Thesis Portfolio

Using ArcGIS to model modern and historic drainage patterns to restore original drainage at Saqsaywaman in Cusco, Peru
(Technical Report)

Exploring the role of engineering in public health: engineering solutions for noncommunicable disease prevention
(STS Research Paper)

An Undergraduate Thesis
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment
Of the Requirements for the Degree
Bachelor of Science in Civil Engineering

Olivia Jeffers
May 8, 2013

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ____ Date: ______________

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Sociotechnical Synthesis

Studying the history of water management and engineering achievements give great insight to causative factors of historic events and yield new perspectives for problems that engineers face today.

The Inca for example, separate from Europe until the Spanish arrived in South America in the 1500s, developed advanced water management techniques without the use of language, the wheel, iron, or steel (Wright, 1999, p. 36). With limited resources and in harsh conditions, the Inca were able to construct sites like Machu Picchu and Saqsawayman in Peru, which have endured over 400 years without maintenance. The site of Machu Picchu for example, was built atop a mountain using only limited spring water and gravity for agricultural terraces and supported a population of over 300 residents (Wright, 1999). With the construction industry lagging in today's difficult economy and water scarcity becoming an increasingly important concern, decoding engineering techniques from a resource-scarce era can offer a new perspective to engineering techniques in the United States today.

Closer to American history, sanitary infrastructure in the United States halved mortality rates in the early 20th century (Cutler & Miller, 2004) and laid the groundwork for future public health research. During the Progressive Era from 1890 to 1920, public health engineers played an important role as a technical elite aiding municipal public health authorities (Melosi, 2008). By the 1940s, however, engineers were effectively removed from the forefront of public health research and policy until present-day (Fee, 1992). The paper examines reasons for this devolvement of engineering in public health and conjectures how engineers might address new public health concerns of incommunicable diseases such as heart disease, diabetes, and cancer, which cost the U.S. over $1.5 trillion each year (Daulaire, 2011).

Studying water management by Incan engineers and the role of engineering in public health offers new perspectives and insights for today's problems of resource scarcity and the rise noncommunicable disease.

I give thanks to Kelly Johnston and the U.Va Scholars Lab for their GIS-related assistance, Brian Smith for helping me understand the current context of engineering disciplines, my mother and father for funding this four-year knowledge expedition, and I graciously acknowledge my thesis advisors for their dedication to education and patience in getting my work out the door. Special thanks to Richard Miksad, my technical advisor, for providing an exciting opportunity for me to use all my talents in modeling data and interests in history and archaeology, to Edward Russell for teaching environmental history and giving me the idea to study sanitation, and to Matthew Eisler for tirelessly encouraging quality in his students and spending many hours guiding my thesis to its final state.

Using ArcGIS to model modern and historic drainage patterns to restore original drainage to Saqsaywaman in Cusco, Peru

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May 1, 2013

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Using ArcGIS to model modern and historic drainage patterns to restore original drainage to Saqsaywaman in Cusco, Peru

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ABSTRACT

Saqsaywaman is the second largest Incan heritage site, settled just North of the capital city of Cusco, Peru. Most of the original site was deconstructed by the Spanish in 1536 and only the large walls, too heavy to move, remain intact. Portions of the walls crumbled in 2009 from excessive water runoff. The aim of the study is to first, immediately relieve the water runoff damage with a non-intrusive drainage canal, and secondarily to design a more permanent drainage canal in accordance with historic Incan drainage techniques. In order to determine the original drainage function of the site, this study collected historic topographic and aerial maps, as well as firsthand accounts dating from the early 1600s to present day, creating historic and present day drainage models using Geospatial Information System software, ArcMap and ArcScene. The team will travel to Peru in August 2013 to gather the remaining topographic data for to increase the accuracy of drainage analyses.

INDTRODUCTION

Saqsaywaman is the second largest Incan heritage site, settled just North of the capital city of Cusco, Peru. Portions of the site are suffering from water runoff damage and the aim of the study is to redirect the water and alleviate damage by using historically accurate water management techniques. The site consists of three megalithic, zigzag walls spanning 400 meters in length, each stone weighting between 160 and 200 tons, sequentially leading up to a strip of land which holds the ruins of three towers. The function of Saqsaywaman, and therefore the water management techniques, is debated, as after the Inca siege of 1536 the Spaniards removed all the stones from the site to construct buildings in the city below, leaving only the megalithic rocks in the walls that they were not capable of moving. With few clues as to original drainage canals and topography, we must cooperate with archaeologists to glean historic function of the site through first-hand accounts and analyses of historic maps.

At present-day the site is protected by the National Institute of Culture (INC) and has hosted a multitude of archaeologists over the last century. In January 2009 portions of the highest wall (see Figure 1), the third wall, suffered water runoff damage and crumbled. Previous research with our partners, the Wright Paleohydrologic Institute indicates that a large, impermeable clay covering placed on the site to protect archaeological remains caused water runoff that the third wall was not designed for, resulting in a portion of the wall collapsing (Miksad, 2011). The study aims to discover the original topography and water management practices of the site, and to design a drainage system that alleviates the immediate runoff threat to the third wall.

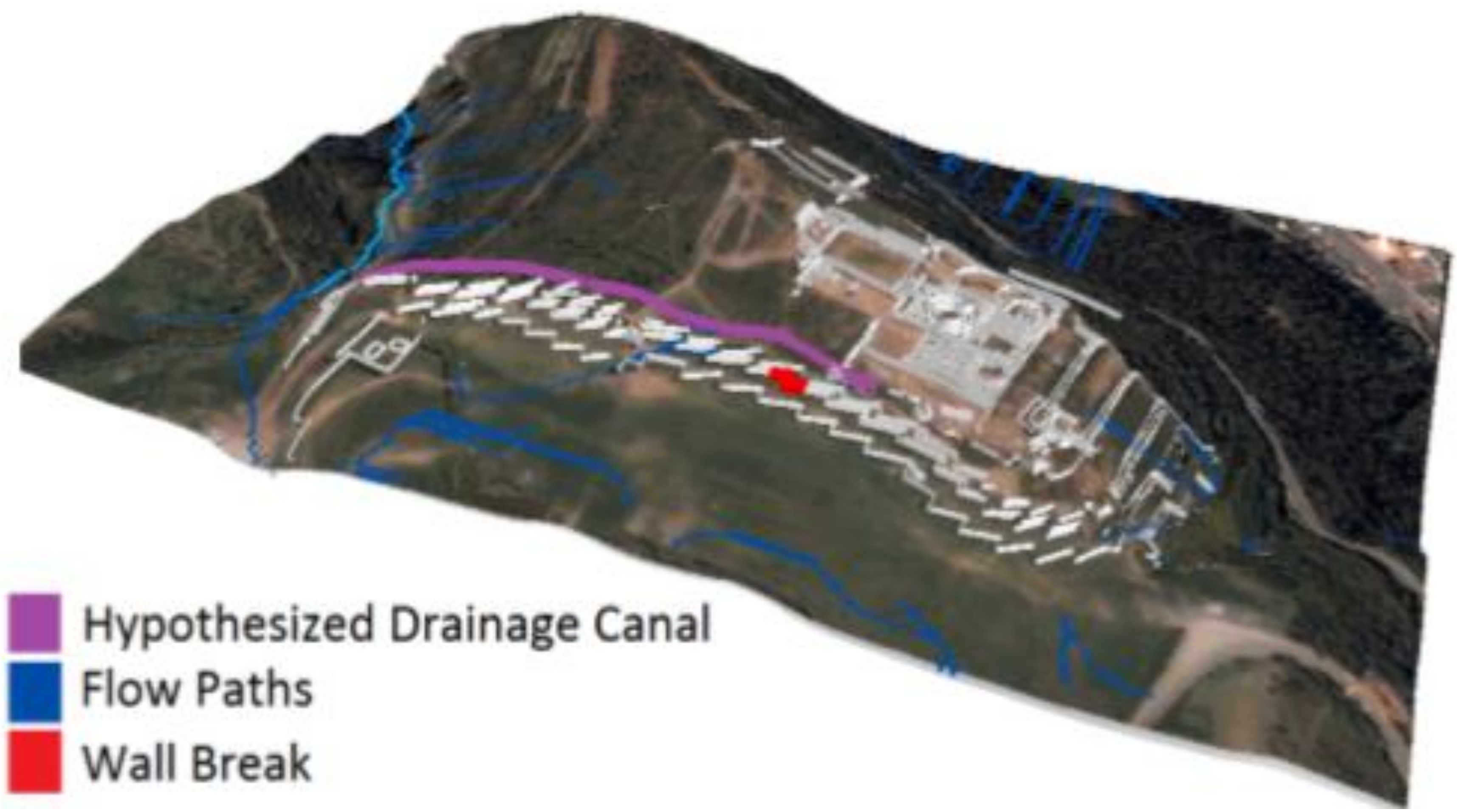


Figure 1: Three-dimensional model by the author of the site in ArcScene detailing the 2009 wall break.

SAQSAYWAMAN IN CONTEXT

The information gleaned from this study is relevant not only to the protection of the site, but also to general studies in Andean engineering which offer clues and insights to sustainable engineering topics. Andean engineering history has flown under the radar for most of the 19th and 20th centuries, generally overshadowed by research on European engineering histories and techniques. The Inca, the largest Andean civilization, faced tremendous challenges in terms of topography and managed to engineer sites such as Saqsaywaman and Machu Picchu without the use of the wheel, steel, or written language (Wright, 1999). With regard to Machu Picchu, which has been well studied, the site included "nearly 2,000 mm per year of rainfall, steep slopes, and landslides" yet the Inca managed to construct Machu Picchu, which remained in the rainforest for 400 years without failure (Wright, 1999, p. 36).

In constructing Saqsaywaman the Inca moved stones, each weighing over 100 tons from quarry to the site, sometimes a distance up to 30 km, without the use of the wheel (de la Vega, 1612, p. 469). In the extreme, rugged Andean topography, a wheel would not have been very useful, and the lack of development of the wheel does not indicate lack of civilization. Vincent R. Lee suggests use of wooden pine as rollers (Lee, 1989) and Garcilaso de la Vega, the firsthand historian of the late 1500s, claims that the stones were dragged by hundreds of Inca using many ropes around the stones (de la Vega, p. 469). Additionally, the masonry at Saqsaywaman and other sites show exquisite craftsmanship. Not even a blade can be fitted between the walls, and at the site, as a trophy to their skill, says de La Vega, the Inca refused to substitute small rocks into the walls and instead carved the large stones to support where other rocks had gaps (de la Vega, p. 469).

Beyond construction methods, the Inca were also masters in water engineering. The site of Machu Picchu used natural springs in the high mountains to supply water for a city of up to 300 people as well as water for agricultural terraces (Wright, 2012). With regard to drainage, writes Kenneth Wright, "It seems the Inca would have had the equivalent of an urban drainage manual similar to the ASCE Manual of Practice No. 77 (ASCE 1992) except that the Inca had no written language" (Wright, 1999, p. 36).

The site at Saqsaywaman was known to have a spring originating at the top of the hill, inside the round tower known as the Muyuc Marca. The spring originated from a long, underground river, the origins and mechanics of the spring a secret known only to the Inca who built the site. As complex as the towers were at the site, were the tunnels running underneath the site (de la Vega, 1612, p. 466-472). It is possible that these tunnels hold clues to an ancient water source, which informs the historic function of water and drainage at the site.

Because of the destruction of the site, it is difficult to determine where original canals ran and what their designs were. Previous research by Richard Miksad at the University of Virginia focuses on drainage ports in the walls to determine where original drainage canals were located. For example, the soil is no longer in its original place, as much was excavated by the Spanish and for archaeological purposes. One location on the east end of the walls has a drainage port that is several feet above the ground. Since water does not jump and the Inca were historically functional water engineers, it can only be assumed that the soil at that portion of the wall was several feet higher. These types of deductions allow us to piece together the original layout and drainage characteristics of the site.

Finally, with regard to applications of this knowledge outside of Andean engineering and to engineering practices today, Inca practices offer insights into sustainable engineering that traditional European-based engineering does not consider. The Spanish in the 1540s were so amazed by the large rock walls that they attributed the workmanship to spiritual and magical beings. However, for the purposes of this paper, we assume that the Inca received no extraterrestrial assistance, and that they used a large labor force and extremely efficient and well thought-out construction practices to design and construct the walls of Saqsaywaman and other sites.

Construction practices in the United States today rely on the power of gasoline and electricity to build structures of steel and city infrastructures. A 2,000 square foot home generates over 8,000 pounds of waste in the United States (EPA, 2004). Just the walls at Saqsaywaman are 130,000 square feet, which generating an equivalent amount of waste is 517,000 pounds of waste, over 600 pine trees. Given the scarce resources and limitation of only human labor, the Inca could not afford so much waste, and designed and constructed the site using only stone, human labor and lives, trees, and rope. Additionally, with water scarcity as a burgeoning issue in the United States, a look at the Inca use of springs and gravity-fed canals may shed light on how to engineer with water efficiency in mind. While the Inca faced different design considerations and resources than the United States currently does, the vast difference in their techniques can undoubtedly provide new perspective to modern day American engineering in the face of budgetary and resource limitations and a growing environmental awareness.

THE PROBLEM

The immediate problem at hand is the runoff from the impermeable clay layer that is damaging the third wall, causing it to crumble. [Figure] The long-term problem is to first determine the original state of drainage at the site and then implement Inca drainage techniques, with the most of the site having been destroyed, limited access to historic topographic maps, and reliance on first person historical records.

Immediate concern: alleviating runoff

To reduce further damage to the third wall, it is important to design and implement a minimally invasive drainage canal along the third wall to prevent further erosion without having the archaeologists remove the clay layer. Using ArcGIS sub-basins were delineated for Kenneth Lohr as a basis for the canal design. The method used to delineate the sub-basins is discussed in Method and Results. For details on the canal design please refer to Lohr's paper titled "Controlling Water Runoff: Protecting the Cultural Heritage Site of Saqsaywaman Peru".

Long-term concern: returning the site to the Inca design

The first step is to determine what the original Inca design was, then to engineer a solution to bring the current site to its historic state. Issues arise with the fact that in 1536, after one of the last wars to overtake the Inca, the Spaniards pulled down every stone from the site and used it to construct the city of Cuzco. Since the Inca had no form of written language, there are no design documents or photographs indicating the original site. A common problem with Inca history is that the history is told by word of mouth, and like any decades long game of telephone, the stories that were transcribed, additionally across a Quechua-Spanish language barrier, yield several timeline inconsistencies. Additionally, stories from each clan of the Inca Empire took undue credit and embellishment for the accomplishments of their ancestors; so singular accomplishments are credited to multiple rulers and varying timelines, the truth lying in the commonalities between all the stories.

The most important first-hand account is that of Garcilaso de la Vega, the son of an Incan princess and a Spanish conquistador who grew up in Cusco in the early 1500s. He wrote eight books on the “Royal Commentaries of the Inca” with substantial details of the site prior to war and its deconstruction. From de la Vega, and always with a grain of salt, we learn that three towers stood upon the site, the central one called Muyuc Marca as a reservoir served by a spring. He recalls stories from his Incan mother of thousands of Inca pulling one large stone by rope; while the number of Inca seems exaggerated, the story gives us insight into the construction methods. We also learn of a maze of underground tunnels that he explored as a boy, after the Spanish takeover and before the siege of 1536.

In addition to these important firsthand accounts, we also have maps from Spanish priests such as Squier and Cristobal de Molina. The map from Squier shows a palace dedicated to Manco Capac, one of the first Inca rulers, which appears on no other map. Later the site is vaguely replaced by a large Spanish ministry, matching with accounts that the conquistadors not only destroyed the Incan people, but made efforts to destroy the cultural remnants of important buildings.

Finally, we have modern topographic maps and land use maps from efforts in 1971 to catalogue the site. The Wright Water Paleohydrologic Institute also has provided detailed topographic information for the top of the site, but not the walls or the slopes leading down from the site. Publicly available satellite topographic information is available but with 30 meter contours, which is not useful for a small site with analysis that relies so heavily and detailed topographic changes. Detailed satellite Digital Elevation Models exist but are not freely available. I am currently talking with Kaart Data who license map data of international tourist locations.

METHODS AND RESULTS

With piecemeal access to information about the original state of the site, creative methods need to be used to, with maximal accuracy, discover the original state of water drainage at the site. The following sections will detail the methods that I have used to create historic and modern day models of the site and glean drainage behavior from those models using old and recent maps and the modeling software ArcMap 10 and ArcScene 10, portions of the ArcGIS software site available by academic license from the University of Virginia.

General topographic information for the site was collected from maps in the 1970s by manually drawing them into ArcMap 10. The detailed top-site information from the Wright Paleohydrologic Institute was imported directly from AutoCad and georeferenced into the model. The contour lines were scaled accordingly, with the general contour lines being every five meters and the detailed contours every meter. A digital elevation model (DEM) was created from the contours, from which a water flowpath was generated. Below are the step-by-step methods used:

Importing historic topographic maps into ArcGIS

Set Up the ArcMap Model

1. "Add a Basemap" and locate Saqsaywaman on the Map.
2. Set a Bookmark with the view so you don't lose it.

Now you can georeference all your maps to the globe to maintain consistency.

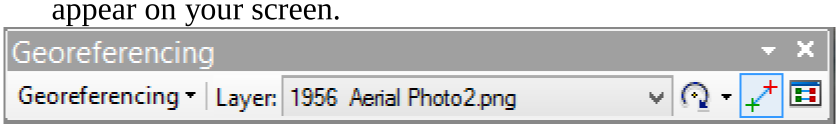
Import and Georeference the Documents

Figure 2: From left-to-right is the Historic Topographic map, the detailed AutoCad map, and the combined contour lines in GIS.

3. "Add Data" and "Connect to Folder" where the maps are located.
4. Select the map and select "Add" which puts it into your Layers.

The map will appear randomly on the globe.

5. Right click on the Map.jpg in the Layers and "Zoom to Layer"
6. Go to "Customize" then "Toolbars" then select "Georeferencing" and the toolbar will appear on your screen.



7. In the Georeferencing Toolbar select the Layer to your Map.jpg
8. Click the "Add Control Points" button and click first on the Map.jpg image then on the corresponding point on the Basemap. You need at least three control points not in the same line to georeference the image.
9. Important. When you are done and satisfied with your work go into the Georeferencing dropdown and select "Update Georeferencing" or you will lose your work.

Draw the Contour Lines

10. Add a new Polyline Shapefile called "Contours" with a Z-dimension for elevation
11. Right click on the new "Contour" in Layers and select "Edit Features"
12. Create a "New Template" for "Contours"
13. Draw each and every topographic line.
14. Open "Edit the Attribute Table" and add elevations for each line.

You now have contours from the historic map and can make a DEM.

Importing AutoCad Maps into ArcGIS

Import the AutoCad File (.dwg) to the Existing Model

1.  “Add Data” and ”Connect to Folder” where the .dwg files are located.

AutoCad versions after 2010 do not import directly into ArcGIS.

2. Select the Topography.dwg file and select all options (Lines, Annotations, Polygons, etc.) and “Add” to your model.
3. Right click on the “Topography.dwg” set of files, select the “Line” file, and “Open the Attribute Table”
4. Figure out which attributes are contour lines. The import merges all the lines into one quasi-shapefile.
5. Click “Selection” then “Select by Attributes” and select for the attributes which are contour lines.
6. Right click on the “topography.dwg” set of files, select the “Line” file, go to “Selection” and select “Create Layer from Selection”
7. Rename the selection TopographyDetail.shp so as not to confuse it with the original.
8. If there is no elevation field, add on, then edit the features and make sure that they scale to the previously added contour lines. With historic maps this can be more artistic than scientific.

You now have all the contour lines you need to generate a DEM.

Water flowpath analysis

1. Go to "Customize" then "Extensions" and select either "3D Analyst" or "Spatial Analyst" to ensure that you will be able to access watershed management tools.
2. On the right side of the screen click the "Search" button and search for "Topo to Raster", select the "Topo to Raster" toolbox
3. Use "Input feature data" to add the Contour.shp and the TopographyDetail.shp to the "Feature layer" list and select "Field" as "Elevation", "Type" as "Contour"

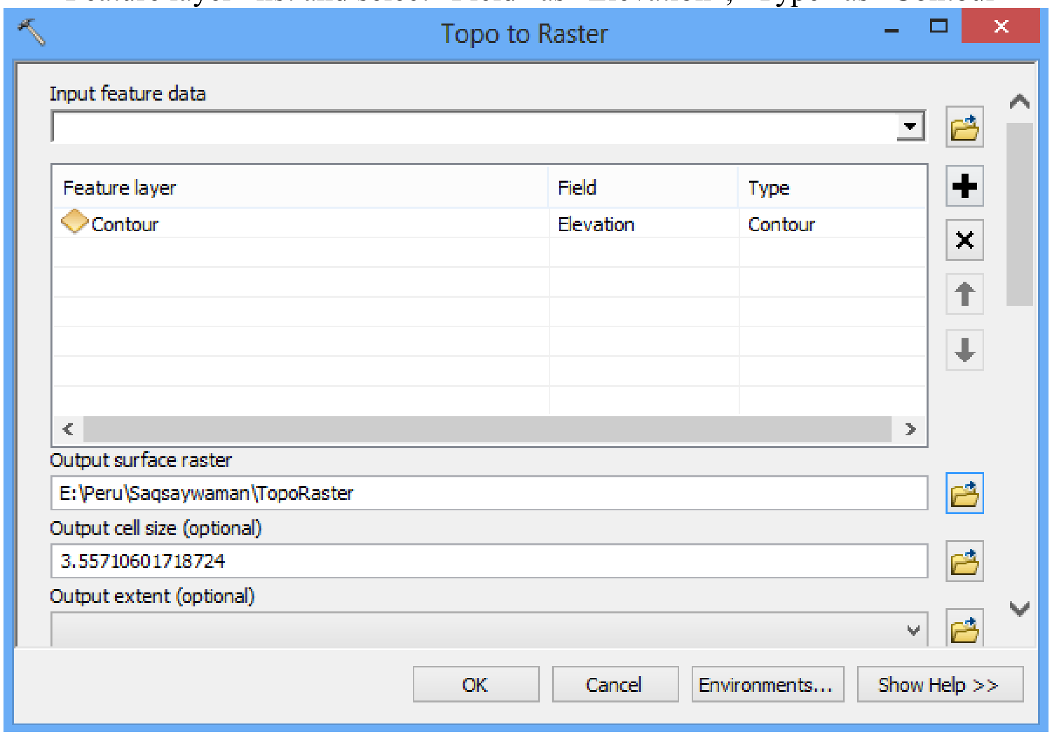


Figure 3: Topo to Raster Tool

4. Set the "Output surface raster" to go where you want it, leave the defaults, hit "OK" and the TopoRaster file will appear in your layers. (see Figure 4)

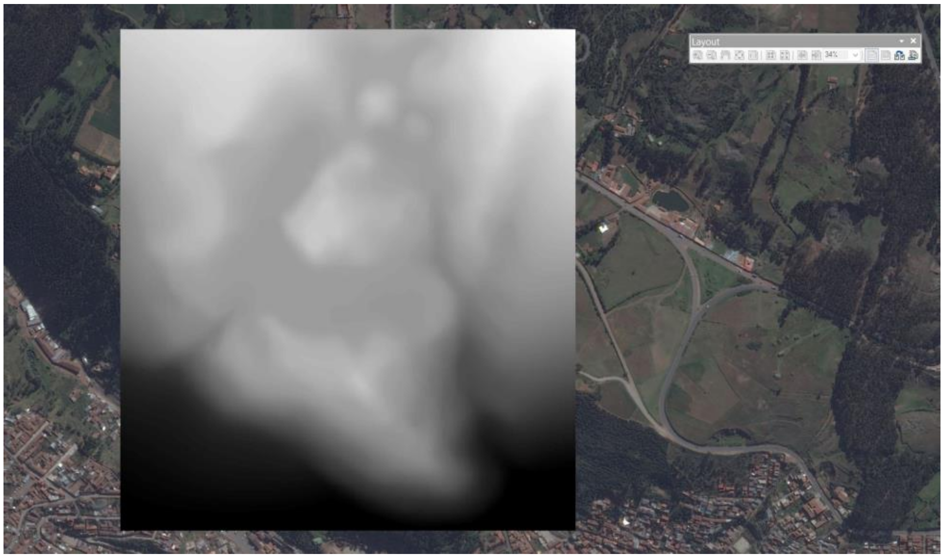


Figure 4: TopoRaster file

5. Search for and run the "Fill" toolbar using the TopoRaster file. This will fill any anomalous depressions and prepare it for the next step. Save the file as TopoFill.
6. Search for and run the "Flow Direction" toolbar using the "TopoFill" raster. You will get a raster file with a lot of colors, save it as "FlowDirec".

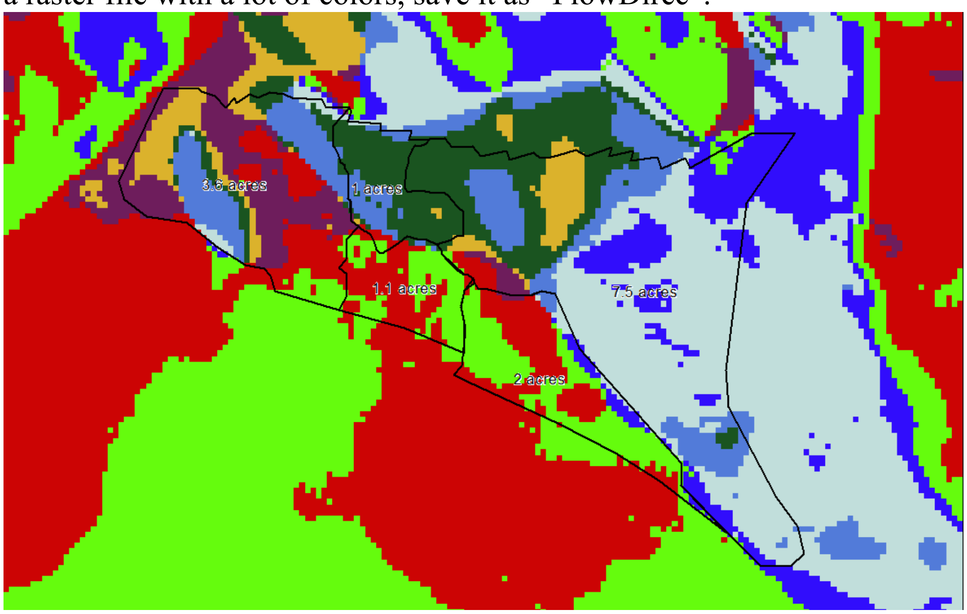


Figure 5: FlowDirec file

7. Search for and run the "Flow Accumulation" toolbar using the "FlowDirec" raster. Set the "Display" settings so that the highest numbers, which indicate the strongest preference for water to flow to that location, are red.

Figure 6: FlowAccum file

8. Search for and run the “Basin” toolbar using the “FlowDirec” and save the Output as a “Basin” raster. The colors represent different basins.

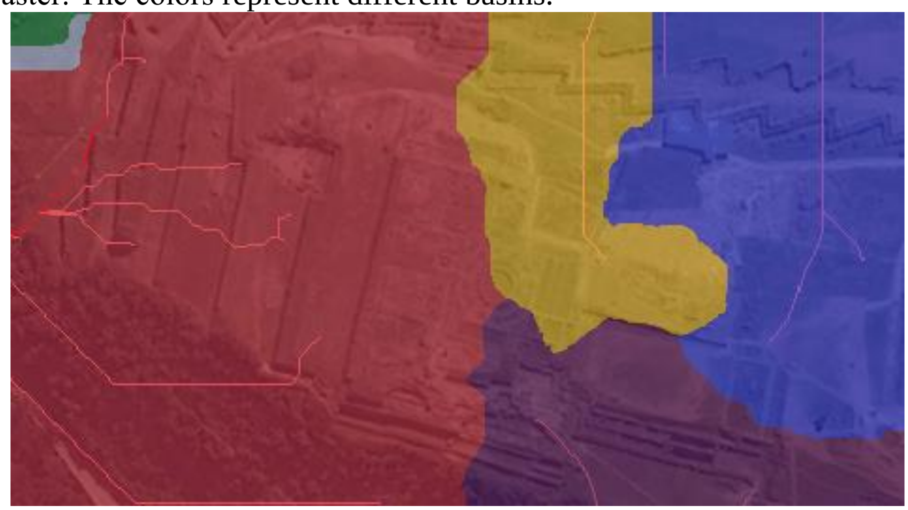


Figure 7: Basin file

9. Create a Polygon Shapefile called “Basins.shp” and Edit Features to match the sub-basin delineations from the “Basin” raster. This can be interpretive as the edges often yield staticy data.
10. Close the Edit session and Open the Attribute Table, “Add Field” and label it “Area_ac”.
11. Right click on the new “Area_ac” column in the Attribute Table and select “Calculate Geometry” being sure to select “acres” as the unit since the Attribute Table does not track units.
12. Right click on the “Basins.shp” and “Add Labels”
13. Use Python Script to addend the word “acres” to the “Area_ac” field

You have now analyzed the water flowpaths of the site and delineated sub-basins necessary to design a drainage canal.

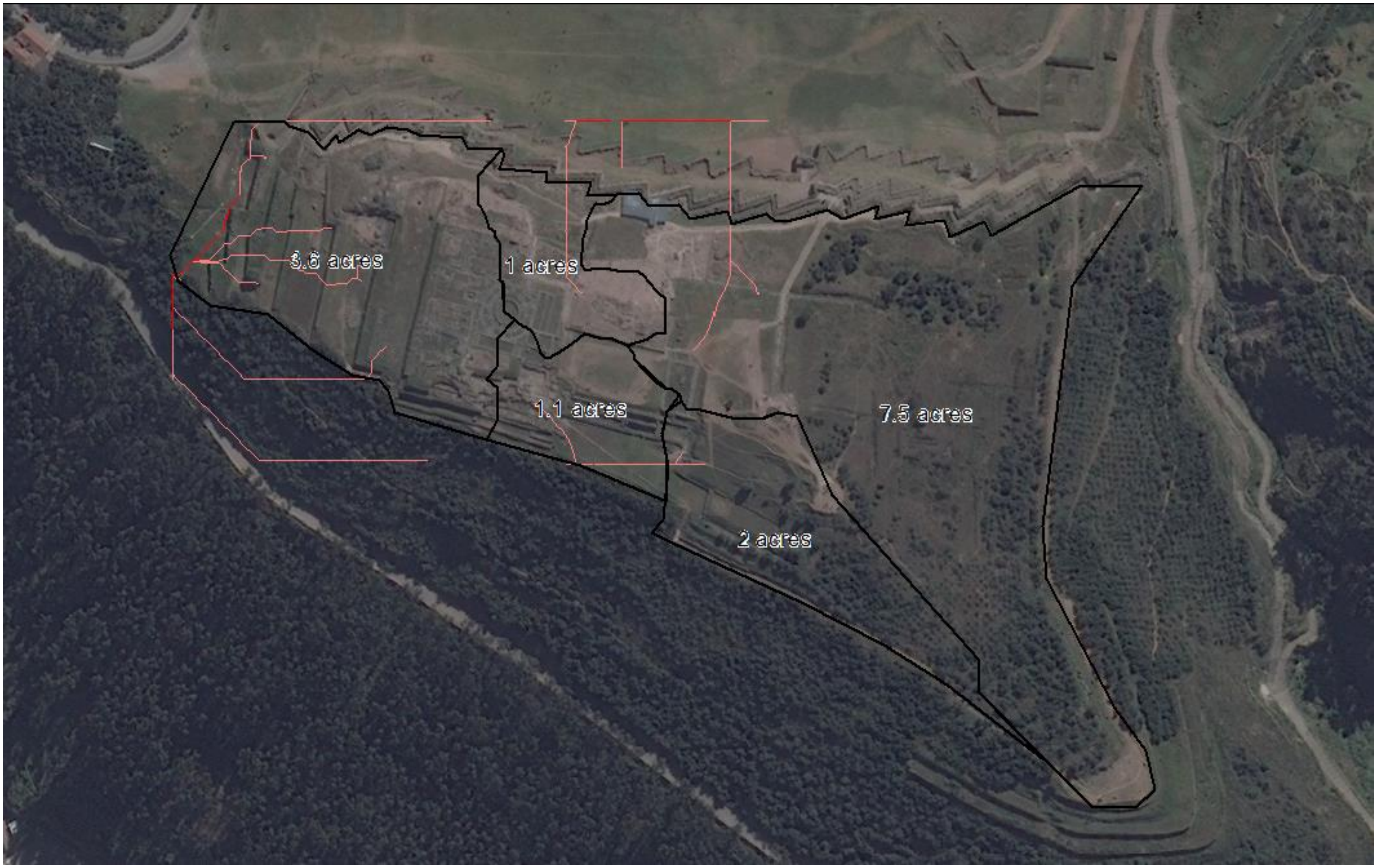


Figure 8: Water Flowpath and Sub-Basin Analysis of Saqsaywaman

Georeferencing maps and aerial images for standard reference

In order to compare maps across time, they need to be georeferenced, or “pinned”, to the same map. It is best to create a separate model from the Water Flowpath Analysis used previously.

1. “Add Data” and ”Connect to Folder” where the maps are located and add all of them into a new model.
2. Using the instructions from the previous section “Import and Georeference the Documents” georeference the maps one by one.
3. In the Georeference Toolbar select the “View Link Table” button and toggle the “Transformation” selection. “1st Order Polynomial (Affine)” is good if the image just needs to be stretched. Further down the list increases in complexity. I used “Spline” often because the Squier Map was hand-drawn and the computer needed to split and sectionalize the document in order to georeference it.
4. Remember to “Update Georeferencing” for each one, or you will lose your work.

This step is rather simple, but tedious. The following images are of the oldest map from Squier in the late 1500s which indicates a “Palace of Manco Capac” overtop the “Colcampata” which is later replaced with a Spanish church. The 1956 aerial map cuts off just at Saqsaywaman, indicating it was not important to capture, and the 1970 aerial map shows great detail the site and its surroundings, as well as light deforestation behind the site.

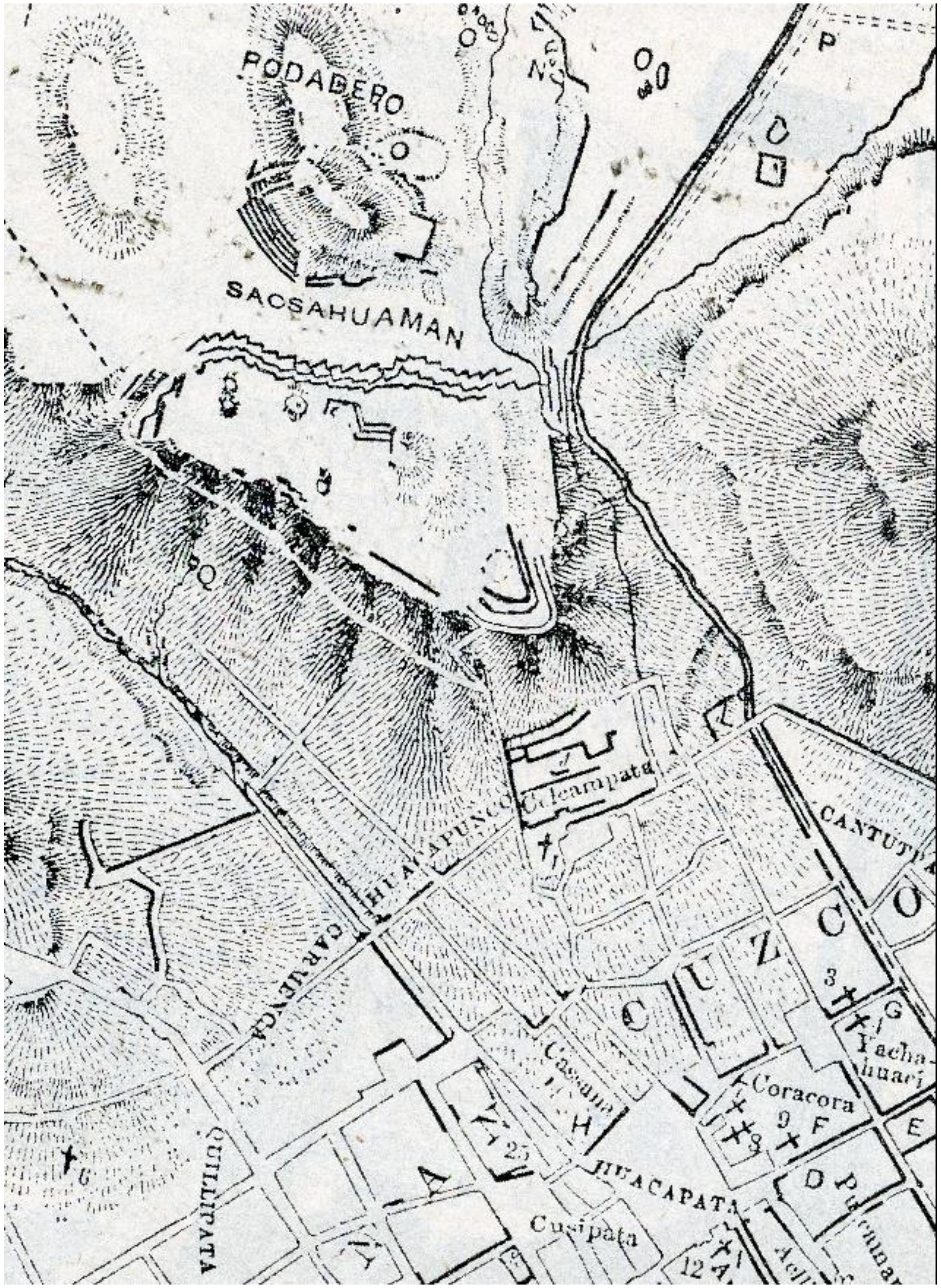


Figure 10: Squier Map

Figure 9: 1956 Aerial

Figure 12: 1970 Aerial

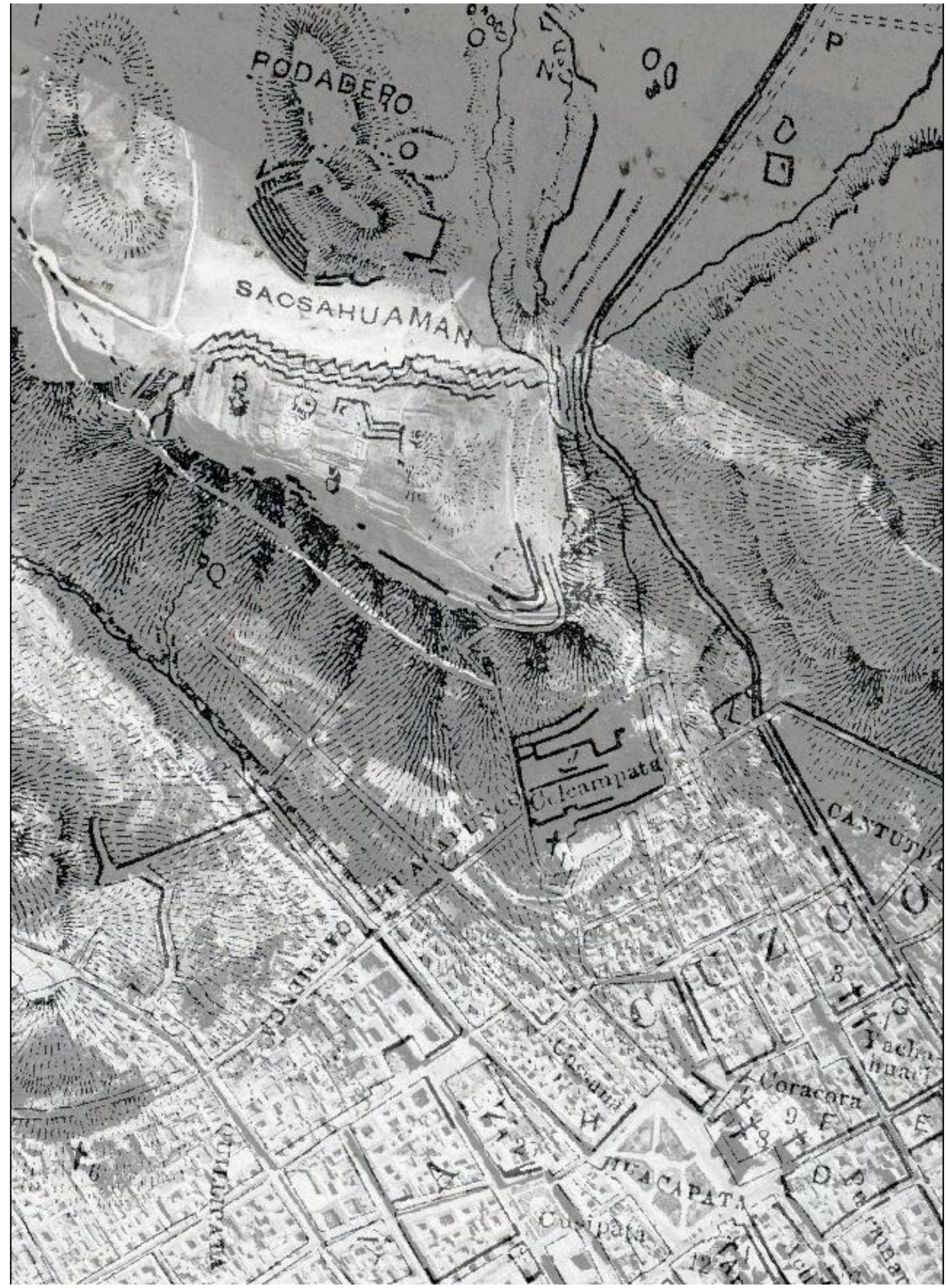
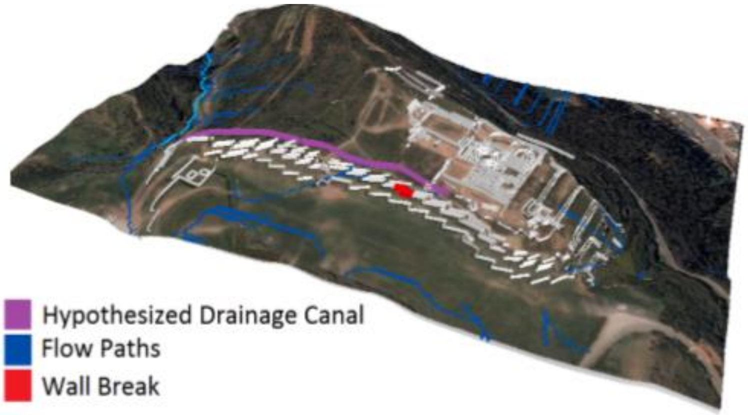


Figure 11: Overlay of Squier, 1956 and 1970 Aerials

ArcScene modeling

To display the information in a three-dimensional way I imported the ArcMap model into ArcScene and modeled Miksad's hypothesized drainage canal along the third wall, the wall break, and flowpaths off the site in its most well-known topographic situation.



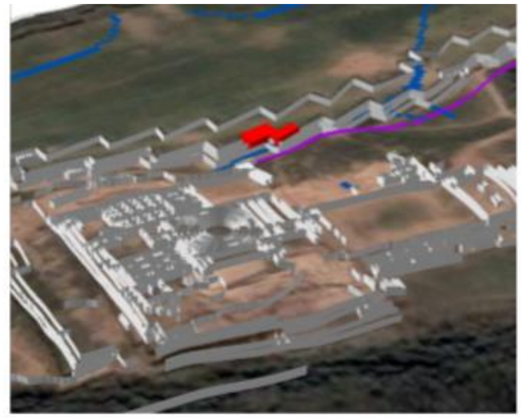


Figure 13: ArcScene Modeling of the Site Flowpaths

FUTURE RESEARCH

To make the model as accurate as possible I will aggregate maps on-site in Washington D.C. at Dumbarton Oaks and the Library of Congress. This will inform a more detailed historic water flowpath analysis. Additional maps with coverage information (affecting the runoff coefficient) as well as more firsthand accounts and analyses done by Peruvian archaeologists are available in these libraries.

I will create a model that can accommodate water flowing through the walls, instead of the just sheet flow over the land. The team will travel to Peru in the beginning of August with a survey station to collect detailed topographic information and retrieve drainage port heights to determine the locations and grades of original drainage canals.

Given the technical limitations of wireless internet and a mobile computer on the field, I will create the model as much as possible ahead of time. I am currently requesting a quote to rent a Lenovo ThinkPad with an Intel Core i7 Processor and 3.3GHz of speed and a Windows Operating System, necessary to run the ArcGIS software.

CONCLUSION

Creating standards for analyses with the ability to georeference aerial and topographic maps to the same globe allows for computer analysis of historic maps, which historically was not easily done without the aid of softwares like ArcMap and ArcScene. Additionally, combining these maps with in-depth cultural knowledge of the site by integrating firsthand accounts of how the site operated pre-deconstruction offers an additional layer of knowledge, not just on how the water flowed through the site, but how the Incas engineered and used the site. We hope to use the knowledge of the historic drainage on the site to reconstruct the site to its original drainage system, alleviate the runoff damage, and bring back a small piece of Peruvian heritage that has been missing for over 400 years.

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Exploring the role of engineering in public health:
engineering solutions for noncommunicable disease prevention

A Research Paper
in STS 4600
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Civil Engineering

Olivia Jeffers
May 8, 2013

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ____ Date: ______________

Approved: ____ Date: ______________
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Abstract

From the 18th to 20th centuries, sanitation was the primary public health concern of America's growing cities. Engineers and physicians worked closely together in developing sewer infrastructure to reduce the spread of communicable disease by unclean water. During the Progressive Era from 1890 to 1920, sanitary engineers were poised to "replace the doctor in the confidence of the public" and become "so important as to be outside of political control" with relation to community health issues (Richards, 1911). In the 1940s, however, a series of events and political pressures divorced engineers from the forefront of public health. Today engineers still work in public health fields such as managing workplace safety and environmental pollution regulations. By the lack of educational programs and job opportunities, engineers are effectively removed from the new public health concern of noncommunicable diseases such as diabetes, heart disease, and obesity. By studying sanitation, this paper investigates the changing relationship between engineering and public health prior to the 1940s. The paper then conjectures how engineers might tackle the new public health concern of food deserts within the physician-engineer framework of the Progressive Era.

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Introduction

"Public health is the science of protecting and improving the health of families and communities through promotion of healthy lifestyles, research for disease and injury prevention and detection and control of infectious diseases" (Centers for Disease Control and Prevention [CDC] Foundation, 2013).

From the first sewers in Rome to the massive water and refuse management infrastructure of the modern American city, engineers have played a vital role in designing infrastructure related to public health. While the impact of engineering on public health is widely experienced by the 270 million Americans who have clean tap water (Environmental Protection Agency [EPA], 2013), the role of engineers in a public health capacity is not well studied. This paper examines historic events leading up to the Progressive Era from 1890 to 1920, where sanitary engineers were lauded as municipal leaders who would "replace the doctor in the confidence of the public" (Owens, 2004, p. 803), and the following reversal in the 1940s when the medical sciences overtook engineering in public health (Fee & Brown, 2002; Fee, 1992; Owens).

American engineers and physicians have worked together intimately, competitively, and sometimes contentiously over the past two hundred years. In 1945 Vannevar Bush, Director of the Office of Scientific Research and Development, attributed the halving of mortality rates in the early 20th century to advances in medical science; in 2004 the National Bureau of Economic Research attributed the same drop in mortality rates to advancements in municipal infrastructure (Cutler & Miller, 2004).

During the 18th through 20th centuries, American engineers and physicians worked together closely to control epidemics of waterborne diseases such as typhoid, yellow fever, and malaria. In 1912, the American Public Health Association (APHA), an association for professionals in public health that is still prominent today, defined the relationship between physicians and engineers in terms of a division of labor: the physician gathers data from the field, giving requirements to the engineer, while the engineer designs the system for operational and price efficiency, preparing the product for market. Some entrepreneurial engineers even took their designs to market into municipal administrations.

For example, drainage engineer and member of the National Board of Health's inspection team Colonel George E. Waring brought unprecedented fame and popularity to sanitary services. In 1881, he won a contentious bid to reform the city of Memphis' defunct sewer system. He later patented aspects of his design, formed a company, and sold his sewer system to other cities. In 1895, he was elected the street-cleaning commissioner of New York City and brought to the city "enthusiasm, salesmanship, and controversy" by expelling political cronies and replacing them with "young men with engineering backgrounds or military training" (Melosi, 2008, p. 111). His entrepreneurial mind, political awareness, and engineering background placed him at the forefront of the Progressive Era engineering movement.

The work of engineers and physicians in public health infrastructure dramatically reduced mortality rates in the United States. The sanitary situation in the United States can be characterized by periods of drought-induced discord in the Jamestown colonies (Blanton, 2000), waves of cholera and typhoid epidemics in the 19th century, halving of urban mortality rates due to sanitary infrastructure in the early 20th century (Cutler & Miller, 2004), and a public water system that provides clean water to 90 percent of Americans today (EPA, 2013).

While mortality from waterborne diseases has followed a steady downward trend in the United States, the role of engineering in public health has fluctuated since the onset of the Progressive Era in the 1890s. This paper investigates this changing role by examining the influences of education, professional identity, and political events on engineering and public health.

Education provides a valuable lens through which to analyze the changing role of the engineering profession in public health. University courses and degrees are deeply influenced by professional associations, which rely on universities for well-trained employees (Noble, 1982). Additionally, most universities keep detailed funding records as well as publicly available yearly course catalogues and university reports. This paper reviews the rise of engineering in public health during the Progressive Era at the Massachusetts Institute of Technology (MIT) as well as the politics behind the eventual removal of engineering from public health programs at the behest of the Rockefeller Foundation in favor of scientific research in the 1940s.

The medical profession, economically reliant on paying clients, suffered during the depression in the 1930s and the American Medical Association (AMA) rallied against national health insurance, which threatened private practice, in the Social Security Act of 1935 (Fee, 1992). While the medical profession was strongly represented by the AMA, public health engineers were never able to form a strong professional association (Kline, 2008).

In addition to lacking strong professional organizations, engineers in public health faced further difficulty during the war when the preeminent belief was that advancements in medical science would cure most public health ailments (Bush, 1945). Educational funding for public health programs from organizations such as the Rockefeller Foundation went to science programs in lieu of engineering management programs (Owens, 2004; Rockefeller Foundation, 1940). After the war, a rise in federally funded building projects took engineers from municipal public health administrative positions (Fee & Brown, 2002).

With the decline of Progressive Era ideals and the belief that medical science could alleviate public health concerns, by the 1950s there were few education programs for engineers at the forefront of public health research and policy (Fee, 1992). Engineers are now involved in public health insofar as their existing role within industry: design and maintenance of buildings and infrastructure with regard to human safety and industrial and municipal waste management programs (Bureau of Labor Statistics, 2010).

The United States now faces a new type of public health issue that takes 70 percent of American lives and costs the U.S. over $1.5 trillion each year: noncommunicable, preventative diseases such as diabetes, heart disease, and cancer (Daulaire, 2011). These diseases most often result from systemic trends in malnutrition and environmental exposure (CDC: Data and Statistics, 2013). While it is outside the scope of this paper to consider the current political state of pharmaceutical companies, healthcare reform, and medical research – it is within the scope of this paper to note that the new field of public health is ripe for entrepreneurial engineering action.

Diabetes alone, for example, costs the U.S. over $174 billion per year in direct medical and indirect loss-of-work costs in 2008 (CDC, 2011). Diabetes death incident rates are double in a food desert (Curry, 2009). A food desert is defined as urban neighborhoods and rural towns without ready access to fresh, healthy, affordable food[1]. Through analysis of census data, the United States Department of Agriculture (USDA) estimates that 13.5 million Americans, 4.5 percent of the population, live in low-income food deserts (USDA, 2013).

Grocery chains do not move into low-income food deserts because low-income residents cannot afford standard food prices. Support organizations have proposed private investments and government subsidies in order to move grocery chains into these areas to alleviate the health problems of obesity and diabetes (Jones, 2013). Both options require significant external funding with the only return on investment being potential health improvements and reduction of medical

[1] "Ready access to food" is defined as having a grocery store within 1 mile in urban areas and 10 miles in rural areas. See Appendix A for a map of food deserts in the Washington, D.C. area.

costs. A low cost engineering solution, however, that operates within the existing economic structure that gets healthy food into food deserts has the potential to turn 13.5 million malnourished, low-income Americans into 13.5 million regular customers. The strategy of taking small profits from a large, low-income customer base has proven successful in by social entrepreneurs in developing countries (Grassl, 2012).

Education is the largest barrier to this type of entrepreneurship, which requires a degree or background in engineering, public health, and business. Programs in public health engineering or environmental health engineering are reserved for specialized graduate and doctorate studies, mostly focused on researching the science behind regulations and not the business applications. In order to consider providing a new type of education for engineers with an interest in public health, it is necessary to first understand the historic role of engineering in public health.

The Progressive Era: "The Sanitarian as the Strong Man"

"[The sanitary engineer] has thus trenched on the ground hitherto held by the medical profession, and has usurped the moral standpoint of the preacher and insisted upon a new basis for law, the people's right to health as well as right of way" Ellen Richards, Conservation by Sanitation, 1912

Engineering in the Progressive Era from the 1890s to 1920s was characterized by "professionalism focused on autonomy and professional responsibility" (Kline, 2008, p. 1020). Engineers were not only trusted to design and build vital infrastructure, but were expected to act as sanitarians, non-partisan municipal administrators, with regard to public health (Richards, 1912). The ideal of professional responsibility was so strong that even prominent figures in the medical profession, at an economic disservice to private practice, proposed that doctors and nurses be salaried underneath the management of the "sanitarian [as] the strongman" (Fee & Brown, 2002, p. 36).

Colonel George E. Waring was an early Progressive Era role model for engineering leadership in municipal management. After successfully selling his patented separate sewer system, in 1895 Waring was elected the street-cleaning commissioner of New York City. His first action was to expel political cronies and replace them with "young men with engineering backgrounds or military training" (Melosi, 2008, p. 111). Waring created the White Wings, a 2,000-large street-cleaning crew that wore uniforms on par with physicians and nurses, as well as the Juvenile Street Cleaning League for 500 youngsters to distribute sanitation information throughout the city. His lasting influence was in viewing sanitation as a "multifaceted community problem" as well as laying the groundwork for the Progressive Era. Like those after him, he "demonstrated faith in municipal government to lead [public health services], aided by a technical elite freed from the influences of patronage" (Melosi, pp. 91-111).

Municipal health and business

While engineers did focus on efficiency and revenues from municipal waste (Melosi, p. 118), the Progressive Era was largely defined by the conflict between municipal health authorities and business interests, who believed that public health measures interfered with the flow of commerce (Fee & Brown, 2002, p. 32). Conflicts between business interests such as factories and those more concerned with public welfare were famously illustrated by Upton Sinclair's *The Jungle*, showing the unsanitary and life-threatening conditions of meatpacking factories in Chicago. The Progressive Era was closely associated with socialist ideals, advocating large nationwide public health reforms and spurred sanitary reform as well as the profession of sanitary engineering (Fee & Brown; Melosi, 2008).

In the conflict between public health and business interests, the medical profession was well positioned to benefit in the case that either side dominated over the other. Public health engineers, who relied on government salaries, advocated health policies that business interests viewed as commercially restrictive, while the AMA, run by "local private practitioners" (Fee &

Brown, p. 36), lobbied for pro-business policies, such as removing national health insurance from the Social Security Act of 1935 (Fee & Brown, p. 36). As this paper will later discuss in detail, the pro-business approach taken by the AMA allowed physicians to survive the shifting political landscape and collaborate with the chemical and biological industries in the 1940s, establishing medical science at the forefront of public health research and policy (Fee, 1992).

Physicians and Engineers

"The intimate relation, regarding matters of public health, which exists between science of biology, the practice of medicine and the science and practice of sanitary engineering, has been the cause of establishing this section" APHA, establishing the Sanitary Engineering Section, 1912

During the Progressive Era, physicians and engineers were encouraged to work together in the light of public health concerns. The Sanitary Engineering Section of the APHA was established in 1912 at the American Society of Civil Engineers (ASCE) in New York City under the charge of joining physicians and engineers in the common goal of providing well-designed and optimized sanitation infrastructure for the benefit of public health (APHA, 1912). The section was later changed to Engineering and Sanitation in 1955 and then changed to Environment Section in 1970 during the environmental movement (APHA, 2013).

At the time of its founding, the relationship between physicians and engineers were framed such that physicians would gather medical data and give the engineers requirements for public health systems, while the engineers would take those requirements and design public works, with focus on "details of design and economy of operation and management" (APHA, 1912).

Throughout the Progressive Era, associations like the APHA, AMA, and Virginia Medical Society called for papers on the topics of public health. The first APHA council in 1912 called for nearly one hundred papers on the topic of sanitary engineering. Representative samples of research topics focus on studying the "physiological and pathological effects of odors," "noxious gases in enclosed spaces," and designing "practical means and methods, efficiencies and costs" of improving ventilation and humidity in enclosed spaces, as well as designing refuse treatment systems (APHA, 1912).

The platforms for engineer-physician interaction not only led to papers, but also led to important public health innovations in the early 20th century. In 1903, for example, the University of Virginia's Chairman of the Faculty and professor of medicine, P. B. Barringer presented to the Virginia Medical Association "An Unappreciated Source of Typhoid Infection." Barringer claimed that the direct spraying of infected refuse onto railroad tracks caused contamination of nearby water supplies and inhalation of typhoid particles by railway workers, for whom typhoid infection rates were the highest. Referring to the uncomfortable lack of toilets on European railways, where typhoid rates were nearly half of American rates, Barringer suggested that American trains implement the newly designed flushable toilet as well as a refuse storage system. By the early 20th century, engineers had designed flushable toilets for the railway, which were then widely adopted on American trains (National Railway Museum, 2010).

Anti-foreign sentiment

While the support of public health during the Progressive Era can be viewed as noble by today's terms, it is important to note that the intense focus on public health was born of anti-foreign sentiments. In 1850, Lemuel Shattuck, a founder of the American Statistical Association who also served on the Boston City Council in 1837, published a cornerstone report on the sanitation of Massachusetts. The report focused on statistical sanitation-health relationships and was the basis for establishing birth and death certificates. Regarding foreign immigrants, however, Shattuck said that "the increase of crime has been very great during the last eight years, but it has been almost entirely the foreign population" (Shattuck, 1850, pp. 137-138). The report concluded that because most urban dwellers were not able to themselves abide by proper sanitation measures, that the responsibility for public health belonged to the state (Melosi, 2008, pp. 34-36).

Ellen Richards, a prominent advocate of sanitary sciences and the role of sanitary engineers as leaders in municipal government, was the first female student to attend MIT and was instrumental in the developing MIT's Department of Chemistry. In her devotion to public health, Richards was also passionate about education and domestic health. In *Euthenics: The Science of Controllable Environment: A Plea for Better Living Conditions as a First Step Toward Higher Human Efficiency*, Richards focuses on education and healthy home environments, and like Shattuck, emphasizes the inherent laziness and low intelligence of the immigrant population. "But with foreign domestics," writes Richards, "whose idea is to get the various duties over as soon as possible, and whose gift is not that of teaching, how is the child to grow into the normal ways of right daily living, unconsciously and effectively?" (p. 93).

The rise of public health concern came from dense, eastern seaboard cities like Boston, Baltimore, and New York. The anti-foreign sentiment reflected in government and scientific publications of the early 20th century are not acceptable in public health practice today. While initially based in anti-foreign sentiment, however, Shattuck's statistical analyses on the link between urban environment, human behavior, and public health spurred the growth of sanitary science, engineers in municipal administration, and development of municipal infrastructure, which are attributed to the halving of mortality rates during the early 20th century (Cutler & Miller, 2004). A growing economic tension, however, between public health engineers and physicians laid the groundwork for the eventual displacement of engineers from the forefront of public health in the 1940s.

The 1940s: The rise of the scientist and fall of the sanitarian

By the 1940s, the APHA and the Municipal Public Health Engineers (MPHE) jointly confirmed the need for "administrators of municipal health departments [to] recognize that control of the environment for the protection and promotion of public health involves engineering principles (American Journal of Public Health and the Nation's Health [AJPH], 1940)." In his paper "The Public Health Engineer and the City Officer" read at the same MPHE Conference, Abel Wolman, Professor of Sanitary Engineering at Johns Hopkins University, stressed the importance of a well-trained engineer, able to operate within the context and specific limitations of each municipality. "To the public health engineer," Wolman wrote, "the city health officer should look for all of those forms of environmental regulation which by training, experience, and technic the medical officer of health cannot supply" (p. 439). The sanitary engineer of the Progressive Era was the basis of the ideal public health engineer of the 1940s, whose responsibility it was to manage all aspects of municipal public health.

The rise of public health education in the United States, which peaked in the 1930s, began with the Welch-Rose Report of 1915, sponsored by the Rockefeller Foundation. Welch-Rose compared the state of American public health education, where only 10 universities offered degrees in public health and only three or four had hygiene[2] laboratories, to Germany where every university had an institute or department of hygiene (Welch & Rose, 1915, pp. 661-662). Public health engineering reached its peak at MIT in the 1930s and declined in the early 1940s when the politics favored research in medical science over engineers as municipal administrators for the advancement of public health (Owens, 2004; Bush, 1945).

[2] The term "hygiene" in the Welch-Rose report is equivalent to "public health" (Fee, 1992)

"The Sanitary Vision at MIT": Public health engineering in education

In training "that elusive individual whom we have been in the habit of calling the 'sanitary engineer' it was necessary to 'avoid the Scylla of the structural engineer and the Charybdis of the laboratory devotee." The end product would be "sanitarians of the environment" Abel Wolman (1924)

In 1913, Samuel Prescott, the Dean of Science at MIT illuminated to the APHA the delineation of sanitary engineering under public health engineers and elaborated upon a new course of study at MIT. For the Bachelor of Science in Public Health Engineering MIT required 6,060 hours of study over four years, where 55 percent of the study is devoted to "general, fundamental, or cultural studies" in addition to scientific and engineering material. Classes included military science, applied mechanics, physics, bacteriology, sanitary engineering, railway & highway engineering, English & history, public health administration, vital statistics, and a thesis (Prescott, 1931, pp. 1097-1098). It was clearly important that the public health engineer have the general knowledge and management skills to execute scientifically-based engineering designs in the social context of municipalities.

Public health engineering had its strongest university roots at MIT and Harvard. The sanitary vision at MIT, using engineering and science to better humanity, began with William Sedgwick, who transformed the natural history courses into a Department of Biology in 1883, and Ellen Richards a sanitary biochemist with great influence on the Department of Chemistry. The Dean of Science, Samuel Prescott, was deeply influenced by the progressive ideas of Sedgwick and Richards, and the philosophy of the institute was focused on using technology for maximal human happiness, whether it was in designing the coffee makers for the perfect cup of coffee or nationwide sanitation systems for the betterment of public health (Owens, 2004).

The Department of Biology, which housed public health studies, trumpeted the Progressive Era ideology of engineers as municipal leaders until the 1930s. Even those in the medical industry were touting Progressive Era reform philosophies. B.S. Warren, a prominent PHS surgeon, "envisioned groups of salaried physicians and nurses working under the supervision of local health departments" and former editor of the New York State Journal of Medicine James P. Warbasse argued that "someday the care for the public health will be organized…as a public service. The sanitarian will be the strong man. His first business will be to keep his death rate low. This he will accomplish with the cooperation of the district hygienists, internists, surgeons, and other specialists" (Fee & Brown, 2002, p. 36).

Fee and Brown proposed that Progressive Era public health ideals declined with pro-business Republicans controlling the White House between 1920 and 1930, as well as the growing strength of the AMA, run by "local private practitioners" who anticipated loss of business in the face of progressive policies such as national health insurance (Fee & Brown, p. 36). Owens additionally hypothesized that the strong pro-sanitarian rhetoric led to tension between physicians and sanitary engineers, as evidenced when the MIT-Harvard Joint School for Health Officers, originally influenced by engineers, separated into an independent School of Public Health led by Harvard Medicine with the aid of a $2 million Rockefeller Foundation grant (Owens, 2004; Rockefeller Foundation, 1921).

The progressive ideas of sanitation and public health engineering lost further traction in 1936 when President of MIT Karl Compton's Rockefeller Foundation proposal for establishing a Department of Biological Engineering was rejected on the grounds of "timing, staffing, and anomalous involvement in public health" (Owens, 2004, p. 804). As chemical engineering had prior received great support and funding in academia, MIT hoped that biological engineering would follow suit. In 1940, Compton won the proposal for $200,000 including more hires in quantitative physical sciences and withdrawing from public health[3].

[3] See Appendix B for the 1941 Annual Report in which the Rockefeller Foundation discusses the historic precedent and reasons for awarding the $200,000 grant to open the Department of Biological Engineering to MIT.

The reasons for the demand by the Rockefeller Foundation are elusive, as they historically funded many projects in the public health arena. In 1921 the Rockefeller Foundation appropriated $2 million, which allowed the joint MIT-Harvard School of Health Officers to separate into the School of Public Health led by Harvard medicine. During this year, the Rockefeller Foundation also appropriated a $250,000 to the School of Hygiene and Public Health at Johns Hopkins University and contributed to public health training in Czechoslovakia and Brazil, and assisted the opening of 25 medical centers in China (Rockefeller Foundation, 1921, p. 7).

By 1945, Vannevar Bush, the Dean of Engineering at MIT and the Director of the Office of Scientific Research and Development, attributed disease control and advancements in life expectancy to a “great amount of basic research in medicine and the preclinical sciences.” Bush wrote that “diabetes has been brought under control by insulin… and the once widespread deficiency diseases have been much reduced, even in the lowest income groups, by accessory food factors and improvement of diet” (Bush, 1945, Chapter 2). With the rising healthcare costs of diabetes today and the 13.5 million low-income Americans living in food deserts who suffer twice the national rate of diabetes, it is clear that the reliance on scientific research to solve public health problems in the 1940s and onward was not a comprehensive or effective solution.

The Rockefeller Foundation cited “anomalous involvement in public health” as the reason for withholding funding for the new Department of Biological Engineering (Owens, 2004, p. 804). Given the Rockefeller Foundation’s extensive funding in basic research and public health schools during the same decade, it is clear that the “anomalous involvement” was the Progressive Era training of engineers as municipal administrators. The removal of the engineering public health program at MIT, one of the leading universities in public health, was indicative of a nationwide trend that supported research in medical sciences over engineering for the advancement of public health (Fee, 1992; Bush, 1945). Given the wartime technical needs of the 1940s, the advancement of scientific medical research in public health, and the economic conflict between physicians and public health engineers, the era of engineers as a technical elite aiding municipal public health authorities became obsolete.

Public health engineering: professional disaggregation

The lack of a strong professional organization left public health engineers vulnerable when medical sciences began to overtake engineering at the forefront of public health research and policy. In 1915, engineering organizations struggled between pro-business and Progressive Era ideologies in revising their code of ethics (Kline, 2008). Because of these philosophical disputes, "attempts to unify the engineering profession, establishing a powerful umbrella organization on the lines of the American Medical Association were frustrated at every turn" (Kline, p. 1020).

The weakness of professional identity can be observed by the history of the only existing professional organization, the American Academy of Environmental Engineers and Scientists (AAEES). The AAEES changed their name and organizational structure six times since being established in 1955 as the American Sanitary Engineering Intersociety Board, which was created under the Committee for the Advancement of Sanitary Engineering of the ASCE with support from APHA, American Water Works Association, and the Water Pollution Control Federation. Once established, the future-AAEES struggled with professional identity, changing in 1966 to the Environmental Engineering Intersociety Board (EEIB), and a year later, the Board turned their roster into an independent organization, the American Academy of Environmental Engineering (AAEE). In 1973, the EEIB and the AAEE merged and both organizations functioned under the American Academy of Environmental Engineers. In January of 2013, the

AAEE became the American Academy of Environmental Engineers and Scientists. Other than the AAEES no public health engineering professional organization established prior to the 1950s, such as the Municipal Public Health Engineers, exists in the United States today.

Public health engineers and sanitary engineers were never able to create a unified and powerful professional organization such as the AMA (Kline, p. 1020). When the private practice of physicians was threatened during the Progressive Era, the AMA lobbied to remove national health insurance from the Social Security Act of 1935 and protected the economic vitality of the medical profession (Fee & Brown, 2002, p. 36). When the public health engineering profession was threatened with pro-medical research policies replacing the role of engineers in public health administration, the weak professional associations of public health engineers were unable to keep the profession of public health engineering intact. The responsibilities of the public health engineer were then dispersed into separate disciplines of environmental science, environmental engineering, occupational health and human safety, and so on. As will be discussed later in the paper, the current state of education in public health engineering reveals the fragmentation of engineering fields in the public health industry.

Engineering and public health today

Each generation is associated with its own public health concerns; the 1920s with Progressive Era reforms to municipal sanitation, the 1950s with focus on reducing industrial pollution from post-War development, the 1970s focusing on clean air, water, and environmental conservation, and the 1990s ushering in workplace air pollution by asbestos, silica dust, and sick building syndrome (Earnest et al., 2006). While the public health problems of the past have been solved, the solutions of the past are often the problems of the future. As such, continual efforts are required to maintain public health standards within a changing technological and social landscape.

Sanitary and civil engineers made reliable, clean water a reality in the United States. Sanitary engineers are now needed to design new types of water and sewer infrastructure, and to maintain existing infrastructure. The cornerstone public health discovery of sanitary engineering, however, has been well-established for over a century: Scientists discovered that humans need clean water to prevent outbreak of communicable disease in urban environments, and engineers developed and built infrastructure meeting those requirements (Melosi, 2008, p. vii).

The United States now faces new types of public health concerns. On a nationwide scale over 8 percent of Americans and growing have diabetes, 36 percent of adults are obese, with 12 percent of children ages 2 to 5 as obese. Heart disease and cancer each cost the U.S. $109 and $219 billion a year, respectively (CDC: Data and Statistics, 2013). These are all classified as incommunicable, preventable disease, and therefore fall under the scope of the CDC.

Given the Progressive Era physician-engineer relationship, where the engineer is to take requirements from physicians and scientists and design and optimize a cost effective infrastructure that will succeed in the market. It is worthwhile to explore the potential role of the Progressive Era physician-engineer relationship in today's context. The following section of this paper analyzes the Progressive Era physician-engineering relationship in the context of food deserts, the previously discussed example of a new public health concern ripe for an engineering solution.

Food deserts: public health engineering in today's context

Food deserts are defined as urban neighborhoods and rural towns without ready access to fresh, healthy, affordable food (USDA, 2013). Food deserts result in higher rates of obesity and diabetes (Curry, 2009), which cost the U.S. over $174 billion per year (CDC: Data and Statistics, 2013), then the engineering question is: how to bring fresh food closer to impoverished neighborhoods? An economically feasible solution must operate within the existing business context (Grassl, 2012). It is not profitable for grocery chains to serve impoverished neighborhoods. Impoverished neighborhoods are often dense, urban centers and do not have the land necessary to grow food. A potential public health engineering solution would be to design a cost effective food-growing platform, such as pre-packaged engineered soil media and indoor or rooftop planters engineered for maximal food production, that operates within the resource constraints of a dense city. By creating such a product and driving the cost down, individual families may be able to grow food, or local entrepreneurs can invest in old warehouses as urban farms and sell food to the community.

The cost to design and produce such a product need only be less than $40 million per year, which is what pharmaceutical companies spend over 12 to 15 years to put one drug to market (Danzon, 2000). Given that all 13.5 million Americans who live in food deserts are potential customers, even with revenue of $1 per year per customer the product will be able to return at least $13.5 million per year. The average diabetes patient spends $7,900 per year on diabetes medications (Herman, 2013). To put a product to market for the low-income, pre-diabetes patient in a food desert, any price point less than $7,900 per year for healthy food is less expensive than a lifetime of medication. There are a multitude of revenue streams: patenting the product and selling use rights to a new occupation of urban farmers or patenting the product and selling the product unit-by-unit to individual homes.

Whole but separate: public health engineering education today

Education is the largest barrier to this type of entrepreneurship, which requires an education or background in engineering, public health, and business. By examining the current state of education programs in public health engineering, it is clear that this type of interdisciplinary thinking, which focuses on using engineering philosophies to design solutions to public health problems with maximum market potential, is not supported within the modern educational framework.

Of the over 7,000 accredited university programs, only 152 offer a bachelor's degree and 158 offer an advanced degree in any type of public health engineering program; combined this is fewer than 5 percent of all universities. This paper defines public health engineering program as one of four separate programs: Occupational Health and Industrial Hygiene, Community Health and Preventative Medicine, Health Services Administration, and Environmental/Environmental Health Engineering, as delineated by the National Center for Education Statistics. See Appendix C for descriptions of each program and the quantity of bachelors and advanced degree-offering institutions for each program.

The programs listed together offer a comprehensive education for an engineer seeking to work at the forefront of the public health industry. The programs experienced individually, however, as is the current state of education, address only singular facets of engineering in the public health context. Environmental Health Engineering is generalized to pollution control instead of the new public health concerns of noncommunicable disease prevention. Without access to public health education for engineering students, or access to engineering programs for public health students, there is no framework for professionals in public health engineering to solve the new public health concerns of noncommunicable disease prevention, or other types of public health concerns that have yet to arise.

Conclusion

While engineering is consistently vital to public health, in the example of municipal infrastructure halving the urban mortality rate in the early 20th century (Cutler & Miller, 2004), the role of engineering relative to the forefront of public health has changed over the last century. During the Progressive Era, sanitary engineers were viewed by leaders in public health and medicine as municipal strongmen, managing salaried physicians and nurses (Fee & Brown, 2002; Richards, 1912). In the 1940s a reversal occurred and the medical profession was favored in cornerstone funding that established the medical and science profession as leaders in public health (Fee & Brown; Fee, 1992; Owens, 2004). Without strong professional associations or educational programs, engineers were unable to maintain a position at the forefront of public health after the 1940s. After the 1940s and until today, engineers took responsibility for pre-established public health concerns, such as meeting and managing environmental and workplace safety regulations, instead of working at the forefront of public health research and policy.

This paper examined the causes behind the changing role of engineers in public health by examining education, economic, and political trends through the Progressive Era and onward. The Progressive Era viewed engineers as a technical elite to aid municipal public health administration, with physicians and nurses as salaried employees (Fee & Brown), putting engineers at odds with most physicians who relied on private practice. For most of the Progressive Era, public health engineers had the upper hand since business in general struggled during the depression of the 1930s (Fee, 1992). Physicians were better positioned in the pro-business context and by the 1940s had formed the AMA, which successfully lobbied for physicians' interests by repealing national health insurance from the 1935 Social Security Act (Fee & Brown, 2002, p. 36).

In 1942, the Rockefeller Foundation refused to fund the new Department of Biological Engineering at MIT due to the "anomalous program of public health" which supported the Progressive Era view of engineers as municipal leaders (Owens, 2004). Karl Compton, MIT's President, responded by removing engineering from public health and placing public health research in medical schools and the chemistry and biology departments. With the attribution of public health accomplishments to basic scientific research instead of infrastructure development and management and weak professional associations, public health engineers were unable to regain a position at the forefront of public health.

Today the United States faces new types of public health problems, noncommunicable diseases such as heart disease, diabetes, and obesity. Engineers are currently employed in managing regulations for workplace safety or environmental pollution, but have little training to address new types of public health threats. Analyses of engineering programs available today at universities show that there is a weak framework and little demand for professional engineers to solve new problems of noncommunicable diseases (see Appendix C).

Using the Progressive Era physician-engineer framework, this paper analyzes a new type of public health concern that is ripe for an engineering solution: food deserts. A food desert is defined as an area with limited access to fresh food based on geography (USDA, 2013). With the medical industry providing the research that diabetes incident rates are twice the national rate in food deserts, and the market opportunity being over $174 billion in diabetes-related costs per year (CDC: Data and Statistics, 2013), the role of the engineer is to develop and optimize a system that brings fresh, healthy food into low-income food deserts. In order to be cost competitive, the cost of research and production needs not be over $40 million per year, which is the average that pharmaceutical companies spend per year for 12 to 15 years to bring one drug to market (Danzon, 2000).

Engineers play an important role in public health by designing products that improve quality of life and aiding governments and corporations in meeting workplace safety and environmental regulations. Engineers, however, are not educated or incentivized to address the new public health concerns of incommunicable disease prevention. To understand how to change incentives to place engineers at the forefront of the public industry, this paper analyzes the changing role of engineers in public health, through the Progressive Era to present-day, and conjectures how engineers can effectively address the new generation of public health concerns.

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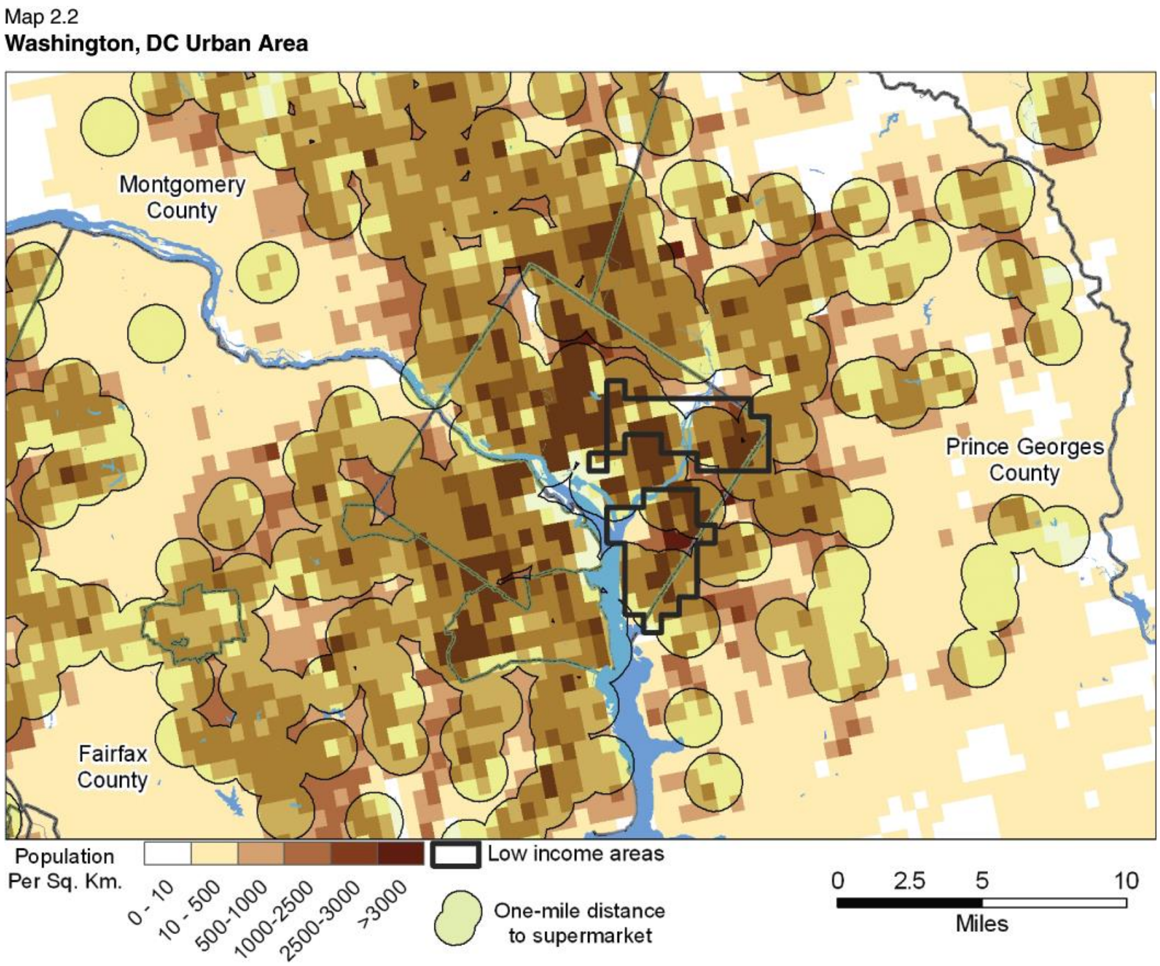
Appendix A: Food deserts in the Washington, D.C. urban area



(United States Department of Agriculture, 2009)

Appendix B: Rockefeller Foundation Annual Record, 1940

"The plan is somewhat analogous to one carried out at the Institute over fifty years ago, when the authorities, realizing the vast opportunities that existed in the application of chemistry to industry, introduced certain lines of training which led to the development of the profession of chemical engineering.

"The Institute has had a long and active record of interests which reach down into basic biology and, at the same time, reach out to practical ends. Their tradition in applied biology goes back more than fifty years, when Professor William T. Sedgwick made some of the first applications of bacteriology in the fields of public water, milk supplies, and sewage treatment. At the Institute there were offered the first courses in America in general bacteriology and industrial hygiene, and also the first courses in the world in sanitary engineering, industrial biology, and food technology."

(The Rockefeller Foundation, 1940, p. 189)

Appendix C: Quantity of education programs related to engineering and public health[4]

Roughly 10 percent of the 1,074 accredited engineering programs have Environmental/Environmental Health Engineering

Of the over 7,000 accredited universities not even 5 percent of universities provide bachelors or advanced degrees in a topic relating to public health engineering.

CIP 2000 Code	Program Name	Program Description	Quantity of 4-Year Bachelor Programs	Quantity of 4-Year Advanced Degree Programs
51.2206	Occupational Health and Industrial Hygiene.	A program that prepares public health specialists to monitor and evaluate health and related safety standards in industrial, commercial, and government workplaces and facilities. Includes instruction in occupational health and safety standards and regulations; health-related aspects of various occupations and work environments; health hazard testing and evaluation; test equipment operation and maintenance; industrial toxicology; worker health and safety education; and the analysis and testing of job-related equipment, behavior practices, and protective devices and procedures.	7	15
51.2208	Community Health and Preventive Medicine	A program that preparespublic health specialists to plan and manage health services in local community settings, including the coordination of related support services, government agencies, and private resources. Includes instruction in public health, community health services and delivery, health behavior and cultural factors, local government operations, human services, health communication and promotion, health services administration in local settings, environmental health, preventive and comparative medicine, epidemiology, biostatistcs, family and community health, and applicable law and regulations.	23	20
51.2211	Health Services Administration	A program that focuses on the application of policy analysis, public administration, business management, and communications to the planning and management of health services delivery systems in the public and private sectors, and prepares individuals to function as health services administrators and managers. Includes instruction in health systems planning, public healthorganization and management, pubic health policy formulation and analysis, finance, business and operations management, economics of health care, organizational and health communications, marketing, human resources management, and public healthlaw and regulations.	43	36
14.1401	Environmental/Environmental Health Engineering	A program that prepares individuals to apply mathematical and scientific principles to the design, development and operational evaluation of systems for controlling contained living environments and for monitoring and controlling factors in the external natural environment, including pollution control, waste and hazardous material disposal, health and safety protection, conservation, life support, and requirements for protection of special materials and related work environments.	79	87

[4] Data gathered from National Center for Education Statistics College Navigator Tool (http://nces.ed.gov/collegenavigator/)

A Stormwater Analysis and Retrofit for Saqsaywaman, Cusco, Peru
Modeling the Hydrologic Regime Using ArcGIS
and Designing a Drainage Canal for the Third Wall
(Technical Topic)

The Changing Face of the Civil Engineering Profession
An Episodic Analysis of the University of Virginia
Focusing on the Typhoid Outbreak (1800s) and the Development of Environmental Engineering (1970s)
(STS Topic)

A Thesis Prospectus
in STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Civil Engineering

By

Olivia Jeffers

December 4, 2012

Technical Project Team Members:
Olivia Jeffers
Kenneth Lohr

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ____ Date:____________

Approved: ____ Date: ____________
Edmund Russell, Department of Science, Technology and Society

Approved: ____ Date: ____________
Richard W. Miksad, Department of Civil and Environmental Engineering

Introduction

The Saqsaywaman site in Cusco, Peru is one of the most important Inca heritage sites, second only to Machu Picchu. Anthropologists have investigated the site over the past century, preserving parts of the site with an impermeable clay layer to protect archaeological findings. An unintended consequence is that the impermeable clay causes water runoff that the site was not designed for, and as a result, the site is weak and subject to erosion and collapse during heavy stormwater events (see Figure 14 in the Technical Appendix). Under the direction of Miksad (Civil and Environmental Engineering) and with the assistance of Wright Paleohydrologic Institute, my colleague Kenneth Lohr and I will produce a 10 to 20 page, double-spaced technical document (without figures and tables) in accordance with American Society of Civil Engineering guidelines, detailing the existing hydrologic regime, where the damage is, the proposed drainage system, and flow drainage results from the proposed drainage system as modeled in ArcGIS. Under the advisement of Russell (STS), I will create a 12 to 16 page, double-spaced paper according to the Undergraduate Thesis Manual guidelines, analyzing changes within the civil engineering profession over history, using the University of Virginia as a case study, with a focus on the typhoid outbreak of the 1800s and the period of environmental engineering from 1978 to present-day. The topics are loosely coupled in that both analyze civil and water resource engineering within the framework culture and history, the technical paper with regard to Inca culture (1200 to 1500) and the STS paper with regard to North American and European cultures (1600 to present-day).

Technical Report Prospectus

A Stormwater Analysis and Retrofit for Saqsaywaman, Cusco, Peru
Modeling the Hydrologic Regime Using ArcGIS
and Designing a Drainage Canal for the Third Wall

The Saqsaywaman site in Cusco, Peru is one of the most important Inca heritage sites, second only to Machu Picchu. The site consists of three zigzag walls made of stones each weighing several tons, supporting an excavated temple at the top of the mound (see Figure 2 in the Technical Appendix). The site has incurred hydrologic changes over the centuries from Spanish excavation and anthropological digs, resulting in damage to the third wall during heavy stormwater events (Miksad, 2011). With the assistance of Wright Paleohydrologic Institute and Richard Miksad of Civil Engineering at the University of Virginia, my colleague Kenneth Lohr and I will produce a 10 to 20 page technical document according to American Society of Civil Engineering (ASCE) guidelines detailing the existing hydrologic regime, where the damage is, the proposed drainage system, and flow drainage results from the proposed drainage system as modeled in ArcGIS. Our work will complement Miksad's investigation of the original drainage canal grades, laying the groundwork for future researchers to use our drainage canal design and modeling system to return the site to its original hydrologic regime using traditional Inca engineering techniques.

South American engineering history has flown under the radar for most of the 19th and 20th centuries, generally overshadowed by research on European engineering histories and techniques. However anthropological findings increasingly show that the history of the Inca in Peru is rich and varied and leaves much more to be discovered (MacQuarrie, 2008).

The Inca had tremendous challenges in terms of topography, for example a wheel is relatively useless in traversing steep and rocky mountains. However they still managed to create a civilization and were expert stone masons (see Figure 3: 12-Point Stone, McEwan, 2008). Most impressively, despite "nearly 2,000 mm per year of rainfall, steep slopes, landslides, and inaccessibility" that the Inca managed to construct Machu Picchu which remained in the rainforest for 400 years without failure (Wright, 1999). Additionally, the Incas designed and construct these temples from stone, without having developed the wheel, steel, or even written language (Wright, 1999).

Working with Miksad to discover the original grade of drainage canals will help in the analysis and recreation of

Inca engineering techniques. It will work off of Kenneth Wright's analysis of Machu Picchu where he determined the grade of drainage canals was between 1.0 and 4.8% which was enough to provide water and fountains to a population of between 300 and 1,000 people, using only gravity-driven water systems (Wright, 1997). Given the growing importance of sustainability and resource conservation, studying the engineering of the "ultimate sustainable engineers" (Wright, 2012) will no doubt be useful for the scientific community, and potentially assist in real-world engineering applications.

Our work will directly benefit the Saqsaywaman site by designing a drainage canal for immediate implementation and providing a standardized, digital elevation model for water runoff analysis which will be used to input historic grade information and the new drainage canal. Our methods will be documented in a systematic fashion for future use on different sites. The work done on this project must be sustainable for the Peruvians to use and maintain. Designing western style drainage canals that are underground and not visible makes maintenance difficult and the canal could entirely be forgotten in several decades because of documentation issues between numerous organizations and languages. While we are currently designing an easily visible, western style drainage canal for immediate relief of excess stormwater runoff, our goal is ultimately to design a drainage system that closely mimics that of the original site before excavation and attempt to return the site to its previous hydrologic condition by removing imperviousness.

Kenneth Lohr and Richard Miksad will travel to Peru during January to obtain data for analysis and research during the Spring Semester 2013. Missing pieces of data are the elevations of original drainage ports on the walls (see Figure 4), which are needed to calculate the original grade of the drainage canals. Miksad is also looking for evidence that there was a drainage canal along the third wall that channeled water in an east-west direction and through drainage ports at the end of the walls. His reasoning for this is that there are holes at the tops of the walls, and there is no reason for these holes unless a pipe was running through it. These pieces of data will fill in the gaps and allow us to fill in the model and provide strong evidence for our conclusions.

Our design approach will distribute the effort between Kenneth Lohr and me such that Kenneth will design the drainage canal for immediate use, while I will build and develop the digital elevation model and input his drainage canal into the model using ArcGIS. We will then model the water flowpaths on the original hydrologic regime using topography data from Wright Institute, and then we will model the water flowpaths with the new drainage canal in place. We will use methods evolved from Pumayalli in 2008 regarding remote sensing in Cusco, however the methods will be adjusted for the size of Saqsaywaman. The model needs to be designed for easy editing so that later when Miksad discovers the original grade of the site, we can input that information into the model as well. The model needs to be visually appealing and compatible with satellite imagery and mapping so that it can be easily used and understood by researchers from both Peru and the United States, and Peruvian officials within the Institute of National Culture of Peru.

The technical report will be a 10 to 20 page document (without figures and tables) in accordance with ASCE guidelines, detailing the existing hydrologic regime and water flowpaths, the cause of the damage to the third wall, the design of the drainage canal to channel water away from the third wall, and a model of the drainage canal and water flowpaths using ArcGIS, with a topic for future research using original grades and Inca design techniques. The paper report will have images of the design and flowpaths, and the electronic report will include complete files with instructions on how to use the data and software. The goal is to provide a useful, accessible, and relevant document for use by the Wright Paleohydrologic Institute, Cotsen Institute of Archaeology, the Institute of National Culture of Peru, and future studies at the University of Virginia.

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Technical Appendix


Figure 14: Wall Erosion from 2009 Storm Event

302. *Cusco. Plano de la fortaleza de Saqsaywaman. 1— Chuquipampa. 2— Torreón de Muyucmarka. 3— Torreón de Sallacmarka. 4— Torreón de Paucamarka. 5— Puerta principal de Tiapunku. 6— Qollqa.*

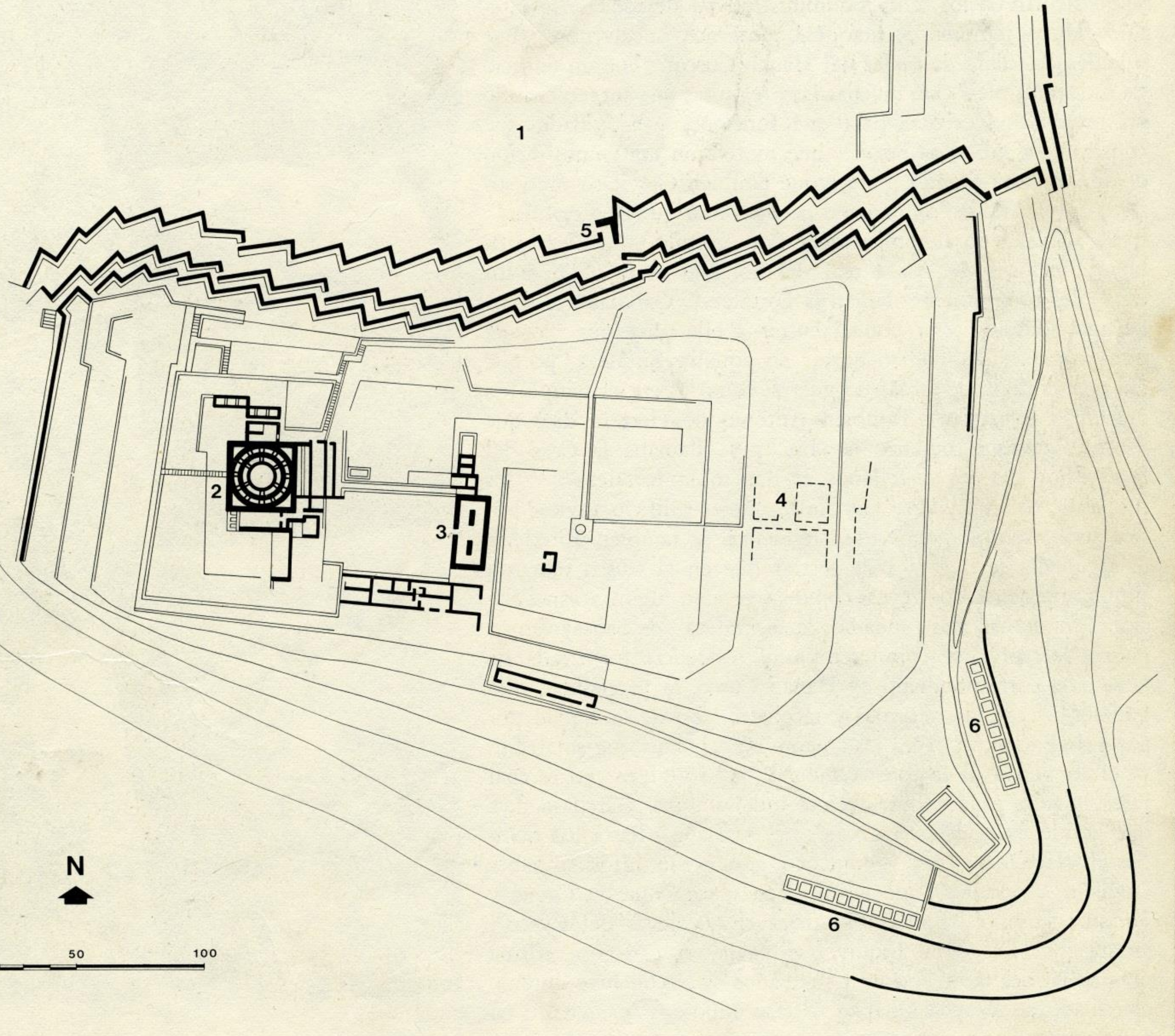

Figure 15: Aerial Map View of Saqsaywaman

Figure 16: Inca 12-Point Stone, edges can still not be separated even by razors (McEwan, 2008)

Figure 17: Inca Drainage Port at Saqsaywaman

STS Research Paper Prospectus

The Changing Face of the Civil Engineering Profession
An Episodic Analysis of the University of Virginia
Focusing on the Typhoid Outbreak (1800s) and the Development of Environmental Engineering (1970s)

Civil engineering has played a pivotal role in human history and civilization, changing and morphing alongside society. However the role of civil engineering in health, environment, and society has been underscored in the general study of history, elaborated by Delgado in his presentation to the International Committee on History and Technology requesting more preservation of civil engineering structures: "if civil engineering is vital for a country, it is likewise vital for explaining and understanding history." Under the advisement of Edmund Russell (STS) I will write a 12 to 16 report meeting the Undergraduate Thesis Manual requirements, studying the changing face of the civil engineering profession through the lens of the University of Virginia, focusing on the Typhoid Outbreak from 1829 to 1859 and the introduction of stormwater management from 1978 to present-day. I aim to answer the question: Why have the responsibilities of civil engineers changed throughout history, particularly with regard to the University of Virginia, and how have and will these changes affect the University in terms of health, the environment, and society?

A review of civil engineering literature and history reveals the importance of civil engineering to building history. For most of history, engineers and architects were synonymous, with engineers building the ancient Pyramids and water engineering marvel of Machu Picchu (Watson, 2012). In the 17th century, a division between military and civilian engineers developed, soon morphing into the separation between architecture and engineering, eventually with the establishment of the Society of Civil Engineers in 1771 by John Smeaton (Watson, 2012). John Smeaton was the first self-proclaimed Civil Engineer and laid the groundwork for the profession by working on public works relating to infrastructure and commerce, e.g.: bridges, canals, flood prevention, etc. (Homes, 1793).

Prior to the 1800s, most civil engineering and health sciences were developed in England and France. The link between population density, poor sanitation, and poor health were present, but the understanding of the causes was different from our present-day germ theory.

For example, the British Medical Journal (Corfield, 1900) reviewed publications of Dr. Bernardino Ramazzini from University of Padua who stated that:

> "All the Men of Learning used to complain of a Weakness in the Stomach… A great many of the Inhabitants of Cities and Towns, and almost all the Lovers of Learning, have Weak Stomachs. There is no hard Student almost but complains of his Stomach: for while the Brain is employed in digesting what the Desire of Knowledge and the love of Learning takes in, the Stomach cannot but make an imperfect Digestion of the Aliment, because the animal Spirits are diverted and taken up in the intellectual Service." – Dr. Bernardino Ramazzini (1703)

This quote correctly links dense population (Inhabitants of Cities and Towns) often associated with universities ("Men of Learning") with fecal-oral illness ("Weak Stomachs"), but attributes it to misallocation of bodily energy instead of to the poor removal of fecal waste matter in densely populated areas.

In the mid-1800s many fecal-oral diseases such as typhoid broke out in the U.S., and civil engineers were charged with improvements to sanitation, which were associated with the disease (Williams, 1911). The scientific theory, however, remained incorrect until the 1900s during the Bacterial Revolution when it was determined that contaminated water instead of bad air (Miasmus Theory) was the cause of the outbreaks (Melosi, 2000). Lucky enough, wrote Melosi, "bad science [still] led to good technology" and civil engineers began working on sanitation and sewers by the early-to-mid 1800s (Millington, 1839).

The Bacterial Revolution spurred a new field of civil engineering, adding sanitary sewers and bacterially-clean water to the growing list of responsibilities. It wasn't until the Clean Water Act in 1978 that civil engineers were tasked by government mandate with cleanliness of the environment, air, and waters with regard to environmental pollution (City of Fargo, 2012). Since then, the topic of stormwater management (controlling the quantity and quality of runoff in urbanized areas) has become of increasing importance, with government policy even changing to acknowledge the boundaries of watersheds in political decision-making (Tyer, 1993).

The history of the University of Virginia from its founding in 1819 to present-day closely follows the changes in the values and responsibilities of the civil engineering profession. As alluded to earlier, the University faced fecal-oral disease from the opening of the University and was extremely motivated to document and solve these problems, since the health of its students, professors, and slaves was vital to its economic success (Schulman, 2003). The University also began to connect poor drainage and sanitation with the typhoid outbreak of 1858 (Board of Visitors, 1858) and later that year followed through on a plan to hire William A. Pratt as a fulltime Superintendent of Buildings and Grounds (Brandt, 2008). Of the $11,822.18 Pratt received to complete his work (Brandt, 2008), the largest portion (40%) (see STS Appendix) of those funds were dedicated to water works and infirmary water and pipe renovations. This indicates that while he was hired as an architect, his job was primarily that of a Waste Management Engineer, a field not yet in existence. The creation of the Committee on Infirmary, Health, Sewers & Drainage in 1886 (Board of Visitors, 1886) shows the connection between sanitation and disease shortly before the official dates of the Bacterial Revolution in the 1900s. The founding of the Department of Environmental, Health, and Safety in 1984 tracks with the addition of clean air and water to the responsibilities of the civil engineer in 1978. The abundance of financial, engineering, and historic documentation provided by the Board of Visitors, Office of the Architect, and University provide an excellent viewpoint of how the civil engineering field has grown with changing values regarding health, environment, and society at the University.

I will use historic documents from the Libraries, primary accounts from Special Collections, maps from the Scholars Lab, plans from the Office of the Architect, and use personal resources from the Department of Civil Engineering and staff on Facilities Management and Department of Environmental, Health, and Safety. I will develop clusters of civil-related events to determine normalcy of the period in order to determine where and why the change occurred. In my STS Paper I will give a brief overview of the history of Civil Engineering in relation to macro-trends in environment, health, and society, and will cross-link those changes with two key periods at the University of Virginia. Using the University as a case study, I will conclude my paper by analyzing the recent work being done in stormwater management at the University, which represents a recent change in the values of civil engineering. Similarly to the addition of sanitary engineering to the civil engineering palette, the addition of stormwater management is strongly driven by new standards in engineering practices, shifting social landscape towards “sustainability”, and local, state, and federal government mandates. I will tie the history of civil engineering and the University into what is currently happening today with stormwater management and its effects on student health, the environment, and societal trends.

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STS Appendix

<u>Funds Provided to William A. Pratt (1858-59) (Brandt, 2008)</u>

** Denotes Responsibilities of a Waste Management Engineer*

Services as an Architect	$240.00
Alteration in lecture rooms and fencing	$236.95
Infirmary Account	$534.76
*Water and gas pipe for the Infirmary**	*$592.65*
Renovation of the University	$4,217.82
*Water works**	*$6,000.00*
Labor	$3,000.00
Total Pay (not including Labor)	**$11,822.18**

Waste Management Engineering	$6,592.65
Portion of Waste Management Engineering (%)	56%