Determining Priority Vegetation Polygons for Common Stand Exam Data
Collection Using a GIS-based Sampling Strategy

By Kristin M. Kolanoski

A Practicum

Submitted in Partial Fulfillment

of the Requirements for the Degree of

Master of Science

in Applied Geospatial Sciences

Department of Geography, Planning, and Recreation

Northern Arizona University

March 8, 2017

Approved by:

Amanda Stan, Ph.D.

Erik Schiefer, Ph.D.

Tony Smith

Acknowledgments

I would like to thank my advisors for giving me guidance during these last several years while I have been working towards obtaining a Master's in Applied Geospatial Sciences from Northern Arizona University. My supervisor Tony Smith also gave me much needed support and encouragement while I was in school and simultaneously working fulltime in the GIS shop on the GMUG. The experience of working on this project was very rewarding for me; it gave me an opportunity to pursue an advanced degree in GIS while providing a needed deliverable for the GMUG.

I also thank my husband Corey and daughter Sienna for their patience and understanding of my commitment to completing this degree and Sally Zwisler for her knowledge and help with understanding all of the components of the regional change detection project before she retired from the US Forest Service in January, 2016. Furthermore, I appreciate Carol Howe's continued dedication to this ongoing project and her coordination and communication with RSAC, GMUG timber staff, and USFS Region 2 Vegetation Applications Coordinator to encourage forward movement of and assist with the mortality update process for the GMUG.

Table of Contents

Determining Priority Vegetation Polygons for Common Stand Exam Data
Collection Using a GIS-based Sampling Strategy

List of Tables and Figures

ABSTRACT

Forests in the western United States have experienced high levels of tree mortality
over the last ten to fifteen years. Climate change has been touted as a major cause
of this mortality. Climate change is associated with an increase or change in biotic
and abiotic agents that serve as environmental stressors to ecosystem function and
structure, testing the ability of certain tree species to respond and survive in
environmental conditions outside of historic variability. Bark beetle infestations and
factors associated with sudden aspen decline (SAD) are examples of these
environmental stressors linked to the unprecedented mortality in spruce (*Picea spp.*),
fir (*Abies spp.*), pine (*Pinus spp.),* and aspen (*Populus tremuloides*) stands across the
western US. The Grand Mesa, Uncompahgre, and Gunnison National Forests (GMUG)
in southwestern Colorado have not been excluded from this tree mortality
phenomenon. Over 229,000 acres of aspen and 223,000 acres of spruce have been
negatively affected by SAD and spruce beetle, respectively on these three Forests
over the last decade. Unfortunately, in addition to the negative effects these
occurrences have had on the health of these forested ecosystems, the
unprecedented tree mortality has also led to inaccurate measurements of stand
condition in US Forest Service (USFS) databases for the GMUG. More specifically,
tree mortality has altered percentages of live and dead trees and corresponding
canopy cover estimations within forested polygons. Accurate characterizations of
existing vegetation structure are needed to plan treatments aimed at building

resilience and recovery of spruce and aspen on the Forests as well as to fulfill the

need of the planning framework for the revision process of GMUG's Land and

Resource Management Plan, which is slated to begin in 2017.   Vegetation polygons

that are created and maintained in a USFS geodatabase system, known as FSVeg

Spatial, are the units that delineate and describe existing vegetation on the GMUG

and other National Forests and Grasslands.   According to the R2 Supplement of the

FSVeg Spatial User Guide, individual polygons are generally homogeneous in

dominant lifeform, species composition, percent crown cover, size, vertical and

horizontal structure, and tree crown condition.   Recorded attributes of polygons

include species, tree size class, crown condition, and canopy cover percentage,

including the percentage of the canopy that is dead.   Remotely sensed data has been

used by the Remote Sensing Applications Center (RSAC) to detect significant change

that has occurred from 1989 until 2014 in these polygons caused by tree mortality.

Because there are over 18,000 forested polygons on the three Forests that have

experienced significant tree mortality, an automated algorithm will be created to

update live and dead canopy cover percentages of each polygon included in the

update procedure. Before the employment of this update, field data at the polygon

level needs to be collected in order to calculate tree mortality rates by species and

size class and build tree mortality rule sets for use in the algorithm. To choose

polygons for field data collection, or common stand exam (CSE) data collection, a

GIS-based sampling strategy was developed and documented using ArcGIS

ModelBuilder (v. 10.3.1). Some of the considerations in building the sampling strategy

were as follows: the strata to which a polygon belonged, proximity of a polygon to

maintained roads, a polygon's location in regards to Wilderness or areas with special

protection designations, a polygon's size, the date at which CSE data collection

occurred if CSE data had been collected in a polygon in previous years, whether or

not reshaping of a polygon in its current state was needed to meet the definition of a

polygon outlined in the R2 Supplement to the FSVeg Spatial User Guide, and the

funds allocated to CSE data collection. The purpose of this Practicum was to

prioritize and select forested vegetation polygons for CSE data collection using a GIS-

based sampling strategy. The polygon prioritization resulting from the sampling

strategy would then provide guidance of where to focus CSE data collection efforts

on the GMUG for the mortality update project (also known as the change detection

project) while trying to minimize the cost of contract data collection.

Chapter Outline

This Practicum document consists of five chapters. Chapter 1 provides an

introduction, leading to the problem statement, project questions, and purpose of

the project.   Chapter 2 consists of a literature review of areas of research applicable

to the vegetation polygon update process discussed in this Practicum. Chapter 3

details the methods used to conduct the GIS work needed to answer the questions

raised in Chapter 1. Chapter 4 presents the results of the GIS work. Chapter 5

discusses the results arising from the GIS work conducted and gives conclusions

drawn from the results. Chapter 5 also provides the reader with an understanding of

any problems, issues, and difficulties encountered while completing tasks outlined in

the methodology section. Chapter 5 also provides a discussion on management

implications of the work completed in this project and how the data used in this

project will continue to be used in improving characterizations of forested vegetation

polygons on the GMUG. The appendices provide additional literature review and

supplemental figures related to the Practicum project.

Chapter One

1.1 Introduction

Forest stands across the western United States and Canada have experienced a

dramatic increase in tree mortality over the last ten to fifteen years (Mueller et al.

2005; Marchetti et al. 2011; Bentz et al. 2010; Michaelian et al. 2011; Anderegg et al.

2013; USDA Forest Service, 2016a). Drought and elevated temperatures have caused

trees to be physically stressed and in turn, more vulnerable to insect and disease

infestations and attacks (Herbertson and Jenkins, 2008; Bentz et al. 2010). Trees

unable to protect themselves from insect and disease attacks due to their weakened

defense mechanisms eventually die. The result is a large number of trees within

stands dying, a process that initiates significant changes in structure, composition,

and function of stands and overall decreased forest health.

Silviculture has been a long standing practice, since the early 20th century in America,

by which various treatments often including some kind of tree removal technique(s)

are applied to create and manage forest stands according to the purpose and

objectives established by the governing agency or landowner (Mustian, 1978, Smith

et al. 1997). Classifying stands prior to designing treatments is essential for

successful implementation of the treatments and accomplishing the desired

objectives. Multiple methods have been utilized to characterize forest stands. The

methods can involve one or more of the following: field reconnaissance and

observations by a silviculturist or forester, detailed vegetation composition data

using field plots such as with common stand exams (CSE), remote sensing data, and

more recently LiDAR data (Moffiet et al. 2005; McRoberts et al. 2010; Pascual et al.

2013; Kelley and Di Tommaso 2015). In general, stand classification involves

determining general differences in composition and structure of the forest across a

landscape, establishing stand boundaries to spatially designate different stands

according to these general differences, and then determining tree species, age class

(by measuring height and diameter at breast height), basal area, and canopy cover or

crown closure, and other related attributes within each of the stands.

The GMUG in southwestern Colorado has experienced an increase in tree mortality,

especially in stands consisting of Engelmann spruce *(Picea engelmannii),* subalpine fir

(Abies lasiocarpa), Douglas-fir *(Pseudotsuga menziesii),* white fir (*Abies concolor)*, and

aspen *(Populus tremuloides)* over the last ten to fifteen years (Marchetti et al. 2011;

Worall et al. 2010; USDA Forest Service, 2016a). Climate change has been linked to

the increase in bark beetle infestation, sudden aspen decline, and other diseases and

insect infestations causing the unprecedented tree mortality on the GMUG (Worall et

al. 2008; Worall et al. 2010; Marchetti et al. 2011; Rehfeldt et. al 2015; USDA Forest

Service, 2016a). Other damage causal agents such as western spruce budworm

(Choristoneura occidentalis) and fir engraver *(Scolytus ventralis)* are also contributing

to the mortality of spruce and fir on the Forests (Todd Gardiner, personal

communication, April 25, 2015). To attempt to address this increase in tree mortality

and decrease in forest health, the GMUG is in the process of implementing

silvicultural treatments under the direction of the Spruce Beetle Epidemic Aspen

Decline Management Response (SBEADMR) project. A Record of Decision (ROD) for

the Environmental Impact Statement (EIS) for SBEADMR was issued and signed by

GMUG's Forest Supervisor in July, 2016. This project has and will implement different

silvicultural and fuels management treatments across the GMUG, focusing on the

promotion of resiliency and recovery within stands consisting of *Picea engelmannii*

(Engelmann spruce) and *Populus tremuloides* (aspen) (USDA Forest Service, 2016a).

Planning for this project was programmatic in nature, which means the project was

designed so that treatments could be implemented once the necessary surveys and

clearances are made and not prior to the ROD of the EIS being signed. Therefore, no

comprehensive stand exam data or forest inventory took place specifically for

planning of SBEADMR prior to it being approved. In many areas on the GMUG, stand

attributes were populated using the original aerial photography interpretation, much

of it occurring in late 1980s and early 1990s, to delineate and describe vegetation

polygons. Therefore, the tabular records of many forested vegetation polygons are

in need of being updated to represent existing conditions on the GMUG for use in the

SBEADMR project.

A vegetation polygon is defined by the R2 Supplement to the FSVeg Spatial User

Guide as an area being generally homogeneous in structure and composition.   More

specifically, a polygon needs to be similar and uniform in dominant lifeform, species

composition, percent crown cover, size, vertical and horizontal structure, tree crown

condition, and occasionally topographic features that may be indicative of vegetative

change such slope breaks (USDA Forest Service, 2016b). Some polygons can be void

of vegetation and are identified by their ground surface cover type such as rock

slides, quarries, glaciers, and wide roads. A forested vegetation polygon is one

having at least 25% of its area consisting of trees (USDA Forest Service, 2016b).

Forested polygons are the focus in this study and whose attributes are to be updated

with the automated algorithm.

Review of stand attributes and spatial delineations of vegetation polygons are

intended to take place prior to determining plot locations for CSE data collection as

well as before any implementation of timber sales and other silvicultural treatments.

If it is determined that edits need to be made to polygons, these edits need to take

place within FSVeg Spatial database prior to plot layout. Stand attributes can be

updated prior to or after CSE data has been collected. Areas can be re-delineated

and reattributed using a variety of different methods, ranging from: 1) field collection

of common stand exam (CSE) point data; 2) interpretation of high resolution aerial

imagery, which provides a moderately accurate approach to classify stands,

depending on the spatial resolution of the data used and interpreted; 3) LiDAR data,

which provides high accuracy in determining stand structure characteristics but not

species composition; and 4) site and stand visits by a silviculturist or forester to

perform qualitative assessments on stands, which provides less accuracy but

potentially more overall species composition and structure information for

characterizing stands. The qualitative assessment involves collecting descriptive

rather than quantifiable information regarding the composition and structure of a

polygon. This assessment is performed using specific agency protocols found within

the R2 Supplement of the FSVeg User Guide. These protocols and the FSVeg Spatial

database is explained further in the Methods section of this document. Nonetheless,

priority of data collection is designated usually for stands where timber sales will

occur in the near future. Other stands in which treatment implementation is not

planned to occur within the next five years usually do not have recently collected

field data associated with them, unless they have been or were supposed to have

been part of a timber sale sometime in the recent past.   Therefore, valid field data is

lacking to adequately characterize and update outdated tabular data for forested

vegetation polygons on the GMUG, especially for forested polygons having timber

that is considered unsuitable for potential timber sale.

Additionally, GMUG foresters have not been able to keep up with the need to

implement several treatments over a large number of acres because such large

increases in tree mortality have happened in a short amount of time. Also,

decreasing annual budgets and correspondingly smaller workforces have contributed

to the challenge of meeting the need for increased data collection and performance

and completion of other duties associated with implementing timber sales. These

challenges come at a time when Forest Plan Revision is scheduled to begin in 2017.

Forest Plan Revision will need to rely on existing data for the different resources to

perform assessments, many of which will involve GIS exercises to determine need for

change and revise current management direction and guidelines to be instituted in

the new Forest Plan. Knowledge of existing vegetation conditions are needed to

ascertain desired future conditions of the different resources on the Forests,

including the forested vegetation. Currently, different methods are being looked at

to more quickly update and determine existing vegetation conditions. One such

method is using remotely sensed data to detect significant change within forested

vegetation polygons due to tree mortality and document that change with a spatial

and tabular data update process.

To apply such technologies to update forested polygons on the GMUG and other

Forests in Region 2, methods used in a pilot study conducted from 2011 to 2014 on

225,000 acres of the Parks Ranger District, Medicine Bow-Routt National Forest in

north-central Colorado are being used (Stam et al. 2015a, Stam et. al. 2015b, Stam et

al. 2015c).   Region 2 is one of nine broad geographic areas managed by the US Forest

Service and includes National Forests and Grasslands within Colorado, South Dakota,

Nebraska, Kansas, and most of Wyoming. The main impetus for developing this

methodology was to address the changes in vegetation polygons due to increased

tree mortality from bark beetle and other insect and disease infestations across

National Forest lands in Region 2.   In the last two years, the Rio Grande and San Juan

National Forests in Colorado have also completed the automated update process for

their forested polygons. On the Rio Grande, 2,680 plots were visited during the 2014

and 2015 field seasons and CSE data was collected from a total of 335 polygons for

the tree mortality update process (Stam et al. 2016). No official report detailing the

update process for the San Juan NF has been released as of yet.

1.2 Problem Statement

The purpose of this study was to determine the number and location of polygons

that were visited in the field during the summer of 2016 and will be visited during the

2017 summer field season for CSE data collection. The purpose of collecting CSE data

is to build tree mortality rule sets. Once built, the rule sets will be implemented in an

automated algorithm originally developed in the pilot study conducted on the

Medicine Bow- Routt NF (Stam et al. 2015a, Stam et al. 2015b, Stam et al. 2015c).

However, the algorithm will be customized with tree mortality rule sets specific to

the GMUG when it is used to update live and dead canopy cover percentages of

forested polygons.

1.3 Practicum Questions

 My research questions addressed in this Practicum included:

1) How many polygons would be included in the base population for sampling

   priority polygons?

2) Which strata would be considered for CSE data collection for mortality rate

   calculation?

3) How many acres of each stratum need to be sampled to accurately portray

   stand conditions in each stratum for CSE data collection?   The goal for CSE

   data collection for this project was to collect data from 10% of each priority

   stratum's acreage. Then the question follows. If the 10% goal cannot be

   attained, then from how many acres in each stratum would data be collected?

4) What and how many criteria would be used in the GIS sampling strategy to

   prioritize the polygons to be visited in the field for CSE data collection?

5) How many priority polygons would result from the GIS sampling strategy?

 Other more specific questions that were asked in this project included:

6) How many vegetation polygons already had recent and valid CSE plot data

   associated with them that reflected existing conditions within the polygons?

7) How many acres of each stratum were covered with recent and valid CSE data

   collection?

The Methods section describes the procedures by which these questions were

addressed.

Chapter Two

Literature Review

2.1 Tree Mortality on GMUG
Forests in the Rocky Mountain region or Region 2, and especially on the GMUG, have

experienced a large amount of tree mortality due to the infestation of bark beetles

(*Dendroctonus* spp*., Scolytus ventralis, and Ips* spp*.).* By 2014, approximately 30% of

the total spruce-fir vegetation (223,000 acres) on the GMUG had been damaged by

bark beetle infestation, indicating a rapidly expanding outbreak on the three Forests

(USDA Forest Service, 2016a).   Based on projected warming and population models,

Bentz et al. 2010 found that thermal regimes conducive to population success of

spruce bark beetle and mountain pine beetle will generally increase throughout this

century even though there are patterns of high spatiotemporal variability for these

regimes. Also, population models suggest that movement of bark beetle populations

to higher latitudes and elevations will occur as a response to increasing temperatures

associated with climate change. Despite the complex nature of bark beetle

interactions with biotic and abiotic factors and the uncertainty associated with

predicting the insects' responses to climate change, many view the decline of spruce

as a response to climate change as inevitable (Bentz et al. 2010).

Modeling has been shown to be a useful tool in showing changes in population

distributions over time and climatic niches, those range of climatic conditions in

which forest tree species are adapted, in response to changing environmental

conditions. Specifically modeling has been used to show areas where spruce will

have the highest likelihood of adapting to and surviving in the next 45 years on the

GMUG (Rehfeldt et al. 2015). The modeling results suggest that land managers

should focus treatment efforts on spruce stands that have a better chance of survival

from climate change effects. Treatments, such as those resulting in basal area

reductions, should be designed to promote conditions within spruce stands that are

more resilient to insect infestations associated with climate change.   Hansen et al.

2010 examined stands consisting predominantly of Engelmann spruce that were

treated with partial cutting as a part of forest management activities on the Apache-

Sitgreaves National Forest in Arizona, Medicine Bow-Routt National Forests in

Colorado and Wyoming, and Dixie-Fishlake and Uinta National Forests in Utah. The

purpose of this examination was to evaluate partial cutting as a preventative strategy

of reducing spruce-beetle caused mortality. Hansen et al. 2010 found that despite the

lack of experimental control for factors such as treatment type and random

assignment to experimental units, partial cutting in the central and southern Rocky

Mountain spruce type resulted in significant reductions in subsequent spruce beetle-

caused tree mortality. The GMUG has incorporated resiliency treatments within the

proposed alternatives of the SBEADMR project in order to address the spruce beetle

epidemic that the Forests are currently experiencing and how to plan for the long

term effects of current and future climate change on spruce-fir forests on the GMUG.

In addition to resiliency treatments, sanitation and salvage treatments also are being

utilized in this project to increase the likelihood of stands currently infected being

able to naturally regenerate and recover from spruce beetle attack over time.

Sudden aspen decline (SAD) has led to increased mortality within aspen stands in the

western United States. On the GMUG, SAD was first detected in 2004 and has been

shown to have affected approximately 31% (over 229,000 acres) of aspen on the

GMUG from 2004 to 2010 (USDA Forest Service, 2016a). Sudden aspen decline has

not been contributed to the infestation and attack of an aggressive primary

pathogen(s) or insect(s) but to the rapid, synchronous branch dieback, crown

thinning and mortality of aspen stems on a landscape scale (Worrall et al. 2010).

Stands most effected by or predisposed to the effects of SAD are those existing in

vegetation transition zones or within the lower elevational gradient of aspen that

experience the driest and warmest conditions during periods of drought (Worrall et

al. 2008, Worrall et al. 2010). Furthermore, declining and damaged stands from SAD

were more prone to the negative effects of secondary insects and diseases as

compared to healthy stands to these same agents (Marchetti et al. 2011). These

secondary agents amplified the impact of SAD on trees that died but may have

otherwise recovered from SAD. Furthermore, Ireland et al. 2014 found that mortality

of younger aspen trees was attributed to lower recent growth rates and higher

frequencies of abrupt growth declines and this correlation occurred regardless of the

presence of SAD. This suggests that aspen stands affected by SAD and consisting of

individuals with slower growth rates may not recover as quickly or at all from SAD as

compared to stands consisting of individuals with higher growth rates. Therefore,

recovery of aspen stands from the effects of climate change and SAD will rely on the

species ability to adapt to these abiotic and biotic stressors and how quickly this

adaptation of those stands takes place.

Planning for shifts in vegetative communities over time as a result of climate change

will become a major challenge to land management agencies to address in future

NEPA (National Environmental Policy Act) analyses. In the SBEADMR EIS, the GMUG

has described management actions and treatments that can be implemented over

the three Forests to address the potential changes in spruce-fir and aspen

communities resulting from climate change. More specifically, the SBEADMR project

proposes treatments within opportunity areas consisting of aspen that encourage

aspen regeneration through thinning, prescribed fire treatments, or a combination of

both. However, more research will need to be conducted and further knowledge

gained through adaptive management practices to highlight the importance of which

forest management practices are successful in equipping stands with the ability to be

resilient and respond to the effects of climate change. Perhaps the precepts of

forest health and sustainability will be redefined as forests are built to be more

resilient to changing climatic conditions.

To better design silvicultural treatments for project planning and establish relevant

and SMART (specific, measurable, assignable, realistic, and time-related) objectives in

the revised Forest Plan for the GMUG, recent tree mortality will be accounted for in

forested polygons on the GMUG by using remotely sensed data to detect significant

change within forested polygons and collecting field data to determine percentage

of dead within different strata of polygons. The percentage of dead for each age and

species class within sampled polygons will be quantified by CSE data previously

collected and still valid to use for this purpose. Validity of field data is based on

criteria that is explained in detail in the Methods section. Percentage of mortality will

also be calculated using CSE data collected in the summer of 2016 and additional CSE

data to be collected in the summer of 2017. To select those polygons from which

field data would be collected, while keeping within budget constraints of the project

and addressing the future needs of GMUG timber shops for CSE data collection, I

created a GIS sampling strategy using ArcGIS ModelBuilder.   Chapter 3 provides

detail for the formulation of the GIS sampling strategy. Below I provide a literature

review discussing applications of ModelBuilder for natural resources management

along with ways in which remotely sensed data has been employed in directing forest

management practices and policy.

2.2 ArcGIS ModelBuilder for Decision Support

The development and technological advances in geographic information systems

(GIS) have been instrumental in advocating efficiency in the way in which resource

specialists, researchers, managers, and educators analyze and decipher relationships,

patterns, and trends among components coexisting on the Earth.   GIS has allowed

humans to visually see how these various components interact, are associated with

one another spatially, and how these components change or differ over time within a

spatial context.

The Environmental Systems Research Institute (ESRI) has made it easier for

individuals to operate a GIS and view and analyze the relationships via a computer,

tablet, personal display assistant (PDA), or smartphone device through ArcGIS

software products and ArcGIS Online (AGOL), online GIS. One of the most commonly

and frequently used ArcGIS products is ArcGIS for Desktop which can be operated

from a desktop computer allowing the user to perform data building and editing,

spatial analysis and geoprocessing, modeling, and map display.

One of the most powerful applications that ArcGIS offers is ModelBuilder. It has

been often utilized as a tool to provide direction in decision making for various

resource areas. For this reason, the workflows organized and executed by models

created by programming languages and applications such as ModelBuilder have been

coined as Spatial Decision Support Systems (SDSS) or DSS (Decision Support

Systems). SDSS are models that incorporate both GIS and nonspatial parameters into

the decision making process; however, the term DDS has also been employed in the

literature to describe decision support models utilizing both spatial and nonspatial

parameters. The uses of ModelBuilder have ranged from the development of a DDS

for delineating homogenous regions based on multiple criteria such as hydrography,

physical environment, socioeconomics, and political-administrative aspects for

integrated water resources planning and management (Coelho et al. 2012) to the

creation of a SDDS to support the timber harvesting decision making process in

Austria by comparing harvesting systems and selecting the best suitable system

based both on stakeholder interests and environmental conditions (Kühmaier and

Stampfer 2010).   Systems such as these were designed to be flexible and adaptable

and provide some objectivity through the creation of a systematic framework that

structures a decision problem and identifies creative decision alternatives.

ModelBuilder offers many advantages in its use for data analysis involving

geoprocessing and examination of spatial relationships. One main advantage is that

it allows the user to integrate multiple geoprocessing functions into a single

workflow (ESRI, 2016, Allen 2011). Tang et al. 2014 used ModelBuilder along with

ArcHydro Tools to develop a protocol for delineating watershed boundaries in the

Rainwater Basin in south-central Nebraska. This protocol involved processing many

different LiDAR datasets through the execution of a multitude of geoprocessing

functions. Tang et al. 2014 was able to rerun the model to perform the same

geoprocessing functions for each of the different datasets. The end product was

defining playa wetland topographic conditions in the Basin.

Another benefit of ModelBuilder is that it requires no special programming skills of

the user, allowing the user to learn relatively easily and quickly how to build, edit, and

manage models (Tang et al. 2014). Chi (2010) used the interface of ModelBuilder to

generate an index of land developability that could be included in social demographic

research. The hope stemming from this work was to encourage demographers who

lack experience in performing spatial analysis of land use and development in relation

to population research to do just this by having access to an easy to use GIS function

such as the land developability index model. Chi 2010 emphasized that ModelBuilder

shows the procedure of the entire analysis via flowchart which helps demographers

who do not use GIS frequently understand and conduct the model with ease.

Other advantages of ModelBuilder are that it enables the user to document analysis

workflows for projects, rerun the same workflow, and modify an existing model by

changing input datasets or functions for alternative analyses. The USFS and Bureau

of Land Management (BLM) have used ModelBuilder to more easily document

geoprocessing steps of geospatial analyses designed to meet planning needs. Dave

Sinton, GIS Specialist for the BLM Uncompahgre Field Office in Montrose, Colorado,

established official geospatial layers for the alternatives in the BLM Uncompahgre

Resource Management Plan (RMP), currently being revised, using ModelBuilder. The

RMP is the BLM equivalent to the Forest Plan or FLMP for the USFS and is an official

NEPA document. These models established not only the layers but also the

documentation on how the layers were created. One example is the target shooting

additions model in the recreation toolset (Figure 1). This model produced potential

sites for target shooting on BLM lands managed by the Uncompahgre Field Office.

Mr. Sinton also helped the BLM's State Planner address and answer questions about

RMP alternatives dealing with mineral extraction. He created a model known as the

TL Calculator whose purpose was to calculate the number of acres having timing

limitations and no surface occupancy for mineral extraction on all land administered

by the Uncompahgre Field Office and specifically in the North Fork area. This model

aided in further developing alternatives addressing mineral extraction issues and

concerns.

The USFS has used ModelBuilder in a similar fashion as the BLM in assisting with

planning efforts. For example, the Rio Grande National Forest (RGNF) in Colorado

has used ModelBuilder in creating a layer that displays those RGNF lands that are or

may be suitable for timber production. Cheryl O'Brien, GIS Coordinator for the RGNF,

created this layer as part of the Forest Plan Revision process. Areas having soils with

high mass movement potential, not owned by the USFS, within Wilderness, Colorado

Roadless areas (CRAs), and other specially designated USFS lands, and consisting of

nonindustrial species such as limber pine, bristlecone pine, pinyon, and juniper were

the criteria used in the model to represent those lands unsuitable for timber

production (Rebain, 2016).

A second example in which ModelBuilder has been used by the USFS is to provide

information support in the area of travel management. In 2015, I produced four

models in Modelbuilder that worked together to produce a road layer for the GMUG

that represented the minimum road set regulated in Subpart A of the Travel

Management Rule (TMR). TMR (Code of Federal Regulations, 2015a, Code of Federal

Regulations, 2015b, Code of Federal Regulations, 2015c) directs National Forests to

balance the use of the Forests by off road vehicles (ORVs) with other uses of the

Forests that may be incompatible with ORV use and with the environmental integrity

of the Forests. Subpart A specifically directs the Forest Service to identify the most

ecologically, economically, and socially sustainable road system in terms of access for

recreation, research, and other land management activities. The created models

assisted with meeting the requirements outlined in Subpart A by identifying those

roads under GMUG jurisdiction that are needed to administer NFS lands and are not

posing high risks to water resources and wildlife. In all, Modelbuilder meets two

critical needs of land management agencies for project and FLMP or RMP planning,

efficient execution of elaborate geospatial analyses and essential workflow

documentation for project records.

2.3 Applications of Remotely Sensed Data in US Forest Service
Remote sensing data has been used in different applications and analyses to view the

Earth for several decades, particularly since the launch of the first of the Landsat

satellites in 1972 (Cohen and Goward 2004). One of most applied uses of remotely

sensed data has been to detect change in land cover and land use (LCLU) over time

(Kennedy et al. 2007, Knorn et al. 2009, Xian et al. 2009, Andrew et al. 2014). In

addition to detecting change in LCLU on USFS lands, the US Forest Service has

utilized remote sensing data to view the state and condition of natural resources

over the landscape and determine the changes in resource condition over time.

Moreover, the agency has applied these remote sensing technologies in directing

natural resource management and policy on USFS lands.

Remotely sensed data has supported the implementation and enforcement of the

TMR.   The use of 1 m IKONOS satellite images overlaid on GIS maps of USFS system

roads helped monitor and identify unofficial, nonsystem roads and trails created by

ORV recreational use and pinpoint hotspot areas where the density of unofficial and

nonsystem trails was highest on the Dixie National Forest in Utah and Bridger-Teton

National Forest in Wyoming (Mayer and Lopez 2011).

For approximately twenty years, the Remote Sensing Applications Center (RSAC) of

the USFS, now the Geospatial Technology Applications Center (GTAC) , has helped

agency field units develop and implementless costly ways to obtain needed forest

resource information. It has conducted multiple projects utilizing and analyzing

remote sensing data to provide assistance in the areas of resource inventory, fire and

fuels, land cover change, and forest health among many others. For example, RSAC

recently examined whether Landsat data could be used to assess and monitor aspen

defoliation from aspen leaf miner in Alaska (Biswas et al. 2016). In addition, RSAC

generated LiDAR-derived 3-D canopy structure derivatives for describing canopy

height and density across the Kaibab Plateau,producing LiDAR forest inventory

models for modeling field-derived forest inventory parameters (Mitchell et al. 2015).

RSAC plans to use these models to help understand the links between 3-D canopy

structure and goshawk demographic performance on the Plateau. These projects,

among many others, have produced improved resource information for agency field

units or, in some cases, supplied first time data that has been invaluable in guiding

resource management planning efforts and has assisted USFS resource specialists

and land managers in making better informed resource management decisions.

2.4 Change Detection for Forest Management
One of the most well-known applications of remote sensing is change detection. The

premise in using remotely sensed data for change detection is that real changes in

objects of interest will be detected based on changes in reflectance values or local

textures rather than changes caused by other factors such as differences in

atmospheric conditions, illumination and viewing angles, and soil moistures (Deng et

al. 2008). Change detection requires the analysis of multitemporal imagery in which

images are acquired at two different times or over a continuous time scale or time

trajectory, to show a change in some aspect of ecosystem condition and/or function

over time (Singh 1989, Coppin et al. 2004). This type of analysis can provide useful

information for land management planning and decision making at local, regional,

national, and global levels (Deng et al. 2008). Changes on the landscape can occur

either due to anthropogenic causes or due to natural disturbance events. Also, the

rate of change can either be abrupt such as change caused by wildfire, logging

activities, or landslides or more gradual such as change from development or

biomass accumulation, allowing change to be assessed as either a categorical or

continuous variable (Coppin et al. 2004). Change detection techniques using

remotely sensed data involve procedures for both change extraction and change

separation and labelling, with one method potentially yielding a significantly

different change map than an alternate method. These techniques will not be

discussed in detail in this paper; however, many can be reviewed in Coppin et al.

2004, Collins and Woodcock 1996, and Singh 1989. Additionally, more simplistic

explanations of many of the change detection techniques can be found in Campbell

and Wynne 2011 and Lillesand et al. 2015.

2.4.1 Use of Spectral Vegetation Indices in Change Detection

Spectral vegetation indices (SVIs) have been instrumental in detecting and extracting

change in vegetation condition both within an image and among image sets. The

purpose of a SVI is to combine the effects of several spectral bands into a single value

to emphasize the unique spectral signature of green vegetation as compared to the

spectral signatures of other materials such as water, snow, bare soil, sand, exposed

rock, concrete, and asphalt. Nevertheless, SVI values can still be affected by

atmospheric effects, viewing and illumination angles, sensor calibration, geometric

registration errors, subpixel water and clouds, snow cover, background materials,

image compositing, and topographic features such as slope and relief.

Most SVIs compare differences between the red and near-infrared (NIR) reflectances

(Figure 1) because certain pigments in plant leaves strongly absorb wavelengths of

red light and plant leaves themselves strongly reflect wavelengths of NIR light. The

NIR region is to the right of the visible region of the electromagnetic spectrum

shown in Figure 2. The greater the difference among the red and NIR reflectances of

the imagery, the greater the amount of green vegetation present in the imagery.

Figure 1. Visual examples of NDVI Calculation

$$\text{NDVI} = \frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$
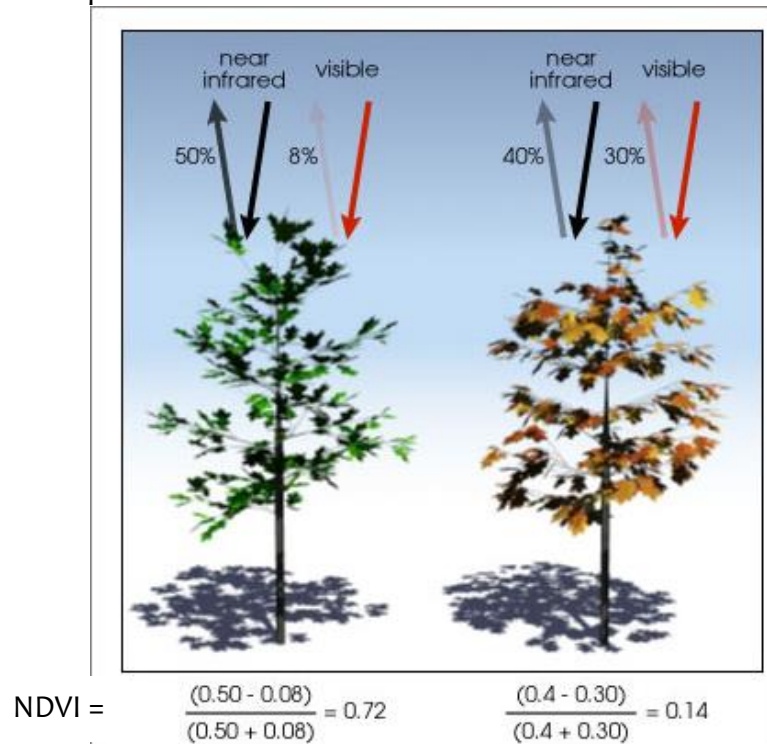
Modified from NASA EROS website
(http://earthobservatory.nasa.gov/Features/MeasuringVegetation/mea
suring_vegetation_2.php)

Figure 2. Electromagnetic Spectrum

Modified from (http://www.raptorphotonics.com/technology/visswir-cameras/)
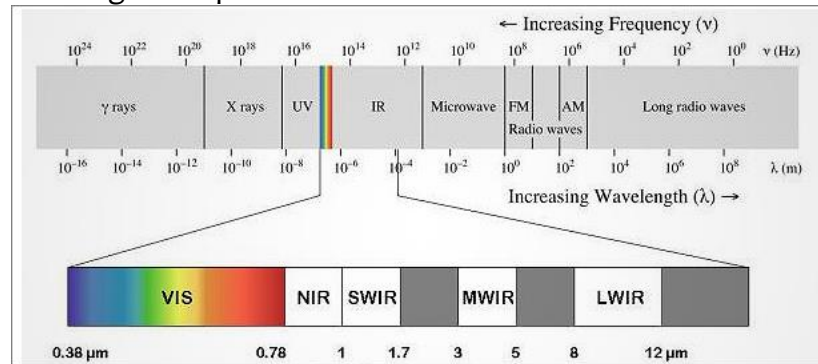
Some of the most used SVIs include NDVI (Normalized Difference Vegetation Index), NDMI (Normalized Difference Moisture Index), Simple Ratio or Ratio Vegetation Index (SR or RVI; RVI = NIR/RED or NIR/VIS), EWDI (Enhanced Wetness Difference Index), and Shortwave Infrared Band Differencing. Existing spectral vegetation indices have been enhanced and others developed to improve upon parameter estimations in various applications. The development and increased popularity of using SVIs, especially those utilizing the shortwave infrared bands (SWIR) (refer to Figure 3), in ecological applications can be linked to the launch of satellites belonging to the Landsat program, the first of which occurred in 1972 (Cohen and Goward 2004). Today, SVIs are being employed with data obtained from more recently launched Landsat satellites (Landsat 7- launched in 1999 and Landsat 8- launched in February 2013) and commercially operated satellites (i.e. fleet of DigitalGlobe satellites- WV-1, WV-2, WV-3, and GeoEye). NDVI and NDMI will be the two SVIs

mentioned and discussed further in this paper as both NDVI and NDMI have been

frequently used to detect and monitor changes in forest stand condition in North

America. Additionally, NDVI was the index used to detect significantly changed

forested polygons on the GMUG over a 25 year period. Although I did not perform

the NDVI classifications, the NDVI classification conducted by RSAC was essential in

providing the changed polygon dataset that would serve as the initial input for the

GIS based sampling strategy created and employed in my Practicum project.

NDVI has been one of the most widely used SVIs in determining the relative density

and health of vegetation across the landscape. NDVI is calculated whereby the

difference between the near-infrared and red reflectances is divided by their sum.

$$NDVI = \ (NIR - RED)/(NIR + RED)$$

NDVI values range from -1 to 1. Areas of barren rock, sand, or snow usually show very

low NDVI values (0.1 or less), whereas sparse vegetation such as shrubs and

grasslands or senescing crops are typically associated with moderate NDVI values

(0.2 to 0.5). No green leaves also gives a value close to zero and dense vegetation is

associated with high NDVI values ranging from 0.6 to 1.0.

NDVI has been used in a variety of ecological applications to assess change detection

on local, regional, and global scales. For example, NDVI derived from MODIS data

was used to determine annual change detection rates from 2003 until 2005 for the

Albemarle-Pamlico Estuary System region in the southeastern US (Lunetta et al.

2006). In addition to determining change detection rates for the area, the study was

able to ascertain advantages and limitations of using MODIS NDVI data for

monitoring change detection at different local scales and within particular land

classification types. A second study derived NDVI from Landsat TM imagery to

examine vegetation cover density and productivity in Yosemite National Park,

California (Potter 2015). NDVI from 1986 to 2013 was analyzed and the findings

showed that overall NDVI decreased in Yosemite NP over the 20+ year time period

examined, contradicting previous predictions of increased NDVIs associated with

altered evapotranspiration fluxes and river flows for the Sierra Nevada. One last

example of how NDVI has been used is showing changes in vegetation cover density

in Hervi Watershed, Iran from 1976 to 2010 (Vahidi et al. 2013). Changes in NDVI

which signaled changes in vegetation cover density during the 34 year time period

were attributed to land use change such as increased urban area extent, road

building, mining activities, non-managed farming, and conversion of dense pastures

(Vahidi et al. 2013).

Similar to but still different from NDVI, NDMI is a measure of vegetation moisture, as

it is sensitive to changes in vegetation leaf structure and water content. It is

calculated as the difference between the NIR and the shortwave infrared (SWIR)

reflectances divided by their sum.

$$NDMI = (SWIR - NIR)/(SWIR + NIR)$$

It can be used to detect subtle changes in vegetation moisture conditions and can be

used for drought monitoring. There are several examples to illustrate its use over the

last decade. NDMI was used to assess areas of vegetation transition between the

years 1985 and 2010 on the central coast of California (Hsu et al. 2012). Another

application of NDMI was its use as an indication of flammability and spreadability of

fire while developing a fire risk model and creating a fire risk map displaying wildland

fire potential for the continental US (Zhang et al. 2014). NDMI has also been

employed in change detection applications for forest management such as detecting

stages of tree mortality from insect infestation (Goodwin et al 2008).

2.4.2 Change Detection of Tree Mortality

The importance of SVIs in characterizing forest stands and the changes they undergo

when natural disturbances take place is well recognized (Skakun et al. 2003, Coops et

a. 2006, Wulder et al. 2006, Goodwin et al. 2008, Wulder et al. 2008, Meddens et al.

2011, Meigs et al. 2011). Much focus has been placed on large scale disturbances in

western North America such as bark beetle infestations and the resulting landscape-

scale tree mortality. Efforts have concentrated on determining the amount and type

of mortality that has occurred and predicting the direction and speed of mortality

into unaffected stands across the landscape. Several studies have investigated the

mortality caused by Mountain Pine Beetle (MPB) in Colorado, USA (Meddens et al.

2011, Meddens and Hicke 2014) and in the province of British Columbia, Canada

(Skakun et al. 2003, Coops et al. 2006, Wulder et al. 2006, Goodwin et al. 2008,

Wulder et al. 2008). Interest also has been placed in trying to understand spectral

trajectories of defoliator and bark beetle disturbances of varying duration and degree

across the landscape. Meigs et al. 2011 was able to detect both short and long

duration changes in spectral reflectance using LandTrendr, a Landsat time series

segmentation algorithm, indicating complex temporal dynamics in insect-affected

forests in the Cascade Range, Oregon, USA. All of these studies have added to the

knowledge about insect infestation from different agents and have led to a better

understanding in how insect infestations spread across the landscape and the nature

and duration of their existence.

2.5 *Remote Sensing Application for Meeting Forest Management Objectives*
The development of forest management objectives is dependent upon the type of

planning being conducted (Wulder et al. 2005). More detail is necessary for

developing objectives that address land management direction over a local rather

than regional or global scales, especially if that direction is tactical or operational in

nature. On the other hand, coarse level data may be appropriate and adequate for

addressing strategic planning goals which can be broader in management direction.

For example, in the province of British Columbia, Canada, Landsat TM (Thematic

Mapper) and ETM+ (Enhanced Thematic Mapper) data, having a medium spatial

resolution of 30 meters, were used to map MPB red attack using multi-date scenes

(Skakun et al. 2003; Wulder et al. 2006, Goodwin et al. 2008). MPB attack has been

categorized in three different stages. Red attack is the stage of mortality before the

needles, which are red in color, drop to the ground. This stage occurs approximately

one year after bark beetles attack the tree. The first stage of attack is known as

green attack and as the stage suggests, the needles on the tree are still green at this

point in time. However, to guide field crews in determining exact locations of red

attack tree clusters and more precise detail in the extent and shape of red attack

stands across the landscape, high spatial resolution imagery from IKONOS (1 m for

panchromatic and 4 m for multispectral spatial resolution) and QuickBird (0.67 m for

panchromatic to 2.44 m for multispectral spatial resolution) were obtained and

classified (Coops et al. 2006; Wulder et al. 2008). In this case, the Landsat data filled

the purpose of bridging strategic and operational planning goals by mapping areas of

and identifying patterns of red attack across the studied landscape for strategic

planning whereas the IKONOS and QuickBird imagery acquisitions were utilized to

provide finer level detail for operational planning.

Strategic planning has played a vital role in developing and implementing Forest

Resource and Land Management Plans (FLMPs) for the Forests and Grasslands in the

USFS system. Strategic planning entails and relies on first understanding the existing

condition of the area of interest before determining a desired condition and what

management actions to apply to reach the desired state. Landsat imagery with 30

meter spatial resolution has played a major role in these types of investigations by

giving a synoptic view of spatial variation over the landscape. Landsat imagery has

been used in many ecological applications over the last 45 years to understand both

spatial and temporal pattern variations within ecosystems. The main reasons for its

prevalent utilization is that the detail the data offers meets the need of detecting

change at the landscape scale and there is over four decades of archived Landsat

imagery available for change detection analysis. Also, since 2008, archived Landsat

scenes are available to download from the United States Geological Survey (USGS)

EROS (Earth Resource Observation Satellites) website at no cost, making these data

economically feasible.

In applying Landsat imagery to forest management applications in the US, Meddens

and Hicke (2014) using Landsat TM 5 and Landsat ETM+ 7 imagery, were able to

estimate the MPB red stage tree mortality from 1996 to 2011 in the forested areas of

northcentral Colorado, USA. Mortality in the study area was found to move from

north to east earlier in the outbreak and then intensify in already attacked stands

later in the outbreak. Also, beetle outbreaks within 30 m grid cells were found to last

3 to 4 years, with grid cells in outbreak areas experiencing an average of 60%

mortality in total and 20% mortality per year. These results helped to increase the

understanding of bark beetle ecology and dynamics in the study area as well as

present methods that could be utilized to map and monitor other tree mortality

events. Unlike the studies that took place in Angstad Creek, BC, Canada (Wulder et

al. 2006; Wulder et al. 2008; Goodwin et al. 2008), this study occurred when mortality

was not expanding into new areas and it was deintensifying in areas that had already

been attacked. Salvage for many areas could have been a management strategy to

take during the second to third year of attack (red and gray attack stages) in riding

areas of dead lodgepole pine. However, because timber is typically not valuable

enough in the US to offset the cost of timber logging, harvest of these trees does not

happen over the scale needed to remove a majority of dead trees. Steep slopes and

inoperable terrain can make logging operations virtually impossible, with helicopter

logging along with its exorbitant cost being the only option to remove trees.

Instead, smaller areas that have been affected and can be accessed with traditional

logging equipment are salvaged. Additionally, the NEPA process can slow down the

process of implementing silvicultural prescriptions in general, even if those

prescriptions manage for recovery and resilience. Therefore, the findings of the

study did not direct management in operational tactics in dealing with the MPB

outbreak but did provide insight regarding how the infestation and resulting tree

mortality manifested across the landscape.

2.5.1 Use of High Spatial Resolution Satellite Data
In many cases, high spatial resolution data can be utilized to address management

inquiries at both the strategic and tactical planning levels. Wulder et al. 2008 was

able to calculate the Red- Green Index (RGI), a ratio of the red to green wavelengths,

for forested stands in Angstad Creek, BC, Canada using QuickBird images acquired

annually during the growing seasons of 2003 to 2006. This measure was used in this

study because previously it had been shown to successfully detect red attack damage

of MPB (Coops et al. 2006). Once the change in RGI (ΔRGI) was calculated for the

initial 2003 image in the time series, a ΔRGI threshold was determined and set for all

images, and field data was referenced to validate the imagery classifications. Red

attack damage was mapped for the study stands in each image with accuracy

percentages ranging from 89% to 93%. Additionally, the G:R (green to red attack)

ratio was calculated for each image/year. A G:R >1 indicates an increasing bark beetle

population whereas G:R < 1 indicates a decreasing population. The methods

identified the red attack stands in the study area as well as determined rates and

direction of the beetle attack. This information helped managers, foresters, and

researchers alike see the spatial variation of green and red attack across the study

area. Additionally, they were able to consider effective management strategies for

making stands more resilient to beetle attack and how this particular assessment

could be used in the future to help guide strategic planning of beetle management

(Wulder et al. 2008).

The GMUG is mainly focusing on forest stands affected by spruce beetle and other

related insects for treatment implementation. As previously mentioned, SBEADMR

treatments are planned to be implemented in the next ten years to help with

recovery and resiliency of Engelmann spruce. Although most of studies reviewed in

this chapter have examined the effects of bark beetle attack on lodgepole pine, a

similar approach to investigating bark beetle attack of Engelmann spruce could be

attempted. However, there may be challenges with utilizing similar methodologies

as Wulder et al. 2008 and Meddens and Hicke 2014. One major challenge is that

many times Engelmann spruce coexist with other conifer species within stands and

do not grow as pure stands as lodgepole pine often does. This can make it difficult to

use remotely sensed data and photo interpretation to differentiate between multiple

tree species growing within mixed conifer stands. This is especially true if both

species are being affected by infestations from different agents and both species

look similar to one another when viewed in imagery due to similar growth form. This

particular situation is taking place on the GMUG, specifically on the Uncompahgre

Plateau where subalpine fir is being killed by spruce budworm and Engelmann spruce

mostly by spruce beetle. Also, often times, the two species are difficult to distinguish

from one another in imagery. Many other photo interpretation characteristics and

clues other than color, texture, aspect, and slope are often used to make a decision

as to which species is being viewed. However, with any type of photo interpretation

there will be errors in interpretation. Keeping errors of commission and omission low

would be important to accomplish when applying methodologies from Wulder et al.

2008 or Meddens and Hicke, 2014 in using remotely sensed data to classify spruce

bark beetle infestation of GMUG spruce-fir forests.

Chapter Three

Methodology

This study is comprised of four phases. Before I detail each of the four phases, I

provide descriptions of the FSVeg and FSVeg Spatial databases and their role in

vegetation polygon updates in general and not specifically for this Praticum. Also, I

explain the tools and applications used to perform GIS analyses and edits for this

Practicum.

3.2 Tools and other Applications

I used ArcGIS 10.3.1, the Natural Resource Information System (NRIS) Geospatial

Interface (GI), and FS Veg Spatial to perform the GIS analyses for this study. I also

utilized ModelBuilder, an extension of ArcGIS, to automate and document repeatable

geoprocessing steps used to produce alternative outputs of priority polygons.

Priority indicates those polygons satisfying multiple criteria that in choosing them for

data collection would potentially lead to a lower cost for CSE data collection for the

mortality update project.

The GI allows the user to have access to "live" transactional data from NRIS that may

not be included in the attribute tables of the same spatial dataset residing on the

local Forest server or through the Spatial Database Engine (SDE) or published to the

Enterprise Data Warehouse (EDW). "Live" data refers to data that is the most

current up to date attribute data for that spatial dataset. The GI connects the NRIS

tabular data to the spatial data that can be obtained via the SDE and then the NRIS

data can be seen in the attribute table of the geospatial layer. I performed parts of

this project's analysis with visualizations of NRIS and SDE data using the GI.

Specifically, the roads and activities layers used as input datasets in the models

created in this Practicum were retrieved from the GI.

3.3 Project Phases

3.1 Descriptions of FSVeg and FSVeg Spatial
Field collected data characterizing forest stand conditions, which is also known as

CSE data, is used to update structure and composition of forested vegetation

polygons. The National Common Stand Exam data collection protocols found in the

FSVeg (Field Sampled Vegetation) Common Stand Exam User Guide are used for

determining the number and arrangement of plots in each polygon from which to

collect CSE data, the specific measurements taken in each plot, and the plot size for

each measurement taken (USDA Forest Service, 2015). The CSE data collected in the

field is uploaded to and stored in the FSVeg tabular database.

Like FSVeg, FSVeg Spatial is a Forest Service database application that holds tabular

data that characterizes forested vegetation polygons. However, unlike FSVeg, FSVeg

Spatial is a national geodatabase system that consists of vegetation polygons and

CSE spatial point locations and associated relationship data tables that display

information on lifeform, layer, species, size, canopy or crown cover percentages, and

local cover types for each unique vegetation polygon delineation. FSVeg is a

database that is not GIS based and is solely dedicated to storing field collected CSE

data, until the data can be used for project analysis and creating reports detailing

timber stand metrics. This database also provides the plot level data to update

tabular records for vegetation polygon attributes in FSVeg Spatial.

Each region of the US Forest Service follows the FSVeg Spatial User Guide to create,

maintain, and update spatial delineations and attributes of vegetation polygons, but

each can have a separate protocol to address specific regional needs relating to

vegetation polygon maintenance.   Region 2 follows a particular protocol outlined in

the R2 Supplement of the FSVeg Spatial User Guide (2016b). More specifically,

Region 2 utilizes a R2 FS Veg Spatial Polygon Vegetation Attributes Form (Figure 3) to

collect information for each polygon such as sampling recorder, species survey

method, sample date, purpose code (method used to collect data, i.e. photo

interpretation, stand exam, walkthrough, quick plot stand exam, etc.), horizontal

continuity, crown condition, canopy closure or canopy cover, tree species, tree and

shrub size class, and dead percentage of each vegetation cover layer. This form may

be completed during photo interpretation of the polygon(s) or during walkthrough

visits. If CSE data is to be collected for polygons, a forester visits those polygons in

the field or views aerial imagery in GIS to determine if polygons need to be spatially

redelineated in FSVeg Spatial prior to designing plot layout. If he/she deems that

polygons need to be redelineated, the R2 attributes form is completed for each

polygon during the field visit/walkthrough and prior to CSE data collection to ensure

Figure 3. Form used during polygon walkthroughs to update existing polygon attributes in FSVeg Spatial

R2 FSVEG SPATIAL POLYGON VEGETATION ATTRIBUTES FORM

Rev 04-17-2014 Zwisler

POLYGON SAMPLE INFORMATION: *bold* fields are **required**

(in **NRIS_VegPoly** table)

|----------------------Setting ID----------------------|

Region Forest District*	Location* (6 chars for R2)	Polygon ID*	Species Survey Method*	Sample Recorder*	Sample Date* MM/DD/YYYY	Purpose Code*

(in **NRIS_VegCharacterizations** table)

Stocking Flag	Regen EV Code	Horizontal Diversity or Continuity*	Crown Condition (Trees)*	Canopy Closure TREES (*required when Species Survey Method is CANOPY)	Photo Project ID	Photo Date	Habitat Structural Stage (observed – not calced from R2Calcs)

(in **NRIS_VegPolyLocal** table)

Change Category	Change Date

SPECIES/COVER ATTRIBUTES: (in **NRIS_VegSubpopulations** table)

|Group & SubGroup|

Life Form/ GSC*	Layer*	Species Symbol* (NRCS TAXA Code)	Tree Size Class* (if tree)	Shrub Size Class* (if shrub)	Plant Cover % (Live)*	% Dead (Previous % Live Cover minus Current % Live Cover)

Remarks (in **NRIS_VegCharacterizations** table)

the necessary edits both to spatial and tabular data are made and posted in FSVeg

Spatial.

The R2 attributes form and a map showing topographic relief or imagery with the re-

delineations of the polygons drawn on it are provided to the FSVeg Spatial editor if

edits are not performed by the data collector himself/herself, in order for the editor

to accurately redraw boundaries of the polygons needing redelineations and make

changes to polygon attributes in FSVeg Spatial. Then, the newly edited polygon

boundaries are used to layout plots for CSE data collection.   Recently an ArcGIS tool

was developed that allows an editor to update live and dead percentages for all

vegetation layers in FSVeg Spatial using CSE plot data rather than data collected

during a walkthrough visit. If the decision is made to use this tool, spatial

redelineation still takes place prior to plot layout and CSE data collection, if needed.

Hence, some vegetation may be missed when collecting plot data as compare to data

collected during a walkthrough.

3.3.1 Phase I

Figure 5 shows the general order in which methods occurred to address the

objectives of this project. The reader can view a more detailed version of Figure 4 in

Appendix B (Figure B-1). The detail provided in Figure B-1 provides the reader

understanding of all of the specific steps taken in each phase to address the research

questions and ultimately produce the final priority polygons for CSE data collection.

Step 1

In the first phase of the study, I examined the deliverable from RSAC that consisted

of a feature class of vegetation polygons on the GMUG. Attributes of the feature

class constituted of a field indicating percent change associated with each polygon

and a field indicating whether or not a polygon needed to be checked for possible

spatial redelineation. RSAC based the need of spatial redelineation of polygons on

two factors. The first factor involved the amount of change detected within each

polygon and the second factor considered the arrangement of change detected

within each polygon.

Figure 4. Generalized flowchart describing project phases and steps within each project phase. Figure B-1 in Appendix B provides more detail for project phases and their steps.
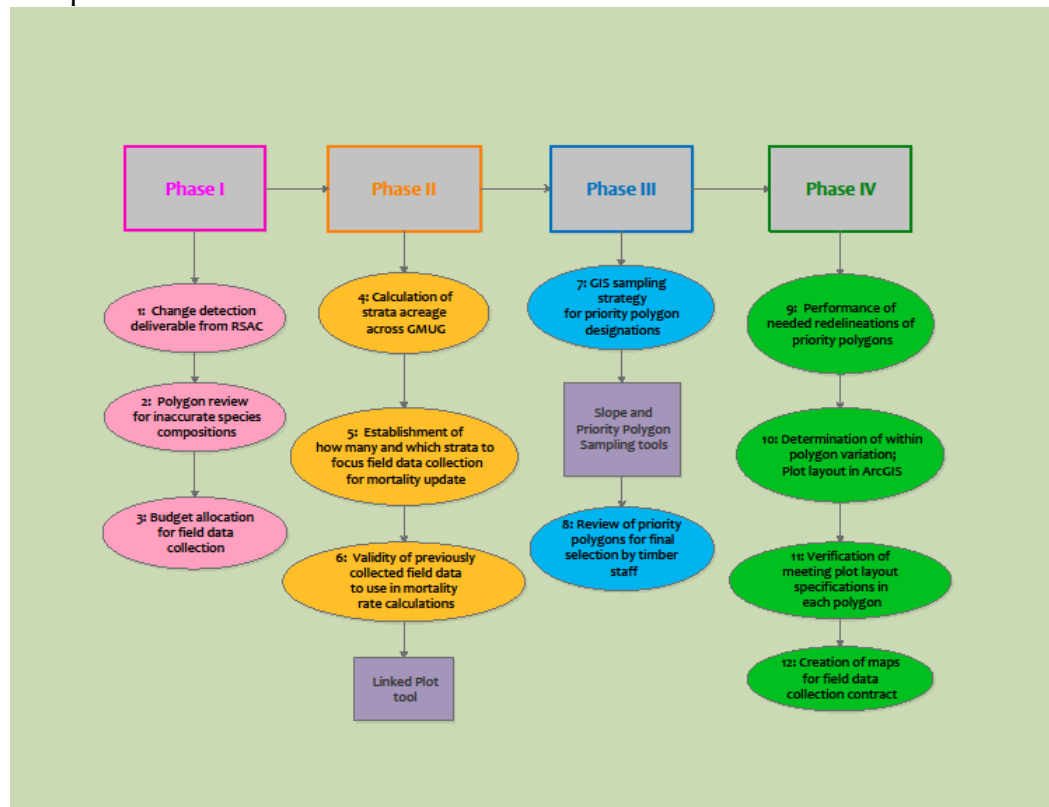
RSAC completed a change detection analysis that identified vegetation polygons in

which 0.001% to 100% of the individual cells or pixels exhibited vegetation change.

This change was derived by analyzing Landsat imagery from 1989 and comparing it to

the same type of imagery from 2014. The two temporal sets of imagery were used to

compute a differenced NDVI for each scene. This calculation resulted in a continuous

difference layer with positive and negative values used to quantify the change in

vegetation that had occurred over the 25 year period within each of the polygons

examined. GMUG selected a threshold of 15% to focus updates on those forested

vegetation polygons displaying 15% or more change in NDVI. These polygons are

referred to as changed polygons from this point forward in the Practicum document.

RSAC looked at landscape pattern metrics of the changed pixels by calculating

fragmentation statistics for each polygon to determine those polygons in which the

change occurred within a contiguous area or if change was distributed throughout

the polygon. Five acres or more of contiguous change adjacent to at least five acres

of no change within a polygon indicated to RSAC that the polygon needed to be

checked for redelineation using aerial imagery. If it was verified from the aerial

imagery that redelineation was needed, polygon modifications occurred prior to CSE

data collection, if selected as a priority polygon, and prior to attribute update.

Step 2
As a part of Phase I, I interacted with the silviculturists and foresters from Ouray,

Norwood, and Gunnison Ranger Districts to gather their knowledge regarding areas

within each of their districts that may have inaccurate species compositions recorded

in FSVeg Spatial. I have initiated but not completed this step, a topic that will be

addressed in Chapter 5.

Step 3
I visited with GMUG GIS and timber staff to ascertain the amount of money allocated

to CSE data collection for the mortality update project. This figure changed multiple

times during the Practicum project. For this reason, I incorporated flexibility within

the project to accommodate and adjust for shifts in funding.   If the amount of funds

changed during the project, the number and location of priority polygons to include

in the contract bid could be easily modified to reflect this change. Unfortunately, a

decrease in funds available for field data collection was more likely to occur than an

increase.

3.3.2 Phase II
Cluster Analysis

A cluster analysis on the vegetation polygons was performed to determine the

number and type of strata that exist across the GMUG.   The process was not a

component of this Practicum project; instead, RSAC performed this analysis prior to

the initiation of this Practicum. The purpose of the cluster analysis was to ensure

that sampled polygons represented all of the different tree species and canopy cover

percentage combinations found across the GMUG to adequately capture the

variation in mortality rates that exist across the GMUG. The details regarding the

cluster analysis can be found in Stam (2015a) and Stam (2016). The completion of the

cluster analysis was essential in moving forward in this Practicum and finishing Phase

II.

GMUG planning, timber, and GIS staff decided the strata to be included in the CSE

data collection and the tree mortality update. This decision was based on several

factors. Budget played a large role in this decision as well as the extent of mortality

found within a stratum. Another factor was the number of polygons within a stratum

that already had relatively current CSE data associated with them to adequately

describe existing vegetative conditions within those polygons and for the strata with

which the polygons were grouped. In general, a greater amount of valid and useful

field data already collected in polygons of a stratum and available to use in the

mortality rate calculations meant less time and money spent on field data collection

in that particular stratum for the mortality update project.

Steps 4 and 5
The expectation was that more mortality would be seen in the strata that contained

mostly Engelmann spruce and subalpine fir, as forest health aerial survey data

collected annually showed the majority of tree damage and "fading" occurring in

Picea engelmanni and *Abies* spp. on the GMUG for the last several years (USDA Forest

Service, 2016a). Additionally, a large amount of attention has been focused on the

increase in SAD observed on the GMUG over the last ten to fifteen years. Although

aspen is not a highly sought after timber product on the GMUG, it is important for

species diversity and valued by many people for its beauty. Aspen stands on the

GMUG bring in noted tourism dollars to surrounding communities during the summer

and fall months. Therefore, planning, timber, and GIS staff agreed upon the strata

consisting of Engelmann spruce, subalpine fir, aspen, and combinations thereof as

priority from which to select polygons to include in the tree mortality update. To

help with solidifying the decision on which strata to focus the mortality update, I

calculated the polygon acreage associated with each stratum in ArcGIS using the

RSAC deliverable feature class in step 4 of Phase II. Step 5 consisted of analyzing and

comparing the approximate cost of field data collection for different acreage

percentages of the priority strata. GMUG's original goal was to collect field data

from a 10% sample of the total acreage associated with a stratum for each priority

strata.

Step 6
In step 6 of Phase II, I identified CSE plot data that had previously been collected on

the Forests on or after 2010 that was still valid for building tree mortality rule sets. I

created a tool using ArcGIS ModelBuilder to perform this step. Although this tool

was implemented in Phase II, I have explained the tool in Chapter Three, Phase IV, in

the same section where the other tool descriptions are located, as I thought it was

appropriate to keep all tool descriptions together to help the reader better

understand why and how the tools were constructed and implemented.

The time that had elapsed since data collection within a polygon affected the validity

of CSE data for describing existing vegetative conditions and hence affected whether

or not the data would be used in building tree mortality rule sets. This decision was

based on a discussion that tool place with the SO timber staff, Matt Bienkowski. CSE

data that was collected prior to 2010 was automatically considered too old for

describing existing vegetative conditions and not used in building mortality rule sets.

Also, I referenced low NDVI year data and CSE plot locations in ArcGIS to determine if

the data suggested that tree mortality had taken place prior to or after CSE data

collection within the polygons.   I have given a more detailed explanation of the low

NDVI year data in Phase III used in this analysis. Similarly, I loaded activity polygon

data from the EDW using the GI and viewed it with CSE point location data to verify

no vegetation altering activities (VAAs) had occurred within polygons since CSE data

collection.

The EDW is the Forest Service one stop shop for accessing FS and non-FS spatial data.

Its purpose is to integrate data from various sources, in formats that can be shared

across the Forest Service and even with the public. Data cannot be edited in the EDW

but the EDW publishes and refreshes USFS spatial datasets that have been edited by

each Forest and Grassland in their respective Forest/Grassland SDE instance on a

frequent and continual basis. The Activity Polygons dataset is refreshed in the EDW

every 24 hours and displays areas in which VAAs have occurred.

I ran a visualization of VAAs on the EDW activity polygons in the GI. I performed a

query to display the Activity polygons in which the activity has occurred since 1989 to

present. I, along with the SO timber staff reviewed the activity polygon query to

ensure that the polygons included in subsequent GIS exercises were only those

whose activity type was considered stand changing or resulted in significant

overstory structure and composition modifications of polygons. A query definition of

VAAs in Figure 5 included activities such as thinnings, salvage, patch clearcuts, group

selection cuts, and wildlife habitat treatments. The Linked Plot model described in

Phase III used the VAA feature class to select those linked plots that potentially may

be valid to calculate mortality rates. More specifically, valid plots are the ones

whereby VAAs occurred prior to the date of plot data collection and not afterward.

Measure_Year was the attribute field in the linked plot dataset indicating the date of

plot data collection.

Figure 5. Definition query for Vegetation Altering Activities (VAAs)

Definition Query:

ACTIVITY = 'Commercial Thin' OR ACTIVITY = 'Group Selection Cut (UA/RH/FH)' OR ACTIVITY =
'Improvement Cut' OR ACTIVITY = 'Overstory Removal Cut (from advanced regeneration)
(EA/RH/FH)' OR ACTIVITY = 'Patch Clearcut (EA/RH/FH)' OR ACTIVITY = 'Precommercial Thin'
OR ACTIVITY = 'Precommercial thinning for visual' OR ACTIVITY = 'Salvage Cut (intermediate
treatment, not regeneration)' OR ACTIVITY = 'Sanitation Cut' OR ACTIVITY = 'Seed-tree Seed
Cut (with and without leave trees) (EA/RH/NFH)' OR ACTIVITY = 'Shelterwood Establishment
Cut (with or without leave trees) (EA/RH/NFH)' OR ACTIVITY = 'Shelterwood Preparatory Cut
(EA/NRH/NFH)' OR ACTIVITY = 'Single-tree Selection Cut (UA/RH/FH)' OR ACTIVITY = 'Stand
Clearcut (w/ leave trees) (EA/RH/FH)' OR ACTIVITY = 'Thinning for Hazardous Fuels Reduction'
OR ACTIVITY = 'Wildlife Habitat Create openings' OR ACTIVITY = 'Wildlife Habitat Intermediate
cut' OR ACTIVITY = 'Wildlife Habitat Mechanical treatment' OR ACTIVITY = 'Wildlife Habitat
Precommercial thinning' OR ACTIVITY = 'Wildlife Habitat Intermediate cut'

Query Builder...

During the winter of 2017, I will archive the invalid points in FSVeg Spatial and give the

valid points along with reports entailing sample design for CSE data collection to the

SO timber staff for review. SO timber staff will make the final determination on the

validity of plot data and which datasets will be used in building tree mortality rule

sets.

Based on an estimate for CSE data collection for the San Juan National Forest and an

IDIQ (indefinite delivery/indefinite quantity) contract plot cost for the Rio Grande

National Forest, costs of CSE data collection on these two Forests ranged anywhere

between $63 to $78 per plot (Sally Zwisler, personal communication, October 20,

2015). IDIQ contracts for CSE stand exam data collection have run approximately $80

to $90 for the Ouray RD of the GMUG since 2014. These contracts haven been

established for data collection on the Uncompahgre Plateau of the Ouray RD from

2014 to 2018. TEAMS (Talent, Expertise, Agility, Mobility, and Simplicity) Enterprise

Unit's costs for CSE data collection on the GMUG were found to be consistently more

expensive, costing approximately $200 per plot (Carol Howe, personal

communication, September 30, 2016). To reduce cost, SO timber staff strived to

secure an IDIQ contract for CSE data collection tasks.

For this Practicum, I used an estimate of $100 per plot to yield a cost estimate for CSE

data collection. Using this estimate, a budget of $35,000 would yield 350 plots.

Major factors that affected cost per plot were the plot location in relation to the

distance from roads in relatively good condition indicated by an operational

maintenance level of 3, 4, or 5 and manageable terrain (<40% slope) for hiking to and

within the polygon. I incorporated these factors and other related factors in Phase IV

when I created the GIS sampling strategy. I also considered travel time to the

polygons from the GMUG SO office and RD offices; however, I did not include this

criterion into polygon sampling, because after further discussion with the GIS and SO

timber staff, they did not feel a least cost path analysis was necessary or worth the

time to conduct to try to further reduce the cost of contract CSE data collection.   A

least cost path analysis would have resulted in route lengths from a GMUG

administrative site to each polygon of interest, thereby providing more information

regarding travel distance and time to reach each priority polygon. Regardless of

whether or not a least cost path analysis was performed, the purpose of the

sampling strategy was to maximize the amount of plots to be visited in the field and

minimize the amount of funds needed for and spent on CSE data collection for the

mortality update project.   Nevertheless, the least cost path analysis would have

pinpointed those priority polygons from which crews would be most efficient in

collecting CSE data. Greater efficiency meant lower cost for contract data collection.

3.3.3 Phase III
Tool Creation
I created six tools using Modelbuilder in ArcMap whose main purpose, when

collectively implemented, was to narrow down polygons from which to collect field

data, keeping in mind factors and traits of polygons that could increase data

collection costs.   The six tools created were 1) linked plot tool, 2) slope tool, 3) first

priority polygon sampling tool, 4) second priority polygon sampling tool, 5) third

priority polygon sampling tool, and 6) final priority polygon sampling tool. I

constructed two tools, the linked plot and slope tools, that each generated a feature

class to be used in other tools. Both feature classes served as inputs into the first

priority polygon sampling tool which then calculated fields for linked plot and slope

status for each polygon. These field calculations were then used in subsequent

polygon selections by the second and third priority polygon sampling tools.   I

constructed the linked plot tool in Phase II. However, I have provided its explanation

in this section with the descriptions of the other five tools to help the reader better

understand the role of each tool and how and when each tool was created during the

Practicum.

Each of the three polygon sampling tools produced a feature class output that

identified first, second, and third priority polygons, respectively. I designed the tools

to start with an input feature class that consisted only of changed polygons; the

reason is that they would be the best polygons to collect field data from to capture

the amount of mortality that has occurred on the GMUG to date. I devised the final

priority polygon sampling tool to first merge first, second, and third priority polygon

selections into one feature class and then to perform an intersection of VAAs

discussed in Phase II (Figure 5) with the priority polygon feature class. Those

polygons intersecting VAAs were excluded as final priority polygons because they

have undergone some sort of silvicultural treatment in the last 35 years and mortality

rates calculated from these polygons would most likely be biased. For these reasons,

these polygons did not move onto the final review by timber staff.

I placed the linked plot and slope tools each in its own file geodatabase whereas all

four polygon sampling tools were located in a separate file geodatabase (Figure 6). I

found that organizing the tools in this manner helped track multiple inputs and

outputs of the tools, especially when re-executing them. Also, grouping all polygon

sampling tools together into one geodatabase made logical sense as they all had a

related purpose, to select and designate priority polygons.

Figure 6. Geodatabase organization of the six models produced to select priority
polygons for CSE data collection
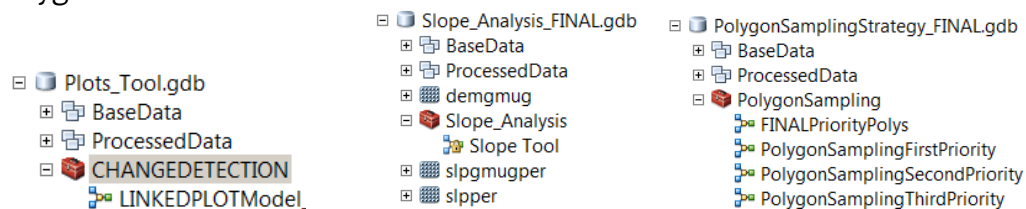
I have provided descriptions for the inputs needed to run each of the six tools and

the outputs derived from each of them. The general tool description can be found in

the tool dialog box when the user first opens the tool. The user can also view the

input and output descriptions when clicking in the space where a user types in or

selects from a drop down menu a file location to retrieve an input or to save a

derived output.

I created the models so that a user could run each model as a tool from a tool dialog

box or from the Modelbuilder window. Using a tool dialog box gives the user control

over the model in two aspects: 1) the user is able to select the feature classes (data)

to be used for each process in the model, and 2) the user can select the location as to

where each of the outputs are to be saved and the name of the output.   Also,

intermediate data is not saved and does not need to be deleted each time the model

is run from a tool dialog box. This is an advantage over running the model from the

ModelBuilder window.

Also during Phase III, I revisited the cost of and budget for contracted CSE data

collection to verify that the allocated funds were adequate to cover the cost of data

collection for the number of plots that were selected and given highest sampling

priority. The purpose of sampling priority designations for polygons was to plan and

prepare for different funding scenarios at the time of contract award and not

necessarily at the time I performed the sampling strategy.   Hence, this designation

strategy gave the GMUG flexibility. If more funding became available before award

of contract, GMUG timber staff would be able to choose an additional number of

polygons and plots whose locations and priority designations would already be

known to include in the contract.

General Overview of Priority Polygon Sampling Tools
In Phase III, I discussed with the GIS and timber staffs the criteria to use to prioritize

vegetation polygons for 2016/2017 field data collection (Table 1).   The criteria

included factors such as within-polygon terrain, polygon acreage, type of land

ownership within each polygon, and polygon's distance from decently maintained

roads. Also, we valued polygons characterized as having potential suitable timber

and not associated with valid, recently collected field data as priority candidates.   We

finalized the criteria to incorporate into the GIS sampling strategy and chose the

criteria that would be used in each sampling tool. I modified two criteria for the

second priority sampling tool that were used in the first priority sampling tool. They

were the criteria concerned with polygon distance from a maintained road and

polygon location in relation to Wilderness, CRAs, and other specially designated

areas. I excluded two criteria used in the second priority sampling tool from the third

priority sampling tool. Moreover, I used one new criterion in the third priority

Table 1. Criteria used in each of the three priority polygon sampling tools to select polygons for CSE data collection

Tool	Polygon Criteria Used for Priority Selection
First Priority Polygon Sampling	1) Significantly changed polygons within priority ctrata
	2) Slopes < 40% or only 5% of area having slopes >= 40%
	3) Not having valid CSE data
	3) Size >= 30 and < 300 acres
	4) Not having any NONFS lands within AND do not intersect NONFS lands
	5) Not within Wilderness, CRAs, or other specially designated areas
	6) Within 1/2 mile of roads with OML of 3, 4, or 5
	7) Within potentially suitable timber areas
Second Priority Polygon Sampling	1) Significantly changed polygons within priority strata
	2) Slopes < 40% or only 5% of area having slopes >= 40%
	3) Not having valid CSE data
	3) Size >= 30 and < 300 acres
	4) No NONFS jurisdiction within or do not intersect NONFS lands

	5) Not within Wilderness, CRAs, or other specially designated areas OR located on the edge of these same land designations* **
	6) Within 1/2 mile of roads with OML of 2,3, 4, or 5*
	7) Within potentially suitable timber areas**
Third Priority Polygon Sampling	1) Significantly changed polygons within priority strata
	2) Slopes < 40% or only 5% of area having slopes >= 40%
	3) Not having valid CSE data
	3) Size >= 30 and < 300 acres
	4) No NONFS jurisdiction within or do not intersect NONFS lands
	5) Within 1/2 mile of roads with OML of 2,3, 4, or 5
	6) Within timber sale planning areas***

* criteria modified from 1st priority polygon criteria; ** criteria excluded from 3rd priority polygon tool; *** new criterion added

sampling tool that was not used in either the first or second priority sampling tools.

Once I ran all three tools, selected polygons based on the criteria used in each of the tools resulted. These tools designated polygons with either a 1, 2, or 3 depending on which criteria the polygon met. Designation assignment consisted of calculating the appropriate number in the Priority attribute field of the resulting selection of polygons.

Detailed Tool Descriptions
Linked Plot Tool
I considered six different criteria to identify the number and location of linked plots that could be used in mortality rate calculations. I excluded all plots from consideration of potentially being used in the mortality rate calculations that met the following criteria:

1) The Activity accomplishment year was after the date of CSE plot data collection.

- I used timber harvest and hazardous fuel treatment activity polygon

  layers (VAAs) to determine the date of when the vegetation in those

  polygons had been altered by treatment activities in relation to the

  date of when the CSE data had been collected.

2) The year of the low point NDVI was greater than the year that plot data had

   been collected.

   - I converted the lowest NDVI year raster to a polygon feature class

     before it was used in the analysis.

   - Each pixel of the raster represented the year(s) in which NDVI

     (greenness) was the lowest. It was broken up into 2 year categories

     (1994-1995, 1996-1997, 1998-1999,…, 2014-2015). For instance, if a pixel

     had a value of 2002, then that meant that NDVI was the lowest in 2002

     or 2003. This would mean that if there was a field sample on this pixel

     with a sample date after 2003, then the field data should be able to be

     used in mortality rate calculations.

   - This was not a change detection raster. Every pixel had a year value

     because all pixels had an NDVI low point. For example, a pixel might

     have had a value of 2006, but this only meant that the lowest NDVI

     value was observed during that time. This could have been caused by a

     dry year or it could have represented an actual disturbance. The main

point being that as long as plot data were collected after the NDVI low

point year, then any change that happened at that plot should already

have been completed.

3) The measure year attribute of the plot feature class was less than 2010, which

indicated that data had been collected prior to 2010.

4) The plots were measured in a polygon in which the strata was not one of the

chosen priority strata.

5) The remaining plots did not span across the polygon when viewing plots and

polygons simultaneously with 1 ft 2012 resource imagery or 1 m 2011 or 2015

NAIP imagery. This situation implied that the plot data did not adequately

quantify stand conditions of the polygon in which the data was collected.

6) The sample design of the plots resulting from the GIS analysis met the CSE

data guidelines and specifications outlined in Zwisler (2016b). This step still

remains to be performed by the GMUG timber staff.

I incorporated the first four criteria into the linked plot tool (Figures 7 and 8). I

examined plots after tool execution to see if they met the fifth criterion. Polygons

meeting the sixth criterion will be determined the winter/spring of 2017.

Figure 7. Linked plot tool as viewed from the ModelBuilder window
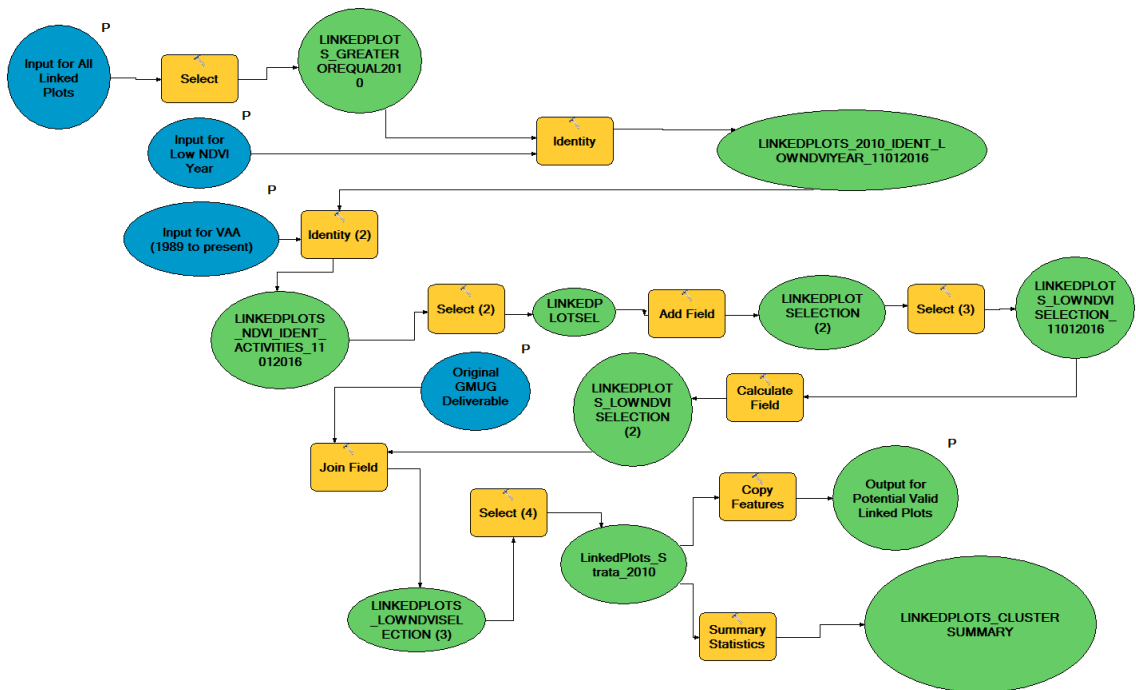
Figure 8. Linked plot tool as viewed from the tool dialog box
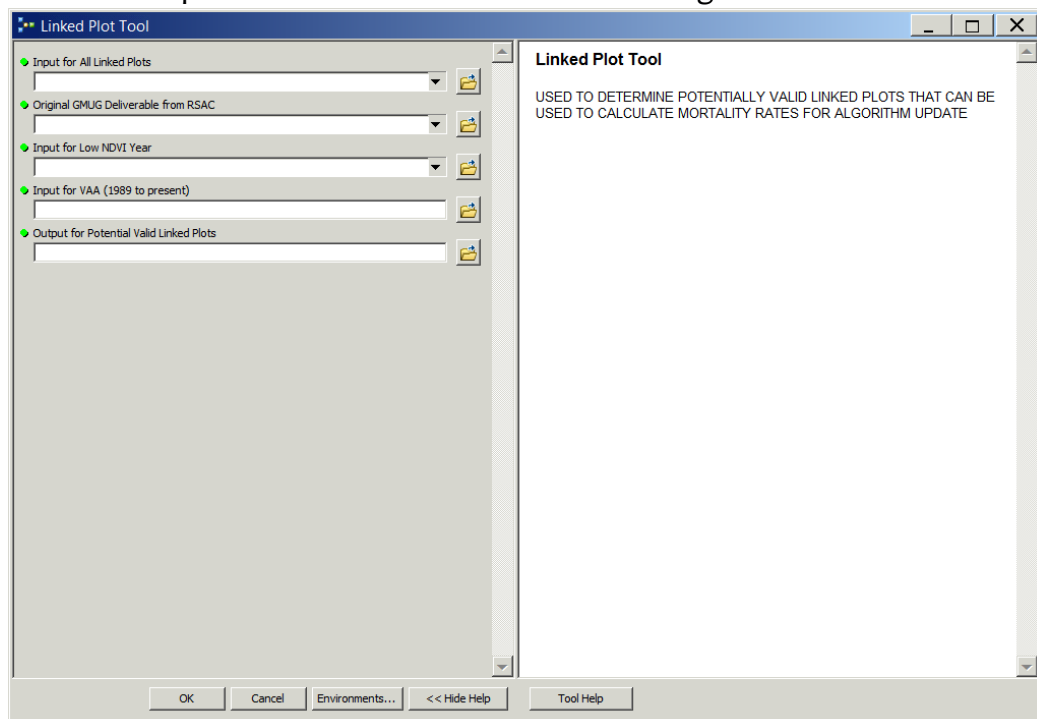
Slope Tool

The slope tool (Figures 9 and 10) created an output feature class that was then used

in the priority polygon sampling tools. The basis of the output was to categorize

those areas within all of the changed polygons into two categories: 1) slopes less

than or equal to 40 percent, and 2) slopes greater than 40 percent. The final output

of the slope tool was a field in the attribute table of the changed polygons that

indicated which polygons had slopes less than or equal to 40 percent or 5% or less of

their area having slopes less than or equal to 40 percent. I, along with the timber

staff, agreed that these polygons would be less difficult to hike and maneuver

around in and would be the easiest from which to collect data in regards to terrain

steepness.

Figure 9. Slope tool viewed from the ModelBuilder window
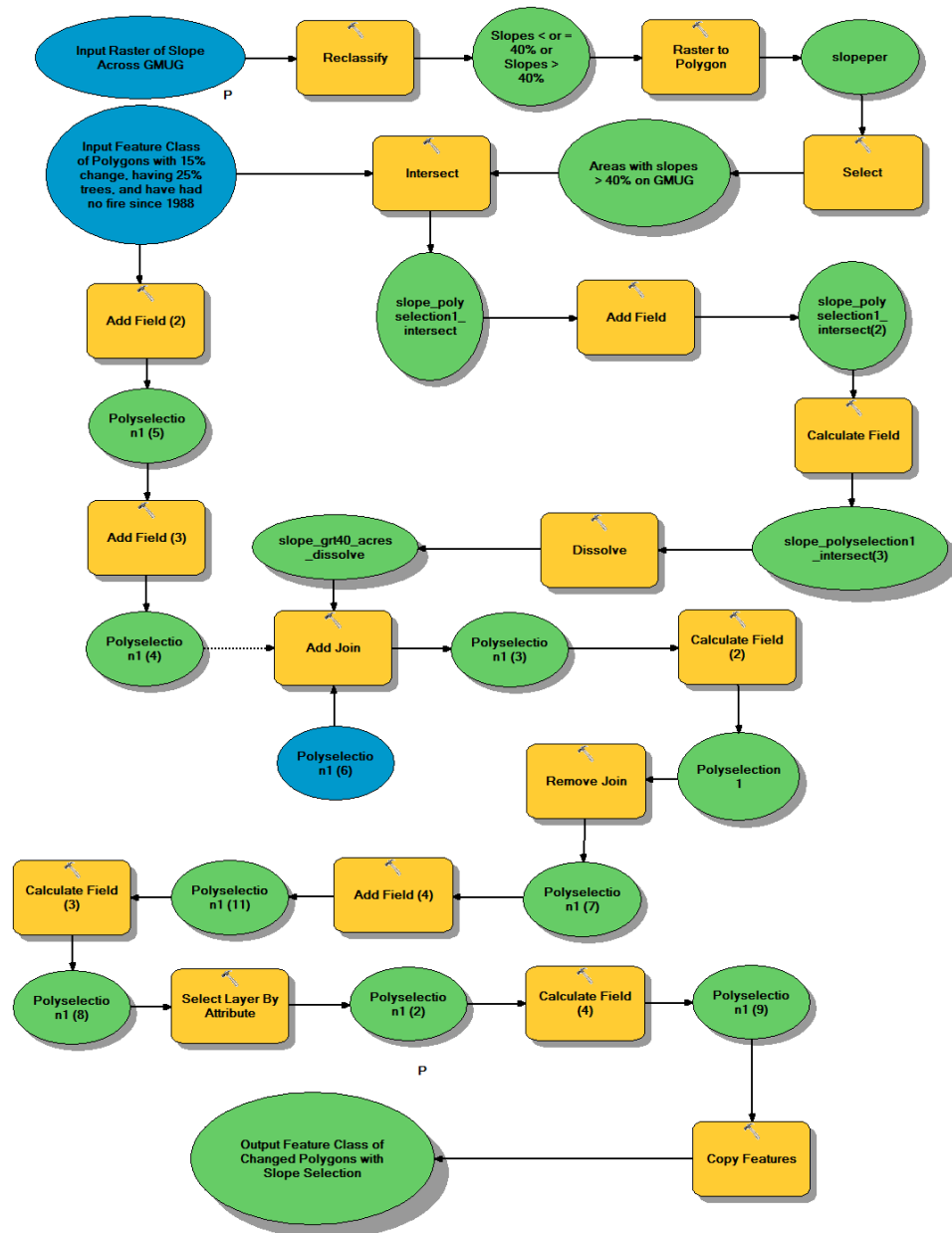
Figure 10. Slope tool viewed from the tool dialog box.
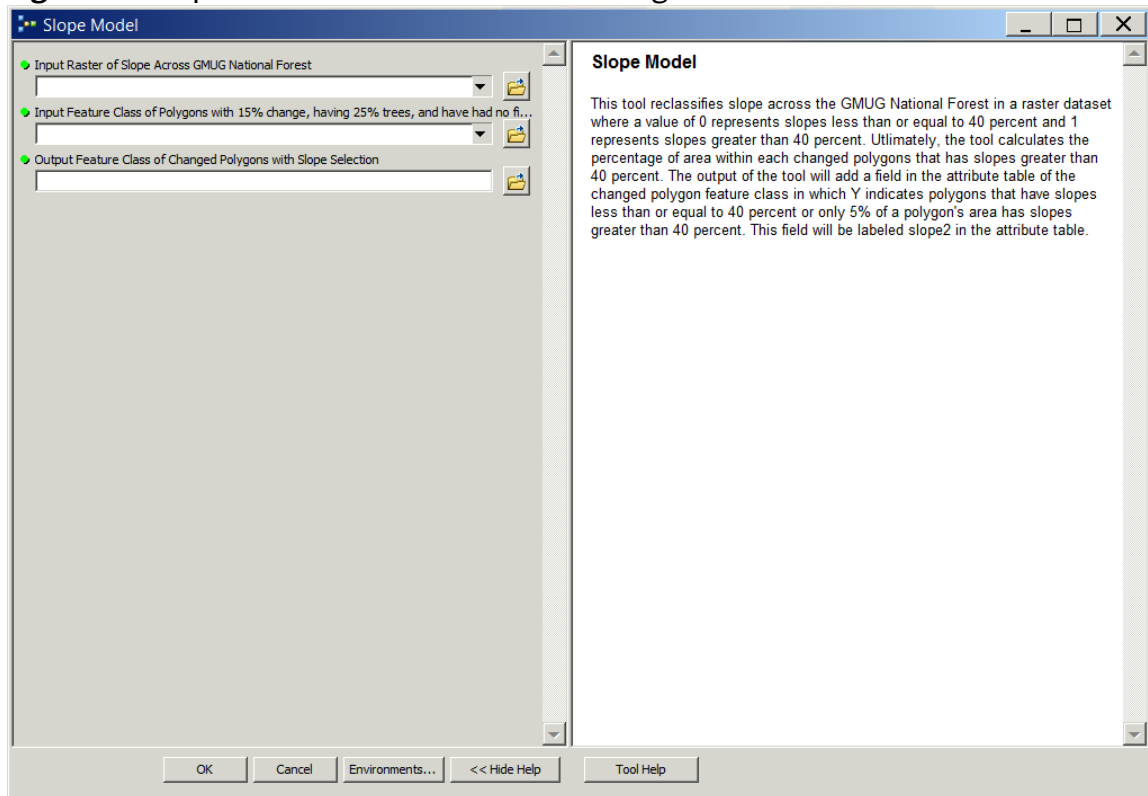
First Priority Polygon Sampling Criteria

First priority polygons were those that would be the first of the changed polygons to

review for plot layout and CSE data collection. These polygons met the slope

criterion, having slopes less than or equal to 40% or 5% or less of the acreage having

slopes greater than or equal to 40%. Crews were also able to access these polygons

within at least a half mile from decently maintained roads as indicated by the

incorporation of criterion six into the first tool (Table 1). I defined decent

maintenance as those roads having an operational maintenance level (OML) of a 3, 4,

or 5. Furthermore, first and second priority tools targeted polygons with potentially

suitable timber. Providing commercial species for timber sale is currently a high

priority for GMUG forest management. Therefore, the GMUG timber program greatly

benefits from CSE data collection targeting polygons with potentially suitable timber.

Proactive data collection allows the timber program to start the initial preparation of

these areas for future timber sale because part of timber sale preparation involves

characterizing existing timber stand conditions through the analysis of CSE data. If

the field data is already collected, foresters can move onto the next stage of timber

sale preparation and are that much closer to reaching the goals of contract bidding

and timber sale award for those stands (i.e. getting the timber cut and removed).

Other criteria used in the first priority polygon sampling tool included land ownership

and land designation status. I ensured that no polygons with mixed ownership

would be selected as priority for two reasons. The first reason was that the USFS

does not manage private or NON-FS lands and two, the GMUG would have to obtain

special permissions to access private land for data collection. If the GMUG collected

data only on the FS portion of polygons having mixed ownership, this action would

result in insufficient vegetation characterization for the polygon according to FSVeg

Spatial standards and not follow FSVeg data collection protocols. Furthermore, I did

not allow the first priority polygons to be within Wilderness, CRAs, or in other

specially designated areas. I included this criterion in the modeling because

according to current and future FLMP policy and direction, these areas will never be

intentionally treated with thinning, harvest, or prescribed burning activities. GMUG

management preferred to target polygons for data collection that can and are

planned to be treated in the next five years to reach treatment accomplishment

goals. Additionally, higher costs for field data collection on Wilderness, CRAs, or

other specially designated areas could have ensued because crews would have

needed more travel time to access most of these areas compared to other FS lands.

This is because most specially designated lands on the GMUG, such as Wilderness

areas, are accessed by driving on unmaintained roads and then hiking the rest of the

way.   Although some non-specially designated lands of the GMUG may be a distance

from FS offices, many of these areas can be reached by driving on roads receiving

some sort of annual road maintenance, thereby resulting in less time to arrive at

these areas as compared to many of GMUG's specially designated areas.

The last two criterion included in the priority polygon sampling tools were choosing

polygons already associated with valid field data and those within a size range of 30

to 300 acres (Table 1).   Polygons characterized by having valid CSE data would help

reduce the amount and cost of field data collection because instead of collecting new

data in those polygons, the already collected data could be used in mortality rate

calculations. I have given a description of what constitutes validity of field data in

Phase II, Step 6 of Chapter 3. SO timber and GIS staff deliberated and chose the

range of polygon size with the purpose of maximizing the amount of data collected

compared to the amount of time needed for data collection to take place within each

polygon. This decision was also influenced by the advice and suggestion of Sally

Zwisler, retired R2 Vegetation Applications Coordinator. Keeping polygon sizes

smaller than 300 but greater than 30 acres minimized the amount of area traversed

and time spent by a crew when collecting data while increasing the probability of

capturing realistic snapshots of tree mortality found within each polygon.

Once I executed the tool (Figures 11 and 12), the fields shown in Table 2 were

calculated. I designed the tool to place a 'Y' in the appropriate field of the attribute

table when that polygon met the criteria represented by that field, except for

Wild_Other_CRAs2 in which case a 'Y-E' was calculated.

Figure 11. First priority polygon sampling tool as seen from the ModelBuilder window

Figure 12. First priority polygon sampling tool as viewed from the tool dialog box
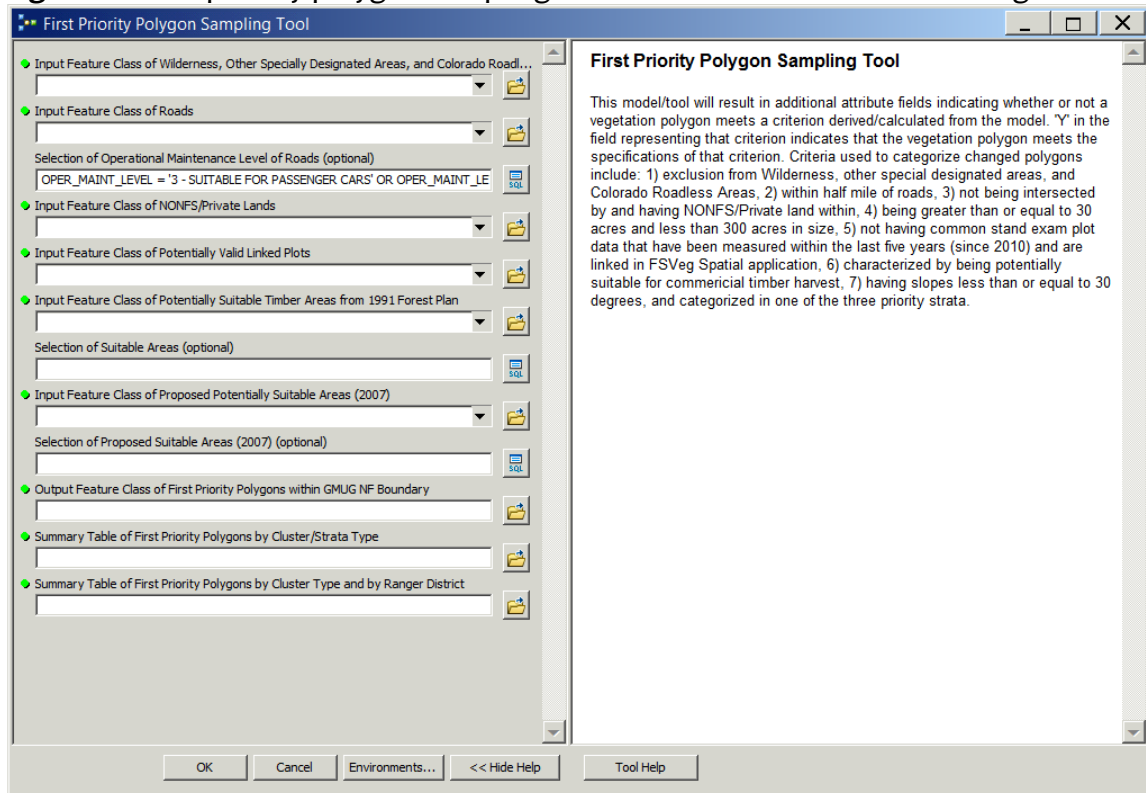
Table 2. Attribute fields calculated by the first priority polygon sampling tool and used by the second and third priority polygon sampling tools for subsequent selections of priority polygons.

Attrribute Field	Polygon Trait	Polygon Has Trait if Field Denoted With	Notes
Roads_halfmi	intersected by a 1/2 mile road buffer	Y	OML field queried for further refinement of road layer.
NONFS	not intersected by or having private or other NONFS land within	NULL	
Size	greater than or equal to 30 acres but less than 300 acres in size	Y	
LinkedPlot	not associated with recently collected, valid plot data that is linked in FSVeg Spatial	NULL	Valid, recently collected linked data could be potentially used in mortality rate calculations.

Timber_91	within areas potentially suitable for commercial timber harvest according to the 1991 GMUG Amended Forest Plan	Y	
Timber2007	within areas potentially suitable for commercial timber harvest according to the 2007 assessment for Forest Plan Revision	Y	This criterion was not used in the priority polygon selection due to Timber-91 being used instead.
Slope	consisted of slopes less than or equal to 40% or only 5% or less of the polygon's area had slopes greater than 40%	Y	
Wild_Other_CRAs	located within Wilderness, other specially designated areas, or CRAs	Y	
Wild_Other_CRAs2	located within Wilderness, other specially designated areas, or CRAs but they were located at the edge of those areas	Y-E	'Y-E' indicates those polygons at the edge of boundaries of Wilderness, CRAs, or other specially designated areas.
ClusterDescription	belonging to one of the three priority strata	Engelmann Spruce, Engelmann Spruce/Subalpine-fir/ Aspen mix' OR 'Lodgepole Pine mix' OR 'Englemann Spruce mix'	
Priority	priority for CSE data collection	1, 2, or 3	This field was indicated with a 1, 2, or 3 depending on which criteria the polygon met.

Once the first tool calculated these fields, the second and third priority polygon sampling tools relied on these fields to perform subsequent selections of changed polygons designated as second and third priority.

Overlaying First Priority Polygons with Vegetation Altering Activities

I intersected first priority polygons with VAAs that had occurred on the GMUG since

1989 (refer to Figure 5) to complete the last step in determining the total number of

first priority polygons left for CSE data collection and determine whether criteria

needed to be excluded from or modified during continued future sampling in order

to increase the number of polygons for data collection.

I excluded polygons that had experienced VAAs because mortality rates calculated

from CSE data collected from these polygons would not reflect accurate amounts of

mortality from insect and disease infestations. The reason is that VAAs usually result

in the removal of any dead trees, except for leaving some snags in the stands for

wildlife. Therefore, activities listed in Figure 6 would most likely result in dead

overstory vegetation being felled and removed from the polygons, thereby affecting

or decreasing mortality found within the treated stands and biasing mortality rate

calculations that would be used in the update algorithm.

Due to many first priority polygons being excluded for field sampling as a result of

VAA intersection, I supplemented the priority polygon sampling strategy with two

additional tools, the second and third priority polygon sampling tools. These tools

selected and assigned polygons as second or third priority meeting the criteria for

such designations (Table 1). I created these two tools to ultimately increase the

acreage, through polygon selection, in each of the three priority strata from which

CSE data would be collected and to move more closely toward reaching the objective

of collecting field data from 10% of the total acreage for each of three priority strata.

Second Priority Polygon Sampling Criteria
Second priority polygons were those that would be the second to review for plot

layout. First, I removed first priority polygons from the changed polygon layer,

including the ones intersected by VAAs, and saved the remaining changed polygons

to a separate feature class labeled Polyselection2. This layer was the sample of

changed polygons used in the second tool from which second priority polygons

would be selected.

I used all of the same criteria in the second priority polygon sampling tool as in the

first priority polygon sampling tool except I modified the selection to also include

those polygons located at the edge of boundaries of Wilderness, CRAs, and other

specially designated areas and those within a half mile of roads having OML of 2, 3, 4,

or 5. Inclusion of these criteria loosened up the restrictions of priority polygons not

being allowed to exist within specially designated areas or accessed by roads with an

OML of 2. OML 2 roads can be accessed only by high-clearance vehicles having four

wheel drive capability and are not suitable for passenger cars. OML 3 roads are

maintained to provide adequate drainage to reduce potholing and washboarding

although user comfort and convenience is a low priority when maintaining the

surface of these type of roads. OML 4 and 5 roads are maintained to provide for a

high to moderate degree of user comfort and provide for convenience and the

protection of investment and resource values. Surfaces of OML 4 and 5 roads are

either paved asphalt, chip sealed, or gravel surface. Broadening criteria five and six

from the first tool in the second priority polygon sampling tool allowed for more

polygons to be considered for CSE data collection (Table 1). The tool (Figure 13)

designated these polygons as second priority for data collection as these polygons

would most likely take a longer time to access due to OML 2 roads not being

maintained and travel to most specially designated areas, in which some second

priority polygons are located, require crews to drive on OML 2 roads. The tool used

Structured Query Language (SQL) to perform a final selection of second priority

polygons. I created SQL expressions of the fields listed in Table 3 to highlight those

polygons to be designated as second priority.

Figure 13. Second priority polygon sampling tool as viewed from the ModelBuilder window

Table 3. Attribute fields and SQL expressions used by second priority polygon
sampling tool to select and designate second priority polygons

Attribute Field	SQL Expression	Additional Expression Used
Roads_halfmi	Rds_halfmi = 'Y'	Operational Maintenance of Roads <>1
NONFS	NONFS IS NULL	
Size	Size = 'Y'	
LinkedPlot	LINKEDPLOT IS NULL	
Timber_91	Timber_91 = 'Y'	
Slope	Slope = 'Y'	
Wild_Other_CRAs and Wild_Other_CRAs2	Wild_Other_CRAs IS NULL OR Wild_Other_CRAs2 = 'Y-E'	
ClusterDescription	ClusterDescription = 'Engelmann spruce/Subalpine-fir/Aspen' OR ClusterDescription = 'Lodgepole Pin mix' OR ClusterDescription = 'Englemann Spruce mix'	

Third Priority Polygon Sampling Criteria

Third priority polygon sampling tool used all of the same criteria as the first and

second tools. However, it did not restrict the selection to those polygons within

specially designated areas or within areas having potentially suitable timber as it did

in the first and second tools. The main focus of the third tool was to select any

polygons within the north and west zone timber sale planning areas not already

previously selected from the first and second tools. I did not include east zone

72

timber sale planning area (Gunnison RD) in the third tool because the feature class

detailing this area was not provided to me at the time. As a way to prevent the

exclusion of any east zone polygons planned for upcoming timber sale, I relied on the

Gunnison RD silviculturist to notice any polygons within the east zone timber sale

planning areas not selected by any of the sampling tools during his review of the

polygons and performance of plot layout. My expectation was that as a result of his

review, he would add to the final priority polygon feature class any within the east

zone timber sale planning area that had not been previously selected. Also, I did not

include linked plot criterion into the third tool because I decided to review the

polygon selections for any valid and recent plot data after the third tool had been

executed.

Figure 14. Third priority polygon sampling tool as viewed from the ModelBuilder
window
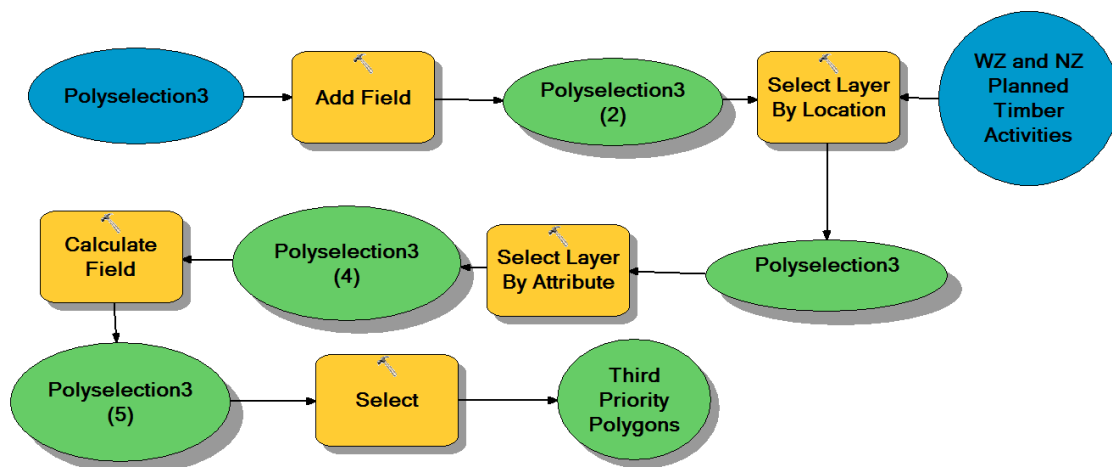
The tool (Figure 14) designated polygons selected by SQL expressions listed in Table

4 as third priority polygons.

Table 4. Attributes fields and SQL expressions used by the third priority polygon
sampling tool to select and designate third priority polygons

Attribute Field	SQL Expression	Additional Expression Used
Roads_halfmi	Rds_halfmi = 'Y'	Operational Maintenance of Roads <>1
NONFS	NONFS IS NULL	
Size	Size = 'Y'	
Slope	Slope = 'Y'	
ClusterDescription	ClusterDescription = 'Engelmann spruce/Subalpine-fir/Aspen' OR ClusterDescription = 'Lodgepole Pin mix' OR ClusterDescription = 'Englemann Spruce mix'	

Final Priority Polygon Tool and VAA Intersection with Priority Polygons
Using the final priority polygon tool, first, second, and third priority polygons were

merged into one feature class (Figure 14). The tool then intersected the merged

feature class with the VAA feature class obtained from the GI (Figure 5). I then

reviewed the VAA intersection with the polygons to determine which polygons had

at least a quarter of their area affected by VAA instead of only a boundary touching a

treatment. The polygons who had a quarter or more of their area affected by VAA

were not included in the final priority polygon feature class. I then delivered this

polygon feature class to the SO timber staff for final review.

Figure 15. Final priority polygon tool as viewed from the ModelBuilder window
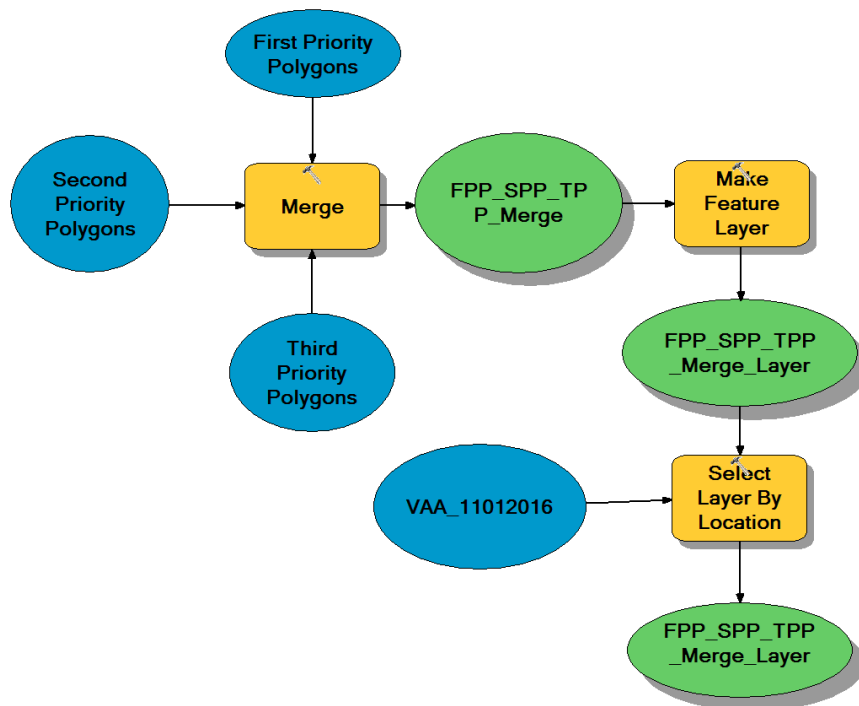
Review of Final Priority Polygons

The SO timber staff reviewed the final priority polygons to ensure agreement of

those polygons selected by the GIS sampling strategy for CSE data collection. Final

priority polygons located on only the Gunnison Ranger District were given to the

Gunnison RD silviculturist for review.   Both the SO timber staff and GIS staff agreed

that this additional review for Gunnison polygons was needed due to a majority of

change due to tree mortality having taken place on the Gunnison RD in comparison

to other districts on the GMUG and a majority of priority polygons selected for 2016

and 2017 CSE data collection being situated on the Gunnison RD. Additionally, the

Gunnison RD silviculturist's help was needed and valued as he has over 30 years'

experience working on the Gunnison. He knows the general condition of and best

access to most forested polygons on the district. For this project, he gave valued

feedback on the results of the GIS sampling strategy and remote sensing analysis

that reinforced the premise to combine data analysis results with field knowledge

during decision making process.   In addition to reviewing the accessibility to

polygons for data collection, he marked those changed polygons he knew needed to

be spatially redelineated, regardless of which polygons were flagged by RSAC for

redelineation. He also helped with redelineation of these polygons prior to plot

layout.

3.3.4 Phase IV
Polygon Redelineation
The Gunnison RD sivilculturist and I redelineated polygons using 1 meter multiband

aerial imagery from the National Agriculture Imagery Program (NAIP) acquired in 2011

and 2015 and 30 cm multiband resource imagery acquired in 2012. The USFS obtained

resource imagery for the GMUG during June through September of 2012. 2011 and

2015 NAIP imagery acquisitions ranged from July to September of 2011 and 2015,

respectively.

All delineations were performed in ArcMap. However, I performed delineations using

the FSVeg Spatial application and the silviculturist redelineated polygons using the

ArcMap editor toolbar. He used this method to save time in completing

redelineations and to be able to finish plot layout in time for the 2016 contract

bidding process. I will be entering the Gunnison RD polygon edits performed by the

silviculturist into FSVeg Spatial the winter and spring of 2017.

I changed the color monitor gun assignments of the imagery's spectral bands in

ArcMap to more easily distinguish between deciduous trees and conifer tree species.

This involved assigning Band 4 (IR) to the red gun, Band 1 (red) to the green gun, and

Band 2(green) to the blue gun, also referred to as false color. I also applied a stretch

to the imagery using standard deviation as the stretch type with n = 2.5. Applying the

stretch to the imagery helped me to distinguish better among dead trees still holding

needles and live trees and particularly among dead and live trees of the same species.

I attempted to utilize three dimensional (3D) digital viewing photo interpretation

techniques with the goal in mind to more clearly define tree species, more accurately

detect differences in stand structure, estimate canopy cover percentages within

polygons, and detect vegetative changes and delineations among homogeneous

polygons. I used ERDAS Stereo Analyst extension in ArcMap to stereoscopically view

stands with digital images.   However, because file sizes of the digital stereo images

being so large and Stereo Analyst's inability to handle and process multiple images

effortlessly, 3D digital viewing using Stereo Analyst was extremely time consuming

and proved to be not worth the time and effort to continue using at that point in the

timeline of the project. Also, fortunately, this process was not essential in

completing the work necessary to accomplish the Practicum's research objectives.

I created a training guide for remote sensing interpretation in the spring of 2016 in an

effort to train the interpreter's eye on the various vegetation types on the GMUG. I

examined and compared recently collected field data of selected polygons to the

species composition and structure identified through the imagery interpretation of

the same polygons. The ultimate purpose of the guide was to help a photo

interpreter know what different tree species looked like in imagery to maximize the

accuracy of tree species identification.

Plot Layout
Step 10 (Figure 4) involved considering the variation within each polygon to address

the primary objective of the stand exam data collection. The primary objective was

to determine the number of plots from which data needed to be collected to

accurately describe the dead tree percentage found within that polygon. A second

objective was to adequately describe stand composition and structure for each

polygon. The purpose of meeting the second objective was to provide stand exam

data for polygons lacking any past and recent data collection and that were

delineated by and attributes assigned from photo interpretation alone.   I referenced

FSVeg CSE User Guide protocol standards to complete this part of step 10.

The FSVeg CSE User Guide describes within polygon variation by calculating the

coefficient of variation (CV). CV is the standard deviation expressed as percent of a

variable's mean. The variable chosen is based on its relevancy in addressing the

objective of the analysis. For example, if the question of the analysis was to

determine a stand's readiness for commercial thinning, basal area would be selected

as the focus variable to calculate existing and desired stand density. Furthermore,

the sample design of stand exam collection for that analysis would be based on the

need to calculate stand density within a predetermined margin of error. For the tree

mortality update project, the primary variable of interest was dead tree percentages

for all species found within the polygons sampled.

After conversations with Sally Zwisler (retired R2 Vegetation Applications

Coordinator) and Matt Bienkowski (SO timber staff) and referencing Chapter Five of

the FSVeg CSE User Guide, we decided upon a general approach to laying out plots.

We assumed low CVs (20% to 40%) for priority polygons within the Engelmann spruce

mix and lodgepole pine mix strata and medium CVs (40% to 60%) for priority polygons

within the Engelmann spruce/subalpine-fir/aspen mix stratum based on past data

collected within polygons belonging to the same strata. With these assumptions in

hand, we devised a general approach to place one plot per 10 acres for the

Engelmann Spruce/subalpine-fir/aspen mix stratum and one plot per 15 acres for

lodgepole pine mix and Engelmann spruce strata (Figure A-1, Appendix A). We felt as

though this strategy would meet two needs: 1) complete plot layout in a consistent

and efficient manner and within the time remaining before contract bid deadline, and

2) yield dead tree percentages within an acceptable range of sampling error.

Moreover, we laid out plots in a random systematic fashion within each priority

polygon. Plots were placed using a systematic grid whose starting point (i.e. plot 1)

within the polygon was randomly placed (Figure 16).   Lastly, we followed the general

rule of thumb listed in the FSVeg CSE User Guide and ensured that no polygon had

less than three plots after plot layout was complete. Therefore, for a handful of

smaller polygons, we utilized the plot per 5 acres and plot per 2.5 acres grids (Figure

17) in finishing plot layout.

After plot layout had been completed, GMUG SO timber staff created a CSE data

collection contract for the bidding process. I produced nine maps, modified by Carol

Howe, showing the location of and the strata to which priority polygons for CSE data

collection belonged using ArcMap. I also utilized the Data Driven tool found in

ArcToolbox to create approximately 462 contract maps, each map showing a

different priority polygon and providing the polygon's unique setting ID. The maps

were a required element to include as part of the contract document that went out

for bid.

Field data collection was planned to begin and end in the summer of 2016. However,

due to lack of contracting personnel to oversee the administrative and legal aspects

of contracting on the GMUG, the contract for CSE data collection was not awarded in

time for much field work to get accomplished in the 2016 summer season. As of

October 2016, TEAMs had collected CSE data for 300 plots all within the lodgepole

pine strata and located on the Gunnison RD. Therefore, the decision was made to

extend the field data collection period into 2017, finishing up data collection by

October 2017.   The contract for 2017 CSE data collection will be created during the

winter of 2017, for bidding to begin spring of the same year.

Figure 16. Systematic grids used for plot layout in Step 10 of Phase IV.
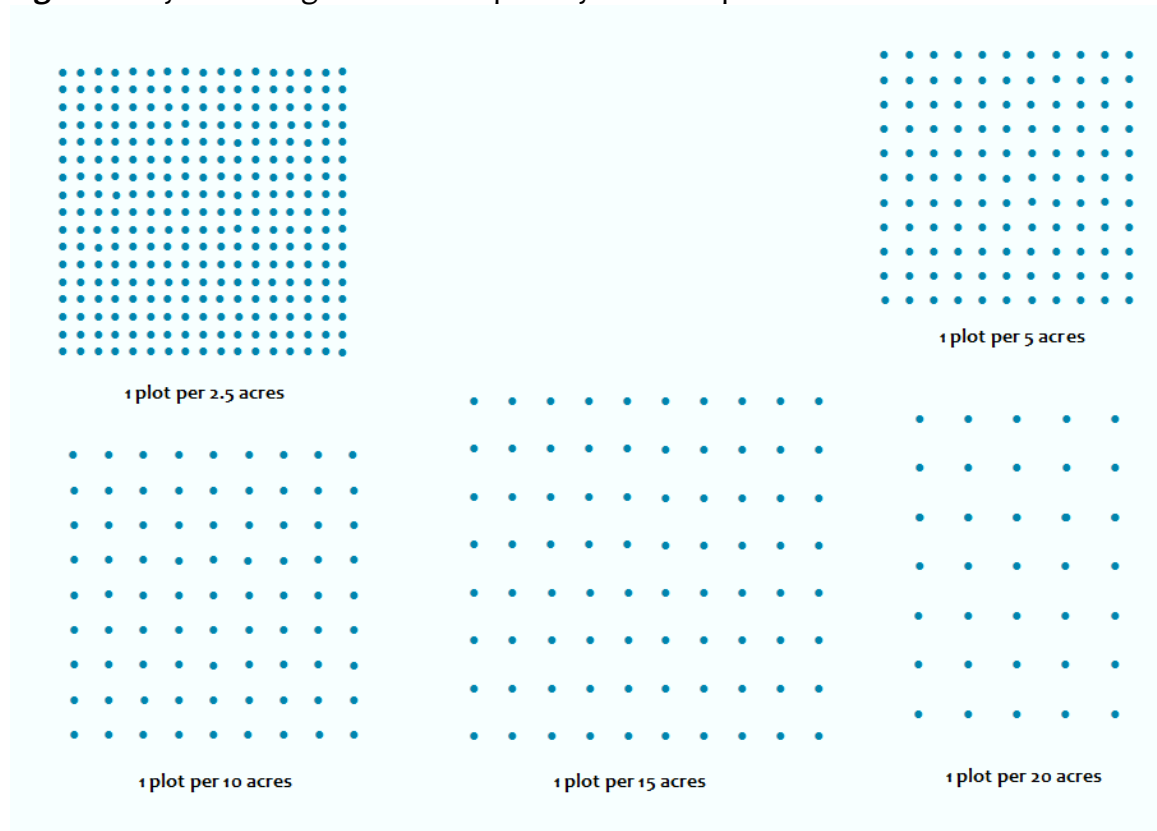
Chapter Four

Results

4.1 Phase I
4.1.1 Cluster Analysis
RSAC's analysis resulted in nine strata being represented in the vegetation polygons

on the GMUG. These strata were labeled lodgepole pine mix, Engelmann spruce mix,

blue spruce/Douglas-fir/aspen mix, Douglas-fir mix, Engelmann spruce/subalpine-

fir/aspen, pinyon-juniper, bristlecone pine mix, ponderosa pine mix, and aspen mix. I

used the Raster Calculator in the Map Algebra toolbox of the Spatial Analyst tools in

ArcMap to calculate the total number of acres across the GMUG in which change was

detected and then the acreages categorized by the corresponding strata (Table 5,

column 2). As a result of the raster analysis, the total number of acres changed from

1989 until 2014 totaled approximately 689,943 acres (Figure 17).

4.1.2 Detected Change and Changed Polygons
18, 525 polygons were found to satisfy the three starting point criteria of 25% of the

polygon consisting of trees, 15% of pixels showing change in NDVI, and no fire within

since 1988. The analysis was originally performed by Sally Zwisler and Carol Howe in

2014. However, I processed and analyzed the data in 2015 to ensure I derived the

same results. These polygons were the baseline population of vegetation polygons

with which the sampling strategy began and are referred to as changed polygons in

the remainder of the Practicum document.

Table 5. Number of acres by strata showing detected change ranging from 1% to 100% from 1989 until 2014 within the GMUG boundary.

Cluster Description	All Changed Acres	Ranking Based on # of Changed Acres	Acreage of polygons in which 15% of pixels changed **	Total Acreage of 15% Changed Polygons**	Percentage of acreage within 15% changed polygons that is actually changed
No Change	2,464,664				
Engelmann Spruce/Subalpine fir/Aspen mix*	292,760	1	275,189	433,326	64
Lodgepole Pine Mix*	133,436	2	125,978	230,043	55
Engelmann Spruce Mix*	120,026	3	105,696	156,293	68
Aspen Mix	47,929	4	34,005	92,618	37
Pinyon Juniper	37,084	5	26,201	76,624	34
Douglas-fir Mix	21,171	6	17,366	40,157	43
Ponderosa Pine Mix	17,804	7	7,802	18,932	41
Blue Spruce/Douglas-fir/Aspen mix	4,698	8	4,342	8,462	51
Bristlecone Pine Mix	3,205	9	2,579	5,161	50
Null Cluster Description	11,830				
Total Acres Changed=	**689,943**		**599,158**	**1,061,615**	**56**

*Priority stratum, ** Polygons with no fire since 1988, 25% treed, within forest boundary

Figure 17. All change (>0% to 100%) in NDVI from 1989 until 2014 on the GMUG. NDVI change is in blue.
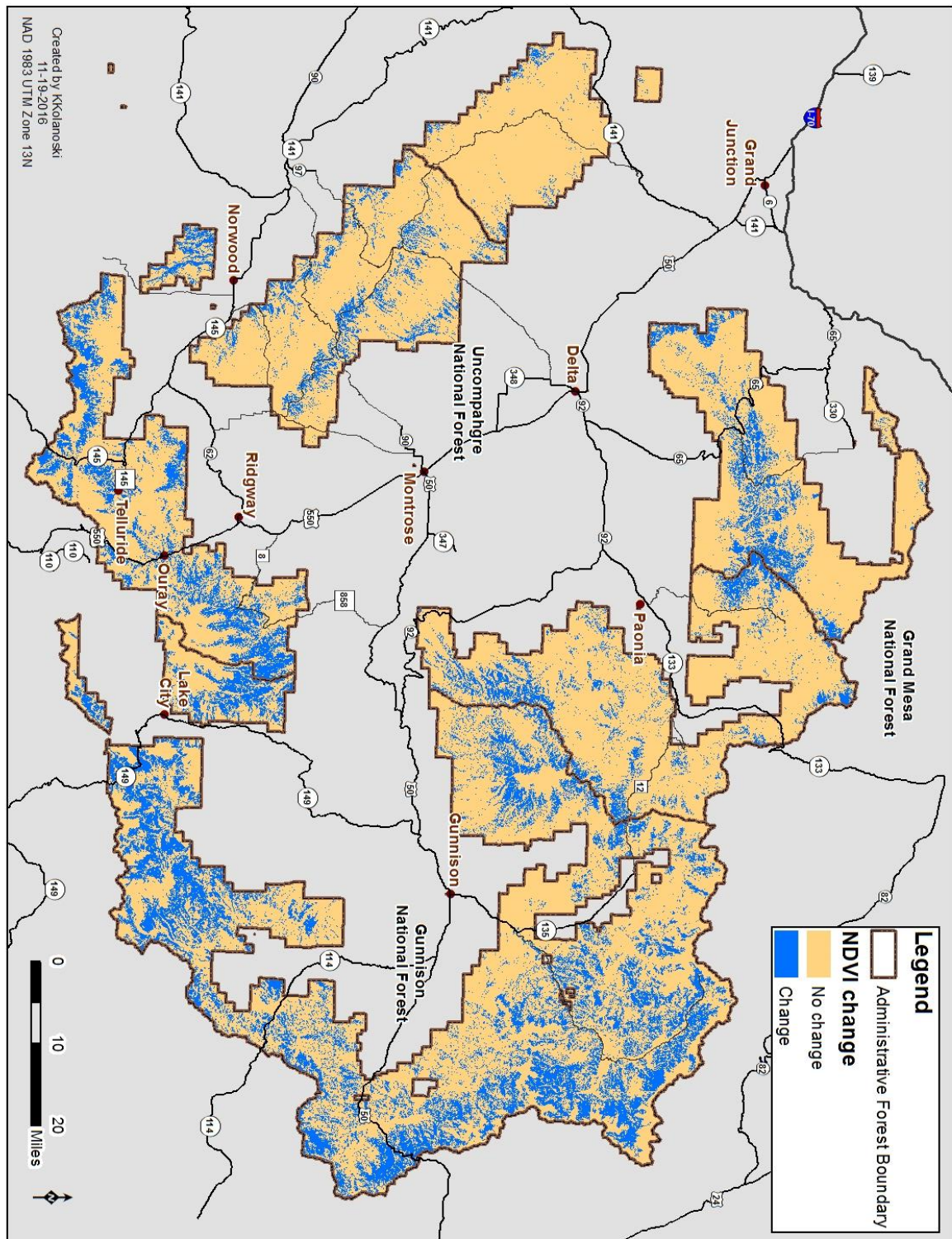
Figure 18. Count acreage of changed polygons by nine strata on the GMUG.
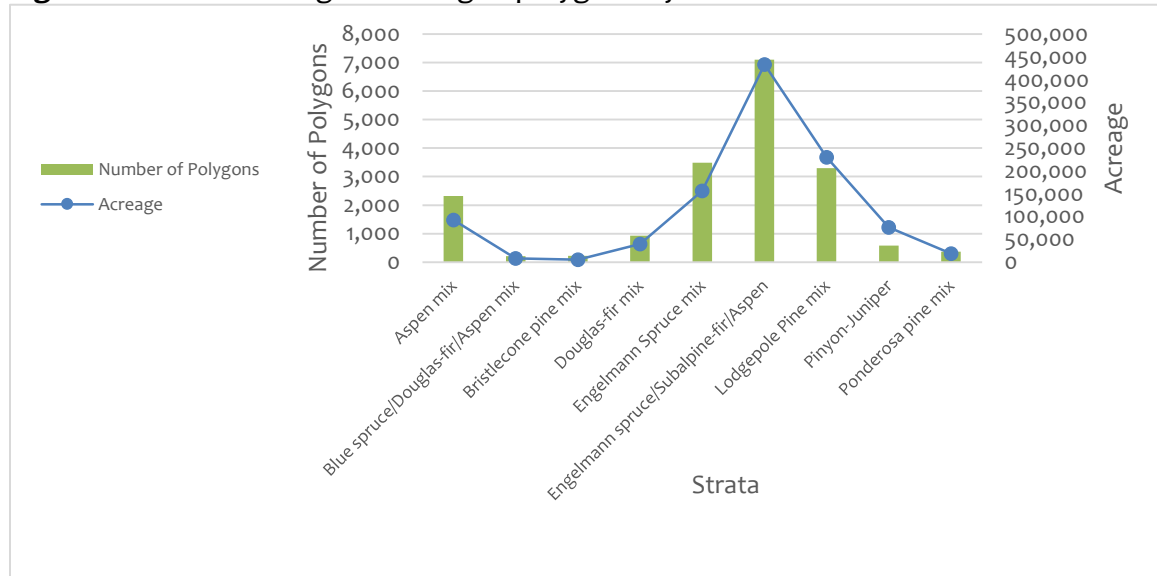
Engelmann spruce/subalpine-fir/aspen mix showed the greatest amount of change

and Bristlecone pine mix the least amount of change by acreage (Figure 18). The

difference in acreages between Table 5, column 2 and Table 5, column 5 and Figure 18

was largely attributed to Table 5, column 2 only including acreage of changed pixels,

whereas Table 5, column 5 and Figure 18 included all acreage within a polygon in

which 15% of its pixels had changed. This comparison shows a large difference

between the actual number of acres in which change was detected using NDVI and

the acreage of polygons that as a whole was considered as changed according to the

15% change threshold. When comparing the acreage of 15% change for each of the

strata and acreage of changed polygons, 55% to 68% of the polygon acreage for the

three priority strata actually had changed when analyzing NDVI differences from 1989

to 2014 (Table 5, column 6).

4.2 Phase II

4.2.1 Priority Strata

Due to a limited budget, GIS and timber staff decided to reduce the number of strata

to include in the polygon sampling strategy from nine to three. The three strata

selected were the strata in which the most change had been detected. In those

three strata, change was detected in 13,894 polygons across 819,663 acres.   These

polygons belonged to Engelmann spruce mix, Engelmann spruce/subalpine-fir/aspen,

and lodgepole pine mix (Figure 18 and Table 6). CSE data collection needs to occur

on approximately 43,000 acres for Engelmann spruce/subalpine-fir/aspen stratum,

23,000 acres for lodgepole pine stratum, and 16,000 acres for Engelmann spruce

stratum to achieve the objective of collecting data from 10% of the acreage for each

priority strata. The approximate cost of CSE data collection from these 82,000 acres,

depending on the sampling intensity used, would be $691,000. For all analyses

performed for this Practicum other than for the results displayed in Table 5, acreages

of changed polygons such as the ones reported in Figure 18 and Table 6 were used.

4.2.2 Linked Plot Tool Results

I performed linked plot analysis so that we could be better informed as to whether

any existing data could be potentially used in the mortality rate calculations for the

three priority strata. I found a total of 1030 linked plots to be potentially valid to use

in mortality rate calculations for six strata, three of which were priority strata. After

selecting only those plots located in polygons belonging to priority strata, 304 plots

remained for consideration. Data had been collected anywhere from 2010 to 2015 in

Table 6. Approximate cost of field data collection using a 10% sample for each of the 3 priority strata.

Cluster Description	Number of Changed Polygons*	Acres of Changed Polygons	10% of Total Acreage	Cost of 1 plot per 10 acres**	Cost of 1 plot per 15 acres**
Engelmann Spruce/Subalpine-fir/Aspen	7,106	433,326	43,333	$433,326	
Lodgepole Pine mix	3,297	230,043	23,004		$153,362
Engelmann Spruce mix	3,491	156,293	15,629		$104,195
Aspen mix	2,321	92,618	9,262		
Pinyon-Juniper	579	76,624	7,662		
Douglas-fir mix	933	40,157	4,016		
Ponderosa pine mix	372	18,932	1,893		
Blue spruce/Douglas-fir/Aspen mix	206	8,462	846		
Bristlecone pine mix	220	5,161	516		
Total=	**18,525**	**1,061,615**	**106,161**	**$690, 883**	

* Changed polygons are those whereby at least 15% of pixels are changed, had not experienced fire since 1988, and at least 25% treed.

**An approximate cost of $100 per plot was used for these cost calculations. This cost was based on costs generated in previous contracts on the GMUG as well as two other National Forests in Region 2.

56 polygons belonging to the three priority strata (Figure 19). More specifically, data

had been collected in forty five plots over 218 acres for the Engelmann spruce mix,

122 plots over 652 acres for the lodgepole pine mix, and 137 plots over 2,878 acres for

the Engelmann spruce/ subalpine-fir/aspen mix (Figure 19).   Polygons associated with

the Engelmann spruce/ subalpine-fir/aspen stratum had been flagged for

redelineation by RSAC. Flagged for redelineation meant that the polygon needed to

be viewed against the backdrop of aerial imagery at a scale of 1:24000 or larger to

verify that the polygon was no longer homogeneous. In this case, the linked plots

associated with polygons needing redelineation would not be used in calculating

mortality rates. Four polygons had been flagged by RSAC as possibly needing

redelineation. Plot data had been collected from 51 plots within these four polygons.

 If after review, the polygons do no portray homogeneous stand conditions, the

decision will be made not to use the polygon's CSE data in building tree mortality rule

sets and plots for those polygons will be archived in FSVeg Spatial. I performed an

initial review of polygon boundaries against the backdrop of NAIP 2015 aerial imagery

and as a result, all polygon delineations used to collect linked plot data did not

appear to need redelineation. Final review of this data by SO timber staff will take

place in the winter of 2017; after the final review, timber staff will make the final

determination as to whether the plot data will be used for calculating mortality rates

for the change detection project. Moreover, sample design criteria of the selected

linked plots will be included in the review to ensure the design used meets the

requirements for the change detection project outlined in Zwisler, 2016. To perform

this task, I will run a sample design report for the desired setting IDs of the polygons

in the FSVeg tabular application to be used in the review.

Figure 19. Bar graph indicating number of possibly valid linked plots to use in building
mortality rule sets.
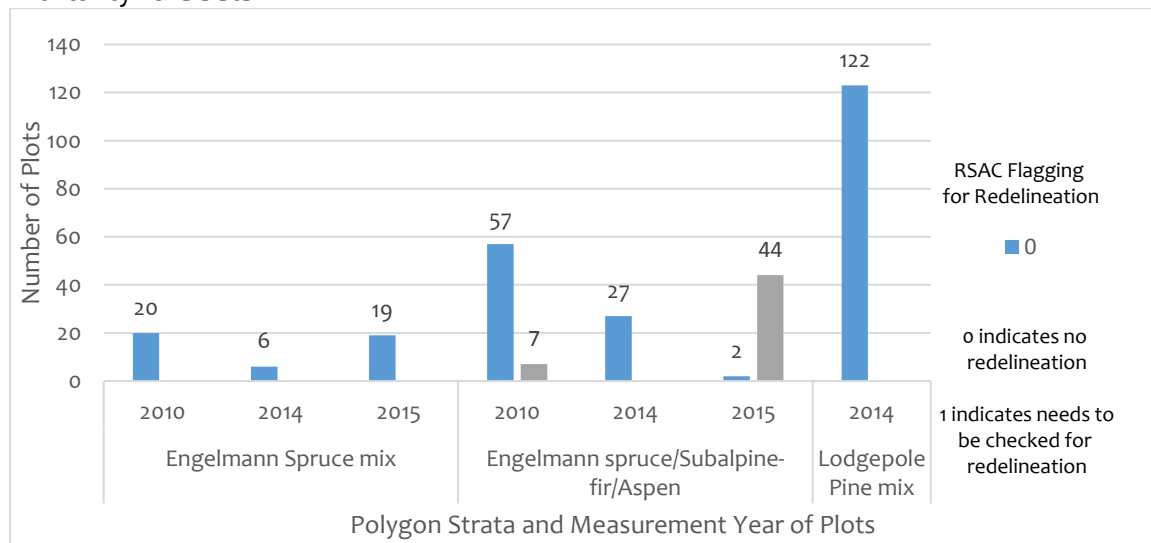
4.3 Phase III
4.3.1 Slope Tool
The slope analysis revealed that 2,277,223 acres had slopes less than or equal to 40

percent and 877,242 acres consisted of slopes greater than 40 percent across the

GMUG. When I converted the slope raster into a polygon feature class and

intersected with vegetation polygons, I found that 6,675 changed polygons had

slopes less than or equal to 40 percent or no more than 5% of their area to be greater

than 40 percent.   These 6,675 polygons equated to 297,700 acres.   I then

incorporated the final output of the slope analysis in the first polygon sampling tool

to add the slope field to the attribute table of the changed polygon feature class.

This field was then utilized in the selection of first, second, and third priority polygons

performed in the polygon sampling tools.

4.3.2 Polygon Sampling Tools

The first priority polygon sampling tool created eight fields in the attribute table of

the changed polygon feature class. The first priority polygon sampling tool used

seven fields to select first priority polygons from all 18,525 changed polygons.

The tool resulted in 574 polygons to be selected as meeting all seven outlined criteria

(Table 7). These polygons were labeled as first priority polygons, indicating that

these polygons were considered as highest priority to visit for field data collection.

Polygons meeting the linked plot criteria (i.e. not having any linked plots) were

included in the sample to select from for field data collection. However, polygons

not meeting the linked plot criteria (having valid linked plots) were not considered

priority from which to collect plot data during the 2016 and 2017 summer seasons as

the linked plot data for those polygons will instead be used in building tree morality

rule sets.

Table 7. Number of changed polygons meeting each criteria. Those not meeting each criteria are shown in parentheses with totals.

Cluster Description	Priority Polygon Criteria							
	Roads with ½ mile buffer	NONFS/ Private Lands	Polygon Size	Linked Plots	Potent-ially suitable timber (1991)	Slope	Wilderness other specially designated areas, and CRAs	First Priority
Aspen mix	725	201	896	10	843	752	1,043	NA
Blue spruce/Douglas-fir/Aspen mix	123	12	88	0	116	120	10	NA
Bristlecone pine mix	49	5	54	0	86	59	27	NA
Douglas-fir mix	218	75	382	0	185	96	504	NA
Engelmann Spruce mix	999	166	1,555	3	1,323	1,026	1,232	238
Engelmann spruce/Subalpine-fir/Aspen	1,787	723	3,087	14	2,065	1,266	2,093	238
Lodgepole Pine mix	1,136	423	1,671	20	1,523	745	960	98
Pinyon-Juniper	106	47	315	0	41	15	24	NA
Ponderosa pine mix	119	27	175	0	192	116	137	NA
Total	5,262 (13,263)	1,679 (16,846)	8,223 (10,302)	47 (18,478)	6,374 (12,151)	4,054 (14,471)	5,473 (13,052)	574 (17,951)

91

Overlaying First Priority Polygons with Vegetation Altering Activities
The first priority polygons remaining from the intersection with the VAA layer

resulted in only 254 polygons. Upon closer examination of the VAA intersection with

first priority polygon selection, many polygons were only touching the boundaries of

VAAs or the edges of polygons were only slightly affected by VAAs (Figure 20).

Therefore, this intersection was ignored and I performed another intersection with

Figure 20. Example of VAA intersection with priority polygons whereby VAAs touch
the boundaries of three priority polygons and have only affected a minute
percentage of the polygons' area.
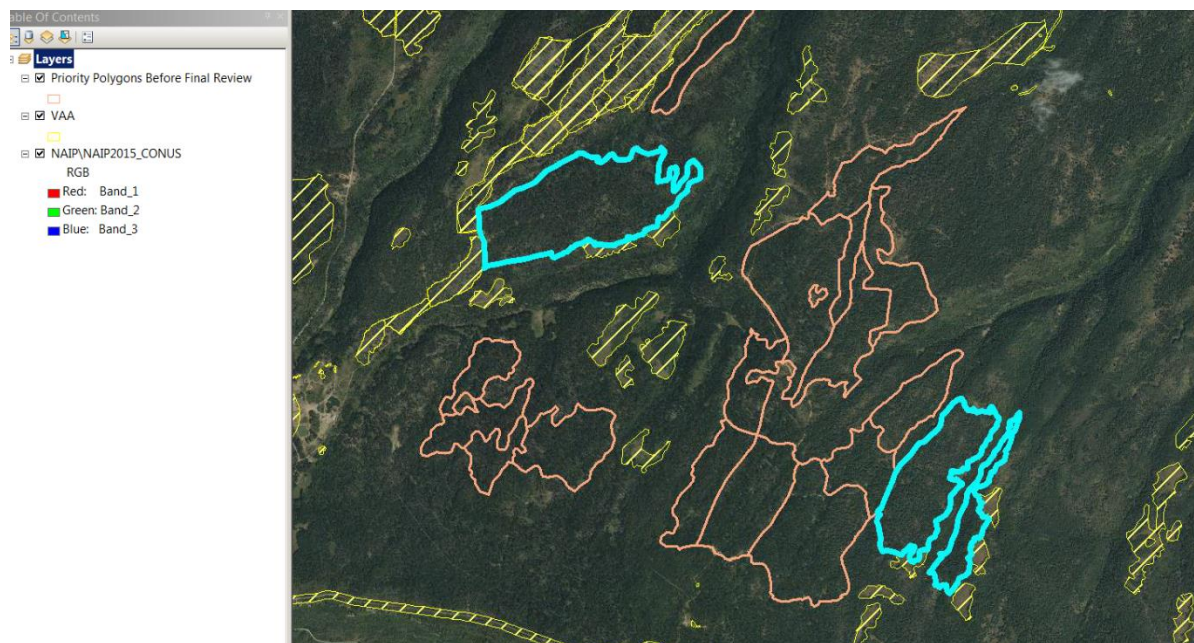
VAAs once all three prioritized polygon selections were made and the three

selections were merged into one feature class.

Second and Third Priority Polygon Selections
The second priority polygon sampling model produced 472 second priority polygons.

Only nine polygons returned as satisfying the criteria to be third priority.

Determination of Final Priority Polygons
Final Priority Polygons with VAAs
I merged first, second, and third priority polygons together into one feature class

resulting in 1055 polygons within the merged feature class. When I performed a

selection by location using the merged polygons and VAA feature class, 49% or 518

polygons intersected with VAAs. Upon further review of the intersection, I

discovered that 636 polygons not to be significantly affected by VAAs. Those 636

polygons were deemed priority polygons to go onto the final stage of review for field

data collection.

Final Selection of Priority Polygons
After several iterations of review by the SO timber staff, SO GIS staff, and Gunnison

RD silviculturist, they determined that 462 out of the 636 polygons would be the final

polygons to be visited in the field for CSE data collection. The reduction was mainly a

result of two different issues: 1) access limitations, and 2) CSE data already existing

for many polygons but still unlinked. That is, many of the polygons excluded from

field data collection consideration as a result from the final review process already

had plot data collected from them; however, the data for these polygons had not

been linked to the polygons in FSVeg Spatial, thereby giving no indication that CSE

data had been collected for these polygons. Furthermore, I was not provided this

information until after completing the GIS sampling exercises and I had given the

priority polygons to timber staff for final review. As a result of the review, 174

additional polygons were excluded from field data collection. Overall, priority

polygon acreage represented approximately 4% of the total acreage for Engelmann

spruce/subalpine fir/aspen mix, 4% of the total acreage of lodgepole pine mix, and 6%

of the total acreage of Engelmann spruce mix on the GMUG (Table 8). These

percentages were all short of the ambitious goal of collecting data from 10% of a

stratum's acreage.

Table 8. Acreage and number of final priority polygons by strata description and by
Ranger District. The number of polygons flagged by RSAC as needing to be checked
for redelineation and the percentage of strata acreage represented by priority
polygons are also included.

Strata according to Ranger District	No Redelineation Check Needed		Redelineation Check Needed		Total Acreage	Percentage of Total Stratum Acreage	Total Number of Polygons
	Acreage	Number of Polygons	Acreage	Number of Polygons			
Engelmann Spruce mix	8,192	125	1148	15	9,340	6%	140
Gunnison	6,361	95	849	12	7,210		107
Norwood	657	12	256	2	913		14
Ouray	276	4	0	0	276		4
Paonia	898	14	43	1	941		15
Engelmann spruce/Subalpine-fir/Aspen	14,400	190	1,395	9	15,795	4%	199
Grand Valley	4,039	51	0	0	4,039		51
Gunnison	3,590	49	206	1	3,796		50
Norwood	1,582	24	425	3	2,006		27
Ouray	1,640	21	570	3	2,211		24
Paonia	3,549	45	194	2	3,743		47
Lodgepole Pine mix	8,682	113	567	10	9,249	4%	123
Gunnison	8,682	113	567	10	9,249		123
Total	31,274	428	3,110	34	34,384		462

4.4 Phase IV

4.4.1 Polygon Redelineation

Only those polygons selected as final priority polygons from the sampling strategy

were redelineated in Phase IV. There were a total of 1236 polygons from all nine

strata that had been flagged by RSAC as possibly needing redelineation.   Only 34 out

of those 1236 polygons were selected as final priority polygons. I reshaped four of

those 34 before plot layout. Three of the four redelineations comprised of only

moving boundaries to match obvious breaks in the tree stand (Figure 21). One

Figure 21. Slight modification in polygon boundary considered as a redelineation.
Yellow line indicates redelineated boundary and black line represents old polygon
boundary.
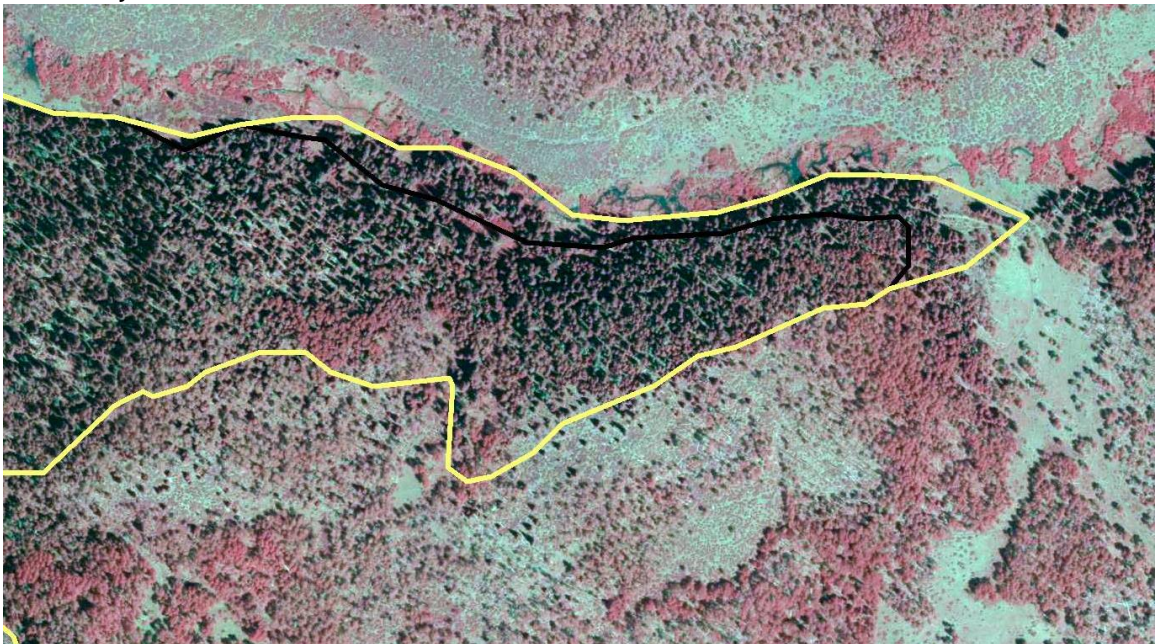
delineation was performed because polygon was not displaying homogeneous

conditions.

On the other hand, the Gunnison RD polygons selected for field data collection were

redelineated based on the review and at the discretion of the Gunnison RD

silviculturist. He redelineated 207 polygons although only 23 polygons were flagged

for redelineation by RSAC (Table 9). He split several of these polygons into smaller

ones based upon the stand characteristics found in the field. After reviewing his

delineations, I determined that the editor would have to have intimate field

knowledge of these polygons in order to come up with some of these same

redelineations as I had a difficult time in determining from imagery how the location

of boundaries were decided upon.

FSVeg Spatial protocols allow for subjectivity in polygon delineations and with any

FSVeg Spatial edits, lumping or splitting of polygons is at the discretion of the editor.

The silviculturist ended up creating sixteen new polygons: six new polygons in the

Engelmann Spruce mix, one in Engelmann spruce/subalpine-fir/aspen mix, and nine in

the Lodgepole pine mix. These new polygons were a consequence of splitting

several polygons to produce more homogeneous stand conditions than previous

delineations (Figure 22).

Figure 22. Result of splitting a large polygon (in black) into several smaller polygons (in yellow). This image shows a split of one lodgepole pine mix polygon into three separate polygons. Yellow line designates new polygon delineations and black line displays old polygon boundaries.
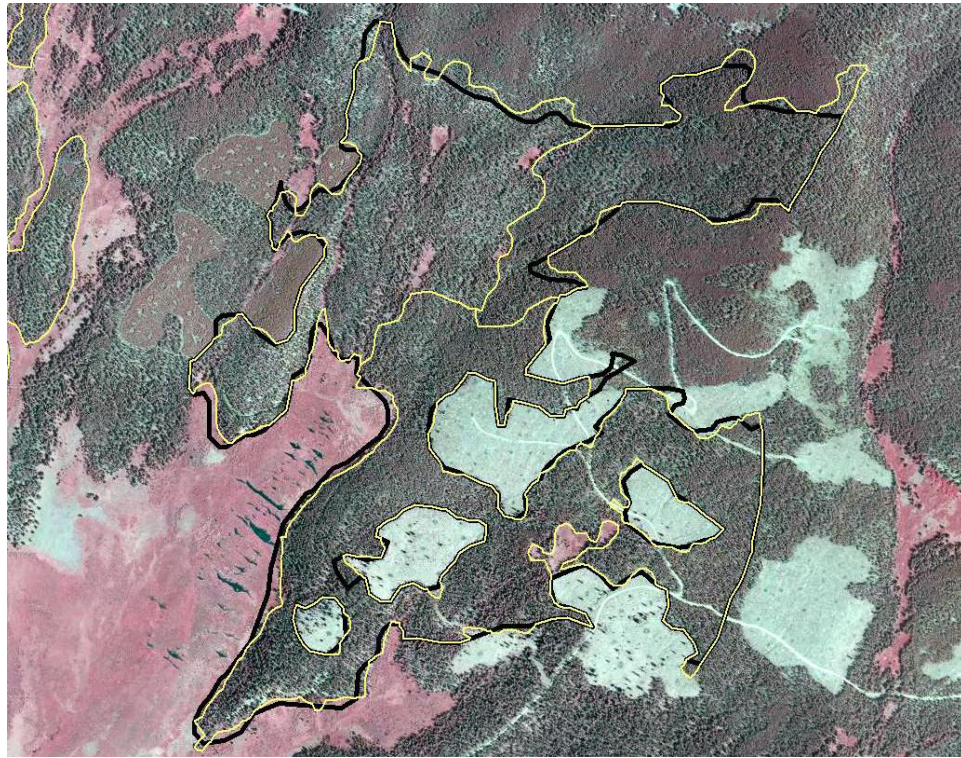
In other cases, the silviculturist edited polygon boundaries to match the edge of tree stands as seen with NAIP or resource imagery. A majority of the delineation changes were a result of viewing polygons with newer and higher resolution imagery as compared to the imagery that was used in original delineations. When viewed with the polygon boundaries, the more recent imagery showed where boundaries could be edited to more accurately reflect divisions and changes in vegetation type and condition and better demarcate edges of tree stands.

Table 9. Priority polygons on Gunnison RD redelineated by silviculturist

Strata	Total Polygons per Strata	Not Flagged by RSAC	Redelineated by Silviculturist	Flagged by RSAC
Engelmann Spruce mix	107	95	70	12
Engelmann spruce/subalpine-fir/aspen	50	49	34	1
Lodgepole Pine mix	123	113	103	10
Total	**280**	**257**	**207**	**23**

4.4.2 Plot Layout and Contract Maps

After polygon redelineation, both the silviculturist and I performed plot layout. The

silviculturist laid out 1,511 plots in 280 polygons that resided on the Gunnison RD. I

laid out 1,328 plots in 182 polygons residing on the other four districts.   Therefore,

the contract maps consisted of a total of 2,839 plots that went out for bid (Figures 23

and 24 and Appendix B, Figures B3-B10 for polygon/strata overview maps).

Figure 23. Example of overview map for priority polygons included in CSE data
collection contract (1 of 9 maps). The red box in the inset map shows the extent of
the main map and the location on the GMUG of the polygons displayed within the
map.

Figure 24. Example of a data driven map for CSE data collection contract. Each map shows one polygon. For this reason, there are 462 maps included in the contract.

Chapter Five

Discussion

In this chapter, I have provided some insight on model building and discussed several

issues ranging from geoprocessing results to data maintenance that arose during the

Practicum. I have divided discussion into subsections based on the issue addressed.

5.1 High Complexity

I completed the steps needed to address my research questions by creating tools

with attributes in Allen (2011) and similar to the ones discussed in Lin et al. 2006.

Although the ability to rerun is inherent with a tool built in ModelBuilder, I would

argue that it is this inherent capability that makes a tool quite useful and effective.

This project's tools allowed steps to be run multiple times to produce several

different derived alternatives. Secondly, the selection of priority polygons required

the incorporation of several different datasets and many of the datasets required

further querying to identify the subset of data needed for priority polygon selection.

Being able to use the same geoprocessing workflows documented in the tools when

needed allowed me to be more efficient in obtaining results by not having to recreate

geoprocessing steps each time before performing subsequent analyses. Also, the

reuse of tools proved valuable in double checking geoprocessing results and

comparing results after I had modified or queried input datasets.

The amount of datasets involved in the analyses added complexity to the model

building. Tang et al. 2014 also had a large number of GIS functions and tools involved

in his model for building LiDAR derived hydrologic feature datasets. Like Tang et al.

2014, I was able to simplify how the analyses were performed through the use of

ModelBuilder and with this use was able to reduce processing time. Furthermore, I

would not have maintained consistency in data analysis if I had manually repeated all

geoprocessing steps each time I needed to do so. Instead, I was able to automate

and repeat all geoprocessing steps as well as reference the workflow documentation

at any time during the project through tool creation and utilization. Overall, I was

able to reduce inefficiency and maintain consistency in data analysis by producing

and using tools for this project.

On the other hand, tools can be difficult to rerun with success if during the building

phase of the tool, the designer is unskilled in constructing the tools using the many

options and functions of ModelBuilder.   For example, I was unskilled in writing and

using Python script when building the tools for this project. If I had incorporated if-

elif-else controls using Python script into the tools, I probably would have made the

tools more efficient to reuse in some aspects (Allen 2011). Within an if-elif-else

control, a Stop tool evaluates an input Boolean value and can cue the model to either

stop running or continue with another process, depending on the value. One simple

way of improving the first priority polygon sampling tool could have been to write an

if-elif-else control to direct the tool to check if certain fields had been deleted prior to

the tool being fully executed again. I would forget many times to delete fields added

and calculated from the tool before rerunning the tool, which would cause problems

in subsequent tool execution. Originally, to address this issue, I added the Delete

Field tool into the first priority polygon sampling tool to delete fields from the

Polyselection1 feature class if those fields existed in the feature class prior to the tool

re-adding and recalculating the same fields. Unfortunately, however, with the

incorporation of the Delete Field tool, a schema lock would occur each time I reran

the tool. For this reason, I decided not to use it and removed the Delete Field tool

from the first priority polygon tool. The incorporation of the Python script control

may not have prevented the schema lock from occurring but it would remind me to

manually delete fields before the tool could be re-executed. This would prevent

committing further errors when running the polygon tool multiple times.

5.2 Cost
I selected $100 per plot estimate for field data collection used in this project because

the SO timber staff's plan was to have the majority if not all of the CSE data collection

on the GMUG covered by IDIQ contract. Costs for past CSE data collection via IDIQ

contract had been a little under $100 per plot. Unfortunately, due to issues with

contracting, only a TEAMS unit could be contracted for the summer of 2016 and its

costs of field data collection per plot were much higher than that under an IDIQ

contract. For this reason, data collection costs for the tree mortality update project

were much more than originally forecasted.   However, a second contract for 2017

CSE data collection will be made in the winter and spring of 2017. The hope is that an

IDIQ contract can be awarded and per plot costs for 2017 CSE data collection will be much lower than the 2016 costs.

Due to limited funds for project implementation, the GMUG decided to limit field collection to only three out of nine strata and update records of tree species only found within those three strata.   The decision to focus on three of nine strata revolved around availability of funds. However, the choice of the three strata to focus on in the update process for the GMUG was based largely on aerial detection survey data (ADS) and other field observations. These surveys and observations showed that a large portion of Engelmann spruce, subalpine fir, aspen, and lodgepole pine tree populations on the GMUG had died over the last twenty years mostly as a result of bark beetle infestations and factors of SAD (US Forest Service, 2016a, Worrall et al. 2010, Marchetti et al. 2011). NDVI analysis results presented in this Practicum agreed with these findings as a majority of change in NDVI on the GMUG was found within the Engelmann spruce mix, Engelmann spruce/subalpine-fir/aspen mix, and lodgepole pine mix strata. The stratum showing the fourth largest change in NDVI was aspen mix.

Although the GMUG decided to fund CSE data collection for 2,839 plots within 462 polygons belonging to three different strata, the RGNF funded field data collection for 2,630 plots within 335 polygons belonging to all eleven strata found on the Forest (Stam et al. 2016). This data collection updated FSVeg Spatial records for all tree

species found on the RGNF. If GMUG funds field data collection for all 462 polygons

at the same plot sampling intensity utilized in the 2016 CSE data collection contract,

tree mortality rates for GMUG may be more accurate than those calculated for the

RGNF due the GMUG having a larger sample size representative of each strata as

compared to the RGNF.

5.3 Use of NDVI Data Compared to Aerial Detection Survey Data
I originally utilized insect and disease infestation activity polygons obtained from

ADS, conducted by Forest Health Protection and its partners, in this analysis to

determine what vegetation polygons on the GMUG had been affected by these

pathogens. After consultation with RSAC, I used low NDVI year raster produced by

RSAC in hopes to better inform GMUG timber and planning staff as to which recently

collected linked and unlinked plot data may still be potentially valid and be used in

mortality rate calculations for the change detection project. Low NDVI year raster

provided a two year range for each pixel on the GMUG when the lowest NDVI (least

green) was detected. The number and location of plots obtained by using this data

layer was similar but not identical to that obtained by ADS data. 120 more plots

resulted from the use of the low NDVI year raster layer rather than ADS data in the

linked plot model. Using ADS data would have yielded a more conservative number

of plots potentially valid for mortality rate calculations. In conclusion, the raster layer

was not necessarily a superior data source than the ADS data in showing where

change from pathogens could and have taken place on the GMUG. Instead, RSAC

preferred the GMUG to use the low NDVI year data source over ADS data for

determining previously collected plot data that potentially could be used in mortality

rate calculations. This preference stemmed from the fact that ADS is subjective in

nature, with no two sketchmappers producing the same mapping results (Klein et al.

1983) (see Appendix A, A.2 Role of Field Collected Data, Aerial Detection Survey Data,

and Remotely Sensed Data for more discussion on this topic). Furthermore, RSAC

regards the use of the raster layer compared to that of ADS data to be a more

objective and consistent approach in deciding which plots to accept and include in

mortality rate calculations.

5.4 FSVeg Spatial Discrepancies

5.4.1 Polygons In Need of Redelineation
I noticed several discrepancies with data maintenance in FSVeg Spatial while

performing analyses for this project. One is that some polygons that had undergone

some sort of vegetation altering treatment had not been redelineated in FSVeg

Spatial after treatment implementation to reflect a change in stand conditions. Also,

I had learned that many polygons on the Gunnison RD had been reshaped by the

silviculturist in the last several years. However, he had not entered these edits into

FSVeg Spatial yet.   These issues bring to light that a more thorough examination of

polygons needs to occur prior to the update algorithm being applied in order to catch

discrepancies like these before any polygon record changes take place by the

automated update.   If polygons such as these are included in the algorithm update,

polygon inaccuracies such as these will just be proliferated rather than addressed and

fixed.

5.4.2 Inaccurate Species Compositions for Some Polygons

The GIS shop plans on conducting ongoing discussions and making a coordinated

effort with the GMUG timber staff to update forested polygons intentionally left out

of the automated update and those not yet known to have inaccurate species

compositions. This will require close collaboration with timber personnel to identify

and edit these polygons in FSVeg Spatial with correct attribute information as

determined from field visits or using foresters' and silviculturists' extensive field

knowledge of these areas. These tasks will take place over time but completing this

work in a timely manner should be goal for the GMUG so as to address and fix these

data discrepancies sooner rather than later.

5.4.2 Linked and Unlinked Plots

I reviewed priority polygons within the west and east timber zone planning areas (7N,

Long Creek, Moore-Payne, and Transfer on the Uncompahgre Plateau of the Ouray

RD and in areas around Kebler Pass and north of Taylor Park on the Gunnison RD) to

determine which polygons data had already been collected. This data collection

effort was separate from that for the mortality update project. Contract and agency

timber crews had collected data from these areas prior to 2016 or during the summer

of 2016 for timber sale preparation. Although the data were not originally collected

for the purpose of calculating mortality rates, timber staff agreed that it would serve

a dual purpose, if possible, to be used for timber sale preparation and in the mortality

update process. Unfortunately, most plot data had not been linked to polygons in

FSVeg Spatial. As a result of not maintaining plot data in FSVeg Spatial by archiving

old plot data and linking newly collected plot data, many of the plots generated from

recent data collection efforts were not and are not found in FSVeg Spatial.

Therefore, this plot data were not included in the base dataset used by the linked

plot tool to determine potentially valid plots. I will be making an extensive effort

during the 2017 winter to link most recent plot data to corresponding polygons for

project areas where this has not been already done in FSVeg Spatial. Once the

linkage is complete, I will gather and finalize all plot data that potentially can be used

in mortality rate calculations to be delivered to the SO timber staff for final review.

5.5 Relationship Criteria
When I examined the result from the first priority polygon sampling tool, I found

several polygons not to be completely within the ½ mile road buffer. I had designed

the tool to select those polygons that intersected any ½ mile road buffer. When I

chose "completely within" (polygons completely within the road buffer) rather than

"intersect" for the relationship type, only 251 of the 574 first priority polygons

resulted and met the selection criterion. Also, I discovered that 36 of 574 polygons

had a majority of their area in unsuitable timber areas and only small areas

intersecting suitable timber areas. This occurrence took place because I chose

'intersect' rather than "have their centroid in" as the relationship type for the

selecting criterion. When I switched the relationship type to "have their centroid in",

499 polygons met the criterion of having a majority of their area as potentially

suitable for commercial timber harvest. Lastly, I did not include proximity of

polygons to large towns as a final determining factor for priority. I did perform a

selection by location to select first priority polygons that were within 20 miles of a

town to see how many priority polygons met this criterion. 448 of 574 polygons

matched this criteria. Because the proximity is based on as the "crow flies" distance

between two locations, I contemplated performing a least cost path analysis to more

accurately determine the route wise distance from a polygon to a town. I would

have then applied route length calculations to select those polygons that were

closest or had the most cost-effective route to town or to an agency office.

However, after discussion with the SO timber and GIS staff about the usefulness of

the analysis, they decided the greater complexity provided by the analysis was not

warranted.

5.6 Conclusions
I successfully addressed the seven research questions raised in this Practicum and

fully answered five of the seven questions (refer to section 1.3). The last two

questions regarding recent and valid CSE data is still in the process of being fully

answered. I have described future work to complete in addressing these two

questions and in helping with the completion of future supervised delineation and

attribute updates to vegetation polygons.

5.6.1 Future Work
Because this work was unable to be finished during the timeframe of the Practicum,

Carol Howe, Resource Information Specialist for the GMUG, and I will be completing

any needed redelineations starting in the winter of 2017. We will start with those

flagged by RSAC but will also include in the review those polygons needing minor

edits. Minor edits entail those arising from differences in imagery used in the original

delineation efforts compared to newer imagery used to perform current

redelineations.

Many vegetation polygons will not be updated using the automated algorithm,

mainly due not collecting field data for nonpriority strata. Therefore, supervised

attribute edits for polygons not included in the algorithm update will need to occur

even after the completion of this Practicum. One way to manage the execution of

needed edits would be to prioritize the excluded polygons from this Practicum's

work and utilize those priority designations to direct future work involving spatial

redelineations and supervised attribute updates.

Archiving old plot data in FSVeg and FSVeg Spatial and linking valid plot data in FSVeg

Spatial will be also an important task to complete winter of 2017. Old plot data is

data that have been collected in the distant past and no longer quantify existing

conditions. Once old plot data is archived, recently collected plot data can be linked

in FSVeg Spatial. The completion of this particular task will be instrumental in

increasing the amount of data made available for mortality rate calculations.

Furthermore, increasing the amount of field data used in calculations should improve

the accuracy of mortality rates.

GIS staff are aware of general locations of some polygons with inaccurate species

compositions. However, exact Setting IDs which are unique identifications for

polygons still need to be identified for exclusion from the automated update. The

attributes of these polygons will need to be updated manually in FSVeg Spatial either

after plot data has been collected or the FSVeg Walkthrough Form (refer to Figure 3)

has been completed as a result of field visits.

In addition to providing information regarding mortality within polygons, plot data

will also aid in updating other stand attributes than just the percentage of dead. GIS

staff will use a newly created FSVeg Spatial tool that applies plot data in calculating

tree cover percentages of all species, both live and dead percentages, found within

the plots of a polygon. Additionally, attributes listed in the FSVeg Spatial

Walkthrough Form will also be updated for every polygon included in the contract.

The data collected on the form will be incorporated into the FSVeg Spatial database

using a database loader tool.

Lastly, I and others in the GMUG GIS shop plan on developing 3D photo

interpretation skills using a new stereo viewing software extension Summit Evolution

which recently started being used by the USFS in the spring of 2016 to test out its

efficiency in stereo viewing as compared to Stereo Analyst. If it proves to be quicker

in downloading and processing image files, we, the GMUG GIS shop, will use Summit

Evolution extension to more clearly detect differences in stand structure and species

composition among vegetation polygons.

5.6.2 Management Implications
Work performed for this Practicum placed emphasis on : 1) the need for consistent

and accurate field data collection across the GMUG, following all FSVeg Spatial and

FSVeg protocols for data collection, 2) the importance of updating polygon

delineations and attributes in the FSVeg Spatial database annually, 3) training

individuals in FSVeg Spatial and FSVeg to be able to correctly and accurately update

structure and composition of forested polygons, and lastly, 4) tasking those trained

individuals with the responsibility of making FSVeg Spatial and FSVeg updates on a

consistent basis.

5.6.3 Final Remarks
Overall, the work performed in this Practicum successfully selected vegetation

polygons from which field data was and will be collected based on several criteria

implemented in a GIS sampling strategy. The criteria helped reduce per plot cost and

maximize the number of plots for field data collection keeping in mind the budget

allocated to this task. Vegetation polygons will be updated once the tree mortality

rule sets are developed from the collected plot data. Once the updates have taken

place, FSVeg Spatial records will be more accurate in reflecting existing conditions for

forested polygons, rather than conditions from more than 25 years ago. These

conditions can then be used to revise the FLMP to provide better guidance in

managing the natural resources on the three Forests. A revised and more current

FLMP will allow the Forests to be more accountable to the citizens of the United

States for the purpose to which the agency was originally created, "Caring for the

Land and Serving the People".

References

Allen, D. W. (2011). *Getting to know ArcGIS ModelBuilder* (1st ed.). Redlands, CA: Esri Press.

Anderegg, L. D. L., Anderegg, W. R. L., Abatzoglou, J., Hausladen, A. M., & Berry, J. A. (2013). Drought characteristics' role in widespread aspen forest mortality across Colorado, USA. *Global Change Biology, 19*(5), 1526-1537. doi:10.1111/gcb.12146

Andrew, M. E., Wulder, M. A., & Nelson, T. A. (2014). Potential contributions of remote sensing to ecosystem service assessments. *Progress in Physical Geography, 38*(3), 328-353. doi:10.1177/0309|333|4528942

Bellante, G., Goetz, W., Maus, P., Wittwer, D., Schrader, B., Johnson, E., Megown, K. (2015). Yakutat foreland existing vegetation map project. (No. RSAC-10106-RPT1). Salt Lake City, Utah: United Stated Department of Agriculture, Forest Service, Remote Sensing Applications Center.

Bentz, B. J., Régnière, J., Fettig, C. J., Hansen, E. M., Hayes, J. L., Hicke, J. A., . . . Seybold, S. J. (2010). Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. *Bioscience, 60*(8), 602-613. doi:10.1525/bio.2010.60.8.6

Biswas, T., Heutte, T., Riley, M., Wittwer, D. T., Maus, P, Megown, K. (2016). A Landsat method to monitor aspen defoliation southwest of Fairbanks, interior Alaska. (No. RSAC-10116-RPT1). Salt Lake City, Utah: United Stated Department of Agriculture, Forest Service, Remote Sensing Applications Center.

Campbell, J. B., & Wynne, R. H. (2011). *Introduction to Remote Sensing* (5th ed.). New York, NY: The Guilford Press.

Chi, G. (2010). Land developability: Developing an index of land use and development for population research. *Journal of Maps,* 609-617. doi:10.4113/jom.2010.1146

Code of Federal Regulations (2015a). Title 36: Parks, Forests, Public Property. Chapter 2: Forest Service, Department of Agriculture. 212: Travel Management. https://www.law.cornell.edu/cfr/text/36/part-212.

Code of Federal Regulations (2015b). Title 36: Parks, Forests, Public Property. Chapter 2: Forest Service, Department of Agriculture. 251: Land Uses. https://www.law.cornell.edu/cfr/text/36/part-251

Code of Federal Regulations (2015c). Title 36: Parks, Forests, Public Property.
Chapter 2: Forest Service, Department of Agriculture. 261: Prohibitions.
https://www.law.cornell.edu/cfr/text/36/part-261

Coelho, A. C., Labadie, J. W., & Fontane, D. G. (2012). Multicriteria decision support
system for regionalization of integrated water resources management. *Water
Resource Management, 26*, 1325-1346.

Cohen, W. B., & Goward, S. N. (2004). Landsat's role in ecological applications of
remote sensing. *Bioscience, 54*(6), 535-545.

Collins, J. B., & Woodcock, C. E. (1996). An assessment of several linear change
detection techniques for mapping forest mortality using multi-temporal Landsat
TM data. *Remote Sensing of Environment, 56*, 66-77.

Coops, N. C., Johnson, M., Wulder, M. A., & White, J. C. (2006). Assessment of
QuickBird high spatial resolution imagery to detect red attack damage due to
mountain pine beetle. *Remote Sensing of Environment, 103*, 67-80.
doi:10.1016/j.rse.2006.03.012

Coppin, P., Jonckheere, I., Nackaerts, K., & Muys, B. (2004). Digital change detection
methods in ecosystem monitoring: A review. *International Journal of Remote
Sensing, 25*(8), 1565-1596. doi:10.1080/0143116031000101675

Deng, J. S., Wang, K., Deng, Y. H., & Qi, G. J. (2008). PCA-based land-use change
detection and analysis using multi-temporal and multisensor satellite data.
International Journal of Remote Sensing, 29(16), 4823-4838.
doi:10.1080/01431160801950162

ESRI. (2016). What is ModelBuilder?-Help|ArcGIS for desktop. Retrieved from
http://desktop.arcgis.com/en/arcmap/10.3/analyze/modelbuilder/what-is-
modelbuilder.htm

Gardiner, T. (2015). In Kolanoski K. (Ed.), *Tree mortality around Ouray, Colorado and
bark beetle effects on Uncompahgre Plateau.*

Goodwin, N. R., Coops, N. C., Wulder, M. A., Gillanders, S., Schroeder, T. A., & Nelson,
T. (2008). Estimation of insect infestation dynamics using a temporal sequence
of Landsat data. *Remote Sensing of Environment, 112*, 3680-3689.
doi:10.1016/j.rse.2008.05.005

Hansen, E. M., Negron, J. F., Munson, A. S., & Anhold, J. A. (2010). A retrospective assessment of partial cutting to reduce spruce beetle-caused mortality in the southern Rocky Mountains. *Western Journal of Applied Forestry, 25*(2), 81-87.

Hebertson, E. G., & Jenkins, M. J. (2008). Climate factors associated with historic spruce beetle (*Coleoptera*:Curculionidae) outbreaks in Utah and Colorado. *Environmental Entomology, 37*(2), 281-292.

Hsu, W. C., Remar, A., Williams, E., McClure, A., Kannan, S., Steers, R., Schmidt, C., & Skiles, J. W. (2012). The changing California coast: Relationships between climatic variables and coastal vegetation succession. *ASPRS 2012 Annual Conference, March 19-23,* Sacramento, California. 12 p.

Ireland, K. B., Moore, M. M., Fulé, P., Zegler, T. J., & Keane, R. E. (2014). Slow lifelong growth predisposes *Populus tremuloides* trees to mortality. *Oecologia, 175,* 847-859. doi:10.10077/s00442-014-2951-5

Kelly, M., & Di Tommaso, S. (2015), Mapping forest with LiDAR provides flexibility, accurate data with many uses. *California Agriculture, 69,* 14-20. doi:10.3733/ca.v069n01p14

Kennedy, R. E., Cohen, W. B., & Schroeder, T. A. (2007). Trajectory-based change detection for automated characterization of forest disturbance dynamics. *Remote Sensing of Environment, 110,* 370-386. doi:10.1016/j.rse.2007.03.010

Klein, W. H., Tunnock, S., Ward, J. G. D., & Knopf, J. A. E. (1983). *Aerial Sketchmapping.* In: Forest Insect and Disease Survey Methods Manual. Davis, California: USDA Forest Service, Forest Pest Management, Methods Application Group, 15 pp.

Knorn, J., Rabe, A., Radeloff, V. C., Kuemmerle, T., Kozak, J., & Hostert, P. (2009). Land cover mapping of large areas using chain classification of neighboring Landsat satellite images. *Remote Sensing of Environment, 113,* 957-964. doi:10.1016/j.rse.2009.01.010

Kuhmaier, M., & Stampfer, K. (2010). Development of a multi-attribute spatial decision support system in selecting timber harvesting systems. *Croatian Journal of Forest Engineering, 31*(2), 75-88.

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2004). In Flahive R., Powell D. (Eds.), *Remote sensing and image interpretation* (5th ed.). New York, NY: John Wiley & Sons, Inc.

Linn, J. P., Bourne, S. G., & Kleiss, B. A. (2006). *Creating a wetland restoration decision support system using GIS tools.* (No. ERDC TN-EMRRP-EM-05). Vicksburg, MS: U.S. Army Engineer Research and Development Center. doi:http://el.erdc.usace.army.mil/emrrp/emrrp.html

Lunetta, R. S., Knight, J. F., Ediriwickrema, J., Lyon, J. G., & Worthy, L. D. (2006). Land-cover change detection using multi-temporal MODIS NDVI data. *Remote Sensing of Environment, 105*(2), 142-154. doi:10.1016/j.rse.2006.06.018

Marchetti, S. B., Worrall, J. J., & Eager, T. (2011). Secondary insects and diseases contribute to sudden aspen decline in southwestern Colorado, USA. *Canadian Journal of Forest Resources, 41*, 2315-2325. doi:10.1139/X11-106

Mayer, A. L., & Lopez, R. D. (2011). Use of remote sensing to support forest and wetlands policies in the USA. *Remote Sensing, 3*(6), 1211-1233. doi:10.3390/rs3061211

McRoberts, R. E., Cohen, W. B., Naesset, E., Stehman, S. V., & Tomppo, E. O. (2010). Using remotely sensed data to construct and assess forest attribute maps and related spatial products. *Scandinavian Journal of Forest Research, 25*, 340-367. doi:10.1080/02827581.2010.497496

Meddens, A. J. H., & Hicke, J. A. (2014). Spatial and temporal patterns of Landsat-based detection of tree mortality caused by mountain pine beetle outbreak in Colorado, USA. *Forest Ecology and Management, 322*, 78-88. doi:10.1016/j.foreco.2014.02.037

Meddens, A. J. H., Hicke, J. A., & Vierling, L. A. (2011). Evaluating the potential of multispectral imagery to map multiple stages of tree mortality. *Remote Sensing of Environment, 115*, 1632-1642. doi:10.1016/j.rse.2011.02.018

Meigs, G. W., Kennedy, R. E., & Cohen, W. B. (2011). A Landsat time series approach to characterize bark beetle and defoliator impacts on tree mortality and surface fuels in conifer forests. *Remote Sensing of Environment, 115*, 3707-3718. doi:10.1016/j.rse.2011.09.009

Michaelian, M., Hogg, E. H., Hall, R. J., & Arsenault, E. (2011). Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest. *Global Change Biology, 17*, 2084-2094. doi:10.1111/j.1365-2486.2010.02357.x

Mitchell, B., Beaty, M., Reynolds, R., Mellin, T., Hudak, A.T., Schaaf, A., Fisk, H. (2015). Creating LiDAR Canopy Structure Layers and inventory models for evaluating northern goshawk habitat quality (No. RSAC-10070-RPT1). Salt Lake City, Utah: United Stated Department of Agriculture, Forest Service, Remote Sensing Applications Center.

Moffiet, T., Mengersen, K., Witte, C., King, R., & Denham, R. (2005). Airborne laser scanning; exploratory data analysis indicates potential variables for classification of individual trees or forest stands according to species. *ISPRS Journal of Photogrammetry and Remote Sensing, 59*, 289-309. doi:10.1016/j.isprsjprs.2005.05.002

Mueller, R. C., Scudder, C. M., Porter, M. E., Trotter III, R. T., Gehring, C. A., & Whitham, T. G. (2005). Differential tree mortality in response to severe drought: Evidence for long-term vegetation shifts. *Journal of Ecology, 93*(6), 1085-1093. doi:10.1111/j.1365-2745.2005.01042.x

Mustian, A. P. (1978). History and philosophy of silviculture and management systems in use today. *Uneven-Aged Silviculture and Management in the Western United States,* Redding, California. 1-10.

Pasual, C., Garcia-Montero, L. G., Arroyo, L. A., & Garcia-Abril, A. (2013). Increasing the use of expert opinion in forest characterization approaches based on LiDAR data. *Annals of Forest Science, 70*, 87-99. doi:10.1007/s13595-012-0232-1

Potter, C. (2015). Changes in vegetation cover and productivity in Yosemite national park (California) detected using Landsat satellite image analysis. *Journal of Biodiversity Management and Forestry, 4*(4) doi: http://dx.doi.org/10.4172/2327-4417.1000148

Rebain, S. (2016). *Logic used to create a GIS model to estimate suitable timber acres.* Unpublished manuscript.

Rehfeldt, G., Worrall, J., Marchetti, S., & Crookston, N. (2015). Adapting forest management to climate change using bioclimate models with topographic drivers. *Forestry, 0*(February), 1-12. doi:10.1093/forestry/cpv019

Singh, A. (1989). Digital change detection techniques using remotely-sensed data. *International Journal of Remote Sensing, 10*(6), 989-1003. doi:10.1080/01431168908903939

Skakun, R. S., Wulder, M. A., & Franklin, S. E. (2003). Sensitivity of the thematic mapper enhanced wetness difference index to detect mountain pine beetle red-attack damage. *Remote Sensing of Environment, 86*, 433-443. doi:10.1016/S0034-4257(03)00112-3

Smith, D. M., Larson, B. C., Kelty, M. J., & Ashton, P. M. S. (1997). In Stano E. (Ed.), *The Practice of Silviculture: Applied Forest Ecology* (9th ed.). Hoboken, N.J.: John Wiley & Sons, Inc.

Stam, C., Goetz, W., Maus, P., Dressen, M., Zwisler, S., Caulkins, J., & Megown, K. (2015a). *Medicine Bow-Routt National Forest: FSVeg database update.* (No. RSAC-10095-RPT1). Salt Lake City, Utah: United States Department of Agriculture, Forest Service, Remote Sensing Applications Center.

Stam, C., Goetz, W., Megown, K., Dressen, M., & Zwisler, S. (2015b). *Forest-wide mortality statistics: Using common stand exam data.* (No. RSAC-10095-Brief1). Salt Lake City, Utah: United Stated Department of Agriculture, Forest Service, Remote Sensing Applications Center.

Stam, C., Goetz, W., Megown, K., Dressen, M., & Zwisler, S. (2015c). *Using common stand exam data to estimate forest-wide mortality: Final report.* (No. RSAC-10095-RPT2). Salt Lake City, Utah: United States Department of Agriculture, Forest Service, Remote Sensing Applications Center.

Stam, C., K. McCallum, W. Goetz, K. McGown, C. O'Brien, K. Lee, & S. Zwisler (2016). *Rio Grande National Forest: FSVeg Spatial Database Update.* (No. RSAC-10119-RPT1). Salt Lake City, Utah: United States Department of Agriculture, Forest Service, Remote Sensing Applications Center.

Tang, A., Li, R., Li, X., Jiang, W., & Hirsch, A. (2014). Capturing LiDAR-derived hydrologic spatial parameters to evaluate playa wetlands. *Journal of the American Water Resources Association, 50*(1), 234-245.

USDA Forest Service. (2014). *FSVeg Spatial User Guide* (10/31/2014 ed.) USDA Forest Service, National Resource Management.

USDA Forest Service (2015). *FSVeg Common Stand Exam User Guide* (v.2.12.6 ed.) USDA Forest Service, National Resource Management (NRM).

USDA Forest Service (2016a). *Final Environmental Impact Statement, Spruce Beetle Epidemic and Aspen Decline Management Response.*

USDA Forest Service. (2016b). *R2 Supplement to the FSVeg Spatial User Guide* (1/6/2016 ed.) USDA Forest Service, National Resource Management.

Vahidi, M., Jafarzadeh, A., Fakerirard, A., Sadeghi, S., Rezaei-Moghaddam, M., Sofia, G., & Tarolli, P. (2013). Digital change detection using remotely sensed data for monitoring land use/land cover in Hervi watershed, Iran. *International Journal of Agriculture: Research and Review, 3*(2), 423-440.

Worrall, J. J., Egeland, L., Eager, T., Mask, R. A., Johnson, E. W., Kemp, P. A., & Shepperd, W., D. (2008). Rapid mortality of *Populus tremuloides* in southwestern Colorado, USA. *Forest Ecology and Management, 255,* 686-696.

Worrall, J. J., Marchetti, S. B., Egeland, L., Mask, R. A., Eager, T., & Howell, B. (2010). Effects and etiology of sudden aspen decline in southwestern Colorado, USA. *Forest Ecology and Management, 260*(5), 638-648.

Wulder, M. A., White, J. C., & Bentz, B. J. (2005). Detection and mapping of mountain pine beetle red attack: Matching information needs with appropriate remotely sensed data. *In: Proceedings of the Joint 2004 Annual General Meeting of the Convention of the Society of American Foresters and the Canadian Institute of Forestry; October 2-6, 2004,* Edmonton, Alberta. 17p.

Wulder, M. A., White, J. C., Bentz, B., Alvarez, M. F., & Coops, N. C. (2006). Estimating the probability of mountain pine beetle red-attack damage. *Remote Sensing of Environment, 101,* 150-166. doi:10.1016./j.rse.200512.010

Wulder, M. A., White, J. C., Coops, N. C., & Butson, C. R. (2008). Multi-temporal analysis of high spatial resolution imagery for disturbance monitoring. *Remote Sensing of Environment, 112,* 2729-2740. doi:10.1016/j.rse.2008.01.010

Xian, G., Homer, C., & Fry, J. (2009). Updating the 2001 National Land Cover database land cover classification to 2006 by using Landsat imagery change detection methods. *Remote Sensing of Environment, 113,* 1133-1147. doi:10.1016/j.rse.2009.02.004

Zhang, Q., Wollersheim, M., Griffiths, S., & Maddox, I. (2014). National fire risk map for continental USA: Creation and Validation. *8th International Symposium of the Digital Earth, 18,* 6 p. doi:10.1088/1755-1315/18/1/012134

Zwisler, S. (2015). In Kolanoski K. (Ed.), *CSE data collection costs and CSE plot layout design.*

Zwilser, S. (2016). *Chapter Z3-Sample Design, Field Data Collection, Data Loading &
Extraction*. Unpublished manuscript.

Appendix A
Supplemental Literature Review

A.1 US Forest Service Background Information

A.1.1 Policy Guiding Land Management Decision Making in the U.S. Forest Service

During the time of its inception in 1905, the U.S. Forest Service was designed to provide forest protection through custodial management (Williams, 2005). Over the years, the mission of the US Forest Service has evolved into "sustaining the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations". This mission is reflected and summarized in the agency's present motto of "Caring for the Land and Serving the People".

When the Multiple Sustained Yield Act of 1960 was passed, the agency's focus was to manage for multiple resources while allowing for the sustainable, multiple use of those resources on Forest Service lands (USDA Forest Service, 2015a). This law specifically calls for the sustained yield of products and services through the establishment and administration of national forests. Products and services includes recreation, range, timber, watershed, and wildlife and fish. Today, this Act still guides the agency in management of its lands and resources. However, since 1960, the National Environmental Policy Act(NEPA) of 1969 and the National Forest Management Act(NFMA) of 1976, have been enacted into law and give additional guidance to the agency in protecting the natural environment of national forests and grasslands.

NEPA was designed "to encourage productive and enjoyable harmony between man and his environment" and details the framework in which the agency is supposed to abide in complying with the requirements of the act (Federal Code of Regulations,

2017). NEPA requires that the US Forest Service among other federal agencies to

take a 'hard look' at or assess the environmental impacts of proposed actions before

implementing those actions. Additionally, the act requires that federal agencies

include or incorporate the public during the decision making process (Auer et al. 2011;

Wells, 2014).   NFMA necessitates the creation of long term management plans for

each Forest and grassland. The first Forest Land and Resource Management Plans

(FLMPs) or also otherwise known as Forest Plans were written in the early 1980s and

for many Forests have guided management on those lands for more than twenty

years. Several Forests have undergone Forest Plan Revisions and are under the

direction of newly revised FLMPs while most Forests still need to undergo this

revision process. Furthermore, Forests that had not undergone the Forest Plan

Revision process or started the process before 2012 postponed the revision process

until the 2012 planning rule and the final planning directives designed to direct

Forests in the implementation of the 2012 planning rule were passed and made

available to them to use in the Forest Plan revision process. As of January, 2015, 19

out of 154 national forests and 20 grasslands in the National Forest System had begun

to revise their FLMPs under the 2012 planning rule (USDA Forest Service, 2015b).

The GMUG started in 2003 to begin revising its 1991 amended Plan. The Forest had

released a proposed Forest Plan on March 15, 2007 but was one of several Forests

who postponed the revision process until a new planning rule was in place and the

final Colorado Roadless Area decision was made (USDA Forest Service, 2015b). In

2017, the Forest is slated to restart the Revision process with the goal to produce a

newly functioning FLMP by 2018/2019 under the guidance of the 2012 Planning Rule.

Currently, the GMUG is still under the direction of the 1991 amended FLMP giving the

current FLMP a lifespan of approximately twenty-five years, approximately 10 years

longer than what was intended for its implementation.

Programs currently planned to be addressed in the newly revised FLMP for the

GMUG include Timber Management, Livestock and Range Management, Watershed

and Aquatic Resources, Wildland Fire and Fuels Management, Minerals and

Geological Resources, Recreation, Invasive Species Management, Insect and Disease

Management, Wildlife Management, and Heritage Resources. The determination of

existing and desired conditions for the multiple resources falling under the direction

of each of these programs will be the first steps in the revision process. The first

steps will also include developing management objectives for each of the resources

once existing and desired conditions have been ascertained. Many different

assessments will need to be performed on existing data to provide current existing

condition information for the different resources on the GMUG, including vegetation

data provided by the FSVeg Spatial application.

A.1.2 Role of Adaptive Management
The US Forest Service faces multiple challenges in currently managing its lands and

resources as well as trying to plan for the future management of these same lands

and resources. These challenges originate from both external and internal forces.

One of the many challenges for the agency is trying to incorporate new knowledge

and information regarding how natural systems, including both ecological and social

systems, respond to applied management strategies and methods while adhering to

NEPA requirements. Benson and Garmestani (2011) suggest that in order to be

successful in embracing new theories and strategies regarding social-ecological

systems, NEPA should be reconfigured to allow for the adaptive cycle of panarchy to

describe the processes of development and decay in a system(s) as well as consider

and plan for the multiple scales on which complex systems work and function. The

premise of panarchy is that change is constant and that even if the change that

occurs is negative, new opportunities arise from the process that has resulted in that

negative change (Benson and Garmestani, 2011).

Adaptive management has been implemented as an environmental management

strategy to help entities, organizations, and agencies to learn what works and does

not work well within a system. In the opinion of Benson and Gramestani (2011),

adaptive management has been underutilized in determining the successes and

failures of certain management actions. If implemented how it was designed,

adaptive management can provide and encourage the implementation of

management strategies and actions that foster and build resilience within natural

systems.   The US Forest Service has addressed the importance of using an adaptive

management approach when implementing NEPA projects. However, the extent to

which the management strategy is utilized is debatable and the success of its

utilization during the lifespan of a NEPA project is difficult to determine due to the

inconsistency and variability of its application during the planning and

implementation phases of these projects. Also, the iterative process of adaptive

management can be difficult to implement within US Forest Service projects for

many reasons. These reasons include the inherent approach to satisfying NEPA

requirements for project planning and implementation (i.e. the front end approach

and linear nature of NEPA), the lack of enforceability of adaptive management

strategies, and the deficiency in consistent system monitoring required for the

successful application of adaptive management.

Benson and Gramestani (2011) suggest that effective implementation of adaptive

management could occur by reworking NEPA so that the iterative process required

of adaptive management replaces the front end approach of the NEPA process that

discourages the acknowledgement of uncertainty in project planning. This reworking

would include proposing more NEPA projects, not just those exclusively proposed for

oil and gas development, which are programmatic in nature and require site specific

analyses before implementation but not prior to approving landscape scale EISes

(Environmental Impact Statements).   This type of approach to project planning

allows for the presence of uncertainty and creates a more open, accepting

environment that fosters learning, an environment in which adaptive management

would thrive.

To date, not many Forests or grasslands have applied this type of programmatic

approach to planning and implementing forest health and fuel management projects

across the landscape. Instead, most Forests have approached project planning and

implementation on a small scale to avoid the lengthy from start to end planning

timeframe and controversial nature of an EIS, including any litigation that may arise

from controversy stemming from the EIS.   The SBEADMR project is an exception.

The GMUG has taken a programmatic approach with this project.   As mentioned in

the Introduction of this document, this project has been designed to address the

extensive impacts of tree mortality from sudden aspen decline (SAD) and infestations

of various damage causal agents including spruce bark beetle on forest health across

the three Forests.   The purpose of the project is "to reduce the safety threats of

falling, dead trees and of managing wildfires on the landscape (safety); improve the

resiliency of stands at-risk of insect and disease (resiliency); and to treat affected

stands via recovery of salvageable timber and subsequent reestablishment of desired

forest conditions (recovery)". Because of the extensive mortality of spruce-fir and

aspen forests on the GMUG over the past decade, the need for the project is "to

manage forest vegetation to bring current and foreseeable conditions closer to

desired conditions on landscapes available for active management" (USDA Forest

Service, 2016).   The approach of the project is programmatic in nature because it

looks at opportunity areas in the type of treatment to be implemented, generally

specified under each developed alternative. An opportunity area consists of the

maximum acreage that could be treated according to the treatment description

provided for a proposed alternative. Furthermore, site specific analyses are designed

to be performed prior to implementation and not prior to the final decision of the EIS

being made and officially approved.   This approach allows for uncertainty to be

present during the planning phase and requires adaptive management to be applied

effectively and in a consistent manner throughout the life of the project in order for

the GMUG to be successful in its approach to fulfilling the purpose of SBEADMR and

being accountable to the public for its management decisions and actions.

Adaptive management is addressed in the Final EIS of SBEADMR as being a part of

national policy and direction outlined in FSM 2020, 2013 Forest Service interim

directive on ecological and resilience. The directive states that adaptive

management "is a system of management practices based on clearly identified

outcomes and monitoring to determine if management actions are meeting desired

outcomes, and if not, to facilitate management changes that will best ensure that

outcomes are met or reevaluated. Adaptive management stems from the

recognition that knowledge about natural resource systems is sometimes uncertain"

(Code of Federal Regulations, 2017). Therefore, adaptive management could be

successfully implemented in the case of SBEADMR if the process is used to gain

knowledge from the application of management actions and assess their

effectiveness in meeting the purpose and reaching the goals and objectives outlined

in the project. The assessments will hopefully bring to light any success or failures of

past actions and decisions. It will be essential to apply those successes and failures in

making the system as a whole more resilient through future treatment

implementation decisions and actions rather than making adaptive management an

avenue for mitigation of negative impacts to resources. Using adaptive management

only to mitigate for negative change could hamper the full potential of adaptive

management in elucidating the uncertainty of complex systems and learning from

how these systems react and respond to certain management decisions and actions.

According to the general technical report PNW-GTR-654 Adaptive Management of
Natural Resources: Theory, Concepts, and Management Institutions, adaptive
management can be broken up into four main phases: Plan, Act, Monitor, and
Evaluate. The concept of adaptive management applies to multiple scales of forest
management, both on a project level scale and a Forest level scale. SBEADMR is
unique in that it applies to both scales, project and Forest levels. The Forest Plan
takes place on a landscape level and generally incorporates all phases of adaptive
management in directing the management of the three Forests. Specifically, the 1991
FLMP for the GMUG provides goals and objectives and standards and guidelines in
directing the management of vegetation (including old growth), cultural resources,
wildlife resources, forest products, water quality, economics, air quality, fire, insects
and disease, and soil resources on the GMUG (USDA Forest Service, 1983; USDA
Forest Service, 1991).

The Forest Plan revision process will reside heavily within the planning phase of
adaptive management. As part of the revision process, spatial and tabular data
obtained for managed resources will need to be analyzed and quantified to
determine the changes that have occurred over the GMUG since the last amended
Forest Plan to set new management allocations for specific uses of land, known as
Management Areas (MAs) on the GMUG. The process of updating MAs will include
calculating percentages of tree species and vegetation types within each of these
MAs across the GMUG. These calculations in addition to other needed analyses
involving vegetation information on the Forests, will need to come from the current

vegetation database for the US Forest Service known as FSVeg Spatial. A discussion

of this database is provided in the Methods section, Chapter Three of this document.

During the assessment phase of the revision process, vegetation polygons obtained

from the FSVeg Spatial database will be used to determine vegetation types and

calculate tree species and vegetation type percentages existing across the GMUG

that will then be used in further analyses for the revision process and documented in

the newly revised Forest Plan.

A.2 Role of Field Collected Data, Aerial Detection Survey Data, and Remotely Sensed Data

Information regarding stand structure (basal area, stand height, canopy cover,

regeneration numbers, percentage of dead (snags), etc.), stand composition (tree

species within stand, regenerating species, etc.) and stand condition (what insect

and pathogens are present within the stand, extent of infestation or infection, etc.)

has long been obtained from stand data collected in the field. Foresters in both

Canada and the US have also been able to use data obtained from aerial observations

(ADS in US; AOS in Canada) to determine the extent of pathogen infestation or

infection in different stands across the landscape. Although both of these types of

data are invaluable in characterizing the health of forest stands, both data types have

their inherent disadvantages. Collection of stand exam data across a large area is

time consuming and expensive. Experience has shown that CSE data collection can

take up to an hour per plot depending on the number of trees in a plot. It may take

more or less time depending on if data on down woody debris or understory

vegetation is collected at the plot too. Moreover, IDIQ and TEAMs contracts have

been signed with costs for field data collection ranging anywhere from

approximately $85 to $100 per plot for IDIQ contracts to $200 per plot for TEAMS

contracts. For these reasons, the data that is produced from stand exam collection

usually does not cover large areas, depending on how detailed the collection

methods being used are, the budget available for the collection, and the number of

people performing the collection.

ADS data is collected in the US by the Forest Health Projection Program (FHP) staff

and State agency cooperators to produce maps of areas affected by different

pathogens across the landscape. The maps are produced from sketchmapping

where surveyors sketch affected areas on a tablet PC that records positions with a

GPS while flying over the landscape in a single-engine, fixed- or rotary-wing aircraft.

Because no two sketchmappers record the same outbreak in exactly the same way,

this method is highly subjective (Klein et al. 1983). Furthermore, according to the

Aerial Detection Survey Fact Sheet, the data is best displayed spatially at small scales

such as 1:100,000 to 1:500,000 and is best used for demonstrating trends rather than

exacting precise measurements. This type of data is very useful in showing patterns

of vegetation response to pathogens across the landscape as long as the following

two conditions are met: 1) the sketchmapper is skilled enough to consistently limit

the errors of commission and omission made during pathogen identification and

affected area sketching and 2) the pathogen infestation or infection has progressed

at a level in the stands to be detectable from the air.   Nevertheless, both field data

and ADS data most likely will not be replaced by the application of remotely sensed

data in characterizing forest stands because each type of data adds different

information to the description of forest stands and play a different role in the

enrichment and development of forest stand characterization. Furthermore, field

data will always be needed to verify the accuracies of classifications derived from

remotely sensed data, but just not to the extent of the field collection required to

quantify stand structure and composition with field data alone.
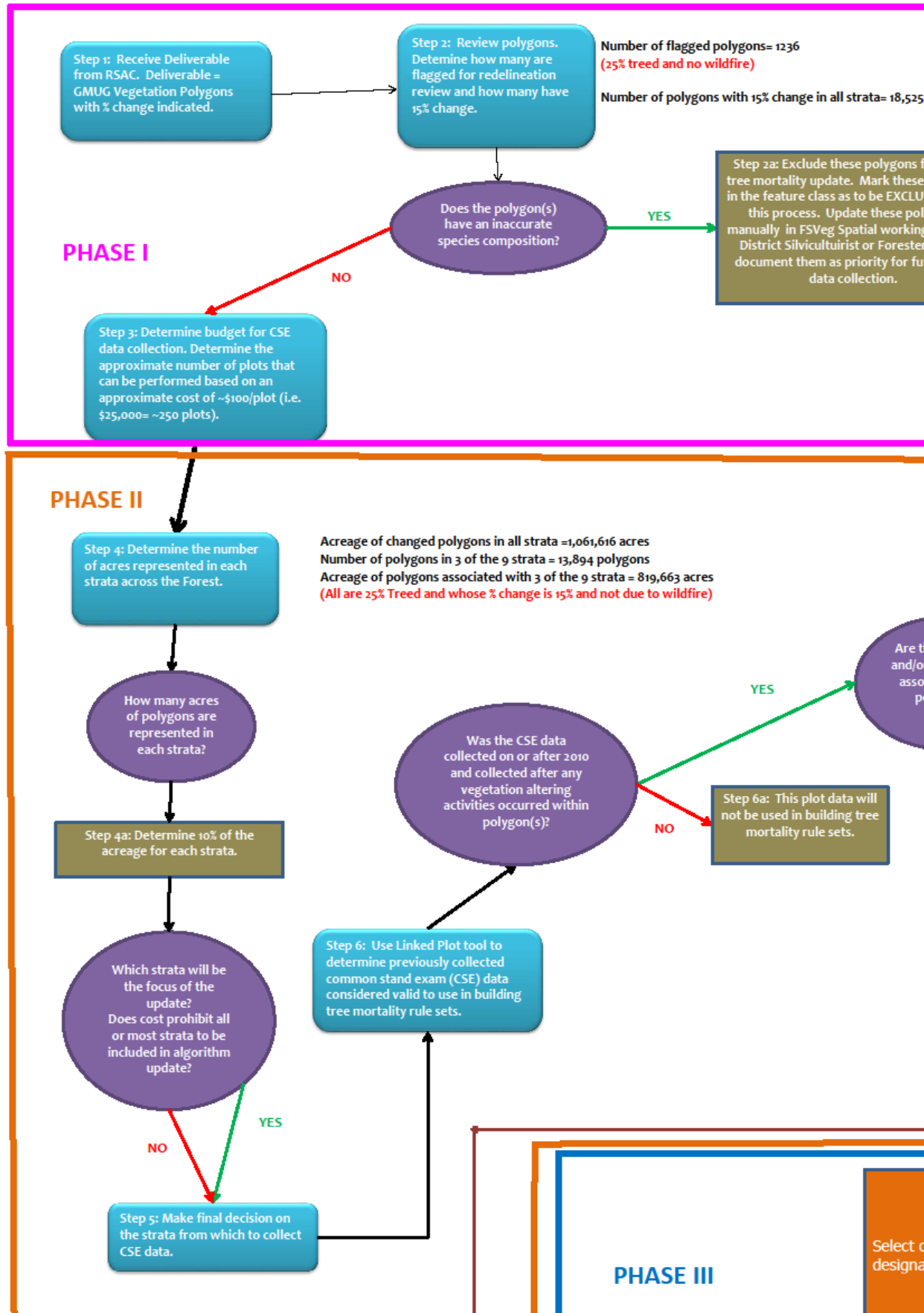
Supplemental Literature Review References

Auer, M., Richards, K., Seesholtz, D., Burnell, F., Freitag, C., & Grice, J. (2011). The U.S. forest service and its responsibilities under the National Environmental Policy Act: A work design problem. *Public Organizational Review, 11*, 135-153. doi:10.1007/s11115-010-0115-6

Benson, M. H., & Garmestani, A. S. (2011). Embracing panarchy, building resilience and integrating adaptive management through a rebirth of the National Environmental Policy Act. *Journal of Environmental Management, 92*, 1420-1427. doi:10.1016/j.jenvman.2010.10.011

Code of Federal Regulations (2017). Title 36: Parks, Forests, Public Property. Chapter 2: Forest Service, Department of Agriculture. 220: National Environmental Policy Act (NEPA) Compliance. http://cfr.regstoday.com/36cfr220.aspx#36_CFR_220p3.

Stankey, G. H., Clark, R. N., & Bormann, B., T. (2005). *Adaptive Management of Natural Resources: Theory, Concepts, and Management Institutions.* (No. PNW-GTR-654). Pacific Northwest Research Station: USDA Forest Service.

USDA Forest Service (1983). *Grand Mesa, Uncompahgre and Gunnison National Forests Land and Resource Management Plan.*

USDA Forest Service (1991). *Final Supplemental Environmental Impact Statement for the Amendment of the Land and Resource Management Plan for the Grand Mesa, Uncompahgre, and Gunnison National Forests.*

USDA Forest Service. (2015a). Laws and regulations - U.S. Forest Service. Retrieved from http://www.fs.fed.us/about-agency/regulations-policies/laws-regulations

USDA Forest Service (2015b). Forest Plan Revision for Grand Mesa, Uncompahgre, and Gunnison National Forests. Retrieved from http://www.fs.usda.gov/detail/gmug/landmanagement/planning/?cid=fsbdev7_0 03223

USDA Forest Service (2016). *Final Environmental Impact Statement, Spruce Beetle Epidemic and Aspen Decline Management Response.*

Wells, K. (2014). Can't see the trees for the forest? The ongoing controversy over assessing the site specific impacts of comprehensive forest management plans. *Ecology Law Quarterly, 41*(553), 553-580.

Williams, G. W. (2005). *The USDA Forest Service- the First Century.* (No. FS-650). Washington, DC: USDA Forest Service, Office of Communication.

Appendix B

Additional Figures

Figure B-1. Flowchart detailing the steps taken to complete the tasks for the
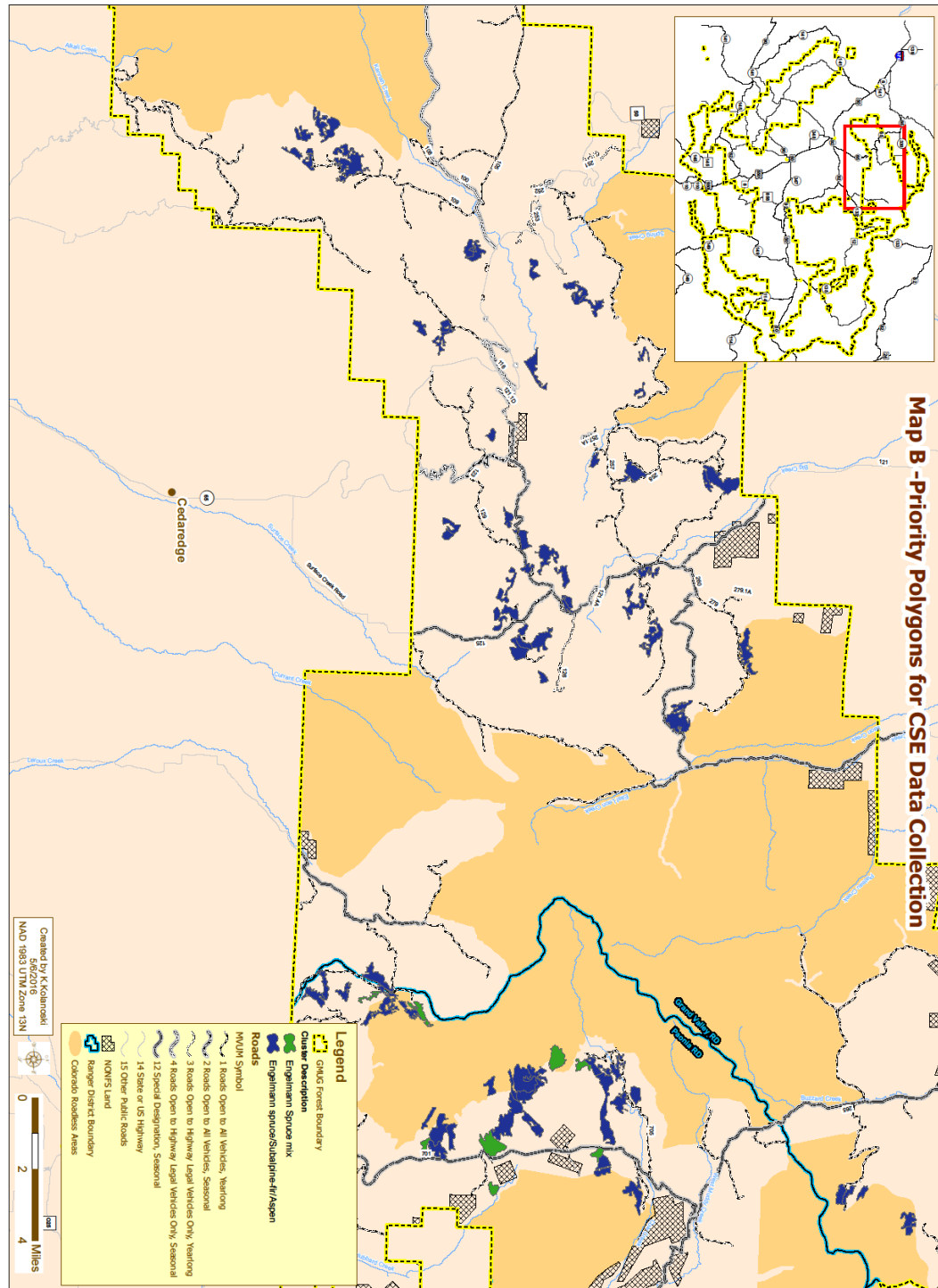Practicum project. Complement to Figure 4 in Chapter 3.

Determining Priority Vegetation Polygons for Common Stand Exam Data
Collection Using a GIS-based Sampling Strategy

PHASE I

**Step 1:** Receive Deliverable from RSAC. Deliverable = GMUG Vegetation Polygons with % change indicated.

Step 2: Review polygons. Detemine how many are flagged for redelineation review and how many have 15% change.

Number of flagged polygons= 1236
(25% treed and no wildfire)

Number of polygons with 15% change in all strata= 18,525

Does the polygon(s) have an inaccurate species composition?

YES

Step 2a: Exclude these polygons f tree mortality update. Mark these in the feature class as to be EXCLU this process. Update these pol manually in FSVeg Spatial working District Silvicultuirist or Foreste document them as priority for fu data collection.

NO

Step 3: Determine budget for CSE data collection. Determine the approximate number of plots that can be performed based on an approximate cost of ~$100/plot (i.e. $25,000= ~250 plots).

PHASE II

Step 4: Determine the number of acres represented in each strata across the Forest.

Acreage of changed polygons in all strata =1,061,616 acres
Number of polygons in 3 of the 9 strata = 13,894 polygons
Acreage of polygons associated with 3 of the 9 strata = 819,663 acres
(All are 25% Treed and whose % change is 15% and not due to wildfire)

How many acres of polygons are represented in each strata?

Are t and/o asso p

YES

Was the CSE data collected on or after 2010 and collected after any vegetation altering activities occurred within polygon(s)?

NO

Step 6a: This plot data will not be used in building tree mortality rule sets.

Step 4a: Determine 10% of the acreage for each strata.

Step 6: Use Linked Plot tool to determine previously collected common stand exam (CSE) data considered valid to use in building tree mortality rule sets.

Which strata will be the focus of the update?
Does cost prohibit all or most strata to be included in algorithm update?

YES

NO

Step 5: Make final decision on the strata from which to collect CSE data.

PHASE III

Select designa

Figure B-2. Map A of Final Priority Polygon Vicinity Map Collection (2 of 9)

Figure B-3. Map B of Final Priority Polygon Vicinity Map Collection (3 of 9)

Figure B-4. Map C of Final Priority Polygon Vicinity Map Collection (4 of 9)
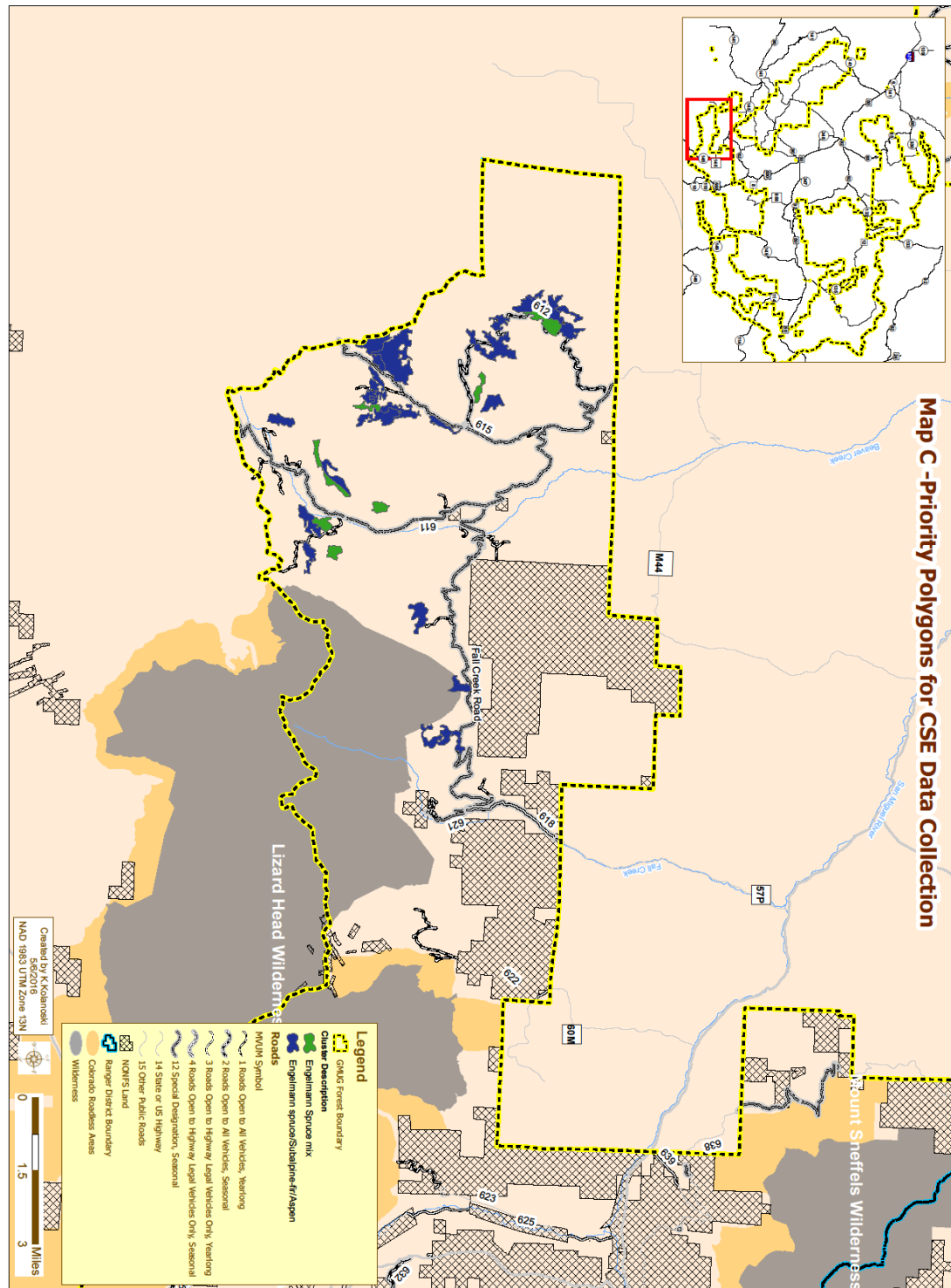
Figure B-5. Map D of Final Priority Polygon Vicinity Map Collection (5 of 9)
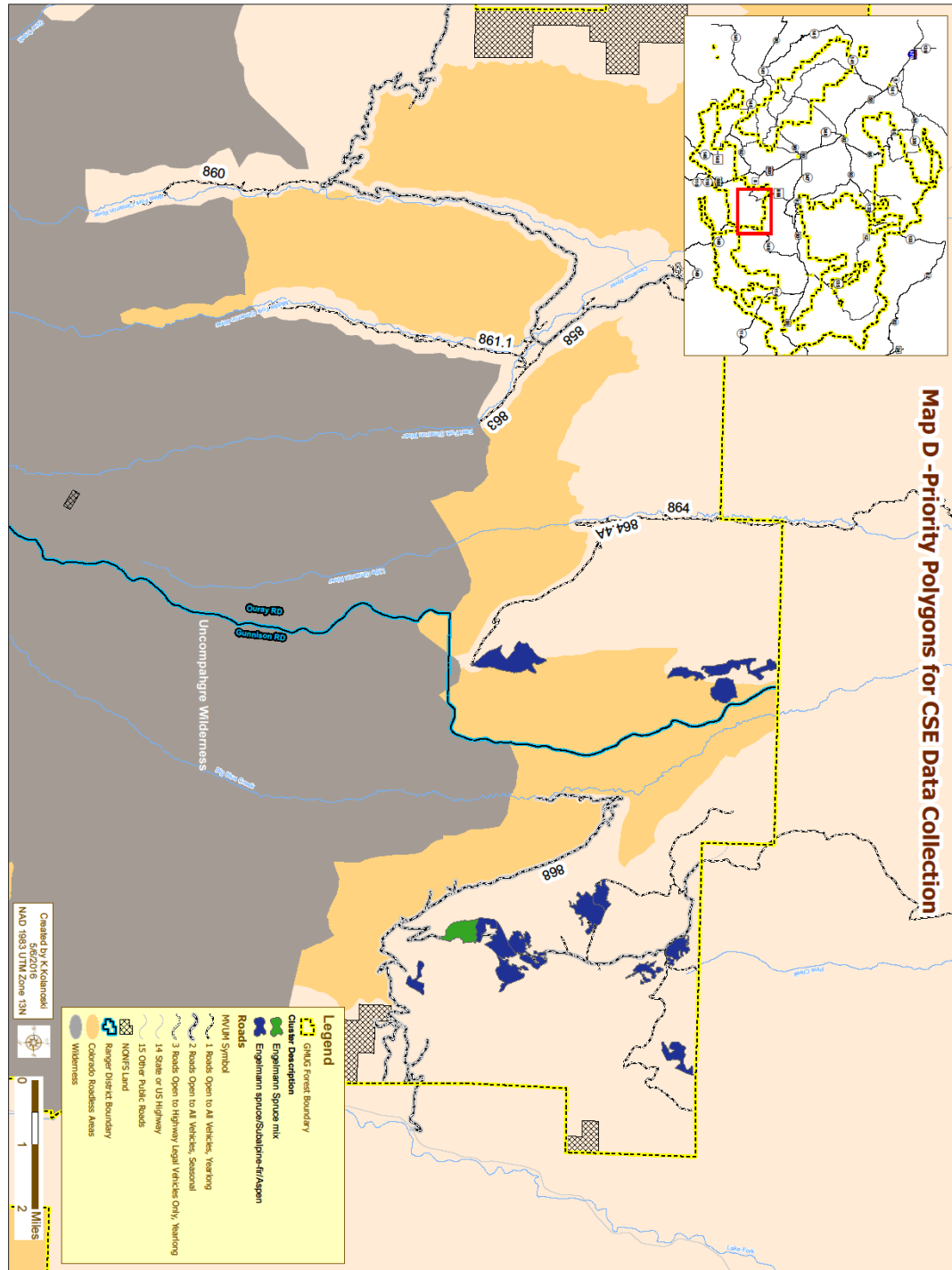
Figure B-6. Map F of Final Priority Polygon Vicinity Map Collection (6 of 9)

Figure B-7. Map G of Final Priority Polygon Vicinity Map Collection (7 of 9)
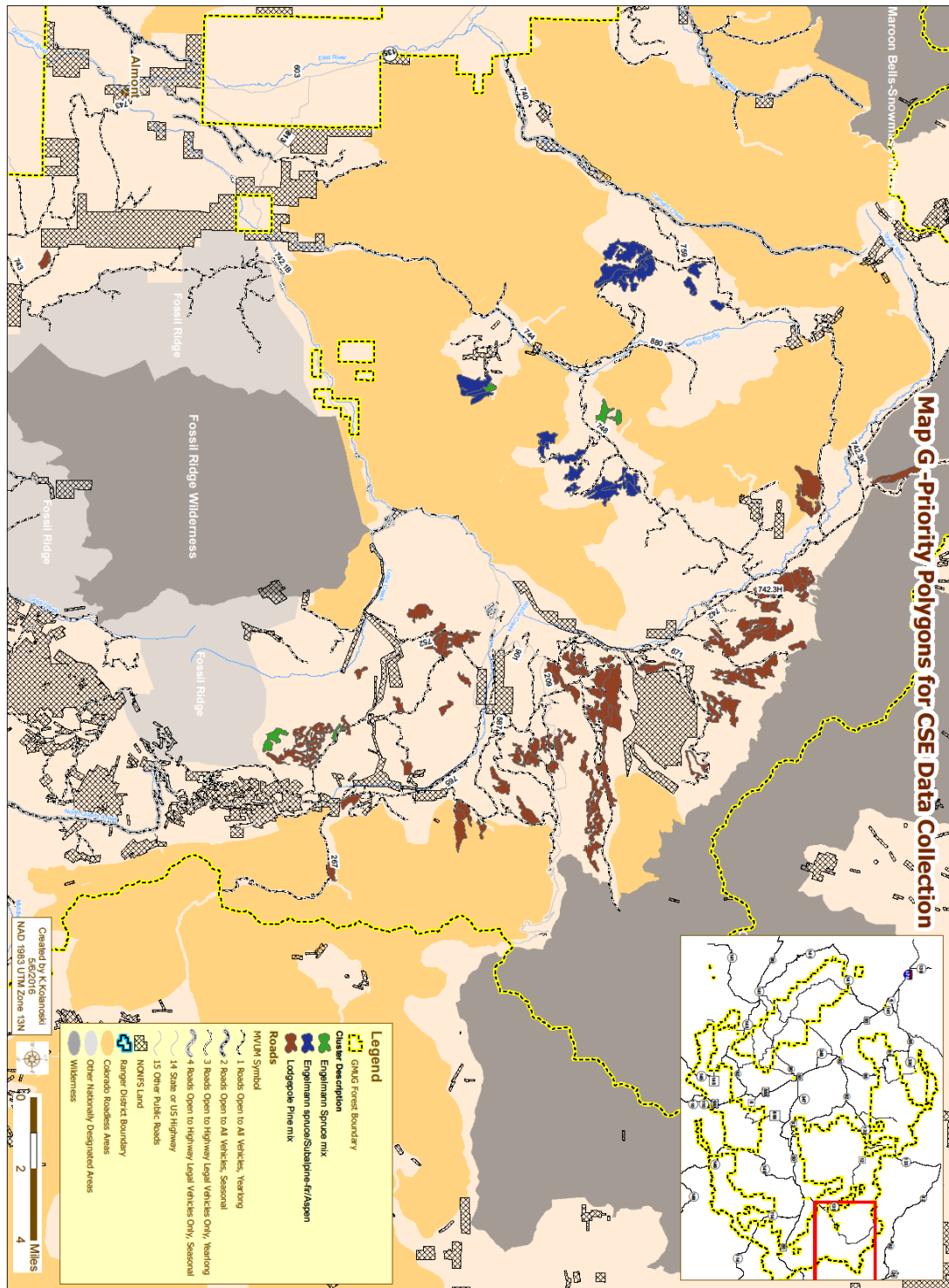
Figure B-8. Map H of Final Priority Polygon Vicinity Map Collection (8 of 9)
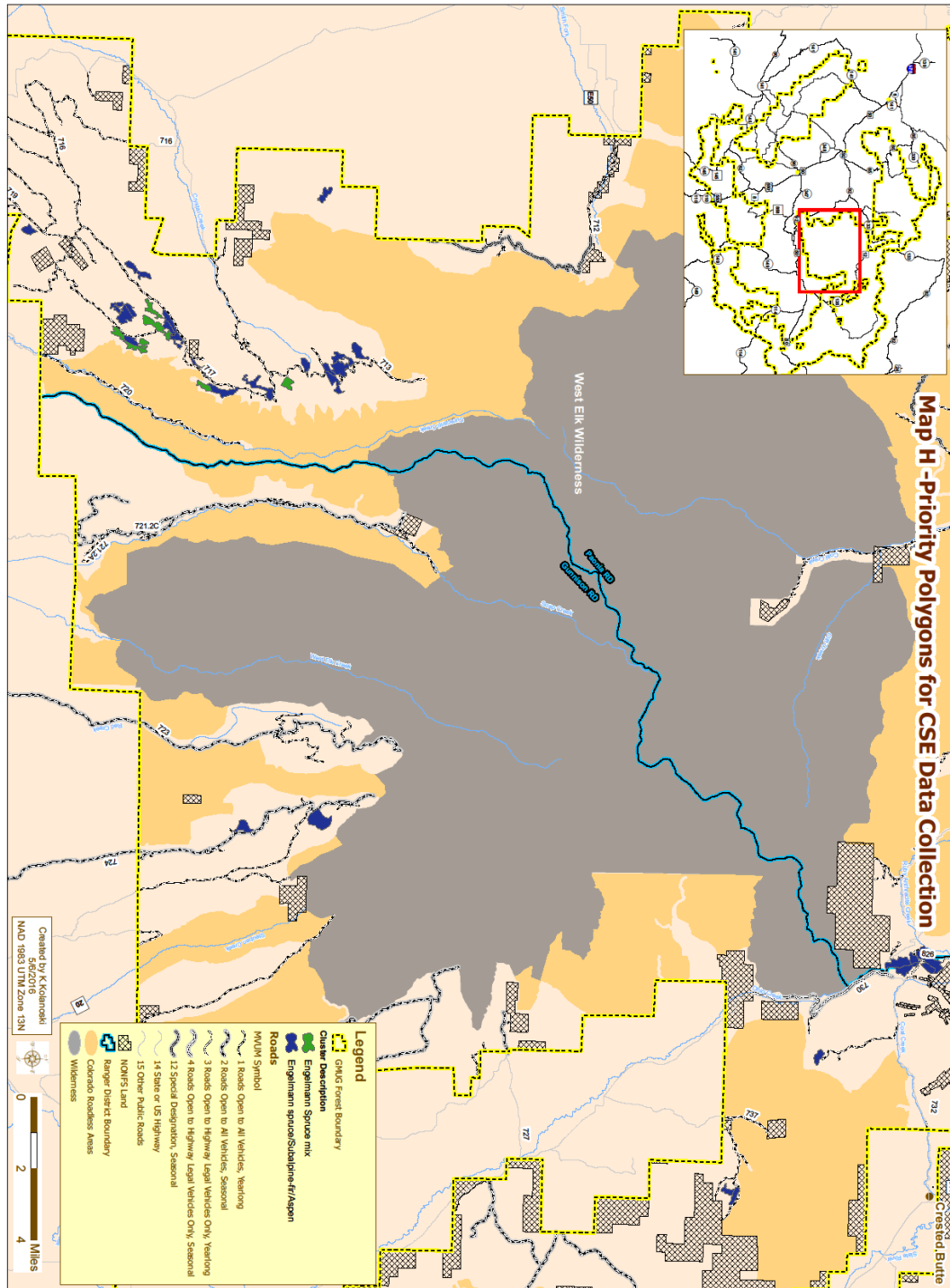
Figure B-9. Map I of Final Priority Polygon Vicinity Map Collection (9 of 9)