Entusi Model Farm Final Report

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Submitted by:

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Capstone Design@Mines

Final Design Report

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Acknowledgments

We would like to thank Tom Karrel, Raymond Bokua, Thomas Byonanebye, Nathan Davis, Anit Koirala, Kristoph Kinzli, Reza Hedayat, Beth Reddy, Alina Handorean, Global Livingston Institute, our donors, and the senior design advisors and teams for their continued support. Our project would not have been possible without their guidance and help along the way.

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College of Engineering and Computational Sciences
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Executive Summary

The Entusi model farm, located in the Lake Bunyonyi area of Southwestern Uganda, serves as an outdoor, hands-on classroom for local farmers to learn new farming techniques and practices. It is supported by the Global Livingston Institute (GLI), a non-profit organization whose goal is to educate students and community leaders on innovative approaches to international development and empower awareness, collaboration, conversations and personal growth. GLI has tasked this team with developing a design for an irrigation system for the model farm that combats the unreliable rain patterns of the area, providing a sustainable source of water for agriculture. The design consists of a low cost, low-maintenance irrigation system that can be easily reproduced by the farmers who visit the Entusi model farm and flexible to different plot sizes. If possible, GLI would like a solution that also creates incentive and appeal for more people to visit the farm. GLI has been the middle-man in communications between the team, the Entusi staff and Ugandan farming community. This report contains the design methodology, engineering analysis, final deliverables, and project review for a check dam water collection system that, after thorough research, the team has gauged as viable solutions for the project requirements.

These designs were chosen for their simplicity, affordability, and ability to be incorporated with other irrigation technologies if needed. This report lays out the social and technical assessment of how these solutions address the needs of the model farm. The social assessment is based on the Bridger and Luloff criteria for sustainable design in developing areas as well as case studies on similar designs implemented in other areas of the world facing similar challenges. The technical assessment is based off of engineering calculations approved by a technical advisor. Due to the team's inability to travel to Entusi, both assessments are preliminary and can be more accurate with in-person input from local farmers and in-field tests and measurements. To address this setback, the report also contains the next steps for a subsequent team to carry out the completion of the project.

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1. Introduction

This report summarizes the team's work through the course of the project including the design approach taken, the engineering analysis, final deliverables, and overview of project management. The check dam system aims to solve the accessibility and reliability problems that the farmers of Lake Bunyonyi currently face. It has been designed around the specific criteria of the model farm, but is meant to be adaptable to any plot in the area. The final deliverables include a pamphlet on the check dam system to spread information on this irrigation method to local farmers as well as preliminary designs for the check dams. The purpose of the following information is to guide the next Entusi Model Farm team to learn from this year's work and continue forward with it.

2. Application of Design Methodology

As part of the Engineering for Communities Design Studio the team emphasized the importance of satisfying the Bridger and Luloff criteria for sustainable community development in their design. These criteria focus on factors such as desirability, feasibility, and viability that are essential to consider in order to fully meet the needs of a community [1]. Through conversations with GLI staff, the team developed a set of design criteria which was used to guide the design process. GLI also had conducted surveys from members of the farmer cooperative at Entusi and the feedback from the responses was also considered throughout the design process.

Project design constraints include:

- Plot sizes of farms are 20 x 30 meters
- Cost to implement design per farmer: $15-$50 (per client request)

Project design criteria include:

- Robust and easily replicable
- Sustainable--farmers can maintain system on their own
- Meets water delivery needs for current crops

Initially, four concepts were considered in the preliminary design process: a system of check dams, a roof rainwater collection system, clay pots, and Volta irrigation. In deciding on a design, our team considered the design constraints and criteria provided by GLI. An assessment of how each design solution addressed these criteria is shown in Table 1.

Table 1: Design matrix utilized to determine main irrigation concept

	Irrigation Needs	Withstanding Performance	Cost	Repeatable Design	**Total / 40**
Roof Runoff Retention	8	7	4	7	**26**
Check Dams	8	9	7	7	**31**
Volta Irrigation	8	7	4	6	**25**
Manual Pot Irrigation	5	7	8	8	**28**

This analysis and decision to move forward with the check dam system design was approved by the client. This became the focus for the project with the hopes that future teams might also consider the other three design alternatives. Because the manual pot irrigation system ranked second highest in the decision matrix, additional information about the technique is included in Appendix G.

The design process included extensive research on the water requirements of regional crops, agriculture techniques, farm acreage, precipitation patterns, and soil type. The team applied an iterative approach to designing the check dams and layout of the system. GLI specified that the design should have a maximum total cost of 50 USD to ensure that it was affordable to local farmers. To achieve this, the team ensured that the proposed solution would utilize local resources to minimize costs, support the local economy, and reduce environmental impacts. Case studies were used to validate the design concept and provide proof of the tangible benefits of check dams. Case studies in Bamyan, Afghanistan and in the Sikar District, India showed an increase in irrigated farmland and subsequently, increased income after the implementation of check dams [2, 3]. In these studies there were also documented environmental benefits including flood mitigation and groundwater recharging [3]. Additional concept validation included confirming our calculations with our faculty advisor, Dr. Kristoph Kinzli, and conducting extensive research on design and construction regulations and guidelines for check dams.

A variety of software programs were used throughout the design process to create visuals and models of the check dam system. There was no survey data available for the site, but the team was given a description of the site with approximate dimensions from the client. Google Earth was also used to view the location of the model farm property and its surroundings. SketchUp was used to create renderings of the property and the check dams system (Figure 1).

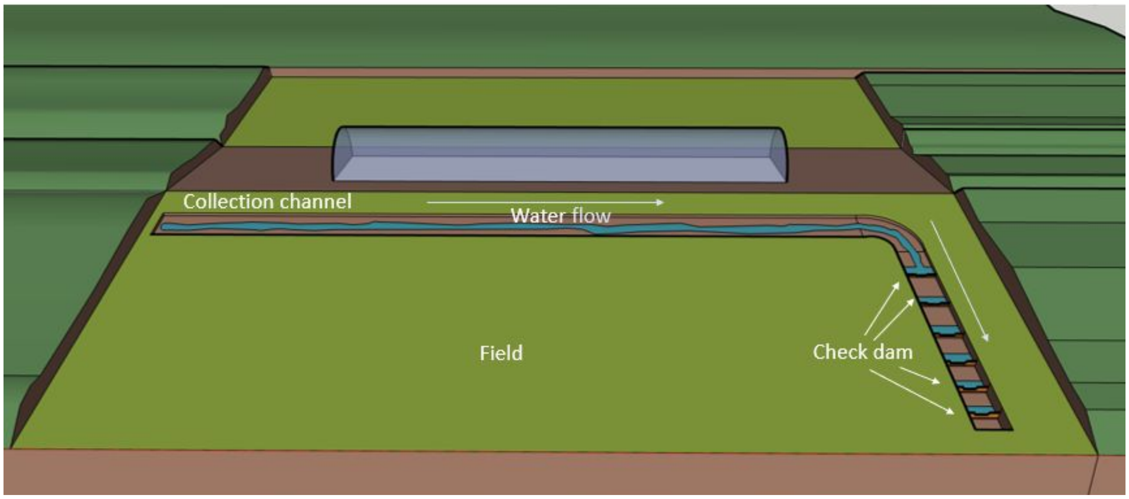


Figure 1: Site rendering showing check dam collection system

Lastly, SolidWorks was used to create a to-scale model of the individual check dams which is shown in Figure 2 of Section 4. Because the team did not have survey data, Civil3D could not be used to create a drawing of the site.

As a part of the iterative design approach, the team collectively brainstormed design ideas on a white board. Sketches are included in Appendix A to show the progression of the design concept throughout the project. The team remained in close communications with the client and staff who work at the Entusi Model Farm to ensure that the check dam system satisfied their goals and was feasible for them to implement.

3. Engineering Analysis

3.1 Background

Due to the physical limitations placed on the project, physical testing to gather necessary data was not achievable until a later date. The team moved forward with engineering analysis despite the lack of data and planned to refine the analysis once data became available. Calculations on a check dam system were performed in order to determine the size necessary for the system. Dr. Kristoph Kinzli signed off on all calculations, which can be found in Appendix B along with detailed calculations and iterations.

3.2 Analysis

Calculations based on water volume, total land use, and physical sizing of the check dams were performed in order to understand the sizing of the entire system. Due to the amount of water needed for agricultural use and the land needed to store that water, several dimensions were assumed to minimize the impact on land use. Assumptions made are listed below in Table 2.

Table 2: List of assumptions and the corresponding parameter for the check dam system.

Parameter	**Assumption**
Shape	Trapezoidal channel
Slope (S)	10% or 0.1
Spacing between dams (ft)	15
Height (h)(ft)	2
Base width (B_w)(ft)	2
Horizontal to vertical ratio (H)	2:1
Length (L) (ft)	73.8
Number of dams	7
Area of Plot (ft^2)	10890
Rainfall (mm)	600 (1.96 ft)

Assumptions were modified from previous iterations to ensure safety and security from trips, falls, or accidents around or in the channel and dam system. Additionally, assumptions were modified to prevent the drowning of both children and adults since the system will be a large body of standing water.

The model farm is on a half-acre plot of land. Roughly one-half (½) of the model farm, or ¼ acre, is used for crops such as potatoes. The length was based on the assumption that the model farm is a perfectly square half-acre plot of land with the dimensions 147.6 ft x 147.6 ft. Based on this assumption the dimensions of the ¼ acre used for growing potatoes is 147.6ft x

73.8 ft. The amount of rain needed for potatoes in a full growing season is 600mm. Potatoes have the largest rainfall requirement out of all the common Ugandan crops [4]. Using the values mentioned above, we calculated the total volume of water that is needed for an entire growing season of potatoes (eq 1).

$$\text{Volume} = \text{rainfall(mm)} * \text{land(acre)} * (1\ \text{ft}/304.8\text{mm}) * (43560\ \text{ft}^2/\text{acre}) \quad \textbf{(eq. 1)}$$
$$V = 21{,}437\ \text{ft}^3$$

This value did not change between the two analyses since this value is the amount of water needed for an entire growing season. Using our assumptions for a trapezoidal channel, Equation 2 was utilized to calculate the volume retained by one dam. Multiplying by the number of dams returns the total volume as seen in equation 3.

$$volume = (h^2 * ((h * H) + Bw))/(2S) \quad \textbf{(eq. 2)}$$
$$Total\ volume = \#of\ dams * (h^2 * ((h * H) + Bw))/(2S) \quad \textbf{(eq. 3)}$$
$$Total\ volume = 840\, ft3$$

Using the assumed height (h), horizontal to vertical ratio (H), and base width (B_w), the top width (eq 4) and area (eq 5) of land the channel utilizes can be determined. The top channel without dams is employed for additional storage and will have the same dimensions as the channel containing the check dams.

$$B_T = (2 * H * h + B_w) \quad \textbf{(eq. 4)}$$
$$B_T = 10\text{ft}$$
$$A = B_T * L \quad \textbf{(eq. 5)}$$
$$A = 738\ \text{ft}^2$$

During initial calculations, it was determined that using the needed volume to determine the base width and top width given a height would pose a safety risk and occupy a high percentage of land. For these reasons, assumptions were changed to reflect those found in Table 2. As stated above all, detailed calculations can be found in Appendix B. The design is able to be scaled up or down depending on plot size with additional sizing available in Appendix C for both the original design and the iterated design.

3.3 Outstanding Analyses and Path forward

Further testing is needed to test infiltration of the soil and determine soil types. Infiltration rate will determine if additional design elements need to be implemented. Moving forward, calculations will have to be reviewed by a professional engineer to ensure that they are accurate. Further, all calculations will be compiled and archived to allow future teams to utilize the current designs. Additional farmer input needs to be included to ensure that design is exactly what is wanted and needed by the community. Testing and implementation of the design on the model farm will have to be performed by a future team due to the limitations placed on the current team due to the COVID-19 outbreak.

4. Final Deliverables

Due to the limited capabilities described in several sections of the report, final deliverables were expected to be CAD renderings, community outreach documents, detailed dimensional drawings with the possibility of implementation if time would allow. All designs and drawings were developed for the model farm itself with the intention of modification to fit other farms in the area. A CAD drawing of the check dams without the channel can be seen below in Figure 2. Additional details and dimensions for the check dams can be found in Appendix D.

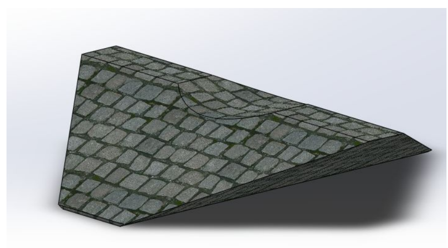


Figure 2: SolidWorks rendering of check dam

Farmer relations are extremely important since the design will be on a model farm for learning the best techniques. A pamphlet, found in Appendix E, was created to communicate to the farmers what a check dam system is, how it will benefit their farms, and how they can implement it on their farms. The pamphlet allows for quick communication of the design and initial feedback. Further testing with farmer feedback is necessary until the pamphlet can be finalized. The Swahili translations should be verified by a native speaker before publication. Additionally, rendering and drawings may be modified to more accurately fit farms outside of the model farm.

The major concern is the farmer’s feedback regarding the overall response to the design. While the Entusi model farm may benefit from the irrigation solution, it cannot be confirmed that the design suits the needs of the local farmers without their direct input. Unfortunately, due to the recent challenges from the COVID-19 pandemic, the team was not able to visit the location and receive feedback for a third iteration. This is the main reasoning behind the team's concerns.

5. Project Management

The original project WBS is shown in Figure 6 of Appendix F. The Research/Planning and Irrigation sections occured as planned, but the Function of Model Farm and Deliverables sections were changed due to our team's inability to travel to Uganda. Had we been able to travel to the model farm, we would have taken GPS coordinates and elevation measurements in order to develop a map and CAD model of the farm, performed a soil analysis and climate analysis, and interviewed stakeholders. Because we could not adequately acquire any of this information, there will be no prototype or finalized site plan. The key deliverable is to compile all of the work and research that our team was able to perform, and in hopes of passing this work onto a future Senior Design team or internship program. We thoroughly enjoyed working with Global Livingston Institute and the Entusi Model Farm, and we strongly encourage Colorado School of Mines to utilize GLI and its partners as clients for future projects.

The canceled trip to Uganda also resulted in changes to the team budget. Table 6 in Appendix F shows the updated budget and expenses. Note that there is currently a $1,056.00 surplus in the project; this was to be spent on in-country costs (such as lodging) for the 4 team members traveling. We do not anticipate making a profit on this project but rather hope to use all the funds to move this project along as far as possible. Any remaining funds or travel credits will be passed onto a future team. Our team is currently waiting on the reimbursement for our airfare tickets.

6. Lessons Learned

Throughout the course of this project, the Entusi Model Farm team has had to configure certain design ideas to best aid the farmers of the Lake Bunyonyi area of Uganda. To our team, a "good design" was first classified as a design that addressed the following criteria:

- Design must be easy to replicate
- Inexpensive to build
- Small enough to fit on model farm plot
- Robust enough to meet the water demands of various crops

As the team has progressed throughout the project, this definition of "good design" has remained fairly unchanged, however with the distress caused by COVID-19, the team has also made it important to include that above all, a good design must be well communicable. Due to the unfortunate events this semester, our team has found that communicating the designs and work that we have to the next team in line to be as important as the project itself. As a result of this virus, the team would have done a few things differently had we had a chance.

First and foremost, fundraising would have been our first objective to start off the project. Even though we lacked a clear project definition to start with, our team knew who we were working for and what the ultimate goal of the project was. Therefore we would have used this knowledge and our connections to begin fundraising as quickly as possible in order to develop a set amount of capital to be used for the project right at the start. Similarly, with these funds our team would have also scheduled to visit Uganda earlier, probably during the first semester as the knowledge we would have gained there during that time would have been invaluable during the course of the project. Unfortunately, our team missed out on this opportunity and therefore are relying on client communication and assumptions through research to finish the final details of the design.

Despite the setbacks associated with this virus and the strain it has put on the Senior Design Capstone, the Entusi Model Farm Team has learned a lot throughout the course of this project. Our team has had a great experience establishing client relations with the personnel on the farm and with GLI and found them to be invaluable in our design process. Being able to learn and semi-experience the culture of other regions and relate them to our own has also broadened our view on how other individuals live and function within their own communities. Most importantly however, it has been a humbling experience in which we as future engineers have had to learn that even with all the technical knowledge we possess, sometimes those who we are trying to help know more on how to solve the problem then ourselves. To be more specific, the Entusi Model Farm Team has come up with a design to benefit the farmers of Kabale Uganda, but without their insight and that of our sponsor GLI, our team would not have been able to come this far nor be as ready to hand the project off to the next Senior Design Team.

7. References

[1] B. Lucero and D. C. Turner, "121st ASEE Annual Conference & Exposition," in Reframing Engineering Capstone Design Pedagogy for Design with Communities, Indianapolis, 2014.

[2] “From the Mountains to the Fields,” Prime Consultants, September 10, 2018. [Online]. available: https://www.primeconsultants.net/blog/id/160. [1/29/2020].

[3] “Socio-Economic Impact of Check Dams,” Progress Harmony Development, Feb. 2015. [Online]. Available: https://www.phdcci.in/wp-content/uploads/2018/11/Check-Dam-Study.pdf. [2/8/2020].

[4] “4. Water management,” FAO emblem. [Online]. Available: http://www.fao.org/ag/save-and-grow/cassava/en/4/index.html. [Accessed: 13-Feb-2020].

[5] K. Bayuk, "Ollas: Unglazed Clay Pots for Garden Irrigation," Permaculture Research Institute, 16 September 2010. [Online]. Available: https://www.permaculturenews.org/2010/09/16/ollas-unglazed-clay-pots-for-garden-irrigation/. [Accessed 16 April 2020].

[6] D. A. Bainbridge, “Buried clay pot irrigation: a little known but very efficient traditional method of irrigation,” *Agricultural Water Management*, 15-May-2001. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378377400001190. [Accessed: 14-Nov-2019].

8. Appendix A: Design Iterations

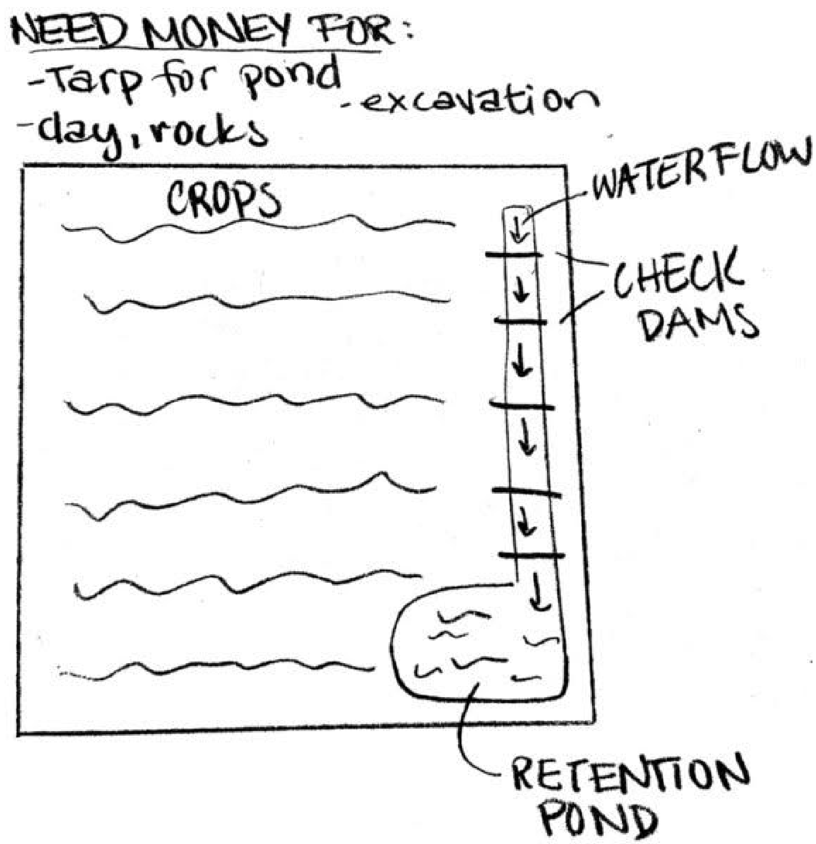


Figure 3: 10/31/2019 - Initial design concept

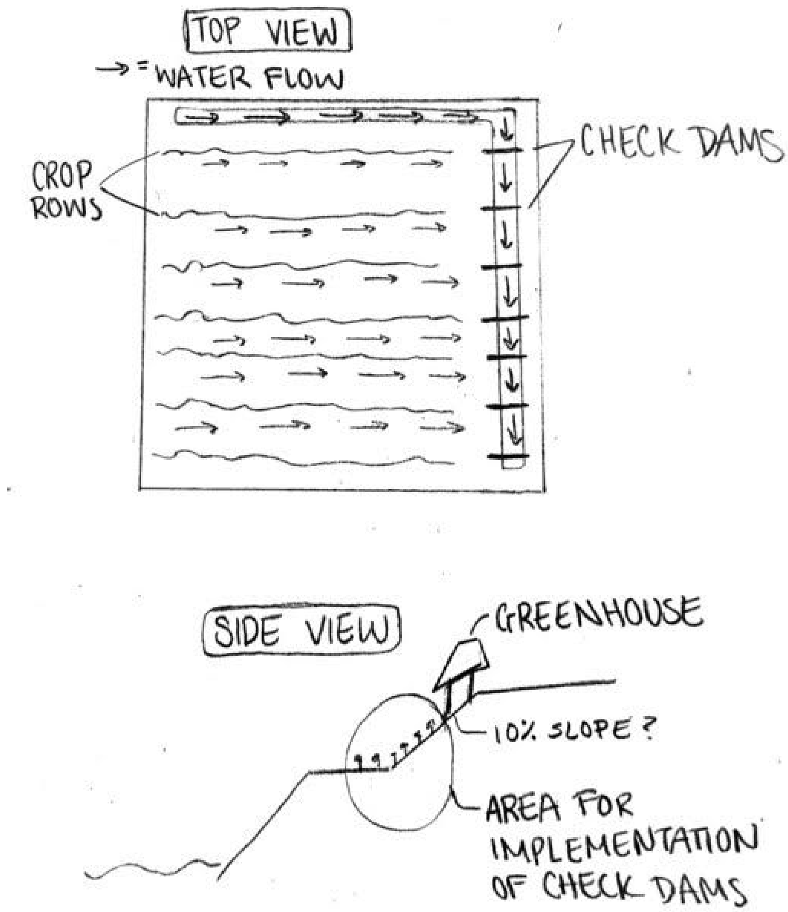


Figure 4: 1/28/2020 - Intermediate design concept

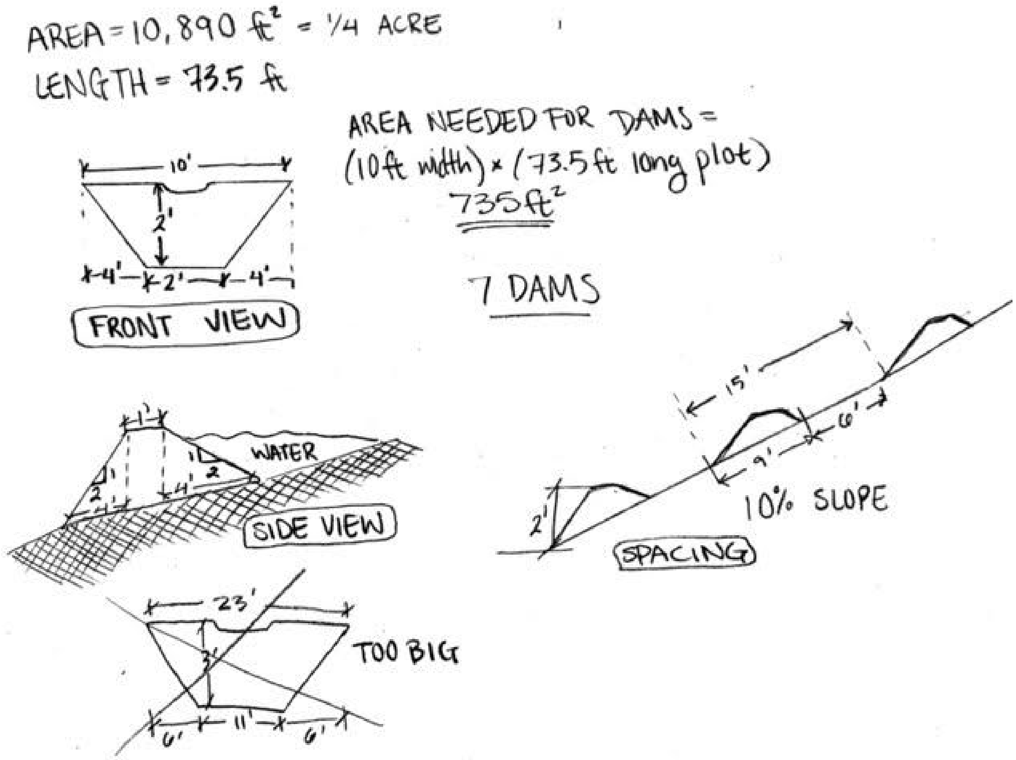


Figure 5: 03/03/2020 - Final Design Concept

Appendix B: Calculations

Table 3: List of Initial assumptions and the corresponding parameter for the check dam system

Parameter	**Assumption**
Shape	Trapezoidal channel
Slope (S)	10% or 0.1
Spacing between dams (ft)	15
Height (h)(ft)	4.5
Horizontal to vertical ratio (H)	2:1
Length (L) (ft)	73.8
Number of dams	7
Area of Plot (ft^2)	10890
Rainfall(mm)	600 (1.96 ft)

Initial Calculations:

$$Volume = rainfall(mm)*land(acre)*(1\ ft/304.8mm)*(43560\ ft^2/acre)$$

$$V=(600*¼*1/304.8*43560)ft^3$$

$$V= 21,437\ ft^3$$

$$volume = (h^2 * ((h * H) + Bw))/(2S)$$

$$Total\ volume = \#of\ dams * (h^2 * ((h * H) + Bw))/(2S)$$

$$((Total\ volume * 2S)/(\#\ of\ dams * h^2)) - h * H = Bw$$

$$((Total\ volume * S)/(\#\ of\ dams * h^2)) - h * H = Bw$$

$$((21,437 * .1)/(7 * 4.5^2)) - 4.5 * 2 = Bw$$

$$B_w=6.1\ ft$$

$$B_T=(2*H*h+B_w)$$

$$B_T=2*2*4.5+6=24.1\ ft$$

$$A= B_T* L$$

$$A=24.1*73.8= 1780ft^2$$

Original top channel calculations:

$$(Volume*.5)/Length=Area$$

$$A=(21,437\ ft^3*.5)/147$$

$$A=72.6\ ft^2$$

$$Area=0.5*((2*H*h+Bw)+Bw)*h$$

$$(Area/h)-H*h=Bw$$

$$Bw=(72.6 /4.5)-4.5*2=7.14 \text{ ft}$$

$$B_T=(2*H*h+B_w)$$

$$B_T=(2*2*4.5+7.14)=25.14\text{ft}$$

Technical Advisor: Dr. Kristoph Kinzli

Technical Advisor Signature:  Date: 02/13/2020

New design using **Table 2**:

$$volume = (2^2 * ((2 * 2) + 2))/(2 * .1)$$

$$Total\ volume = 7 * (2^2 * ((2 * 2) + 2))/(2 * .1)$$

$$Total\ volume = 840\ ft3$$

$$B_T=(2*H*h+B_w)$$

$$B_T=2*2*2+2=10 \text{ ft}$$

$$A= 10* 73.8$$

$$A=10*73.8= 738 \text{ ft}^2$$

iterated top channel calculations:

$$Area=0.5*((2*H*h+Bw)+Bw)*h$$

$$Area=0.5*((2*2*2+2)+2)*2$$

$$Area=12 \text{ ft}^2$$

Appendix C: Dam sizing

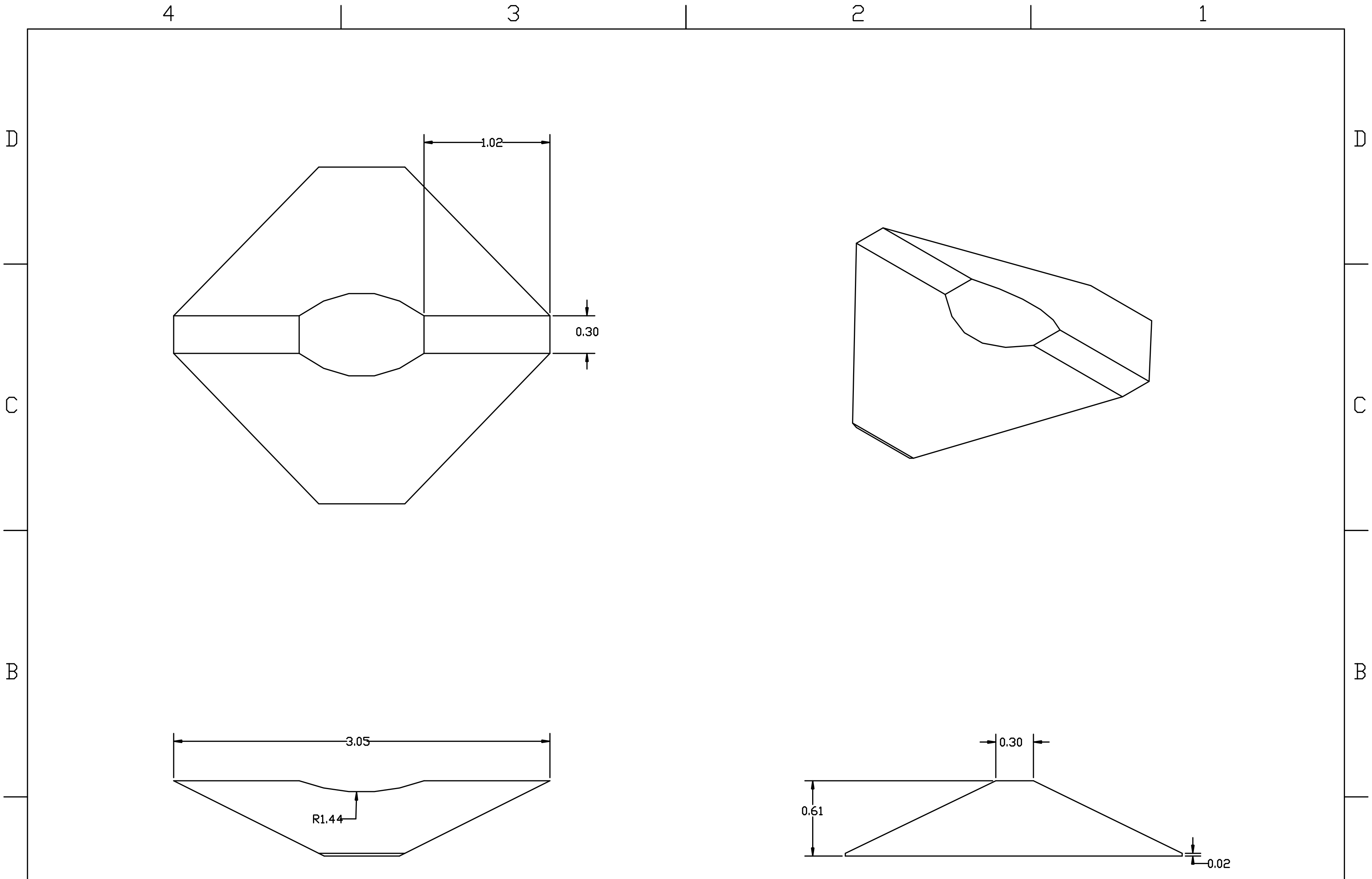
Table 4: Sizing across different plot sizes for the original design

Design	Design Area (Acre)	Design Area (ft^2)	Water Volume held (ft^3)	Number of Dams	Height (ft)	Base Width (ft)	Top Width (ft)
A	1/4	10890	21437	7	4.5	6.1	24.1
B	1/2	21780	42874	14	4.5	6.1	24.1
C	1	43560	85748	18	5.5	4.75	26.7
D	5	217800	428740.2	24	9	4	40

Table 5: Sizing across different plot sizes for the iterated design

Design	Design Area (Acre)	Design Area (ft^2)	Water Volume held (ft^3)	Number of Dams	Height (ft)	Base Width (ft)	Top Width (ft)
A	1/4	10890	840	7	2	2	10
B	1/2	21780	1680	14	2	2	10
C	1	43560	2160	18	2	2	10
D	5	217800	2880	24	2	2	10

Appendix D: Check Dam dimension plan in meters



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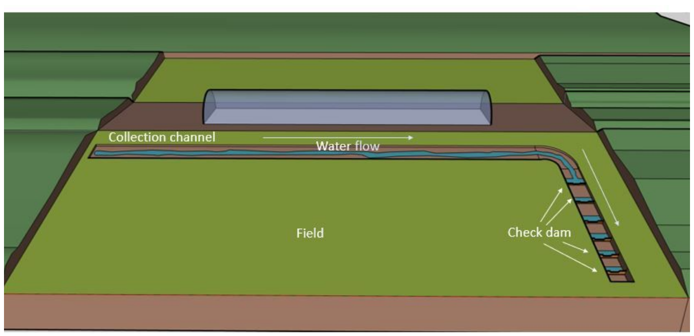
Appendix E: Check Dam System pamphlet

Background

Asili

A check dam is a method of irrigation that allows water to be captured and stored in individual ponds while reducing runoff. The design presented in this brochure will illustrate the steps that need to be taken to properly design a robust and functioning check time on your farm.

Angalia bwawa ni njia ya umwagiliaji ambayo inaruhusu maji kutekwa na kuhifadhiwa katika mabwawa ya kibinafsi wakati wa kupunguza kukimbia. Ubunifu unaowasilishwa katika brosha hii utaonyesha hatua ambazo zinahitaji kuchukuliwa ili kubuni vizuri wakati mzuri wa kuangalia na kufanya kazi katika shamba lako.



Our Team

American students from Colorado School of Mines

Carlos Diaz: electrical engineering
Emily Jones: environmental engineering
Jacob Kohl: civil engineering
Elena Lundeen: civil engineering
Anli Ni: civil engineering
Brenna Treanor: civil engineering

Contact Info

Email: entusimodelfarm@gmail.com
Jacob's WhatsApp: +1(719)271-3378

Check Dams for Irrigation

Sizing and Calculations

For ¼ acre model farm with **7 dams**, dam dimensions are:

Max Depth (m)	Base width (m)	Top width (m)
0.6	0.6	3

Area (m^2)	70 (~7% of plot)
Volume (m^3)	43.6

*Sizing differs with plot dimensions and slope of land. These dimensions only apply to the model farm, but the land usage should stay fairly consistent.

Construction and Materials

Rock

Cinder Blocks

Bamboo

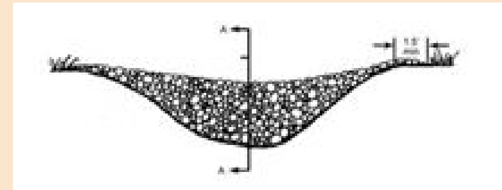
Mortar

Wood

Maintenance

During Construction:

- Dam sides should be higher than center.



- Place heavier stones at base and downstream.
- Do not construct in an active waterway.

After rain event:

- Inspect check dams and drainageway for damage immediately after rain.

Ongoing Maintenance:

- Remove sediment often, but no later than when the sediment is ½ the height of the dam.
- Maintain design height, cross-section, and flow-through characteristics.
- Keep the check dam free of weeds.

Appendix F: Project Management

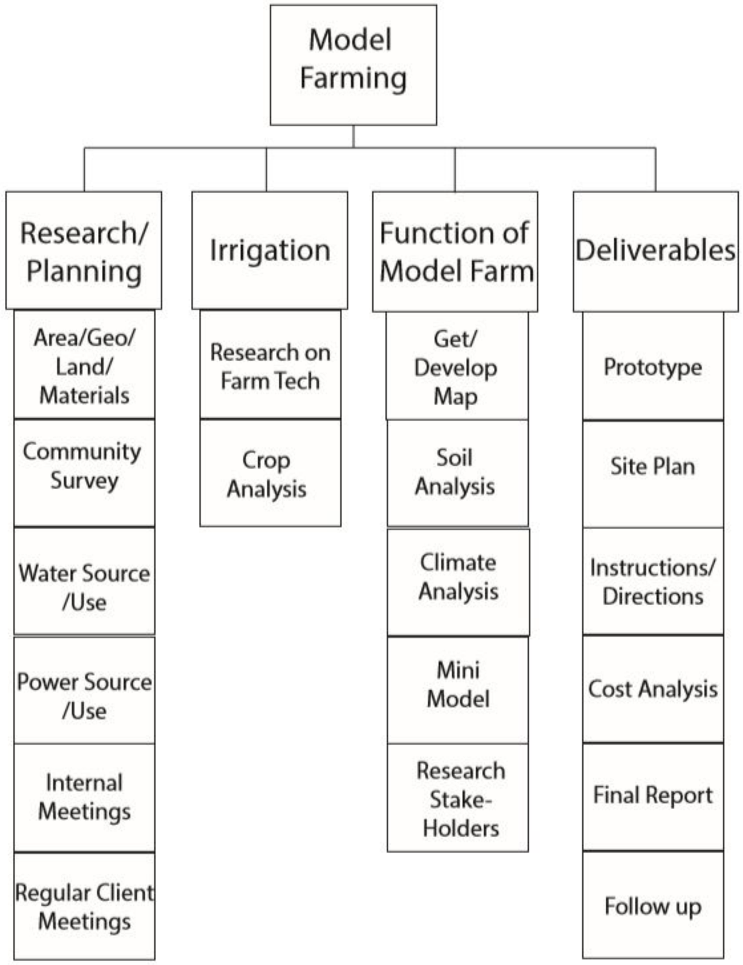


Figure 6: Original WBS

Table 6: Updated Budget as of April 16, 2020

Expenses	
4 Team Members' Airfare	$4,372.00
Total Expenditures:	**$4,372.00**
Income	
GoldMine Fundraising Round 1:	$3,628.00
CAPSTONE Funding	$1,800.00
Total Revenues:	**$5,428.00**
Net Total:	**$1,056.00**

Appendix G: Clay pot irrigation

This fourth design concept utilizes small clay pots, sometimes referred to as ollas, that will be buried into the soil. This irrigation system was thought to have originated in Africa about 4,000 years ago, though this is only a hypothesis [5]. The containers will be filled with water, which will slowly leach out into the surrounding soil as the soil dries out. Water can be placed into the containers by hand or piping. This system relies on changes in soil moisture to irrigate the ideal amount of water to crops. Containers for this design are typically porous clay, but can also be impermeable materials with holes poked in the sides. Ideally, locally-sourced clay pots would be used to reduce costs and provide a sustainable source for the pots. Using locally sourced clay pots also adds jobs to the community and can support local economies. If clay pots are not available or too costly, plastic bottles or containers may be used. Unlike clay pots, which allow moisture to seep through, any other material must have holes drilled into the container to allow water to pass through.

Clay pots generally have a wide body and a narrow neck to prevent evaporation. Often a rock or tile is used to cover the opening of the pot to further reduce evaporation losses. Figure 7 illustrates one such clay pot irrigation system.

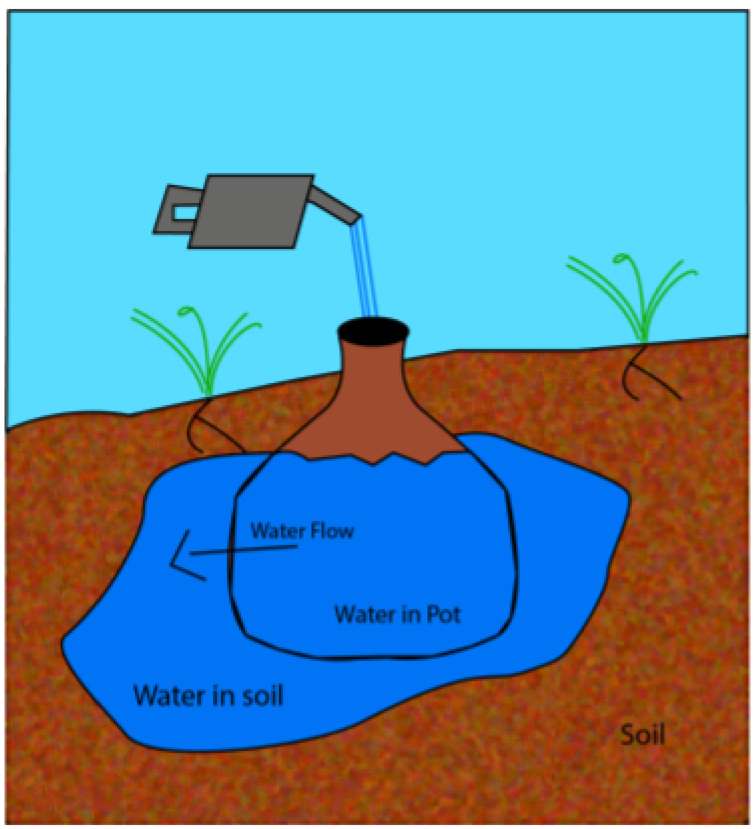


Figure 7: Pot irrigation system showing the flow of water from the pot into soil

Water usage in clay pot irrigation is believed to utilize up to 90% less water than conventional irrigation methods [6]. According to a study conducted in India using melons, the pot irrigation method yielded 25t/ha of melons using 2cm/ha of water. Normally, when using an agricultural method called flood irrigation, 33t/ha of melons using 26cm/ha of water was produced [6].

Clay pots are a traditional method of irrigation and as such there are few publications on what sizing, materials, and spacing yield the best results. However, Bainbridge offers some guidance on typical sizing of pot and spacing along with other considerations in his article "Buried clay pot irrigation: a little known but very efficient traditional method of irrigation" [6]. Bainbrige states that one common mistake with pot irrigation is placing plants too far from the pot and outside the wetted soil area. This can be easily solved by educating farmers on the technique and proper spacing. This type of irrigation is applicable to all plants and can be used anywhere, however, it is best suited for plants that grow above ground and are not uprooted during harvest, such as coffee or fruit trees.