum discharge (Elger 563). Looking at the section factor of Manning's equation, seen later in this section, $AR_h^{2/3}$ and substituting in the hydraulic radius $R_h = A/P$ yields the following $A(\frac{A}{P})^{2/3}$. As the channel's cross-sectional area increases, the discharge will increase, but as the wetted perimeter increases, the discharge will decrease. Thus, there is a maximum ratio of depth to width of a channel geometry. That ratio of cross-sectional area to wetted perimeter will provide the best hydraulic section for a given channel shape (Elger 563).

Using the theory of best hydraulic section on the Muyuqmarka channel segments is a safe assumption because the Inca typically filled their water channels between one-third and one-half the maximum channel capacity (insight taken from Dr. Miksad). Filling a channel to the maximum holding capacity creates more friction along the channel walls and the flow would appear more turbulent. The Inca created their channels both for efficiency and appearance (insight from Dr. Miksad). Thus it is appropriate to determine best hydraulic section for uniform flow for each of the 146 channel segment cutouts, since the Inca would have maximized the efficiency of their water channels as well as please the eye.

To calculate the best hydraulic section for the 146 channel segment cutouts, the channel cross-sections were assumed to be one of three categorical shapes, a rectangle , a semicircle , or a trapezoid . These assumptions were made by eyeballing each irregular shape and closely classifying them into a regular shape. The equations used to calculate their best hydraulic section for uniform flow is expressed below.

In the best rectangular hydraulic section, the shape's cross-sectional components, area and perimeter, are combined into one equation and the perimeter is then minimized by differentiating the equation with respect to the width, B. The result, Equation 2, is expressed in terms of the channel depth, y (Atil 37).

Equation 2

$$P = 4y$$

The best hydraulic section for a rectangle occurs when the perimeter is four times the channel depth, y, and the area is 2 times the channel depth squared (Atil 37). For the hydraulic radius with the best rectangular hydraulic section, substitute the area and perimeter equations into the hydraulic radius equation, $R_h = {}^{A}/_{P}$. The result is Equation 3.

Equation 3

$$R_h = \frac{A}{P} = \frac{2y^2}{4y} = \frac{y}{2}$$

In the best hydraulic section for a semicircle, since a semi-circular shape is itself a best hydraulic section (Atil 34), the shape's cross-sectional components, area and perimeter, are inputted into the hydraulic radius equation. The result is Equation 4 (Atil 37).

Equation 4

$$R_h = \frac{y}{2}$$

(where y is the depth of water in the channel)

Similar to the best hydraulic section for a rectangle and a semicircle, the best hydraulic section for a trapezoid is half the depth of water in the channel. Figure 8, taken from Larry Mays *Water Resources Engineering* book, shows the best hydraulic section equations used for all three shapes.

Table 5.1.3 Best Hydraulic Sections

Cross-section	Area A	Wetted perimeter P	Hydraulic radius R	Top width T	Hydraulic depth D
Trapezoid, half of a hexagon	$\sqrt{3}y^2$	$2\sqrt{3}y$	$\frac{1}{2}y$	$\frac{4}{3}\sqrt{3}y$	$\frac{3}{4}y$
Rectangle, half of a square	$2y^2$	$4y$	$\frac{1}{2}y$	$2y$	y
Triangle, half of a square	y^2	$2\sqrt{2}y$	$\frac{1}{4}\sqrt{2}y$	$2y$	$\frac{1}{2}y$
Semicircle	$\frac{\pi}{2}y^2$	πy	$\frac{1}{2}y$	$2y$	$\frac{\pi}{4}y$
Parabola, $T = 2\sqrt{2}y$	$\frac{4}{3}\sqrt{2}y^2$	$\frac{8}{3}\sqrt{2}y$	$\frac{1}{2}y$	$2\sqrt{2}y$	$\frac{2}{3}y$
Hydrostatic catenary	$1.39586y^2$	$2.9836y$	$0.46784y$	$1.917532y$	$0.72795y$

Source: Chow (1959).

Figure 8*: Table of best hydraulic sections (Mays)*

The three equations for the best rectangular hydraulic section, the best semi-circular hydraulic section, and the best trapezoidal hydraulic section have the same hydraulic radius equation, $^{1}/_{2}\,y$. Moving forward, for the remainder of this thesis, the best hydraulic section is termed as the most efficient section. Where the most efficient section describes a regular shape with the shape's perimeter minimized for the most discharge through a given section.

The hydraulic radius is not only used to compare the geometry of the 141 segments, but it is also used in the Chezy-Manning calculation to find the total volumetric flow rate, Q. The Chezy-Manning equation is a combination of two fluid mechanic equations, the Chezy equation and the Manning equation. The Chezy equation is given by:

Equation 5

$$Q = CA\sqrt{R_h S_O}$$

This equation finds the volumetric flow rate (*Q*) by multiplying the coefficient *C* (influenced by the friction factor of the channel) and the cross-sectional area of the channel (*A*) by the square root of the hydraulic radius (R_h) of the channel and the slope of the channel (S_O) (Elger 560). The Manning equation is written as:

Equation 6

$$C = \frac{R_h^{(\frac{1}{6})}}{n} \text{ (in SI units)}$$

Equation 6 calculates the coefficient *C* by dividing the hydraulic radius (R_h) by the resistance coefficient (*n*), also known as the Manning's coefficient. The resistance coefficient has different values depending on the channel's boundary surface (Elger 561).

When the Chezy and Manning equations are combined, the result is as follows:

Equation 7

$$Q = \frac{1.0}{n} \mathrm{A} \; R_h^{(\frac{2}{3})} \; S_O^{(\frac{1}{2})} \text{ (in SI units)}$$

The Chezy-Manning equation is the most commonly used equation to find the discharge in a uniform flow (Elger 561). For the purpose of this research, Equation 7 was used to calculate and compare the theoretical flow rate for each stone segment constructed within the Muyuqmarka channels. In actuality, each channel stretch can only have one flow rate throughout its given length. With this in mind, the theoretical flow rate may vary from channel segment to channel segment, but the flow rate within the channel stretch must remain the same throughout its length. Equations 1 to 7 were used in the analysis of the Muyuqmarka channel segments. This analysis is shown later in the results as well as in the appendices at the end.

To takeaway, there were two ways to calculate and compare the hydraulic radius. Equation 1 shows the first way of using the channel's actual shape, or irregular shape, to find three hydraulic radii cases (full-flowing channel, half-full-flowing channel, and a third-full-flowing channel). The other way to calculate the hydraulic radius is to calculate the best hydraulic section for uniform flow, or most efficient section. The most efficient section assumes a regular shape, such as a rectangular, and then manipulates parameters to find the hydraulic radius. In later sections these two methods are compared and their results are shown in tables.

For further clarification on the two methods, Table 1 shows the workflow for both method 1 (actual shape) and method 2 (assumed shape).

Table 1: Channel cross-section hydraulic radius workflow

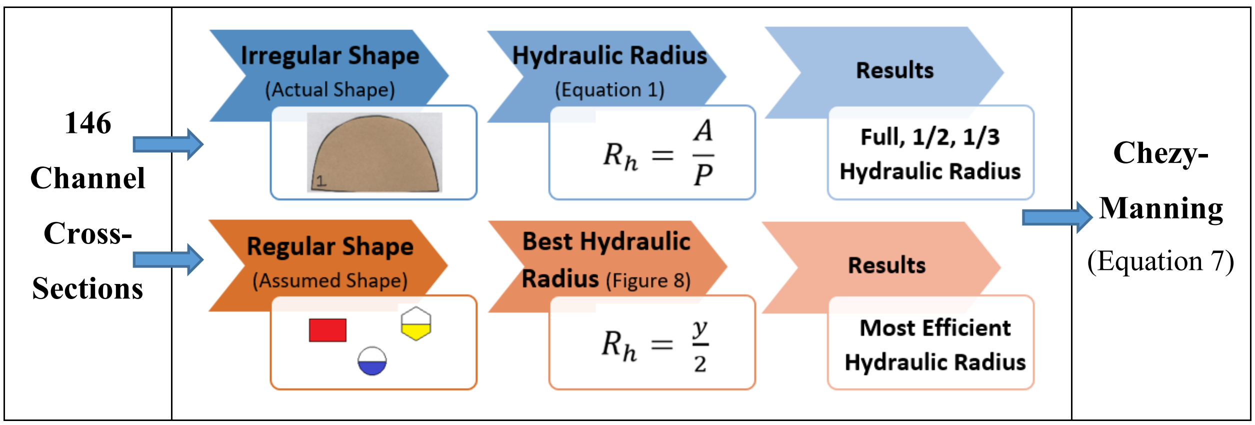


Table 1 shows the 146 channel cross-section hydraulic radius workflow for two methods. The first method took the irregular cross-section shape, calculated Equation 1, and found the hydraulic radius for a full-flowing channel, a half-full-flowing channel, and a third-full-flowing channel. The second method assumed a regular shape from the irregular cross-section shape and then calculated that shapes most efficient hydraulic radius. Both method results are then used to calculate the Chezy-Manning equation. These results are compared in later sections.

B. DATA COLLECTED

On-site data taken at the Archaeological Park of Saqsaywaman for the Muyuqmarka was collected from June 22 to July 10, 2017. The data collected includes the following: quantitative data, qualitative data, and geospatial data.

Quantitative Data

The quantitative data taken for 141 stone segments and their stone carved-out channels include the following: the stone's height, the stone's length, and the stone's width as well as the carved-out channel's length. Along with the noted dimensions, there are 146 channel cardboard cutouts calculated with each channel's area and wetted perimeter. 170 stones were noted and numbered, but only 141 stones were dimensioned. This data is presented in the results section under subsections D and E.

***Figure 9**: Stone segment (Photo by Author)*

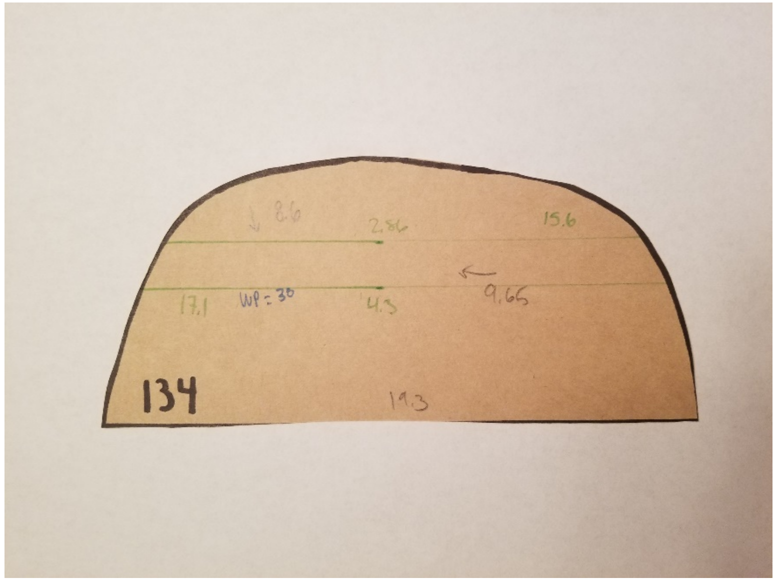


Figure 10*: Channel cross-section cutout*

Figure 9 is a stone segment that was dimensioned and numbered and Figure 10 is a dimensioned channel cross-section cutout.

Qualitative Data

The qualitative data taken for the 141 stone segments and their carved-out channels include the following: cardboard channel cross-section cutouts, stone color, stone type, stone picture, stone roughness or smoothness, if the stone was in-situ, if the stone appears out of place, if another stone could have been placed on it, and any unique carved stone features. There are two types of stone noted for the stone segments, stones that appeared to be andesite and stones that appeared to be limestone. Andesite is fine-grained igneous rock and limestone is grainy sedimentary rock. All 141 stone segments' stone type were recorded according to whichever they were most similar to. Extra notes were taken if the stone had any unique carved stone feature. This data is presented in the results section under subsection E. Stone Segment Detailed Notes.

Geospatial Data

The geospatial data taken shows the location for the 170 stone segments. Those stone segments are shown in an ArcGIS map.

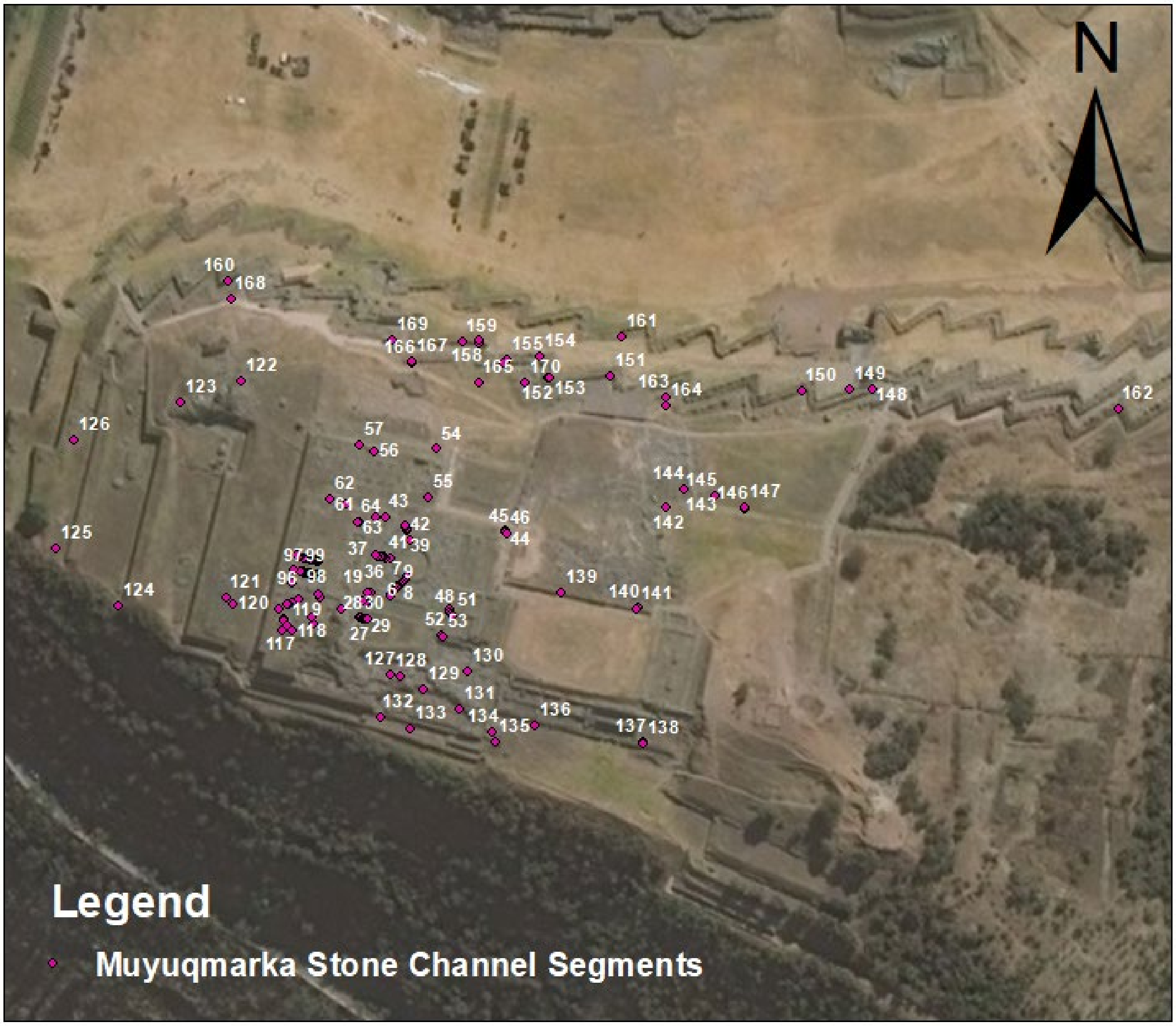


Figure 11: *Map of Muyuqmarka 170 Stone Channel Locations*

C. TOOLS USED FOR ANALYSIS

Three programs and various engineering tools and materials were used for analysis:

- Microsoft Excel 2013 was used to compare and calculate all the fluid mechanic equations for the 141 channel segments. This includes tabling all the quantitative data taken from the field and calculating the hydraulic radius, the Chezy-Manning's equation, and most effient section for uniform flow.

- ESRI ArcMap 10.5.1 was used to combine and display collected Global Positioning Points (GPS) taken from the summer of 2014 to the summer of 2017. This program digitized and mapped out the location of 170 channel segments. As well as created an interpolated surface of the Muyuqmarka.
- Microsoft Word 2013 was used to format the data into tables. The results section, along with Appendices 1 to 5 show the accumulation of data. The subsection D within results is the main catalogue table detailing each 141 channel segments' stone number, GPS location, most efficient section for uniform flow, and stone type. This subsection also gives a picture of the channel segment and its cross-section.
- Total Station and Trimble apparatuses were used to collect topographic coordinate point data, Northing (Y), Easting (X), and Elevation (Z). A total station device gathered points from 2014 to 2015 and a Trimble device gathered GPS points and from 2016 to 2017. Both devices accurately collected the northing, easting, and elevation of each point, however, the Trimble GPS equipment obtained survey-grade points accurate to 4mm in the XY direction and 8mm in the Z direction (Saqsaywaman).
- Chalk, thin metal wire, cardboard paper, and ruler were used to collect data on the Muyuqmarka channel segments. Chalk noted and kept track of the channel segments; thin metal wiring outlined the channel bottoms and took the cross-section shapes; cardboard paper traced out the cross-sections; ruler dimensioned the stone segments and the carved channels.

D. WORK PROCESSES AND ASSUMPTIONS

- *Collecting the Muyuqmarka Field Data*

In order to catalogue the channel segments around the Muyuqmarka, most, if not all, of the channel segments were mapped. The segments were found around the Muyuqmarka, the terraces below the Muyuqmarka, the Paukarmarka, and along the Great Walls that enclose Saksaywaman. The most difficult part was finding each of the segments, as they were scattered and often isolated from other evidence. Once the segments were noted on a map, the next step was to dimension, cut out, and create a numbering system for the channels.

Each segment was given a unique number, counting from 1 onward. The lower numbers are located around the Muyuqmarka. The higher numbers are found on the terraces below the Muyuqmarka, the Paukarmarka, and the Great Walls. In total, 170 channel segments were found and indicated on a map. However, only 141 channel segments were dimensioned and given a cross-section cutout. If a single segment needed another cutout due to height/width variations on the segment, the segment was given a decimal number. For example, if segment 1 had two cutouts, the first cutout would be 1.1 and the second cutout would be 1.2. There are more than 141 cutouts because of this method.

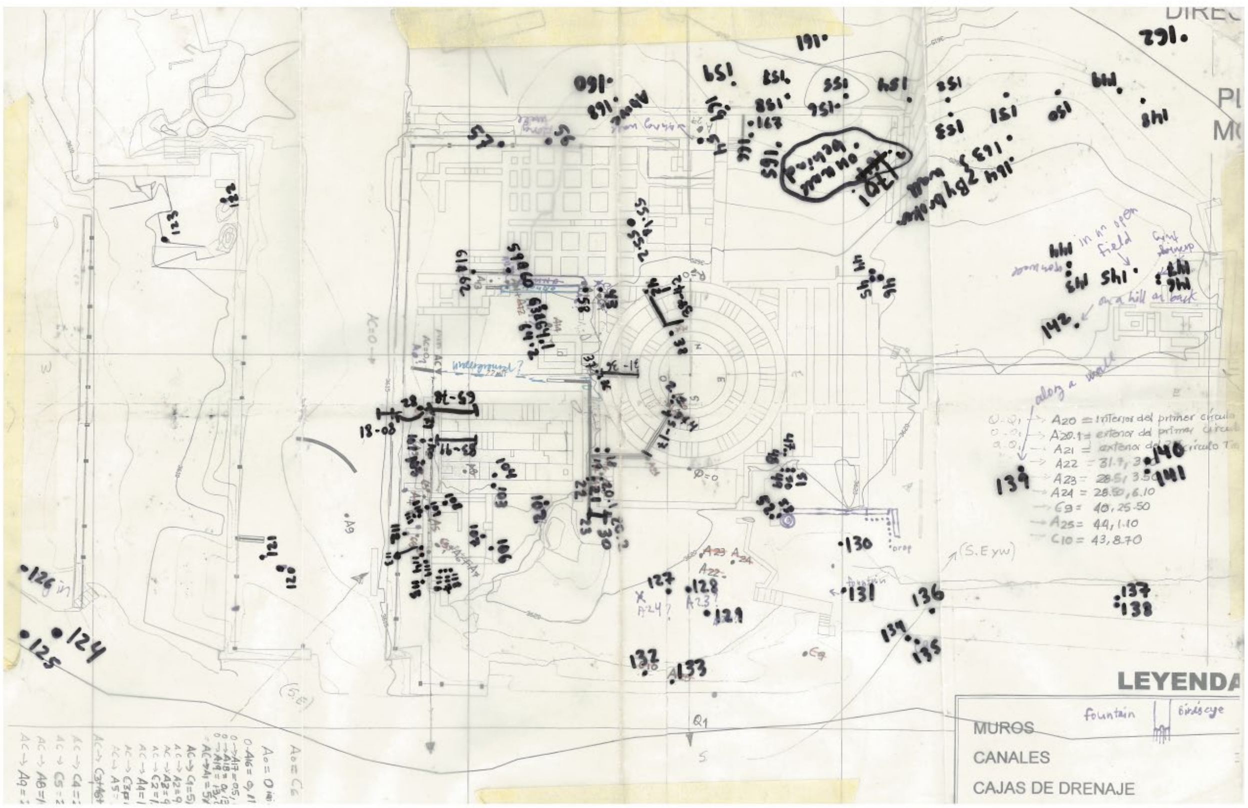
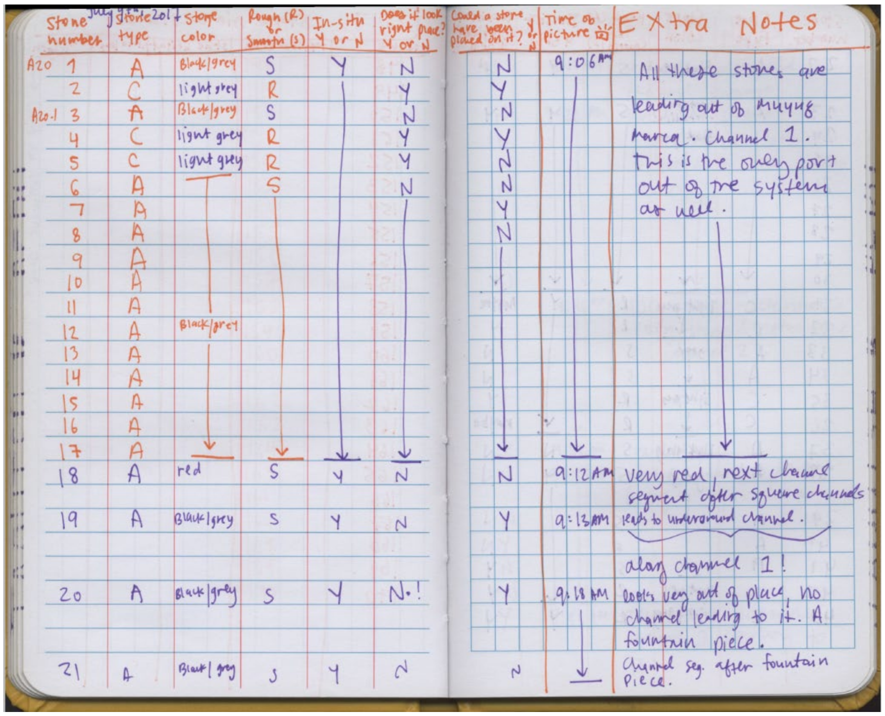


Figure 12*: Map of Muyuqmarka stone channel locations*

The channel's dimensions recorded include: stone width, stone height, stone length, and channel length. The width was taken at the widest part of the segment, the height was taken at the highest part of the segment, and the length was taken at the longest part of the segment. After measuring these dimensions, the thin wire was used to form the shape of the channel. The formed wire was then traced and cut out on the thick cardboard paper. The channel cross-section wire form was measured at the deepest part of the channel. If more cutouts of a single segment were needed, it was indicated in the numbering system (1.1, 1.2).



July 9th, 2017

Stone number	Stone type	Stone color	Rough (R) or Smooth (S)	In-situ Y or N	Does it look right place? Y or N	Could a stone have been placed on it? Y or N	Time of picture	Extra Notes
A20 1	A	Black/grey	S	Y	N	N	9:06 AM	All these stones are leading out of Muyuq marca. Channel 1. This is the only part out of the system as well.
2	C	light grey	R		Y	Y		
A20.1 3	A	Black/grey	S		N	N		
4	C	light grey	R		Y	Y		
5	C	light grey	R		Y	N		
6	A		S		N	N		
7	A					Y		
8	A					N		
9	A							
10	A							
11	A							
12	A	Black/grey						
13	A							
14	A							
15	A							
16	A							
17	A							
18	A	red	S	Y	N	N	9:12 AM	very red, next channel segment after square channels
19	A	Black/grey	S	Y	N	Y	9:13 AM	leads to underground channel. along channel 1!
20	A	Black/grey	S	Y	N.!	Y	9:18 AM	looks very out of place, no channel leading to it. A fountain piece.
21	A	Black/grey	S	Y	N	N		Channel seg. after fountain piece.

***Figure 13**: Qualitative stone segment data*

Figure 13 are scanned notebook pages containing the qualitative stone data for stones 1 to 21.

Along with the cutouts and numbered map, the locations of the channel segments were recorded with GPS equipment. The GPS device, produced by Trimble and distributed by Isetek S.A. in Lima, Peru, which included two Trimble R5 receivers, a TSC3 Data Collector, and two Zephyr 2 antennas, charted and stored survey-grade GPS topographic coordinate points (Saqsaywaman). A base station (one antenna and one receiver mounted on a tripod) was located on a geodetic survey marker on the Muyuqmarka, the following coordinates are given below, and the rover (the other receiver and antenna mounted on a 2 m poll) collected the GPS data (Saqsaywaman).

Table 2: Geodetic survey marker

Northing (Y)	8504585.320 m
Easting (X)	177056.748 m
Elevation (Z)	3600.27 m

Source: Ministry of Culture, June 2016

All the GPS data collected used the following projection information:

Table 3: GPS projection information

Projection	UTM, Zone 19S
Datum	WGS84
Geoid Model	EGM96

To download the point data from the Trimble, the controller was connected to a laptop and imported and processed through the Trimble Business Center software. The end product is a CVS file consisting of the point name, point code, and northing, easting, and elevation coordinates (Saqsaywaman). The CVS file was imported into ArcMap and used to model the site at the Muyuqmarka.

All together there were 170 channel segment locations recorded with GPS around the Muyuqmarka, the terraces below the Muyuqmarka, the Paukarmarka, and along the Great Walls. However, with previous GPS data collected from 2014 to 2016, there are more topographic points that depict the area around the Muyuqmarka, hence, using ArcMap interpolation methods, all the points collected from the Muyuqmarka were manipulated to map the terrain around the Muyuqmarka.

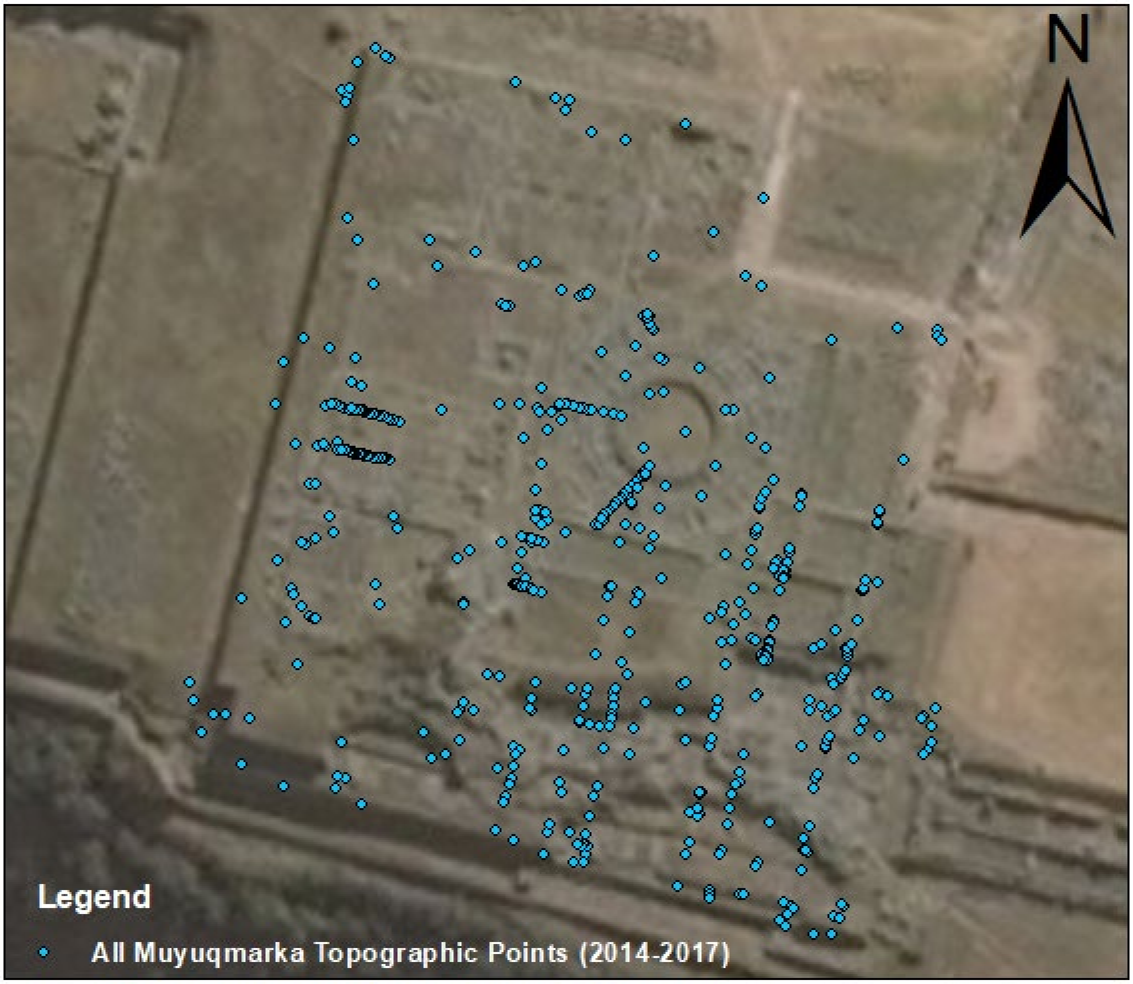


Figure 14: Map of all collected Muyuqmarka topographic points

Figure 14 shows all the Muyuqmarka collected topographic points from 2014 to 2016. These points were interpolated to create a surface and find the slope of the surrounding area. The interpolated map is shown in Appendix 6. Due to the lack of detail in the surface, the interpolated terrain was not used for slope analysis.

Finally, while on-site, the following characteristics were noted for each channel segment: the stone type, the stone color, whether the stone was rough (R) or smooth (S), whether the segment was in-situ, whether the segment appears to be located in the right place, whether another stone could have been placed on it, the time a picture was taken of the stone, and any extra notes needed to describe the segment.

- *Organizing the Muyuqmarka Data*

After collecting the channel segment data, the next step was to organize the data and prepare it for calculations. The stone segment measurements and detailed channel notes were recorded in excel. These tables are found in results as well as Appendix 1. The channel GPS locations were mapped in Esri ArcMAp 10.5.1. The ArcMap, called Muyuqmarka, is attached as a digital attachment. The channel cross-sections' area and perimeter were dimensioned using an online program called SketchAndCalc. The cross-sections were also scanned as pdfs and are shown in the catalogue of channel segments, found in results subsection D. The catalogue also records each channel's stone name, GPS location, hydraulic radius (most efficient, full, and half), stone type, and photo of stone.

- *Analyzing the Muyuqmarka Data: Engineering Criteria for Channel Misconfiguration*

The criteria used to determine the similarities and differences in the channel segments are the following: hydraulic radius, stone type, and stone color. The three Muyuqmarka channels were evaluated by this criteria to see what stone segments were incorrectly reconstructed. If two stones are hydraulically similar, then their cross-sectional area for flow, hydraulic radius, would be similar as well. To add, the Inca would have kept their channels similar in stone type and stone color. It is unlikely that they mixed stones in their channel ways (insight from Dr. Miksad). As mentioned earlier, Valcárcel did not use engineering judgement during the 1930s when reconstructing the Muyuqmarka channels and thus many channel segments are hydraulically misplaced. By using the hydraulic radius of each channel segment, not only are the channel segments visibly misplaced but also mathematically misplaced.

The first step in analyzing the data was to find the area and wetted perimeter of the 146 irregular-shaped cross-section channel cutouts. This step used an online program to dimension the area and perimeter of a full-flowing channel, a half-full-flowing channel, and a third-full-flowing channel. For the most efficient-flowing channel, since it assumes a regular shape, the depth of water in the channel, y, was measured and inputted in the best hydraulic section equations for a rectangle, semi-circle, and trapezoid shown in Figure 8. An example of a dimensioned cross-section is below in Figure 15.

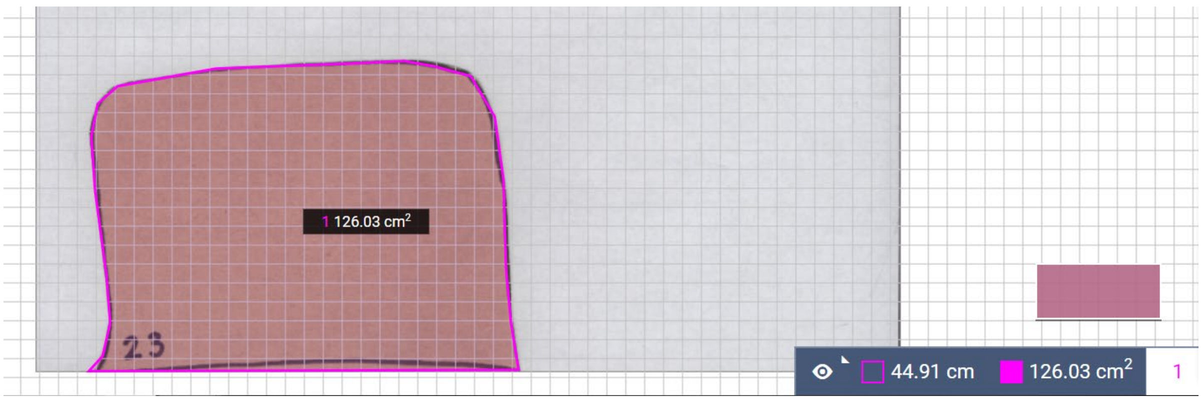


Figure 15: *Dimensioned cross-section (screenshot taken from SketchAndCalc)*

The cross-section 23 in Figure 15 was dimensioned using the online program called SketchAndCalc.

After finding the area and perimeter of each 146 cross-sections, using Equation 1, the hydraulic radius was found for a full-flowing channel, a half-full-flowing channel, and a third-full-flowing channel. For the most efficient hydraulic section method, the 146 cross-sections were estimated into three shapes, a rectangle, a circle, or a trapezoid. Then using the equations shown in Figure 8 for that particular shape, their most efficient hydraulic radius was found. Again, the most efficient hydraulic section is a regular shape with the shape's perimeter minimized for the most discharge through a given section. The hydraulic radii results for each of the Muyuqmarka's three channels are recorded in the results. The hydraulic radii results for all the stone segments are in Appendices 2 to 5.

Once the hydraulic radius was found for a most-efficient-flowing channel, a full-flowing channel, a half-full-flowing channel, and a third-full-flowing channel, the next step was to use the Chezy-Manning's equation to find the volumetric flow-rate, discharge Q, through each channel cross-section shape. Using Equation 7, the volumetric flow-rate was found for each scenario. These results are shown in Appendices 2 to 5. For the resistance coefficient (n), also known as the Manning's coefficient, it was assumed to be 0.035 for each channel segment.

Shown in Figure 16, the channel segments fall under rock cuts that are smooth and uniform and the n value is normal (Phillips 13). The channel slope, S_O, was assumed to be 1 %. This assumption was taken from previous sites and disclosed by Dr. Richard Miksad. At first all the GPS points collected from 2014 to 2017 were taken and interpolated in ArcMap to create a topographical map of the Muyuqmarka. This was done specifically to find the slope of each channel, however, the map was not accurate enough to take a fair reading of each channels' slope, so the assumption of 1 % was taken instead.

Table 5. Composite values of *n* for stable constructed channels.

[Modified from Chow (1959)]

Type of channel and description	*n* value Minimum	Normal	Maximum
A. LINED OR BUILT-UP CHANNELS			
a. Concrete			
1. Finished	0.011	0.015	0.016
2. Unfinished	.014	.017	.020
b. Gravel bottom with sides of			
1. Formed concrete	.017	.020	.025
2. Random stone in mortar	.020	.023	.026
3. Dry rubble or riprap	.023	.033	.036
B. EVACUATED OR DREDGED CHANNELS			
a. Earth, straight and uniform			
1. Clean, after weathering	.018	.022	.025
2. Gravel, uniform section, clean	.022	.025	.033
b. Earth, winding and sluggish			
1. Earth bottom and rubble sides	.028	.030	.035
2. Stony bottom	.025	.035	.040
3. Cobble bottom and clean sides	.030	.040	.050
c. Rock cuts			
1. Smooth and uniform	.025	.035	.040
2. Jagged and irregular	.035	.040	.050

Figure 16*: Table of Manning's coefficient values taken from American Society of Civil Engineers (U.S. Geological Survey)*

This concludes the work in Microsoft Excel 2013 and Microsoft Word 2013. As mentioned before, the volumetric flow-rate results for most-efficient-flowing channel, a full-flowing channel, a half-full-flowing channel, and a third-full-flowing channel is found in Appendices 2 to 5.

The second part of the analysis was performed in Esri ArcMap 10.5.1. Taking the GPS'd topographic coordinate point data, Northing (Y), Easting (X), and Elevation (Z), the location of

170 channel segments were digitized and mapped on the Muyuqmarka site. The first step was to convert the GPS points into a CVS file consisting of the point name, point code, and northing, easting, and elevation coordinates. The CVS file was opened and the x, y, and z data was updated and adjusted to the correct corresponding field. Once the fields were corrected, the tables were exported as a shapefile.

To create a map with just the 170 channel locations, just the 170 channel data points were added to an individual map, but to create a topographical map of the site, all the data points taken from 2014 to 2017 were exported as a shapefile and merged using the Merge tool in ArcGIS. The digital map of the channel locations is added as a digital attachment.

For a topographical map of the Muyuqmarka, two interpolation methods were used. The interpolation methods performed were the Spline with Barriers and the Inverse Distance Weighted (IDW). Taking the GPS points, the Spline with Barriers tool minimizes the curvature of the topographic surface with smoothing parameters. The higher the smoothing parameter the smoother the surface. The Inverse Distance Weighted (IDW) tool combines the GPS points within a certain radius to find a new interpolated elevation. It uses linear distance weighing for the surface where the further the points are, the less weight it is given and the closer the points are, the more weight it is given to determine the surface elevation (*ArcGIS*). The Spline with Barriers method was the best interpolation method for the site because it most accurately depicted the terrain around the Muyuqmarka. Appendix 6 shows the image of the interpolated Muyuqmarka surface. As mentioned earlier, the interpolation methods were performed to help find the slope of the Muyuqmarka channels. However these methods were unhelpful in finding the level of accuracy needed for the slope and so the slope was assumed to be 1 %.

E. SOURCES OF ERROR

The sources of error are as follows: the accuracy of the dimensioned stone channel segments, as well as the accuracy of the channel cross-sections, assuming rectangular, semi-circular, and trapezoidal shapes when calculating the most efficient hydraulic section, and assuming variables in equations such as the slope in the Chezy-Manning equation.

Due to the large amount of data collected by hand, there is due to be inaccuracies in measurement. Even trying to dimension each stone in a similar fashion, there is bound to be some discrepancies. These discrepancies are embedded in each equation and calculation.

IV. RESULTS

A. FINAL PRODUCTS

The final products include the accompanying sections in the results as well as the following appendices and digital attachment.

- Appendix 1: Stone Segment Dimensions
- Appendix 2: Most Efficient Discharge for 146 Cross-sections
- Appendix 3: Full Discharge for a 146 Cross-sections
- Appendix 4: Half-Full Discharge for 146 Cross-sections
- Appendix 5: Third-Full Discharge for 146 Cross-sections
- Appendix 6: Interpolated Muyuqmarka Surface
- Digital Attachment: Muyuqmarka: ArcMap topographic Data Points

B. THREE MUYUQMARKA CHANNELS

In this section the following tables and graphs are the results for the three Muyuqmarka channels. The three channels, shown below in Figure 17, make up 29 of the 141 channel segments and 29 of the 146 cross-sections. Channel 1 is comprised of 17 channel segments and cross-sections, segments 1 to 17. The total length of the channel 1, adding together all the lengths of each segment, is 7.23 meters. Channel 2 is comprised of 7 channel segments and cross-sections, segments 31 to 37. The total length of the channel 2, adding together all the lengths of each segment, is 5.49 meters. Channel 3 is comprised of 5 channel segments and cross-sections, segments 38 to 42. The total length of the channel 3, adding together all the lengths of each segment, is 2.33 meters. However for channel 2 and channel 3, channel segments are missing from the opening port of the Muyuqmarka inner circle. Unlike channel 1 where channel segments lead out of the Muyuqmarka, channel 2 and 3 appear shorter in length where in reality they would be closer to the length of channel 1 if starting from the opening port of the Muyuqmarka inner circle.

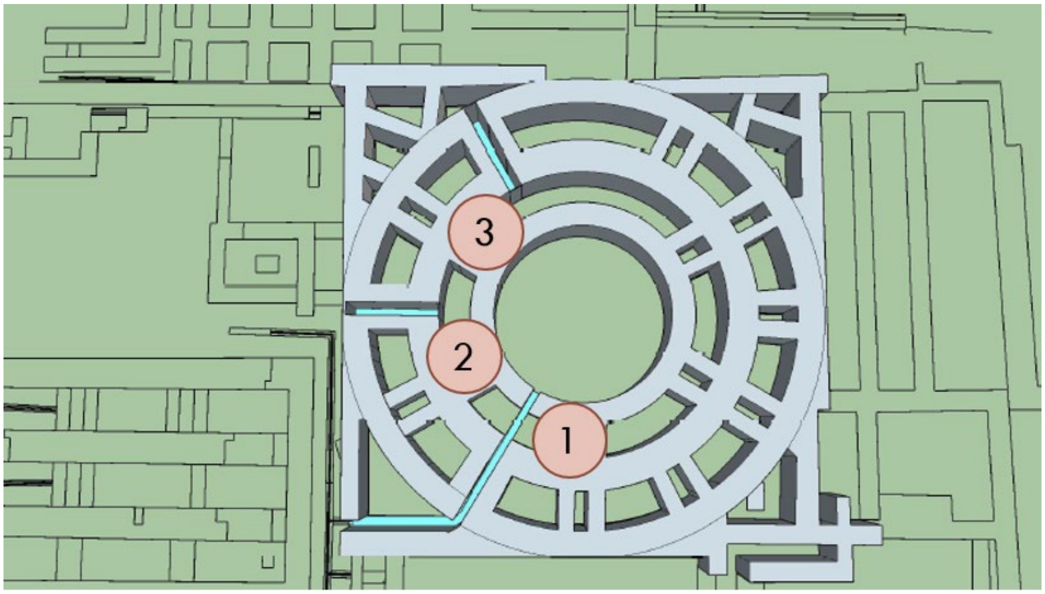


Figure 17*: Digital reconstruction of the Muyuqmarka showing each of the three channels (Morrisset)*

Figure 17 shows where each channel is. Moving in a clockwise fashion, channel 1 is first.

Three hydraulic cases were used to analyze the three Muyuqmarka channels. Case 1 was the most-efficient-flowing channel case, which used the most efficient hydraulic section for the hydraulic radius, case 2 was the full-flowing channel case, and case 3 was the half-full-flowing channel case.

Table 4: Most-efficient-flowing channel

	Case 1: Most-Efficient-Flowing Channel				
	Stone Channel	**Assumed Channel Shape**	**Most Efficient Area (cm^2)**	**Most Efficient Wetted Perimeter (cm)**	**Most Efficient Hydraulic Radius (cm)**
Channel 1 (from 1 to 17)	1		95.57	24.50	3.90
	2		15.59	10.39	1.50
	3		82.46	23.90	3.45
	4		16.75	10.77	1.56
	5		18.86	11.43	1.65
	6		7.28	7.10	1.03
	7		10.40	8.49	1.23
	8		22.85	13.52	1.69
	9		17.30	10.95	1.58
	10		35.07	15.59	2.25
	11		47.20	18.08	2.61
	12		61.83	22.24	2.78
	13		67.28	23.20	2.90
	14		47.24	19.44	2.43
	15		58.75	21.68	2.71
	16		89.78	26.80	3.35
	17		213.00	41.28	5.16
Channel 2 (from 31 to 37)	31		40.86	18.08	2.26
	32		11.53	8.94	1.29
	33		1.63	3.36	0.49
	34		6.25	6.58	0.95
	35		27.71	13.86	2.00
	36		106.46	27.16	3.92
	37		90.54	25.05	3.62
Channel 3 (from 38 to 42)	38		24.10	12.92	1.87
	39		206.16	37.79	5.46
	40		205.41	37.72	5.45
	41		277.17	43.82	6.33
	42		478.64	61.88	7.74

Table 5: Full-flowing channel

Case 2: Full-Flowing Channel				
	Stone Channel	**Full Total Area (cm^2)**	**Full Wetted Perimeter (cm)**	**Full Hydraulic Radius (cm)**
Channel 1 (from 1 to 17)	1	79.87	22.51	3.55
	2	31.03	16.25	1.91
	3	74.40	21.49	3.46
	4	33.02	16.16	2.04
	5	41.28	19.64	2.10
	6	14.93	12.23	1.22
	7	22.64	14.09	1.61
	8	36.37	16.79	2.17
	9	30.70	15.90	1.93
	10	43.61	17.22	2.53
	11	46.31	17.75	2.61
	12	50.12	19.01	2.64
	13	57.77	20.23	2.86
	14	46.87	19.40	2.42
	15	51.10	20.04	2.55
	16	67.65	22.55	3.00
	17	101.84	28.70	3.55
Channel 2 (from 31 to 37)	31	62.31	22.61	2.76
	32	24.88	16.14	1.54
	33	7.31	12.22	0.6
	34	17.02	16.01	1.06
	35	46.18	19.13	2.41
	36	91.46	25.21	3.63
	37	75.00	23.85	3.14
Channel 3 (from 38 to 42)	38	20.95	12.27	1.71
	39	89.97	28.60	3.15
	40	112.32	29.07	3.86
	41	152.87	33.70	4.54
	42	222.61	40.01	5.56

Table 6: Half-full-flowing channel

Case 3: Half-Full-Flowing Channel				
	Stone Channel	**Half-Full Total Area (cm^2)**	**Half-Full Wetted Perimeter (cm)**	**Half-Full Hydraulic Radius (cm)**
Channel 1 (from 1 to 17)	1	32.34	14.82	2.18
	2	12.16	12.55	0.97
	3	29.84	14.57	2.05
	4	14.01	12.81	1.09
	5	17.6	15.45	1.14
	6	5.78	9.16	0.63
	7	9.01	11.5	0.78
	8	16.25	13.12	1.24
	9	12.56	12.65	0.99
	10	16.88	12.12	1.39
	11	19.09	11.99	1.59
	12	22.04	12.71	1.73
	13	25.88	14.12	1.83
	14	19.28	12.54	1.54
	15	20.94	12.6	1.66
	16	30.21	14.81	2.04
	17	46.66	17.65	2.64
Channel 2 (from 31 to 37)	31	28.84	17.09	1.69
	32	9.49	11.12	0.85
	33	2.97	8.88	0.33
	34	6.03	11.15	0.54
	35	18.48	13.75	1.34
	36	38.22	16.09	2.38
	37	30.35	14.41	2.11
Channel 3 (from 38 to 42)	38	7.92	7.42	1.07
	39	31.29	14.32	2.19
	40	39.53	16.14	2.45
	41	54.27	18.71	2.9
	42	94.24	24.47	3.85

Table 4 shows each channels' stone channel number, most efficient area, most efficient wetted perimeter, and most efficient hydraulic radius. Table 5 shows each channels' stone channel number, full area, full wetted perimeter, and full hydraulic radius. Table 6 shows each channels' stone channel number, half-full area, half-full wetted perimeter, and half-full hydraulic radius. As the dimensions change from full to half-full channels, the area, wetted perimeter, and hydraulic radius decrease. There are discrepancies between the most efficient case and the full case where the parameters in the most efficient case are bigger and have a bigger hydraulic radius compared to the parameters in the full case. These discrepancies are due to the assumption made in the most efficient case where some channel cross-sections are rectangular in shape, some are semi-circular in shape, and others are trapezoidal in shape. When assuming any shape it could have taken area away or added area to the shape which in turn changes the other parameters.

Table 7: Channel 1 comparison of hydraulic radii

		Actual Shape		Assumed Shape	
	Stone Channel	**Full Hydraulic Radius (cm)**	**Half-Full Hydraulic Radius (cm)**	**Most Efficient Hydraulic Radius (cm)**	
Channel 1 (from 1 to 17)	1	3.55	2.18	3.90	
	2	1.91	0.97	1.50	
	3	3.46	2.05	3.45	
	4	2.04	1.09	1.56	
	5	2.10	1.14	1.65	
	6	1.22	0.63	1.03	
	7	1.61	0.78	1.23	
	8	2.17	1.24	1.69	
	9	1.93	0.99	1.58	
	10	2.53	1.39	2.25	
	11	2.61	1.59	2.61	
	12	2.64	1.73	2.78	
	13	2.86	1.83	2.90	
	14	2.42	1.54	2.43	
	15	2.55	1.66	2.71	
	16	3.00	2.04	3.35	
	17	3.55	2.64	5.16	

Table 8: Channel 2 comparison of hydraulic radii

	Stone Channel	Actual Shape		Assumed Shape	
		Full Hydraulic Radius (*cm*)	Half-Full Hydraulic Radius (*cm*)	Most Efficient Hydraulic Radius (*cm*)	
Channel 2 (from 31 to 37)	31	2.76	1.69	2.26	
	32	1.54	0.85	1.29	
	33	0.60	0.33	0.49	
	34	1.06	0.54	0.95	
	35	2.41	1.34	2.00	
	36	3.63	2.38	3.92	
	37	3.14	2.11	3.62	

Table 9: Channel 3 comparison of hydraulic radii

	Stone Channel	Actual Shape		Assumed Shape	
		Full Hydraulic Radius (*cm*)	Half-Full Hydraulic Radius (*cm*)	Most Efficient Hydraulic Radius (*cm*)	
Channel 3 (from 38 to 42)	38	1.71	1.07	1.87	
	39	3.15	2.19	5.46	
	40	3.86	2.45	5.45	
	41	4.54	2.90	6.33	
	42	5.56	3.85	7.74	

Tables 7 to 9 shows each channels' stone channel number and compares their most efficient hydraulic radius, full hydraulic radius, and half full hydraulic radius. In each of the three channels it appears that the most efficient case tends to give the largest hydraulic radius. As seen in Table 10, the most efficient case also tends to have the higher discharge.

Table 10: Comparisons of discharge for different hydraulic cases

Channel 1				Channel 2				Channel 3			
Stone Number	Total Discharge, Q (cm^3/s)			Stone Number	Total Discharge, Q (cm^3/s)			Stone Number	Total Discharge, Q (cm^3/s)		
	Full	Half-Full	Most Efficient		Full	Half-Full	Most Efficient		Full	Half-Full	Most Efficient
1	530.87	155.45	676.53	**31**	349.94	116.80	201.05	**38**	85.51	23.63	104.32
2	136.46	34.02	58.36	**32**	94.86	24.40	39.04	**39**	551.89	150.54	1825.32
3	486.48	137.50	537.94	**33**	14.83	4.09	2.87	**40**	790.19	205.21	1816.41
4	151.91	42.49	64.24	**34**	50.65	11.44	17.26	**41**	1196.88	315.37	2708.41
5	193.53	54.85	75.25	**35**	237.44	64.30	125.69	**42**	1997.07	661.56	5348.71
6	48.72	12.15	21.14	**36**	616.98	194.41	756.22				
7	88.74	21.88	34.01	**37**	459.95	142.48	609.31				
8	173.97	53.55	92.62								
9	136.01	35.72	67.04								
10	231.50	60.15	172.07								
11	250.76	74.37	255.62								
12	273.29	90.89	349.25								
13	332.23	110.74	390.92								
14	241.11	73.38	243.95								
15	272.50	83.94	326.29								
16	402.05	138.83	574.30								
17	676.93	254.88	1817.28								

Table 10 compares each channels' cross-section's total discharge for a most-efficient-flowing channel, a full-flowing channel, and a half-full-flowing. Ideally out of the three cases, the best results, in terms of most efficient volumetric flow-rate, should come from the first case, the most-efficient-flowing channel, and the worst results should come from the second case, the full-flowing channel. Comparing the two cases for channel 1 cross-section 1, the larger discharge comes from the most efficient case with 676.53 cm^3/s and the smaller discharge comes from the full case with 530.87 cm^3/s. However these results are not consistent with other stone cross-sections. In some instances the full cross-sections have more discharge than the most efficient cross-sections. As mentioned earlier the variation in results is due to assuming the shapes for the most efficient case. Whereas the full, half-full, and third-full case use the actual shape of the channel's cross-section. By assuming the shape, area is either added or taken away and the parameter is also altered, which affects the hydraulic radius and the discharge.

When calculating the most efficient hydraulic section for all three shapes, the rectangle, the semicircle, and the trapezoid have the same equation for best hydraulic section (seen in Figure 8). Their best hydraulic section occurs when the depth of water in the channel, y, is half. For the half-full case, the hydraulic radius is also calculated from the halfway depth of water in the channel. An example of the percent difference between the volumetric flow-rate for a most efficient channel segment and the volumetric flow-rate for a half-full channel segment is shown below.

$$Q_{Most\ efficient}\,vs.\,Q_{Half}$$

Example: Channel 1, Stone Cross-section 1

	Total Area (cm^2)	**Hydraulic Radius** (cm)	**Discharge, Q** (cm^3/s)
$\boldsymbol{Q_{Me}}$ (cm^3/s)	95.57	3.90	676.53
$\boldsymbol{Q_{H}}$ (cm^3/s)	32.34	2.18	155.45

Percent Difference:

$$Q_{Most\ efficient}\,vs.\,Q_{Half}$$

$$\frac{Q_{Me} - Q_H}{Q_{Me}}\ x\ 100\% = 77 \text{ percent difference}$$

The most efficient volumetric flow-rate has a larger area and hydraulic radius. It makes sense then that the total discharge is also larger. The percent difference between the most efficient hydraulic radius versus the half-full hydraulic radius is 77%. Considering the most efficient case and the half-full case both use half the water depth to calculate the hydraulic radius and since the most efficient case overestimates the discharge for many of the channel segments, the following Muyuqmarka calculations use the half-full computations for analyzing.

Figure 18 graphs each of channel 1's 17 half-full hydraulic radii.

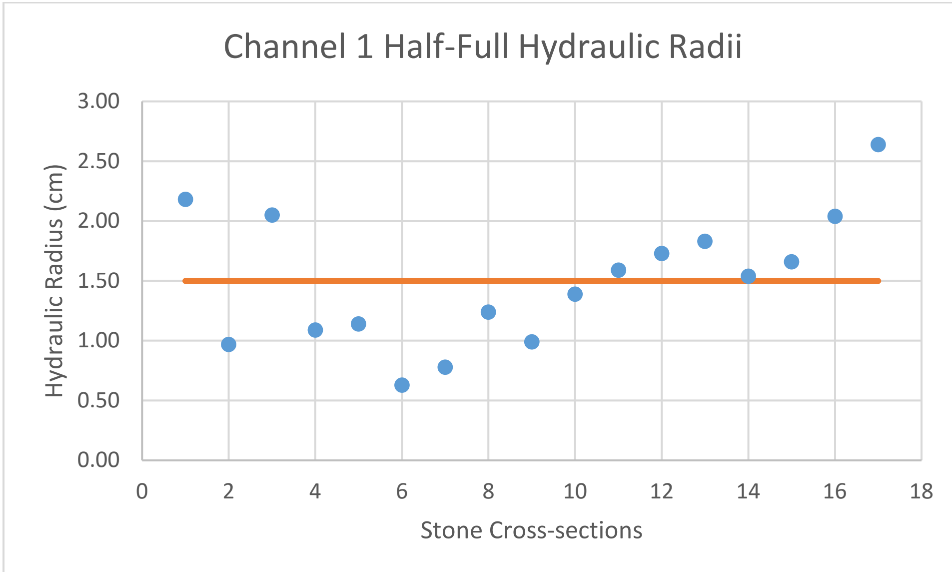


***Figure 18**: Channel 1 half-full hydraulic radii*

The y-axis is the hydraulic radius and the x-axis is the stone cross-section. The orange line represents the mean of channel 1's hydraulic radii. The mean, 1.50 cm, is the average of all 17 cross-sections. By graphing the mean it shows in relation to one another where the stone cross-section hydraulic radii lie. It also shows what hydraulic radii are outliers and don't fit within the channel. For example, the hydraulic radius for stone cross-section 17 is more than a full centimeter larger than the mean. It can be deduced that stone segment 17 is not a part of channel 1 and was misplaced.

To take away from Figure 18, the half-full hydraulic radius mean of channel 1 is 1.50 cm. To find the typical operational flow rate of channel 1, a range of plus/minus 0.50 cm was given to the mean. Stone segments 4, 5, 8, 10, 11, 12, 13, 14, and 15 fell within that range and their half-full hydraulic radii as well as their areas were averaged together. Using the average half-full hydraulic radius of 1.50 cm and average area of 19 cm^2 for all nine stone segments, Equation 7 calculated the typical operational flow rate of channel 1 to be 70.51 $\frac{cm^3}{s}$.

Table 11 shows the statistics for channel 1's half-full hydraulic radii. The maximum hydraulic radius is 2.64 cm and the minimum hydraulic radius is 0.63 cm. Most channel segments have a hydraulic radius between 1.00 cm and 2.00 cm. Even though 1 centimeter is a large range, it is apparent that anything outside of the 1.00 cm to 2.00 cm range is an outlier to the rest of the channel segments.

Table 11: Channel 1 half-full hydraulic radii statistics

Mean	1.50 cm
Median	1.54 cm
Max	2.64 cm
Min	0.63 cm
Diff	2.01 cm
St Dev	0.54 cm

Table 12 displays channel 1's half-full hydraulic radii from least to greatest. It is color coded to show which cross-sections group together. The smallest and largest hydraulic radii are red and the hydraulic radii between them are yellow/orange.

Table 12: Channel 1 comparison of half-full hydraulic radii

Stone Cross-Section	**Hydraulic Radius (cm)**
6	0.63
7	0.78
2	0.97
9	0.99
4	1.09
5	1.14
8	1.24
10	1.39
14	1.54
11	1.59
15	1.66
12	1.73
13	1.83
16	2.04
3	2.05
1	2.18
17	2.64

Figure 19 graphs each of channel 2's 7 half-full hydraulic radii.

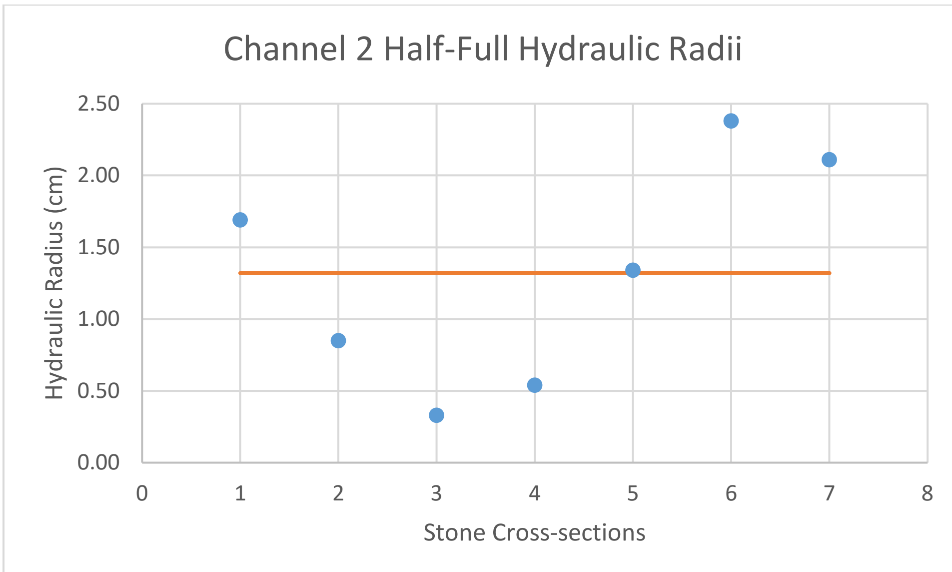


Figure 19: *Channel 2 half-full hydraulic radii*

The y-axis is the hydraulic radius and the x-axis is the stone cross-section. The orange line represents the mean of channel 2's hydraulic radii. The mean, 1.32 cm, is the average of all 7 cross-sections. It is hard to find similar cross-sections because they range from a hydraulic radius of 0.33 cm to 2.38 cm. The three main outliers in channel 2 that are stone cross-sections 3, 6, and 7. It can be deduced that channel 2 is not hydraulically compatible because of the wide range of hydraulic radii.

To take away from Figure 19, the half-full hydraulic radius mean of channel 2 is 1.32 cm. To find the typical operational flow rate of channel 2, a range of plus/minus 0.50 cm was given to the mean. Stone segments 31, 32 and 35 fell within that range and their half-full hydraulic radii as well as their areas were averaged together. Using the average half-full hydraulic radius of 1.29 cm and average area of 18.9 cm^2 for all three stone segments, Equation 7 calculated the typical operational flow rate of channel 2 to be 64.23 $\frac{cm^3}{s}$.

Table 13 shows the statistics for channel 2's half-full hydraulic radii. The maximum hydraulic radius is 2.38 cm and the minimum hydraulic radius is 0.33 cm. This range is larger than the range in channel 1 and there are no segments that are similar in channel 2.

Table 13: Channel 2 half-full hydraulic radii statistics

Mean	1.32 cm
Median	1.34 cm
Max	2.38 cm
Min	0.33 cm
Diff	2.05 cm
St Dev	0.78 cm

Table 14 displays channel 2's half-full hydraulic radii from least to greatest. It is color coded to show which cross-sections group together. The smallest and largest hydraulic radii are red and the hydraulic radii between them are yellow/orange. It appears that since the range of hydraulic radii is so wide, none of the segments are grouped together.

Table 14: Channel 2 comparison of half-full hydraulic radii

Stone Cross-Section	**Hydraulic Radius (cm)**
33	0.33
34	0.54
32	0.85
35	1.34
31	1.69
37	2.11
36	2.38

Figure 20 graphs each of channel 3's 5 half-full hydraulic radii.

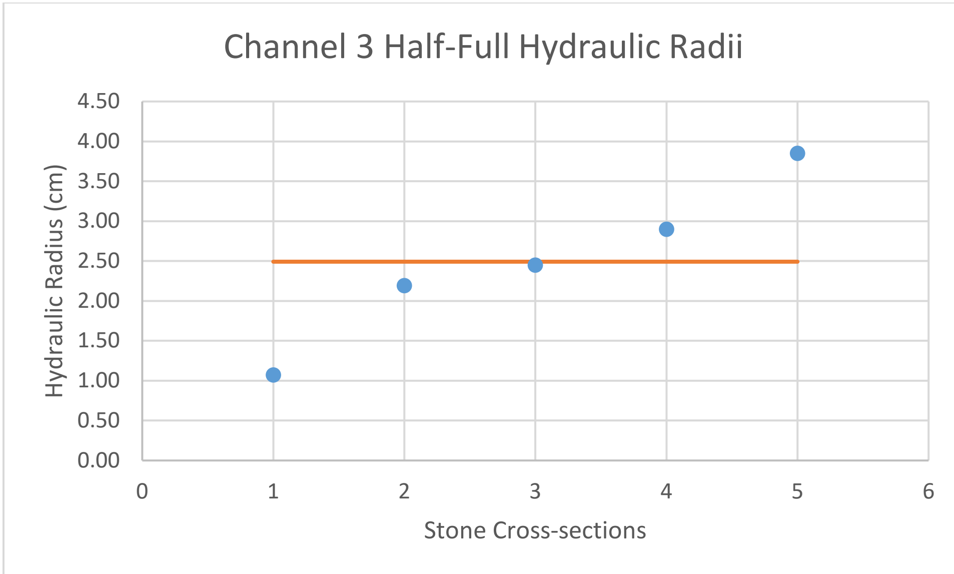


Figure 20*: Channel 3 half-full hydraulic radii*

The y-axis is the hydraulic radius and the x-axis is the stone cross-section. The orange line represents the mean of channel 3's hydraulic radii. The mean, 2.49 cm, is the average of all 5 cross-sections. The two outliers in channel 3 are stone cross-sections 1 and 5. With a high hydraulic radius average, stone cross-section 1, with a hydraulic radius of 1.07 cm, is out of place.

To take away from Figure 20, the half-full hydraulic radius mean of channel 3 is 2.49 cm. To find the typical operational flow rate of channel 3, a range of plus/minus 0.50 cm was given to the mean. Stone segments 39, 40, and 41 fell within that range and their half-full hydraulic radii as well as their areas were averaged together. Using the average half-full hydraulic radius of 2.5 cm and average area of 42 cm^2 for all three stone segments, Equation 7 calculated the typical operational flow rate of channel 3 to be 220.23 $\frac{cm^3}{s}$.

Table 15 shows the statistics for channel 3's half-full hydraulic radii. The maximum hydraulic radius is 3.85 cm and the minimum hydraulic radius is 1.07 cm. Compared to channel 1 and channel 2, channel 3 has the biggest difference between the maximum and the minimum hydraulic radius.

Table 15: Channel 3 half-full hydraulic radii statistics

Mean	2.49 cm
Median	2.45 cm
Max	3.85 cm
Min	1.07 cm
Diff	2.78 cm
St Dev	1.02 cm

Table 16 displays channel 3's hydraulic radii from least to greatest. It is color coded to show which cross-sections group together. The smallest and largest hydraulic radii are red and the hydraulic radii between them are yellow/orange.

Table 16: Channel 3 comparison of half-full hydraulic radii

Stone Cross-Section	Hydraulic Radius (cm)
38	1.07
39	2.19
40	2.45
41	2.90
42	3.85

Tables 17 to 19 present each channel with their three criteria of channel segment stone type, channel segment stone color, and hydraulic radius. The criteria was used for determining whether or not stones fit together, qualitatively and quantitatively. From the three channels, channel 1, presented in Table 17, is the most uniform channel with its stone type, stone color, and hydraulic radii. Channel 1 also has the most stone segments, but when looking at all three tables, Table 17 has the most uniform cross-sections in a given section compared to channel 2 and 3. With fewer channel segments in channel 2 and 3 it is harder to see the uniformity of the channel. These two channels appear to be less uniform and have more segments out of place. The channel segments from channel 2 and 3 with the lower hydraulic radii would fit better in channel 1. However what could have happened is when the Inca made the three channels, all three channels had similar hydraulic radii. Meaning all three channels would have been built with the hydraulic radii similar to channel 1. With 500 years passing a lot of stone segments could have been passed around and put in different places on site.

Table 17: Channel 1 half-full case criteria

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Hydraulic Radius (cm)	Discharge, Q (cm^3/s)
6	Andesite	black/grey	0.63	12.15
7	Andesite	black/grey	0.78	21.88
2	Limestone	light grey	0.97	34.02
9	Andesite	black/grey	0.99	35.72
4	Limestone	light grey	1.09	42.49
5	Limestone	light grey	1.14	54.85
8	Andesite	black/grey	1.24	53.55
10	Andesite	black/grey	1.39	60.15
14	Andesite	black/grey	1.54	73.38
11	Andesite	black/grey	1.59	74.37
15	Andesite	black/grey	1.66	83.94
12	Andesite	black/grey	1.73	90.89
13	Andesite	black/grey	1.83	110.74
16	Andesite	black/grey	2.04	138.83
3	Andesite	black/grey	2.05	137.5
1	Andesite	black/grey	2.18	155.45
17	Andesite	black/grey	2.64	254.88

Table 18: Channel 2 half-full case criteria

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Hydraulic Radius (cm)	Discharge, Q (cm^3/s)
33	Andesite	grey	0.33	4.09
34	Andesite	grey	0.54	11.44
32	Limestone	light grey	0.85	24.40
35	Limestone	light grey	1.34	64.30
31	Limestone	light grey	1.69	116.80
37	Andesite	black/grey	2.11	142.48
36	Limestone	light grey	2.38	194.41

Table 19: Channel 3 half-full case criteria

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Hydraulic Radius (cm)	Discharge, Q (cm^3/s)
38	Andesite	grey	1.07	23.63
39	Andesite	grey	2.19	150.54
40	Andesite	grey	2.45	205.21
41	Andesite	grey	2.90	315.37
42	Limestone	light grey	3.85	661.56

C. ALL MUYUQMARKA CHANNEL SEGMENTS

In this section the following tables, along with more tables in the Appendix, show examples of hydraulically mismatched channel segments, hydraulic analysis for all 141 channel segments and 146 cross-section cutouts, and 146 cross-section half-full hydraulic radii statistics. Table 20 shows three scenarios where there are mismatched stones. The first scenario compares channel segments 1 and 2. The second scenario compares channel segments 49, 50, and 51. The third scenario looks at channel segment 127. Each of the scenarios analyze the channel segments' stone type, stone color, and full hydraulic radius. There are also pictures to show the visible existing issues and there are concluding written issues about each scenario.

Table 20: Examples of hydraulically mismatched channel segments

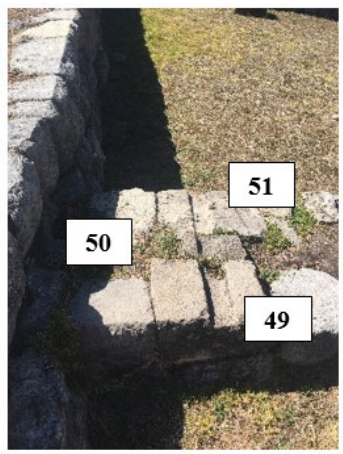
	Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Full Hydraulic Radius (*cm*)	Stone Photos	Dilemmas
Scenario 1	**1** **2**	**Andesite** **Limestone**	**Black/ grey** **Light grey**	**3.55** **1.91**		**- Mixed stone type** **- Misplaced appearance** **-Hydraulically mismatched**
Scenario 2	**49** **50** **51**	**Andesite** **Andesite** **Limestone**	**Black/ grey** **Black/ grey** **Light grey**	**1.95** **1.69** **1.74**		**- Mixed stone type** **- Misplaced appearance** **- Stones lead to nowhere**
Scenario 3	**127**	**Andesite**	**Grey**	**5.63**		**- Free-standing stone** **- Largest hydraulic radius = what does it match?**

Table 20 displays just a couple examples of where channel segments around the Muyuqmarka do not match. Looking at Table 20's quantitative and qualitative comparison of current in-situ channel segments, it is apparent that Valcárcel's 1930s reconstruction inaccurately reassembled the Muyuqmarka seen in Inca times.

Table 21 displays all 146 cross-section half-full hydraulic radii from least to greatest. It is color coded to show which cross-sections group together.

Table 21: All 146 channel cross-section comparison of half-full hydraulic radii

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Half-Full Hydraulic Radius (cm)	Discharge, Q (cm^3/s)
99	Andesite	grey	0.29	1.52
121	Andesite	black/grey	0.31	1.81
94	Limestone	light grey	0.32	1.67
33	Andesite	grey	0.33	4.09
89	Andesite	grey	0.33	1.39
97	Andesite	light brown	0.33	1.41
90	Andesite	black/grey	0.37	2.28
96	Andesite	light brown	0.37	1.87
84	Andesite	grey	0.39	2.44
86	Andesite	black/grey	0.4	2.14
92	Andesite	light brown	0.4	2.26
88	Andesite	grey	0.41	2.17
91	Andesite	light brown	0.41	2.78
93	Andesite	black/grey	0.41	2.1
85	Andesite	light brown/grey	0.46	3.38
52	Andesite	black/grey	0.47	8.03
87	Andesite	grey	0.48	3.31
98	Andesite	grey	0.49	3.28
34	Andesite	grey	0.54	11.44
113	Andesite	black/grey	0.56	5.3
118	Andesite	grey	0.56	6.81
108	Limestone	light grey	0.57	6.87
135	Limestone	grey	0.59	7.54
81	Andesite	grey	0.6	5.26
107	Limestone	light grey	0.6	6.56
95	Andesite	grey	0.62	5.96
106	Limestone	light grey	0.62	6.73
6	Andesite	black/grey	0.63	12.15
125	Limestone	light grey	0.63	12.74
83	Andesite	grey	0.66	6.43
131.2	Andesite	grey	0.67	6.39
66	Andesite	black/grey	0.68	6.81
65	Andesite	black/grey	0.69	7.51
75	Andesite	black/grey	0.71	7.9
78	Andesite	black/grey	0.71	7.81

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Half-Full Hydraulic Radius (cm)	Discharge, Q (cm^3/s)
129.2	Andesite	grey	0.73	8.34
100	Andesite	black/grey	0.74	8.89
68	Andesite	grey	0.75	8.94
7	Andesite	black/grey	0.78	21.88
72	Andesite	grey	0.78	10.17
74	Andesite	grey	0.78	9.95
77	Andesite	black/grey	0.78	9.97
61	Andesite	grey	0.79	14.68
53	Limestone	light grey	0.8	22.03
76	Andesite	light brown	0.81	10.81
119	Limestone	grey	0.81	14.3
124	Andesite	grey	0.81	13.18
129	Andesite	grey	0.81	10.57
105	Limestone	light grey	0.83	11.58
67	Andesite	grey	0.84	11.84
70	Andesite	black/grey	0.84	13.24
82	Limestone	light grey	0.84	12.86
32	Limestone	light grey	0.85	24.4
112	Limestone	light grey	0.85	13.15
69	Andesite	grey	0.86	13.05
138	Limestone	grey	0.88	18.88
140	Andesite	grey	0.89	32.92
80	Andesite	light brown - reddish	0.9	14.24
71	Andesite	black/grey	0.91	15.84
48	Limestone	light grey	0.93	27.11
73	Andesite	grey	0.93	15.2
101	Andesite	red	0.95	16.43
116	Limestone	grey	0.96	20.68
2	Limestone	light grey	0.97	34.02
47	Limestone	light grey	0.98	33.03
109	Limestone	light grey	0.98	20.45
9	Andesite	black/grey	0.99	35.72
50	Andesite	black/grey	0.99	25.44
20.1	Andesite	black/grey	1.02	20.33
51	Limestone	light grey	1.02	26.06
117	Andesite	grey	1.02	23.29
59	Andesite	light brown - reddish	1.06	31.96

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Half-Full Hydraulic Radius (cm)	Discharge, Q (cm^3/s)
38	Andesite	grey	1.07	23.63
136	Andesite	grey	1.07	47.43
103	Andesite	light brown - reddish	1.08	23.6
4	Limestone	light grey	1.09	42.49
5	Limestone	light grey	1.14	54.85
104	Andesite	grey	1.16	37.16
130	Andesite	grey	1.17	28
62	Andesite	grey	1.2	36.87
102	Andesite	black/grey	1.2	32.6
8	Andesite	black/grey	1.24	53.55
49	Andesite	black/grey	1.25	39.73
20.2	Andesite	black/grey	1.26	38.74
60	Andesite	light brown - reddish	1.26	38.38
114	Andesite	black/grey	1.3	41.32
56	Limestone	light grey	1.31	42.71
115	Limestone	light grey	1.31	80.71
21	Andesite	black/grey	1.34	50.87
35	Limestone	light grey	1.34	64.3
57	Andesite	grey	1.38	49.16
141	Limestone	grey	1.38	75.32
10	Andesite	black/grey	1.39	60.15
46	Limestone	light grey	1.5	58.02
110	Andesite	grey	1.5	63.93
22	Andesite	black/grey	1.53	60.78
55.2	Andesite	grey	1.53	56.77
14	Andesite	black/grey	1.54	73.38
11	Andesite	black/grey	1.59	74.37
44	Limestone	light grey	1.61	66.62
131.1	Andesite	grey	1.61	75.4
79	Andesite	grey	1.62	67.55
54	Andesite	black/grey	1.64	94.6
15	Andesite	black/grey	1.66	83.94
31	Limestone	light grey	1.69	116.8
126	Limestone	grey	1.72	83.29
12	Andesite	black/grey	1.73	90.89
120	Andesite	red	1.75	111.38
133	Andesite	grey	1.77	84.77

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Half-Full Hydraulic Radius (cm)	Discharge, Q (cm^3/s)
58	Andesite	black/grey	1.78	103.98
123	Andesite	grey	1.8	180.28
13	Andesite	black/grey	1.83	110.74
43	Limestone	light grey	1.84	116.77
139	Andesite	black/grey	1.87	109.95
45	Limestone	light grey	1.91	112.42
128	Andesite	light brown	1.91	104.57
122	Limestone	grey	1.95	114.38
55.1	Andesite	grey	2	127.97
16	Andesite	black/grey	2.04	138.83
3	Andesite	black/grey	2.05	137.5
37	Andesite	black/grey	2.11	142.48
1	Andesite	black/grey	2.18	155.45
39	Andesite	grey	2.19	150.54
111	Andesite	grey	2.21	159.56
19	Andesite	black/grey	2.25	164.74
63	Andesite	grey	2.27	207.25
18	Andesite	red	2.35	188.03
36	Limestone	light grey	2.38	194.41
40	Andesite	grey	2.45	205.21
17	Andesite	black/grey	2.64	254.88
26	Andesite	black/grey	2.66	280.97
64.1	Andesite	black/grey	2.74	327.47
134	Limestone	light grey	2.75	322.68
41	Andesite	grey	2.9	315.37
24	Andesite	black/grey	2.93	340.66
25	Andesite	black/grey	2.95	357.76
23	Andesite	light brown - reddish	2.97	369.52
27	Andesite	black/grey	3.12	387.57
132	Limestone	grey	3.28	473.18
28	Andesite	black/grey	3.3	467.57
29	Andesite	black/grey	3.37	493.07
137	Limestone	grey	3.39	480.19
64.2	Andesite	black/grey	3.52	608.11
30	Andesite	black/grey	3.7	638.56
42	Limestone	light grey	3.85	661.56
127	Andesite	grey	4.3	947.19

There are multiple stones that have the same hydraulic radius as well as stone type. For example, stone cross-sections 56 and 115 have the same hydraulic radius of 1.31 cm and stone type (limestone). However both cross-sections are found on different locations around the Muyuqmarka site. It is interesting to see limestone stones and andesite stones have the same hydraulic radius. For example two different stone types, stone 6 and stone 125, have cross-sections with a hydraulic radius of 0.63 cm. It lends to question whether the Inca did in fact mix their stone channels with different stones.

Table 22 shows an example of how to use the data found in Table 21 to reconstruct the Muyuqmarka channels. Table 22 takes stone segment 38 from channel 2 and shows that stone segment 103 is similar in both hydraulic radii and discharge. Not only does the table show the quantitative data for both stone segment 38 and 103, but it also shows the stone segments' stone photo and stone cross-section. This is an example of how the data within this thesis can be used to help restore the original Inca design of the Muyuqmarka.

Table 22: Example of restoring channel 2 to original design

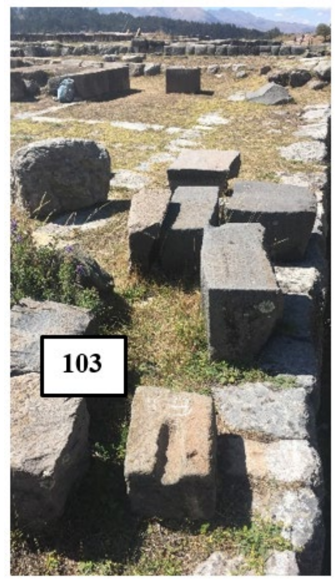
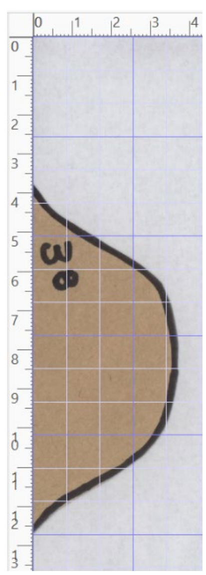
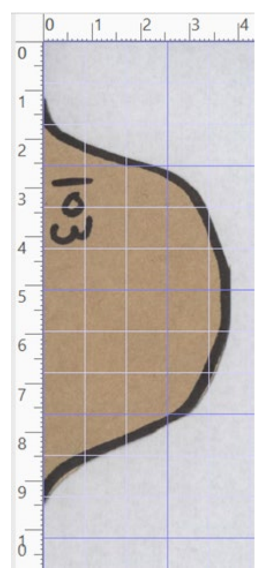
	Channel Segment from Channel 2	
Stone Cross-section	38	103
Channel Segment Stone Type	Andesite	Andesite
Channel Segment Stone Color	grey	light brown - reddish
Half-Full Hydraulic Radius (cm)	1.07	1.08
Discharge, Q (cm^3/s)	23.63	23.60
Photo of Stone		
Stone Cross-section (cm)		

Table 23 contains the half-full hydraulic radii statistics for the 146 channel cross-sections. The average of all 146 channel cross-sections is 1.35 cm.

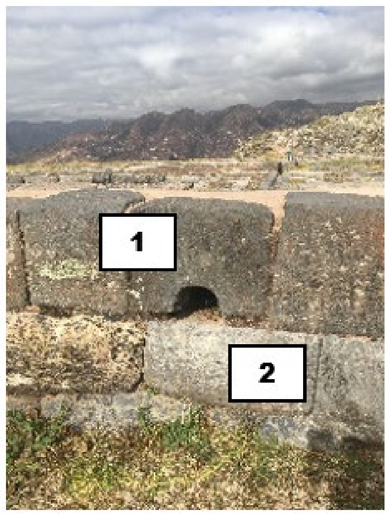
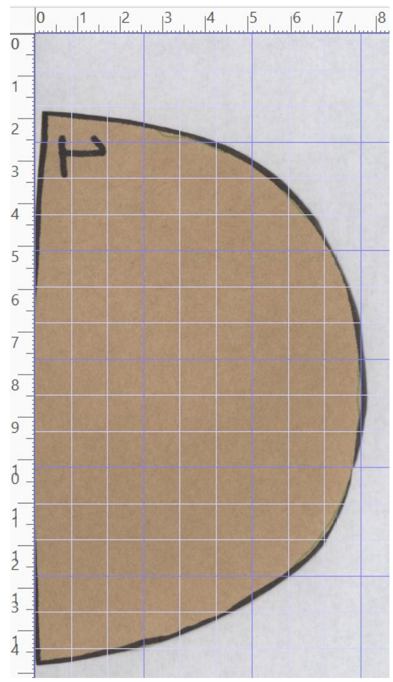
Table 23: All 146 channel cross-section half-full hydraulic radii statistics

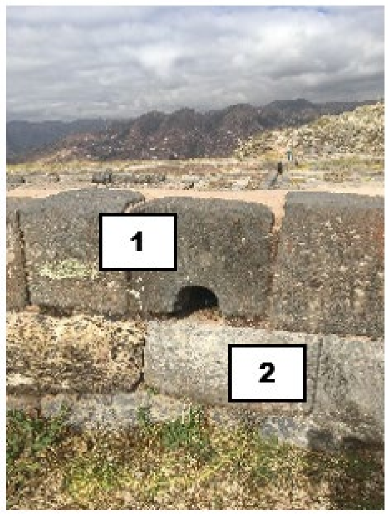
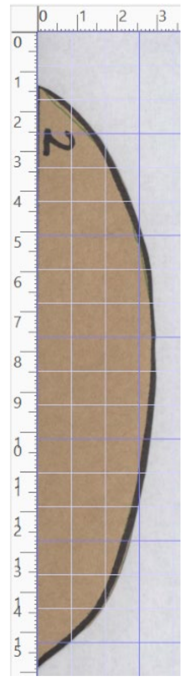
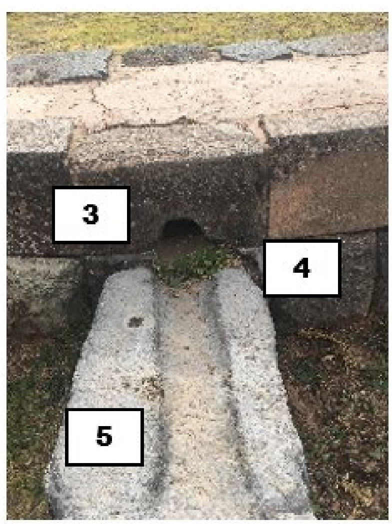
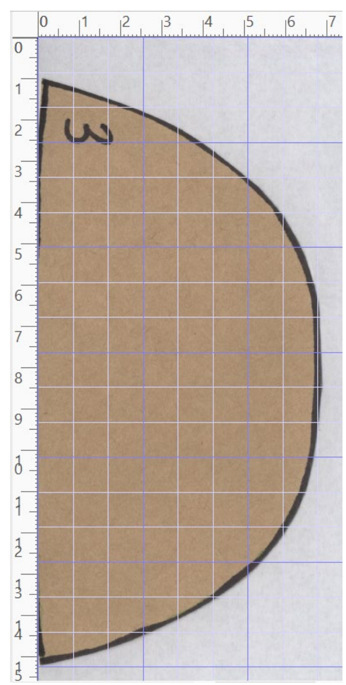
Mean	1.35 cm
Median	1.07 cm
Max	4.30 cm
Min	0.29 cm
Diff	4.01 cm
St Dev	0.87 cm

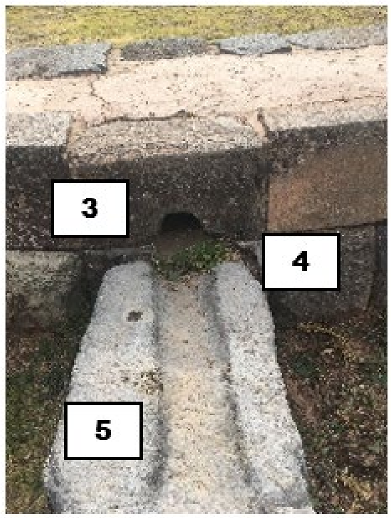
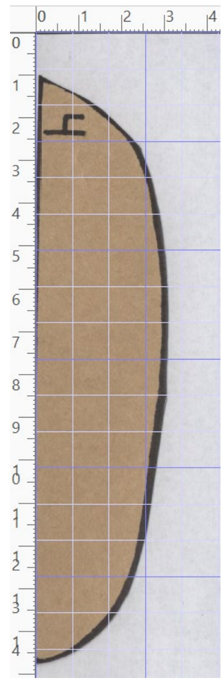
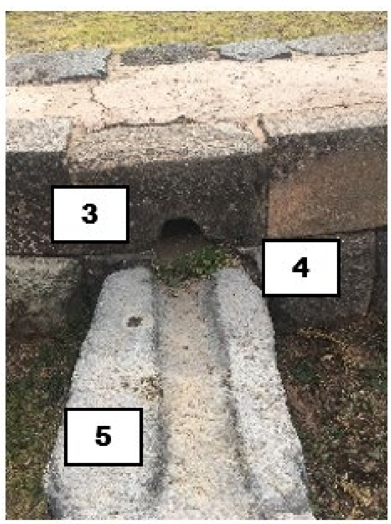
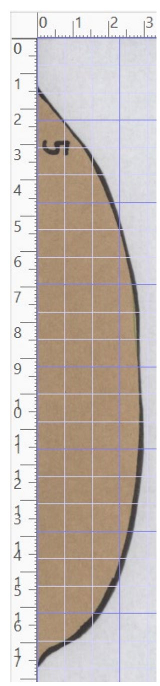
D. CATALOGUE OF ALL 141 CHANNEL SEGMENTS

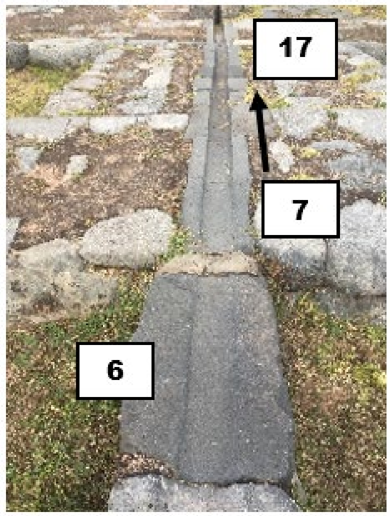
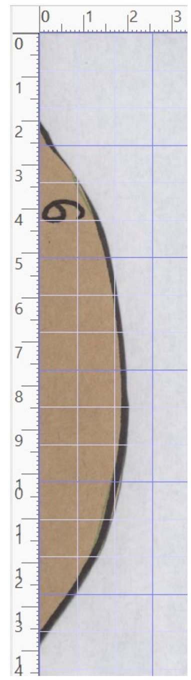
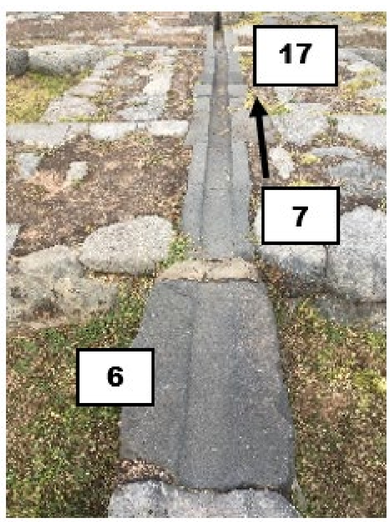
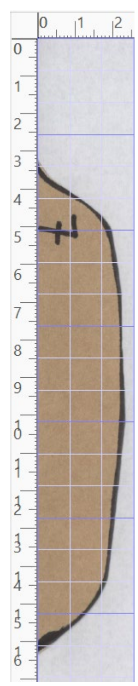
Table 24 is a comprehensive catalogue of all 141 channel segments. This table includes each channel segments' stone number, GIS point in ArcMap, hydraulic radius for a half-full-flowing channel, hydraulic radius for a most-efficient-flowing channel, stone type, photo of stone, and stone cross-section image.

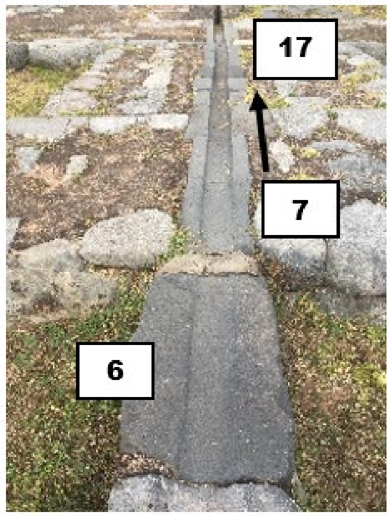
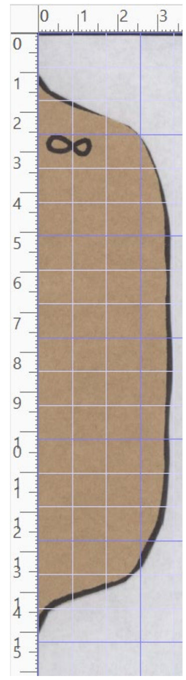
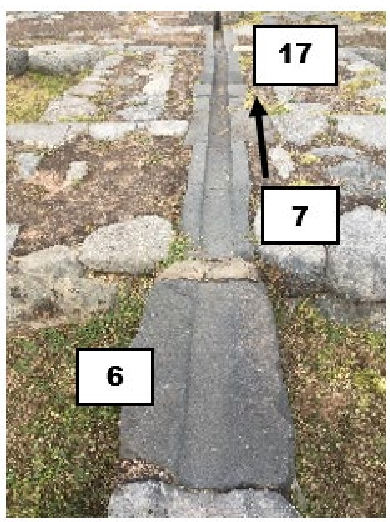
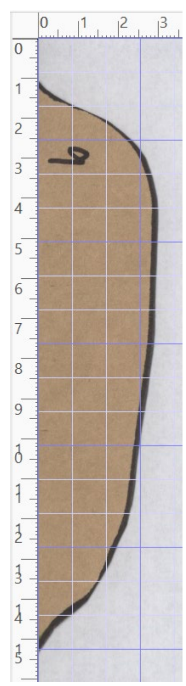
Table 24: Catalogue of all 141 channel segments

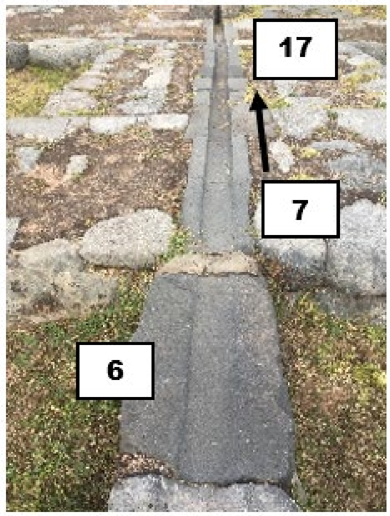
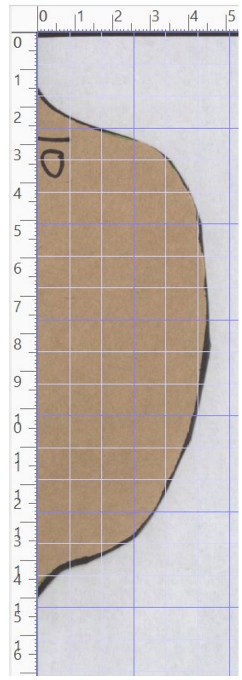
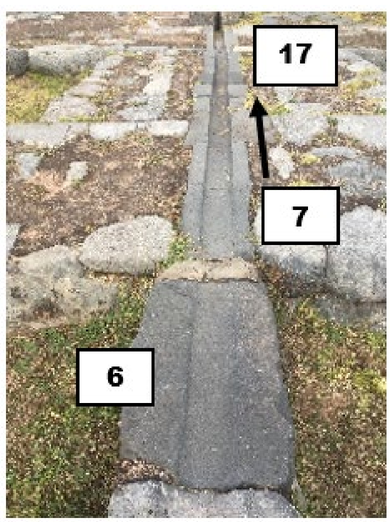
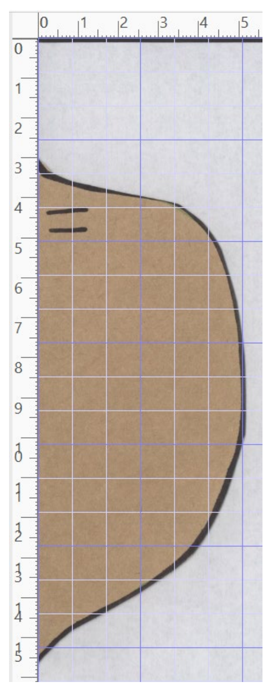
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
1	**1**	**2.18**	**3.90** 	**Andesite**		

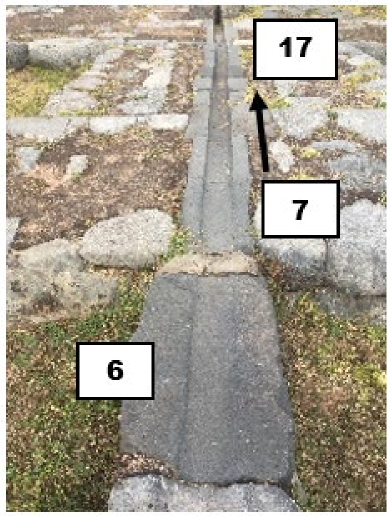
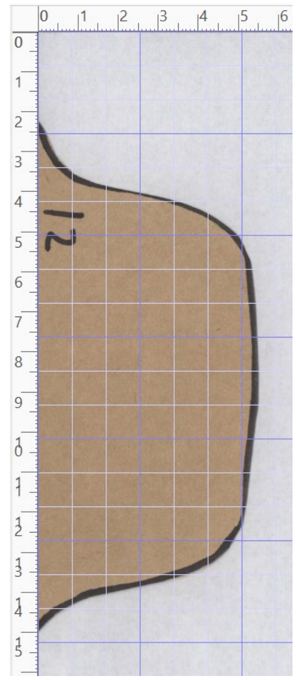
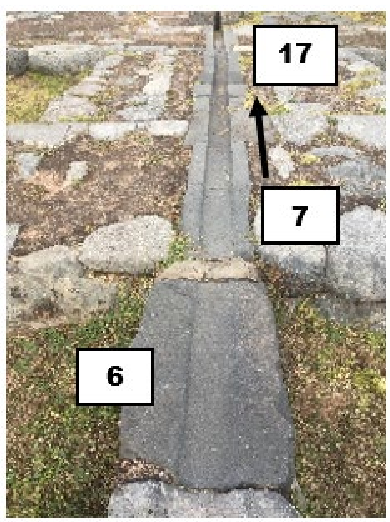
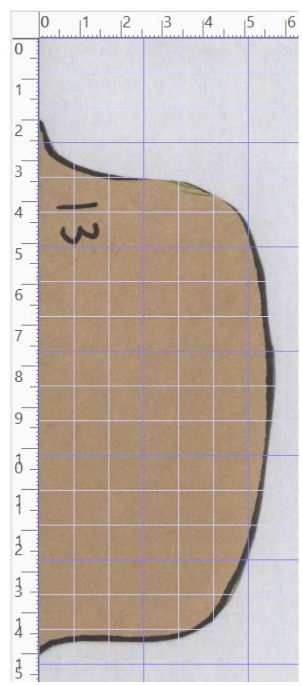
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
2	2	0.97	1.50	Limestone		
3	3	2.05	3.45	Andesite		

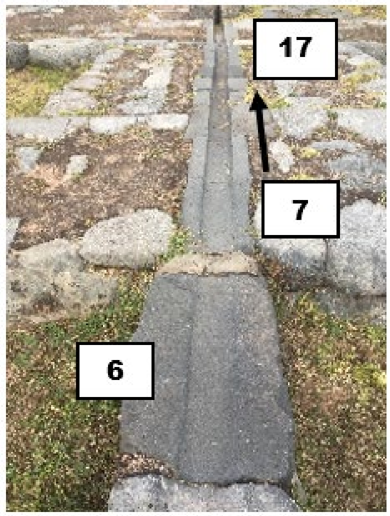
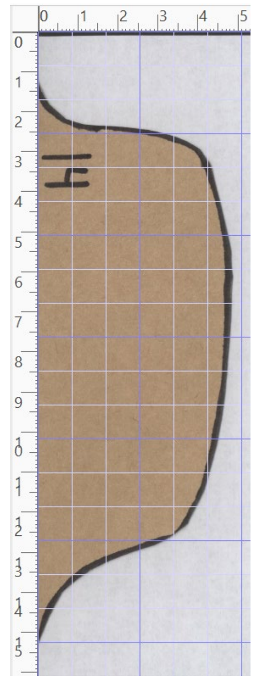
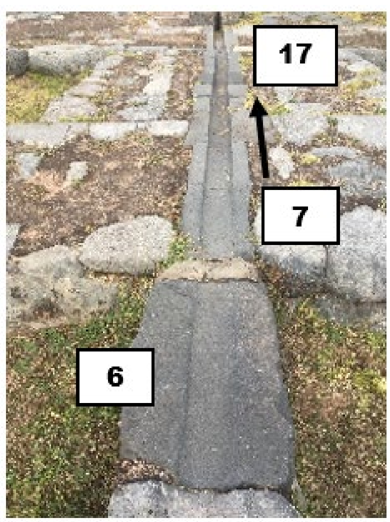
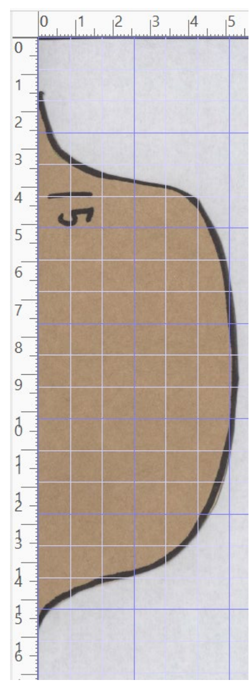
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
4	4	1.09	1.56	Limestone		
5	5	1.14	1.65	Limestone		

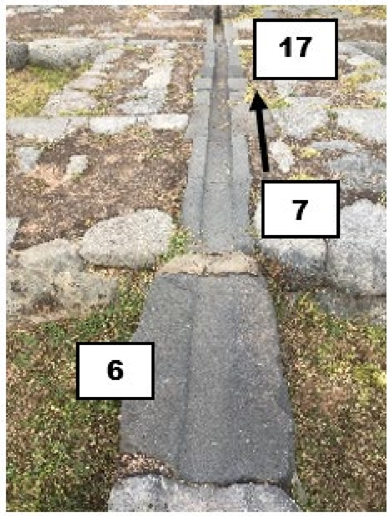
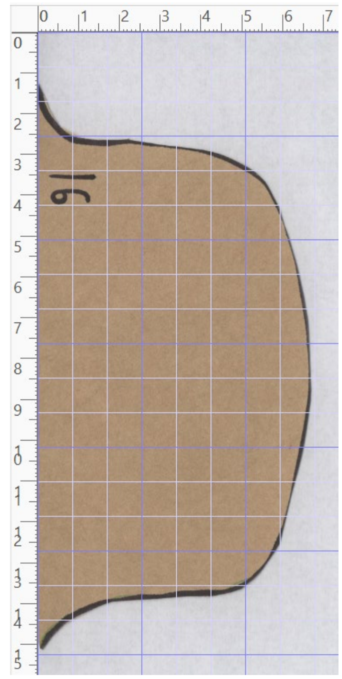
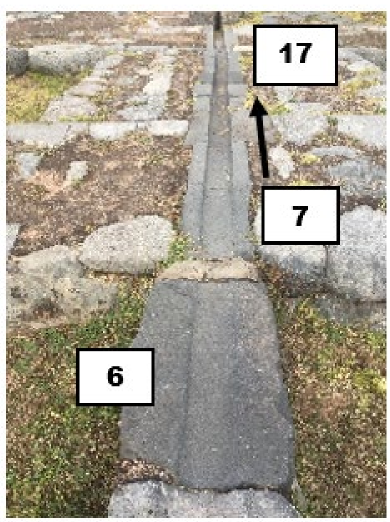
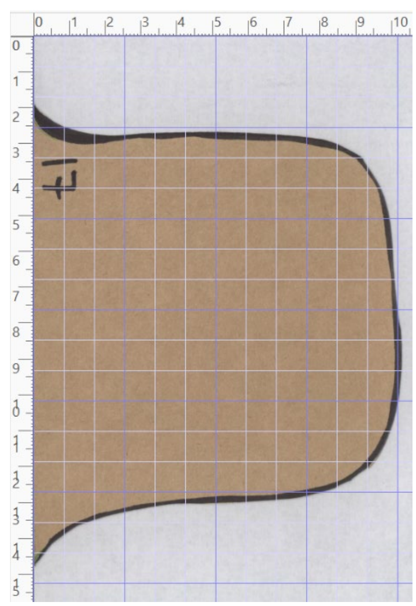
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
6	6	0.63	1.03	Andesite		
7	7	0.78	1.23	Andesite		

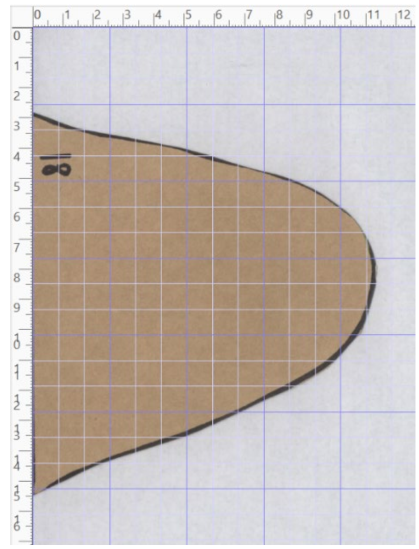
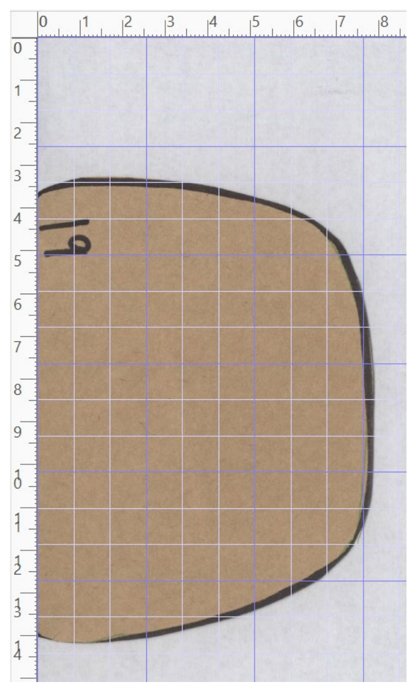
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
8	8	1.24	1.69	Andesite		
9	9	0.99	1.58	Andesite		

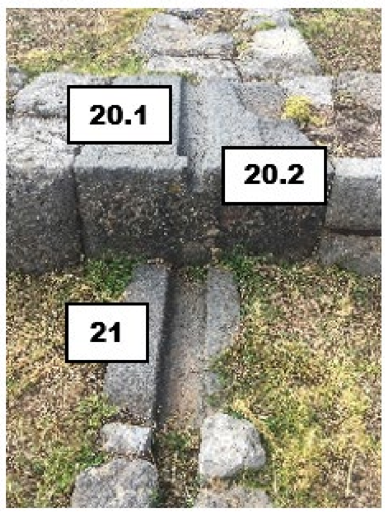
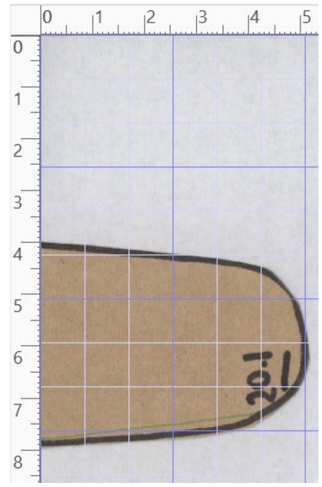
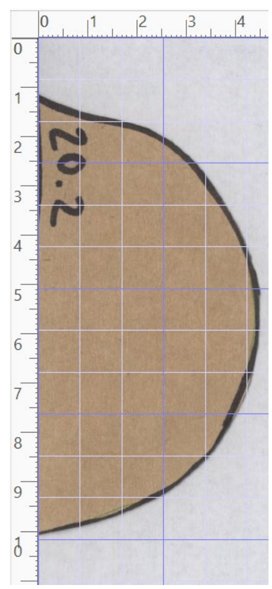
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
10	10	1.39	2.25	Andesite		
11	11	1.59	2.61	Andesite		

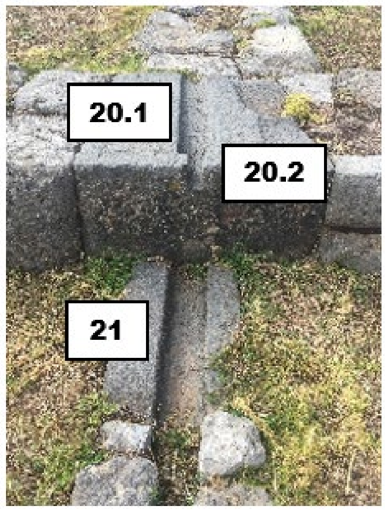
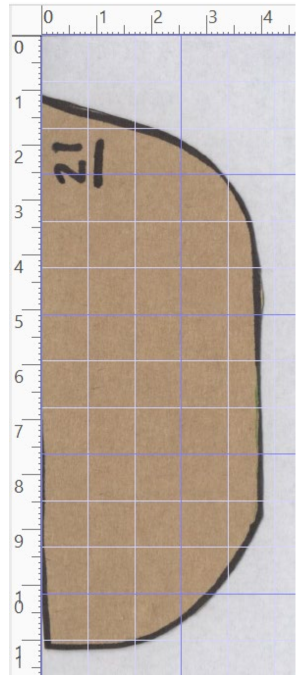
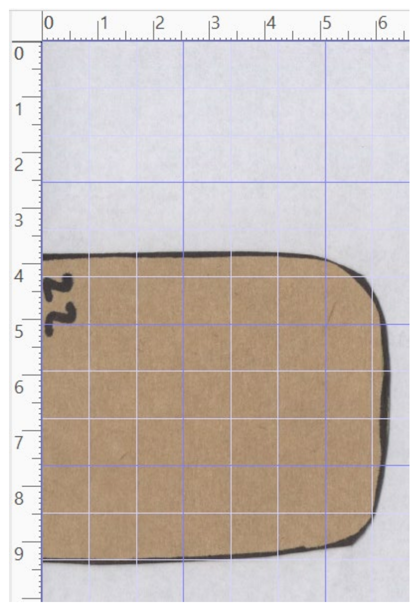
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
12	12	1.73	2.78	Andesite		
13	13	1.83	2.90	Andesite		

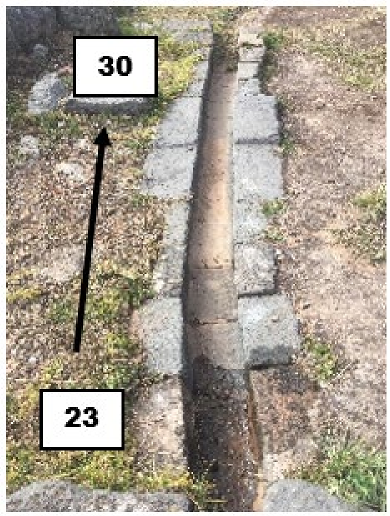
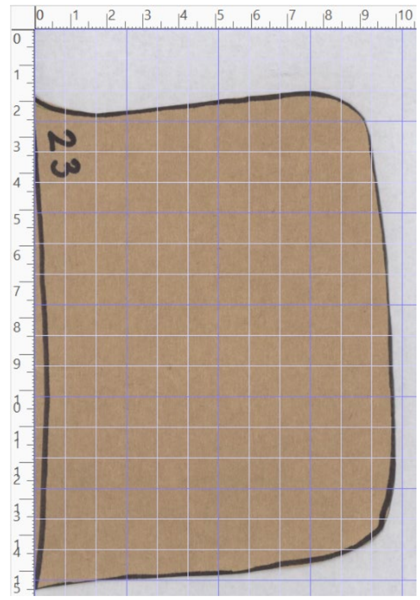
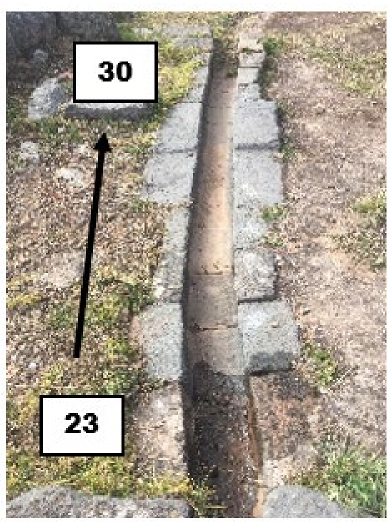
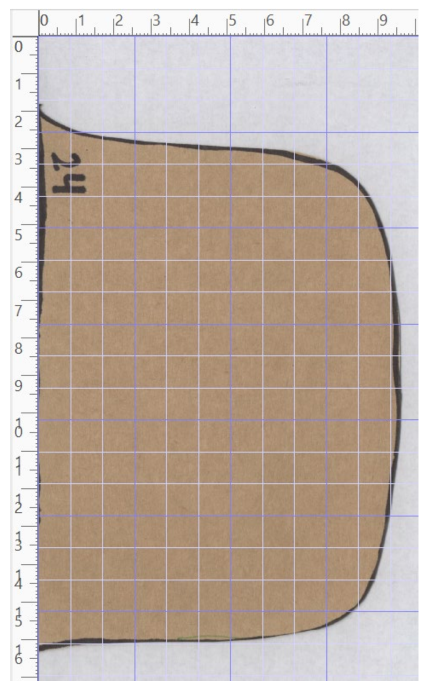
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
14	14	1.54	2.43	Andesite		
15	15	1.66	2.71	Andesite		

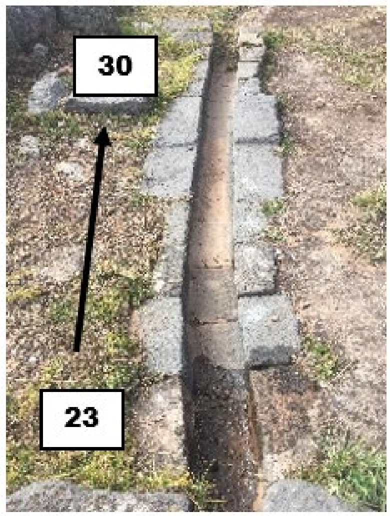
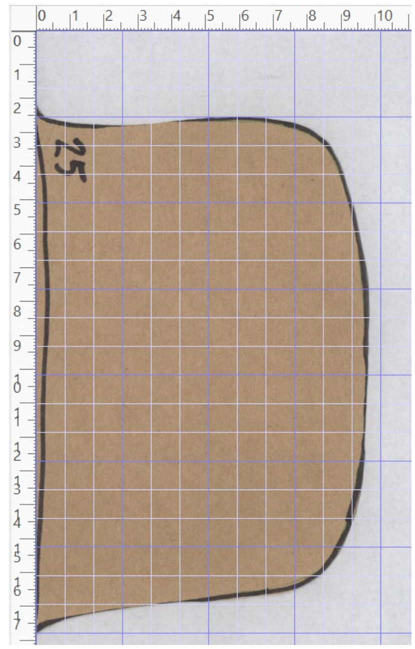
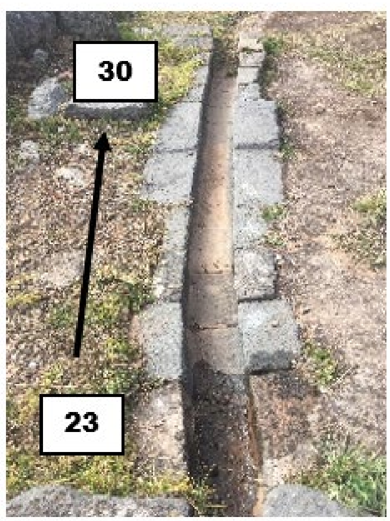
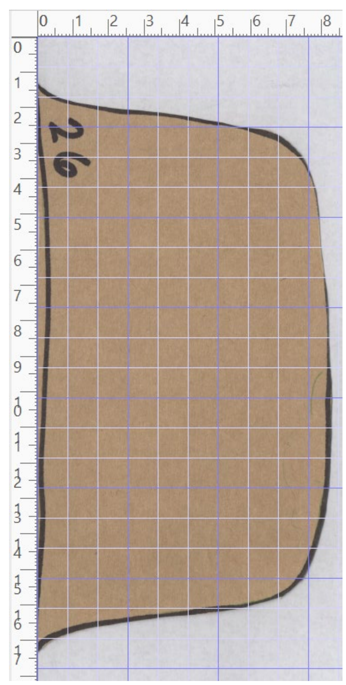
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
16	16	2.04	3.35	Andesite		
17	17	2.64	5.16	Andesite		

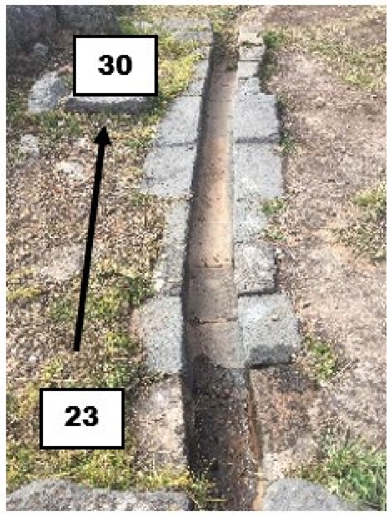
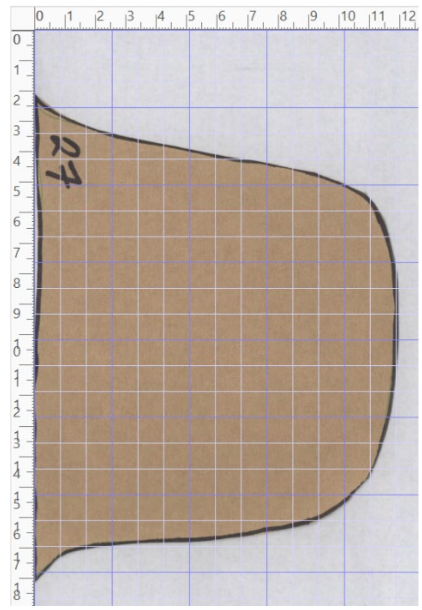
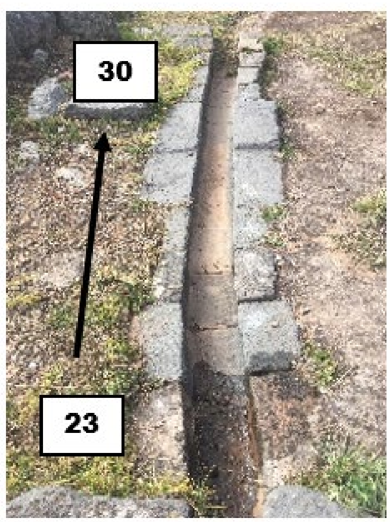
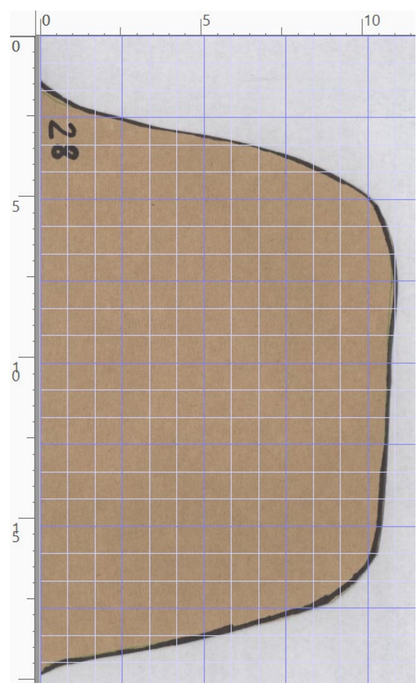
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
18	18	2.35	5.72	Andesite		
19	19	2.25	3.98	Andesite		

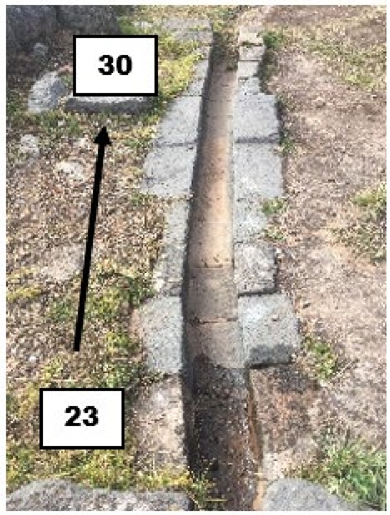
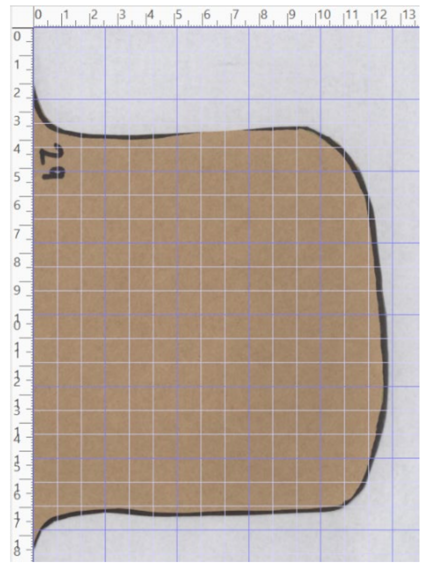
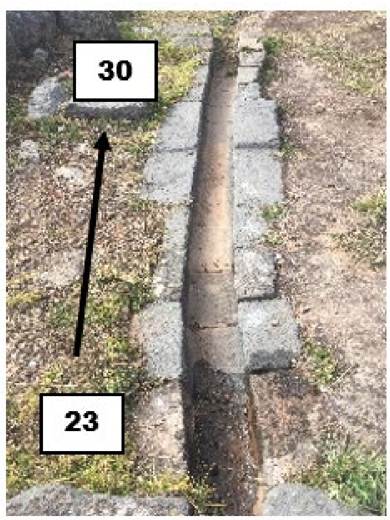
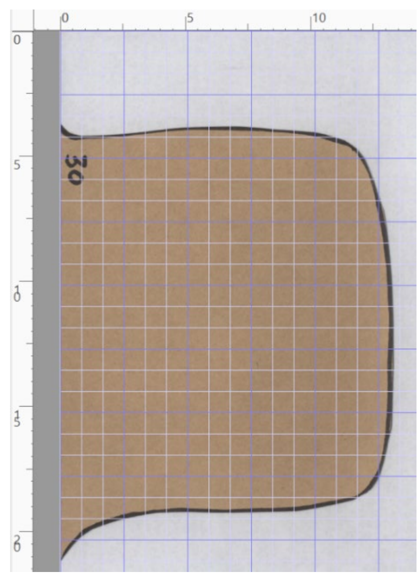
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
20.1 / 20.2	20	1.02, 1.26	2.58, 2.28 (2) (1)	Andesite		

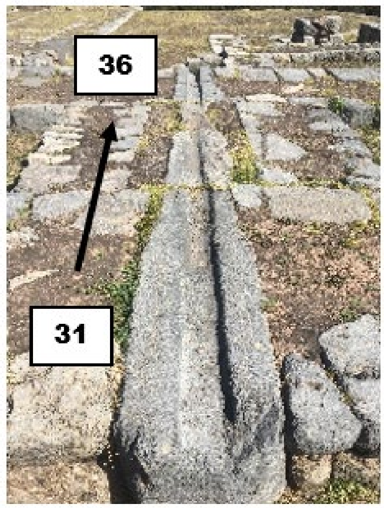
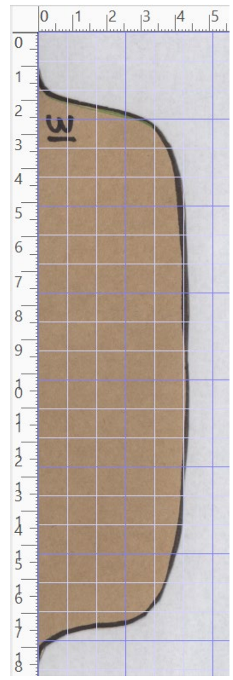
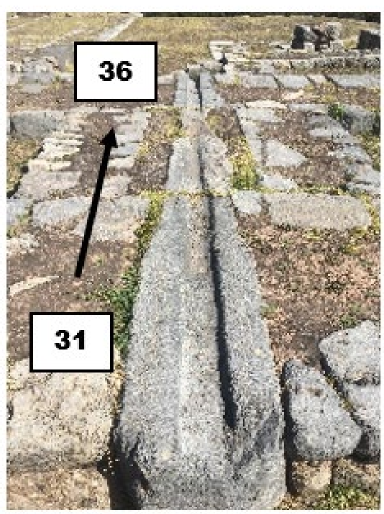
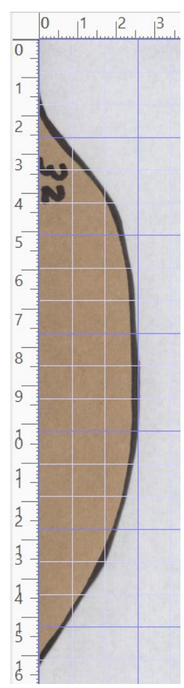
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
21	21	1.34	1.98	Andesite		
22	22	1.53	3.15	Andesite		

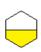
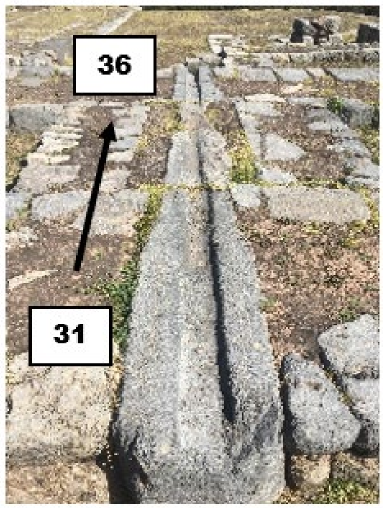
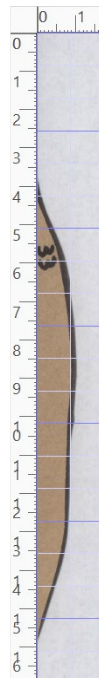
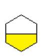
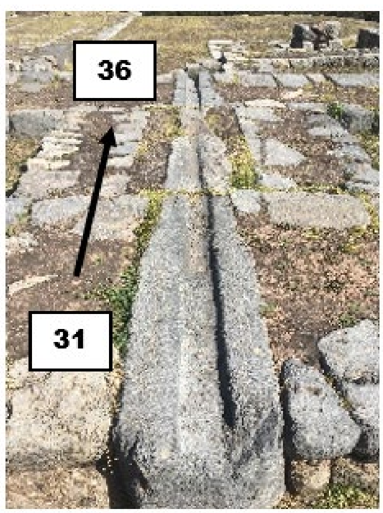
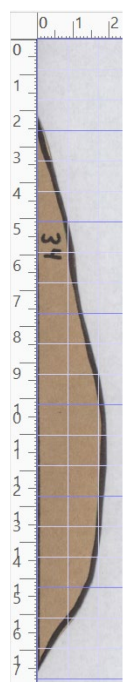
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
23	23	2.97	5.10	Andesite		
24	24	2.93	5.00	Andesite		

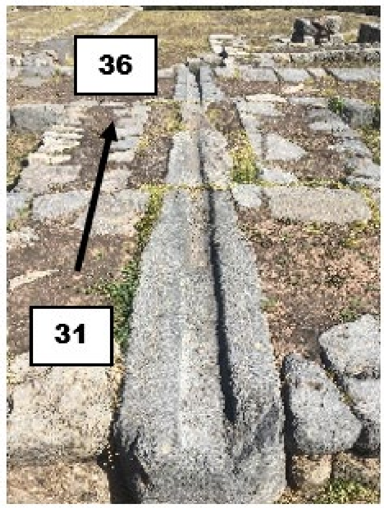
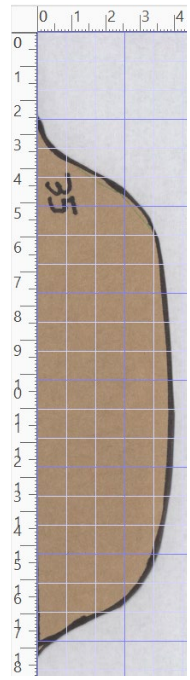
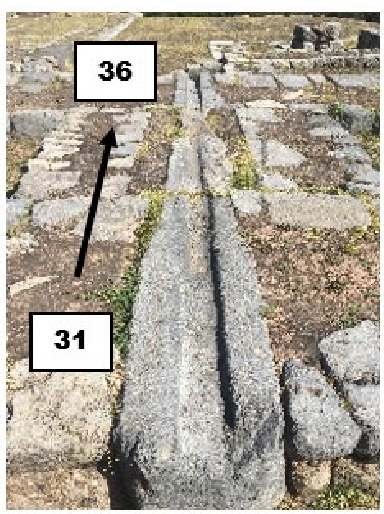
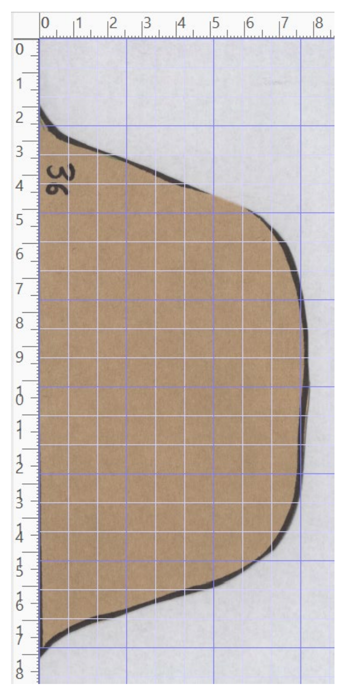
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
25	25	2.95	4.94	Andesite		
26	26	2.66	4.18	Andesite		

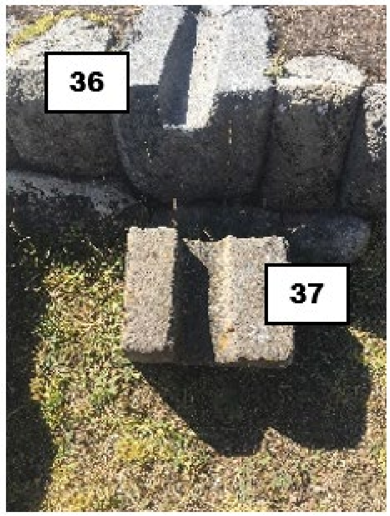
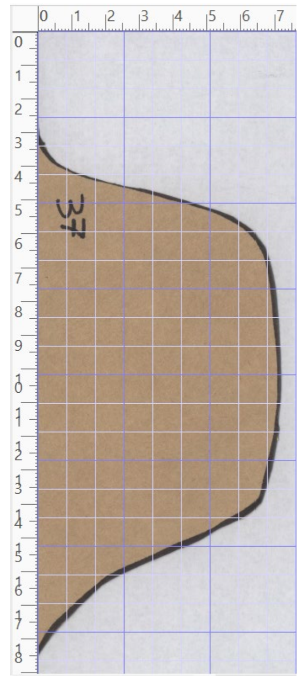
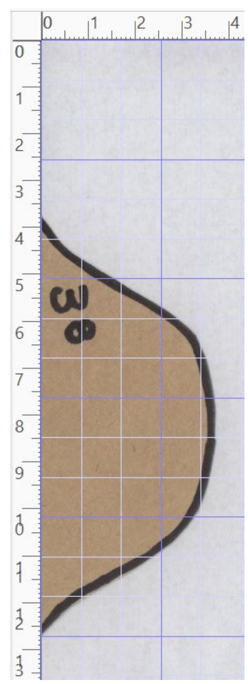
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
27	27	3.12	6.05	Andesite		
28	28	3.30	5.56	Andesite		

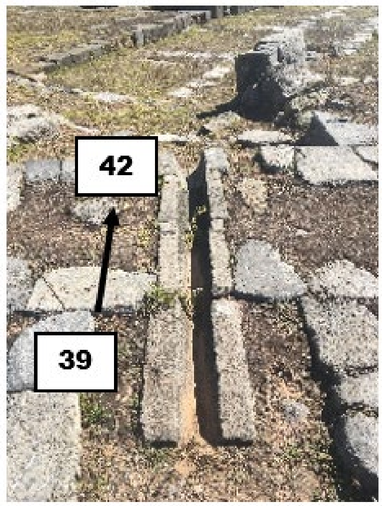
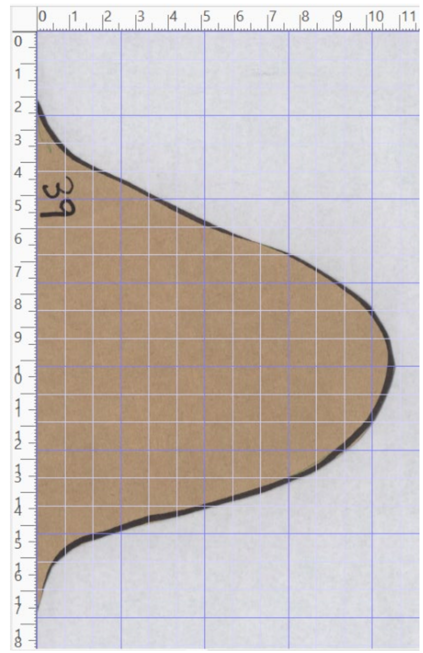
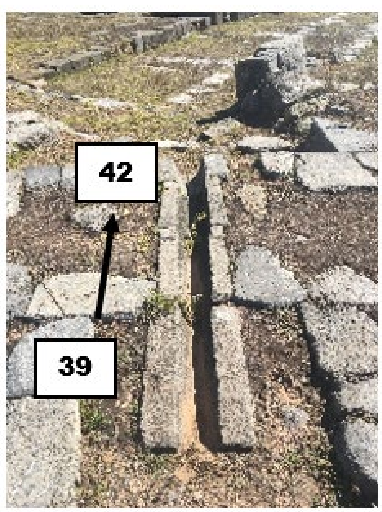
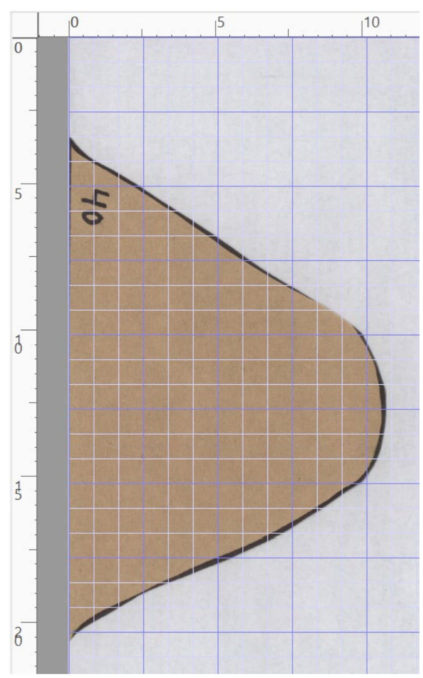
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
29	29	3.37	6.27	Andesite		
30	30	3.70	6.63	Andesite		

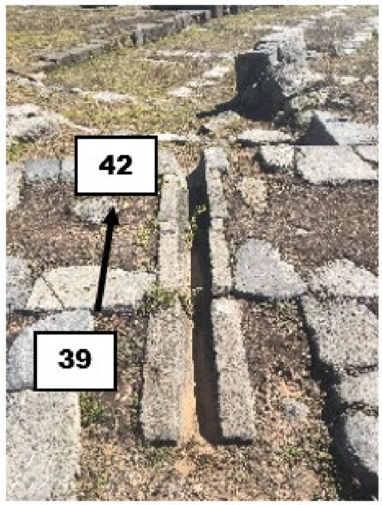
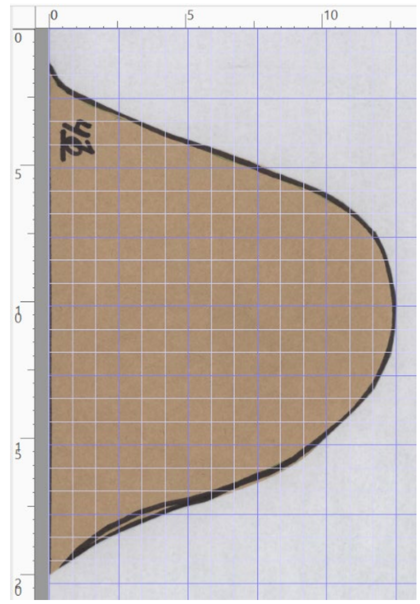
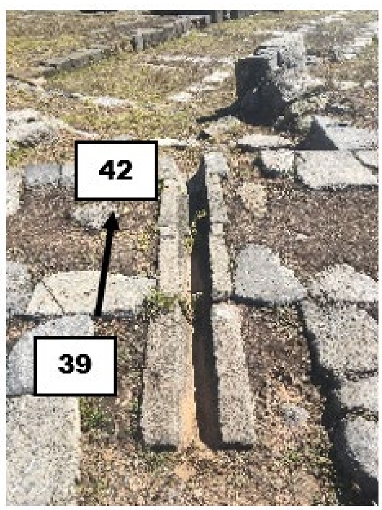
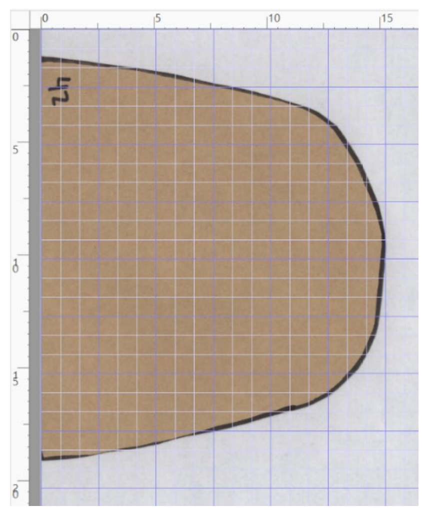
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
31	31	1.69	2.26	Limestone		
32	32	0.85	1.29	Limestone		

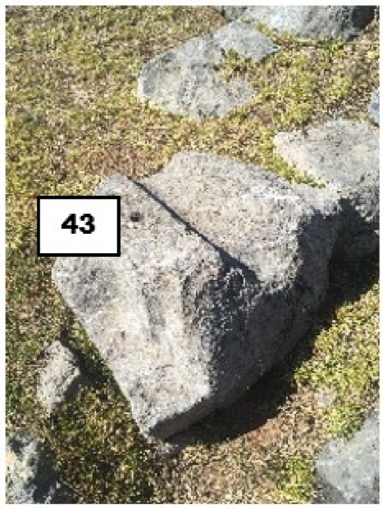
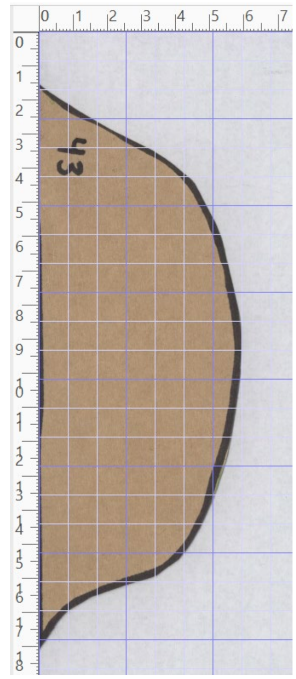
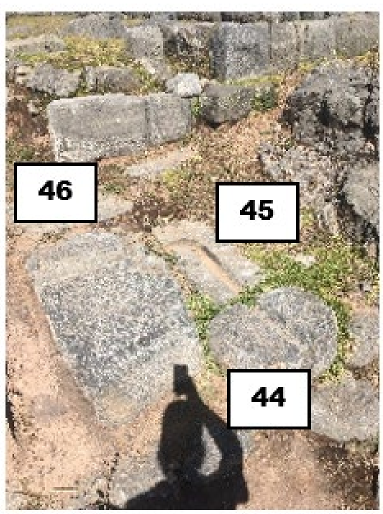
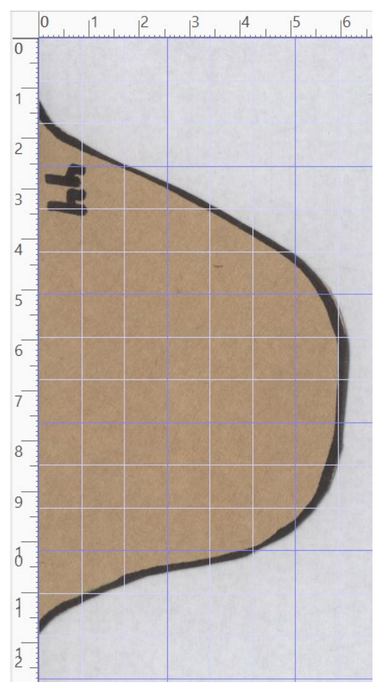
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
33	33	0.33	0.49 	Andesite		
34	34	0.54	0.95 	Andesite		

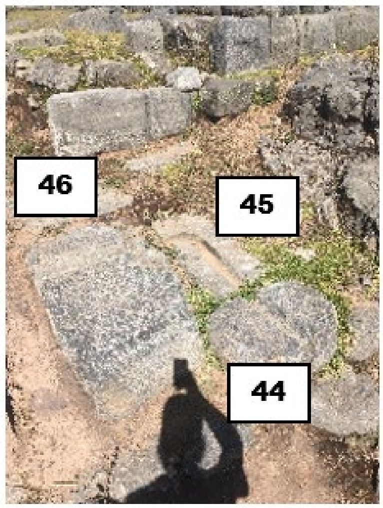
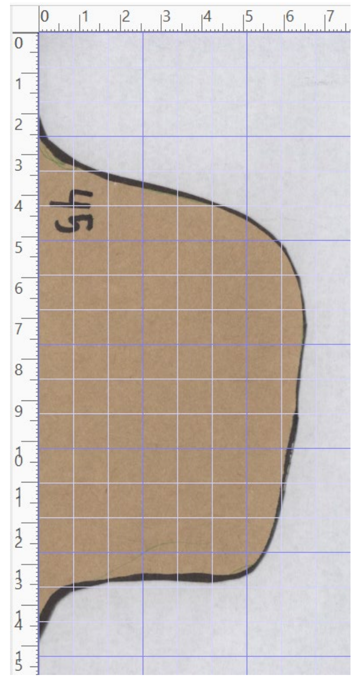
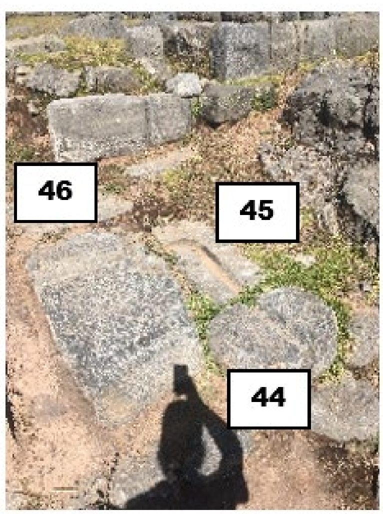
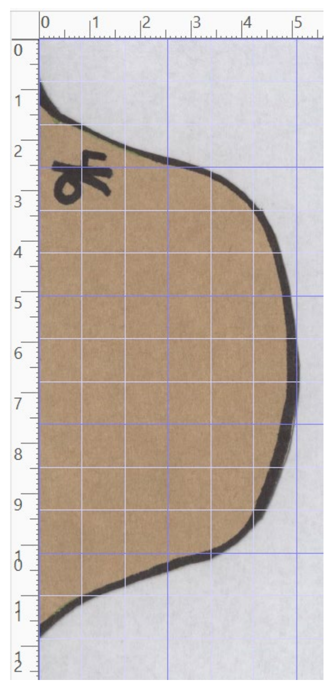
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
35	35	1.34	2.00	Limestone		
36	36	2.38	3.92	Limestone		

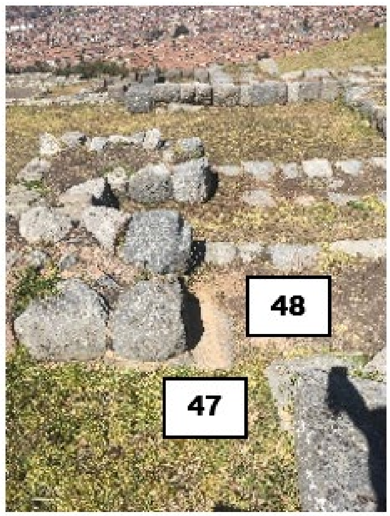
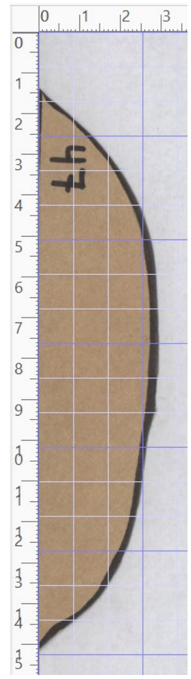
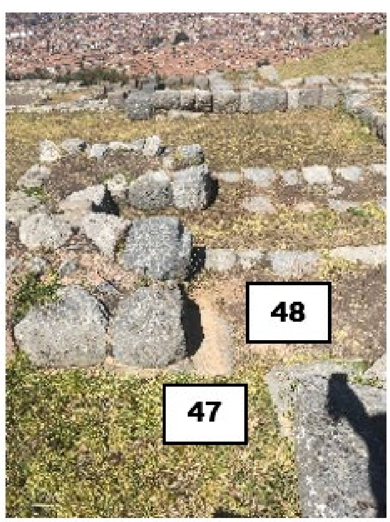
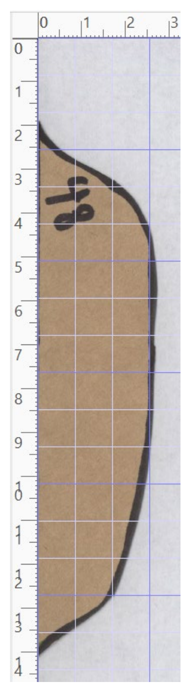
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
37	37	2.11	3.62	Andesite		
38	38	1.07	1.87	Andesite		

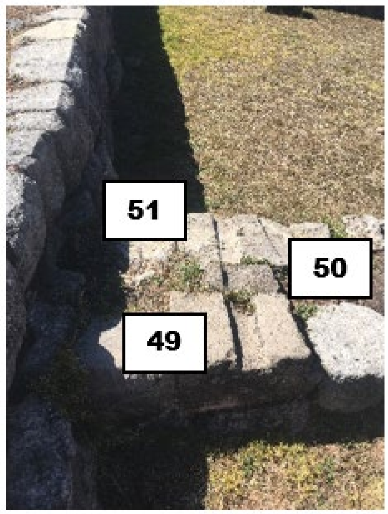
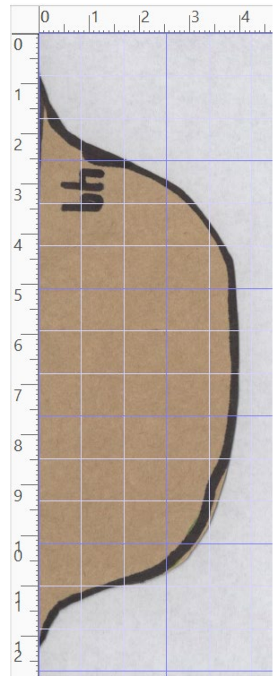
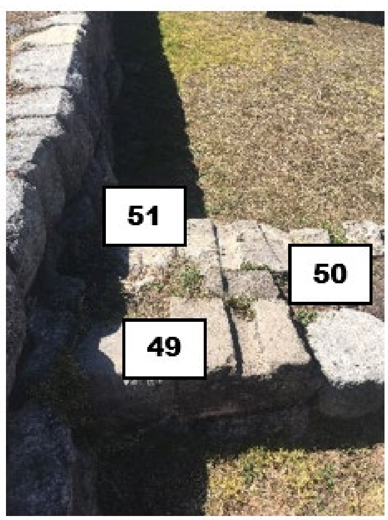
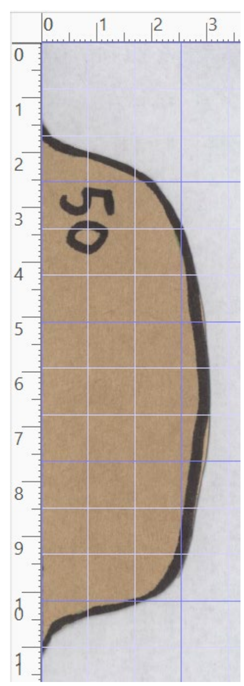
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
39	39	2.19	5.46	Andesite		
40	40	2.45	5.45	Andesite		

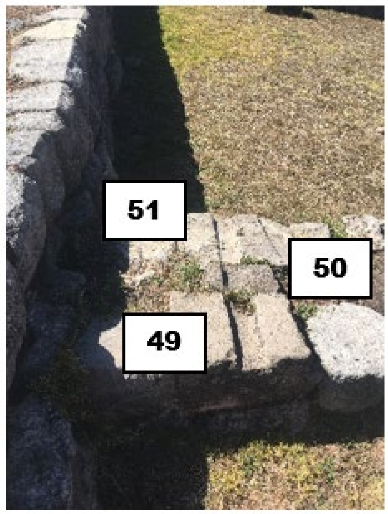
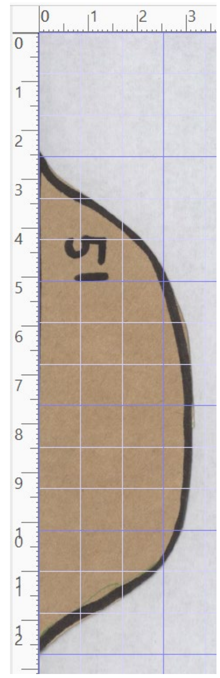
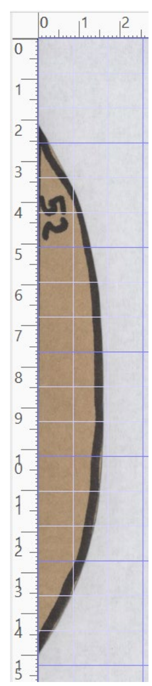
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
41	41	2.90	6.33	Andesite		
42	42	3.85	7.74	Limestone		

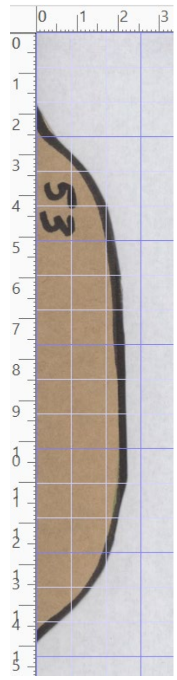
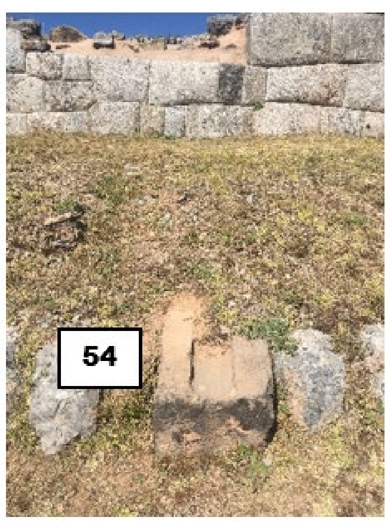
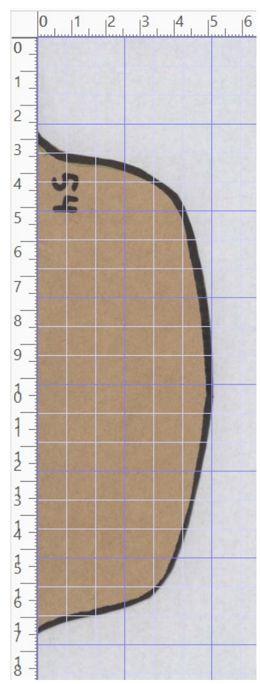
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
43	43	1.84	2.98	Limestone		
44	44	1.61	3.05	Limestone		

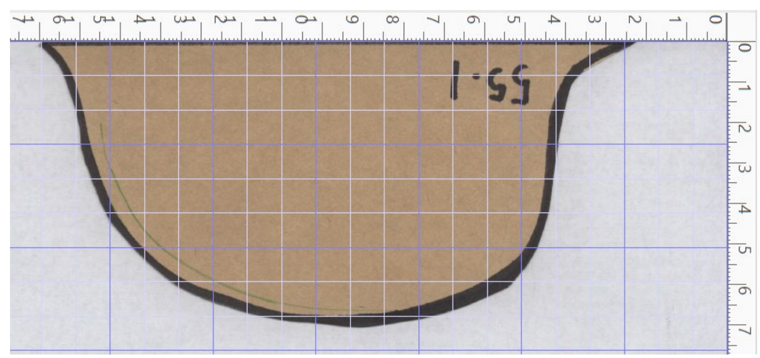
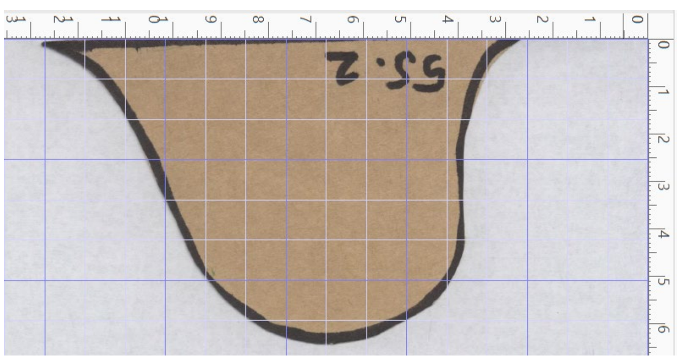
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
45	45	1.91	3.31	Limestone		
46	46	1.50	2.59	Limestone		

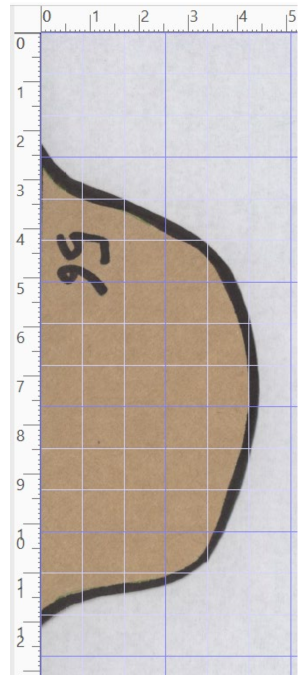
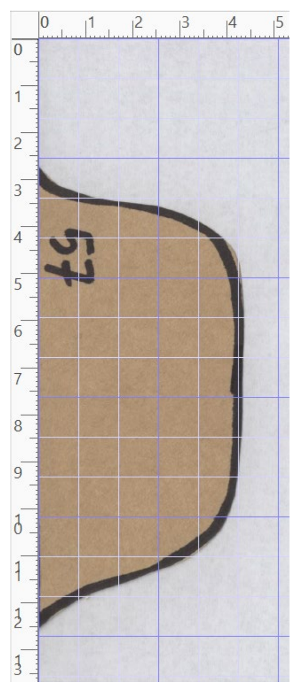
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
47	47	0.98	1.46	Limestone		
48	48	0.93	1.36	Limestone		

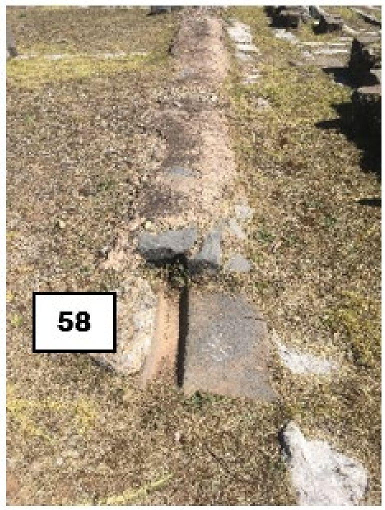
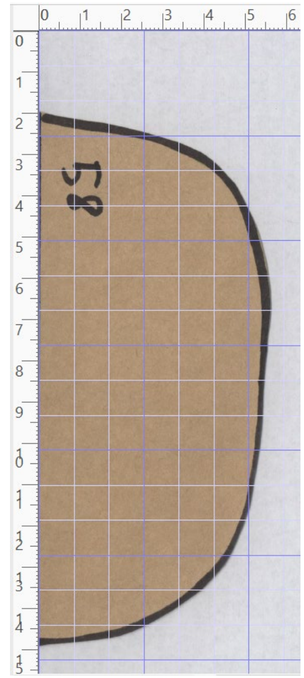
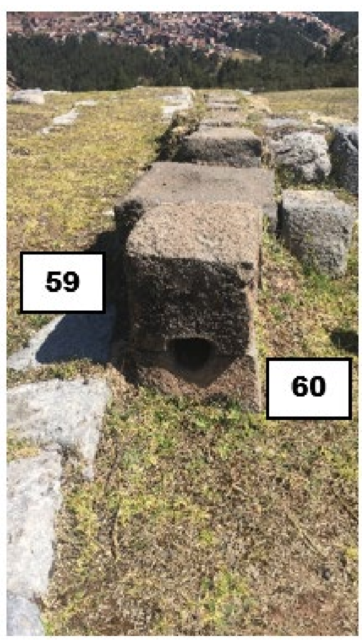
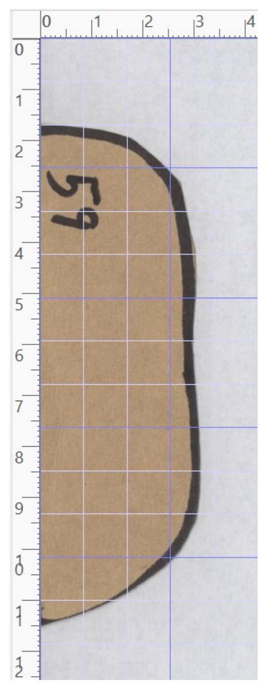
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
49	49	1.25	1.95	Andesite		
50	50	0.99	1.56	Andesite		

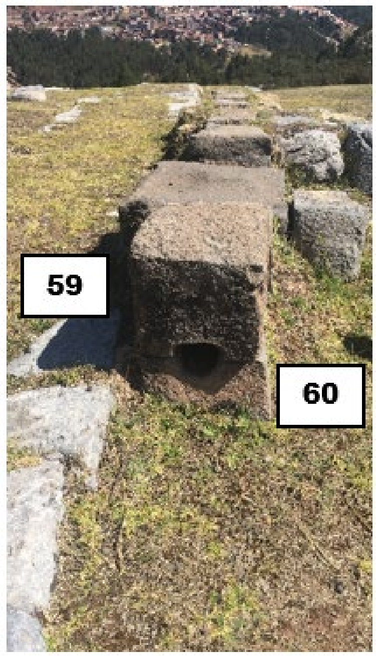
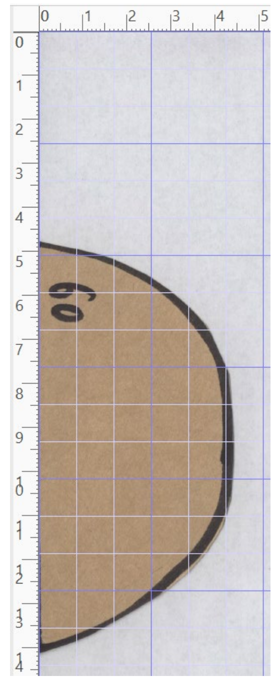
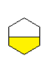
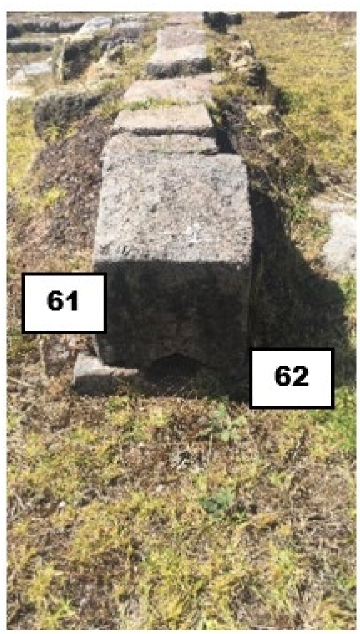
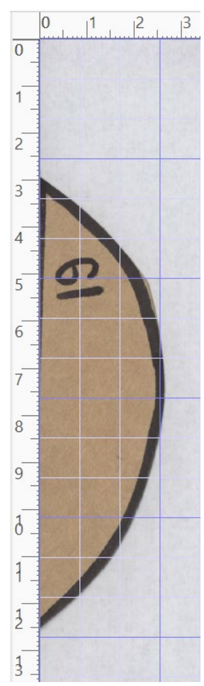
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
51	51	1.02	1.57	Limestone		
52	52	0.47	0.75	Andesite		

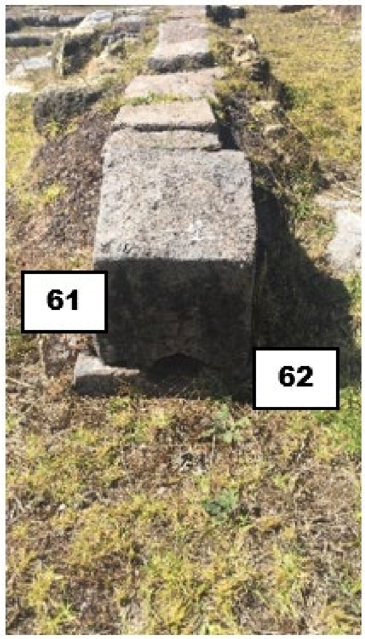
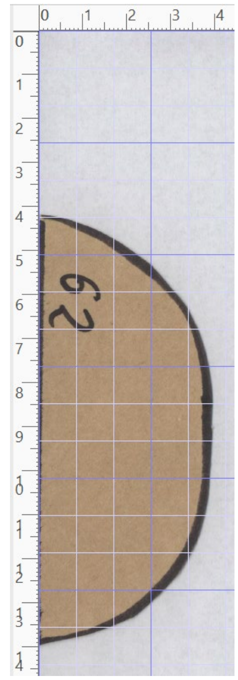
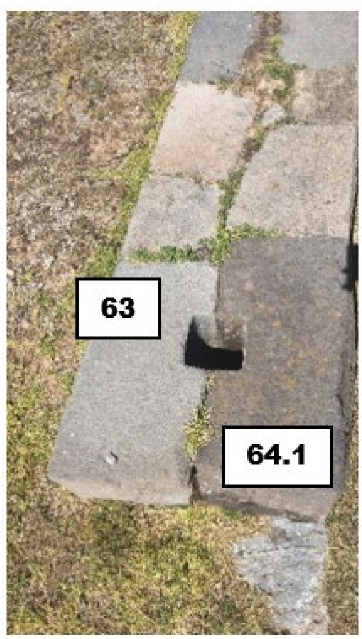
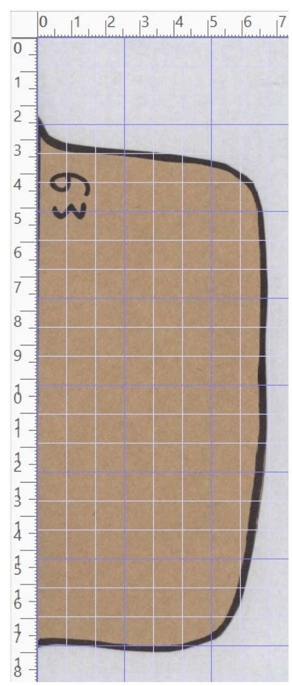
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
53	**53**	**0.80**	**1.14**	**Limestone**		
54	**54**	**1.64**	**2.52**	**Andesite**		

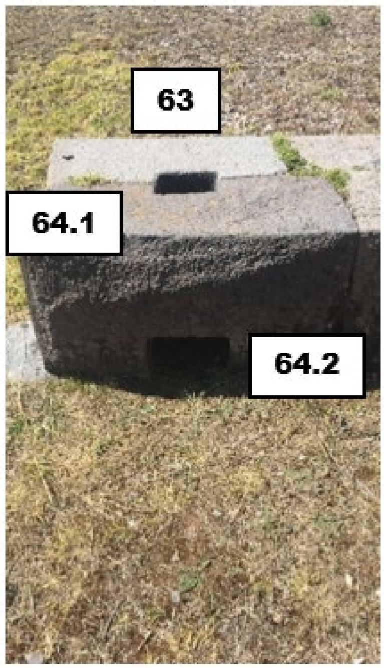
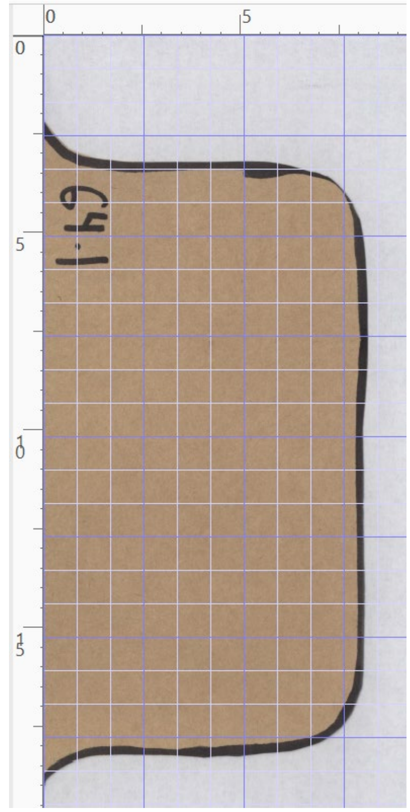
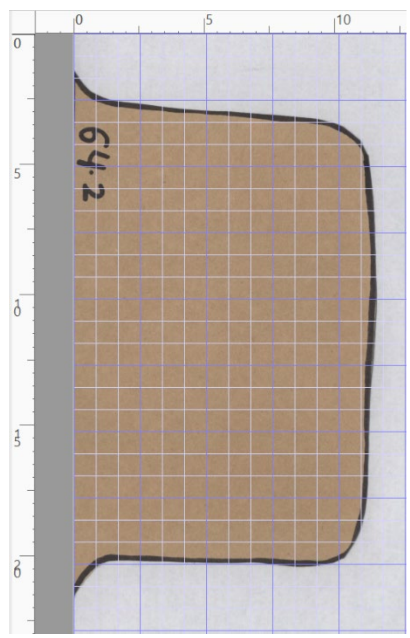
55.1 / 55.2	55	2.00, 1.53	3.45, 3.24 (1) (2)	Andesite		 

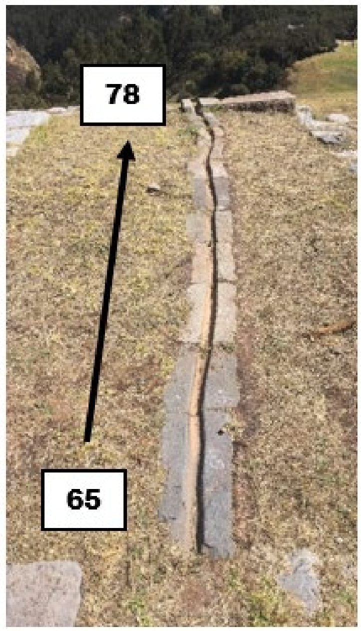
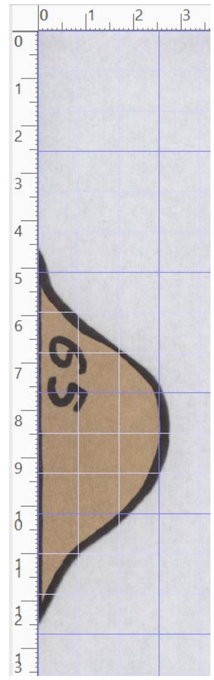
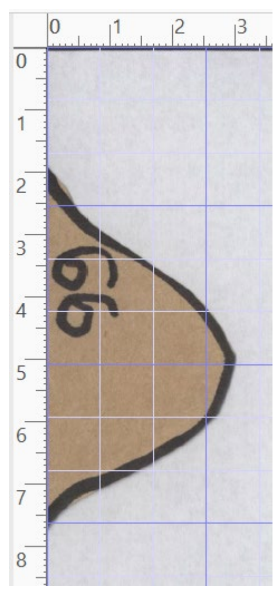
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
56	56	1.31	2.26	Limestone		
57	57	1.38	2.19	Andesite		

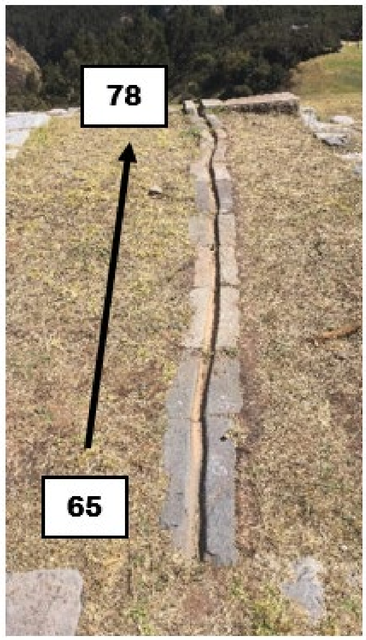
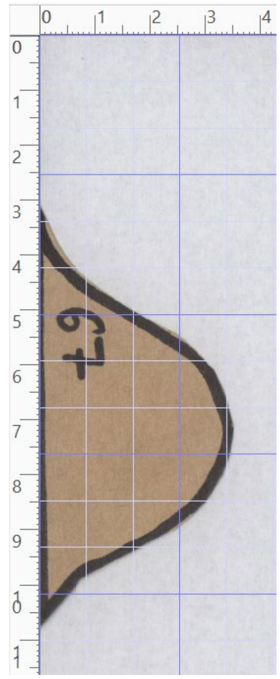
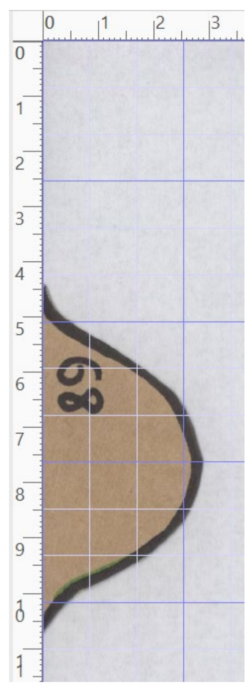
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
58	58	1.78	2.81	Andesite		
59	59	1.06	1.57	Andesite		

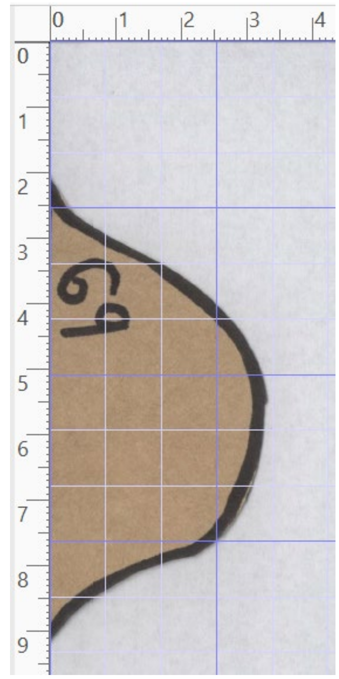
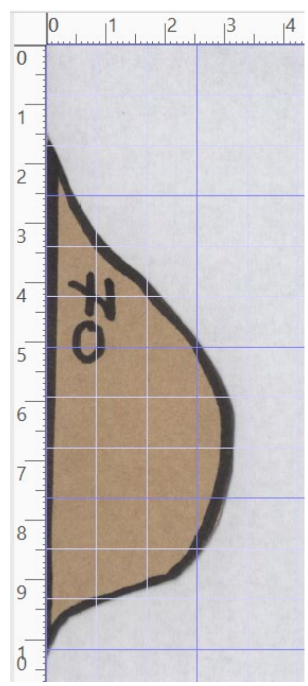
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
60	60	1.26	2.22 	Andesite		
61	61	0.79	1.35 	Andesite		

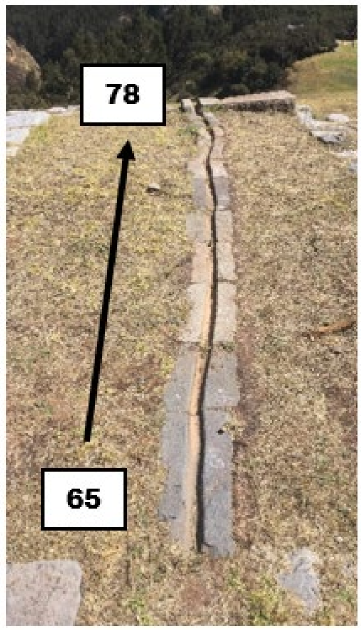
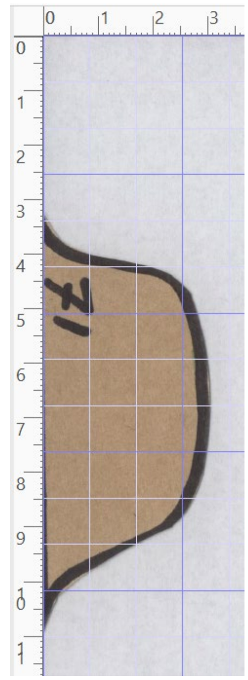
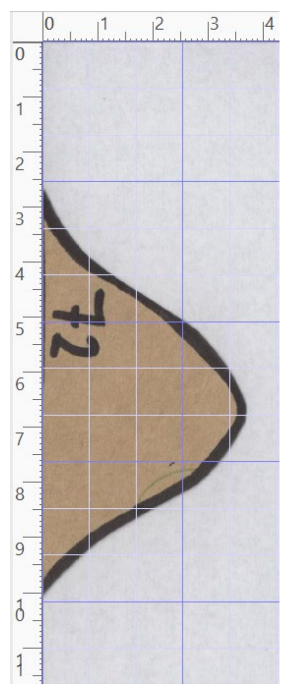
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
62	62	1.20	1.93	Andesite		
63	63	2.27	3.35	Andesite		

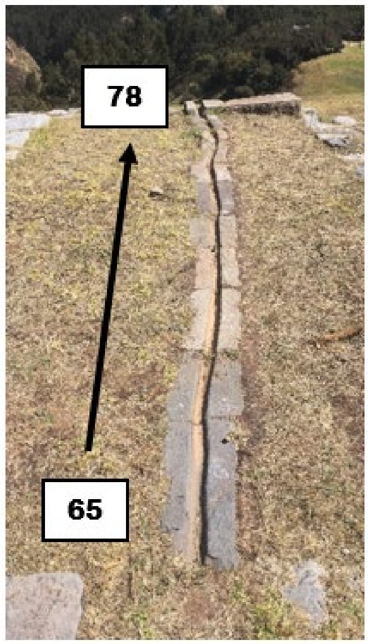
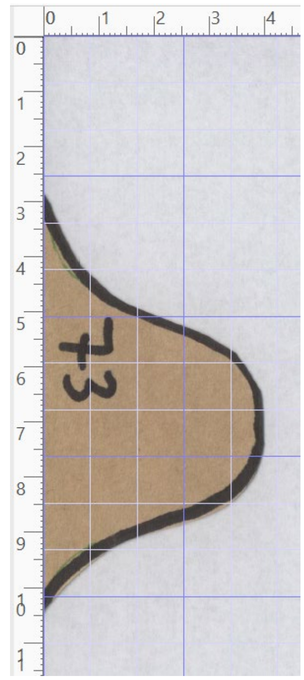
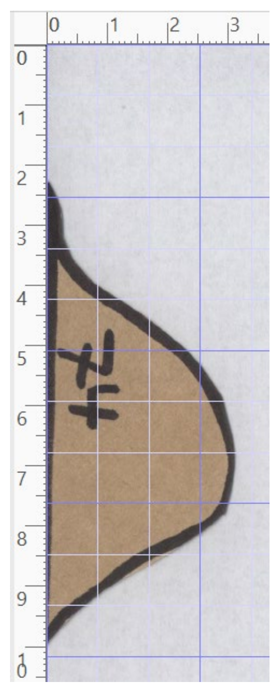
64.1 64.2	64	2.74, 3.52	4.15, 5.80 (1) (2)	Andesite		 

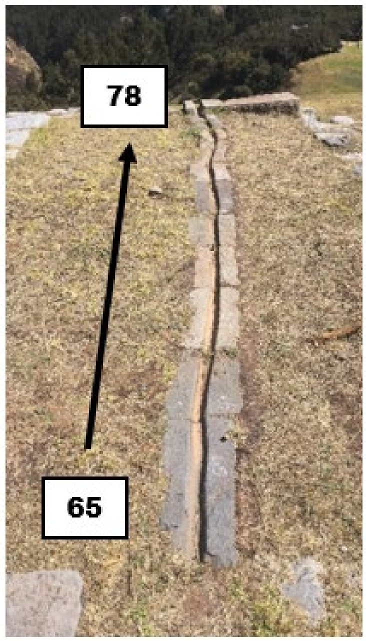
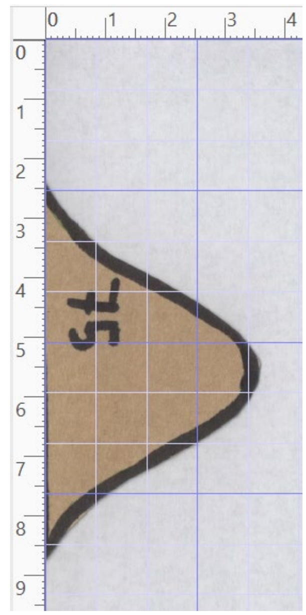
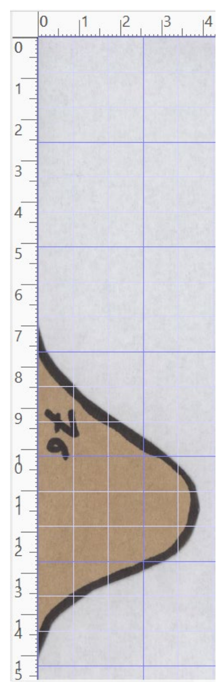
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
65	65	0.69	1.36	Andesite		
66	66	0.68	1.50	Andesite		

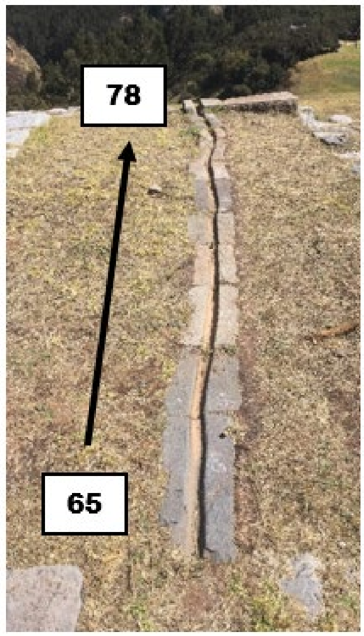
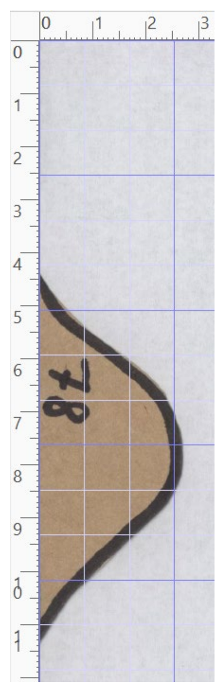
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
67	67	0.84	1.76	Andesite		
68	68	0.75	1.50	Andesite		

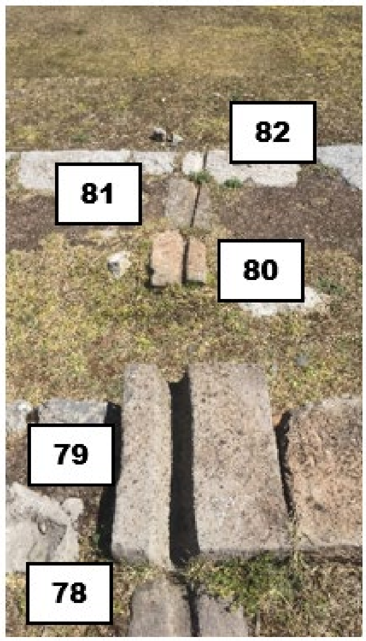
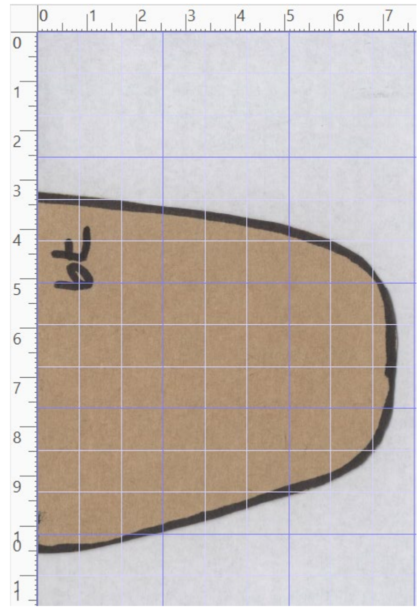
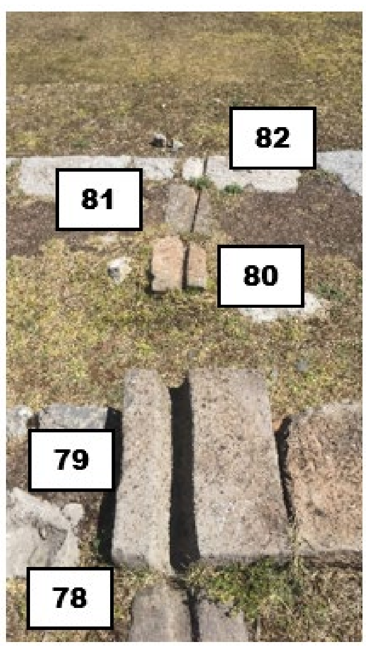
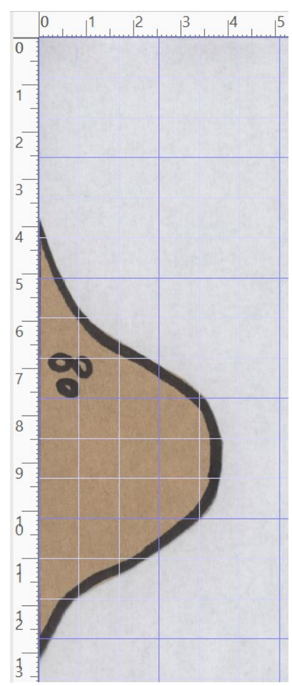
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
69	69	0.86	1.61	Andesite		
70	70	0.84	1.53	Andesite		

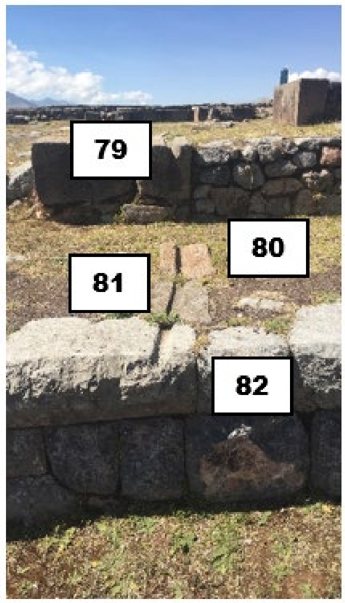
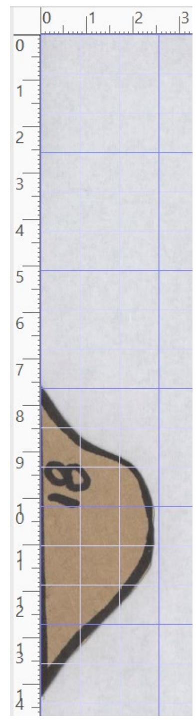
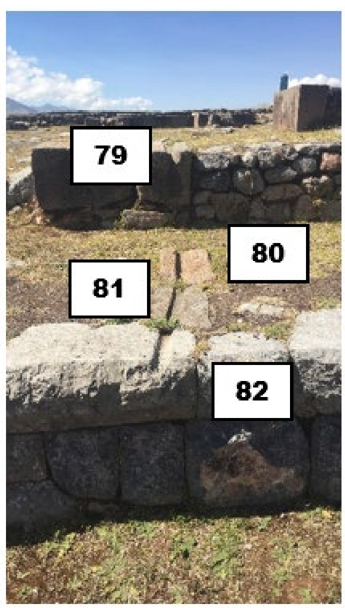
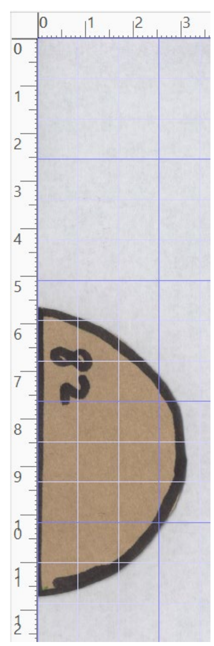
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
71	71	0.91	1.50	Andesite		
72	72	0.78	1.85	Andesite		

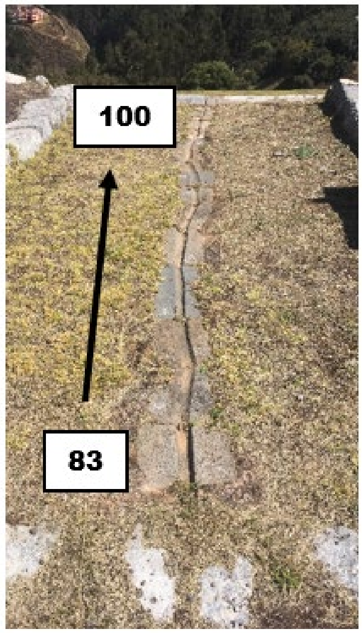
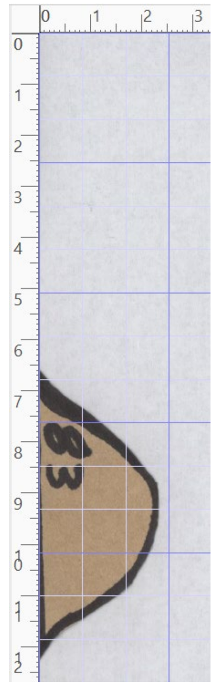
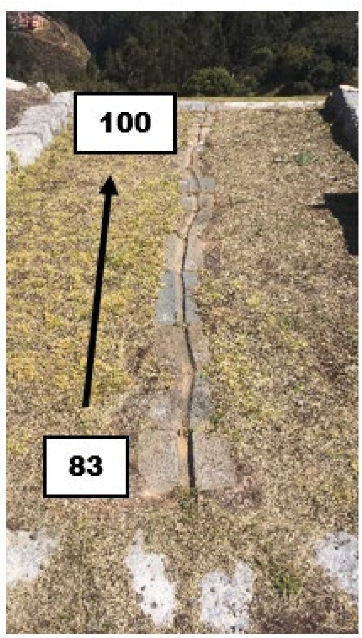
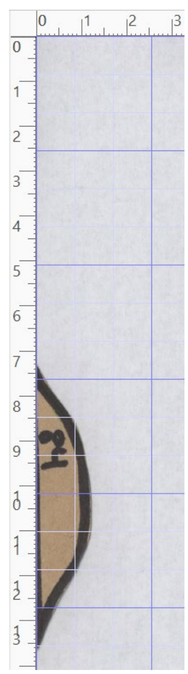
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
73	73	0.93	2.04	Andesite		
74	74	0.78	1.54	Andesite		

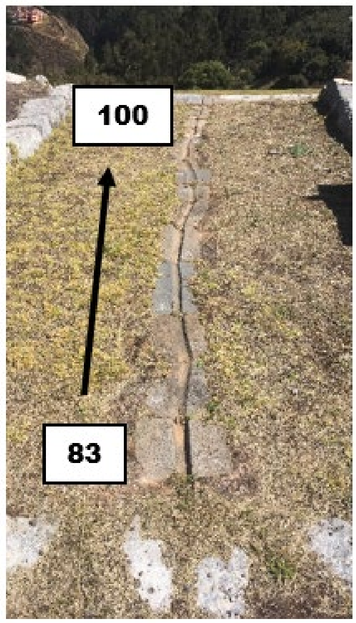
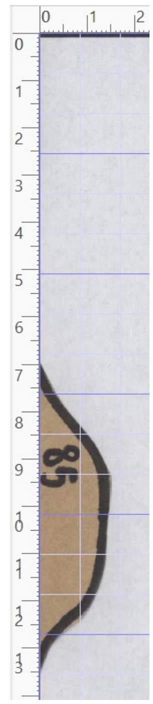
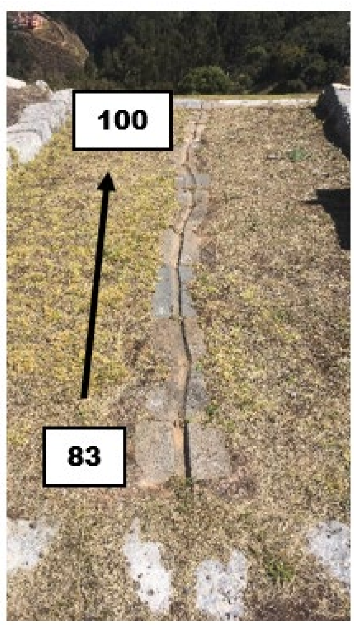
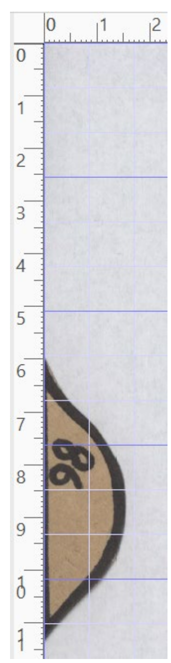
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
75	75	0.71	1.83	Andesite		
76	76	0.81	1.93	Andesite		

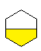
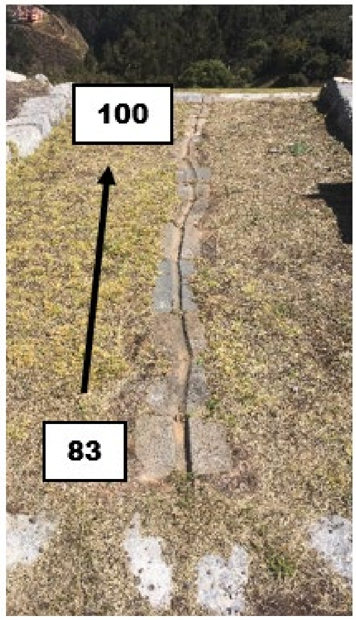
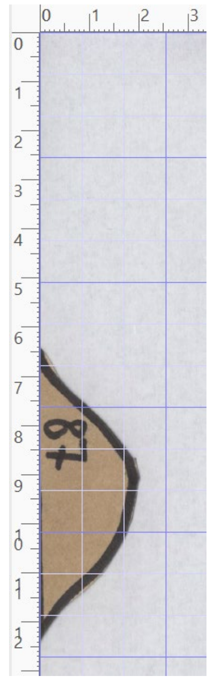
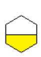
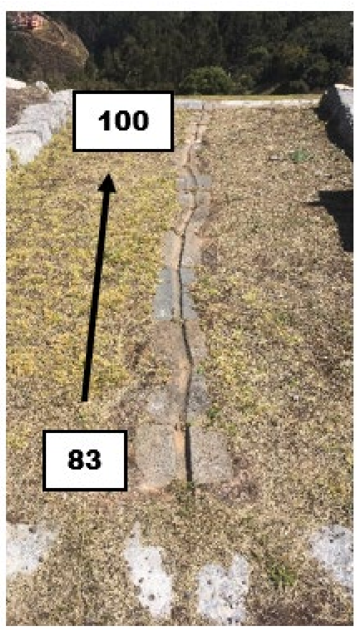
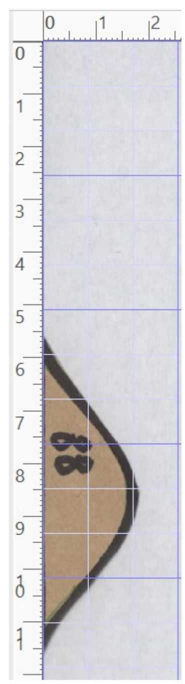
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
77	77	**0.78**	**1.44**	**Andesite**		
78	78	**0.71**	**1.42**	**Andesite**		

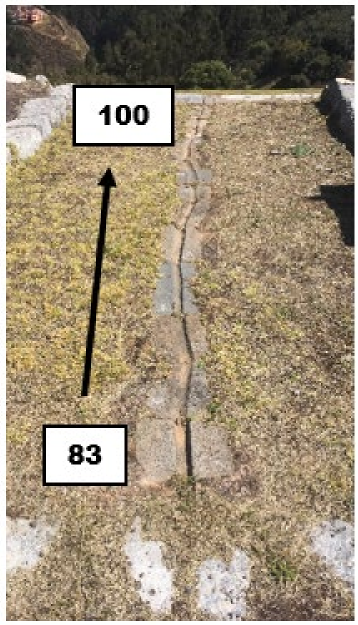
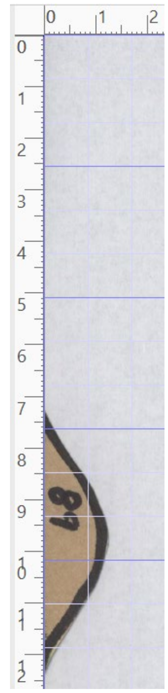
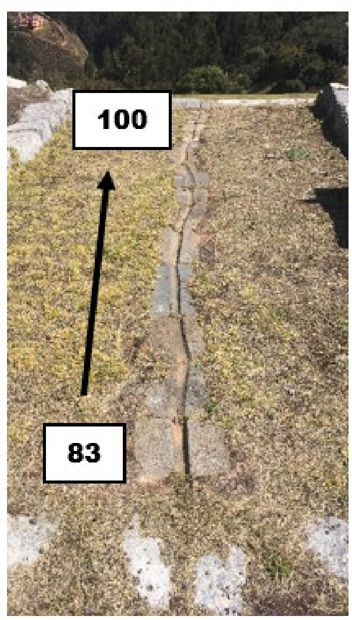
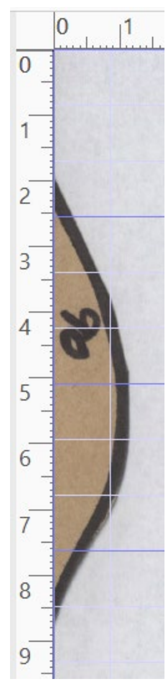
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
79	79	1.62	3.64	Andesite		
80	80	0.90	1.94	Andesite		

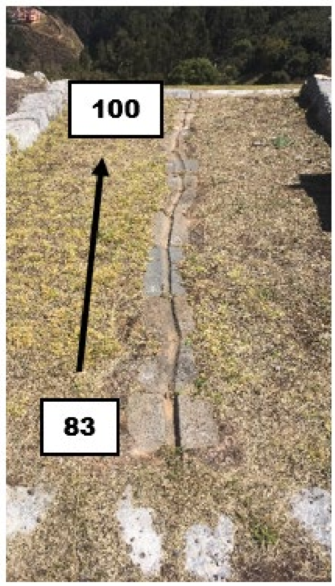
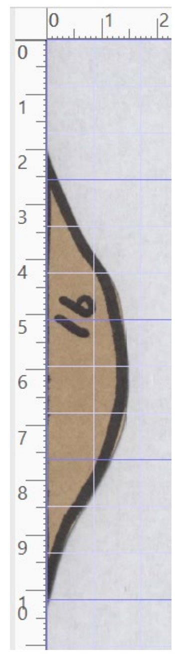
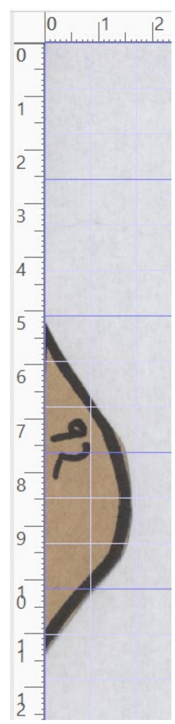
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
81	81	0.60	1.20	Andesite		
82	82	0.84	1.59	Limestone		

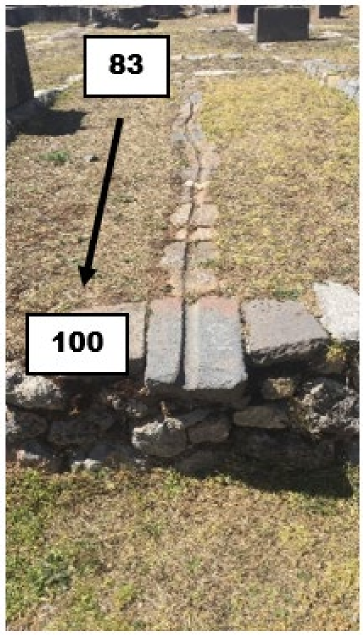
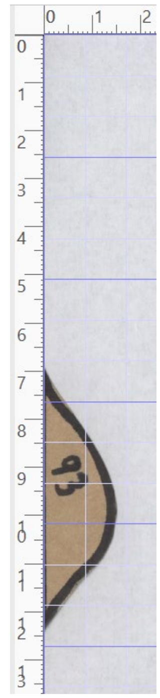
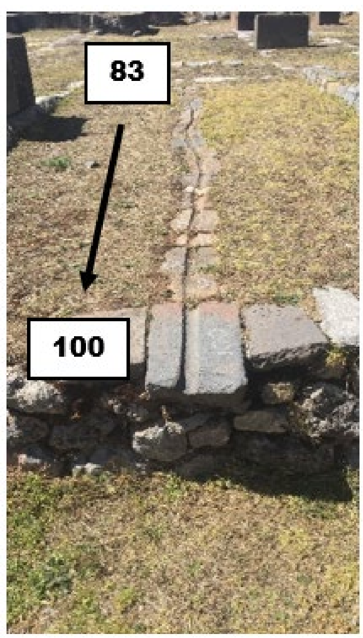
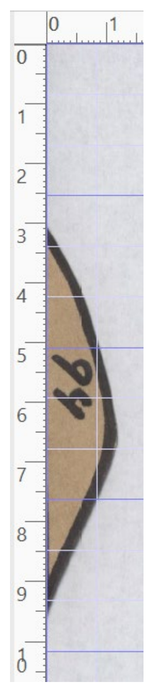
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
83	83	0.66	1.25	Andesite		
84	84	0.39	0.63	Andesite		

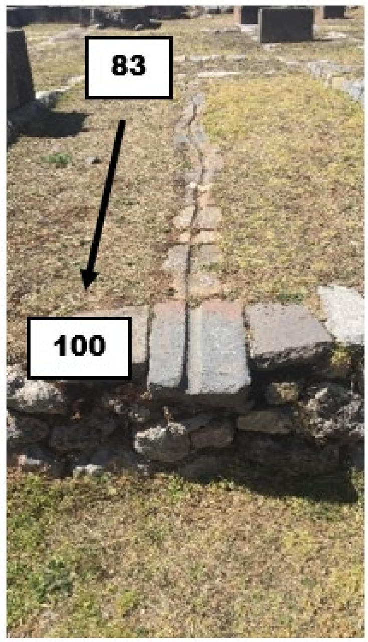
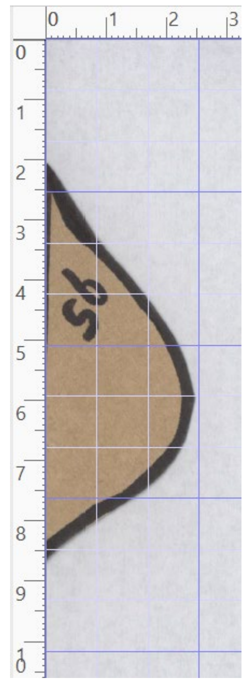
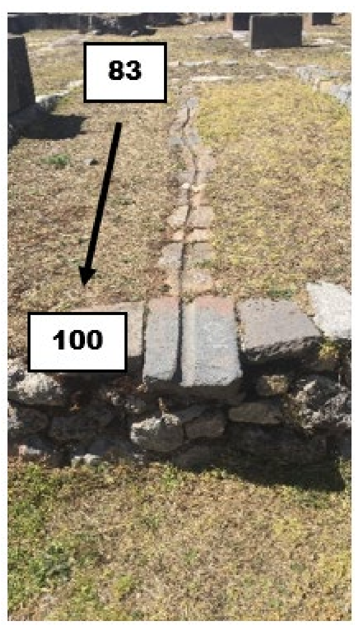
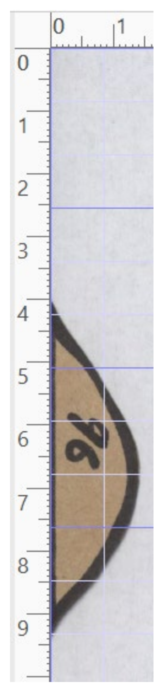
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
85	85	0.46	0.73	Andesite		
86	86	0.40	0.75	Andesite		

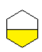
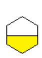
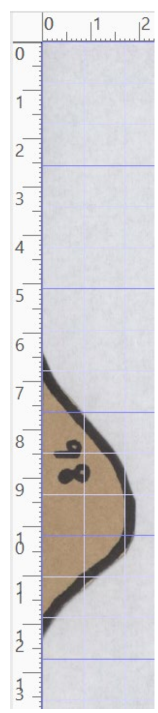
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
87	87	0.48	1.00 	Andesite		
88	88	0.41	0.85 	Andesite		

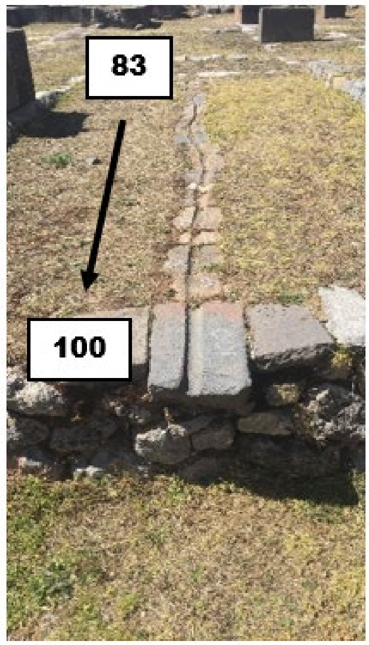
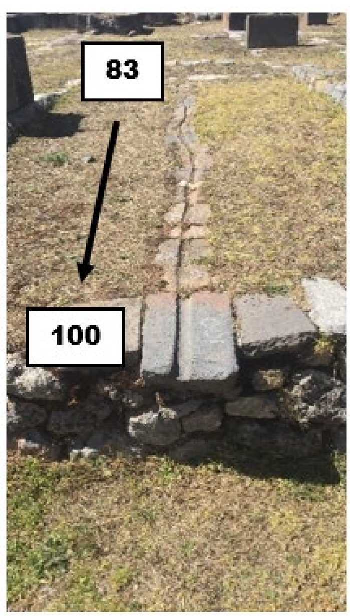
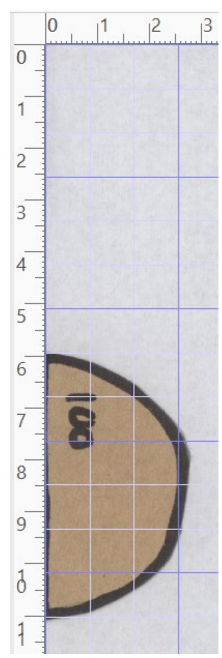
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
89	89	0.33	0.65	Andesite		
90	90	0.37	0.60	Andesite		

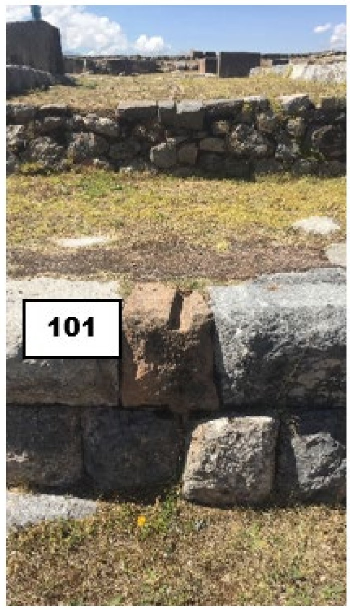
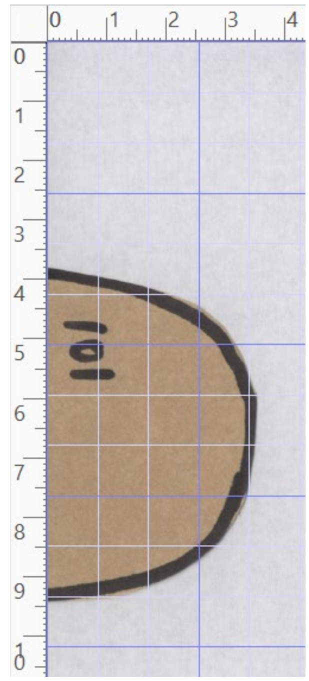
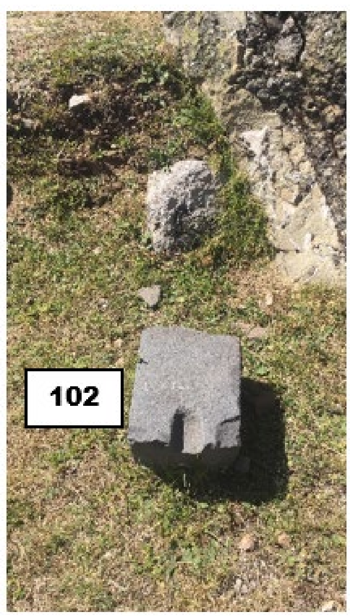
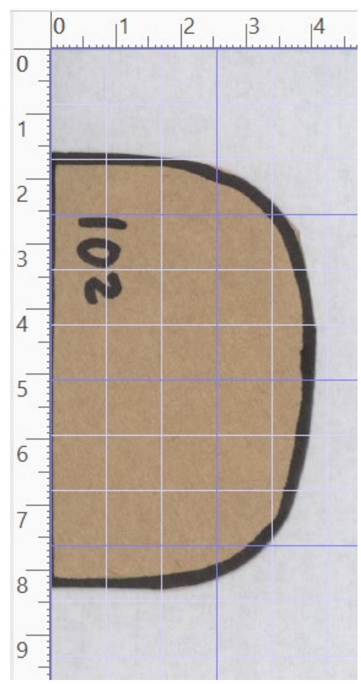
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
91	91	0.41	0.73	Andesite		
92	92	0.40	0.79	Andesite		

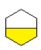
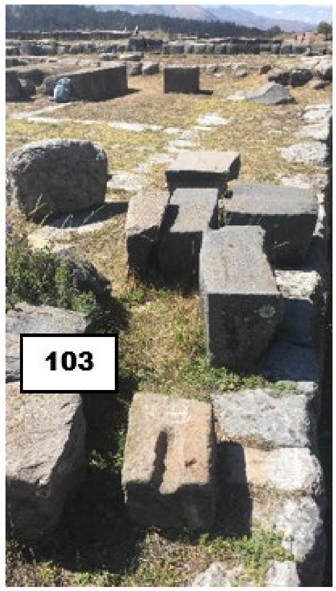
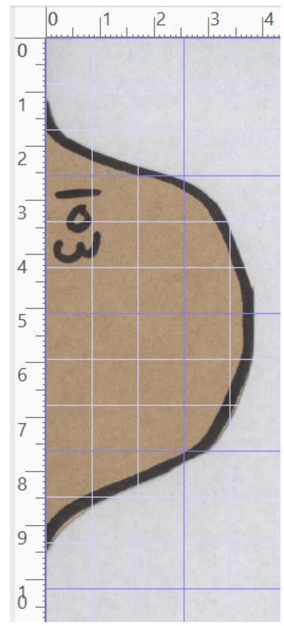
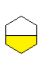
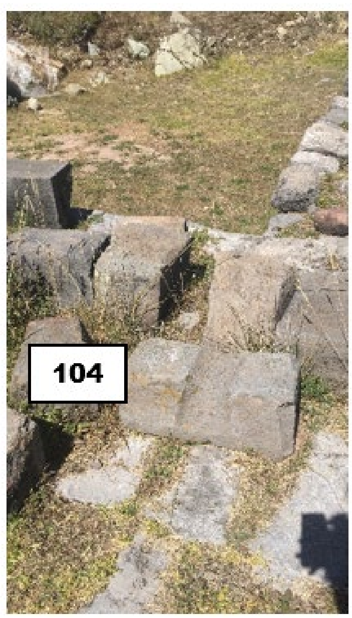
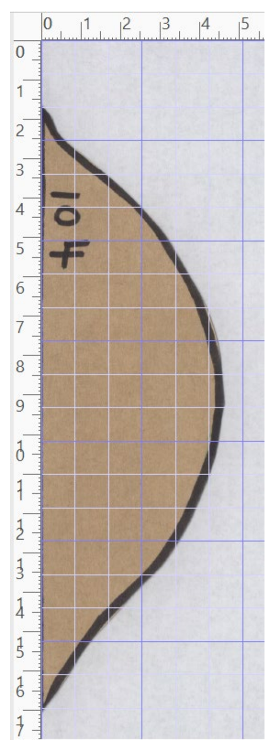
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
93	93	0.41	0.79	Andesite		
94	94	0.32	0.65	Limestone		

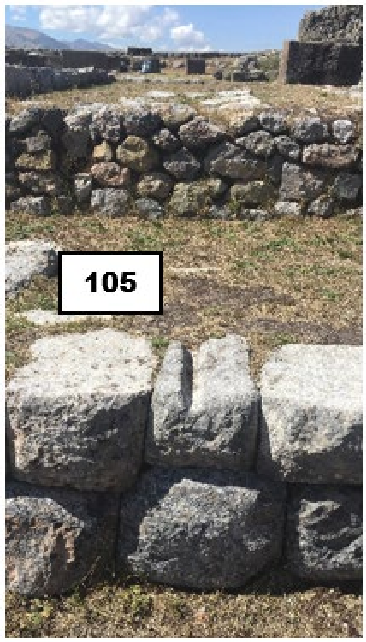
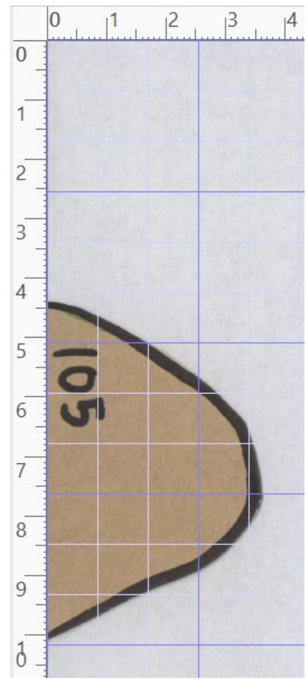
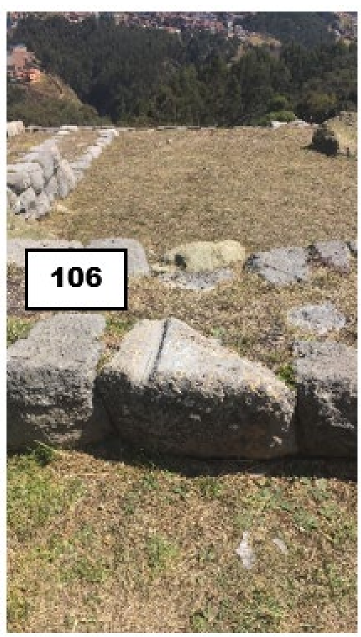
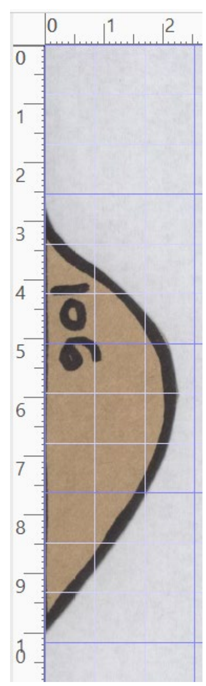
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
95	95	0.62	1.22	Andesite		
96	96	0.37	0.71	Andesite		

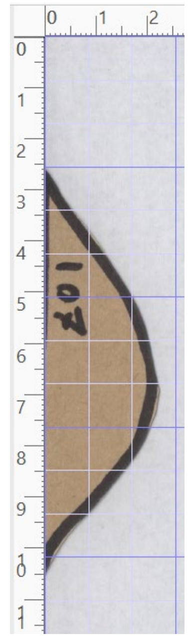
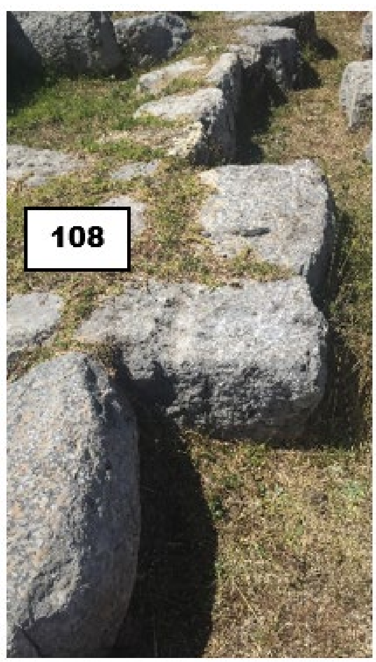
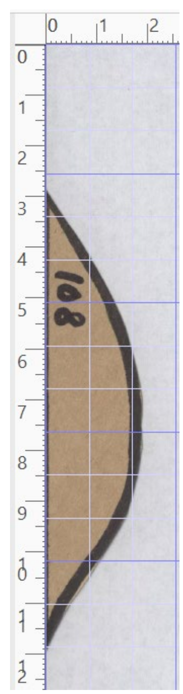
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
97	97	0.33	0.61 	Andesite		
98	98	0.49	0.96 	Andesite		

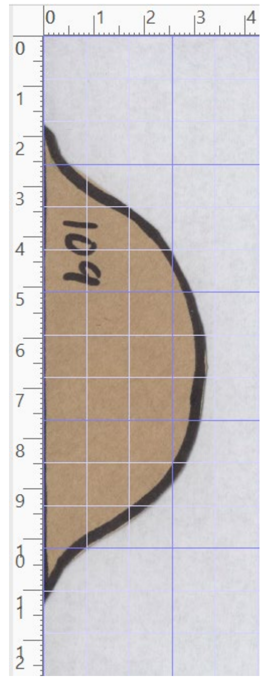
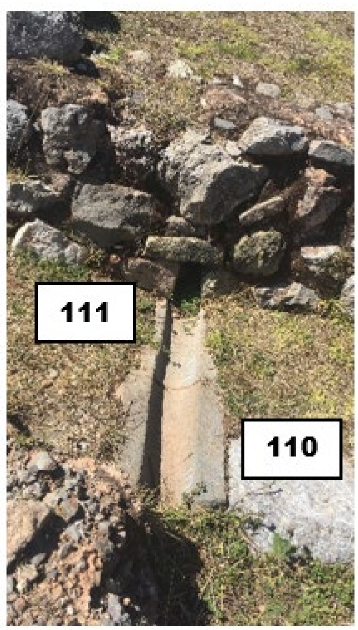
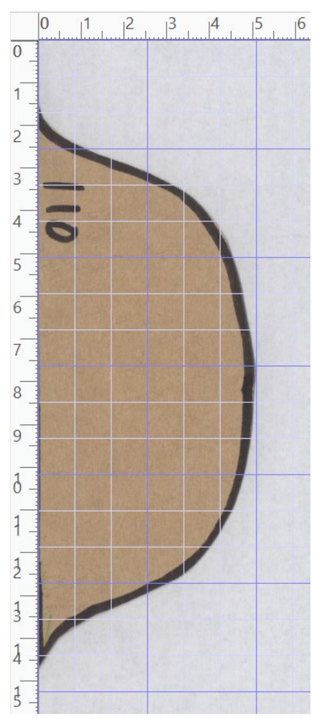
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
99	99	0.29	0.49	Andesite		
100	100	0.74	1.38	Andesite		

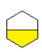
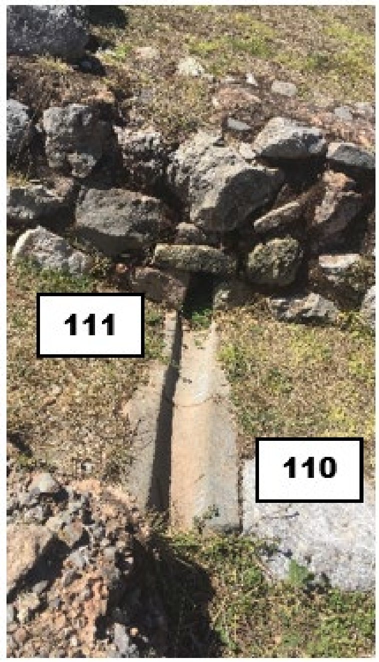
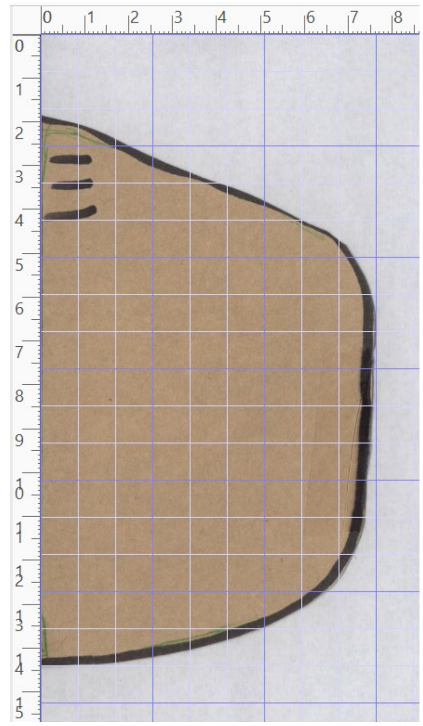
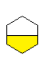
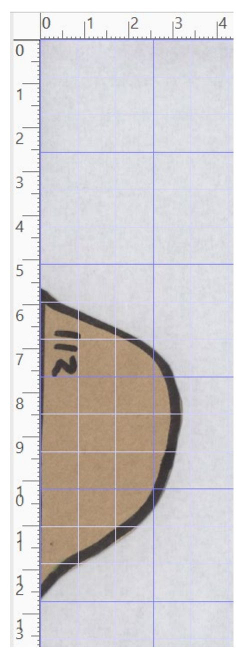
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
101	101	0.95	1.76	Andesite		
102	102	1.20	2.02	Andesite		

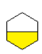
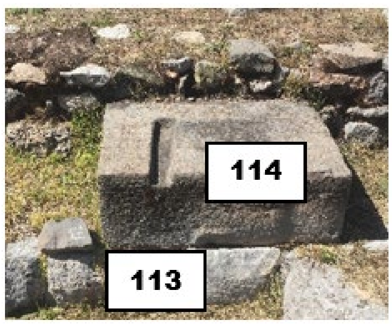
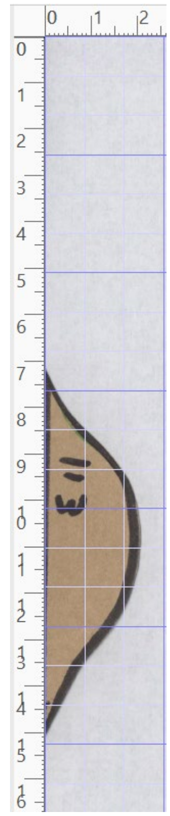
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
103	**103**	**1.08**	**1.90** 	**Andesite**		
104	**104**	**1.16**	**2.30** 	**Andesite**		

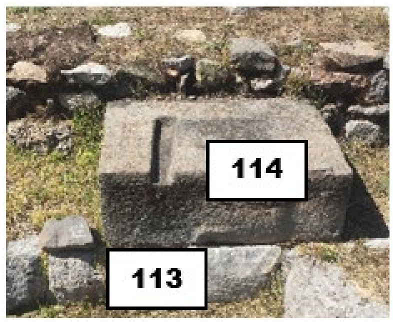
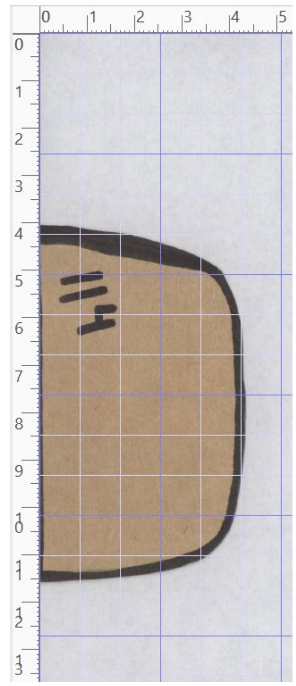
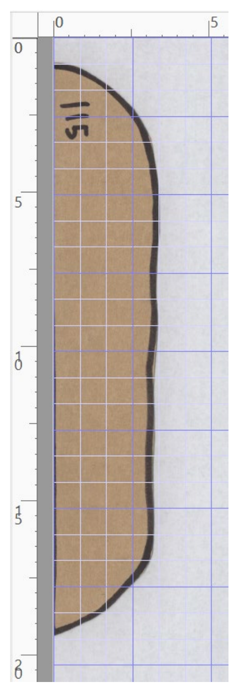
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
105	105	0.83	1.79	Limestone		
106	106	0.62	1.18	Limestone		

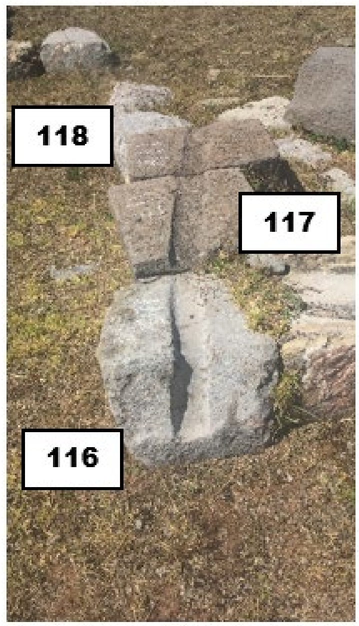
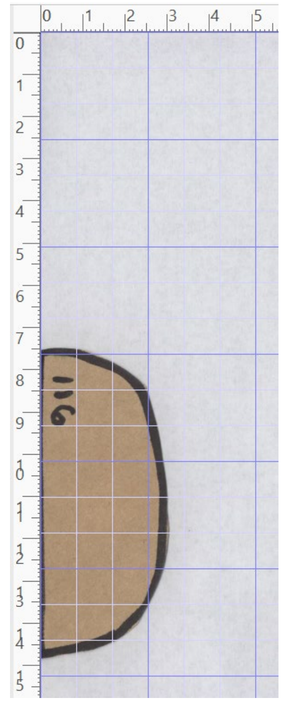
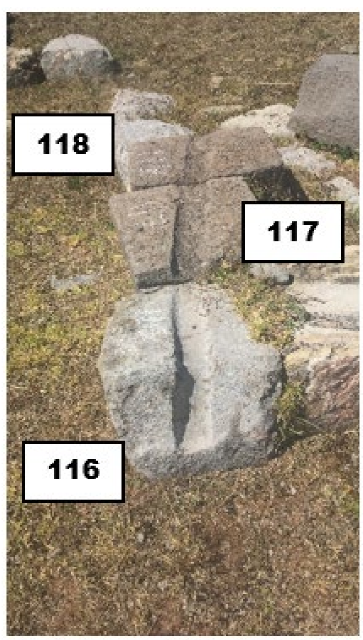
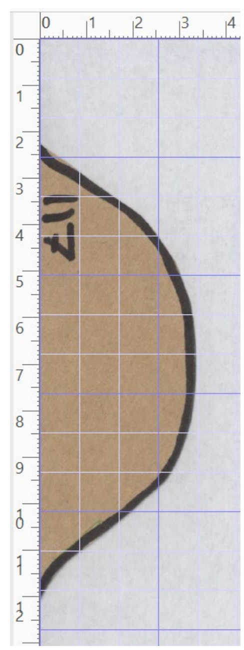
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
107	107	0.60	1.18	Limestone		
108	108	0.57	0.98	Limestone		

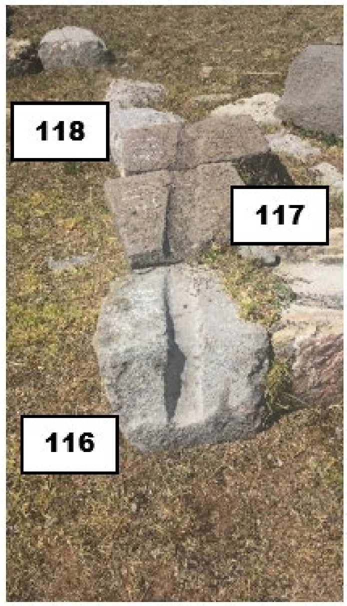
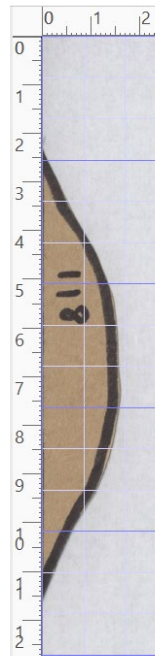
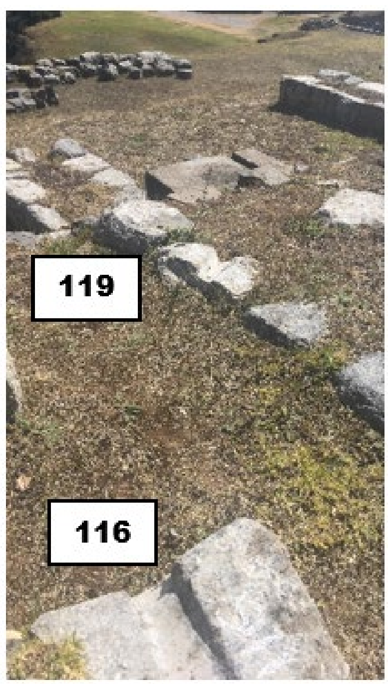
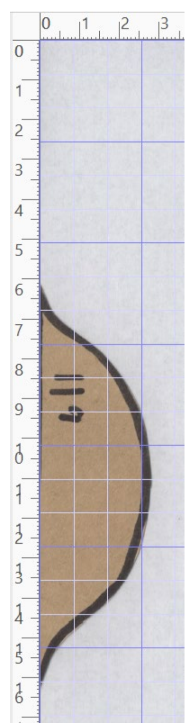
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
109	109	0.98	1.68	Limestone		
110	110	1.50	2.48	Andesite		

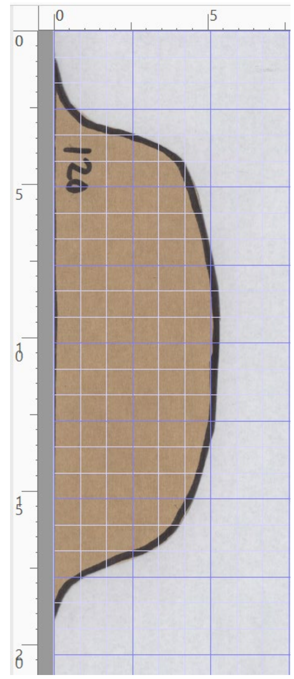
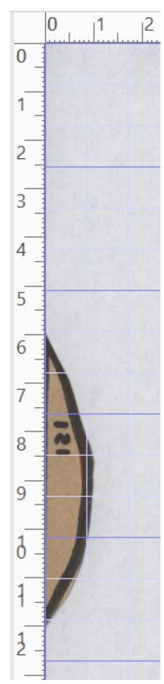
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
111	111	2.21	3.82 	Andesite		
112	112	0.85	1.63 	Limestone		

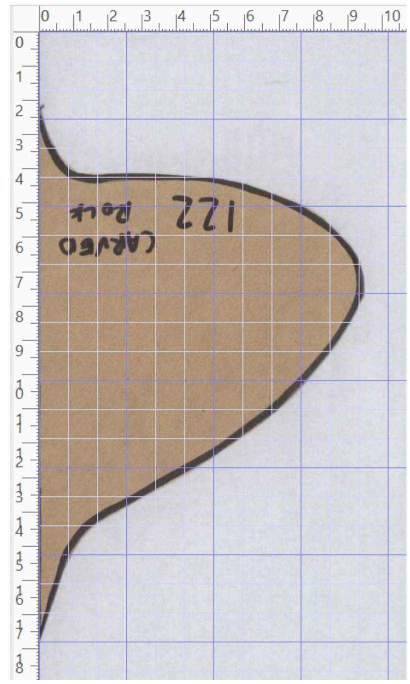
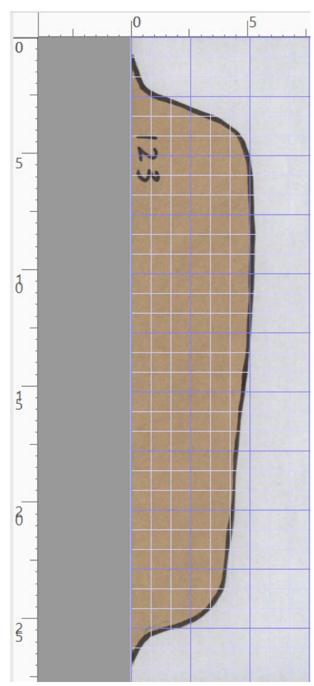
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
113	113	**0.56**	**1.00** 	**Andesite**		

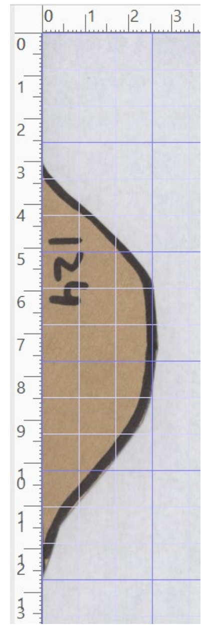
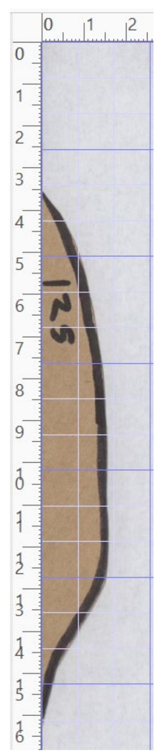
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
114	114	1.30	2.15	Andesite		
115	115	1.31	1.69	Limestone		

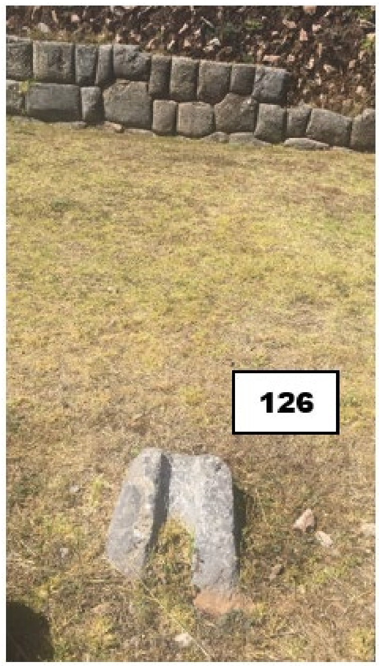
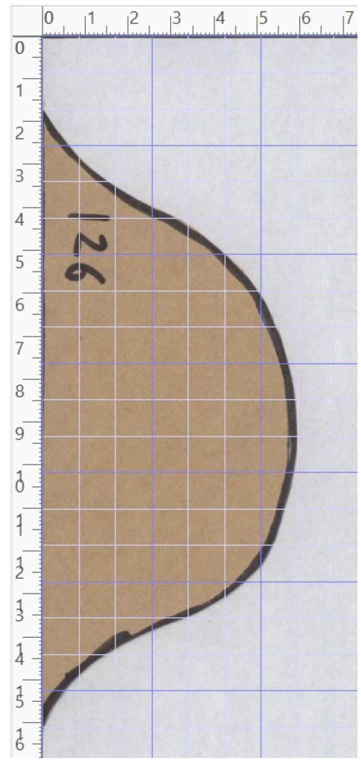
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
116	**116**	**0.96**	**1.50**	**Limestone**		
117	**117**	**1.02**	**1.71**	**Andesite**		

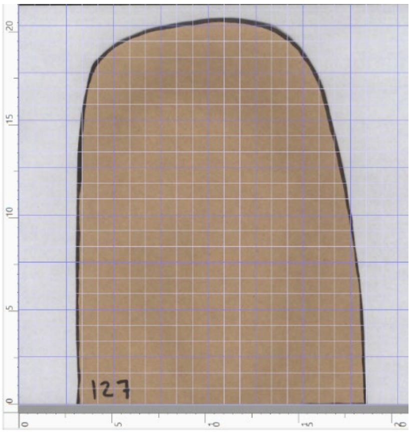
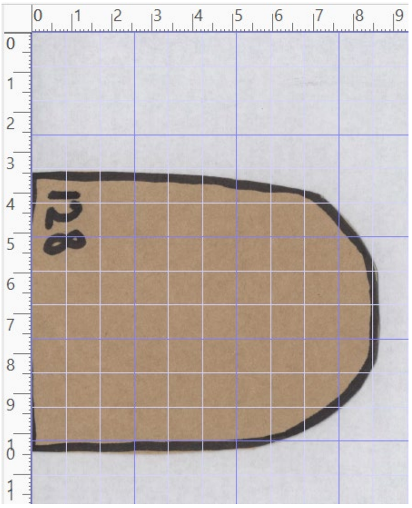
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
118	118	**0.56**	**0.84**	**Andesite**		
119	119	**0.81**	**1.37**	**Limestone**		

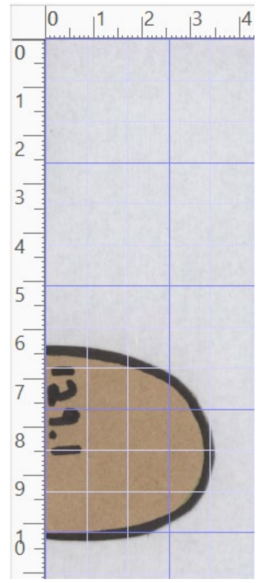
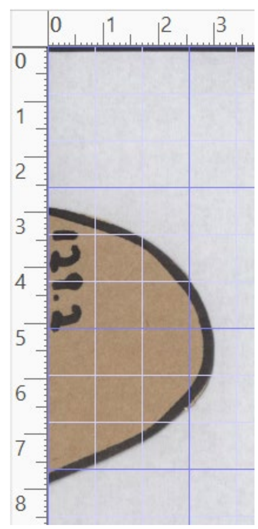
Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
120	120	1.75	2.65	Andesite		
121	121	0.31	0.51	Andesite		

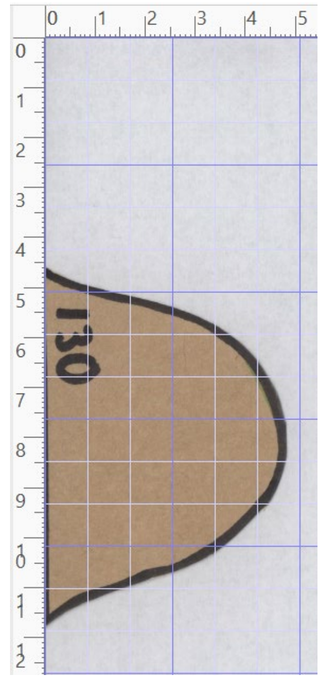
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
122	122	1.95	4.79	Limestone		
123	123	1.80	2.62	Andesite		

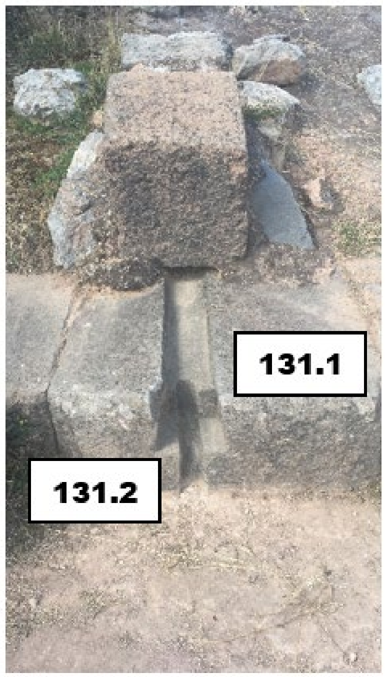
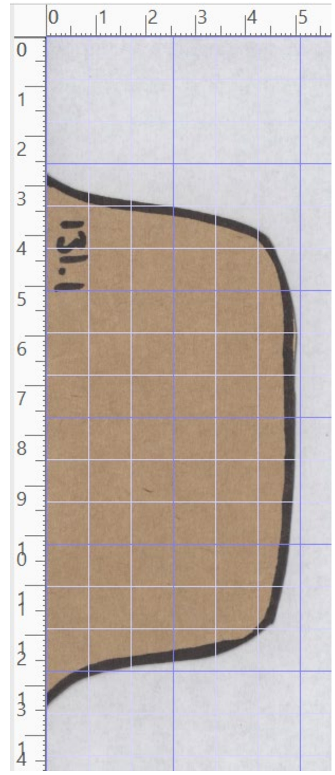
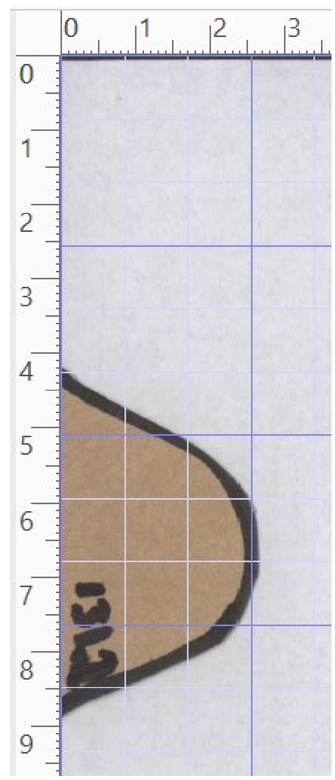
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
124	124	0.81	1.33	Andesite		
125	125	0.63	0.83	Limestone		

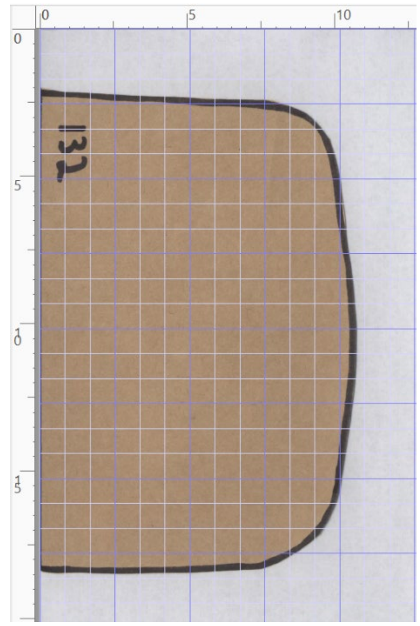
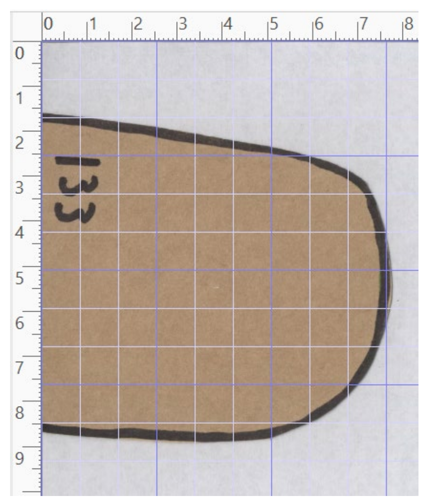
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
126	126	1.72	3.00	Limestone		

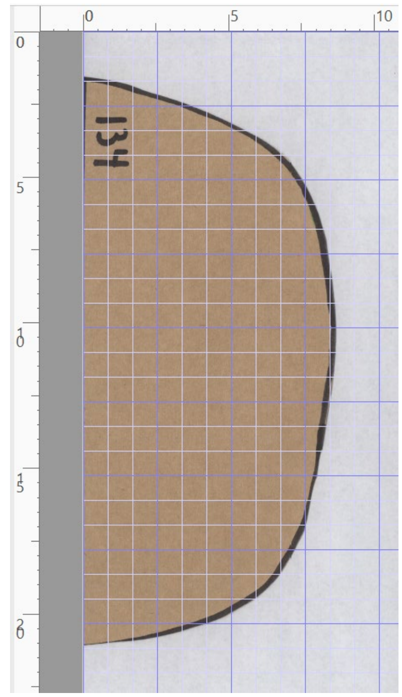
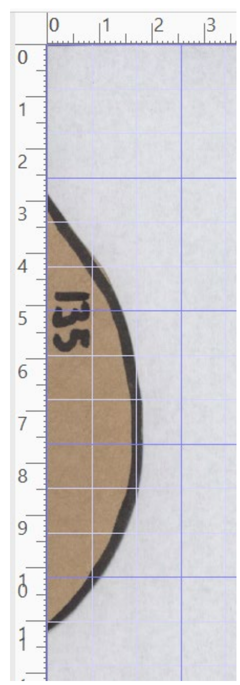
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
127	127	**4.30**	**10.33**	**Andesite**		 (Enlarged picture at the end)
128	128	**1.91**	**4.33**	**Andesite**		

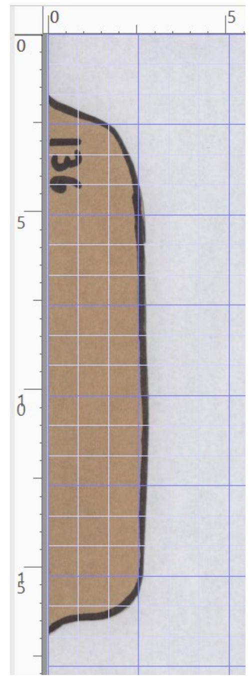
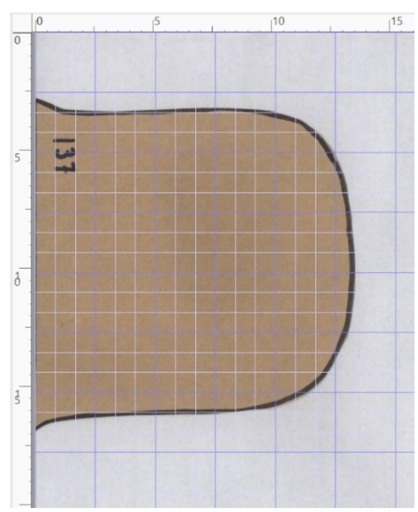
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
129.1 / 129.2	129	0.81, 0.73	1.74, 1.47 (1)  (2) 	Andesite		 

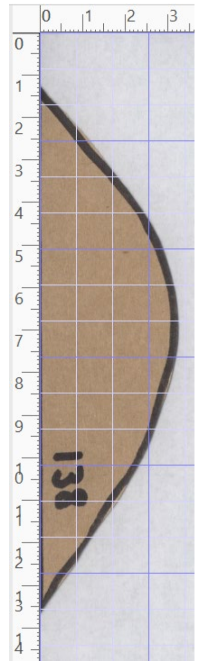
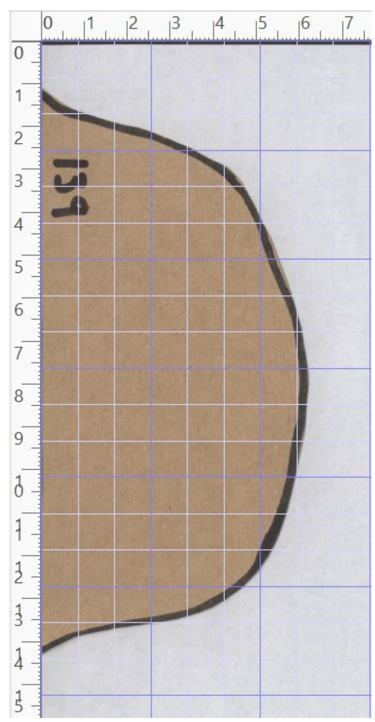
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
130	130	1.17	2.40	Andesite		

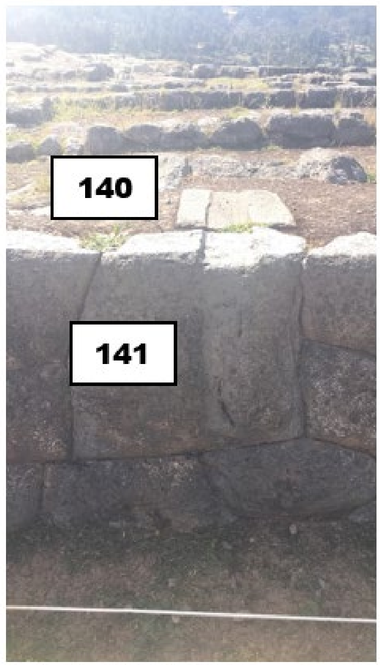
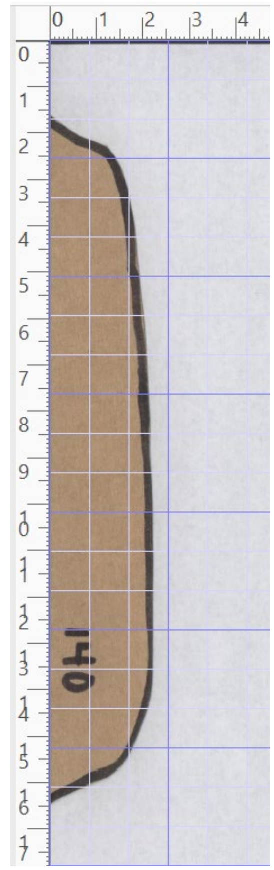
131.1 131.2	131	1.61, 0.67	2.50, 1.33 (1) (2)	Andesite		

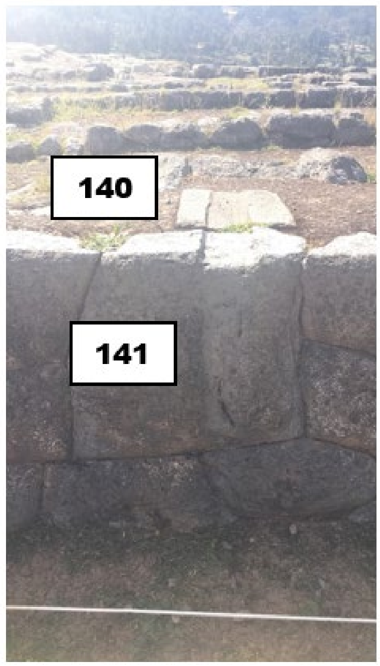
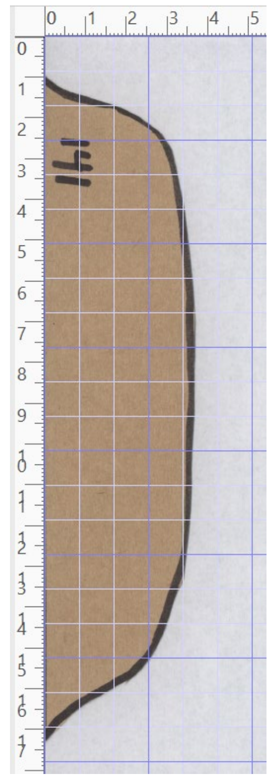
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
132	132	3.28	5.41	Limestone		
133	133	1.77	3.85	Andesite		

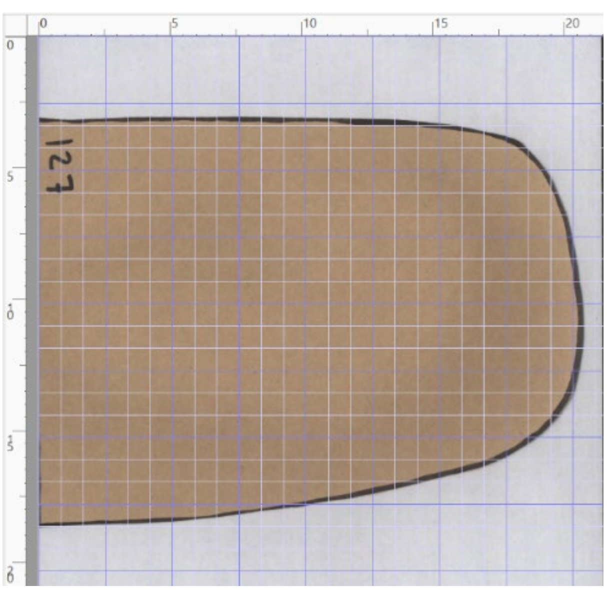
Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
134	134	2.75	4.38	Limestone		
135	135	0.59	0.93	Limestone		

Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
136	136	1.07	1.39	Andesite		
137	137	3.39	6.73	Limestone		

Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
138	138	0.88	1.56	Limestone		
139	139	1.87	3.13	Andesite		

Stone Number	GIS Point	Hydraulic Radius (R_H)		Stone Type	Photo of Stone	Stone Cross-section (cm)
		HALF-FULL	MOST EFFICIENT			
140	140	**0.89**	**1.18**	**Andesite**		

Stone Number	GIS Point	Hydraulic Radius (R_H) HALF-FULL	Hydraulic Radius (R_H) MOST EFFICIENT	Stone Type	Photo of Stone	Stone Cross-section (cm)
141	141	1.38	1.88	Limestone		



(Stone Cross-section 127)

E. STONE SEGMENT DETAILED NOTES

Table 25 includes detailed notes, recorded during the summer of 2016, about each stone segment. The notes included stone cross-section, channel segment stone type, channel segment stone color, if the stone was rough or smooth, whether the stone was in-situ, if the stone looked to be in the right place, if the stone could have been placed in that location, and any other detailed notes.

Table 25: Stone Segment Detailed Notes

Stone Cross-section	Channel Segment Stone Type	Channel Segment Stone Color	Rough (R) or Smooth (S)	In-situ (Y or N)	Does it look like the right place? (Y or N)	Could a stone have been placed on it?	Extra Notes
1	Andesite	black/grey	S	Y	N	N	All these stones are leading out of the Muyuc Marca. Channel 1. This is the only port out of the system as well
2	Limestone	light grey	R	Y	Y	Y	
3	Andesite	black/grey	S	Y	N	N	
4	Limestone	light grey	R	Y	Y	Y	-
5	Limestone	light grey	R	Y	Y	N	-
6	Andesite	black/grey	S	Y	N	N	-
7	Andesite	black/grey	S	Y	N	Y	-
8	Andesite	black/grey	S	Y	N	N	-
9	Andesite	black/grey	S	Y	N	N	-
10	Andesite	black/grey	S	Y	N	N	-
11	Andesite	black/grey	S	Y	N	N	-
12	Andesite	black/grey	S	Y	N	N	-
13	Andesite	black/grey	S	Y	N	N	-
14	Andesite	black/grey	S	Y	N	N	-
15	Andesite	black/grey	S	Y	N	N	-
16	Andesite	black/grey	S	Y	N	N	-
17	Andesite	black/grey	S	Y	N	N	-
18	Andesite	red	S	Y	N	N	Very red, next channel segment after square channels
19	Andesite	black/grey	S	Y	N	Y	Leads to underground channel (along channel 1)

20.1	Andesite	black/grey	S	Y	N	Y	Looks very out of place, no channel leading to it.
20.2	Andesite	black/grey	S	Y	N	Y	A fountain piece.
21	Andesite	black/grey	S	Y	N	N	Channel segment after fountain piece
22	Andesite	black/grey	S	Y	N	N	Lead to an underground channel passage
23	Andesite	light brown - reddish	S	Y	Y	N	On south side of Muyuc Marca. Looks like it leads to the priestly sector
24	Andesite	black/grey	S	Y	Y	N	
25	Andesite	black/grey	S	Y	Y	N	-
26	Andesite	black/grey	S	Y	Y	N	-
27	Andesite	black/grey	S	Y	Y	Y	-
28	Andesite	black/grey	S	Y	Y	N	-
29	Andesite	black/grey	S	Y	Y	N	-
30	Andesite	black/grey	S	Y	Y	N	-
31	Limestone	light grey	R	Y	Maybe	N	Long stone! Channel 2
32	Limestone	light grey	R	Y	Y	N	Long stone! Channel 2
33	Andesite	grey	S	Y	N	N	Channel 2
34	Andesite	grey	S	Y	N	N	-
35	Limestone	light grey	R	Y	Y	N	-
36	Limestone	light grey	R	Y	Maybe	N	-
37	Andesite	black/grey	S	N	N	N	Random piece
38	Andesite	grey	S	Y	N	N	Part of channel 3, no port leading to it, no channel leading after
39	Andesite	grey	S	Y	N	N	-
40	Andesite	grey	S	Y	N	Y	-
41	Andesite	grey	S	Y	Y	N	-
42	Limestone	light grey	R	Y	Y	N	-
43	Limestone	light grey	R	Y	Y	Y	All alone, possibly channel 3 leading to it

44	Limestone	light grey	R	Y	N	Y	Random 3 channels with no water leading to it or any water leading away. Has a bend in it. One of the only ones the channel is cut far on the side of the stone segment
45	Limestone	light grey	R	Y	N	Y	-
46	Limestone	light grey	R	Y	N	Y	-
47	Limestone	light grey	R	Y	Y	Y	At the moment, no channels are leading to it, but there can be a channel leading away from it from Muyuc Marca. Can lead to priestly sector
48	Limestone	light grey	R	Y	Y	Y	Leads from 47, possibly to 49
49	Andesite	black/grey	S	Y	N	Y	Leads to priestly fountain
50	Andesite	black/grey	S	Y	N	N	Possibly leading from 48
51	Limestone	light grey	R	Y	Y	Y	-
52	Andesite	black/grey	S	Y	N	Y	Leads to priestly fountain, light/worn cut channel leads to 53?
53	Limestone	light grey	R	Y	Y	Y	Leads to priestly fountain
54	Andesite	black/grey	S	Y	N	N	Very random, no channel leading to it, between caliza stones
55.1	Andesite	grey	R/S	N	N	N	2 cuts on channel. 1 wider channel cut on top & 1 narrower cut on side

55.2	Andesite	grey	R/S	N	N	N	-
56	Limestone	light grey	R	Y	Y	N	All alone.
57	Andesite	grey	S	Y	N	N	All alone. Out of place.
58	Andesite	black/grey	S	Y	N	N	Leading from 43 & leads into an underground. Hard clay on top of underground channel. Could come from channel 3
59	Andesite	light brown - reddish	S	Y	N	N	Channel with channels on top of them. Not sure where water comes from. Channel 3?
60	Andesite	light brown - reddish	S	Y	N	N	-
61	Andesite	grey	S	Y	N	N	-
62	Andesite	grey	S	Y	N	N	End of channel with channels on top
63	Andesite	grey	S	Y	N	N	Square channel cut, looks like it would fit with 64
64.1	Andesite	black/grey	S	Y	N	N	2 square cuts, 1 on side & 1 on top. Miksad thinks this was used to take water out of the Muyuc Marca
64.2	Andesite	black/grey	S	Y	N	N	-
65	Andesite	black/grey	S	Y	N	N	Beginning of a channel
66	Andesite	black/grey	S	Y	N	N	Where does it come from?
67	Andesite	grey	S	Y	N	N	In channel
68	Andesite	grey	S	Y	N	N	It's a curved/not straight channel fitting
69	Andesite	grey	S	Y	N	N	-
70	Andesite	black/grey	S	Y	N	N	-
71	Andesite	black/grey	S	Y	N	N	-
72	Andesite	grey	S	Y	N	N	-
73	Andesite	grey	S	Y	N	N	-
74	Andesite	grey	S	Y	N	N	-

75	Andesite	black/grey	S	Y	N	N	-
76	Andesite	light brown	S	Y	N	N	-
77	Andesite	black/grey	S	Y	N	N	-
78	Andesite	black/grey	S	Y	N	N	-
79	Andesite	grey	S	Y	N	N	Last stone before drop off
80	Andesite	light brown - reddish	R/S	Y	N	N	Has a curved cut, like side view!
81	Andesite	grey	R/S	Y	N	N	Channel cut @ an angle
82	Limestone	light grey	R	Y	Y	Y	Looks like it would be there, channel cut @ end of stone segment
83	Andesite	grey	S	Y	N	N	Part of another Channel that leads off.
84	Andesite	grey	S	Y	N	N	
85	Andesite	light brown/grey	S	Y	N	N	
86	Andesite	black/grey	S	Y	N	N	Where does water come from?
87	Andesite	grey	S	Y	N	N	-
88	Andesite	grey	S	Y	N	N	-
89	Andesite	grey	S	Y	N	N	-
90	Andesite	black/grey	S	Y	N	N	-
91	Andesite	light brown	S	Y	N	N	-
92	Andesite	light brown	S	Y	N	N	-
93	Andesite	black/grey	S	Y	N	N	-
94	Limestone	light grey	R	Y	N	N	Random limestone stone
95	Andesite	grey	S	Y	N	N	-
96	Andesite	light brown	S	Y	N	N	-
97	Andesite	light brown	S	Y	N	N	-
98	Andesite	grey	S	Y	N	N	-
99	Andesite	grey	S	Y	N	N	-
100	Andesite	black/grey	S	Y	N	N	Last stone before drop to 101
101	Andesite	red	S	Y	N	N	Angled cut. Random place between 2 limestone stones on wall. Leading from 100
102	Andesite	black/grey	S	N	N	N	Fountain drop
103	Andesite	light brown - reddish	S	N	N	N	Fountain drop

104	Andesite	grey	S	N	N	N	2 channel cuts, both wide cuts. 1 on top & one on side
105	Limestone	light grey	R	Y	Y	N	Channel cut on side of stone segment. None leading to it, but looks in place. There must have been a channel leading to it @ some point.
106	Limestone	light grey	R	Y	Y	N	Cut on side of stone segment & angled
107	Limestone	light grey	R	Y	Y	N	Cut on side of stone segment & angled
108	Limestone	light grey	R	Y	Y	N	Cut on side of stone segment
109	Limestone	light grey	R	Y	Y/Maybe	Y/N	Lighter stone. J drop. Drop from fountain, so stone on top
110	Andesite	grey	S	Y	N	N	Channels lead out from port under the ground where is one beginning pf port?
111	Andesite	grey	S	Y	N	N	-
112	Limestone	light grey	R	Y	N	N	Cut on side of stone segment, doesn't look like stone is in the right place
113	Andesite	black/grey	S	N	N	N	Fountain drop, very small, looks broken
114	Andesite	black/grey	S	Y	N	Y	Fountain drop on side of stone segment. There would have been another stone on top of it. No fountain around
115	Limestone	light grey	R	N	N	Y	Looks like a channel/other segment fit on it

116	Limestone	grey	R	Y	N	N	J-drop. Cut is angled on a stone segment -
117	Andesite	grey	S	Y	N	N	Angled cuts on stones. 117 & 118 look like they go together. Where is water coming from for this?
118	Andesite	grey	S	Y	N	N	-
119	Limestone	grey	R	Y	Y	N	Angled cut on channel. Channel is leading to somewhere random
120	Andesite	red	S	N	N	Y	Really pretty red. Deep. Long piece. Piece on top.
121	Andesite	black/grey	S	N	N	Y/N	Fountain drop. Faded out.
122	Limestone	grey	R	Y	Y	N	BIG ROCK. Carved into rock channel leads to R1 complex
123	Andesite	grey	S	N	N	N	Wide channel cut
124	Andesite	grey	S	N	N	N	-
125	Limestone	light grey	R	N	N	N	-
126	Limestone	grey	R	N	N	N	Looks like it was thrown into the ground.
127	Andesite	grey	S	N	N	Y	Cut on side of stone, big channel cut/deep channel cut. It actually has 2 cuts in the stone. One on the side & one on the bottom
128	Andesite	light brown	S	N	N	N	Angled cut on stone
129.1	Andesite	grey	S	Y	Maybe	Y	It is the angled fountain drop. Has a bend in the drop
129.2	Andesite	grey	S	Y	Maybe	Y	-

130	Andesite	grey	S	Y	Maybe	N	Don't know how water is getting to it and where it is going. Random
131.1	Andesite	grey	S	Y	N	N	Looks like it would fit on 129. The two can go together. Fountain piece
131.2	Andesite	grey	S	Y	N	N	-
132	Limestone	grey	R	Y	Y	Y	Looks like part of the wall & looks like it was there. Possibly bath/fountain behind it.
133	Andesite	grey	S	N	N	N	Cut on side of segment & angled cut
134	Limestone	light grey	R	N	N	Y	Wide cut
135	Limestone	grey	R	Y	Y	N	-
136	Andesite	grey	S	N	N	N	Faint channel cut, curved channel cut
137	Limestone	grey	R	Y	N	N	Very random channels, where did they get water & where did it go?
138	Limestone	grey	R	Y	N	N	-
139	Andesite	black/grey	S	N	N	N	Very out of place. On top of limestone stones
140	Andesite	grey	S	Y	N	N	Fainted cut, leads to a limestone stone
141	Limestone	grey	R	Y	Y	Y/N	J-drop, part of wall, part of a water drop

V. CONCLUSION, FUTURE WORK, AND RECOMMENDATIONS

There are three concluding thoughts to take away from this research. The first is that each of the three Muyuqmarka channels have channel segments that are visibly and hydraulically misplaced. The second is that mixed stones, both limestone and andesite, have similar hydraulic radii. The third takeaway is that when compared to the most efficient channel case, the half-full channel case not only provided more accurate results, but also used the actual shape of the channel.

The first takeaway is that all three Muyuqmarka channels are hydraulically mismatched and inaccurately display the original channel configuration of the Inca. This is apparent when first looking at the channel pieces and then confirmed when closely analyzing each channels' hydraulic radii. Within a given water channel the hydraulic radii should be similar for transporting water through a cross-section. In some cases, for example in channel 2 and channel 3, the hydraulic radii differ so much that it would have been impossible for certain stones to be constructed within that channel. The data shows that all three channels have skewered hydraulic radii.

The next takeaway is that limestone and andesite stones had similar hydraulic radii. There appeared to be more andesite stones than limestone, but the limestone channel segments were mixed in with the andesite channels segments. Prior knowledge indicates that the Inca did not mix their stones types. However, looking at the hydraulic analysis the Incans may not have actually been consistent when constructing their channels with certain stone types. On the other hand, when the Spanish conquistadors arrived, what could have happened as well is that more limestone segments were misplaced than andesite segments.

The final takeaway is the half-full channel case accurately represented the current shape of the channel segment. Although the most efficient channel case assumed a perfect shape, it misrepresented the amount of discharge through a channel cross-section by overestimating, and in some cases underestimating, volumetric flow-rate. The half-full hydraulic section used an online program to accurately calculate the channel's irregular shaped parameters whereas the most efficient hydraulic section assumed a known shape for the channel and used equations to calculate that shape's parameters. Ideally the most efficient channel case should produce the best results in terms of most efficient discharge, but its discharge should not exceed the discharge of the full-shaped channel, in which cases it did. For this reason, since both the most efficient hydraulic section and half-full hydraulic section used half the channel depth to calculate the hydraulic radius, the half-full hydraulic section was used for the analysis of the 146 channel cross-sections. Thus the lasting contribution of this work was the usage of the actual shape of the channel versus an assumed shape.

Moving forward the data presented in this thesis could be used as evidence as to why the Muyuqmarka in its current state inaccurately represents the original Inca structure. The inconsistency in each channels' hydraulic radii point to the improper channel configuration. As mentioned earlier, the lasting contribution of this thesis is the use of the actual shape of the channel to calculate the hydraulic radii and discharge. Compared to the assumed channel shape, the actual, irregular channel shape accurately captures the area of the channel flow and does not overestimate or underestimate the given area. Not only can this data be used to prove the questionable reconstruction, but it can also be used in support of restoring the channels to their original design. The detailed catalogue of channel segments, stone segment detailed notes, and appendices can aid in deciding where to put each channel segment.

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VII. APPENDICES

A. APPENDIX 1: Stone Segment Dimensions

Stone Segment	Stone Segment Width (cm)	Stone Height (cm)	Stone Length (cm)	Channel Length (cm)
1	38.10	30.48	44.45	44.45
2	45.72	Buried	Buried	Buried
3	49.53	9.50	9.50	9.50
4	55.88	24.00	Buried	Buried
5	43.18	25.50	99.00	99.00
6	41.91	28.00	112.00	112.00
7	30.48	Buried	110.00	110.00
8	29.21	Buried	121.80	121.80
9	52.07	Buried	154.00	154.00
10	36.07	Buried	96.00	96.00
11	43.18	Buried	126.00	126.00
12	39.37	Buried	110.00	110.00
13	31.96	Buried	271.33	271.33
14	38.74	Buried	216.00	216.00
15	26.67	Buried	197.60	197.60
16	37.59	Buried	305.20	305.20
17	36.83	Buried	234.00	234.00
18	49.53	184.00	624.00	624.00
19	41.91	110.50	178.50	178.50
20.1	58.42	207.00	432.00	54.00
20.2	58.42	218.50	456.00	399.00
21	29.21	Buried	321.60	321.60
22	18.54	141.40	292.90	292.90
23	38.10	Buried	205.80	205.80
24	39.37	Buried	187.00	187.00
25	33.53	Buried	200.10	200.10
26	31.75	Buried	206.40	206.40
27	50.80	Buried	787.50	787.50
28	38.10	Buried	208.00	208.00
29	36.83	Buried	241.65	241.65
30	40.64	Buried	249.20	249.20
31	53.34	406.00	1928.50	1928.50
32	43.18	Buried	1254.00	1254.00
33	25.91	Buried	480.50	480.50
34	27.18	Buried	608.00	608.00
35	54.61	Buried	1095.60	1095.60
36	49.28	510.00	918.00	918.00
37	40.64	350.00	455.00	455.00
38	27.43	306.00	468.00	468.00
39	35.56	Buried	832.50	832.50
40	31.50	Buried	809.40	809.40
41	34.54	Buried	819.00	819.00
42	55.88	400.00	560.00	560.00
43	64.52	656.00	758.50	758.50
44	45.72	462.00	651.00	651.00
45	34.29	Buried	1333.00	1204.00

Stone Segment	Stone Segment Width (cm)	Stone Height (cm)	Stone Length (cm)	Channel Length (cm)
46	105.41	594.00	1478.40	1478.40
47	55.88	Buried	810.00	810.00
48	35.56	207.00	529.00	529.00
49	41.91	437.10	470.00	470.00
50	25.40	Buried	336.00	336.00
51	46.99	284.20	563.50	539.00
52	48.26	Buried	675.00	675.00
53	52.83	714.00	739.50	535.50
54	35.56	598.00	1102.40	1102.40
55.1	30.48	609.50	848.00	848.00
55.2	30.48	621.00	864.00	459.00
56	26.16	303.05	672.22	672.22
57	26.92	353.28	640.32	640.32
58	49.78	Buried	1372.00	1372.00
59	24.89	467.40	872.10	872.10
60	25.40	319.00	Buried	Buried
61	26.67	501.50	902.70	902.70
62	31.50	Buried	Buried	Buried
63	62.74	823.50	793.00	793.00
64.1	67.82	961.00	830.80	558.00
64.2	67.82	Buried	844.20	648.90
65	22.10	Buried	1282.00	1282.00
66	26.16	Buried	943.74	943.74
67	21.59	Buried	1170.00	1170.00
68	20.32	Buried	1056.00	1056.00
69	26.42	Buried	1051.90	1051.90
70	19.05	Buried	183.60	183.60
71	24.64	Buried	1276.50	1276.50
72	24.64	Buried	1050.00	1050.00
73	21.34	Buried	937.20	937.20
74	20.32	Buried	468.00	468.00
75	16.51	Buried	292.00	292.00
76	22.35	Buried	703.00	703.00
77	34.29	Buried	697.50	697.50
78	26.42	Buried	1003.20	1003.20
79	38.86	1178.10	1617.00	1617.00
80	26.67	Buried	1365.00	1365.00
81	25.40	Buried	1516.80	1501.00
82	71.37	800.00	1336.00	912.00
83	27.94	Buried	753.30	753.30
84	21.59	Buried	861.00	861.00
85	21.59	Buried	954.50	954.50
86	22.10	Buried	1554.00	1554.00
87	23.37	Buried	1360.00	1360.00
88	22.35	Buried	1298.60	1298.60
89	21.59	Buried	913.50	913.50
90	26.16	Buried	906.40	880.00
91	21.08	Buried	845.50	845.50
92	21.59	Buried	1188.00	1188.00
93	22.86	Buried	873.60	873.60
94	16.51	Buried	368.00	368.00

Stone Segment	Stone Segment Width (cm)	Stone Height (cm)	Stone Length (cm)	Channel Length (cm)
95	16.00	Buried	818.40	818.40
96	22.86	Buried	987.00	987.00
97	17.78	Buried	437.00	437.00
98	22.86	Buried	892.80	892.80
99	16.26	Buried	795.40	795.40
100	26.67	539.00	1666.00	1666.00
101	24.13	1148.40	1138.50	891.00
102	25.40	740.00	1430.00	380.00
103	24.89	121.20	1414.00	808.00
104	51.56	867.00	816.00	714.00
105	25.40	927.00	1802.50	1380.20
106	57.15	1196.00	1560.00	1560.00
107	46.99	1575.00	1522.50	1365.00
108	53.85	1028.20	1484.00	1113.00
109	45.72	1444.50	1776.20	695.50
110	24.89	Buried	1890.00	1890.00
111	27.94	Buried	1635.00	1635.00
112	57.15	1265.00	1705.00	1155.00
113	21.59	388.50	832.50	377.40
114	83.31	1198.40	3192.00	2072.00
115	48.26	1073.50	1921.00	1921.00
116	34.29	1197.00	1687.20	1026.00
117	35.05	632.50	1552.50	1610.00
118	41.66	638.00	1020.80	1044.00
119	43.94	Buried	1567.80	1170.00
120	45.72	1534.00	4130.00	4130.00
121	33.02	1428.00	1725.50	892.50
122	Carved	Carved	Carved	3480.00
123	55.88	1331.00	1210.00	1210.00
124	36.83	1037.00	1952.00	1952.00
125	36.07	861.00	2127.90	2127.90
126	27.94	868.00	1810.40	1810.40
127	60.45	1712.50	1837.50	1837.50
128	38.50	30.50	33.50	33.50
129.1	29.00	35.00	31.50	19.00
129.2	29.00	35.00	31.50	8.50
130	18.50	Buried	Buried	Buried
131.1	61.00	25.00	73.50	63.50
131.2	61.00	25.00	73.50	Unsure
132	106.00	27.00	49.00	49.00
133	33.00	30.00	28.00	28.00
134	76.00	51.00	65.50	45.00
135	37.30	22.00	39.50	39.50
136	65.80	29.00	45.00	46.50
137	48.00	Buried	38.00	38.00
138	37.50	Buried	42.50	42.50
139	44.00	34.00	32.50	32.50
140	38.00	Buried	46.00	46.00
141	70.00	63.00	31.00	31.00

B. APPENDIX 2: Most Efficient Discharge for 146 Cross-sections

Stone Segment	Most Efficient Shape	Depth, y (cm)	Most Efficient Area (cm^2)	Most Efficient Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
1	Circle	7.80	95.57	24.50	3.90	676.53
2	Trapezoid	3.00	15.59	10.39	1.50	58.36
3	Trapezoid	6.90	82.46	23.90	3.45	537.94
4	Trapezoid	3.11	16.75	10.77	1.56	64.24
5	Trapezoid	3.30	18.86	11.43	1.65	75.25
6	Trapezoid	2.05	7.28	7.10	1.03	21.14
7	Trapezoid	2.45	10.40	8.49	1.23	34.01
8	Rectangle	3.38	22.85	13.52	1.69	92.62
9	Trapezoid	3.16	17.30	10.95	1.58	67.04
10	Trapezoid	4.50	35.07	15.59	2.25	172.07
11	Trapezoid	5.22	47.20	18.08	2.61	255.62
12	Rectangle	5.56	61.83	22.24	2.78	349.25
13	Rectangle	5.80	67.28	23.20	2.90	390.92
14	Rectangle	4.86	47.24	19.44	2.43	243.95
15	Rectangle	5.42	58.75	21.68	2.71	326.29
16	Rectangle	6.70	89.78	26.80	3.35	574.30
17	Rectangle	10.32	213.00	41.28	5.16	1817.28
18	Trapezoid	11.43	226.28	39.59	5.72	2066.63
19	Rectangle	7.96	126.72	31.84	3.98	909.31
20.1	Rectangle	5.15	53.05	20.60	2.58	284.73

Stone Segment	Most Efficient Shape	Depth, y (cm)	Most Efficient Area (cm^2)	Most Efficient Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
20.2	Circle	4.55	32.52	14.29	2.28	160.72
21	Trapezoid	3.95	27.02	13.68	1.98	121.54
22	Rectangle	6.30	79.38	25.20	3.15	487.36
23	Rectangle	10.20	208.08	40.80	5.10	1761.47
24	Rectangle	10.00	200.00	40.00	5.00	1670.87
25	Rectangle	9.88	195.23	39.52	4.94	1617.93
26	Rectangle	8.35	139.45	33.40	4.18	1033.01
27	Rectangle	12.10	292.82	48.40	6.05	2777.81
28	Rectangle	11.11	246.86	44.44	5.56	2212.31
29	Rectangle	12.53	314.00	50.12	6.27	3048.91
30	Rectangle	13.25	351.13	53.00	6.63	3538.76
31	Rectangle	4.52	40.86	18.08	2.26	201.05
32	Trapezoid	2.58	11.53	8.94	1.29	39.04
33	Trapezoid	0.97	1.63	3.36	0.49	2.87
34	Trapezoid	1.90	6.25	6.58	0.95	17.26
35	Trapezoid	4.00	27.71	13.86	2.00	125.69
36	Trapezoid	7.84	106.46	27.16	3.92	756.22
37	Trapezoid	7.23	90.54	25.05	3.62	609.31
38	Trapezoid	3.73	24.10	12.92	1.87	104.32
39	Trapezoid	10.91	206.16	37.79	5.46	1825.32
40	Trapezoid	10.89	205.41	37.72	5.45	1816.41

Stone Segment	Most Efficient Shape	Depth, y (cm)	Most Efficient Area (cm^2)	Most Efficient Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
41	Trapezoid	12.65	277.17	43.82	6.33	2708.41
42	Rectangle	15.47	478.64	61.88	7.74	5348.71
43	Trapezoid	5.95	61.32	20.61	2.98	362.40
44	Trapezoid	6.10	64.45	21.13	3.05	387.27
45	Rectangle	6.61	87.38	26.44	3.31	553.96
46	Trapezoid	5.18	46.48	17.94	2.59	250.43
47	Trapezoid	2.92	14.77	10.12	1.46	54.30
48	Trapezoid	2.72	12.81	9.42	1.36	44.94
49	Trapezoid	3.90	26.34	13.51	1.95	117.48
50	Rectangle	3.11	19.34	12.44	1.56	74.18
51	Trapezoid	3.13	16.97	10.84	1.57	65.35
52	Trapezoid	1.50	3.90	5.20	0.75	9.19
53	Trapezoid	2.27	8.93	7.86	1.14	27.75
54	Rectangle	5.03	50.60	20.12	2.52	267.38
55.1	Circle	6.90	74.79	21.68	3.45	487.86
55.2	Trapezoid	6.48	72.73	22.45	3.24	454.99
56	Trapezoid	4.51	35.23	15.62	2.26	173.09
57	Rectangle	4.37	38.19	17.48	2.19	183.75
58	Trapezoid	5.61	54.51	19.43	2.81	309.77
59	Trapezoid	3.14	17.08	10.88	1.57	65.91
60	Circle	4.44	30.97	13.95	2.22	150.56

Stone Segment	Most Efficient Shape	Depth, y (cm)	Most Efficient Area (cm^2)	Most Efficient Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
61	Trapezoid	2.70	12.63	9.35	1.35	44.07
62	Trapezoid	3.85	25.67	13.34	1.93	113.51
63	Rectangle	6.70	89.78	26.80	3.35	574.30
64.1	Rectangle	8.30	137.78	33.20	4.15	1016.60
64.2	Rectangle	11.60	269.12	46.40	5.80	2482.16
65	Trapezoid	2.72	12.81	9.42	1.36	44.94
66	Trapezoid	3.00	15.59	10.39	1.50	58.36
67	Trapezoid	3.51	21.34	12.16	1.76	88.71
68	Trapezoid	3.00	15.59	10.39	1.50	58.36
69	Trapezoid	3.22	17.96	11.15	1.61	70.48
70	Trapezoid	3.05	16.11	10.57	1.53	60.99
71	Trapezoid	3.00	15.59	10.39	1.50	58.36
72	Trapezoid	3.70	23.71	12.82	1.85	102.10
73	Trapezoid	4.07	28.69	14.10	2.04	131.64
74	Trapezoid	3.08	16.43	10.67	1.54	62.60
75	Trapezoid	3.66	23.20	12.68	1.83	99.18
76	Trapezoid	3.86	25.81	13.37	1.93	114.30
77	Trapezoid	2.87	14.27	9.94	1.44	51.86
78	Trapezoid	2.84	13.97	9.84	1.42	50.43
79	Trapezoid	7.28	91.80	25.22	3.64	620.62

Stone Segment	Most Efficient Shape	Depth, y (cm)	Most Efficient Area (cm^2)	Most Efficient Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
80	Trapezoid	3.88	26.07	13.44	1.94	115.88
81	Trapezoid	2.40	9.98	8.31	1.20	32.19
82	Circle	3.17	15.78	9.96	1.59	61.31
83	Trapezoid	2.49	10.74	8.63	1.25	35.51
84	Trapezoid	1.25	2.71	4.33	0.63	5.65
85	Trapezoid	1.45	3.64	5.02	0.73	8.40
86	Trapezoid	1.50	3.90	5.20	0.75	9.19
87	Trapezoid	2.00	6.93	6.93	1.00	19.79
88	Trapezoid	1.70	5.01	5.89	0.85	12.83
89	Trapezoid	1.30	2.93	4.50	0.65	6.28
90	Trapezoid	1.20	2.49	4.16	0.60	5.07
91	Trapezoid	1.45	3.64	5.02	0.73	8.40
92	Trapezoid	1.58	4.32	5.47	0.79	10.56
93	Trapezoid	1.58	4.32	5.47	0.79	10.56
94	Trapezoid	1.30	2.93	4.50	0.65	6.28
95	Trapezoid	2.43	10.23	8.42	1.22	33.27
96	Trapezoid	1.42	3.49	4.92	0.71	7.94
97	Trapezoid	1.22	2.58	4.23	0.61	5.30
98	Trapezoid	1.92	6.39	6.65	0.96	17.75
99	Trapezoid	0.97	1.63	3.36	0.49	2.87

Stone Segment	Most Efficient Shape	Depth, y (cm)	Most Efficient Area (cm^2)	Most Efficient Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
100	Circle	2.76	11.97	8.67	1.38	42.38
101	Trapezoid	3.52	21.46	12.19	1.76	89.38
102	Trapezoid	4.04	28.27	13.99	2.02	129.07
103	Trapezoid	3.80	25.01	13.16	1.90	109.62
104	Trapezoid	4.60	36.65	15.93	2.30	182.46
105	Trapezoid	3.57	22.07	12.37	1.79	92.81
106	Trapezoid	2.36	9.65	8.18	1.18	30.78
107	Trapezoid	2.35	9.57	8.14	1.18	30.43
108	Trapezoid	1.95	6.59	6.75	0.98	18.50
109	Trapezoid	3.35	19.44	11.60	1.68	78.33
110	Trapezoid	4.95	42.44	17.15	2.48	221.86
111	Trapezoid	7.63	100.83	26.43	3.82	703.40
112	Trapezoid	3.25	18.29	11.26	1.63	72.25
113	Trapezoid	2.00	6.93	6.93	1.00	19.79
114	Rectangle	4.30	36.98	17.20	2.15	176.00
115	Rectangle	3.37	22.71	13.48	1.69	91.89
116	Trapezoid	3.00	15.59	10.39	1.50	58.36
117	Trapezoid	3.42	20.26	11.85	1.71	82.77
118	Trapezoid	1.67	4.83	5.79	0.84	12.24
119	Trapezoid	2.73	12.91	9.46	1.37	45.38

Stone Segment	Most Efficient Shape	Depth, y (cm)	Most Efficient Area (cm^2)	Most Efficient Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
120	Trapezoid	5.30	48.65	18.36	2.65	266.20
121	Trapezoid	1.01	1.77	3.50	0.51	3.20
122	Trapezoid	9.58	158.96	33.19	4.79	1290.57
123	Rectangle	5.24	54.92	20.96	2.62	298.19
124	Trapezoid	2.66	12.26	9.21	1.33	42.35
125	Trapezoid	1.66	4.77	5.75	0.83	12.04
126	Trapezoid	6.00	62.35	20.78	3.00	370.57
127	Rectangle	20.65	852.85	82.60	10.33	11553.90
128	Trapezoid	8.65	129.60	29.96	4.33	982.91
129.1	Trapezoid	3.47	20.86	12.02	1.74	86.04
129.2	Trapezoid	2.93	14.87	10.15	1.47	54.80
130	Trapezoid	4.80	39.91	16.63	2.40	204.39
131.1	Rectangle	5.00	50.00	20.00	2.50	263.15
131.2	Trapezoid	2.65	12.16	9.18	1.33	41.92
132	Rectangle	10.81	233.71	43.24	5.41	2056.57
133	Trapezoid	7.70	102.69	26.67	3.85	720.74
134	Trapezoid	8.75	132.61	30.31	4.38	1013.51
135	Trapezoid	1.85	5.93	6.41	0.93	16.08
136	Rectangle	2.78	15.46	11.12	1.39	55.00
137	Trapezoid	13.45	313.33	46.59	6.73	3189.57
138	Trapezoid	3.12	16.86	10.81	1.56	64.80

Stone Segment	**Most Efficient Shape**	**Depth, y (cm)**	**Most Efficient Area (cm^2)**	**Most Efficient Wetted Perimeter (cm)**	**Hydraulic Radius, R_h (cm)**	**Discharge, Q (cm^3/s)**
139	Trapezoid	6.25	67.66	21.65	3.13	413.19
140	Trapezoid	2.36	9.65	8.18	1.18	30.78
141	Rectangle	3.75	28.13	15.00	1.88	122.19

C. APPENDIX 3: Full Discharge for 146 Cross-sections

Stone Segment	Full Area (cm^2)	Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
1	79.87	22.51	3.55	530.87
2	31.03	16.25	1.91	136.46
3	74.40	21.49	3.46	486.48
4	33.02	16.16	2.04	151.91
5	41.28	19.64	2.10	193.53
6	14.93	12.23	1.22	48.72
7	22.64	14.09	1.61	88.74
8	36.37	16.79	2.17	173.97
9	30.70	15.90	1.93	136.01
10	43.61	17.22	2.53	231.50
11	46.31	17.75	2.61	250.76
12	50.12	19.01	2.64	273.29
13	57.77	20.23	2.86	332.23
14	46.87	19.40	2.42	241.11
15	51.10	20.04	2.55	272.50
16	67.65	22.55	3.00	402.05
17	101.84	28.70	3.55	676.93
18	97.36	27.64	3.52	643.98
19	74.40	22.60	3.29	470.42
20.1	16.35	12.00	1.36	57.41
20.2	29.52	13.77	2.14	140.23
21	33.66	15.03	2.24	164.62
22	32.59	16.44	1.98	146.94
23	126.03	31.02	4.06	916.84
24	119.87	29.50	4.06	872.10
25	132.52	30.97	4.28	997.95
26	111.55	28.05	3.98	800.00
27	145.24	33.34	4.36	1106.88
28	162.73	33.73	4.82	1327.50
29	164.42	37.21	4.42	1264.98
30	194.22	39.41	4.93	1607.01
31	62.31	22.61	2.76	349.94
32	24.88	16.14	1.54	94.86
33	7.31	12.22	0.60	14.83
34	17.02	16.01	1.06	50.65
35	46.18	19.13	2.41	237.44
36	91.46	25.21	3.63	616.98
37	75.00	23.85	3.14	459.95
38	20.95	12.27	1.71	85.51
39	89.97	28.60	3.15	551.89
40	112.32	29.07	3.86	790.19
41	152.87	33.70	4.54	1196.88
42	222.61	40.01	5.56	1997.07
43	68.42	22.02	3.11	416.25
44	43.24	17.83	2.43	223.00
45	58.97	21.41	2.75	331.06
46	38.58	16.66	2.32	192.94
47	28.48	15.57	1.83	121.70

Stone Segment	Full Area (cm^2)	Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q $(cm^3/_s)$
48	24.77	14.37	1.72	101.74
49	29.67	15.23	1.95	132.23
50	21.38	12.68	1.69	86.54
51	22.47	12.95	1.74	92.70
52	13.40	13.48	0.99	38.13
53	20.84	14.27	1.46	76.64
54	59.55	20.46	2.91	346.84
55.1	71.03	22.67	3.13	434.54
55.2	38.20	17.80	2.15	181.59
56	30.80	14.59	2.11	144.81
57	32.82	15.19	2.16	156.72
58	59.92	19.76	3.03	358.67
59	25.28	13.37	1.89	110.44
60	30.30	13.95	2.17	145.20
61	17.06	11.44	1.49	63.62
62	29.97	13.97	2.15	142.43
63	92.02	25.99	3.54	610.75
64.1	120.32	30.17	3.99	864.53
64.2	195.22	39.05	5.00	1630.77
65	10.54	9.93	1.06	31.34
66	9.35	8.74	1.07	27.94
67	13.64	10.67	1.28	45.90
68	10.26	8.90	1.15	32.23
69	13.90	10.22	1.36	48.75
70	15.31	11.27	1.36	53.65
71	15.26	10.75	1.42	55.07
72	13.74	10.54	1.30	46.85
73	15.97	11.76	1.36	55.95
74	12.77	10.41	1.23	41.81
75	11.19	9.61	1.16	35.39
76	14.84	11.66	1.27	49.80
77	11.88	9.51	1.25	39.37
78	9.81	8.85	1.11	30.02
79	41.82	18.05	2.32	209.21
80	18.00	12.76	1.41	64.69
81	8.93	8.46	1.06	26.45
82	13.78	9.39	1.47	50.84
83	7.68	7.41	1.04	22.47
84	4.37	6.64	0.66	9.45
85	5.73	7.08	0.81	14.22
86	4.57	6.13	0.75	10.74
87	6.39	7.09	0.90	17.03
88	5.81	7.00	0.83	14.66
89	3.18	5.36	0.59	6.42
90	4.38	7.11	0.62	9.06
91	6.68	8.92	0.75	15.74
92	5.58	6.96	0.80	13.76
93	4.50	6.24	0.72	10.34
94	3.85	6.85	0.56	7.49
95	9.15	8.34	1.10	27.81
96	4.32	6.02	0.72	9.89

Stone Segment	Full Area (cm^2)	Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
97	3.03	5.68	0.53	5.69
98	6.02	7.14	0.84	15.35
99	3.58	6.77	0.53	6.69
100	10.24	8.11	1.26	34.18
101	15.00	9.88	1.52	56.61
102	23.73	12.56	1.89	103.62
103	20.03	12.03	1.67	80.39
104	44.24	18.59	2.38	225.31
105	13.28	9.48	1.40	47.50
106	8.82	8.49	1.04	25.85
107	9.98	9.19	1.09	30.13
108	9.96	9.84	1.01	28.69
109	17.96	11.69	1.54	68.32
110	45.17	17.73	2.55	240.74
111	77.16	22.82	3.38	496.64
112	14.70	10.21	1.44	53.55
113	8.71	8.77	0.99	24.77
114	28.41	13.81	2.06	131.30
115	54.09	21.87	2.47	282.64
116	17.74	10.85	1.64	70.35
117	21.68	12.51	1.73	89.37
118	8.95	9.81	0.91	24.05
119	16.70	11.71	1.43	60.45
120	68.59	23.44	2.93	400.92
121	3.80	6.46	0.59	7.62
122	72.02	26.42	2.73	401.54
123	103.43	31.00	3.34	659.83
124	15.00	11.28	1.33	51.83
125	13.37	13.15	1.02	38.62
126	52.43	19.60	2.68	288.67
127	280.27	49.75	5.63	2535.31
128	53.73	21.11	2.55	286.18
129.1	11.10	8.84	1.26	36.91
129.2	10.19	8.18	1.25	33.71
130	23.33	12.82	1.82	99.36
131.1	42.68	17.44	2.45	221.45
131.2	8.04	7.47	1.08	24.13
132	161.41	33.67	4.79	1311.15
133	46.91	19.29	2.43	242.37
134	137.24	29.75	4.61	1086.61
135	10.00	9.31	1.07	29.97
136	35.85	18.24	1.97	160.72
137	159.69	35.53	4.49	1242.60
138	23.53	14.00	1.68	95.03
139	59.85	19.93	3.00	355.93
140	25.39	16.35	1.55	97.28
141	46.65	19.64	2.38	237.28

D. APPENDIX 4: Half-Full Discharge for 146 Cross-sections

Stone Segment	Half- Full Area (cm^2)	Half- Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
1	32.34	14.82	2.18	155.45
2	12.16	12.55	0.97	34.02
3	29.84	14.57	2.05	137.50
4	14.01	12.81	1.09	42.49
5	17.60	15.45	1.14	54.85
6	5.78	9.16	0.63	12.15
7	9.01	11.50	0.78	21.88
8	16.25	13.12	1.24	53.55
9	12.56	12.65	0.99	35.72
10	16.88	12.12	1.39	60.15
11	19.09	11.99	1.59	74.37
12	22.04	12.71	1.73	90.89
13	25.88	14.12	1.83	110.74
14	19.28	12.54	1.54	73.38
15	20.94	12.60	1.66	83.94
16	30.21	14.81	2.04	138.83
17	46.66	17.65	2.64	254.88
18	37.22	15.83	2.35	188.03
19	33.54	14.88	2.25	164.74
20.1	7.04	6.93	1.02	20.33
20.2	11.60	9.18	1.26	38.74
21	14.62	10.88	1.34	50.87
22	15.99	10.42	1.53	60.78
23	62.60	21.08	2.97	369.52
24	58.19	19.84	2.93	340.66
25	60.81	20.58	2.95	357.76
26	51.28	19.31	2.66	280.97
27	63.49	20.33	3.12	387.57
28	73.88	22.41	3.30	467.57
29	76.84	22.83	3.37	493.07
30	93.50	25.30	3.70	638.56
31	28.84	17.09	1.69	116.80
32	9.49	11.12	0.85	24.40
33	2.97	8.88	0.33	4.09
34	6.03	11.15	0.54	11.44
35	18.48	13.75	1.34	64.30
36	38.22	16.09	2.38	194.41
37	30.35	14.41	2.11	142.48
38	7.92	7.42	1.07	23.63
39	31.29	14.32	2.19	150.54
40	39.53	16.14	2.45	205.21
41	54.27	18.71	2.90	315.37
42	94.24	24.47	3.85	661.56
43	27.26	14.85	1.84	116.77
44	16.96	10.52	1.61	66.62
45	25.55	13.37	1.91	112.42
46	15.52	10.37	1.50	58.02

Stone Segment	Half- Full Area (cm^2)	Half- Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
47	11.68	11.86	0.98	33.03
48	9.97	10.74	0.93	27.11
49	12.01	9.64	1.25	39.73
50	8.95	9.02	0.99	25.44
51	9.00	8.82	1.02	26.06
52	4.62	9.73	0.47	8.03
53	8.95	11.19	0.80	22.03
54	23.85	14.58	1.64	94.60
55.1	28.21	14.10	2.00	127.97
55.2	14.97	9.79	1.53	56.77
56	12.47	9.50	1.31	42.71
57	13.87	10.04	1.38	49.16
58	24.75	13.88	1.78	103.98
59	10.75	10.13	1.06	31.96
60	11.54	9.19	1.26	38.38
61	6.03	7.67	0.79	14.68
62	11.45	9.57	1.20	36.87
63	41.96	18.46	2.27	207.25
64.1	58.52	21.35	2.74	327.47
64.2	91.95	26.11	3.52	608.11
65	3.37	4.89	0.69	7.51
66	3.09	4.56	0.68	6.81
67	4.65	5.53	0.84	11.84
68	3.79	5.05	0.75	8.94
69	5.05	5.87	0.86	13.05
70	5.20	6.18	0.84	13.24
71	5.92	6.53	0.91	15.84
72	4.19	5.35	0.78	10.17
73	5.59	6.02	0.93	15.20
74	4.11	5.27	0.78	9.95
75	3.48	4.91	0.71	7.90
76	4.35	5.36	0.81	10.81
77	4.13	5.32	0.78	9.97
78	3.44	4.86	0.71	7.81
79	17.16	10.61	1.62	67.55
80	5.35	5.95	0.90	14.24
81	2.59	4.32	0.60	5.26
82	5.04	5.97	0.84	12.86
83	2.98	4.54	0.66	6.43
84	1.61	4.18	0.39	2.44
85	1.99	4.34	0.46	3.38
86	1.37	3.40	0.40	2.14
87	1.88	3.88	0.48	3.31
88	1.38	3.39	0.41	2.17
89	1.01	3.03	0.33	1.39
90	1.56	4.27	0.37	2.28
91	1.76	4.28	0.41	2.78
92	1.45	3.59	0.40	2.26
93	1.33	3.23	0.41	2.10
94	1.26	4.00	0.32	1.67

Stone Segment	Half- Full Area (cm^2)	Half- Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
95	2.86	4.59	0.62	5.96
96	1.27	3.44	0.37	1.87
97	1.03	3.12	0.33	1.41
98	1.84	3.74	0.49	3.28
99	1.21	4.14	0.29	1.52
100	3.81	5.16	0.74	8.89
101	5.96	6.29	0.95	16.43
102	10.10	8.41	1.20	32.60
103	7.87	7.32	1.08	23.60
104	11.81	10.22	1.16	37.16
105	4.58	5.50	0.83	11.58
106	3.24	5.23	0.62	6.73
107	3.21	5.31	0.60	6.56
108	3.50	6.14	0.57	6.87
109	7.25	7.39	0.98	20.45
110	17.11	11.44	1.50	63.93
111	32.93	14.91	2.21	159.56
112	5.13	6.04	0.85	13.15
113	2.72	4.83	0.56	5.30
114	12.11	9.28	1.30	41.32
115	23.62	18.06	1.31	80.71
116	7.45	7.78	0.96	20.68
117	8.07	7.95	1.02	23.29
118	3.52	6.32	0.56	6.81
119	5.77	7.14	0.81	14.30
120	26.88	15.39	1.75	111.38
121	1.37	4.36	0.31	1.81
122	25.67	13.18	1.95	114.38
123	42.67	23.73	1.80	180.28
124	5.32	6.59	0.81	13.18
125	6.10	9.76	0.63	12.74
126	20.33	11.84	1.72	83.29
127	125.36	29.15	4.30	947.19
128	23.80	12.48	1.91	104.57
129.1	4.25	5.23	0.81	10.57
129.2	3.60	4.93	0.73	8.34
130	8.82	7.53	1.17	28.00
131.1	19.21	11.93	1.61	75.40
131.2	2.92	4.36	0.67	6.39
132	75.07	22.91	3.28	473.18
133	20.28	11.46	1.77	84.77
134	57.48	20.87	2.75	322.68
135	3.76	6.40	0.59	7.54
136	15.91	14.93	1.07	47.43
137	74.49	21.98	3.39	480.19
138	7.21	8.22	0.88	18.88
139	25.34	13.54	1.87	109.95
140	12.48	14.07	0.89	32.92
141	21.24	15.36	1.38	75.32

E. APPENDIX 5: Third-Full Discharge for 146 Cross-sections

Stone Segment	Third- Full Area (cm^2)	Third- Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
1	18.33	11.81	1.55	70.21
2	8.09	11.10	0.73	18.72
3	16.37	11.56	1.42	58.98
4	7.85	11.42	0.69	17.47
5	9.13	13.14	0.69	20.46
6	3.03	7.80	0.39	4.61
7	5.07	10.43	0.49	8.96
8	9.27	11.68	0.79	22.70
9	7.65	11.08	0.69	17.07
10	10.65	10.67	1.00	30.39
11	11.35	10.10	1.12	35.05
12	12.60	10.58	1.19	40.45
13	14.47	11.87	1.22	47.18
14	11.99	10.98	1.09	36.33
15	12.40	10.99	1.13	38.40
16	17.59	12.31	1.43	63.76
17	28.83	14.11	2.04	132.63
18	19.93	11.39	1.75	82.69
19	20.04	12.01	1.67	80.55
20.1	4.18	5.20	0.80	10.33
20.2	6.63	7.50	0.88	17.45
21	8.71	9.32	0.93	23.79
22	9.96	8.20	1.21	32.40
23	40.35	17.67	2.28	199.92
24	34.78	16.17	2.15	165.58
25	36.25	17.11	2.12	170.85
26	30.15	16.20	1.86	130.34
27	38.40	16.07	2.39	196.10
28	45.84	18.54	2.47	239.48
29	48.66	18.84	2.58	261.72
30	60.46	20.94	2.89	350.26
31	17.64	15.54	1.14	54.84
32	5.28	9.65	0.55	10.09
33	2.02	8.51	0.24	2.21
34	3.29	8.22	0.40	5.11
35	11.37	12.42	0.92	30.63
36	23.41	13.47	1.74	96.68
37	18.81	11.98	1.57	72.60
38	4.37	5.95	0.73	10.16
39	17.38	10.64	1.63	68.87
40	21.53	11.89	1.81	91.39
41	31.35	14.37	2.18	150.67
42	56.88	19.44	2.93	332.46
43	13.78	12.23	1.13	42.63
44	9.69	8.19	1.18	30.97
45	15.28	11.10	1.38	54.02
46	9.08	8.65	1.05	26.80

Stone Segment	Third- Full Area (cm^2)	Third- Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
47	5.69	9.57	0.59	11.50
48	5.98	9.52	0.63	12.53
49	6.81	8.19	0.83	17.20
50	4.84	7.79	0.62	10.07
51	4.79	7.35	0.65	10.29
52	3.07	8.47	0.36	4.46
53	4.52	9.67	0.47	7.78
54	13.86	12.82	1.08	41.71
55.1	16.95	11.87	1.43	61.41
55.2	8.84	7.69	1.15	27.72
56	6.85	7.80	0.88	17.95
57	8.74	8.61	1.02	25.22
58	14.14	11.76	1.20	45.68
59	6.21	8.89	0.70	13.97
60	6.62	7.39	0.90	17.58
61	3.02	6.15	0.49	5.37
62	6.66	7.92	0.84	16.95
63	26.00	16.29	1.60	101.46
64.1	37.4	18.51	2.02	170.78
64.2	59.51	22.38	2.66	326.34
65	1.94	3.85	0.50	3.51
66	1.61	3.33	0.48	2.83
67	2.63	4.29	0.61	5.42
68	1.90	3.77	0.50	3.44
69	2.66	4.55	0.58	5.31
70	2.61	4.75	0.55	5.00
71	3.21	5.34	0.60	6.53
72	2.35	4.07	0.58	4.66
73	3.16	4.56	0.69	7.07
74	2.17	3.99	0.54	4.13
75	1.72	3.41	0.50	3.11
76	2.42	3.99	0.61	4.95
77	2.26	4.18	0.54	4.29
78	1.84	3.68	0.50	3.31
79	10.27	8.13	1.26	34.29
80	2.96	4.50	0.66	6.40
81	1.67	3.65	0.46	2.83
82	2.91	4.75	0.61	6.00
83	1.50	3.38	0.44	2.49
84	1.10	3.65	0.30	1.41
85	1.25	3.79	0.33	1.70
86	0.91	3.00	0.30	1.17
87	0.79	2.77	0.29	0.98
88	0.79	2.66	0.30	1.00
89	0.38	2.04	0.19	0.35
90	0.83	3.52	0.24	0.91
91	1.20	3.69	0.33	1.62
92	0.92	2.88	0.32	1.23
93	0.77	2.60	0.30	0.98
94	0.74	3.15	0.23	0.80

Stone Segment	Third- Full Area (cm^2)	Third- Full Wetted Perimeter (cm)	Hydraulic Radius, R_h (cm)	Discharge, Q (cm^3/s)
95	1.57	3.59	0.44	2.58
96	0.70	2.65	0.26	0.82
97	0.45	2.15	0.21	0.45
98	1.01	2.86	0.35	1.44
99	0.72	3.29	0.22	0.75
100	2.15	4.19	0.51	3.94
101	3.70	5.23	0.71	8.39
102	6.02	6.99	0.86	15.57
103	4.11	5.77	0.71	9.37
104	8.42	9.10	0.93	22.84
105	2.56	4.20	0.61	5.26
106	1.57	3.85	0.41	2.47
107	1.60	3.98	0.40	2.49
108	2.04	4.97	0.41	3.22
109	3.94	5.95	0.66	8.55
110	9.94	9.71	1.02	28.85
111	19.69	12.04	1.64	78.09
112	3.15	4.99	0.63	6.62
113	1.28	3.76	0.34	1.78
114	7.41	7.79	0.95	20.48
115	14.1	16.47	0.86	36.32
116	4.25	6.63	0.64	9.03
117	4.45	6.47	0.69	9.91
118	1.80	5.07	0.36	2.58
119	3.17	5.88	0.54	6.00
120	15.80	13.49	1.17	50.16
121	0.85	3.70	0.23	0.91
122	13.63	9.62	1.42	49.13
123	25.75	21.88	1.18	82.01
124	2.79	5.16	0.54	5.29
125	3.39	8.33	0.41	5.32
126	11.62	9.59	1.21	37.73
127	76.78	22.18	3.46	502.00
128	14.35	9.58	1.50	53.68
129.1	2.49	4.13	0.60	5.08
129.2	1.89	3.73	0.51	3.43
130	4.52	5.61	0.81	11.18
131.1	13.09	10.51	1.25	43.29
131.2	1.66	3.41	0.49	2.94
132	46.51	19.29	2.41	238.94
133	11.84	8.79	1.35	41.26
134	33.23	17.57	1.89	145.20
135	1.98	5.25	0.38	2.95
136	10.24	14.01	0.73	23.74
137	45.60	17.42	2.62	247.46
138	3.97	6.62	0.60	8.07
139	14.31	11.25	1.27	48.00
140	6.71	12.97	0.52	12.36
141	12.41	13.82	0.90	33.00

F. APPENDIX 6: Interpolated Muyuqmarka Surface