RainCat Center Pivot Model

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Abstract

Center pivot irrigation systems have a 75%-90% efficiency rate. However, environmental factors such as wind and soil type can easily decrease the system's efficiency. Often, farmers get stuck between two choices: wasting time to check all their systems - or potentially wasting water.

With the *RainCat* Center Pivot, farmers can be assured that each field is being watered correctly. The *RainCat* is a center pivot mathematical model that customizes the water application based on environmental and operational variables. This model is converted into an algorithm for the mobile application, *EvenStreamin*.

Keywords: Application Rate; Infiltration Rate; Center Pivot Irrigation; Precision Agriculture; Variable Rate Irrigation; Xamarin; Azure; ArcGIS.

Contents

1 Introduction

Farming began around 12,000 years ago [1], and it is estimated that the first irrigation system was introduced 8,000 years ago in the Middle East's Jordan Valley [2]. Since then humans have continued to bring technological advancements into the agriculture industry; such as introducing genetic engineering in crops, or programming autonomous tractors. But, there is always more room for improvement. The negative effects of farming are prevalent: aquaphor and river depletion, erosion of coastlines, habitat destruction, and excessive amounts of chemical fertilizers [3]. It is critical that as humans advance agriculture technology there should be an emphasis on sustainability.

1.1 *Problem Statement*

Growing up in a rural farming town, I saw the benefits of precision agriculture technology. However, this technology is not always the most efficient. Through working on farms, I realized two issues:

1. Incorrectly set center pivots lead to flooding or drying out a field.

2. Time and resources are wasted on tasks that could be automated.

The issue of water is critical for farmers since agriculture accounts for "approximately 80 percent of the Nation's consumptive water use" [4]. With this in mind, a farmer must choose precise watering systems. Center pivot irrigation systems are the most popular sprinkler system in the world. A center pivot's uniform water application is the reason for their 75%-90% efficiency rate [5]. However, uniformity is easily affected by operating conditions and environmental factors. A non-uniform application can result in overwatering or underwatering areas of a field [6]. Overwatering wastes water and causes root damage, while underwatering stresses crops. Both options lead to poor crop yields [5].

As for the second issue, my work on the farm consisted of hand checking fields. Entire workdays could be spent driving to each field and documenting crop growth and moisture levels. Making sure the watering systems were working correctly was one of the biggest reasons for checking each field by hand. However this wasted multiple resources, such as gas for driving and time that could be utilized elsewhere.

1.2 *Solution Statement*

My senior capstone project attempts to address both issues through the *RainCat* Center Pivot Model, and the *EvenStreamin* mobile application.

1.2.1 *RainCat Center Pivot Mathematical Model*

The *RainCat* Center Pivot is a mathematical model that targets the issue of water waste. The model optimizes each drop head sprinkler to release the least amount of water that is needed to evenly water the soil below it. This is accomplished by having the rate of water being applied equal the rate at which the soil can absorb water. Once the soil can no longer absorb anymore water - a rate of zero - then the sprinkler head will shut off. The design and components are discussed in later sections.

1.2.2 *EvenStreamin Mobile Application*

The EvenStreamin mobile application allows farmers to remotely monitor their fields. The app is cross-platform, allowing both Android and iOS users to download the app. Specific functionality that will reduce time and resources spent checking fields manually includes:

- Running and stopping a pivot remotely.
- Getting relevant statistics, such as how much water will be used.

1.2.3 *The Project: EvenStremain & RainCat*

The complete project is then a combination of the *RainCat* mathematical model, and the *EvenStreamin* mobile application. To get real time watering statistics, the *RainCat* mathematical model will be implemented as an algorithm within the *EvenStreamin* app.

This provides farmers with accurate information about how the field is being watered, and how much water the model predicts the sprinkler system will use.

1.3 *Background Information*

Agricultural terminology is prevalent within this project, refer to the Glossary for a table of all terminology. *EvenStreamin* is a precision agriculture mobile application. **Precision agriculture** is a "technology-based management system that collects and organizes data to optimize profits, sustainability, and protection of the environment" [7]. The optimizations of the project occur within the center pivot irrigation system. **Center pivots** irrigate fields in a circular pattern around a central pivot point [5]. The **central pivot point** is a stationary structure connected to a water supply - this is what the main water pipe rotates around. For reference use Figure 1.

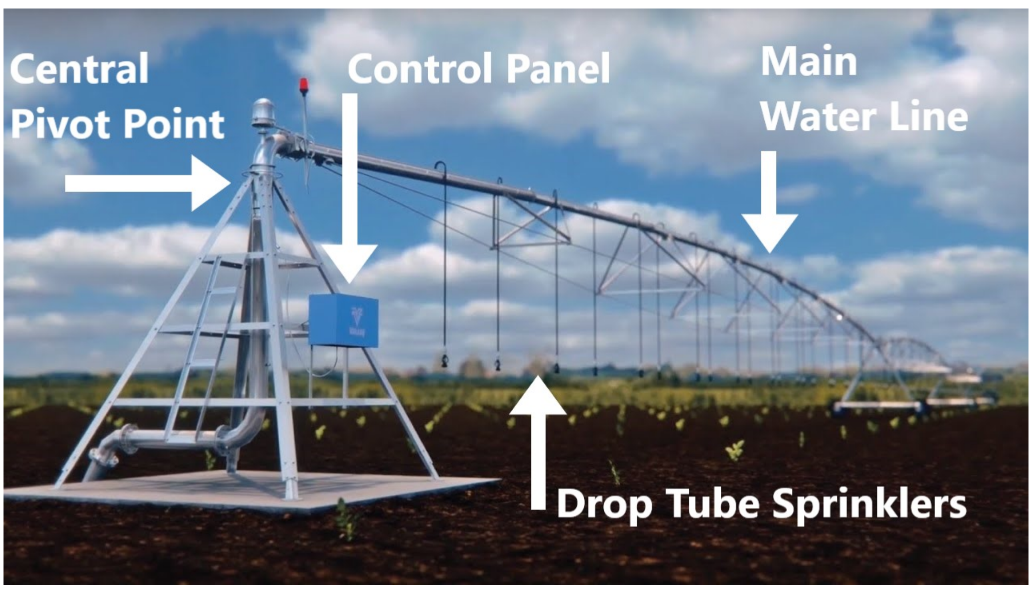

Figure 1: Diagram of a Center Pivot Irrigation System [8]

Spaced throughout the length of the main water pipe are drop tube sprinklers. **Drop tube sprinklers** hang below the pipe and are used to water individual sections of the field. The distance between each sprinkler and the type of sprinkler head will vary. A center pivot is controlled through a piece of hardware called the control panel. The **control panel** gives the center pivot commands on starting, stopping, and changing direction.

1.4 *Relevant Words*

Other farming mobile apps and precision center pivots already exist within the agriculture industry. I will discuss the following:

- Valley 365
- SmartIrrigation

Valley Irrigation is a big inspiration for my project. Their Valley 365 product is a remote crop management mobile app. Similar to *EvenStreamin*, the app acts as a command and control center for all Valley Irrigation center pivots [9]. This mobile app has an abundance of other functionality such as:

- Viewing data on soil moisture, crop type, crop development, and weather information.
- Irrigation recommendations.
- Computer vision to spot health concerns in the fields.

SmartIrrigation, is a company that has developed multiple, crop-specific mobile applications that give users irrigation tips [10]. Since it is crop-specific, the calculations and predictions are more accurate. However, it might be a hassle for farmers that grow multiple crops.

2 RainCat Center Pivot Model

The *RainCat* project has been split into three steps:

1. Center Pivot Components
2. Model Components
3. Algorithm Design

2.1 *RainCat Center Pivot Components*

Due to the nine month time constraint, and both projects being single person projects - it was not a realistic goal to model all variations of center pivots. So, it was necessary to narrow down specific assumptions of the *RainCat* Center Pivot to make it easier to produce the model and algorithm. The main components of the *RainCat* Center Pivot include:

1. Center Pivot Specifications
2. Sprinkler Specifications
3. Field Specifications

All components are explained in their respective sections below.

2.1.1 *Center Pivot Specifications*

Refer to Figure 2. For this section, the center pivot specifications focus on the central pivot point, main water line, spans, and drive units.

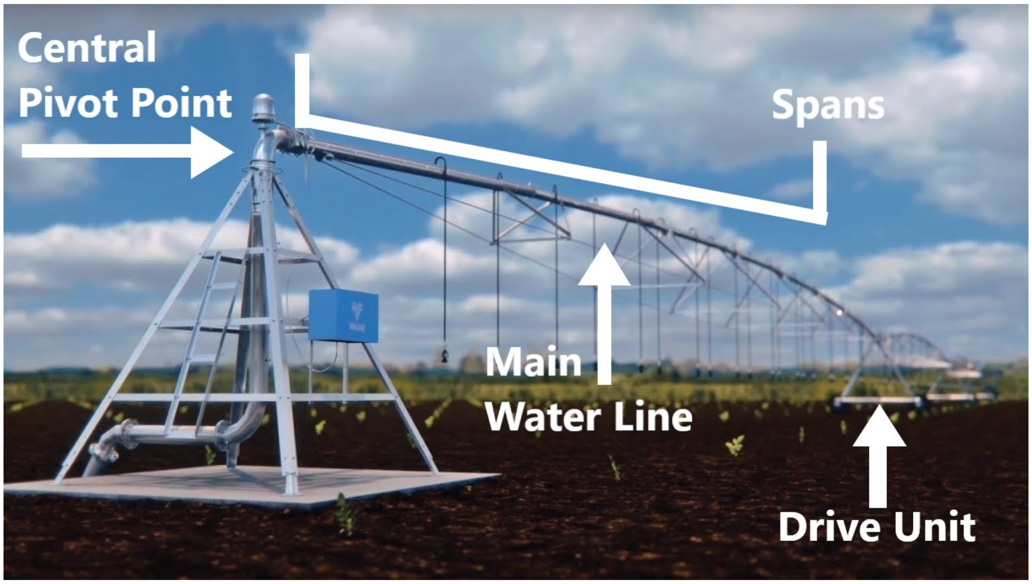

Figure 2: Center Pivot Specifications [8]

A center pivots length is determined by the length and number of spans that it is made up of. **Spans** consist of the main water pipeline, sprinklers, and a supporting structure of trussing that holds the weight between towers [11]. Spans come in multiple sizes so that a center pivot can fit any field size. However, the *RainCat* Center Pivot will be a constant length. Farmers choose a set length and never add or take away spans to make it shorter or longer. The lengths the *RainCat* Center Pivot can be are:

- 150 Meters
- 300 Meters
- 400 Meters

The next specification is how a center pivot moves - which relies on drive units. **Drive Units** are the parts of the center pivot that touch the ground, and have specific hardware for movement [11]. The **Last Regular Drive Unit** (LRDU) is the last drive unit on a pivot. Refer to Figure 3.

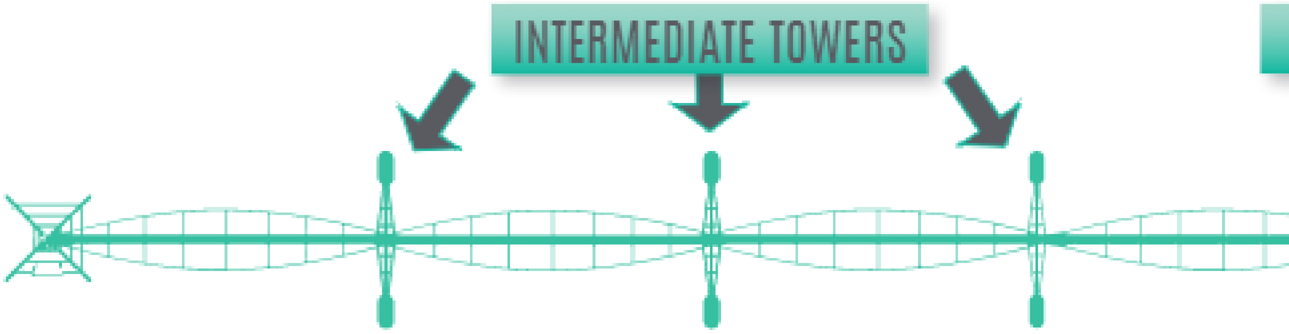

Figure 3: Diagram drive units [11]

The actual movement of a center pivot relies on the chain reaction of these drive units. The LRDU moves first, and continues to move until a switch connecting the LRDU and second-to-last drive unit is triggered. Now both the last and second-to-last drive units move until the third-to-last switch is triggered. This cycle continues until all drive units have caught up, at which the last drive unit runs again. Refer to Figure 4.

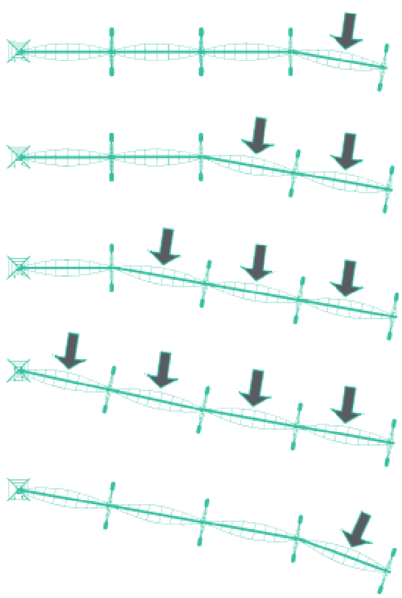

Figure 4: LRDU Movement [11]

2.1.2 *Sprinkler Specifications*

Sprinkler settings are incredibly diverse, and any change will modify the model. For this section, the specifications focus on the sprinkler head type, sprinkler spacing, and wetted diameter. Refer to Figure 5.

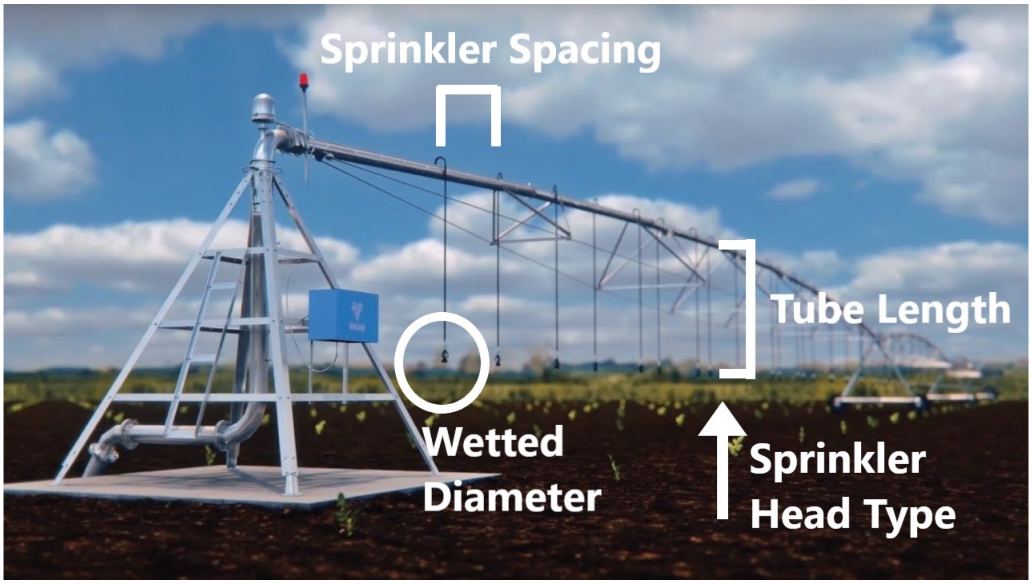

Figure 5: Sprinkler Specifications [8]

Choosing a specific sprinkler head to model is tricky because a sprinkler head that is beneficial in one type of terrain might not be in another. Figure 6 shows the three main sprinkler types. Mid-elevation spray application (MESA) have the highest pressures rates of 25-40 psi, with a 78%-80% efficiency. Low-elevation spray application (LESA) operate on 6-15 psi, with 88%-97% efficiency. Low-energy precision application (LEPA) operate on 15 psi, with a 95% efficiency [12].

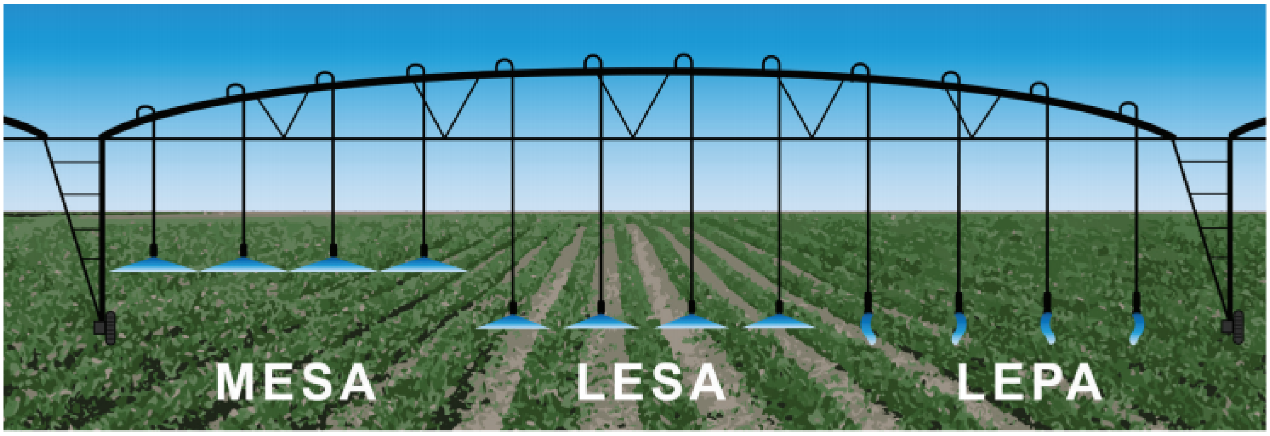

Figure 6: Sprinkler Types [12]

The end decision was to use the LESA sprinkler types. Being closer to the ground means that less water is lost to evaporation. A study showed that LESA sprinklers have 18% more water reach the ground than MESA sprinklers [13]. LESA sprinklers are 1-6 feet above the field - while LEPA sprinklers are 0-3 feet above. This means LEPA is more prone to ponding on certain soil types [14].

Sprinkler spacing and varying wetted diameters can be used to accomplish different watering needs. A diagram of different combinations can be seen in Figure 7.

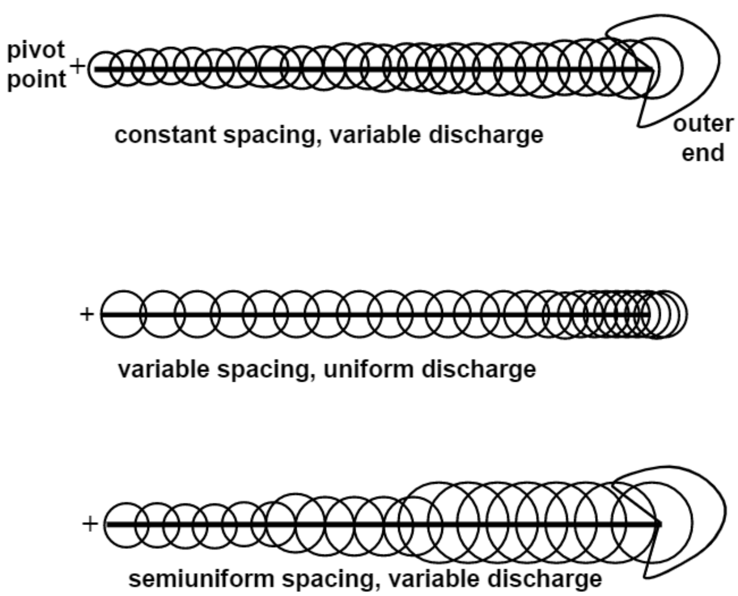

Figure 7: Different spacing and discharge [14]

The *RainCat* Center Pivot will have constant spacing and uniform discharge. Specifically, there will be 5 feet spacing between each sprinkler. Uniform discharge allows us to specify that each sprinkler will have a wetted diameter of 6 feet. **Wetted diameter** is the circular region underneath the sprinkler that gets watered. Wetted diameter influences the rate of water that is applied from each sprinkler head.

2.1.3 *Field Specifications*

Along with the hardware of the *RainCat* Center Pivot, it is helpful to set limitations on the environmental variables around the center pivot. Specifically, the actual field that is being watered. For this model, it is assumed that the field has no crops. This is necessary because crops and their canopy interfere with the wetted diameter and how water percolates into the soil.

The same way that it is not realisitic to model all center pivot variations, it is also not realistic to model all crop types. Adding crops into the model would require research into transpiration and evapotranspiration.

Another field specification is the soil type. Soil type plays an important role in the model. As seen in Figure 8, there is a lot of variation when it comes to soil type.

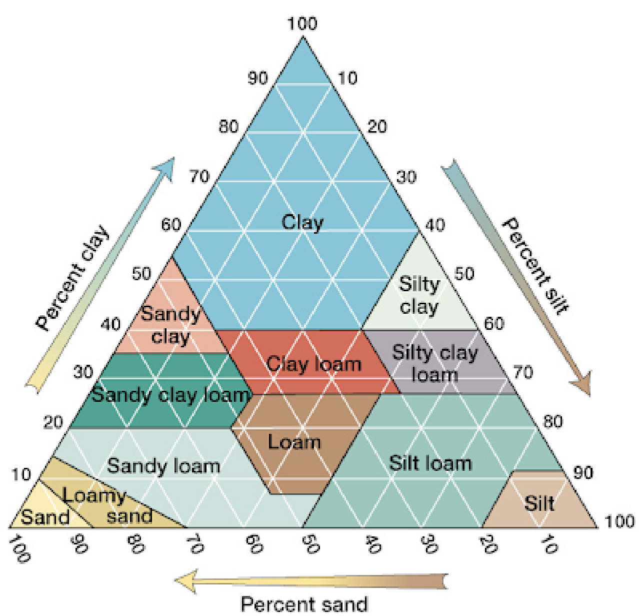

Figure 8: Graph of Soil Types [15]

Soil is classified by particle diameter, and the three major classes include sand, silt, and clay. **Sand** is loose and single grained, these are the largest particles. **Silt** is between sand and clay in size. **Clay** is the finest-textured soil [5]. For this project the following soil types are utilized:

- Clay
- Silty Clay
- Silty Clay Loam
- Sandy Clay
- Clay Loam
- Sandy Clay Loam
- Fine Sandy Loam
- Loam
- Find Sand
- Loamy Fine Sand
- Loamy Sand
- Course Sand
- Sand

2.2 *RainCat Model Components*

With the *RainCat* Center Pivot specifications set - the equations and variables needed to develop the model become less abstract. The next focus is then the *RainCat* Model. The goal of the model is to take in environmental and operational data in order to reduce overwatering.

Consider Figures 9 through 12. As the center pivot crosses over each area, the individual sprinkler behavior changes. So an area that is boggy or ponded over receives less or no water from the sprinklers above. However, sandy areas require a normal amount of water.

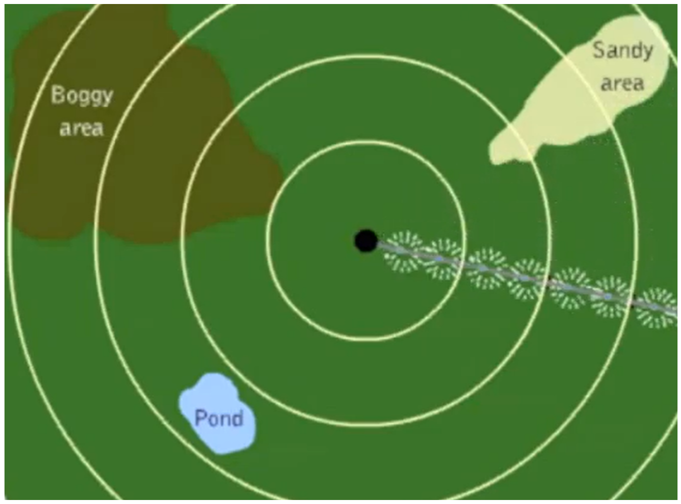

Figure 9: Ideal Center Pivot Set Up [16]

Figure 10: Boggy

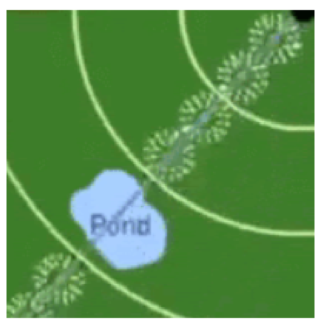

Figure 11: Ponded

Figure 12: Sandy

Looking at the images it becomes clear: in order to create an ideal watering system there must be information on each sprinkler head, as well as information on the soil below it. Thus, the two biggest components to the *RainCat* Model are:

1. Soil Instantaneous Infiltration Rate

2. Sprinkler Instantaneous Application Rate

2.2.1 *Instantaneous Infiltration Rate*

Infiltration is the process of water from precipitation or irrigation entering the soil [5]. The *RainCat* Model will utilize the Natural Resource Conservation Service (NRCS) variation of the Kostiakov's equation for infiltration as seen in Equation 1 [5]:

$$i = 600at^b + c \tag{1}$$

where:

$$i = \text{depth of infiltration, mm}$$
$$t = \text{time, hr}$$
$$a, b, c = \text{Natural Resource Conservation Service specific constants [5]}$$

Taking the derivative of Equation 1 with respect to time results in the instantaneous infiltration rate. **Instantaneous Infiltration Rate** is the rate of change in ponded depth of water on the soil surface [5]. The Natural Resource Conservation Service instantaneous infiltration rate can be seen in Equation 2.

$$\frac{di}{dt} = 600ab(t)^{b-1} \tag{2}$$

where:

$$\frac{di}{dt} = \text{instantaneous infiltration rate, mm/hr}$$
$$t = \text{time, hr}$$
$$a, b = \text{Natural Resource Conservation Service specific constants [5]}$$

The instantaneous infiltration rate is not the same for all parts of the field, and changes over time [17]. In Kostiakov's base equation, the constants a and b can signify many different variables such as: crops, moisture, rainfall, and soil surface conditions [18]. This allows for the model to take in many different variables that affect infiltration rate, but makes it difficult to model if we don't have that empirical data.

Luckily the Natural Resource Conservation Service created a table that generalizes the constants to only rely on soil type. Thus, the main focus for the model will be how soil type modifies instantaneous infiltration rate. The soil type heavily influences the infiltration rate. Table 1 shows the Natural Resource Conservation Service constants that were used for this project. The intake family corresponds to a specific soil type, which results in the a b constants.

Table 1: NRCS Constants [5]

Intake Family	a (cm)	b	Soil
0.01	0.0620	0.661	Clay
0.15	0.0701	0.683	Silty Clay
0.3	0.0925	0.720	Silty Clay Loam
0.35	0.0996	0.729	Sandy Clay
0.4	0.1064	0.736	Clay Loam
0.45	0.1130	0.742	Sandy Clay Loam
0.5	0.1196	0.748	Fine Sandy Loam
0.6	0.1321	0.757	Loam
0.7	0.1443	0.766	Fine Sand
0.8	0.1560	0.773	Loamy Find Sand
0.9	0.1674	0.779	Loamy Sand
1.0	0.1786	0.785	Course Sand
1.5	0.2283	0.799	Sand

When graphing instantaneous infiltration rate, it will have exponential decay, as seen in Figure 13.

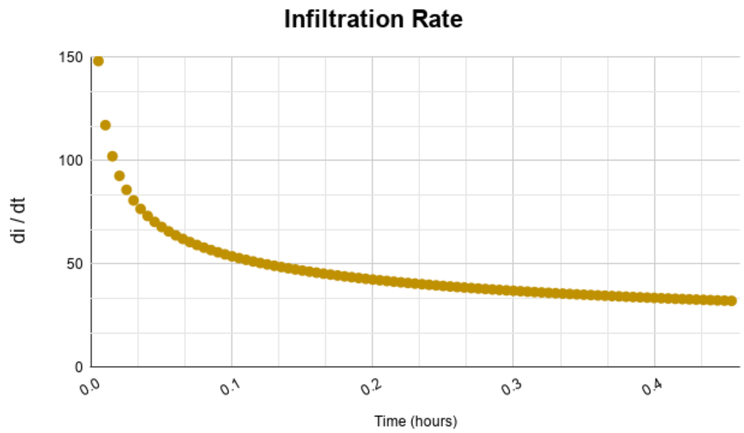

Figure 13: Infiltration Rate

2.2.2 *Instantaneous Application Rate*

The next component of the *RainCat* Model is the instantaneous application rate of the center pivot sprinklers. **Instantaneous Application Rate** is the peak intensity of water application at a specific point [5]. Note that this is being modeled by an ellipse and is a function of time. The time starts when the specific point in first wetted, and ends at time equal to s. The instantaneous application rate is shown in Equation 3.

$$\frac{da}{dt} = \left(\frac{da}{dt}\right)_{max} \sqrt{\left(1 - \frac{\left(t - \left(\frac{s}{2}\right)\right)^2}{\left(\frac{s}{2}\right)^2}\right)} \tag{3}$$

where:

$$\frac{da}{dt} = \text{Instantaneous Application Rate, mm/hr}$$

$$t = \text{Length of time after a point is first wetted, hr}$$

$$s = \text{Time a specific sprinkler spends over one point, hr}$$

$$\frac{da}{dt}_{max} = \text{Maximum application rate, mm/hr}$$

To better understand instantaneous application rate, refer to Figures 14 through 16. For Figure 14, the first drop of water has just hit the specific point in the field. This is time equals zero. For Figure 15, the sprinkler is directly over the specific point in the field. It is at its max application rate, and time is equal to $\frac{s}{2}$. For Figure 16, time is now equal to s, and the sprinkler has finished its rotation over that one spot.

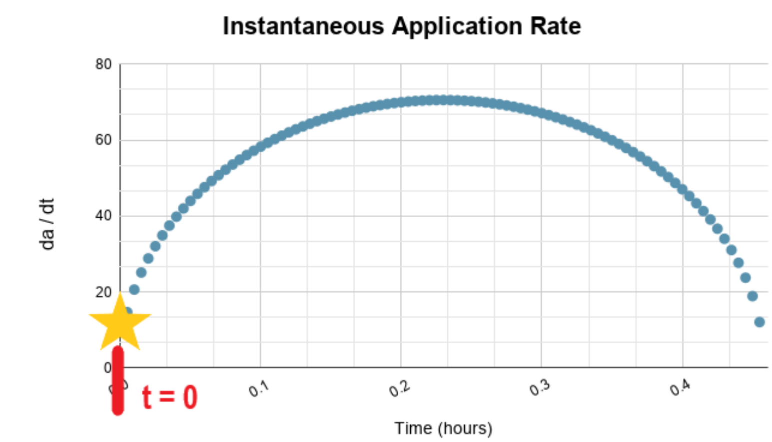

Figure 14: Start Time

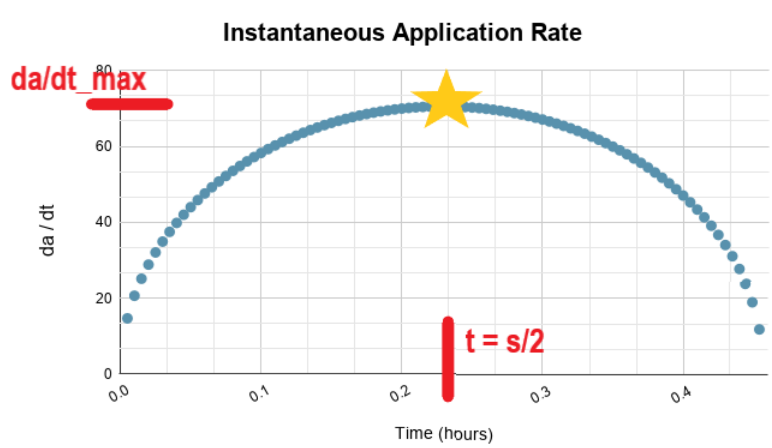

Figure 15: Max Application

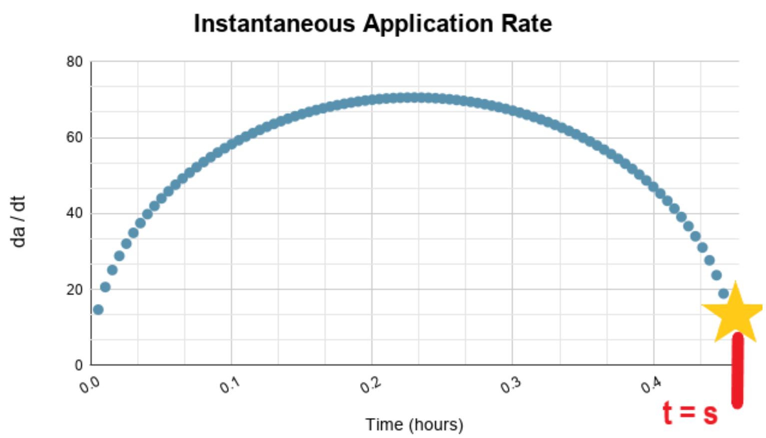

Figure 16: End Time

Due to the circular characteristics of a center pivot, the instantaneous application rate increases the further from the central pivot point the sprinkler is [6]. Figure 17 is a visual representation of how the application rate changes for different points along the center pivot.

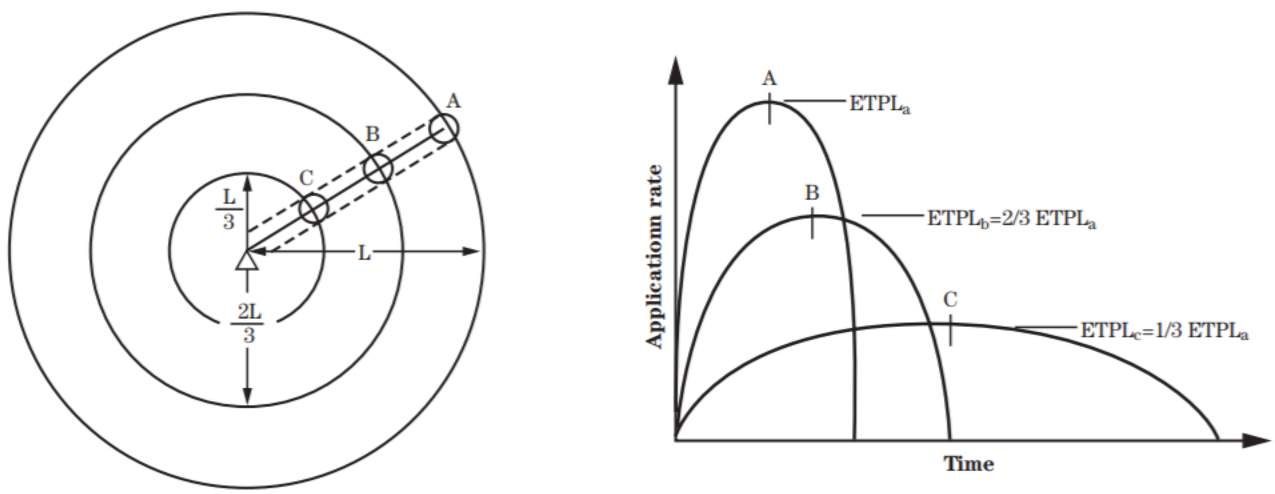

Figure 17: Diagram of water application rates at different points along the center pivot [6]

The sprinkler specifications mentioned earlier have a large impact on instantaneous application rate. The equations s and $\frac{da}{dt}_{max}$ both rely heavily on these specifications. Each equation is described below.

First, is s as seen in Equation 4. This is the time a sprinkler spends over one point.

$$s = \left(\frac{D_w}{2\pi r}\right) T_{rev} \tag{4}$$

where:

$$\begin{aligned} D_w &= \text{Wetted Diameter, m} \\ r &= \text{Distance to the sprinkler, m} \\ T_{rev} &= \text{Time of one full revolution, hr} \end{aligned}$$

Note that s is sprinkler specific because of r. For example, if we have an 150 meter center pivot with 5 meter sprinkler spacing, then we have 30 sprinklers total on the main waterline. So r changes depending on which of the 30 sprinklers we are solving for.

Another sprinkler specification that s relies on includes the wetted diameter D_w. As seen in Figure 18, s is proportional to the wetted diameter covered. However, note the green line - this shows how s is a slight approximation.

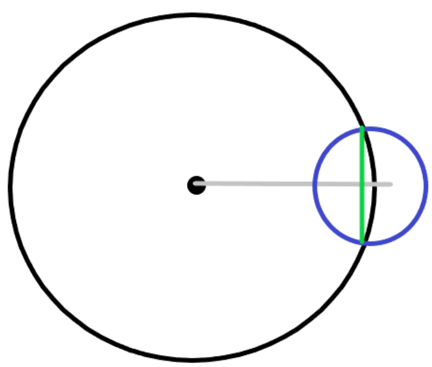

Figure 18: s Time Approximation

The next equation is $\frac{da}{dt}_{max}$ as seen in Equation 5. This is the maximum application rate of the sprinkler. Recall that this was shown in Figure 15 from the instantaneous application rate example.

$$\frac{da}{dt}_{max} = \left(\frac{4}{\pi}\right)\left(\frac{i_a}{s}\right) \tag{5}$$

where:

$$i_a = \text{Total water that reaches soil, mm}$$
$$s = \text{Time a sprinkler spends over one point, hr}$$

2.3 *RainCat Algorithm Design*

With the individual components modeled, it is easier to compare the sprinkler instantaneous application rate against the soil instantaneous infiltration rate. Graphing the equations on the same table - as seen in Figure 19 - reveals a lot about how they interact. Note that the instantaneous application rate exceeds the instantaneous infiltration rate after the first intersection. This is where overwatering can occur.

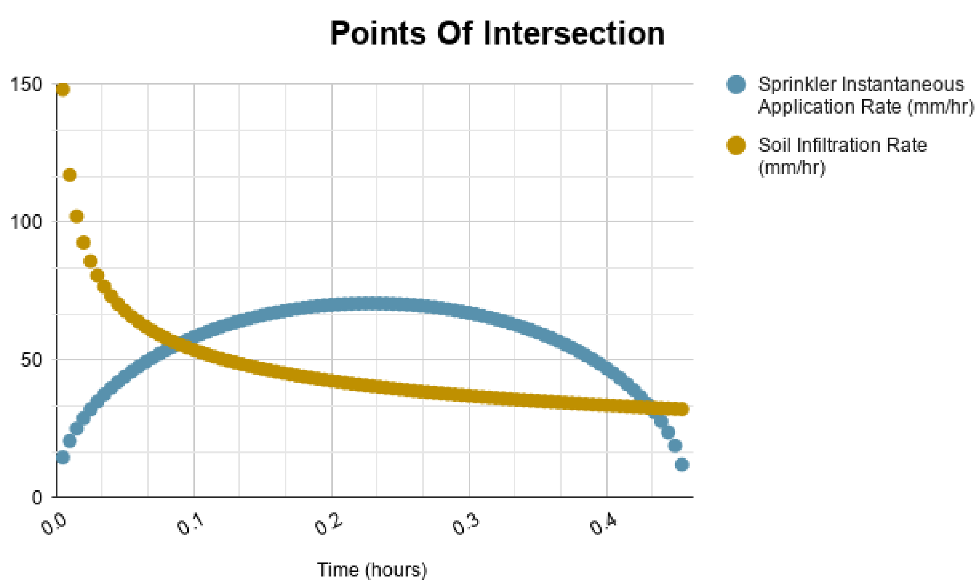

Figure 19: Points of Intersection

The goal of the project is to reduce overwatering. So, the next step is to develop an algorithm that handles what a sprinkler should do between the first and second intersections.

Due to time remaining in the semester, the ultimate choice was to turn the sprinkler off at the first intersection, and turn it back on at the second intersection. Then repeat this process for the entire revolution.

Figures 20 and 21 represent the first part of the algorithm. From t_0 to the first intersection t_1 the pivot runs. This is displayed as the light blue color in Figure 21. From t_1 to t_2 the pivot will be shut off. This is displayed as the light red color.

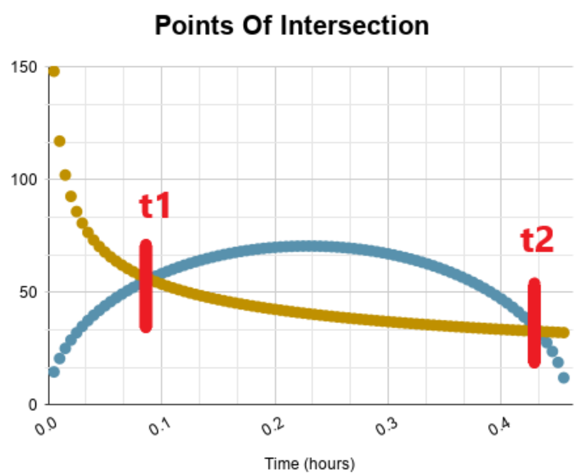

Figure 20: Points of Intersection

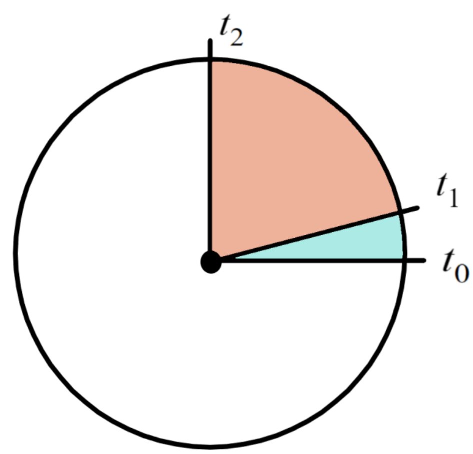

Figure 21: Single Slice

Note that the example above is only a single slice. The sprinkler still needs to rotate around the rest of the field. Thus, the previous example is repeated until a full revolution is complete, as seen in Figure 22.

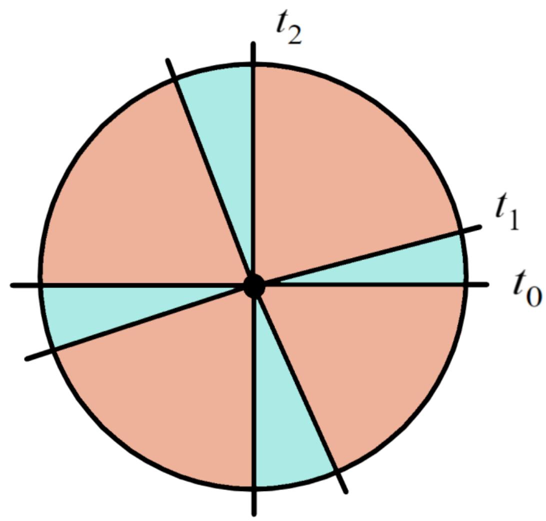

Figure 22: Multiple Slices

To get the number of slices, n, complete the following: find the circumference, and using the time spent traveling solve for the distance traveled, as seen in Equation 6:

$$d = \frac{c}{t_{rev}} \left(t_2 - t_0\right) \tag{6}$$

where:

$$\begin{aligned} d &= \text{Distance traveled, m} \\ c &= \text{Circumference of the field at a specific sprinkler, m} \\ t_{rev} &= \text{Time to complete one revolution, hr} \\ t_0 &= \text{Start time, hr} \\ t_2 &= \text{Second intersection, hr} \end{aligned}$$

With the distance traveled known, solve for n as seen in Equation 7:

$$n = \frac{c}{d} \tag{7}$$

where:

$n =$ Number of times t_0 to t_2 is repeated

$c =$ Circumference of the field at a specific sprinkler, m

$d =$ Distance traveled, m

With the full revolution complete, the water usage for that one sprinkler can now be calculated. Thus the algorithm is as follows: let n be the number of times t_0 to t_2 is repeated. The amount of water used by that sprinkler is the integral from t_0 to t_1, times n.

$$W_r = \left(\int_{t_0}^{t_1} \frac{da}{dt} dt\right) * n \tag{8}$$

where:

$W_r =$ Depth of water applied for a sprinkler, mm

$\frac{da}{dt} =$ peak intensity of water application at a specific point, mm/hr

$n =$ Number of times t_0 to t_2 is repeated

$t_0 =$ Start time, hr

$t_1 =$ First intersection, hr

3 EvenStreamin Mobile Applicaiton

3.1 *EvenStreamin Components*

The four main components of the *EvenStreamin* mobile application include:

1. Cross-Platform Mobile Framework
2. MVVM Design Pattern
3. Azure Database
4. ArcGIS SDK

All four components are explained in their respective sections below.

3.1.1 *Xamarin*

Cross-platform mobile development is the creation of software that is compatible with multiple mobile operating systems. To do cross-platform development, I utilized both **Xamarin** and **Xamarin.Forms**. Xamarin is an open-source framework for cross-platform mobile development [19], while Xamarin.Forms is a User Interface (UI) framework on top of Xamarin. With these two components together, the shared codebase is written such that Xamarin handles the business logic and Xamarin.Forms handles the UI elements.

3.1.2 *MVVM Design Pattern*

Design patterns help structure applications to make them more maintainable and reusable [20]. **Model-View-ViewModel** (MVVM) is a design pattern that separates the business logic from the graphical user interface (GUI) logic. Refer to Figure 23 for the component structure. MVVM is broken up into three groups [20]:

- **Models**: Encapsulates the application's data.
- **Views**: The View represents the visual elements, and controls what the user sees on the screen.

- **View Models**: The ViewModel is the connection between the View and the Model.

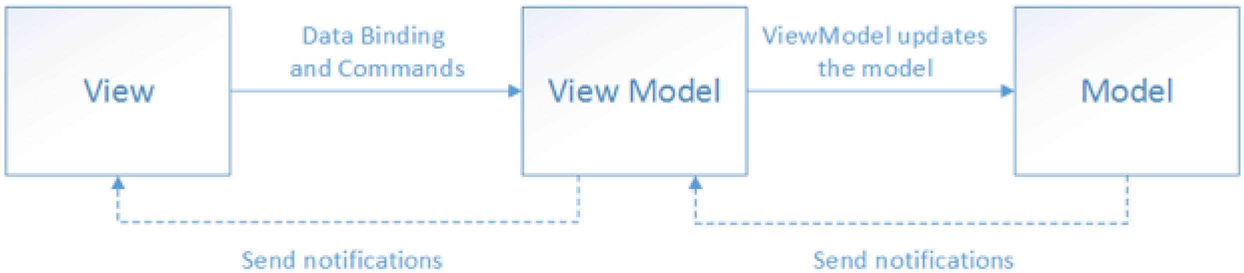

Figure 23: Model-View-ViewModel components [21]

3.1.3 *Azure*

The *EvenStreamin* mobile application has account and field information that persists even after the user has closed or logged out of the app. This information needs to be easily accessible. Therefore, a database is a necessary component of the mobile application. A database is an "organized collection of structured information" which is controlled by a database management system (DBMS) [22].

This is accomplished by creating a backend service and web API using Azure Functions bound to Azure Table Storage. **Azure** is a cloud computing platform owned by Microsoft.

3.1.4 *ArcGIS*

ArcGIS is a geographical information system (GIS) software created by the Environmental Systems Research Institute (Esri). This software is used to visualize, edit, manage, and analyze geographic data [23].

Development with ArcGIS Online is made possible through ArcGIS Software Development Kits (SDK). An SDK contains a range of tools such as libraries, Application Programming Interfaces (API), programming tools, and documentation. In order for *EvenStreamin* to utilize ArcGIS functionality, I incorporated the ArcGIS Runtime SDK for .NET into the application.

3.2 *EvenStreamin User Interface*

As for the actual user interface, many styling choices were made to make the app user friendly. The example screenshots below show the iOS interface on an iPhone 12 Pro Max iOS 14.4 simulator. To see the Android and iOS implementations side by side refer to Appendix 1.

The first usability goal was efficiency. Thus, *EvenStreamin* needed a minimal, easy to navigate, design. Pages that are frequently used require only a few taps to navigate to. The home page and toolbar are the best examples of this, as seen in Figure 24 and 25

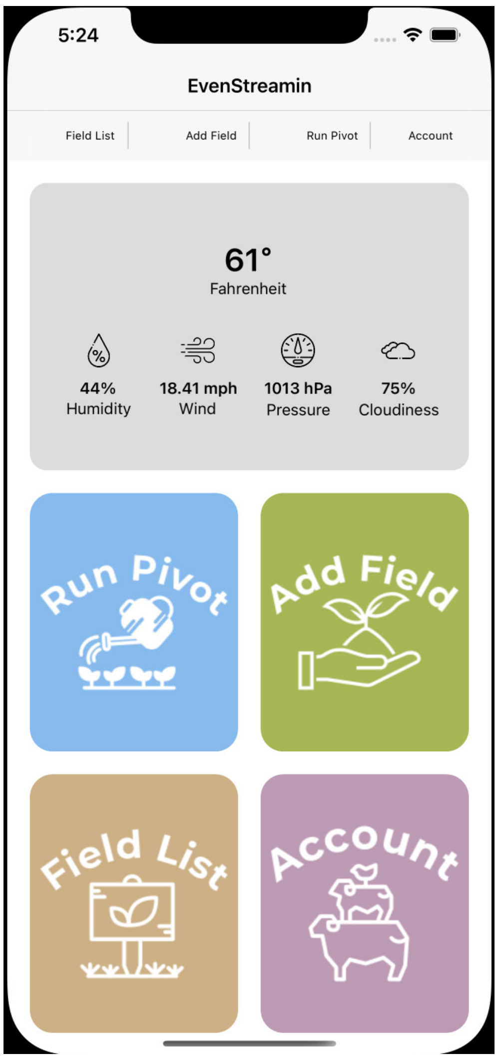

Figure 24: Home Page

Figure 25: Toolbar

The second usability goal was consistency - which is completed by reusing styling concepts. Typefaces, buttons, and labels are all visually consistent throughout the app. The design reuses components and behaviors. The reusability allows users to recognize visual cues, rather than having to think about what to do. This is best accomplished through how information is displayed. Figures 26 through 31 show that account and field pages use the same styling choices. All of the information is preceded with an italicized header, and the information itself is bolded.

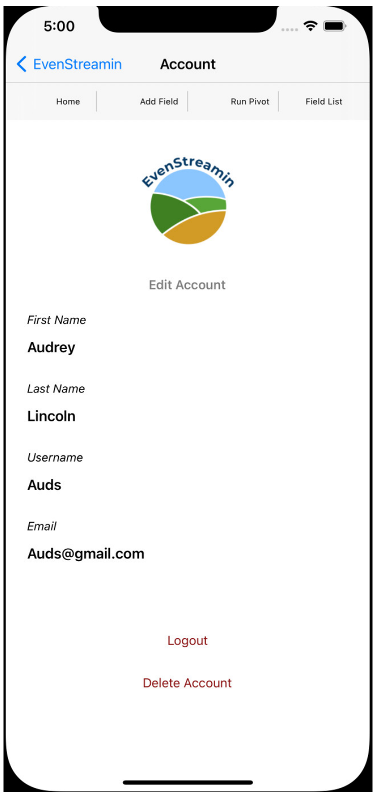

Figure 26: iOS Account

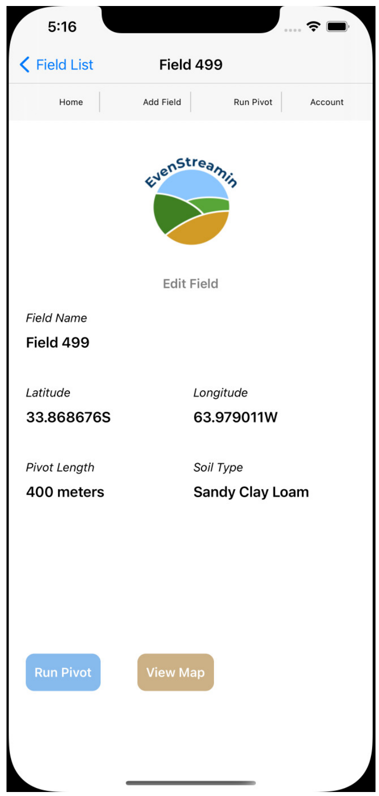

Figure 27: Stopped Field

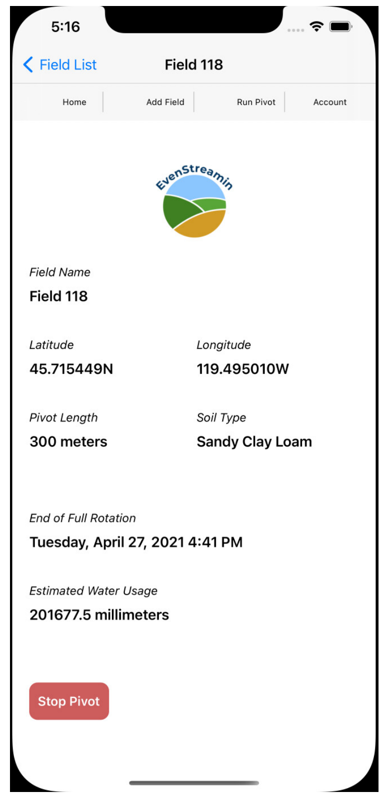

Figure 28: Running Field

The final usability goal was to be useful. This is accomplished through the remote functionality to turn pivots on. The first way to turn on a pivot is through the 'Run Pivot' page, as seen in Figure 29. The second way is through the 'Stopped Pivot' page, as seen in Figure 30.

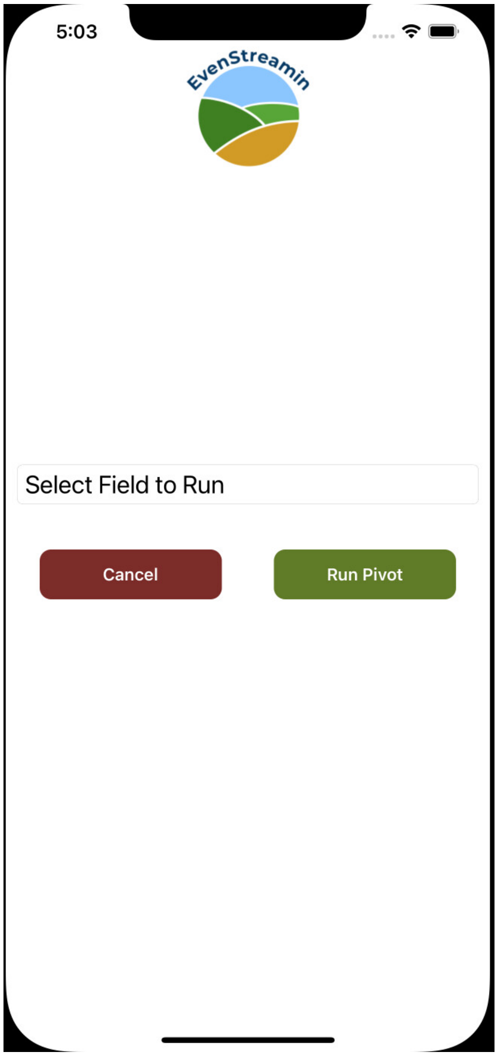

Figure 29: Run Pivot Page

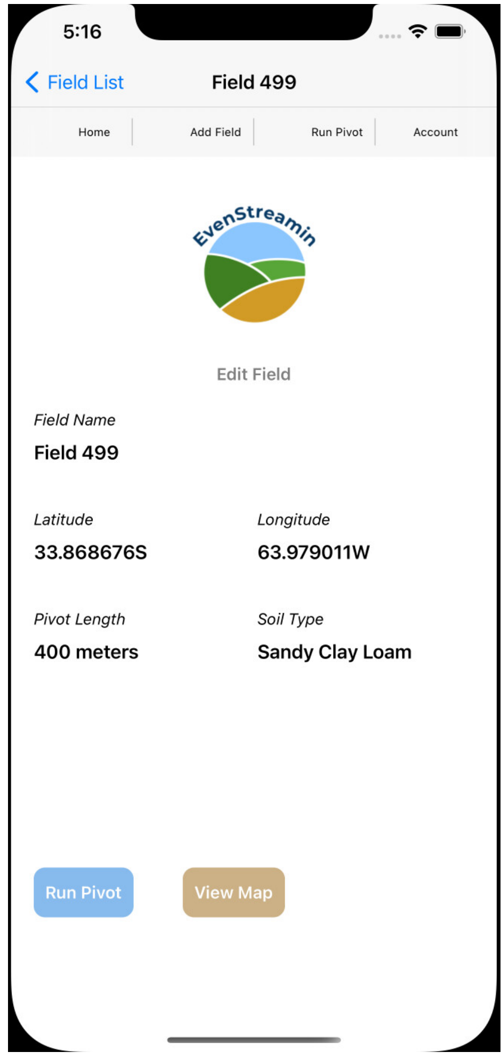

Figure 30: Stopped Field Page

4 EvenStreamin and RainCat

Implementing the *RainCat* algorithm consited of two parts:

- What is the end time of the running pivot?
- What is the total water usage of the pivot?

4.1 *Algorithm: End Time*

Based on the previous center pivot specifications, it takes exactly 24 hours for a pivot to finish one rotation. So the implementation utilizes the DateTime functionality of Xamarin to add 24 hours to the time when the center pivot is remotely turned on.

4.2 *Algorithm: Total Water Used*

Getting the total water usage was the main focus of this project. As seen in the *RainCat* Algoithm Design section, the algorithm needs to find two intersections. However, neither equation is linear, so the intersections - if they happen at all - must be approximated. C# does not have any equation approximating libraries unlike other languages. So I had to iterate through both equations by time, checking for an intersection.

If the intersections are found then the code follows the equations explained in the *RainCat* Algorithm Design section.

However, if the intersections do not exist that means the sprinkler will never overwater the field. So $n = 1$, and the integral is from t_0 to s.

4.3 *RainCat Information UI*

When a user chooses to run one of their pivots, the *RainCat* Algorithm is called to calculate the end time of the pivot, as well as how much water it expects to use. The field pages with running pivots display this watering information, as seen in Figure 31.

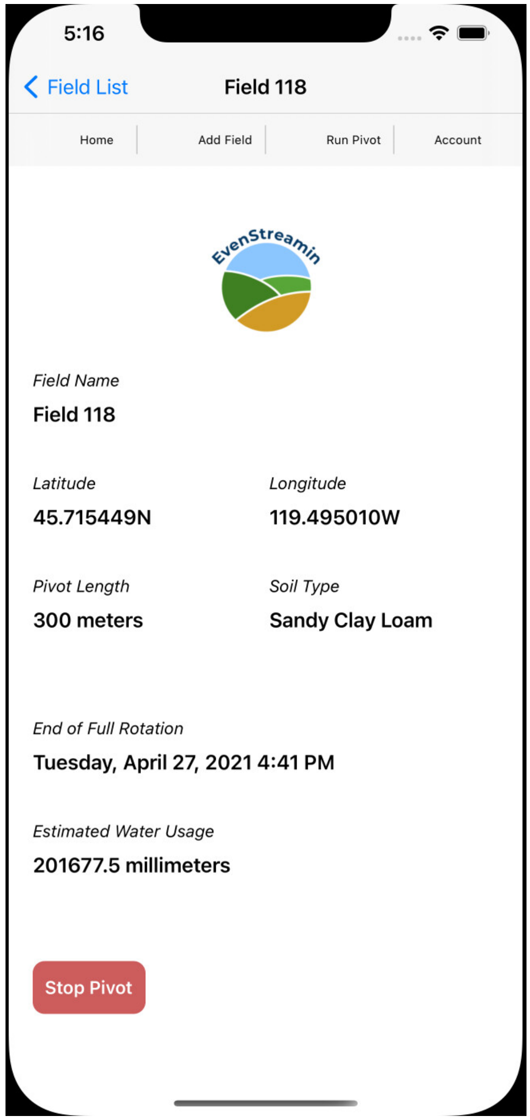

Figure 31: Running Field Page with *RainCat* Watering Information

The application rate is the depth of water that the irrigation system applies during a period of time, and is expressed in units of millimeters per hour. That is why the total applied water in is millimeters

5 Future Work

There are three main projects that could extend my senior capstone:

1. Hardware Control Panel
2. Machine Learning Problem Detection
3. Generalized *RainCat* Model

The first project listed is to build the actual control panel of a center pivot. At the moment ArcGIS geolocation relies on the user too much. It is assumed that they will correctly hold their phone right next to the center pivot. But in software development it isn't safe to assume that the user will follow directions. Thus, building the actual control panel of the center pivot could result in more exact coordinates. Rather than using ArcGIS, the software would now interact with the control panel which would have a GPS within it.

The second project would be to utilize machine learning to monitor different aspects of a field. Right now *EvenStreamin* helps to remotely monitor water usage. However, water usage is not the only thing that is important when growing crops. Being able to monitor crop growth, or catch early stages of pests and diseases would be beneficial to farmers. Since the application is already connected to ArcGIS, future developers could easily utilize the maps and machine learning capabilities of ArcGIS. Valley Irrigation's mobile application was the inspiration for this future work, which can be seen in Figure 32

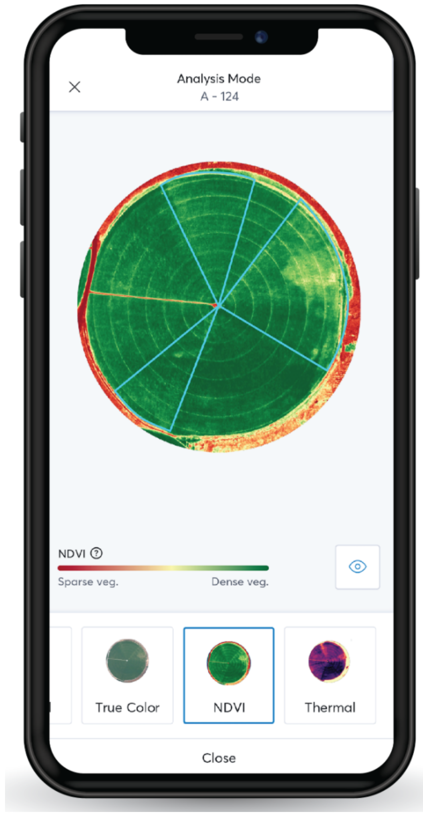

Figure 32: Valley Growth Analysis [9]

Finally is the *RainCat* model. Right now the model is too strict - the center pivot, sprinklers, and soil type can only have a handful of variations. To make the app work in more than just the perfect case, there needs to be a lot of work done on generalizing the model. This means adding different center pivot and sprinkler specs, and allowing for more specific soil types. One big addition that needs to happen is to allow for crops. This would be a large undertaking as you have to model crop growth as well.

Glossary

TERM	DEFINITION
ArcGIS	Geospatial software to view, edit, and analyze geographic data. The ArcGIS software is used to get the coordinates of each field.
ArcGIS Online	Web and cloud based platform that allows ArcGIS users to share their maps and data without having to install an ArcGIS desktop application.
Average Application Rate	The rate of water application over a wetted area [24].
Azure	Cloud computing platform owned by Microsoft.
Center Pivot Irrigation	Irrigates fields in a circular pattern around a central pivot point, creating a circular layout [5].
Central Pivot Point	Stationary structure connected to a water supply, that the main water pipe rotates around.
Control Panel	A piece of hardware attached to the pivot point that gives commands to the center pivot machine. They control starting, stopping, changing directions, running wet versus dry, and much more.
Cross-platform mobile development	Creation of software that is compatible with multiple mobile operating systems.
Database	“Organized collection of structured information” which is controlled by a database management system (DBMS) [22].
Design patterns	Structure applications to make them more maintainable and reusable [20].

Drive Units	Part of the center pivot that touches the ground, and have specific hardware that allows for movement. It consists of a basebeam, drive train, wheels, and various structural supports [11].
Drop Tube Sprinkler	Sprinklers that hang below the main water pipe.
EvenStreamin	A cross-platform mobile application for farmers to make accounts and manage the watering of their fields remotely.
Integrated Development Environment (IDE)	Software application that provides an environment for software development. Has a source code editor, build tools, and a debugger.
Infiltration Rate	The rate at which water can enter the soil. The infiltration rate is not the same for all parts of the field nor is it even the same at one point all of the time [17].
Instantaneous Application Rate	The peak intensity of water application at a specific point. Due to the circular characteristics of a center pivot, the instantaneous application rate increases the further from the central pivot point the sprinkler is [6].
LRDU	Last Regular Drive Unit is the last drive unit on a pivot.
Model-View-ViewModel (MVVM)	Design pattern that separates the business logic from the graphical user interface (GUI) logic.
Precision Agriculture	Technology-based management system that collects and organizes data to optimize profits, sustainability, and protection of the environment [7].
RainCat	The mathematical model of the center pivot sprinkler system.
Relational Database	Database that is organized as sets of tables with rows and columns [22].

Software development kits (SDK)	An SDK contains a range of tools such as libraries, application programming interfaces (API), programming tools, and documentation.
Span	Consist of the main water pipeline, sprinklers, and a supporting structure of trussing that holds the weight between towers [11]. Spans can come in different sizes so that a center pivot can fit any field size.
SQLite	Library that provides a relational database management system.
Workloads	Used to modify Visual Studio and contain tools needed for the specific programming languages or platforms being used [19].
Xamarin	Open-source framework for cross-platform mobile development [19]. Xamarin is built on top of a .NET framework - which handles memory allocation and garbage collection [25].
Xamarin.Forms	Open-source User Interface (UI) framework on top of Xamarin.

Table 2: Table of Terms and Definitions

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6 Appendices

6.1 *Appendix 1 - Android and iOS User Interface*

The iOS interface is on an iPhone 12 Pro Max iOS 14.4 simulator, while the Android interface is on a Pixel 2 Pie 9.0 API 28 simulator.

Account Deletion Alert

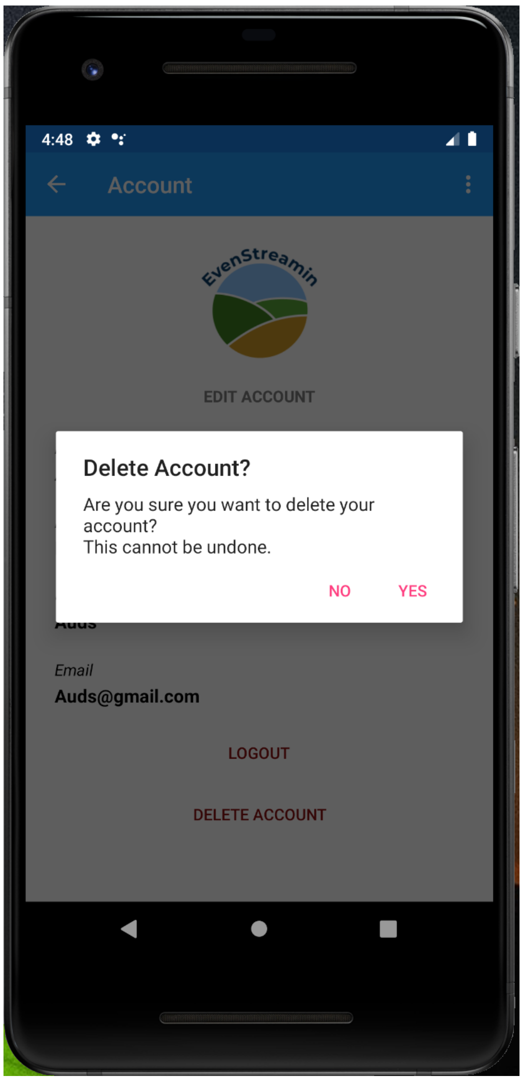

Figure 33: Android

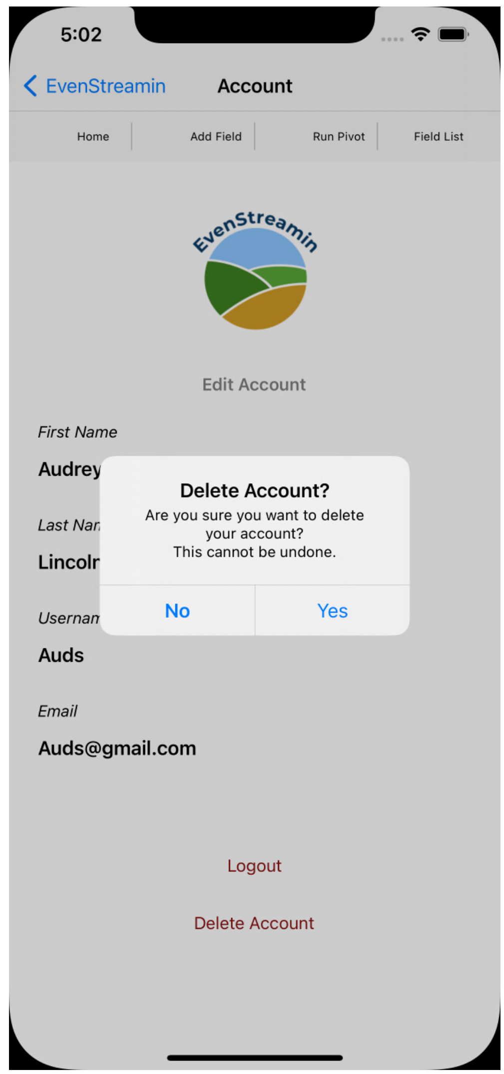

Figure 34: iOS

Account Edit Popup

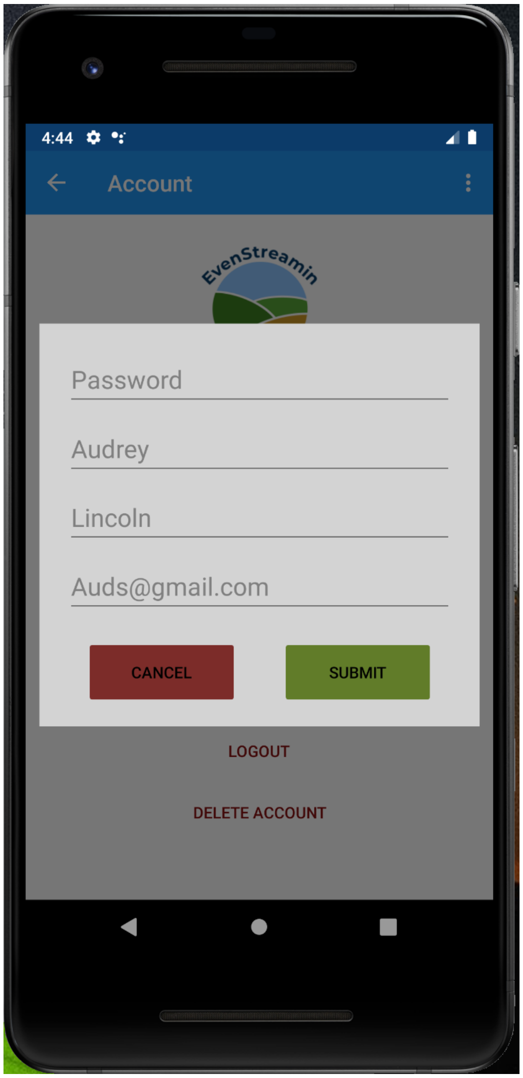

Figure 35: Android

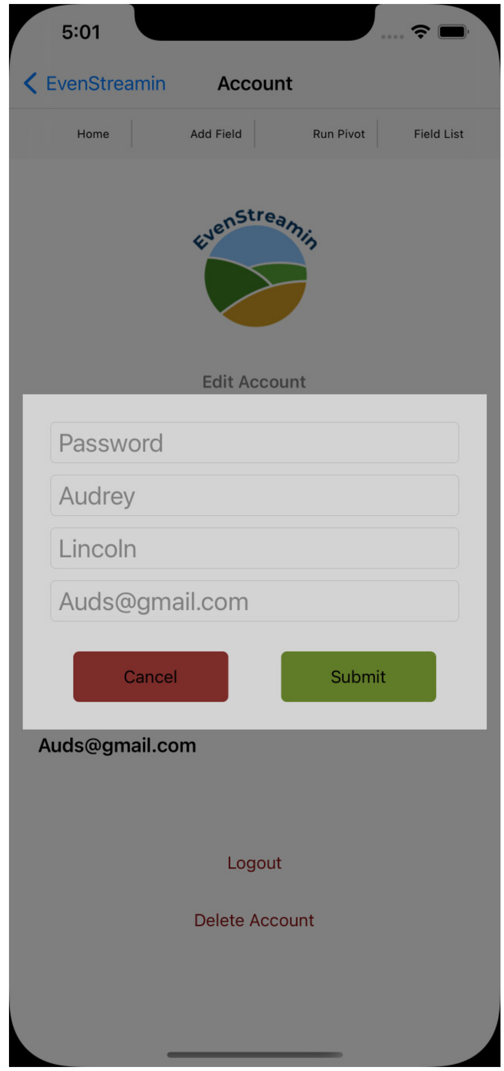

Figure 36: iOS

Account Edit Alert

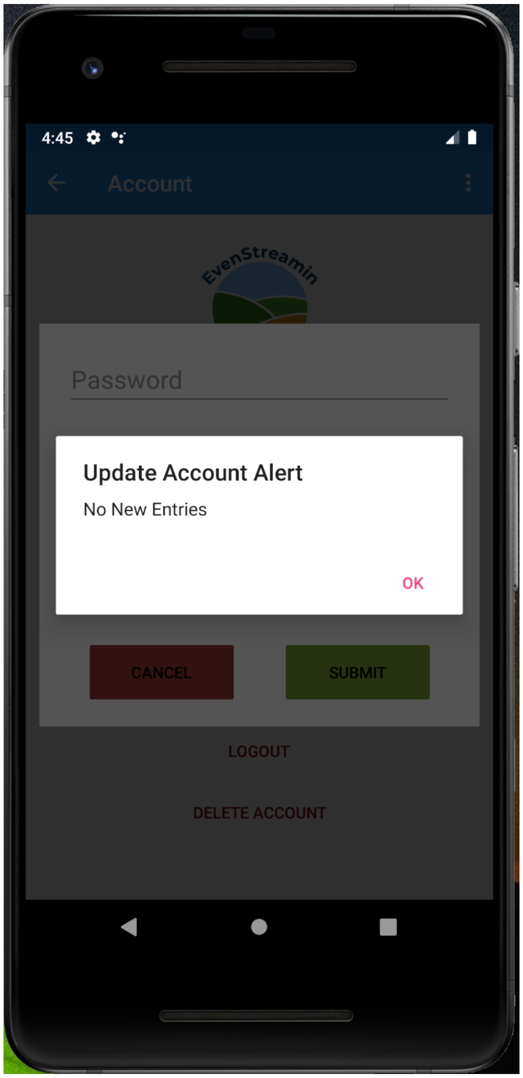

Figure 37: Android

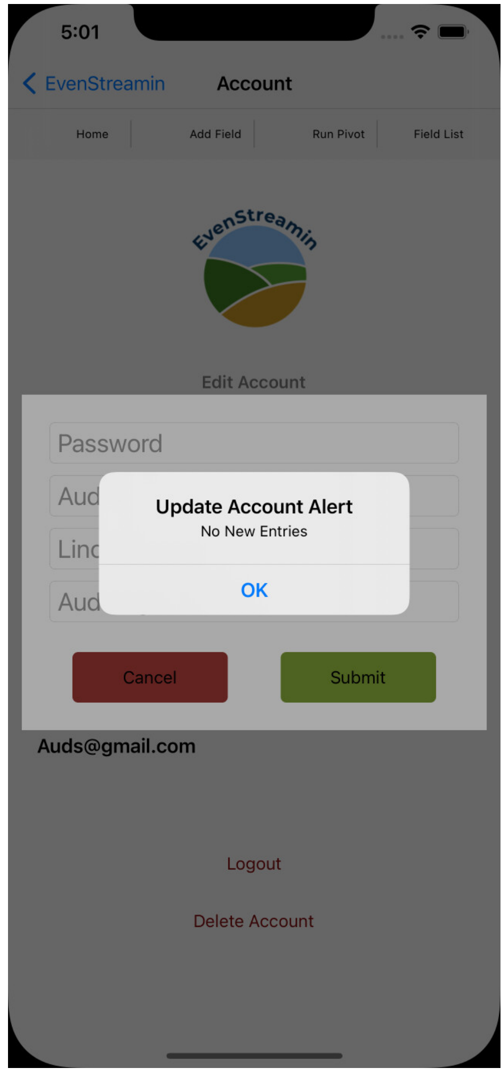

Figure 38: iOS

Account Logout Alert

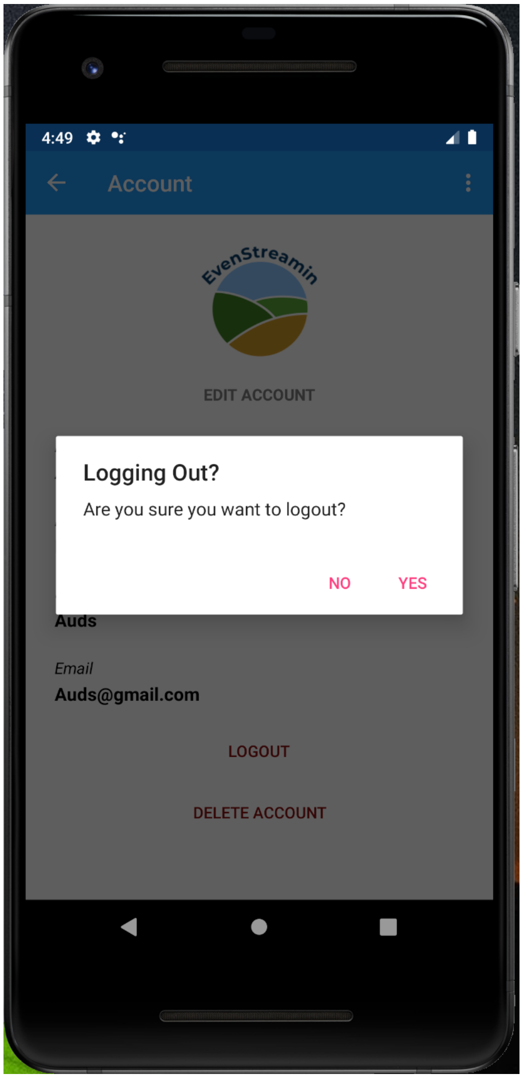

Figure 39: Android

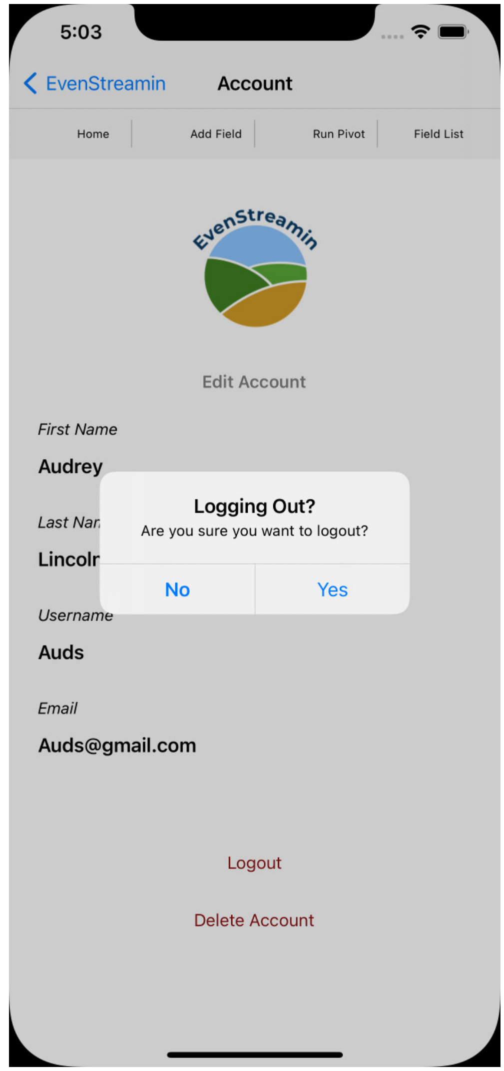

Figure 40: iOS

Account

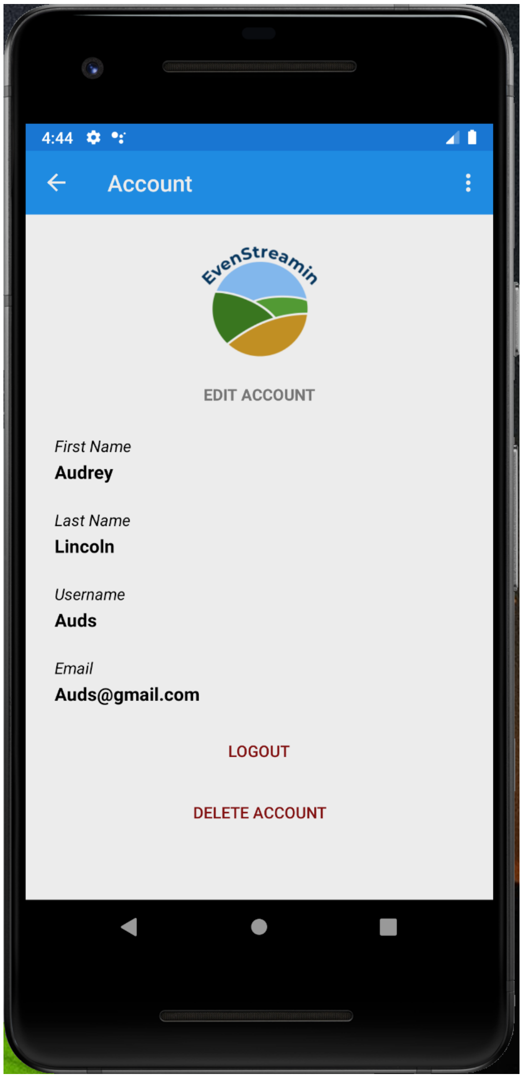

Figure 41: Android

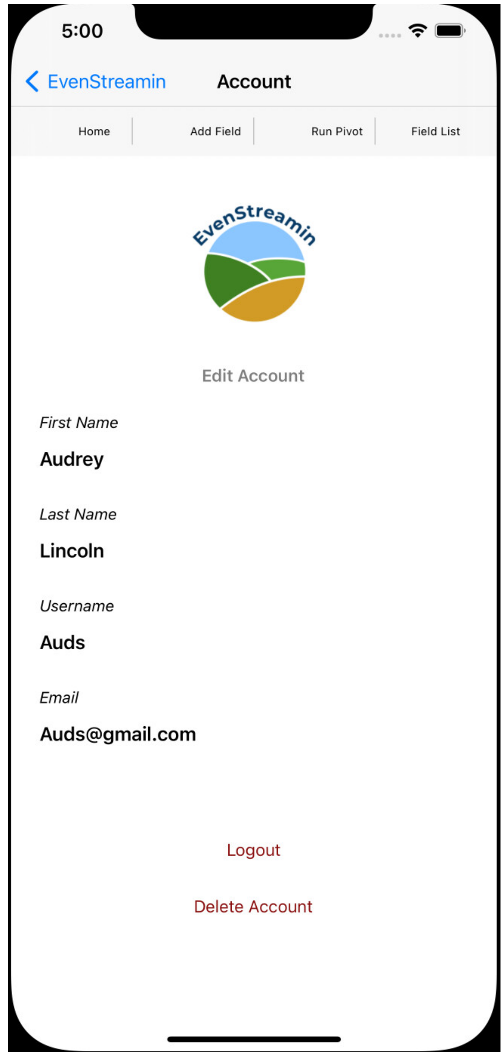

Figure 42: iOS

Add Field Fill Out Alert

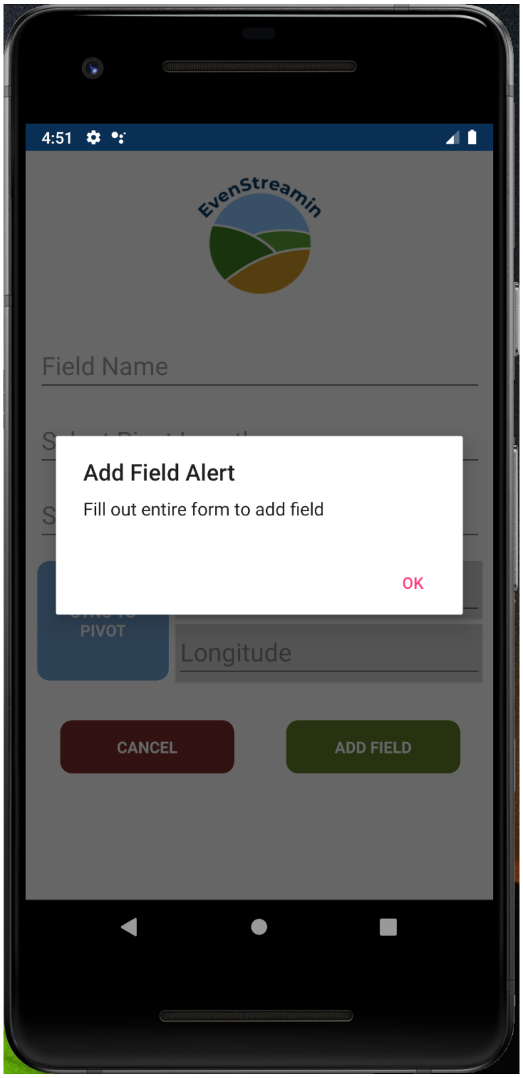

Figure 43: Android

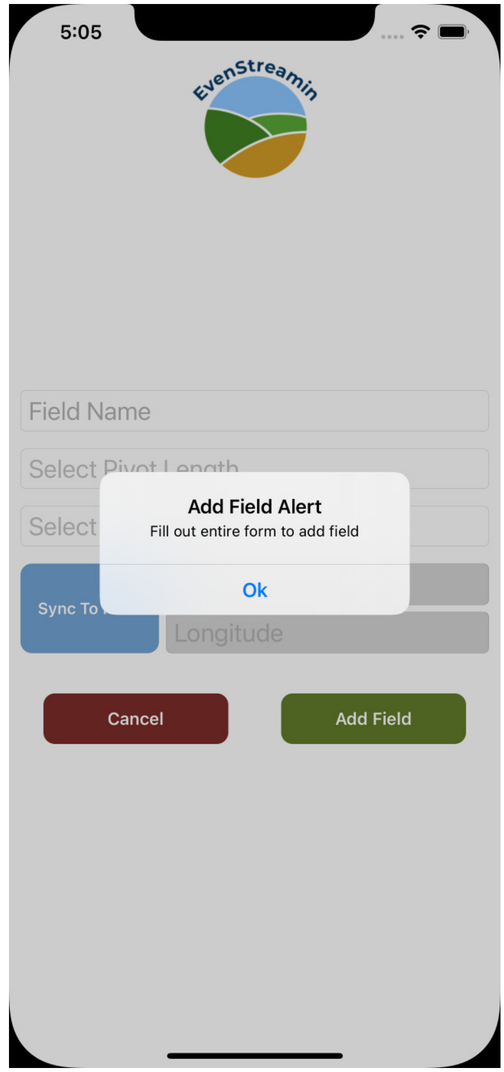

Figure 44: iOS

Add Field Location Alert

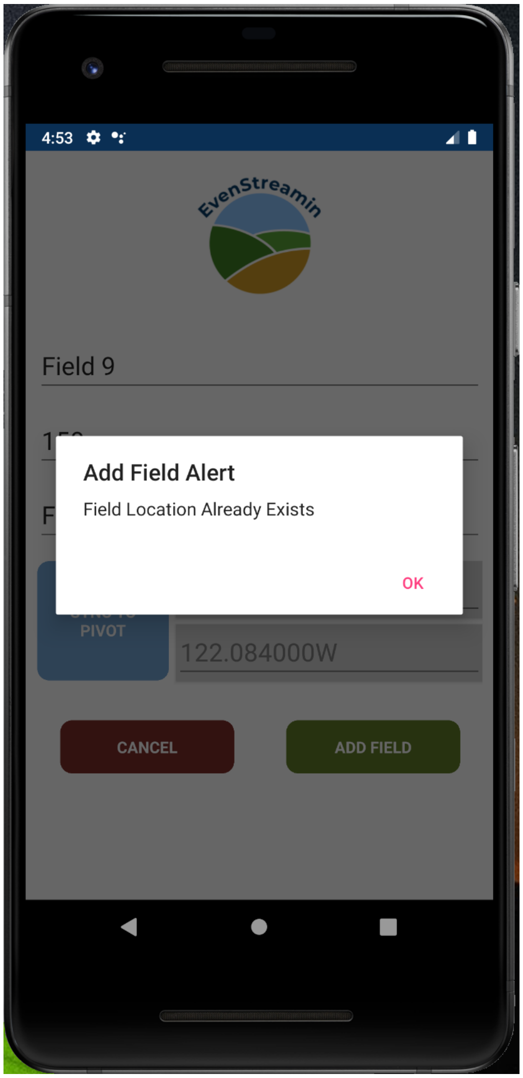

Figure 45: Android

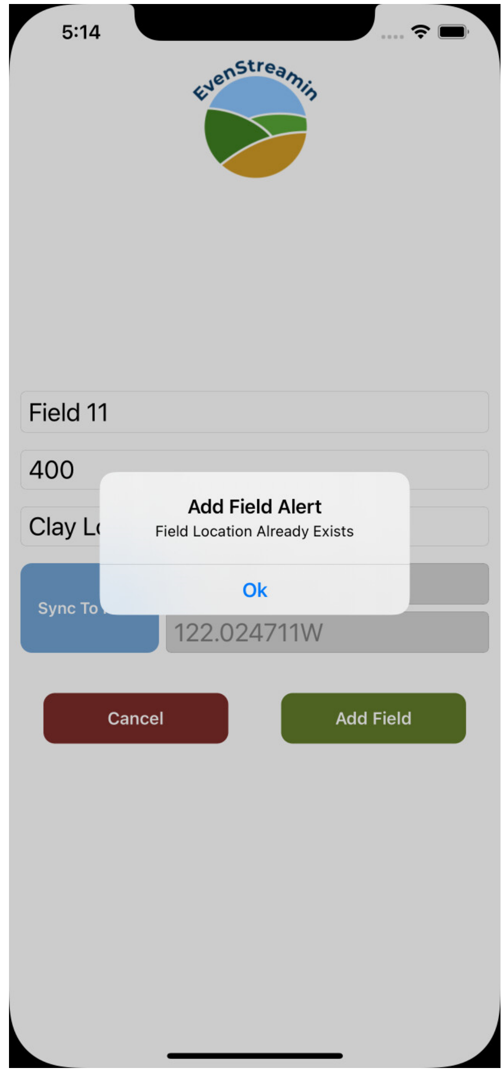

Figure 46: iOS

Add Field Pivot Selection

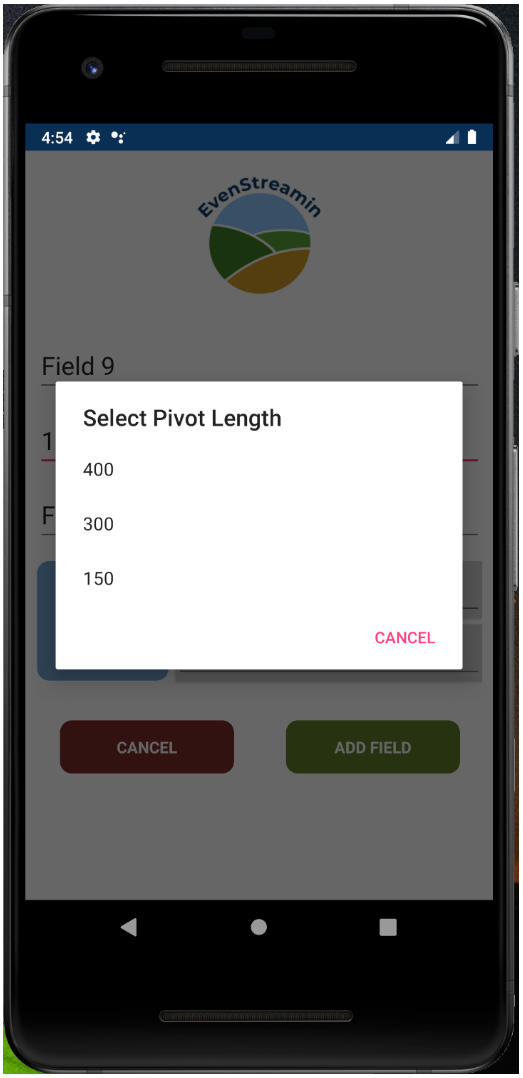

Figure 47: Android

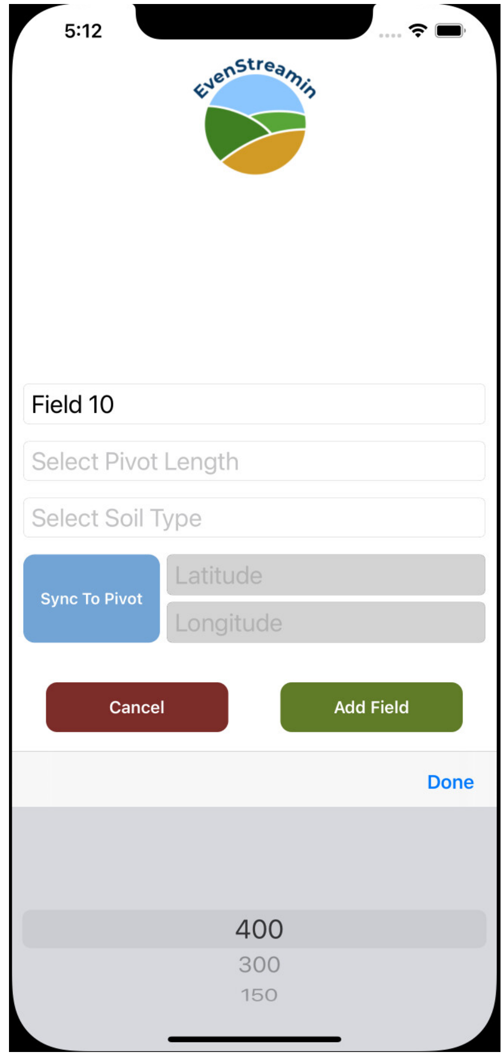

Figure 48: iOS

Add Field Soil Selection

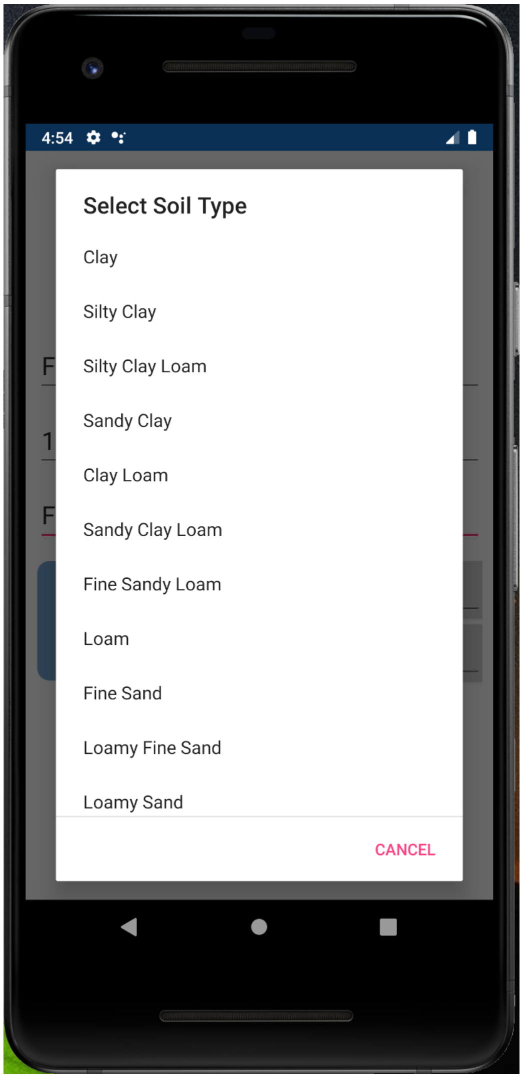

Figure 49: Android

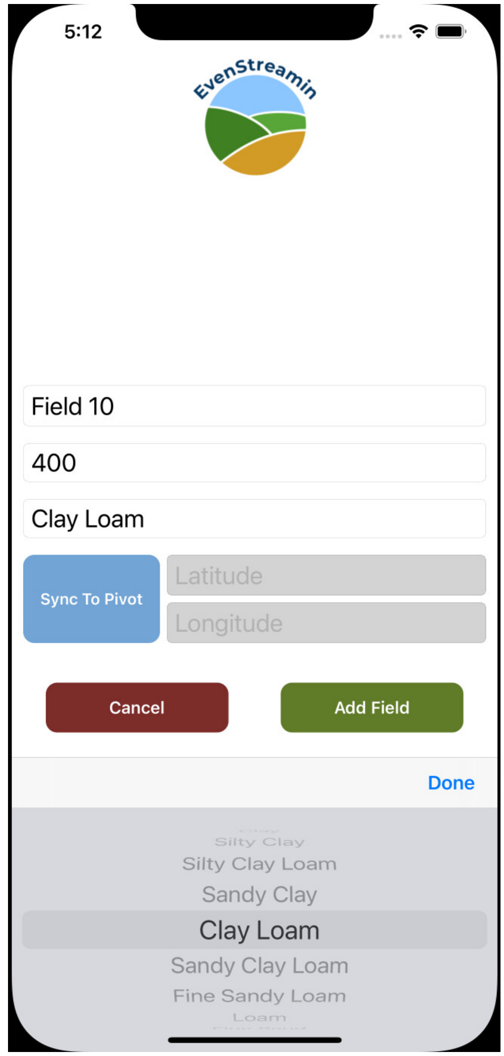

Figure 50: iOS

Add Field Sync To Pivot

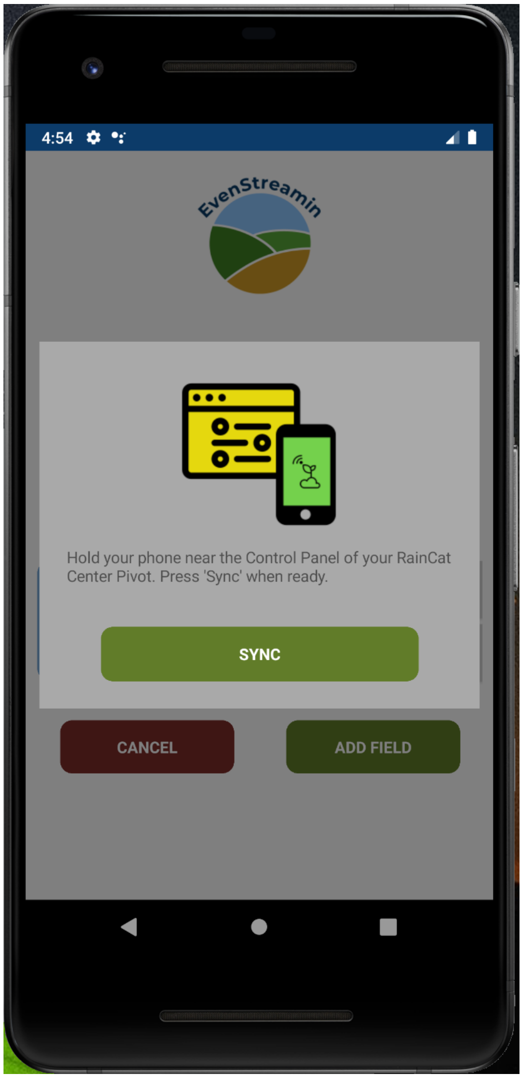

Figure 51: Android

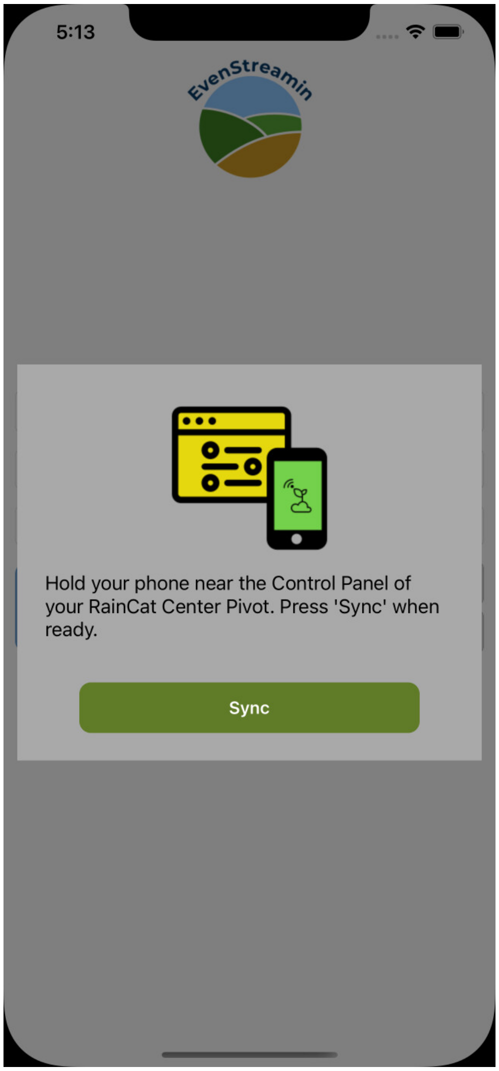

Figure 52: iOS

Add Field

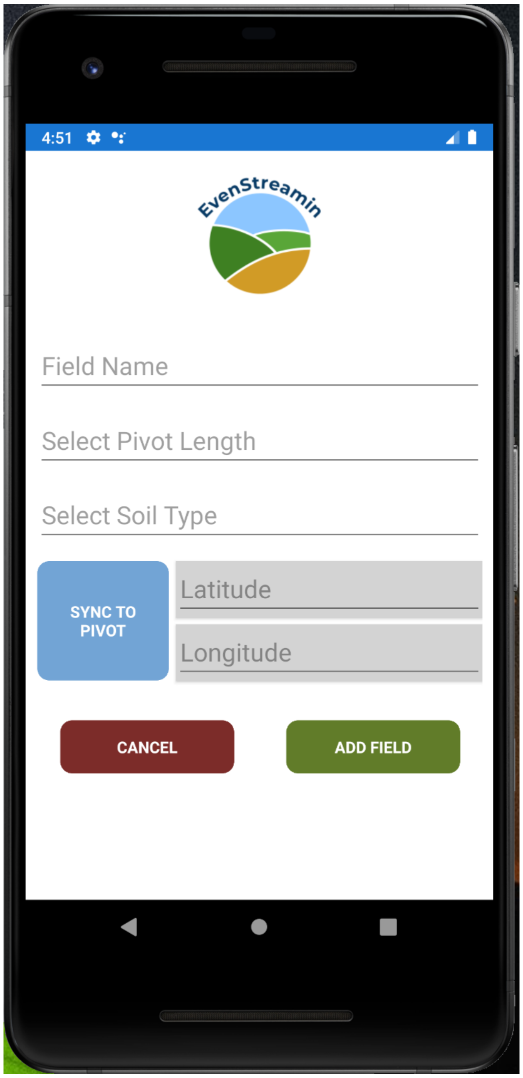

Figure 53: Android

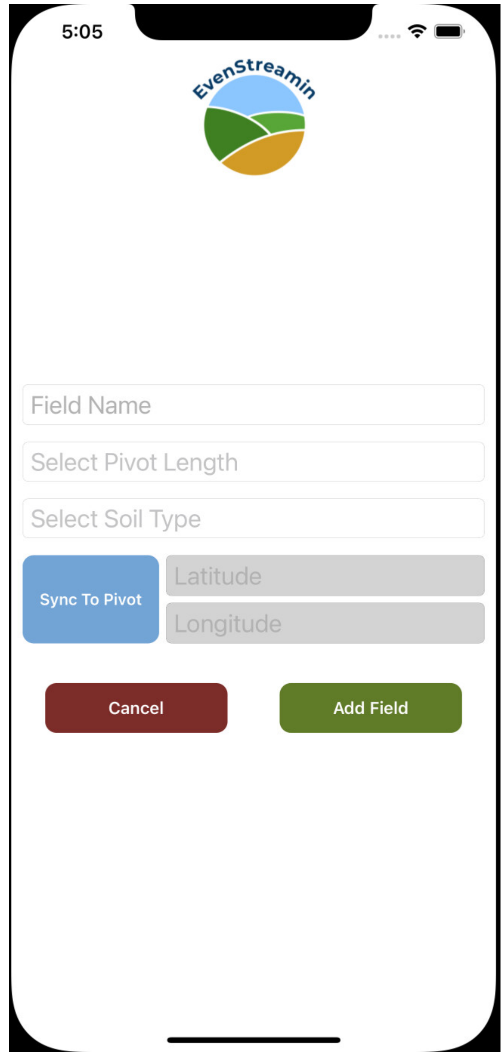

Figure 54: iOS

Field List Delete

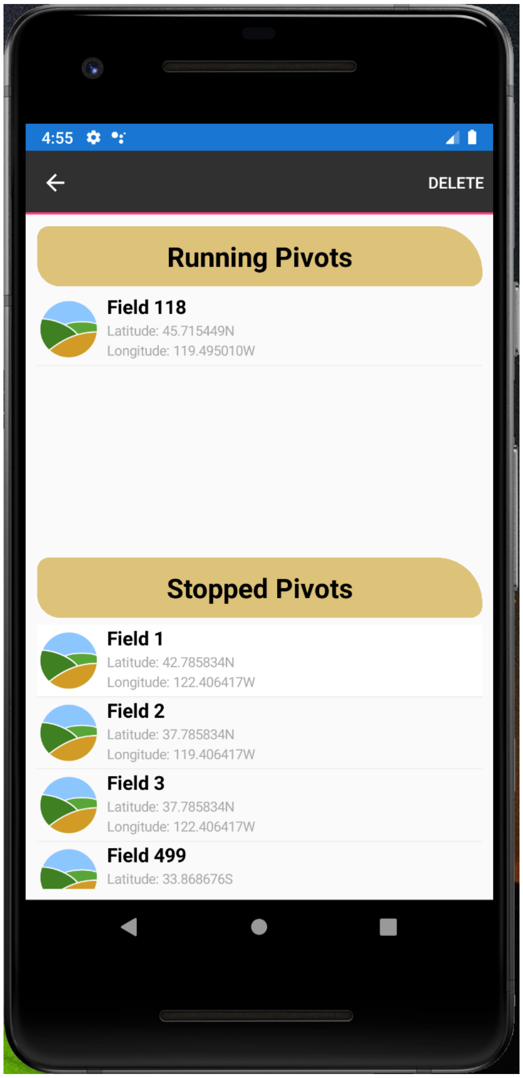

Figure 55: Android

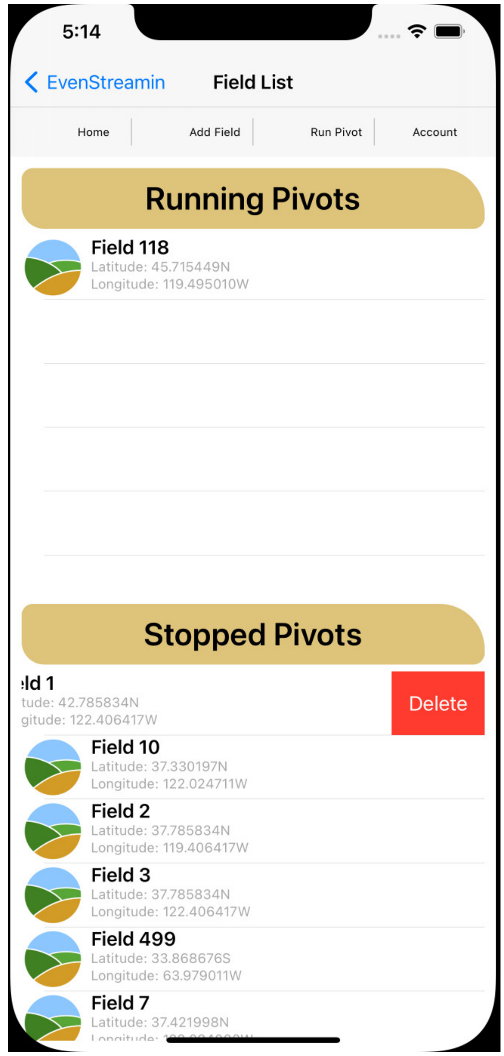

Figure 56: iOS

Field List Delete Alert

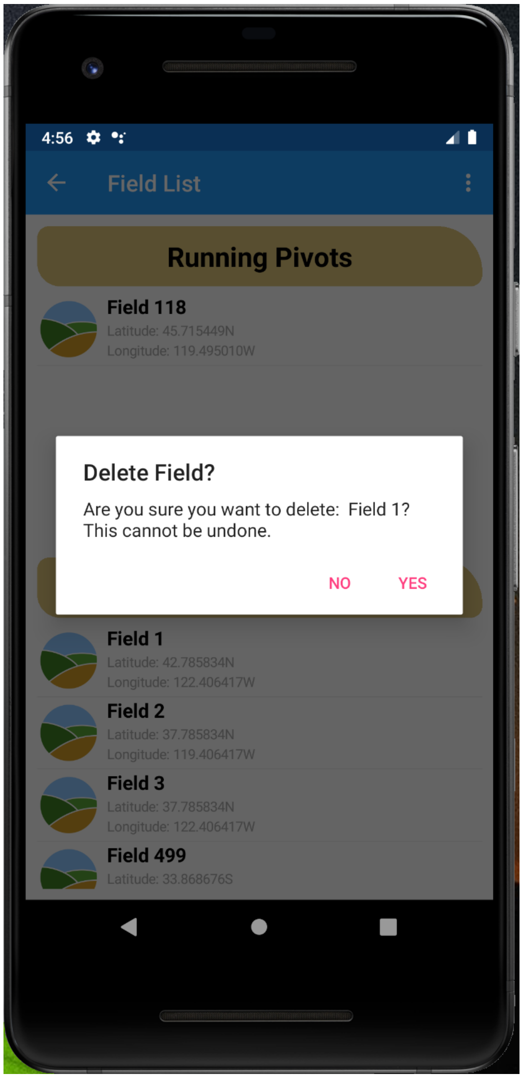

Figure 57: Android

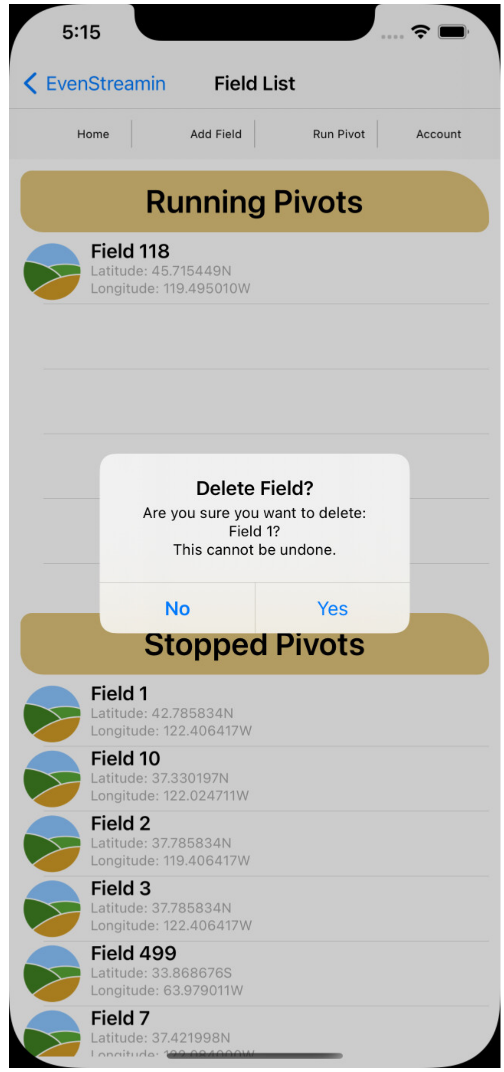

Figure 58: iOS

Field List

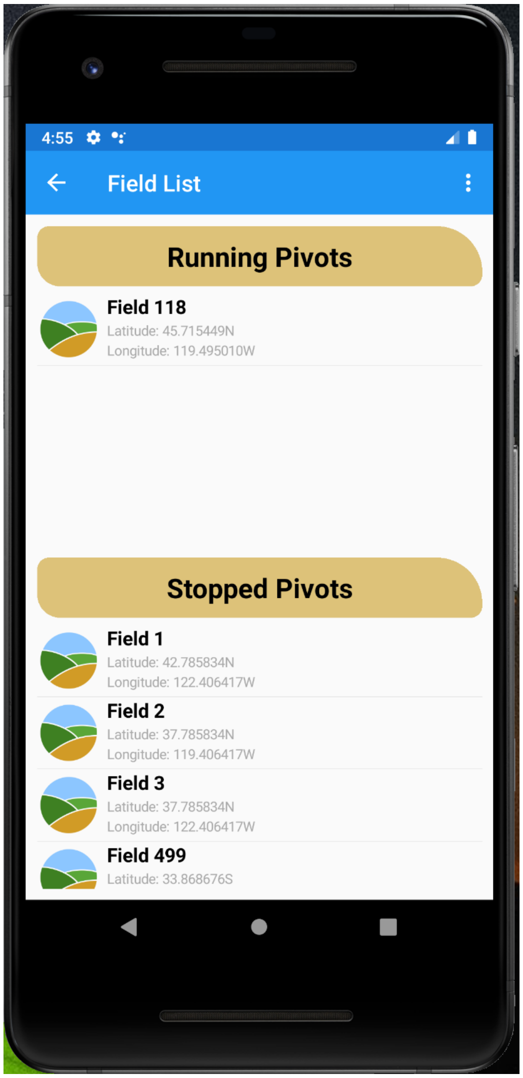

Figure 59: Android

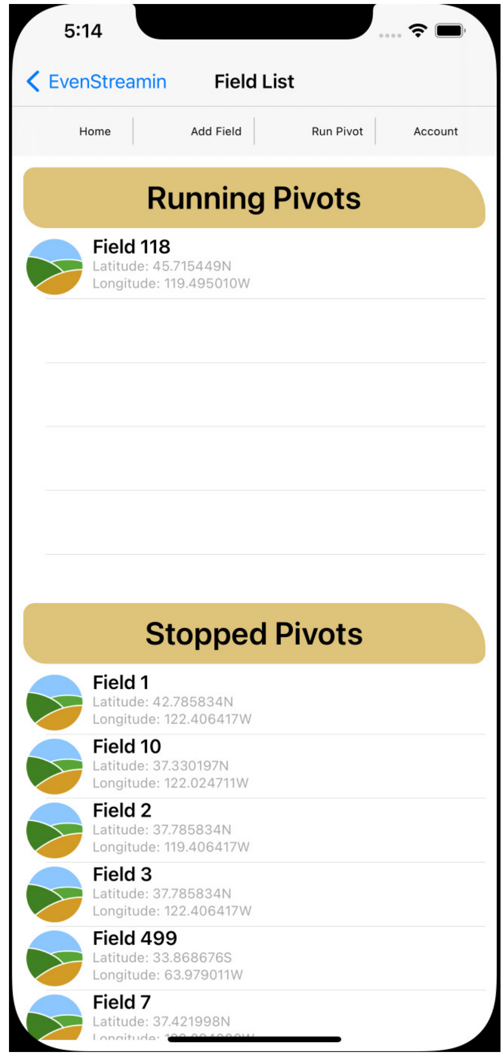

Figure 60: iOS

Home

Figure 61: Android

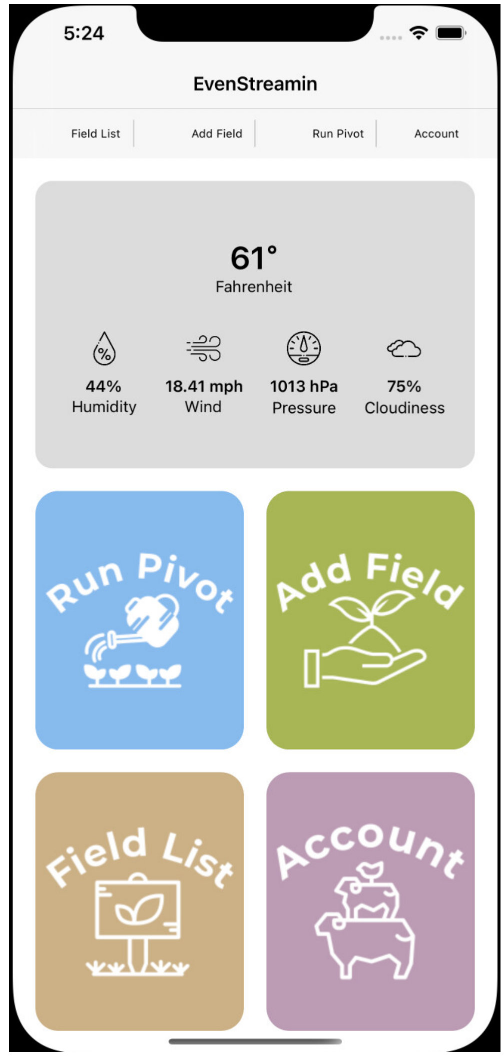

Figure 62: iOS

Login Fill Out Alert

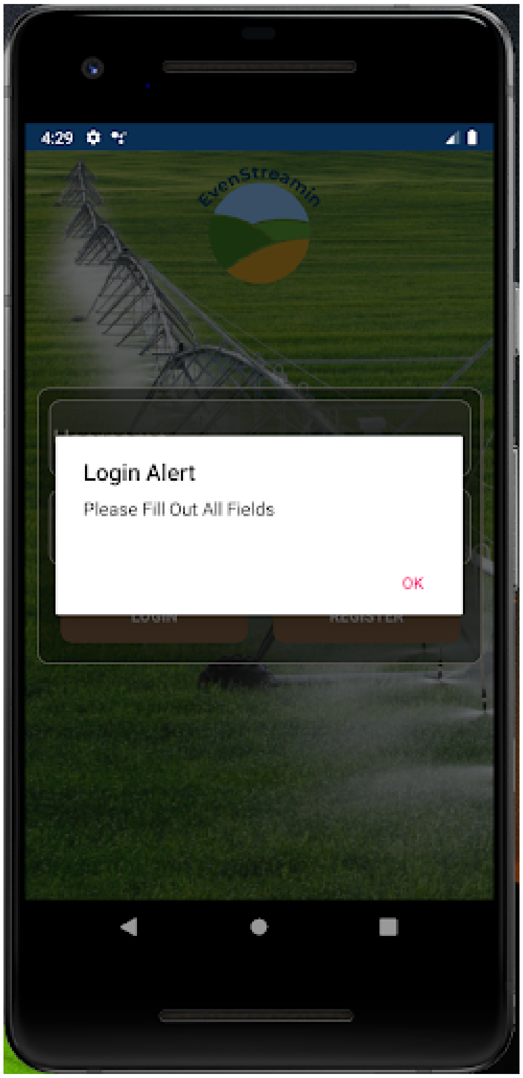

Figure 63: Android

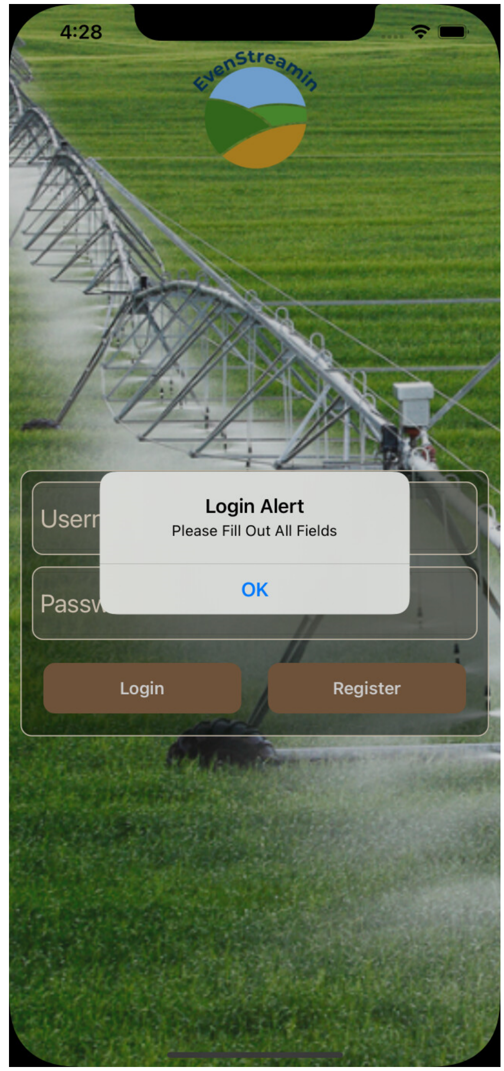

Figure 64: iOS

Login

Figure 65: Android

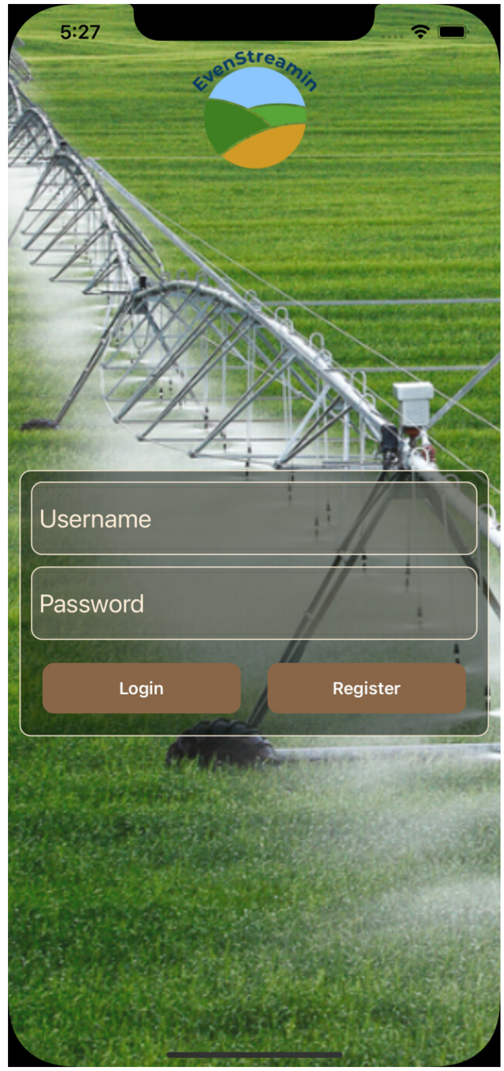

Figure 66: iOS

Registration User Exists Alert

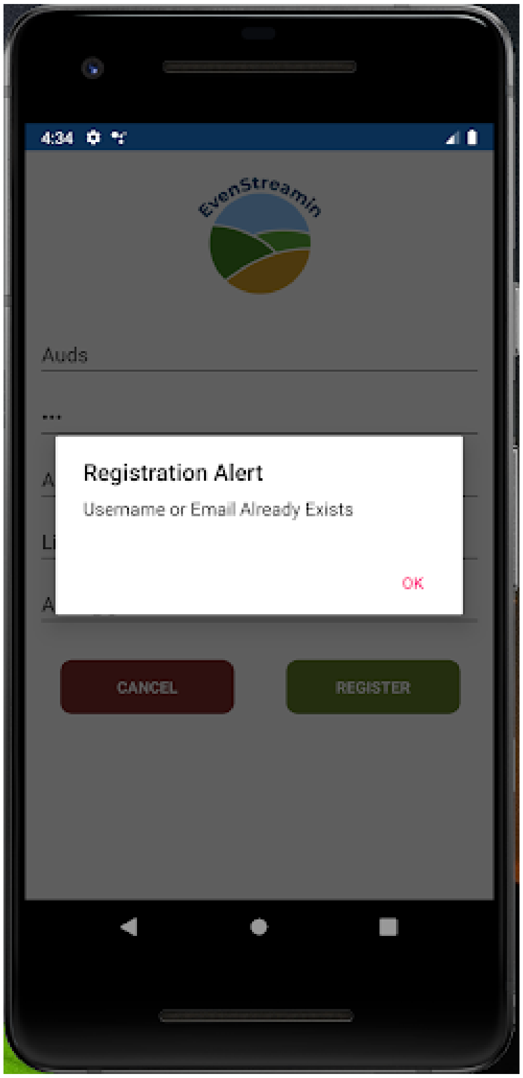

Figure 67: Android

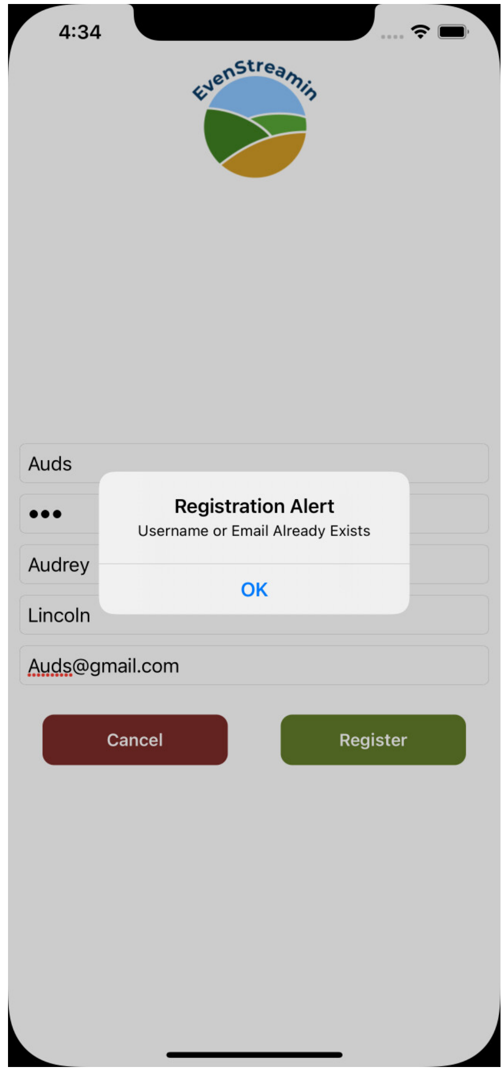

Figure 68: iOS

Registration Fill Out Alert

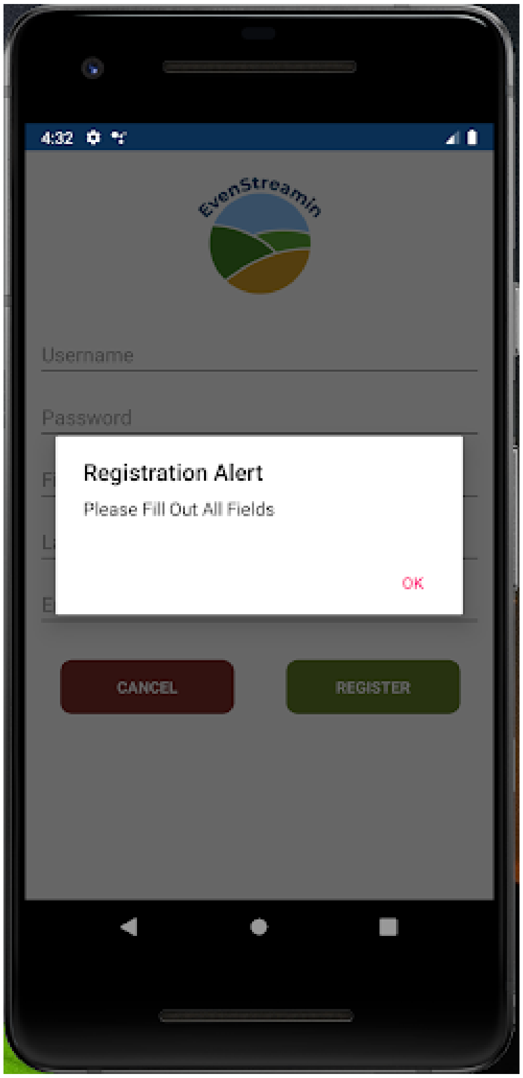

Figure 69: Android

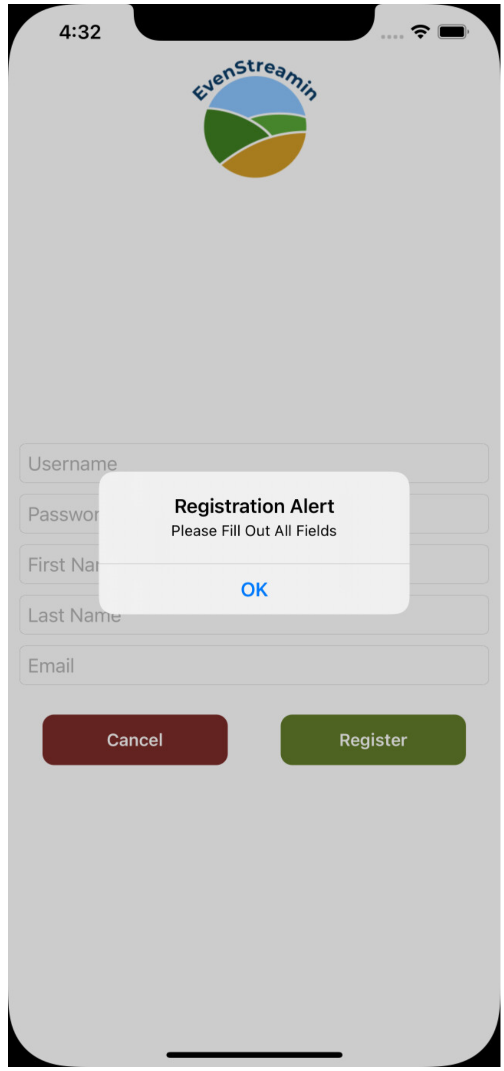

Figure 70: iOS

Registration

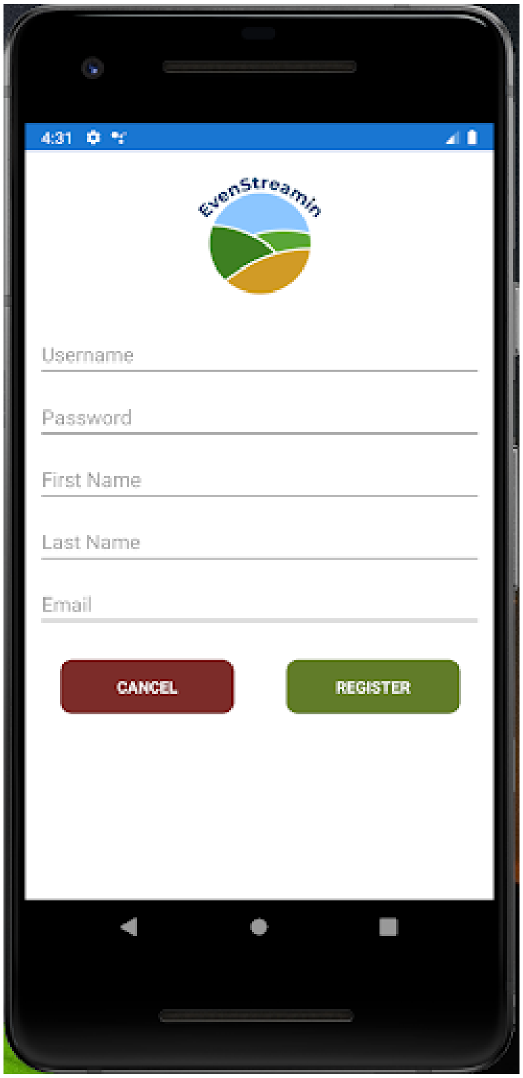

Figure 71: Android

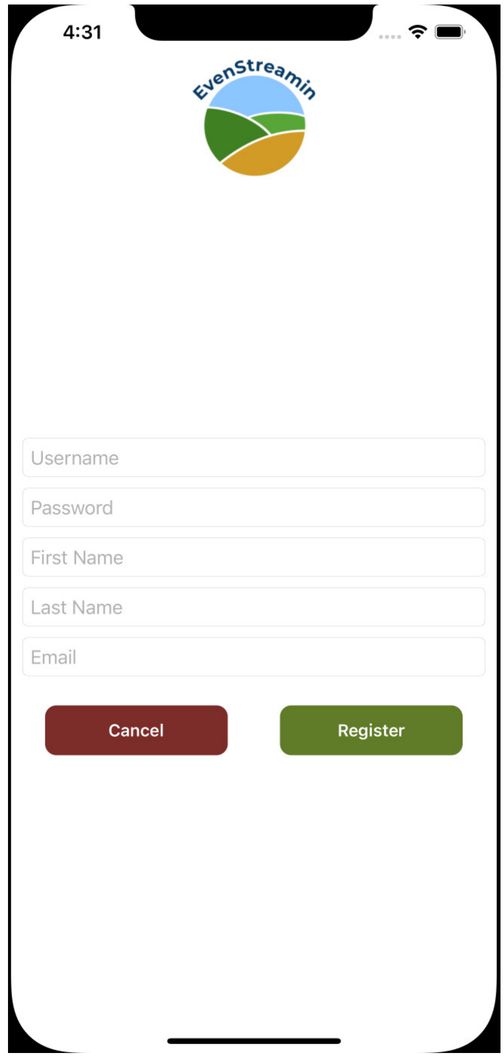

Figure 72: iOS

Running Field

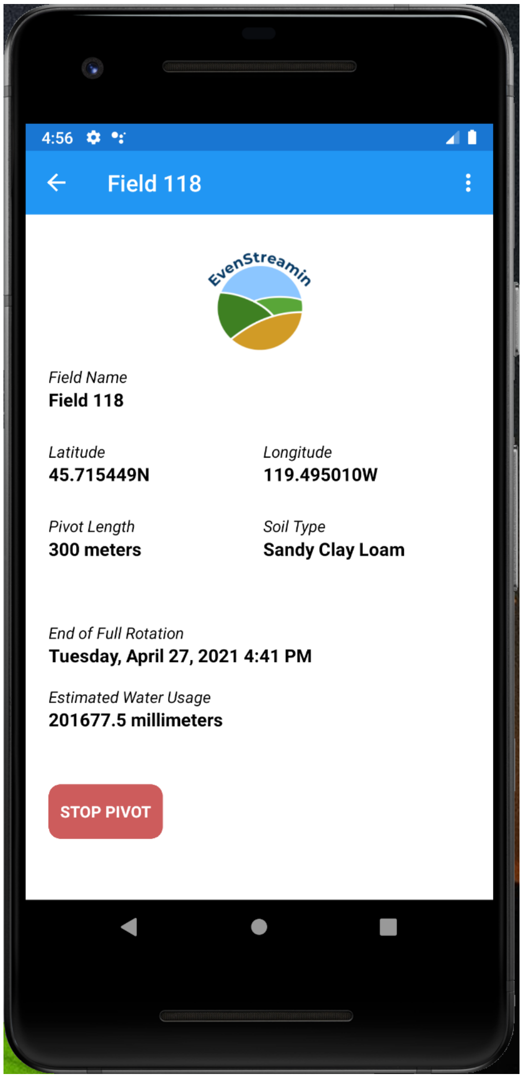

Figure 73: Android

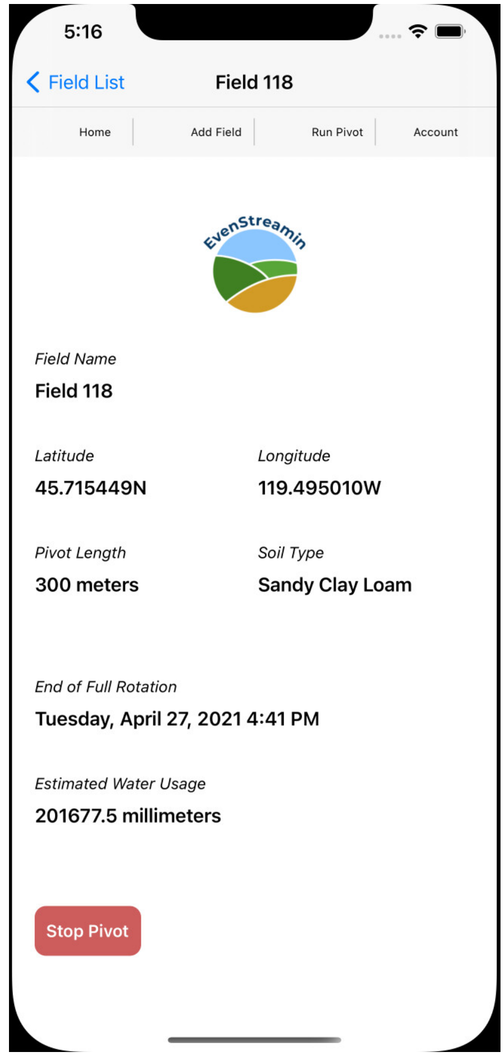

Figure 74: iOS

Run Pivot Alert

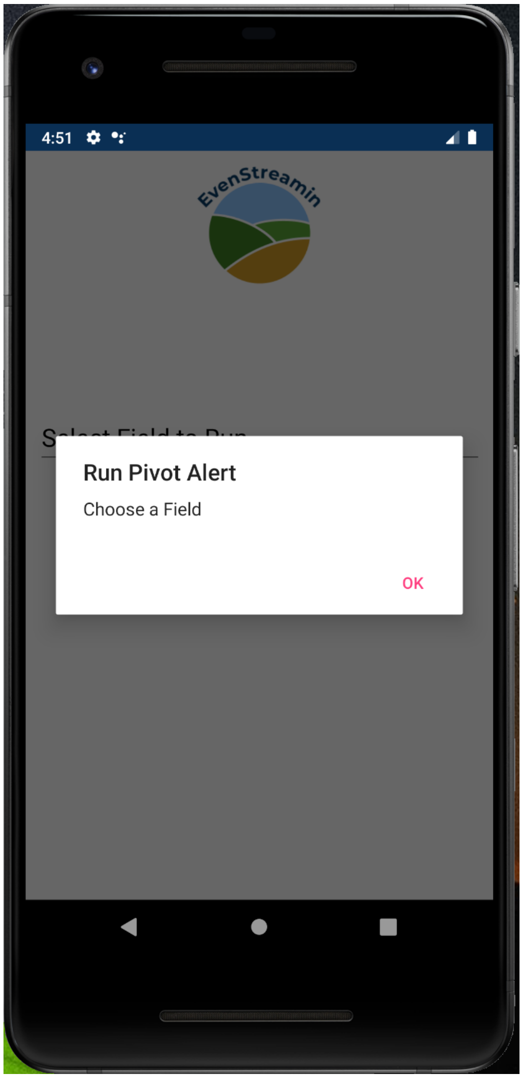

Figure 75: Android

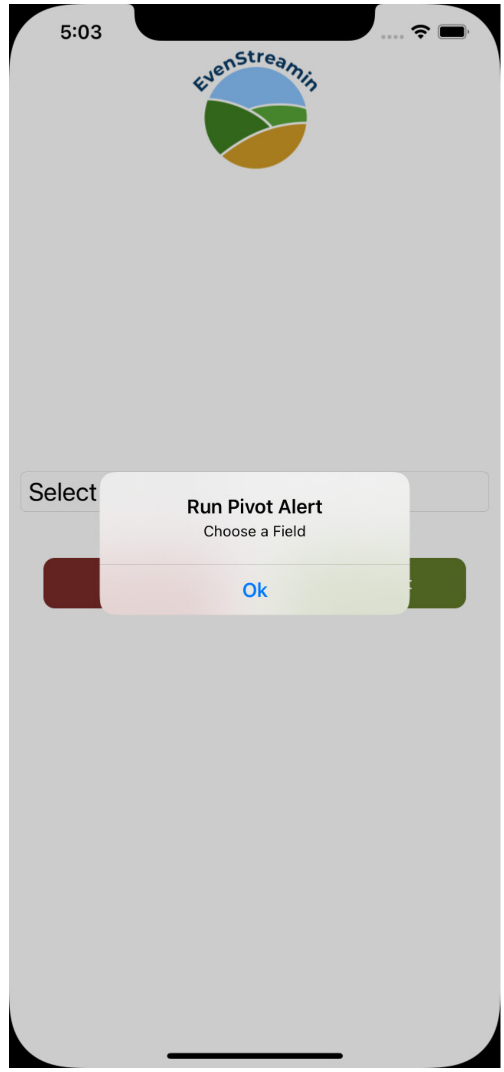

Figure 76: iOS

Run Pivot Selection

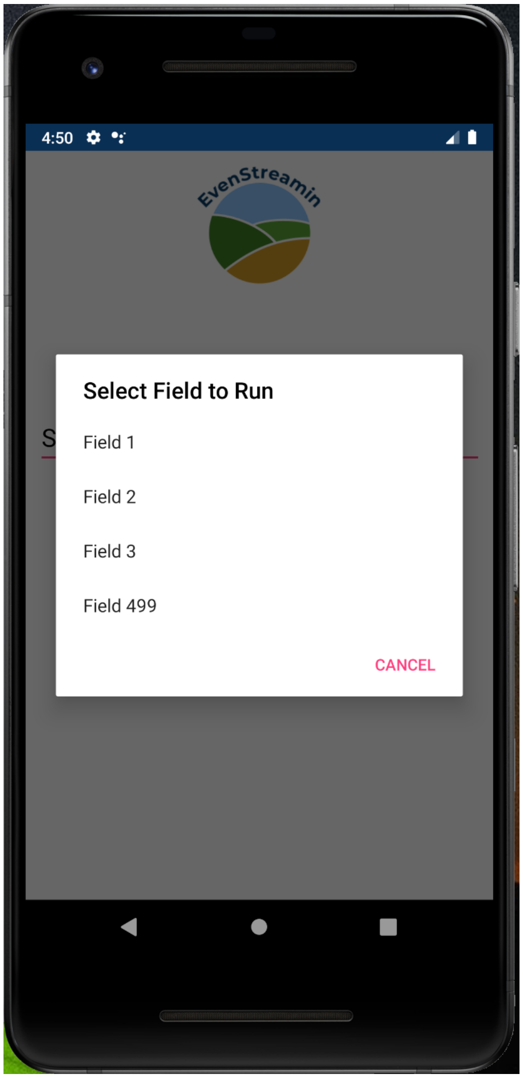

Figure 77: Android

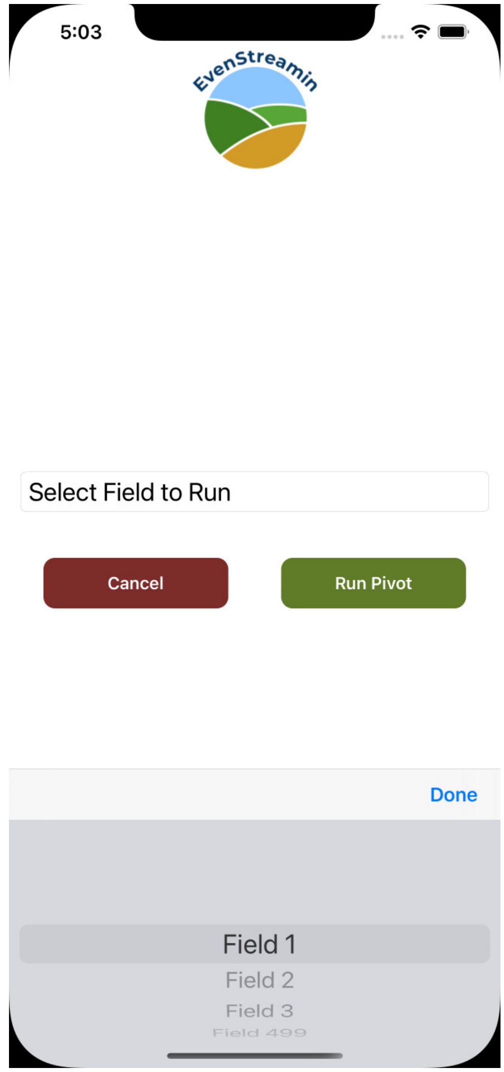

Figure 78: iOS

Run Pivot

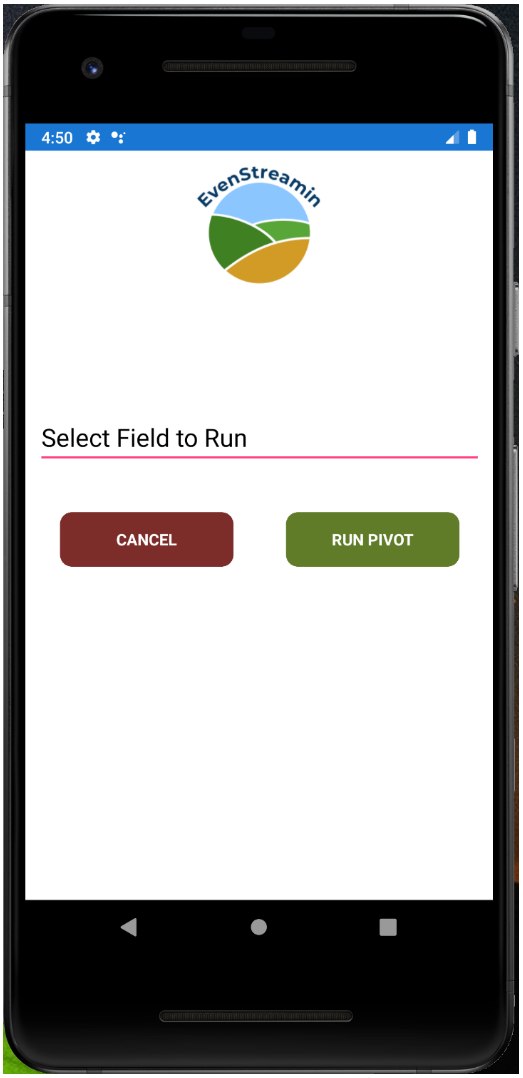

Figure 79: Android

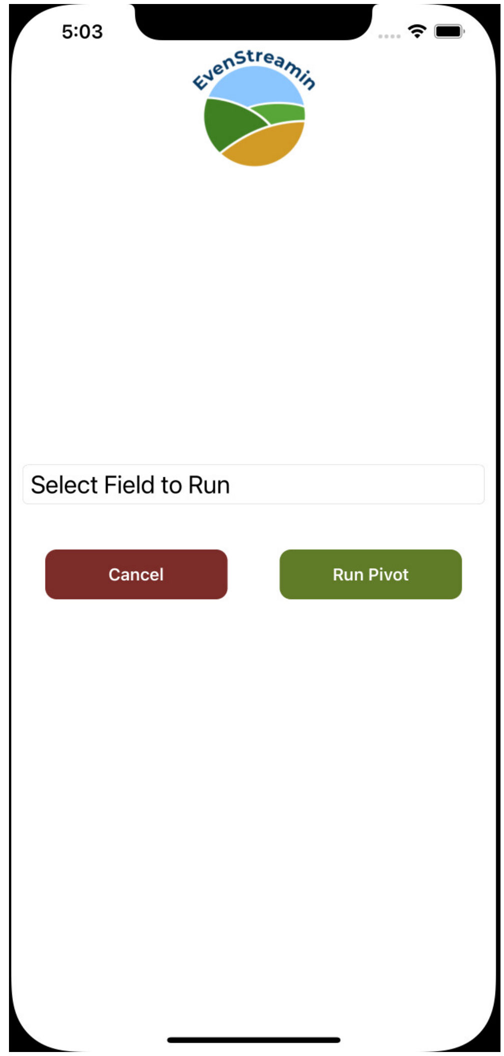

Figure 80: iOS

Stopped Field Edit

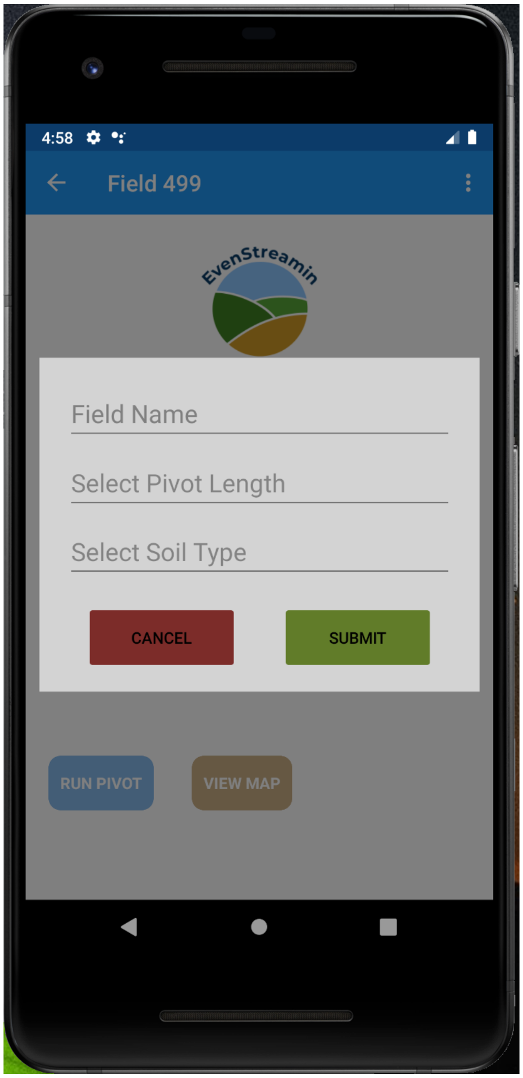

Figure 81: Android

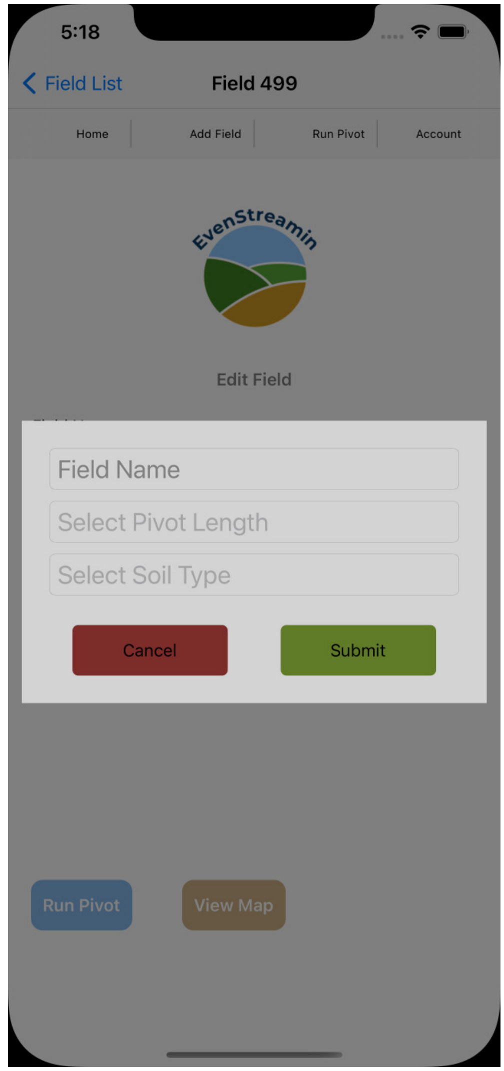

Figure 82: iOS

Stopped Field Edit Alert

Figure 83: Android

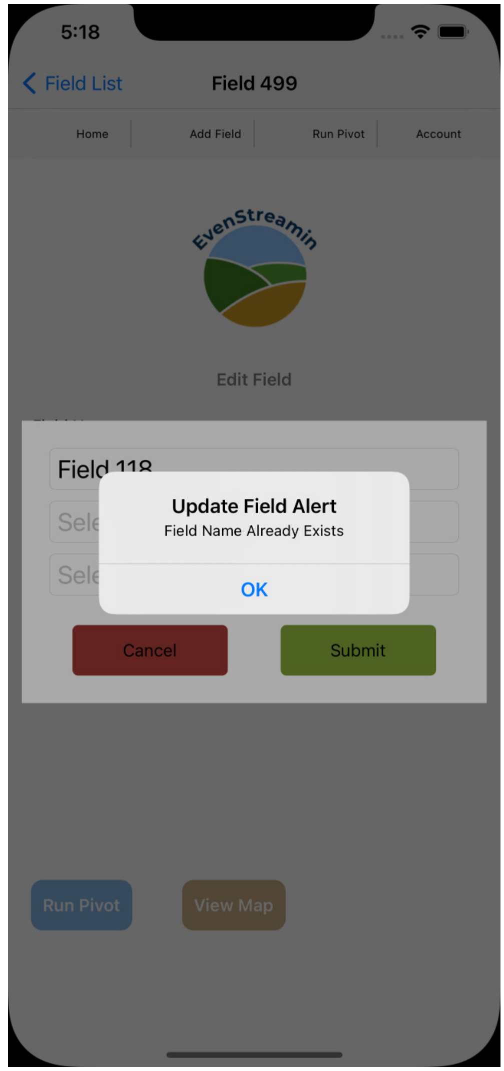

Figure 84: iOS

Stopped Field Map View

Figure 85: Android

Figure 86: iOS

Stopped Field

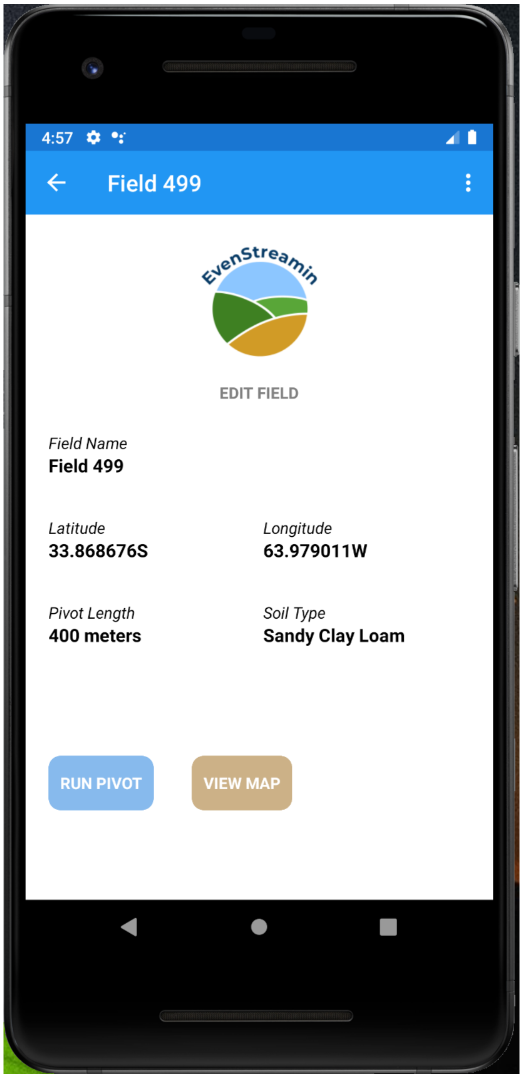

Figure 87: Android

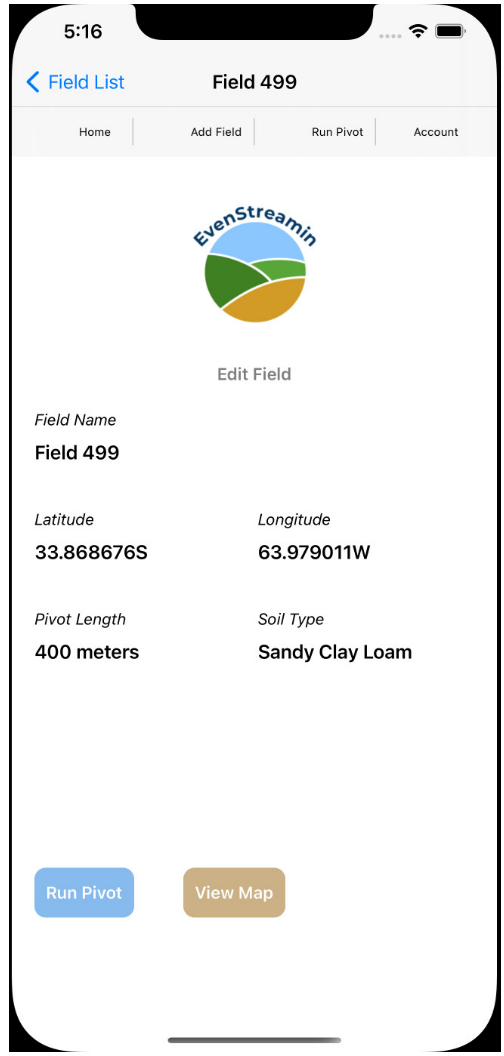

Figure 88: iOS

Toolbar

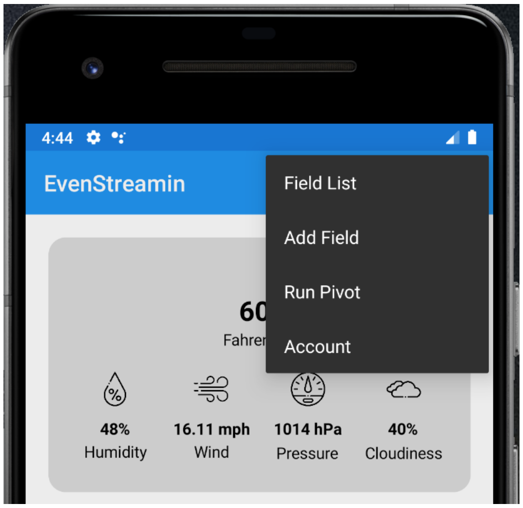

Figure 89: Android

Figure 90: iOS

6.2 *Appendix 2 - CS Fall Sprint Notes*

6.2.1 *Fall Sprint 1*

Localization

- Hardware Localization
  - Add GPS Tracking with the Google Maps API to Your Raspberry Pi Project
  - How to read GPS data with Python on a Raspberry Pi
  - How to Use a GPS Receiver With Raspberry Pi 4
- Software/API Localization
  - Qt Positioning API
  - Xamarin Forms Geolocation

Platform Research

- Cross-Platform Mobile Development
- 11 Popular Cross-Platform Tools for App Development in 2020
- 7 Popular Cross-Platform App Development Tools That Will Rule in 2020

Xamarin Research

- Xamarin documentation
- Xamarin.Forms Documentation
- How to Run a Xamarin.Forms iOS App from Windows (Using Visual Studio 2019)
- eXtensible Application Markup Language (XAML)
- Microsoft Docs on Nuget

ArcGIS

- What is ArcGIS Online
- Get started with ArcGIS Online
- ArcGIS for Student

ArcGIS and Xamarin

- ArcGIS Runtime SDK for .NET
- ArcGIS for Developers

- ArcGIS Runtime SDK for .NET: Building Xamarin Apps

Database Research

- Store Data in a Local SQLite.NET Database
- Xamarin.Forms Local Databases
- Working With SQLite In Xamarin.Forms Application

6.2.2 *Fall Sprint 2*

Xamarin Hello World

- Getting Started With Xamarin Using Visual Studio 2019 for Android and iOS
- How to Build a Xamarin Forms App

App Development

- Xamarin.Forms ListView
- Xamarin.Forms CollectionView Layout
- Xamarin: Open page from string
- Xamarin.Forms Navigation in C# — Xamarin 101 [10 of 11]
- Adventures in Mobile
- Understanding Xamarin Forms Navigation
- Xamarin.Forms Grid
- Xamarin.Forms ToolbarItem

UI Design

- Xamarin forms Good Looking UI Samples pages
- Absolute Layout Bounds for centering - Stack overflow
- Free Logo Design
- XamUI Login Page UI Kit

6.2.3 *Fall Sprint 3*

App Development

- How to use Navigation.InsertPageBefore in a ViewModel class in xamarin forms?
- Dropdown In Xamarin Forms Dropdown List Picker Xamarin form Dropdown
- Xamarin.Forms.PancakeView

6.3 *Appendix 4 - CS Spring Sprint Notes*

6.3.1 *Spring Sprint 1*

Weather API

- 03 - Working With Weather API — Complete Mobile App In Xamarin Forms - The Weather App
- OpenWeatherMap
- Agriculture Monitoring API

6.3.2 *Spring Sprint 2*

Soil Type API

- ArcGIS Soil Type Map
- Ambee Soil Api
- Soil Grids REST API

Visualization

- Next Level Maps With ArcGIS For .NET — The Xamarin Show
- ArcGIS Set initial map location
- ArcGIS Display Map

6.3.3 *Spring Sprint 3*

Azure

- Microsoft Azure for Beginners: Introduction - Scott Duffy
- Windows Azure Platform explained
- What is Microsoft Azure and How does Microsoft Azure Works
- Mastering Xamarin.Forms - very helpful book goes along with this Github Repo
- Table storage - Azure Docs
- Azure Storage documentation - Azure Doc

- Updating and Deleting Table Storage Entities with Azure Functions
- How do I update that entity's property value? - StackOverflow
- Azure Functions Table Binding: How do I update a row? - StackOverflow
- Integrating Azure Table Storage To Azure Function - C#Corner
- CloudTable Class - Microsoft Docs
- Azure Developer Tutorial: HTTP Trigger Functions with C# and .NET Core
- Azure Function returns 500 internal server error - Stack Overflow
- Explore Storage Account of Azure Functions
- HTTP Methods
- Learning Postman
- Android and iOS apps using Xamarin + Azure

UI Updates

- Weather fields in API response
- Part 2. Essential XAML Syntax

Weather Icons

- FlatIcon Weather 214
- FlatIcon Weather 142
- FlatIcon Weather 255

6.4 *Appendix 5 - Math Notes*

- Understanding Center Pivot Application Rate
- Managing sprinkler irrigation systems
- Reducing and Evaluating Irrigation Runoff
- LESA Sprinklers
- Inherent Factors Affecting Soil Infiltration
- CENTER PIVOT IRRIGATION SYSTEM LOSSES AND EFFICIENCY
- Development of the revised USDA–NRCS intake families for surface irrigation
- SPRINKLER PACKAGE WATER LOSS COMPARISONS
- Operating Characteristics of Center Pivot Sprinklers
- How a Center Pivot Irrigation Machine Works
- Pivot Basics
- VARIABLE RATE IRRIGATION ON CENTER PIVOTS. WHAT IS IT? SHOULD I INVEST?