University of Redlands

Monitoring and Quantifying Change in the Tropical Rainforest

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

by

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The report of Jessica Pierce is approved.

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Abstract

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The Mamoni Valley Preserve (MVP) is a conserved area of rainforest in Panama. The conservation of tropical rainforests has a global impact due to their ability to sequester vast amounts of carbon imperative in regulating the earth's climate. Due to increased deforestation of these areas, the landcover is constantly changing. Daniel Klooster uses GIS to aid MVP stakeholders. Klooster needed a tracking and monitoring system of landcover change events to know where deforestation is prominent and mitigate this issue. A data entry platform was created to record landcover change events. To quantify these changes events, a toolbox that calculated distances of vulnerable areas to at risk of deforestation was created. This toolbox output was used to create maps conservation stakeholders of the MVP use to aid in the conservation and management of the rainforest.

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List of Acronyms and Definitions

AGO	ArcGIS Online
CSS	Center for Spatial Studies
GHG	Green House Gasses
GIS	Geographic Information System
GPS	Global Positioning System
MAD	Multivariate Alteration Detection
MIP	Major Independent Project
MVP	Mamoní Valley Preserve
SAR	Synthetic Aperture Radar
UAV	Unmanned Aerial Vehicle

Chapter 1 – Introduction

The Mamoni Valley Preserve (MVP) covers a large area of contiguous rainforest in the heart of Panama with conditions that keep landcover constantly changing due to prominent deforestation.

The management of this land has global implications because rainforests store vast amounts of carbon dioxide which play a key role in balancing the earth's climate (Rainforest Trust, 2017). In order to better conserve this land, there must be knowledge of where things are changing and being deforested. Geographic information systems (GIS) is a critical conservation tool in aiding forestry management efforts with the ability to map landcover. The more we know, the better we can conserve.

Figure 1-1: Panama: The Isthmus of the Americas.

1.1 Client

Daniel Klooster, a Professor of Environmental Studies at the University of Redlands, has worked closely with the stakeholders of the MVP since 2017. Klooster, along with the University of Redlands Center for Spatial Studies, has led a month-long field study course with students, applying GIS to aid in research and data collection of the MVP study area. Klooster aids in conservation efforts of the MVP by providing useful information to the stakeholders with his expertise in Geography. The MVP has been conserved since the 1990s with the goals of protecting indigenous people who reside in the area and preserving this stretch of tropical rainforest (The Mamoni Valley Preserve, n.d). Using GIS technologies, Klooster has provided landcover classifications, high quality imagery taken with drones, as well as carbon content maps to the stakeholders. Klooster needs a central place to hold the data collected throughout the years to monitor and analyze areas that have undergone change or deforestation.

1.2 Problem Statement

The MVP lacks a system to track landcover change events and the ability to monitor these changes. To mitigate deforestation, stakeholders must be aware of areas that are already deforested or at-risk of being deforested. Deforestation in the tropical rainforest is prominent due to agriculture and logging. The rainforests of the MVP are no exception. There is a need to identify areas of the MVP that are vulnerable to deforestation.

1.3 Proposed Solution

To monitor landcover change events, the MVP needs a tracking platform to discern where the landcover is changing. Therefore, an application using GIS was created to record and update change events.

To identify these change events' risks of further deforestation, a toolbox that quantifies changes was created. The toolbox calculated areas undergoing change and their vulnerability to deforestation. This information was vital for stakeholders to aid in conservation efforts. With knowledge of where things are changing and their distances to areas prone to deforestation, stakeholders can make informed decisions regarding the management of the MVP.

1.3.1 Goals and Objectives

This project's goal was to use GIS to help stakeholders with conservation efforts to make decisions about the MVP. More specifically, the project aimed to provide a place to monitor and track landcover change events, quantify these changes, and provide helpful information via maps for stakeholders.

This project's objectives to address these goals were as follows. The first objective was an easy to use data entry system with necessary information regarding the landcover of the MVP. The next objective was to quantify changes to identify areas vulnerable to deforestation. The last objective was the creation of maps that show areas at-risk of deforestation.

1.3.2 Scope

This project provided a place to store data about changes in landcover in the MVP in a web application. This data is contained in a feature class with important information regarding each landcover change event. The application provided the ability to record and update events. The application also included different layers and imagery regarding the landcover of the MVP.

The data recorded was then used as an input to a geoprocessing toolbox in ArcGIS Pro, specifically made for the MVP. The toolbox quantified and analyzed areas of change. The tool allowed for visualization of at-risk areas of the preserve that created vulnerability maps.

1.3.3 Methods

Discussions about how to collect data and what type of analyses would be implemented using this data was on-going but nonetheless achieved. With the creation of a web application via AGO, current up-to-date data regarding the landcover of the MVP may be easily recorded. The web application contained different base maps of the MVP from different years to input change events consistent with time. These base maps consisted of drone imagery from 2017-2019, panchromatic aerial imagery from 2000, and pan-sharpened satellite imagery from 2011. In this web application, there were layers regarding MVP hydrology, terrain, and elevation to give the user more information relating to the landcover. The landcover change event feature layer allowed the user to input information about where the change happened, the classification of the change that occurred, the date, and any comments or attachments necessary. To update these changes, a relation table was created to update the status of each change.

The change event feature layer was then used as an input layer to an ArcGIS Pro toolbox created to quantify at-risk areas of change. The toolbox consisted of two tools; the first was named Change Event Metrics, which was a script tool created from a ModelBuilder that was exported to a python script. This tool updated the change event feature class by updating different fields that measured risks. Once these fields were updated, the second tool, the Summary Statistics ModelBuilder, summarized these events into hexagons. This tool calculated important statistics from the Change Event Metrics tool. The resulting summarized hexagon layer was used to make vulnerability maps.

1.4 Audience

The audience for this report includes students with an understanding of GIS, GIS professionals, and those interested in rainforest conservation management. MVP stakeholders as well as students studying this area in Panama may find this project especially informative.

1.5 Overview of the Rest of this Report

The rest of the report goes as follows, chapter one has introduced the project. Chapter two is a literature review of topics pertaining to this project. Chapter three discusses the system design and analysis. Chapter four covers the database design and all data used for

this project. Chapter five explains how the project was implemented, and chapter six provides the project's results and analysis. Lastly, chapter seven, gives a summary of this paper and future work to be done.

Chapter 2 – Background and Literature Review

This chapter will discuss topics pertaining to this project. An in-depth review of the background material and review of literature will be covered. This chapter will first discuss basic Panamanian geography of the specific study area, the conservation efforts of the Mamoní Valley Preserve (MVP), and the client's work that has been done for the MVP. The following sections will cover the type of data being collected and previous work that has been done.

2.1 Background

This section will cover the background of basic Panamanian physical geography as well as highlighting the importance of the conservation work being done in the area. Panama's tropical rainforests are filled with rich biodiversity. Tropical rainforests are complex systems with dense greenery and diverse species that live in harmony; two pictures of the landscape are shown in Figure 2-1. Rainforests have a unique forest structure that allow them to assist in regulating the climate due to the vast layers of towering trees as well as an abundance of shrubs due to constant rainfall. Deforestation on any scale in the tropical rainforest has consequences that have global implications including detrimental effects on ecological, water, and carbon cycles (Kumar, 2020). Rainforests are exceptional because they are home to almost half of the world's species (National Geographic Society, 2015). The Panamanian rainforest is home to species from the great migration, species who traveled from back and forth from the Americas, south to north and north to south, when these continents collided (NASA, n.d.). Deforestation results in the loss of species and habitats, this means deforestation in this highly biodiverse area has serious consequences on ecosystems. Panama contains more species of birds than the entire country of the USA. For these reasons, Panama is an ideal place to research and protect ecological systems and the rainforest.

Panama, being a third world country, has ongoing pressures on land-use because of how valuable and lucrative rainforests are. Panama's watersheds, including the MVP, face slash-and-burn agricultural practices that have detrimental effects not only from deforestation, but those residing downstream. This practice of controlled burning of the rainforest for agriculture contributes to greenhouse gas emissions (GHG) because the carbon dioxide in the trees are being released (Kumar, 2020). There is trend of exploitation of tropical rainforests that has put pressure on local communities to convert their land for agriculture which thus leads to increased GHG. The MVP stakeholders are aware of these issues and is one of many different efforts to face this problem.

Figure 2-1: Panama's Landscape.

More specifically, the study area of this project, the 12,900 acre Mamoni Valley Preserve shown in Figure 2-2, located in the heart of Panama and is one of twenty ecological hot spots on Earth (The Mamoni Valley Preserve, n.d.). This location receives greater than 80 inches of rain annually which allows for millions of species of fauna and flora to flourish. The study area is located along the narrowest stretch of land between the Pacific and Caribbean Sea, separated by just 30 miles. This rainforest contains mature trees able to hold 0.022 metric tons, which translates to about fifty pounds, of carbon per year. Correspondingly, these trees play a key role in the carbon sequestration of rainforests which assist in balancing global temperatures (Rainforest Trust, 2017). The MVP borders the continental divide which separates drainage basins into the Caribbean and Pacific; the MVP's main drainage outlet, Río Mamoni, flows to the Pacific. Along with being home to millions of plant and animal species, the MVP is also home to native communities and tribes. The work to preserve this area is therefore crucial due to illicit deforestation and expansion of the agricultural frontier, which effects local communities and their livelihoods. This includes indigenous communities such as the Guna Yala whose territory borders the MVP (Forests of the World, n.d.).

The MVP is protecting this vast area of essential and valuable land and the native communities who reside in the area. The MVP accomplishes this by intending to be a buffer zone from the Pan-American Highway corridor, a powerhouse of deforestation. The MVP's conservation efforts measurements of success include the amount of conserved forested land, aiding in the protection of the rights of Indigenous Peoples, and promoting scientific research (Geoversity, n.d.).

Figure 2-2: Panama and the Mamoni Valley Preserve

Daniel Klooster, Professor of Environmental Studies at the University of Redlands, works closely with MVP stakeholders, by guiding a month-long field study course to the preserve. The University of Redlands Center for Spatial Studies travels along with Klooster providing GIS technologies and aids in the GIS work and application. The work that has been done includes student-led GIS projects that aid stakeholders in management and conservation of the MVP. Along with educating students about both the physical and social geography of the area, research is a significant part of the work that is done. Field work and carbon tree sampling plots are used to calculate the amount of carbon that is held in the different landcover types. High quality imagery is delivered through drone imagery of the watersheds which allow landcover types to be classified over large areas. Carbon sequestration as well as landcover maps of the watersheds in the MVP have been delivered to stakeholders the past three years Klooster has led this course. Figure 2-3 includes examples of both the landcover and carbon maps done for the MVP in 2018 for the La Bonita sub-watershed. Klooster's work has assisted the MVP in its efforts to effectively manage the land as well as gain knowledge of the landcover.

Figure 2-3: Landcover and Carbon Content Maps (Center for Spatial Studies, 2018)

2.2 Spatio-Temporal Data

Spatio-temporal data is data associated with a time and a place (Allen, Edwards, Bédard, 1995). Since the landcover of rainforests are constantly changing due to deforestation and regrowth, it is important to track these changes. Remarkable amounts of rainfall and exceptional biodiversity allow for the dynamic nature of the rainforests; therefore, understanding how to model real-life change is vital in order to monitor and better conserve the landcover. That being the case, to model landcover change, there must be knowledge of where landcover change happens and when. Accordingly, spatio-temporal models play a key role in modeling “dynamic phenomena” (Stefanakis, 2014, p. 121).

Concepts regarding temporal data modeling have been a topic of discussion since the 1990s. These concepts are helpful in identifying how real-life changes will be recorded in a GIS model. In this project there needed to be a way to identify how to model changes in landcover over a vast area over time. Different approaches and philosophies have long disputed over regarding temporal modeling. There are object-based approaches from early literatures that define an object as an event, in order to model change with time

(Egenhofer & Golledge, 1998). In this case regarding landcover, the event or point does not change, but that land cover type may be changed. This view of change is related to a Langranian view of modelling change which classifies change based on an object or entity that is changing (Feng, 2004; Langran & Chrisman, 1988).

Object-oriented modeling (OO) seems to be the most popular approach in spatio-temporal data models. This approach allows for an object's identity to be consistent with a specific point in time, time being used to evaluate the transformation of the object (Siabato, Ilarri, Manso-Callejo, Claramunt, 2018). In this project, the event would be the point in space where landcover has undergone some type of change.

Temporal information in temporal data is captured through time stamps. There are three different types of time stamps which include instant, interval, and spans (Stefanakis, 2014). An instant time stamp is a single moment; an interval time stamp consists of two moments that represent a duration of time; and lastly spans which represent a given length of time (Stefanakis, 2014). These time stamps are associated with each event, or object (Allen, 1983). In the case of landcover, significant changes happen over a large period in which the change span is unknown; therefore, instant timestamps would be best to represent each event. In this case, the classifications of the events change by their attribute value, landcover type, and there is a time stamp associated with each. In order to model using this approach the data must have a record that includes the attribute value and the time stamp (Stefanakis, 2014).

2.3 Imagery

Mapping landcover can be done in a variety of ways from direct observation, local knowledge, satellite imagery or Unmanned Aerial Vehicle (UAV) imagery. The use of satellite imagery is extremely costly, yet seems to be the most ideal considering the vast area satellites can cover. However, due to weather conditions in the tropics that experience extreme amounts of rainfall, other means of gathering data must be implemented due to cloud coverage in satellite images. Figure 2-4 below shows how cloud cover in the MVP may affect useful satellite imagery.

Other means of data collection regarding landcover may be ideal, such as direct field data collection or through Unmanned Aerial Vehicles (UAV). In terms of data collection for this project (covered more in depth in section 4.4), data collected will come from a variety of these sources, from local knowledge of areas to UAV, also referred to as drone imagery. UAV imagery is especially useful for small scale changes due to the spatial resolution of their images that provide accurate clear images (Kakaes, Greenwood, Lippincot, Meier, Wich, 2015). In all, UAV imagery has been used to track changes due to the high-resolution imagery, affordability, and long-term monitoring potential (Zhang, Hu, Lian, Fan, Ouyang, Ye, 2016). Figures 2-4 and 2-5 show satellite imagery compared to drone imagery of the same area of the MVP. Figure 2-4 is an example of the satellite imagery Basemap that contains cloud cover and is unclear. Figure 2-5 is the drone imagery Basemap which is clearer and contains no cloud cover.

Figure 2-4: Satellite Imagery

Figure 2-5: Drone Imagery (Center for Spatial Studies)

2.4 Previous Work

Previous work regarding temporal landcover change in the MVP has been done by a masters student at the University of Redlands. Abigail Bohman used Synthetic Aperture Radar (SAR) and drone imagery to detect areas of change in the MVP. Due to the high volume of cloud coverage in tropics and the specific study area of the MVP, clear imagery is very difficult to attain; SAR imagery is therefore used due to its ability to penetrate through clouds. drone imagery was used as reference for areas detected by the SAR satellite imagery to ground truth areas where the forest had changed. In order to identify changes in an area where change happens quickly, the project involved two images taken at different times to be inspected for changes in landcover with a geoprocessing tool in ArcGIS Pro. This tool involved the use of Multivariate Alteration Detection (MAD) to detect changes between two images, as shown in Figure 2-6 (Bohman, 2019).

Figure 2-6: Multivariate Alteration Detection Results over the MVP (Bohman, 2019)

The MAD results of values near zero indicate that those areas have experienced no change. To attain a clear visual of change, Bohman set a threshold to make patterns more visible. The threshold applied to the MAD results is shown in Figure 2-7. The project delivered an automated workflow for interpreting SAR imagery with field observation to deliver the areas that have changed in a map (Bohman, 2019).

Figure 2-7: Threshold Results in the MVP (Bohman, 2019)

2.5 Summary

This chapter has covered an in-depth background of the project, a literature review of the concepts of the work and data being collected, and previous work that has been done for MVP. It is important to understand the importance of the study area and the biodiversity rainforests hold. This area is home to indigenous tribes and millions of species that survive off the land and need protection from deforestation. The next chapter will be an analysis of the project's system and design.

Chapter 3 – Systems Analysis and Design

This chapter will cover the systems analysis and design of the project. This section will include the requirements and deliverables of the project to accomplish the goal of using GIS to help preserve the rainforest in the Mamoni Valley Preserve (MVP).

3.1 Problem Statement

The MVP lacks a system to track landcover change events and the ability to monitor these changes. To mitigate deforestation, stakeholders must be aware of areas that are already deforested or at-risk of being deforested. The MVP experiences extreme weather conditions and deforestation that keeps the landcover constantly changing. Monitoring deforested areas will allow MVP stakeholders to better manage these areas of tropical rainforest.

3.2 Requirements Analysis

The requirements of this project have been decided with the client, Daniel Klooster, and have undergone changes throughout project implementation. As the project was started and new issues and questions became apparent, requirements were changed. In the end, the requirements included a data entry platform that allows for a user-friendly way to upload and update landcover change events, a tool to analyze vulnerable areas that have changed, and the creation of simple landcover change maps. Environmental Systems Research Institute (ESRI) software must be used for this project due to the client's preference. Correspondingly, data will be entered through an ArcGIS Online (AGO) web application then further analyzed in ArcGIS Pro.

The first deliverable was the Data Entry Web Application using AGO with simple data editing features, imagery, and a place to update landcover change events. The application needed to provide a place to easily monitor and store landcover information of MVP. The second deliverable was the Analytical Reporting tool that quantifies areas of the landcover change events at risk of deforestation. The tool must have allowed for visualization of areas undergoing change and the creation of simple maps. The next deliverable was a set of vulnerability maps to show areas at risk of deforestation. The last deliverable was a document containing information about how to use the web application and the toolbox (Appendix A). The requirements and resulting deliverables are shown in Table 3-1.

Table 1. System Requirements Table

Deliverable	Requirement
Data Entry Web App-ArcGIS Online	<ul style="list-style-type: none">• User-friendly data entry platform using ESRI software• Change event layer with specified information• Contain different types of imagery• Monitoring events
Analytical Reporting Tool- ArcGIS Pro	<ul style="list-style-type: none">• Visualize changes• Quantify at-risk (of being deforested) areas
Vulnerability Maps	<ul style="list-style-type: none">• Maps showing areas that have changed• Maps showing areas at risk of being deforested
User Guide	<ul style="list-style-type: none">• Word document

3.3 System Design

The system design consisted of three major components, a data entry platform for landcover change events, a tool that analyzed and quantified these areas of change, and the creation of maps with important information for conservation purposes. The three components are shown below in Figure 3-2. Each step of the project could not have begun until the previous step was completed, therefore the order of these three components was important when planning the system's workflow.

Figure 3-1: System Design

3.4 Project Plan

In the beginning stages of this project, the requirements were simply to provide a place to track and monitor changes in landcover for the client. The client wanted a monitoring system that would provide information to provide narratives regarding changes to the landcover through time, as well as analyze areas undergoing significant amounts of change. However, due to lack of data regarding historical changes to the landcover, the narrative could not be done, but the monitoring and tracking system could. Thus, after research regarding how to track changes in landcover, an application with data entry and update ability was decided upon. Next was the task of how to quantify these changes being recorded.

Once the client established the available data, the requirements regarding the analyses of changes were settled. Landcover change event areas would be quantified by their distances to deforested or highly vulnerable areas. Due to access to existing data the client provided regarding landcover, hydrology, and roads, quantifying areas of change using these components would be implemented. At first, the requirement for analyses was one geoprocessing tool, however the client wanted the data aggregated on different scales, and this added a new component to the project involving summarization as the last step. This requirement changed, adding a toolbox with a script tool that calculated

distances, and a ModelBuilder model that could aggregate this information to easily analyze vulnerable areas of the MVP.

In conclusion, there were a few changes made throughout the project's implementation. As the project went on, concerns were brought up and adjustments were made. For instance, data availability pushed the project's scope, and the client's needs changed as the project unfolded, which changed the requirements. Constant communication attributed to the project's success due to the changes that were made.

MVP Landcover Change Event			
Project	Duration	Start	Finish
Plan		1/1/2020	3/1/2020
Requirements Analysis		1/1/2020	2/1/2020
Scope		1/1/2020	3/1/2020
Design		3/1/2020	4/1/2020
Infrastructure Design		3/1/2020	4/1/2020
Develop		4/1/2020	7/1/2020
Web Application		4/1/2020	5/1/2020
Data Collection via Web App		5/1/2020	6/1/2020
ModelBuilder/Python Script		6/1/2020	7/1/2020
Test		7/1/2020	7/5/2020
Test script tool		7/1/2020	7/5/2020
Deploy		7/5/2020	7/10/2020
Show to client		7/5/2020	7/10/2020

Figure 3-2: Project Plan

3.5 Summary

In summary, it is important to note that the requirements were created to solve the problem. To better conserve this area of tropical rainforest in the MVP, there must be a way to identify at-risk areas and monitor areas undergoing changes. To show areas that are undergoing deforestation and are at risk, a web application to record changes in the landcover, a tool to quantify these vulnerable areas, and maps to show this information, was needed. The project design therefore was based on these objectives and resulted in three main deliverables: a data entry platform, a toolbox, and maps. The following chapter will discuss the data used in this project and an in-depth description of the project's geodatabase.

Chapter 4 – Database Design

Chapter four will discuss data used in the project regarding the landcover of the Mamoni Valley Preserve (MVP). The section will cover the conceptual model of the project, the logical data model, data sources, and data collection methods.

4.1 Conceptual Data Model

The relationships among the project's entities will be explained in this section. The project is built off the landcover change event points. The toolbox calculated vulnerable areas near these events. The areas calculated are the distances of each event to the nearest road, river, and deforested area. The relationship among these entities is that landcover change events near these features are more prone to deforestation due to accessibility. To retrieve more information regarding areas, rather than just calculated distances, these points are aggregated into polygons. This aggregation results in a summarized feature class with information regarding deforested areas and the risk of those areas prone to further deforestation.

Figure 4-1: Conceptual Model

4.2 Logical Data Model

This section will describe all feature classes and tables that were used in this project's implementation. This will cover all the existing data used in this project's GIS implementation and the data in the project's ArcGIS Pro geodatabase. Most feature classes used in this project were not contained in the ArcGIS geodatabase.

The most important feature class which the project relied upon was the Landcover Change Event point feature class. This layer was the input for the toolbox and has a related table called Observation Log that contains the current status of each landcover change event. This feature class was a hosted feature class that was accessed through an ArcGIS enterprise account hosted by the University of Redlands Center for Spatial Studies (CSS). This feature class was accessed through the ArcGIS Online (AGO) portal when being used in ArcGIS Pro.

The first component of the project, the AGO web application, contained feature classes and imagery provided by the CSS and were accessed through their server. Different base maps, shown in Figure 4-2, of the Mamoni Valley Preserve (MVP) from different years such as Aerial Mosaic 2000, Pansharpened Imagery 2011, and Drone Imagery from 2017-2019 were accessed through the CSS AGO geosrv portal, section 4.3 will explain in depth about this server. All feature classes in the application were pulled from this server such as Landcover, Roads, Hydrology, Points of Interest, Elevation, and the Mamoni Watershed Boundary.

Figure 4-2: Basemap Gallery for AGO Web Application

The second component of the project took place in ArcGIS Pro version 2.5 in a Project Called Landcover Change Event Tool. The feature classes used were accessed through the AGO portal. The input feature class for the toolbox was the Landcover Change Event feature class. The parameters of the first tool included the Landcover, Hydrology, and Roads feature classes. Reference data such as the Mamoní Watershed Boundary was used for the environment setting when running the tools in the toolbox.

The output feature class was also contained in the ArcGIS pro geodatabase, called the Summarized Hexagon feature class. The output feature class contained a related table called Hexagon Summary Counts, this table shown in Figure 4-3 under standalone tables, that contained the percent of each landcover change event classification for each polygon. Figure 4-3 shows the project's ArcGIS geodatabase and feature classes contained inside.

Figure 4-3: ArcGIS Pro Geodatabase

4.3 Data Sources

The data in this project was collected from the University of Redlands Center for Spatial Studies (CSS). These layers were contained in an ArcGIS Enterprise SQL Server geodatabase called geosrv that contains all layers in a Panama geodatabase. All layers were in the same coordinate system, NAD 1983 UTM Zone17N (WKID 26917) because the layers are in the same study area of Panama and this is the best suited projection. The reason UTM Zone 17N was used is because this projection is where Panama has the least deformities.

These layers consisted of all the feature classes used in the web application and toolbox in this project. The web application included different imagery and basemaps that were retrieved from the CSS portal. The toolbox used Roads, Rivers, and Landcover feature classes that were also pulled from this portal. Metadata regarding these layers are included in Appendix C.

4.4 Data Collection Methods

Data collection for the project consisted of collecting layers from the CSS. The other data collection done was of the landcover change events in the MVP Landcover Change Monitor web application on AGO. This data collection involved scanning existing imagery for landcover change events for the landcover change event feature class.

4.5 Summary

This section covered the conceptual data model, the logical data model, data sources, and collection methods. It is important to note that there were three main components to the conceptual model that involved the input feature class for the tools, the toolbox to quantify changes, and the desired maps the client had asked for. The logical model discussed all the layers used to achieve the desired results and products for the client. The next chapter will discuss how the project was implemented.

Chapter 5 – Implementation

All previous chapters have set the stage for chapter 5 which is a detailed explanation about the specific work that was done to aid in conservation efforts for the Mamoni Valley Preserve (MVP). The purpose of this chapter is to provide a detailed workflow, step-by-step, of how this project was implemented.

5.1 Data Entry Web Application

The beginning stage of this project was the creation of a data entry web-application. The web application had to provide the ability to record and update changes to monitor change events. The web application contained base-maps with existing imagery to help pin-point areas undergoing change from different years as well as key layers regarding the landcover. Figure 5-1 is an image of the editing widget that provided a form to fill out necessary information regarding the landcover change event.

Figure 5-1: Data Entry Widget

The data editing widget was the key feature that allows users to input key fields that hold information regarding each landcover change event. There are five types of user-specified classifications of each event: Burn/Fire, Pasture Conversion, Reforestation, Structure, and Other. These were the five domains of the classification field. The second most important field was the landcover/forest type that each event fell inside. This has to do with the type of landcover the event exists within, and these fields provide extra information about the area. Figure 5-2 shows the landcover type versus landcover change event classification fields and their domains.

Figure 5-2: Landcover Type and Landcover Change Classification Domains

Different basemaps were used for users to explore the landcover in different time periods. The most useful and recent imagery was the drone imagery that provided high quality imagery used to upload landcover change events. An example is shown in Figure 5-3 below of an event that was recorded using drone imagery and the drone used for this project, the DJI Phantom 4 V2.

Figure 5-3: Drone Imagery-Burn Area and Phantom 4

For monitoring purposes, a related table was created so the user could update the current status of each event. The bottom of each change event pop-up had a related table option named Observation Log with the current landcover type of each event and the date observed (see Figure 5-4).

Figure 5-4: Observation Log

5.2 Landcover Change Event Quantifier Toolbox

Once the data entry web application was created and the landcover change event layer had the necessary data, a toolbox that calculated at-risk areas was created. The toolbox created for this project provided analyses of vulnerable areas the client needed to aid in conservation efforts. The toolbox, called Landcover Change Event Quantifier, contains two main components, a script tool and a ModelBuilder tool. Both tools were created using geoprocessing tools in ArcGIS Pro version 2.5.

5.2.1 Script Tool

The script tool was a combination of different geoprocessing tools in one simple step. Due to the model being incredibly long, a Python script was utilized to create an easy-to-use script tool. The original model is attached in Appendix B at a link at the end of the code due to the inability to fit on a single page. The script tool, named Change Event Metrics, used ArcPy, a Python package with functions to perform geographic information analyses (ESRI, 2020). ArcPy contains a geoprocessing library with geoprocessing tools ArcGIS Pro uses in its toolboxes. The Python script used for the script tool can be found in Appendix B.

There were six geoprocessing tools used in this script tool. The first tool was Copy Features, which created a copy of the input feature class Landcover Change Event, which prevented overwriting information. This copied feature layer was used as the input feature class for the Near tool, which was the second tool used in the script tool. The Near tool was run three different times with three layers used as parameters: landcover, hydrology, and roads. However, for the landcover layer, a third tool was used called Select by Attribute and was performed prior to the Near analysis so that the landcover

selected was pasture or already burned area. A fourth tool, Feature to Line, was used to ensure that events within these areas and their distances were calculated. Once the Near tool was run for each feature class, the fifth tool, Add Join, was used to join the Landcover Change Event Copy and original feature class to calculate the fields in the original input layer. The sixth tool, Calculate Field, was then used to populate distance fields. This resulted in three new fields in the original feature class that contained each event's distance to the nearest road, river, or already deforested area. Figure 5-5 shows an image of the script tool created.

This script tool contains four input parameters and two outputs. The first input was the Landcover Change Event Metrics point feature class. The second input was the Landcover feature, the third was the Hydrology, and the fourth was the Roads feature class. These inputs may be accessed from the Center for Spatial Studies ArcGIS Online (AGO) server unless these layers are downloaded on the desktop. The output feature classes were the results from running the Copy Features tool and the Feature to Line tool. Both outputs will appear in the user specified location. These feature classes may be deleted or kept, however, every time the tool is run, they will be the output.

Figure 5-5: Script Tool

5.2.2 ModelBuilder Tool

After the Change Event Metrics tool ran successfully, the data needed to aggregate information into smaller polygons of the preserve was derived. The second tool was a ModelBuilder tool named Summary Statistics. This tool was much simpler than the model previously created and is shown in Figure 5-6. This model consisted of two geoprocessing tools. The purpose of this tool was to summarize data in hexagons in the MVP study area, to create maps with information regarding areas with landcover change events.

Figure 5-6: Summary Statistics and ModelBuilder Diagram

The Summary Statistics model involved an initial creation of a hexagon layer using the Generate Tessellation tool (Figure 5-7). The parameters set for this tool was custom extent using the MVP Watershed Boundary feature as well as setting the size of the hexagons to 3.5 square kilometers.

Figure 5-7: Generate Tessellation Geoprocessing Tool

The next tool was the Summarize Within tool, the input summary features being the Landcover Change Event feature class, and input polygons was the hexagon layer. The tool summarized the fields calculated in the Change Metrics tool in each hexagon. The summarize within tool calculated the minimum, maximum, mean, and standard deviation of each distance field to road, river, and deforested area, shown in Figure 5-7. The tool also created a separate table that calculated the percentage of each type of landcover change event. This was done using the group field, selecting the Classification field, and checking the Add Group Percentages box, as shown in Figure 5-8.

Figure 5-8: Summarize Within Tool

5.3 Summary

This chapter covered how this project was implemented. An in-depth description of how the three main components of the project were executed was explained. The first part of this chapter covered how the web application was set up and how the toolbox was executed to get the information needed to make the vulnerability maps. The next chapter will discuss the results of the project and the maps that were created.

Chapter 6 – Results and Analysis

Chapter 6 will discuss the results of this project's goal in aiding the client, Daniel Klooster, in conservation efforts for the Mamoni Valley Preserve (MVP). This chapter will reflect on the project's outcome, give an in-depth analysis of the finished product, and the utility of the deliverables. The main deliverables for this project were a web application, a toolbox, and maps.

6.1 Web Application

The web application provided a place to visualize and record landcover change events. The basemaps provided different imagery to customize what users wanted to see in specific years. The application contained significant information regarding past and present landcover statuses of the MVP. Figures 6-1 through 6-4 show the web application and Basemap options. Figure 6-1 is a Basemap of pansharpened satellite imagery from 2011 which has prominent cloud cover. Figure 6-2 is aerial mosaic imagery from 2000, this is the oldest imagery available for the MVP. Figure 6-2 is drone imagery which is the highest quality and most recent imagery available for the area. Lastly, Figure 6-4 is a terrain Basemap of ten-meter contours of the MVP.

Figure 6-1: Web Application Basemap: Pansharpened 2011

Figure 6-2: Web Application Basemap: Aerial Mosaic 2000.

Figure 6-3: Web Application Basemap: Drone Imagery 2015-19

Figure 6-4: Web Application Basemap: 10 m Contour

The client may use this web application to monitor where events take place and how they can change in time using the observation log, as shown in Figure 6-5.

Figure 6-5: Web Application's Observation Log

The web application provided simple widgets to make the application as user friendly as possible for the client. The five widget icons are shown in Figure 6-6.

Figure 6-6: Web Application Widgets- from left to right: Edit, Basemap, Measure, Legend, and Layer List

6.2 Script Tool Results

The first component of the toolbox deliverable was a script called Change Event Metrics. The script resulted in updated fields in the original Landcover Change Event feature class. The three updated fields were the distance from each event to the nearest road, the nearest river, and nearest deforested area, in meters. These three layers-Roads, Rivers and Deforested Area-were chosen because the more accessible an area is, the more likely it is to be deforested (World Wild Fund, 2020). The Deforested Areas were derived from the Landcover feature class. Figure 6-7 shows an image of the updated fields in the attribute table.

Distance to Roads	Distance to Rivers	Distance to Burn/Pasture
320.83016	129.886643	6062.518125
126.821518	79.40637	6774.993572
886.711531	215.320643	31.735621
1976.324833	293.971232	1972.384872
571.525029	46.440855	66.392171
821.264353	33.154223	2.124471
671.334643	514.675668	989.388222
2594.731852	204.57344	404.551161
3361.513323	414.614329	720.505021
2744.630405	320.329328	525.763975
1296.660368	169.164829	1329.928178
1091.518066	11.375901	306.598547
1579.601042	76.719757	397.970318

Figure 6-7: Change Event Metrics Script Tool Fields

6.3 Summary Statistics Results

The second component of the toolbox was the Summary Statistics ModelBuilder tool which summarizes the data calculated in the Change Event Metrics script tool and aggregated the data into polygons. The first output of this tool was a feature class that contained data summarized by minimum, maximum, mean, and standard deviation for each distance field. Figure 6-8 is an image of the resulting attribute table for the summary statistics of the distance to Roads field. The Null values are polygons that did not contain any events.

Average Distance_Roads	Minimum Distance_Roads	Maximum Distance_Roads	Standard Deviation Distance_Roads
221.36669	54.602865	422.200211	186.151848
347.848125	347.848125	347.848125	0
<Null>	<Null>	<Null>	<Null>
223.825839	126.821518	320.83016	137.184826
<Null>	<Null>	<Null>	<Null>
<Null>	<Null>	<Null>	<Null>
<Null>	<Null>	<Null>	<Null>
425.510483	293.703375	557.317591	186.4034
661.461651	661.461651	661.461651	0

Figure 6-8: Summary Statistics Fields for Distance to Roads

The second output for the Summary Statistics tool was a related table, Hexagon Summary Counts, which provided information regarding the percentage of each classification of each event in each hexagon. This is shown in Figure 6-9.

Join ID	Classification	Percent of point count	Count of Points
4	Structure	50	1
8	Natural_Reforest	50	1
8	Pasture	50	1
9	Planned_Reforest	100	1
13	Pasture	100	1
17	Pasture	100	2
18	Pasture	50	1

Figure 6-9: Related Table: Hexagon Summary Counts

6.4 Results from Toolbox

The third deliverable was landcover vulnerability maps. The output feature class, Summarized Hexagon, from the Summary Statistics tool contained vital information for the stakeholders regarding events and their distances to vulnerable areas. By summarizing this data, easily readable maps were made with information and metrics that may be used to aid in conservation. Maps with point counts were made to see areas with the most change events, as shown in Figure 6-10.

Figure 6-20: Landcover Change Event Count Map

The Summarized Hexagon feature class allowed for specific maps to be created based on metrics specified by the user. For example, if the user would like to see areas most prone to deforestation, they may symbolize the Summarized Hexagon feature layer by the deforested area field. Shown in Figure 6-11 is a map of minimum distances from each event to the nearest road for each hexagon. Events with the shortest minimum distance were classified as areas most vulnerable to deforestation due to the area's proximity to a road. Red indicates there is a high risk of a vulnerable area to a road.

Figure 6-31: Disturbed Areas Proximal to Roads

The next map was symbolized by the area's proximity to the nearest river. The field used was the average distance of the events in each hexagon to the nearest river. The at-risk hexagons in red are areas which contained events closest to a river shown in Figure 6-12.

Figure 6-42: Disturbed Areas Proximal to Rivers

The next map details an area's vulnerability to an already deforested area. This is the highest risk metric since deforestation is most prominent near the edges of already deforested areas. The field used to symbolize this map was the average distance of events to already deforested areas, the higher the hexagon's average distance was, the more at-risk the area is. The red hexagons are sections of forest that contained events most vulnerable to deforested areas, as shown in Figure 6-13.

The Landcover feature class contained the deforested areas used to calculate these distances. However, this feature class only covered a portion of the study area. This map is therefore skewed toward hexagons that contained events near this Landcover feature class.

Figure 6-53: Disturbed Areas Proximal to Deforested Areas

As seen in Figure 6-13, the reason the red hexagons were skewed in the upper right portion of the watershed is because drone imagery is only available for this area. The digitization of the polygons in the Landcover feature class in the MVP have only been done using drone imagery. Figure 6-14 shows the drone imagery available and the digitized Landcover feature class. This problem will be reduced once the data in the Landcover feature class expands outward covering more area of the MVP.

6.5 Discussion

This section will discuss the results of the web application, toolbox, and maps. The web application holds much utility for monitoring landcover events and analyzing the area with different basemaps. The toolbox ran smoothly, and the client may use these tools with a simple click of a button to update metrics and summary fields.

The vulnerability maps remain a concern. The maps contained many hexagons that had no data, which means there is much more data to be recorded. The absence of data is clearly seen in the vulnerability maps that could not have been noticed by simply looking at the attribute table. Due to the lack of data regarding events and landcover information, the most important metric, distance to deforested areas, is unreliable. In spite of this issue, there is a lot of valuable information for stakeholders to aid in conservation efforts with the data provided from this project. The feature class created in the project, Summarized Hexagons, hold valuable information regarding areas with change events.

6.6 Summary

This chapter covered the results and provided analyses of the project with visuals of each deliverable. The utility of each component of the project was explained and the resulting maps were shown. This chapter also covered the issues with the final product and how they could be improved in the future. The next chapter will be a summary of this project and discuss future work in detail.

Chapter 7 – Conclusions and Future Work

This paper has covered the entirety of the project from the background, to implementation, and results. The project sought to meet Daniel Klooster's goal in using GIS to aid in conservation efforts for the Mamoni Valley Preserve (MVP). This section will deliver a summary of this project and how the client's goal was met. The last part of this chapter will discuss future work of the project.

7.1 Project Summary

The MVP is a conserved area of tropical rainforest in Panama that holds a great deal of ecological value. This conservation work being done in the preserve is vital in the fight against climate change and deforestation is the main concern. The client, Daniel Klooster, works closely with stakeholders by using GIS to aid in the management and conservation of the MVP. Klooster needed a way to use GIS to monitor, track, and visualize areas of landcover change. Once the requirements of the project were set, four deliverables were decided upon: a data entry system that records and updates landcover change events, a toolbox to quantify changes, a user guide, and maps to show areas vulnerable to deforestation. Then began the project planning stage. This phase was difficult due to changes in requirements and external factors that affected the project.

The project was then implemented after the planning phase. The project implementation started with the creation of a web application which allowed for data entry for users to record and update landcover change events and basemaps of the study area with imagery from different years. The next step of the project was the creation of a toolbox which contained a script tool and ModelBuilder tool in ArcGIS Pro. This toolbox calculated distances of events to areas most prone to deforestation. The output of the toolbox allowed for the last phase of project to be started, which was the creation of landcover vulnerability maps. These maps held important information for stakeholders of the MVP to identify areas vulnerable to deforestation.

In all, this project produced results that provided important information for stakeholders of the MVP. The maps can be used as tools to aid in decision making for conservation purposes. However, there is room for the project to be expanded.

7.2 Future Work

As discussed in the previous chapter, there are different parts of this project that may be improved upon. Once more data is added to the landcover feature classes, more information will be available. The landcover data includes the landcover change events, drone imagery, and landcover type data. This data is available in only certain areas of the study area, therefore there is vital information missing in all other parts of the MVP. Once the data is expanded to more areas of the MVP, the output of the toolbox will provide more information, with greater utility for stakeholders to aid in conservation.

Future work for this project would be a notification scheduling system that flags event sites at a specified cycle. This would aid in the monitoring of landcover events by providing a certain interval in which a person should check up on the events. This project may also be improved once higher quality Digital Elevation Model (DEM) data is available. Due to the lack of lidar data, the DEM data currently available is only obtained from radar, which detects the top of the tree canopies instead of the ground. The project will be improved once more accurate DEM data is available because it will provide accurate hydrology layer. This will provide once more accurate and useful metrics for events and their distances to rivers and therefore provide more accurate vulnerability maps for areas at risk of deforestation.

The final way the project may be improved is by aggregating data into each subwatershed over the MVP. Again, once accurate DEM data is provided, there are tools in ArcGIS Pro which can provide accurate delineations of subwatersheds. This will provide information regarding the vulnerability of each subwatershed, which will be incredibly helpful for stakeholders.

Works Cited

- Allen E., Edwards G., & Bédard Y. (1995). Qualitative causal modeling in temporal GIS. In *Spatial Information Theory. A Theoretical Basis for GIS*, A. U. Frank and W. Kuhn (Eds.). Springer Verlag, Berlin, 397--412.
- Allen, James F. (1983). Maintaining knowledge about temporal intervals. *Communications of the ACM* 26, 832-843
- Bohman, A. (2019). Testing Multivariate Alteration Detection for Tropical Deforestation using Synthetic Aperture Radar (SAR) and Drone Imagery in Mamoni Valley, Panama (Master's thesis, University of Redlands). Retrieved from https://inspire.redlands.edu/gis_gradproj/280
- Egenhofer, M. J., & Golledge, R. G. (1998). *Spatial and temporal reasoning in Geographic information systems*. New York: Oxford Univ. Press
- ESRI. What is ArcPy? (n.d.). Retrieved July 2, 2020, from <https://pro.arcgis.com/en/pro-app/arcpy/getstarted/what-is-arcpy-.htm>
- Feng, CC. (2004). Probing Barriers to the Integration of Geographic Information Systems and Hydrologic Models, 14–19.
- Forests of the World. (n.d.). PANAMA. Retrieved March 25, 2020, from <https://www.forestsoftheworld.org/programs/panama>
- Hornsby, K., & Egenhofer, M. J. (1997). Qualitative representation of change. *Spatial Information Theory A Theoretical Basis for GIS*, 15–33. doi:10.1007/3-54
- Kakaes, K., Greenwood, F., Lippincot, M., Meier, P., & Wich, S. (2015). Drones and aerial observation: new technologies for property rights, human rights, and global development a primer. Chapter 7: 63. 10.1007/3-54063623-4_40
- Kumar, V., & Kumar, S. (2018). <http://www.historystudies.net/dergi/birinci-dunya-savasinda-bir-asayis-sorunu-sebinkarahisar-ermeni-isyani20181092a4a8f.pdf>. *History Studies International Journal of History*, 10(7), 241-264. doi:10.9737/hist.2018.658
- Langran, G., & Chrisman, N. R. (1988). A Framework For Temporal Geographic Information. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 25(3), 1-14. doi:10.3138/k877-7273-2238-5q6v
- NASA. (n.d.). Rainforests of Panama Retrieved March 25, 2020, from <https://earthobservatory.nasa.gov/images/4150/rainforests-of-panama>
- National Geographic Society. (2015, April 30). Rainforest. Retrieved April 22, 2020, from <https://www.nationalgeographic.org/encyclopedia/rain-forest>
- Rainforest Trust. (2017). “Climate Change Series Part 1 – Rainforests Absorb, Store Large Quantities of Carbon Dioxide.” Retrieved from <https://www.rainforesttrust.org/climatechange-series-part-1-rainforests-absorb-store-large-quantities-carbon-dioxide>
- Stefanakis, E., (2014). *Geographic Databases and Information Systems*. Edition 1.0; Fredericton, NB, Canada; September 2014
- Siabato W., Claramunt C., Ilarri S., & Callejo M. (2018). A Survey of Modelling Trends in Temporal GIS. *ACM Comput. Surv.* 51, 2, Article 30, <https://doi.org/10.1145/3141772>
- The Mamoni Valley Preserve. (n.d.). Retrieved December 1, 2019, from <http://www.mamonivalleypreserve.org/the-mamoni-valley-preserve/>

World Wildlife Fund. (2020) Deforestation and Forest Degradation. Retrieved July 08, 2020, from <https://www.worldwildlife.org/threats/deforestation-and-forest-degradation>

Zhang, J., Hu, J., Lian, J., Fan, Z., Ouyang, X., & Ye, W. (2016). Seeing the forest from drones: Testing the potential of lightweight drones as a tool for long-term forest monitoring.

Appendix A. MVP Landcover Change Monitor and Toolbox User Guide

1. Landcover Change Monitor AGO Web Application

A. Application Components

Before you begin editing, it is wise to explore the components of the application, the layers you may turn on and off and the basemaps available. The widget next to the basemap icon is a measuring tool you may use to measure an area in Acres.

B. HOW TO: Add New Features

Once you have explored the application's main components and have the settings you would desire, you may begin editing. The editing widget is the first icon shown below. To add a new change event you must choose the classification type, and add it to the map. Once added to the map you must fill in the necessary fields.

C. HOW TO: Update existing events

In order to update existing events, you must select the desired event, and scroll to the bottom of the pop-up and clicker observation log under related tables. Here, click the + sign to add the current status of the event.

2. Landcover Change Toolbox

A. How to run script

The script tool is easy to the run, and only involved user inputs for specific fields. If these fields are not in your projects Geodatabase, they are available on ArcGIS Online through the CSS Server. This tool has two outputs involved to run the tool which will appear in your project's geodatabase. These layers are up to your discession to be kept keep or deleted. These outputs will repeatedly appear each time the tool is run.

B. How to run ModelBuilder

After the metrics tool is run, the Summary Statistics ModelBuilder is then ready.

Once the ModelBuilder is opened, click the Run button to run this tool.

This tool will update the Smmarized Hexagon feature class.

Appendix B. Script tool- Python Script

```
"""
MVP Landcover Change Event Metrics Script Tool
By Jessica Pierce
University of Redlands

"""
import arcpy

def LCChangeMetrics(): # LC Change Quantifier

    # To allow overwriting outputs change overwriteOutput
    option to True
    arcpy.env.overwriteOutput = True

    LC_Change_Event_Hosted_FL = arcpy.GetParameter(0)
    Landcover = arcpy.GetParameter(1)
    Hydrology_2_ = arcpy.GetParameter(2)
    Roads = arcpy.GetParameter(3)
    LC_Change_Event_Copy = arcpy.GetParameter(4) # for
where to put copied feature class
    LandCover_FeatureToLine = arcpy.GetParameter(5) # for
where to put feature to line output

    # Process: Select Layer By Attribute (Select Layer By
Attribute)
    Landcover_2_, Count =
arcpy.SelectLayerByAttribute_management(Landcover,
"NEW_SELECTION", "Type = 'PAS' Or Type = 'BRN'")

    # Process: Copy Features (Copy Features)

arcpy.CopyFeatures_management(LC_Change_Event_Hosted_FL,
LC_Change_Event_Copy)

    # Process: Feature To Line (Feature To Line)
    with arcpy.EnvManager(extent="688316.37663877
1023200.19178244 710249.997327876 1032510.91234963"):
        arcpy.FeatureToLine_management(Landcover_2_,
LandCover_FeatureToLine)
```

```

# Process: Near (Near)
with arcpy.EnvManager(extent="688316.37663877
1023200.19178244 710249.997327876 1032510.91234963"):
    LandcoverchangeEventCopy =
arcpy.Near_analysis(in_features=LC_Change_Event_Copy,
near_features=[Roads], search_radius="",
location="NO_LOCATION", angle="NO_ANGLE",
method="PLANAR")[0]

# Process: Add Join (2) (Add Join)
_0_Layer2 =
arcpy.AddJoin_management(LC_Change_Event_Hosted_FL, "Name",
LandcoverchangeEventCopy, "Name", "KEEP_ALL")[0]

# Process: Calculate Field (4) (Calculate Field)
_0_Layer2_2_ =
arcpy.CalculateField_management(_0_Layer2,
"L0Landcover_Change_Event.Distance_Roads",
"!LandcoverchangeEventCopy.NEAR_DIST!", "PYTHON3", "",
"TEXT")[0]

# Process: Near (3) (Near)
if _0_Layer2_2_:
    LandcoverchangeEventCopy_2_ =
arcpy.Near_analysis(LC_Change_Event_Copy,
[Output_Feature_Class], "", "NO_LOCATION", "NO_ANGLE",
"PLANAR")[0]

# Process: Add Join (3) (Add Join)
if _0_Layer2_2_:
    _0_Layer3 =
arcpy.AddJoin_management(LC_Change_Event_Hosted_FL,"Name",
LandcoverchangeEventCopy_2_, "Name", "KEEP_ALL")[0]

# Process: Calculate Field (5) (Calculate Field)
if _0_Layer2_2_:
    _0_Layer3_2_ =
arcpy.CalculateField_management(_0_Layer3,
"L0Landcover_Change_Event.Distance_Deforest",
"!LandcoverchangeEventCopy.NEAR_DIST!",
"PYTHON3","", "TEXT")[0]

# Process: Near (2) (Near)
if _0_Layer2_2_ and _0_Layer3_2_:

```

```

Updated_Input_Features =
arcpy.Near_analysis(LC_Change_Event_Copy, [Hydrology_2_],
"", "NO_LOCATION", "NO_ANGLE", "PLANAR")[0]

# Process: Add Join (Add Join)
if _0_Layer2_2_ and _0_Layer3_2_:
    _0_2_ =
arcpy.AddJoin_management(LC_Change_Event_Hosted_FL, "Name",
Updated_Input_Features, "Name", "KEEP_ALL")[0]

# Process: Calculate Field (3) (Calculate Field)
if _0_Layer2_2_ and _0_Layer3_2_:
    _0_4_ = arcpy.CalculateField_management(_0_2_,
"L0Landcover_Change_Event.Distance_Hydrology",
"!LandcoverchangeEventCopy.NEAR_DIST!", "PYTHON3", "",
"TEXT")[0]
arcpy.AddMessage("Distance fields updated.")

# Original ModelBuilder:
#file:///C:/Second%20Semester/MIP/images/LC%20Change%20Quantifier.svg

```

Appendix C. Hydrology and Roads Metadata

*These layers and metadata were retrieved through the University of Redlands Center for Spatial Studies

Hydrology

Name	hydrology
Source	Multiple: gps, digitizing, other
Type	Line
Accuracy	varies
Extent	Northwest Panama
Year	varies

Fields

Name	Type	Length	Notes
Name	Text	100	
NameAliases	Text	100	Comma separated
Difficulty	Short		1-5 (5 is most difficult)
Source	Text	100	Data source (Who)
Month	Short		Two digit
Year	Short		Four digit
Method	Text	100	How is was created
Accuracy	Text	100	
Notes	Text	100	
Classification	Text	50	

Roads

Name	Roads
Source	Multiple: gps, digitizing, other
Type	Line
Accuracy	varies
Extent	Northwest Panama
Year	varies

Fields

Name	Type	Length	Notes
Name	Text	100	
NameAliases	Text	100	Comma separated
RouteNumber	Short		
Source	Text	100	Data source (Who)
Month	Short		Two digit

Year	Short		Four digit
Method	Text	100	How is was created
Accuracy	Text	100	
Notes	Text	100	

Notes/Questions

- Imported all roads from OpenStreetMap from an extract here: https://geonode.wfp.org/layers/ogcserver.gis.wfp.org%3Ageonode%3Apan_trs_roads_osm
 - Source was given as OSM
 - Used SurfaceType and RoadClass when available
 - Erased watershed roads from OSM to give priority to our road sources

Digital Elevation Model – 30m

Name	DEM_SRTM_30_Mamoni
Source	30m SRTM (Shuttle Radar Topography Mission) http://dwtkns.com/srtm30m/
Type	Raster
Resolution	30m
Extent	Northwest Panama
Year	2000

- Elevation in meters. Used to generate derivative elevation products – slope, hillshade, contours, flow direction, etc.

Trails

Name	trails
Source	Multiple: gps, digitizing, other
Type	Line
Accuracy	varies
Extent	Northwest Panama
Year	varies

- Fields

Name	Type	Length	Notes
Name	Text	100	
NameAliases	Text	100	Comma separated
Difficulty	Short		1-5 (5 is most difficult)
Source	Text	100	Data source (Who)
Month	Short		Two digit
Year	Short		Four digit
Method	Text	100	How is was created
Accuracy	Text	100	
Notes	Text	100	