

Rails to Trails Web Mapping Application for the Great Redwood Trails:

Mapping Northern California's Trails

by

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Table of Contents

Dedication.....	ii
Acknowledgements.....	iii
List of Figures.....	viii
Abbreviations.....	ix
Abstract.....	xi
Chapter 1 Introduction.....	1
1.1. Overview.....	1
1.2. Study Area.....	3
1.3. Motivation.....	10
1.4. Methodology Overview.....	11
1.5. Structure of Thesis.....	12
Chapter 2 Related Work.....	13
2.1. Existing Hiking Applications.....	13
2.2. Tourist-Facing Applications.....	16
2.3. Apps Utilizing Real-Time Data and Low-Maintenance Apps.....	18
2.4. Web Map Development.....	21
2.4.1. Web Map Design and Development Process.....	22
2.4.2. User-Focused Design.....	23
2.4.3. Interactive Design.....	25
Chapter 3 Project Planning and Data Preparation.....	27
3.1. Preliminary Client Discussion.....	27
3.1.1. GRT User.....	29
3.1.2. App Design.....	29
3.2. Esri Software Requirements.....	30

3.2.1. ArcGIS Pro.....	31
3.2.2. ArcGIS Online	31
3.2.3. ArcGIS Web AppBuilder.....	32
3.2.4. ArcGIS Web AppBuilder Developers Edition.....	32
3.2.5. Tech Transfer/Web Server	34
3.3. Data	35
3.3.1. Counties Layer	36
3.3.2. Trailhead Layer	36
3.3.3. Hiking Trails Layer.....	36
3.3.4. Wildfire Layer.....	37
3.3.5. Weather Events Layer.....	39
3.3.6. Data from other WebMap Layers	39
3.3.7. Yelp Data from Widget.....	41
3.4. Great Redwood Trail Agency (GRTA) Data Prep.....	42
3.5. Entity-Relationship Diagram	48
3.6. Database Creation and Set-Up	50
3.7. ModelBuilder Workflows	52
Chapter 4 Development Process	54
4.1. WebMap Development	54
4.2. Symbology	56
4.2.1. Hiking Trails Symbology.....	56
4.2.2. Wildfire Symbology.....	56
4.2.3. Trailhead Symbology	57
4.2.4. USA Weather and Warnings Symbology	57
4.2.5. Counties Symbology.....	57

4.2.6. Highways Symbology	58
4.2.7. Recreational Routes Symbology	58
4.2.8. Campground Symbology	58
4.3. Widget Development	58
4.3.1. Restaurant Locator Widget Creation	60
4.3.2. Radar Widget Creation	61
4.3.3. Layers List Widget Creation.....	62
4.3.4. Wildfire and Weather Information Widget Creation	62
4.3.5. Wildfire Filtering Widget Creation.....	63
4.4. UX/UI Design	63
Chapter 5 Results	67
5.1. Database Results	67
5.2. ModelBuilder Results	67
5.3. Widget Customization Results.....	69
5.3.1. Restaurant Locator Widget	71
5.3.2. Radar Widget	73
5.3.3. Layers List Widget.....	75
5.3.4. Wildfire and Weather Information Widget.....	75
5.3.5. Wildfire Filtering Widget	75
Chapter 6 Conclusions	78
6.1. Issues Faced with Data and Software	78
6.1.1. Data Issues	78
6.1.2. USC Web Server Issues	79
6.2. Application Results Discussion	79
6.2.1. Database.....	80

6.2.2. Web Map Symbology	80
6.2.3. Widget Construction	82
6.2.4. Application Limitations	83
6.3. Future Development.....	83
6.3.1. Future Design.....	84
6.3.2. Other Software Available	85
References.....	86
Appendix A Existing Hiking Apps.....	91
Appendix B Attributes of GRT datasets defined	94

List of Figures

Figure 1 Project Area	4
Figure 2 Fire hazard map showing the severity of fires in the project area.....	9
Figure 3 Mock trail application to understand the visualization aspect of trail data	29
Figure 4 GRT app Development Process.....	34
Figure 5 Fire Data from the GRT Geodatabase	38
Figure 6 Additional Layers Visualized	41
Figure 7 Imported Esri Legacy Map Package with Trail Data	45
Figure 8 Entity-Relationship Diagram.....	50
Figure 9 Datasets Without Relationships.....	51
Figure 10 Web Map on AGOL	55
Figure 11 Manifest.JSON file	61
Figure 12 Esri ModelBuilder Workflows	68
Figure 13 Splash Screen Message Mobile Version	70
Figure 14 Desktop Version of GRT App.....	71
Figure 15 Restaurant Locator Mobile Version	72
Figure 16 Widget with Populated Restaurants.....	73
Figure 17 Radar Widget Mobile Version.....	74
Figure 18 Mobile Version of Wildfire Filtering Widget	76

Abbreviations

AGOL	ArcGIS Online
APP	Application
CAL FIRE	California Department of Forestry and Fire Protection
CSDGM	Content Standard for Digital Geospatial Metadata
ERD	Entity Relationship Diagram
FAQ	Frequently Asked Questions
FHSZ	Fire Hazard Severity Zone
GIS	Geographic information system
GRT	Great Redwood Trail
GRTA	Great Redwood Trail Agency
HTML	HyperText Markup Language
ID	Identifier
IT	Information Technology
IRWIN	Integrated Reporting of Wildland-Fire Information
JS	JavaScript
JSON	JavaScript Object Notation
MS	Microsoft
NAD	North American Datum
NCRA	North Coast Railroad Authority
NEXRAD	The Next Generation Weather Radar
NIFC	National Interagency Fire Center
NOAA	National Oceanic and Atmospheric Administration

PFA	Portuguese Forest Authority
Pro	ArcGIS Pro
S.B	Senate Bill
SaaS	Software as a Service
SMART	Sonoma-Marin Rail Transit
TMCs	Traffic Management Centers
QGIS	Quantum Geographic Information System
UGC	User-Generated Content
URL	Uniform Resource Locator
US(A)	United States of America
USGS	United States Geological Survey
USC	University of Southern California
VHFHSZ	Very High Fire Hazard Severity Zones
WGS	World Geodetic System

Abstract

Many online applications exist that allow users to search for hiking trails, but none have yet included the new Great Redwood Trail project that spans from San Francisco to Humboldt Bay in California. This “rails to trails” project is repurposing 320 miles of historic railway tracks in northwest California into public hiking trails. The new trails exemplify a positive relationship between human-created infrastructure and nature. Rather than creating more industrial waste, the Great Redwood Trail Agency is revitalizing the railway tracks for the purpose of promoting environmentalism and activeness in nature. For this project a mobile web mapping application was developed to familiarize hikers and the public with these trails. The Great Redwood Trail application provides an interactive digital map of the trails and includes relevant information and points of interest in surrounding areas aimed at stimulating the local economy, which is vital in garnering community support for trail development. Lastly, the app includes real-time wildfire information since this is now an incessant natural hazard in the Northern California region. Ultimately, this project aspires to showcase repurposed railways to hiking trails, promote local communities, and help ensure safety of app users.

Chapter 1 Introduction

With the decline of the timber industry in Northern California, a push to improve the region's economic state while maintaining its ecological sustainability began in the late 2010's (Guilfoil 2022). One such means is the nascent and exciting Great Redwood Trail project (GRT), a "rails to trails" initiative connecting Marin, Sonoma, Mendocino, and Humboldt counties in California via 320 miles of reclaimed and unused railroad. The GRT provides opportunities for ecotourism, recreation, and preservation along its course. The project described herein maps the trails for the public through a web mapping application. The GRT web and mobile GIS application, henceforth referred to in this thesis as the GRT app, includes five custom widgets that allow users to access information on the hiking trails, local amenities, and wildfire and weather updates in a user-friendly digital map interface.

1.1. Overview

The Great Redwood Trail Agency (GRTA) is the organization that leads the rails to trails project (Guilfoil 2022). Its predecessor institution was the North Coast Railroad Authority (NCRA), formed by the California Legislature pursuant to the North Coast Railroad Authority Act (Great Redwood Trail n.d.). The Act was intended to ensure continuation of railroad services in Northwestern California and envisioned railroads in this region playing a significant role in the transportation freight (Great Redwood Trail n.d.). The purpose of the NCRA was to maintain 316 miles of rail line. However, the NCRA struggled with rail preservation and lacked consistent funding. The NCRA was eventually disbanded and later re-envisioned as the GRTA under California Senate Bill 69 (2021). This bill ensures that the GRT receives funding and support at a state level (California Senate - Open States 2021-2022).

Various organizations from Marin, Sonoma, Mendocino, and Humboldt counties in California make up the GRTA. In addition to the GRTA, the Sonoma-Marín Rail Transit (SMART) agency worked to further the development of the hiking trails. The SMART agency oversaw part of the trail up to Cloverdale, while the GRTA is responsible for trail development from Cloverdale to Humboldt Bay. Additionally, the state Coastal Conservancy assists in organizing and planning the master plan for the GRT. The master plan consists of developing the railway lines into hiking trails from the San Francisco Bay to the Humboldt Bay shoreline. The GRTA's mission is to masterplan, design, construct, operate, and maintain the Great Redwood Trail.

The GRTA strives to connect the five counties through the Great Redwood Trail, as well as support the local communities surrounding the trail. When managing funding for the trail and making decisions on how to best promote further trail development, a steering committee consisting of representatives from each county leads the charge.

The GRTA proposed to repurpose 320 miles of railroad track into a continuous walkable and bikeable trail beginning in Marin County and ending in Humboldt County (Guilfoil 2022). It is well on its way and has the potential to revitalize small towns in Northern California, draw crowds to bed-and-breakfasts and bakeries, and allow locals and tourists alike to enjoy the splendor of the redwoods of Northern California. This project could benefit individuals, families, and local economies.

The GRTA was commissioned to further the trail development while encouraging engagement with the public. Public awareness of the trail development is vital in securing funding, participation, and tourism for the surrounding areas. To increase public awareness of and interaction with the trails. The GRTA proposed that a web and mobile app focused on public

users, in particular hikers, be developed. The GRT app developed as part of this thesis was designed to support the rails to trails GRT effort by developing a prototype for the GRT app. The GRT app is intended to serve the communities involved by providing easy to access information on trails, local points of interests, weather, and fire warnings in the area.

1.2. Study Area

The GRT app contains unique features beyond existing trail apps, the latter described in detail in Chapter 2 of this thesis. Digital, interactive maps of the Great Redwood Trails have never before been mapped to be included in other existing trail apps to date, so including these trails in the GRT app was considered vital in publicizing the repurposed railroad tracks. The decision to include weather and real-time fire data in the GRT app was particularly important in that the area surrounding the trails is susceptible to wildfires (California Department of Forestry and Fire Protection n.d.). Another unique feature of the GRT app design is a custom widget that allows users to find restaurants in their proximity so users may engage with the wider local community and thus help stimulate the local economy.

The region containing the Great Redwood Trails consists of five major counties in Northern California, including Marin, Sonoma, Mendocino, Humboldt, and Trinity Counties in Figure 1. Nearly half of the population resides in Sonoma County, and another quarter in Marin County, which are both in the San Francisco metro area. Four out of the five counties border the Pacific Ocean which helps bring in tourism for Marin, Sonoma, Mendocino, and Humboldt Counties. Landlocked Trinity County does not border the Pacific Ocean but can still bring in trails tourism to stimulate its local economy. The following sections discuss the geography, fire susceptibility, demographics, and economy of each county. The demographic makeup for the counties differs amongst one another, however, the total percentages for each of the counties'

demographics do not add up to 100% as reported by the U.S. Census Bureau Quickfacts: Marin County, California 2020-2022, due to the Census methods for calculating these statistics.

Nonetheless, the topographic makeup, fire vulnerability, and demographics of the five counties contributed to the overall design of the GRT app.



Figure 1 Project Area

Marin County's terrain includes natural sites, such as forests, beaches, and parks that attract tourists and hikers (Blake et al. 2000). The county encompasses a total area of 828 square miles including ecological biodiversity in protected plants and animals. As a result of the varying landscape in Marin County, the topography includes flat lands, coastal zones, and rolling hills and brush covering areas of Mount Tamalpais (Marin Magazine n.d.). This vast terrain includes vegetation such as oak trees, firs, and redwoods that are surrounded by water, canyons, and valleys (Ferguson 2022). With varying microclimates, the residential areas in the hilly areas of Marin County are highly susceptible to wildfires due to flammable natural vegetation and long-term drought conditions.

As of 2020 thru 2022, Marin County's demographics consist of about 84.7% white population, 16.8% Hispanic population, 6.9% Asian population, and 2.9 African American population (U.S. Census Bureau Quickfacts: Marin County, California 2020-2022). As of 2022 approximately 64% of its total population contribute to the labor force, with 103,990 people being employed.

Sonoma County's landscape is made up of valleys, plains, forests, and beaches that bring in a wide variety of people to enjoy the terrain through trails. Similarly, to the topography of Marin County, Sonoma County has considerable biodiversity and varying microclimates in the region (Tourism Official Site | SonomaCounty.com n.d.). The coastal cities typically experience fog and cooler temperatures brought by winds from the Pacific Ocean, while inland cities experience higher temperature and less fog. Cities near the Sonoma Mountains experience the warmest temperatures due to their distance from the ocean. Most of the county receives a significant amount of rainfall, with cities near the Russian River yielding the greatest amount.

Sonoma County is highly susceptible to wildfires due to extreme droughts and heat (Permit Sonoma n.d.).

Sonoma County's demographics consist of 86.1% white population, 28.3% Hispanic population, 4.8% Asian population, and 2.1% African American population as of 2020 thru 2022 (U.S. Census Bureau Quickfacts: Sonoma County, California 2020-2022). About 65% of its total population participates in the labor force, with 177,333 people being employed.

Mendocino County accounts for 3,878 square miles and a part of the World Wildlife Fund's Pacific temperate rainforests ecoregion, which is the largest temperate rainforest ecoregion on the planet (Olson 2019). The temperate rainforests are filled with diverse vegetation and contain an equable climate that serves as ideal conditions for visitors. The county's topography consists of redwood forests and is one of the three counties in the Emerald Counties, the other two being Humboldt and Trinity counties (Visit Mendocino County – Room to Roam n.d.). Mendocino County consists of hills, canyons, and flat lands alongside rivers. The hilly areas experience drier weather which further fuels wildfires (Frontline 2022). In addition, the vegetation consists of grass, oak trees, and brush that are highly flammable. The canyon area in this county consists of rugged terrain in higher elevations with challenging access which can hinder firefighters' ability to contain wildfires.

Mendocino County's demographics consist of 85.7% white population, 27.2% Hispanic population, 2.4% Asian population, and 1.1% African American population during the year series of 2020 thru 2022 (U.S. Census Bureau Quickfacts: Mendocino County, California 2020-2022). As of 2023, approximately 58% of its total population occupies the labor force, with 23,335 people being employed.

Humboldt County contains dense areas of ancient redwood forests that exist only in certain areas of Northern California, making this county a majestic place to visit. This county consists of 4,052 square miles of forest, mountains, and access to water bodies. The coastal lands of the county are surrounded by dense amounts of redwood forests (Humboldt n.d.). The varying elevation can contribute to wildfires spreading to remote areas. The large forests surrounding the county are also susceptible to wildfires as are many of the homes throughout the area (Fire Season | Humboldt County, CA - Official Website 2021). This county is separated into two distinct areas, the northeast and southwest, which are highly susceptible to wildfires, and the coastal areas and river valleys, which have a lower risk of wildfires.

As of 2020 thru 2022, Humboldt County's demographics consist of an approximately 83% white population, 13% Hispanic population, 3% Asian population, and 1% African American population (U.S. Census Bureau Quickfacts: Humboldt County, California 2020-2022). As of 2023, about 60% of the total population participate in the labor force, with 35,482 people being employed.

Trinity County is unique in that it encompasses 3,208 square miles and has no incorporated cities, but wilderness areas, scenic rivers, and many outdoor recreation activities attract tourists to the area (U.S. Census Bureau Quickfacts: Humboldt County, California 2020-2022). One of the three Emerald Counties, the Trinity Alps, Trinity River, and Trinity Lake surround Trinity County. The mountains provide the county with diverse vegetation, trails, and historic logging tracts (Welcome to the Visit California Homepage n.d.). The river and lake provide the county with a watershed filled with fish and wildlife. This mountainous terrain in conjunction with dense vegetation makes it difficult for firefighters to respond to fire related events. The topography of Trinity County includes rugged mountains and rugged hills. This

terrain fuels wildfires as intense winds may contribute to wildfires even spreading uphill (Maizlish et al. 2021). Dense vegetation also serves as a wildfire ignitor that can cause wildfires to spread throughout the county.

Trinity County's demographics consist of 82.6% white population, 7.9% Hispanic population, 2.1% Asian population, and 0.7% African American population from the 2020 thru 2022-year series (U.S. Census Bureau Quickfacts: Trinity County, California 2020-2022). As of 2023, 43% of its total population participates in the labor force, with 1,540 people being employed.

The population of the five counties is vastly dispersed but the counties do share similar characteristics. The commonality amongst the five counties include nature, outdoor recreation opportunities, and wildfire vulnerability. The natural beauty of the counties brings in tourists and stimulates each county's economy. Additionally, the landscape of the counties provides the ideal terrain for hikers to trek along the Great Redwood Trail. But, along with the unique terrain comes susceptibility to wildfires. The area of interest to the GRT consists of redwood trees that are highly susceptible to wildfire. Since redwood bark can serve as either a resister or enabler of fire damage, depending on the tree's cambium layer, wildfires are a common occurrence (Fritz 1931). Thin trees are more vulnerable to fire damage, as are large trees that have sustained previous fire damage (Fritz 1931). The wildfire information included in **Error! Reference source not found.** shows the susceptibility of the five counties to wildfires.

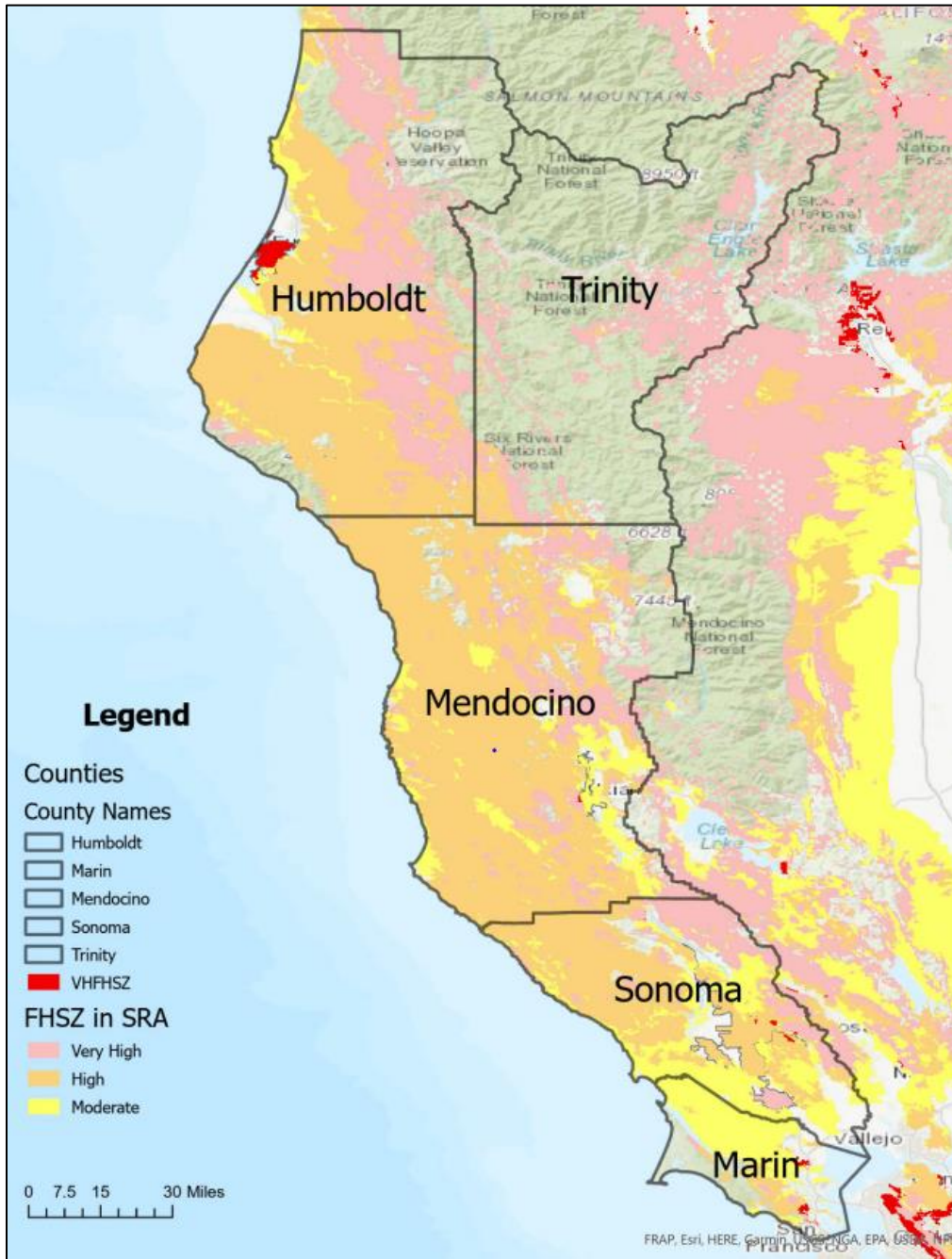


Figure 2 Fire hazard map showing the severity of fires in the project area (California Department of Forestry and Fire Protection n.d.)

A Fire Hazard Severity Zone (FHSZ) is a mapped area that designates zones that are susceptible to fire hazards as created by the California Department of Forestry and Fire

Protection (California Department of Forestry and Fire Protection n.d.). These FHSZ zones are categorized by varying levels of severity: moderate, high, and very high. The FHSZ maps illustrate where wildfire susceptibility could be high, but the maps do not predict where a wildfire will occur. Additionally, the FHSZ maps act as a way for local governments and citizens to take wildfire precautions and be prepared. **Error! Reference source not found.** shows fire severity zones for State Responsibility Area (SRA).

1.3. Motivation

The GRT app development is an important contribution to the GRTA by making information about the Great Redwood Trails easily accessible via the internet. Rather than going through traditional public awareness routes such as paper flyers or word-of-mouth promotion, a web and mobile app allows anyone living anywhere to view the trails. Online access to hiking trails helps share information about ongoing trail developments. Such public visibility about trail development can garner funding and public support for the completion of the rails to rails efforts, as well as contribute to local economies as previously mentioned. The five counties have natural habitats that surround the Great Redwood Trail, environments resplendent with native beauty perhaps known to users unfamiliar with this region. In summary, the region of the GRT app includes information about these five counties, Marin, Sonoma, Mendocino, Trinity, and Humboldt. The trails cover hundreds of miles of terrain and run through several cities as well, in the five counties.

The GRT app is focused on highlighting the amazing work being conducted by the GRTA and other stakeholders to revitalize unused railroad track into hiking and biking trails and highlights the new trails (Guilfoil 2022). But the app will go further than just including trails. It

encourages users to interact with local businesses and engages community by including restaurants in the surrounding areas. Also, the app promotes safety for users by mapping out live fire streaming data. This is to ensure that users have the most up to date information to make the best decisions. The application is developed to serve the clients, the GRTA.

1.4. Methodology Overview

The GRT app's goal is to allow users to access information about the existing Great Redwood Trails, repurposed railroad tracks to trails, local restaurant information, wildfire location, and weather updates on web and mobile devices. Through discussions with the clients, the application was created using Esri's ArcGIS Application Programming Interface (API) for JavaScript and Web AppBuilder frameworks. Web AppBuilder's framework consists of pre-built widgets, templates, and customizable widgets and interactive web maps. Application users can access the Web AppBuilder app through web browsers or their mobile phones as long as users have internet access. A widget is a tool that can be further customized to allow users more interactivity within a given application (ArcGIS Solutions Web AppBuilder Widgets | ArcGIS Solutions n.d.). These widgets serve to address specific needs of users and can provide unique functionality in an application.

The design of the GRT app includes built-in features which require no customization such as map zooming, panning, and choice of map extent (boundaries), allowing users to search the five-county region using standard web map tools they may be accustomed to using with other web GIS software such as Google Maps or Apple Maps. The five customized widgets developed as part of this thesis incorporate several of these built-in features in that they work to extend the users map search capabilities. The users can filter data to produce user-specific results, such as finding specific areas that are affected by wildfires in near real-time or are experiencing serious

weather conditions in real-time. The GRT app also allows users to turn off spatial data layers in order to better view specific information of interest to them, such as locating wildfires or local restaurants in their proximity. The development of this design is explained in detail in Chapter 3 of this thesis.

1.5. Structure of Thesis

The following chapters, sections, and subsections are organized by research, application requirements, software usage, and customization of the application. The second chapter discusses the research conducted on existing related applications and guiding tutorials. This research provided a basis for deciding on key functionalities and features needed in the GRT App. The third chapter discusses the prerequisites needed in order to begin the application development. The database creation and web map creation are both described in this section. Additionally, this chapter details the software used to develop the application. Chapter 3 discusses the various Esri platforms utilized to create the database, design the web map, and develop the application and its widgets. The fourth chapter explains the customization of the widgets that comprise the tools within the application. Chapter 5 illustrates the outcome of the application development process. From the final database to the end design of the application, the results of the creation of the Great Redwood Trails application are described. Chapter 6 provides concluding considerations, such as the overall benefits to the community and GRT app users, limitations to the app development, and thoughts about future software required to expand upon the GRT app.

Chapter 2 Related Work

Many sections of the GRT are open to the public, so it is critical that users can safely and intelligently navigate the trail. The necessary research for the development of the app includes analyzing existing hiking applications and their functionalities that pertain to the GRT app to understand the design and functions of current apps that are most applicable to the clients' design requests. Additionally, researching existing tourist-facing apps is vital in ensuring how to best serve users. Also, a user-friendly interface is paramount to guarantee that an app is successful and usable. In addition, the next section of research involved understanding how to incorporate real-time data. Utilizing real-time data can be challenging, so reviewing existing apps that already include real-time data serves as guidance for the GRT app. General guides are described that assisted with designing the customized components of the app. Lastly, the final section of this chapter discusses web map design. The goal of this design process is ultimately to foster a positive user experience with the GRT app.

2.1. Existing Hiking Applications

To better understand existing hiking applications and their key features, research on seven popular hiking applications similar in design and functionality to the client's requests for functionality in the GRT app was conducted and is summarized in Appendix A. Each application's key features were reviewed as part of this thesis work. Understanding what tools work well versus those that do not in a hiking app was paramount to present to the clients to better understand their priorities for the GRT app. The author's experiences and opinions about each of the existing hiking trail apps tested as part of this thesis work were shared with the clients to better understand the key features to be incorporated into the GRT app. This section describes existing apps tested.

AllTrails is currently the leader of existing hiking apps (AllTrails 2010). AllTrails was presented by the clients as a guide for choosing important functionality for the GRT app. Some key features of AllTrails include its extensive hiking trails inventory, variety of basemaps, downloadable maps, and other social exercise and networking features. Subsequent testing of AllTrails by the author led to inspiration for the GRT app development. For example, some positives of AllTrails include its filtering capabilities and categorization of trails. Users can filter hiking trails based on accessibility, distance, and level of difficulty. Some negatives of AllTrails include its cluttered home page design.

Gaia GPS includes its offline capabilities and highly detailed 3D maps through subscription (Gaia GPS: Hiking Trail Maps, Ski Touring, 4x4 Offroad App 2021). The best features of Gaia GPS are the easy-to-read maps illustrating mountain ranges and their peaks, an important feature which allows for photos to be uploaded to the application by users, and elevation. Some critiques of Gaia GPS were that the screen split into two maps could cause confusion for users, and the functionality is geared towards mountain peaks and mountainous terrain. The feasibility of replicating the intricate maps in the design of the GRT app was discussed with the clients.

PeakVisor was explored for its detailed 3D (three dimensional) maps of mountainous terrain. The technology utilized by PeakVisor models' terrain illustrates the precise landscape of mountains but is only available through purchase. PeakVisor allows users to not only explore mountains, but surrounding trails, summits, and parking areas (Peakvisor App 2017). Similarly, to Gaia GPS, PeakVisor is a mountain-focused app, meaning users have focused access to information about viewpoints and mountain peaks rather than hiking trails. So, the lack of hiking

trails is a weak point in the app. The split screen and 3D views within PeakVisor were discussed with the clients.

The Hiking Project was researched because of its publicly sourced hiking information (Hiking Project 2016). The Hiking Project utilizes publicly crowdsourced data to gather real-time data from users. The Hiking Project utilized a MapBox basemap and permits customization of maps by end users. The application includes widgets that allow users to narrow the location or area they wish to hike in. Some limitations in the application involve its unique use of crowd sourced data, which lacks quality control. Inaccurate information could mislead users. Additionally, the search bar produced a list of hikes that does not populate the map, so users must switch back and forth between a trails list and the actual map. Consideration of inclusion of crowdsourced data in the GRT app was a key feature discussed with the clients throughout the exploration of the Hiking Project.

Recreation.gov was reviewed because it includes information about hiking trails, including their condition (Recreation.gov 2022). However, it extends into allowing users to book recreational activities. For example, users can book lodging, campsites, kayaking, and other available activities (Recreation.gov 2022). Similarly, to the Hiking Project, Recreation.gov uses MapBox to allow developers to create custom maps. Recreation.gov populates data and lists next to the map, allowing users to view search results and a map at the same time. The addition of activities and booking choices add uniqueness to the app, however, they are also the app's downfall. The extra activities make it difficult for users to find information on actual trail data. Similarly, the booking feature takes away from being able to plan out a hike. Recreation.gov was discussed with the clients to determine if local businesses should be included in the GRT app.

Far Out app was explored because it contains detailed hiking guides (FarOut n.d.). The information on trails includes distance, elevation, waypoints, water sources, and campsites. These trails are viewable in the form of topographic maps or satellite maps. The app also features live tracking to assist hikers in following trails. Additionally, trail map access is available offline without any data usage. The biggest limitation of the Far-Out app is that accessing trail guides with detailed information requires purchase. The highly descriptive trail guide format of Far Out app was shared with the clients.

Cairn app was researched for its extensive safety features (Fit Club 2019). The app allows users to record their hikes or runs and provides users with individual activity statistics. Additionally, users can share their hikes along with their location. The Cairn app developers promote the location sharing feature as a key to safety. Continuing with safety precautions, the Cairn app allows users to locate where others have had access to cell phone coverage along a specific trail. If users do not have access to cell phone reception, the offline capabilities of the app are extensive. Users can send time specific messages and share their location. The main limitation of the Cairn app is that it focuses more on safety than on providing an extensive trail repository. The Cairn app was shared with the clients as an example of offline app capabilities, and to discuss if some of the safety features of Cairn might be recommended to be replicated.

2.2. Tourist-Facing Applications

The GRT app is a hiking app that also allows users to gain access to local restaurant information. This is important in going beyond existing hiking applications and including tourism features in the application. Working with local communities that are impacted by the Great Redwood Trails is paramount in ensuring support and collaboration with the GRTA Team

and these communities. The following studies describe the importance of such user-friendly features.

It was important to understand the relationship mobile phones play in tourism and decision making. A study by Wang et al. (2011) explored stories of those who travel and use smartphones for planning and making travel-related decisions. The results of the study show that utilizing phones for travel purposes can change tourists' behavior and emotional states by addressing a wide variety of information needs. For example, phones provide instant information which then enables tourists to share experiences and "store" memories more effectively (Wang et al. 2011). The implications of these findings are important in that they suggest an immense potential for smartphones in changing many aspects of the tourism business. This component of utilizing smartphones to stimulate tourism is a significant contribution of the GRT app.

Smartphones, especially, play a key role for hikers through their access to the internet that allows for real-time research of trails and updates on their conditions. Increasingly, hikers opt to bring their smartphone along for hikes. The inclusion of smartphones on hikes has been studied by Anderson and Jones (2017). They conducted a survey to assess hikers' preferences and found that 95% of respondents to their survey prefer to bring a smartphone when they go hiking. Their survey discusses the increasing role of cell phones in hiking expeditions. Rather than rely on static or printed maps, hikers now utilize apps to navigate through trails (Anderson and Jones 2017). The use of phones and apps when hiking has led to debate over whether this leads to meaningful hiking interactions or distracts users while hiking. Anderson and Jones (2017) discuss both sides of the debate, but ultimately conclude that cell phones already exist in hiking interactions and do improve hiking experiences. They conclude that bringing a cell phone on a hike is like bringing a tool that can hinder or further an experience. This decision is up to

the hiker or cell phone user. The respondents from Anderson and Jones's (2017) survey reportedly used their cell phones in positive ways, creating a positive experience with their cell phones and nature. Thus, hikers who have access to the GRT app can make real-time decisions that can positively impact their hiking experience.

2.3. Apps Utilizing Real-Time Data and Low-Maintenance Apps

The inclusion of real-time data in the GRT app was an integral part of the app and served to add uniqueness to it. Live data allows users to digest up-to-date information which impacts their decisions. From deciding which trails to use to avoiding certain areas, the inclusion of live wildfire information in the application is intended to help keep users safe. The following section covers existing literature about similar uses of real time data.

Real-time information can provide the public with live updates that support decision making. Specifically, real-time data incorporation in public safety components, such as fire maps, can promote safety and inform citizens of the location of wildfires. For example, Teodoro and Duarte (2013) conducted a study to explain the process of creating and sharing of real-time forest fire risk maps for the Northwest of Portugal. This study wanted to ensure accessibility to the maps by utilizing three open-source desktop GIS software all while creating plug-ins written in Python to publish such maps (Teodoro and Duarte 2013). The Portuguese Forest Authority (PFA) requires cities and towns in Portugal to produce annual fire risk maps, so the goal of this study was to aid the mapping efforts of these municipal entities' maps that will aid cities and towns in Portugal in producing annual fire risk maps that the rules of the PFA require. The project employed three open-source desktop GIS software and creating plug-ins written in Python to publish maps. Another goal was to utilize open software programs such as QGIS and develop tools which can be freely used by other professionals. The concept of accessible fire

maps influenced the decision to include wildfire data in the GRT app, in particular data that does not require paid subscriptions or for personal user information to be accessed.

Similarly, information on weather events is useful in providing users with the most up-to-date information that can help with decision making. On the fly risk assessment provides relevant information on environmental conditions. This factor was vital when developing the GRT app, as hikers should possess current information on weather conditions. For example, Barnett (2016) discusses landslide risk in Western Washington and its effect on the population and surrounding environment. First, real-time landslide triggering variables are used to generate a model to report up to date risks to the local areas. The model is shared and published through a web application to be utilized and replicated in different regions to make assessments on landslide risk (Barnett 2016). The goal was to create a portable, automated method for assessing landslide risk to a particular area, providing an opportunity to improve safety. Barnett's application (2016) replaced typically static information with near-real time updates on landslide risk. Similarly, the GRT app is intended to provide real-time weather and future forecasts to help improve the safety of hikers.

In addition to live data on fire occurrences and weather events, a mobile app in which all data is updated regularly and in a timely manner is also important. If an app is difficult to maintain and requires extended periods of time to update, then users may miss out on key information. To better understand the creation of a minimal maintenance app, a study by Neene et al. (2017) provided guidance. The goal of the study by Neene et al. (2017) was to create an app that maps property easily and quickly. The application was useful to help local jurisdictions in developing countries to easily overcome the challenges they typically experience when mapping property. The application is fully mobile, multi-user, real-time, and fast. Also, the users

do not have to be GIS experts. The app was low cost because the data and software used to build it was free or inexpensive. In the app, the user access simple forms to record property attributes (owner, address, land, and building info), draw polygons (draw with satellite image and GPS), and capture images (pictures of the property) for consenting property owners. The property information is saved in a PostgreSQL database. The tool can be used by anyone, even those with no GIS experience (Neene et al. 2017). This app is an easy to maintain app that does not require a software developer to maintain, so it can be easily replicated by non-developer professionals.

Similarly, to the importance of a low-maintenance app, an app that does not require extensive software development knowledge is vital to the design of the GRT app. The future maintenance of an app is just as important as the preliminary development. Ensuring robust performance, accuracy, and minimal downtime for app maintenance is vital. Specifically, for the GRT app, a seamless management strategy was prioritized, so that future developers of the GRT app would have a straightforward to update the app. To provide guidance in how to create an app that is accessible to all developers of all skill levels, a study by Wiley (2018) created a wildfire tracking service that required minimal GIS or software development knowledge. The aim of the Wiley (2018) study was to create a Web GIS that does not require GIS background or specific fire management knowledge, but still has a credible source to provide information on wildfire preparation in Santa Barbara County (Wiley 2018).

This web GIS tool is extremely useful in increasing wildfire awareness and preparedness for the Santa Barbara County community. The author discusses some limitations that they believed were hindering the application. They included the overall coding knowledge of the author, the ability to edit the widgets and features because of source limitations, and the addition

of crowd-sourcing tools. Incorporating crowd-sourcing tools can strengthen an application. By adding comments or real-time updates from the community about wildfire status can provide quick, updated information on wildfires that some static websites can. The application aims to provide its users with up-to-date tracking information about nearby and surrounding wildfires. Additionally, users can access the web application via any source of device and without any previously needed credentials. This makes the application equitably accessible to all. The layout of the page also highlights the usability of the application. The various sources of information input into creating a rich map of wildfires in the county, the widgets chosen, and the format of the map all add to an easily readable and understandable application. The web application is directed for all, no matter their GIS knowledge or wildfire knowledge. This factor is important in that it guided the author to create a project that is simple yet resourceful. Lastly, the author desires to further develop the application by creating a section to allow for user input. This represents the “user-generated content” by allowing the users to add data, furthering their interaction and applicability to the web mapping application.

2.4. Web Map Development

The creation of the GRT app web map involved relying on existing literature for guidance on effective and ineffective practices. Web map literature discusses the design and development process for creating the most efficient map. Additionally, the importance of components such as a user-focused design and an interactive design were heavily prioritized. Understanding these practices influenced decisions about which components would be prioritized in the GRT app and web map. The following subsections go into detail about this literature review concerning the design and development process of a web map, how to create a user-centered map, and the importance of creating interactivity in a map.

2.4.1. Web Map Design and Development Process

When creating a web map, the design is important in producing the final web map that will be integrated into a mobile app such as the GRT app. First, the design component consists of thinking through and visualizing the final map. Many questions and considerations impact the design of a map. From user friendliness to deciding the color of certain features, designing a map incorporates a variety of elements. The development process builds off the design stage by constructing the theoretical components of the design. Developing a web map incorporates all the aesthetic elements needed, but also includes programming and constructing. The following section discusses the two processes and their eventual joining to create a final map.

Existing literature discuss topics from how to avoid a poor design to steps to create the most user-friendly map. These topics emphasize the importance of consistency, easy viewing, attention grabbing, best formatting, and template design. However, the most crucial factor a developer should consider is knowing their web map user (Hansen 1971). Understanding who the target audience is vital in designing a map. Although the design workflow differs for app developers, understanding the user requirements ensures how the map functions, the widgets included, and how any unique features should perform. Building from the design process, the development process ensures that the main project goals are brought to fruition.

The development environment consists of GIS-based software that allows for programming and editing of web maps. Developers must decide early on which web map tools to add to a web map to make it useful for the user. With the array of technological options for developers, there exists the possibility of not only creating an oversimplified map but creating a map with too much information (Haklay 2010). In the development process, developers decide how much information to convey and where to convey it on the map. Without this decision making, maps can become too busy and distract users from the relevant information. It is up to

the map developers to determine how the users will consume the map and how long it will take them to consume. Therefore, the design of the GRT app web map prioritized key spatial data layers that were symbolized to ensure clarity in content of each layer and that none of the layers were hidden from the user. Rather than overwhelming a GRT app user, the web map within the GRT app focuses on key components. For example, the key layers in the web map are the hiking layers. So, symbolizing each trail segment in a way that is eye-catching but not overwhelming ensured that users can digest the information they are looking at. Additional layers include for example the counties of the project area, the trailhead points, the location of wildfires, intended to aid in navigation, local resources, and safety options, as previously mentioned. The symbology choices for each layer play a significant role in determining how user consumes the information presented by the developer. The GRT app web map symbology choices were made so that each layer's content, or purpose, was obvious and not obscured.

2.4.2. User-Focused Design

As stated in Chapter 1, the users of the GRP app are assumed to be the general public, in particular people who hike trails. When creating a web map within a web or mobile GIS app, centering the design around the users is of the utmost importance. It is the users that interact most with a web map within the app and determine whether the design is successful (Fleming 1998). To create a product that will benefit its users, one must have a good understanding of the psychology of the users as well as being familiar with the web and mobile GIS technology being used to develop the design. This focus on combining psychology and technology stems from Donald Norman's human-centered design approach (Norman 2013). Prioritizing human needs ensures that developers understand these as design requirements then accommodate those needs in the development stage. Thus human-centered design is a process that works to create a design

that fulfills the needs and capabilities of the intended users. This approach requires developers to create memorable or pleasurable experiences for their users to ensure longevity of a product.

User-centered design is a concept that is now at the forefront of web mapping design with the explosion of cell phones using mobile web GIS apps every day. As users are becoming more mobile so must their maps. Creating a web map that is not only compatible for mobile users but also focuses on their needs while they are on the go is vital in the user-centered design approach. To ensure users' needs are met, web cartographers can design the most successful map by focusing on user interfaces, map functionality, and the interactive components (Tsou 2011). User interface is described as the tool that allows users to communicate with the map (Haklay 2010). User interface design is the process of creating tools and functionality that then allows for interaction with the map. This design process ensures that users can extract the information they need from the map. So, part of the user interface design process is to decide what buttons will best convey the desired information and where these buttons should be placed in the app and web map helps create a user focused map design (Cybulski and Horbinski 2020). The creation of web and mobile GIS tools, buttons, or widgets is what sets the stage for user interactivity. The GRT app and web map tools were designed and placed in the most efficient places within the app, to gain insights and feedback to iterate the design. The process of understanding how the user interacts with the map begins with the first design testing. In summary, the layout of the GRT app was determined to prioritize the web map and use of the widgets with the intent of strengthening the map interaction user experience. In a nutshell, the design focused on how users interact with the widgets that populate results into the web map, then how they consume the resulting map. Ultimately this is a map centric user design.

2.4.3. Interactive Design

A pivotal component of a web map is its interactivity for users. Generally, users expect to be able to easily manipulate, zoom, and filter information displayed on a web map. The interactive design should ensure that users can do the right things – what they are expecting to do - at the right time (Rosson and Carroll 2001). Interactivity strengthens the communication between the map and user. Meaning, the user requests the map to perform a function and the map responds to the request and produces a result. For the GRT app, successful interactivity means users are able to utilize widgets to find area-specific information on trails, restaurants, weather events, and wildfires displayed on a web map. The widget design allows each GRT app user to have a tailored experience with the GRT app and its web map through their specific widget requests.

Roth (2017) emphasizes the importance of interdisciplinary practices of cartography. Since technological advancements have led us to rethink how we visualize and create maps, Roth (2017) discusses the need to use mapping technologies alongside traditional cartographic practices to design maps for web and mobile applications (Roth 2017). Through focusing on the user and their needs, maps and mapping tools can evolve to suit not only user needs but increase interactivity with maps. Each user has a different justification or need to access or look for information. Therefore, the cartographic or web map interaction needs to satisfy each user's needs at each stage of the process. Finding the balance between the amount of web map interaction required and the complexity of these interactions is particularly important in creating a user-friendly experience. The user and who they are or what they want is at the core of customization. The user's needs, experiences, and knowledge are all factors that affect the cartographic interaction's effectiveness.

In conclusion, visualizing geospatial data in a web or mobile GIS application requires key guidelines. Web maps exist to answer questions users have, such as finding the location of something or obtaining directions to a certain point. Web maps must be designed so that users can visualize the answers to their questions. Also, a good web map design means that the transferal of data to a map accurately reflects the geospatial information (Kraak and Brown 2014). Thus, the goal of the GRT app is for a user to be able to easily locate places and points on the map and understand the symbology used to represent an object or a location. Symbology, object placement, and visualizing data accurately were all elements of the GRT app's web map composition (Muehlenhaus 2013). The decisions about what to display on the GRT app web map involved two critical web map making elements: how to display information and what the user interaction should be with this information.

To summarize chapter 2, detailed research was conducted on existing hiking tourist applications to aid in the design of the GRT app. The components deemed most useful by the clients were incorporated into this design, also taking into consideration the use of real-time local resource data as well as up-to-date trails information typically included in existing hiking apps. Finally, the GRT app and web map within it were designed by the processes described above, following user-focused and interactive web map design best practices recommended for the GRTA's intended audience. The next chapter described the implementation of this research in the GRT app development process.

Chapter 3 Project Planning and Data Preparation

The first step in the development of the GRT app involved in-depth collaborations concerning the design with the clients, as described in Chapter 2. This Chapter describes subsequent discussions with the clients to finalize the user scenario, web and mobile GIS software requirements, the spatial data collected, stored, and incorporated into the GRT app, and customized GIS-based workflows created to facilitate long-term maintenance of the data within a web or mobile GIS app.

In Section 3.1, the initial client discussions took place in order to determine what a GRT user will require of the app and the app's overall design. Next, Section 3.2 discusses the software for the GRT app. Section 3.2 discusses the functionality of Esri's various platforms that were used in this thesis. Section 3.3 highlights the key datasets used in the GRT app. Section 3.4 describes how the initial data provided by the GRTA were prepared for use in the GRT app were conducted. Section 3.4 details the spatial data analysis steps taken to prep and upload the data into a spatial database. Section 3.5 discusses the next step of creating an entity-relationship diagram with the datasets. Section 3.6 explains the creation of the spatial database and how the data were added to the database. Section 3.7 explains the three ModelBuilder workflows created as part of this thesis that facilitate data maintenance. This chapter focuses on data preparation steps that led to the creation of the GRT database that fed into the GRT app.

3.1. Preliminary Client Discussion

From the initial client meeting, it was determined that an Esri-based application would be the best platform with which to develop the GRT app. This decision was made because of Esri's Web AppBuilder platform that contains customizable widgets and its easy maintenance. The initial meeting with the GRTA team provided an opportunity to present a mockup trail app and

discuss which platform would be best suited for the GRT app. The initial research conducted for the clients discussed in Chapter 2 was presented to the clients, summarized in Appendix A. The table of hiking apps in Appendix A displays the functionalities and widgets of various applications that have similar purposes to those of the GRT app. This research was presented to the clients to gather feedback on key functionality they require in the app. Through these discussions with the clients, the initial application (GRT app) was created using Esri's ArcGIS Application Programming Interface (API) for JavaScript and Web AppBuilder framework. The Web AppBuilder framework consists of pre-built widgets, templates, and the ability to customize widgets as well as a web map incorporated into the app. Users can access Web AppBuilder apps through web browsers or using mobile devices, as long as users have internet access.

The first application development stages included creating a mockup application design to show the clients how the user interface would appear as shown in **Error! Reference source not found.** To provide an example of a hiking application interface, the Santa Monica mountains trail data was chosen. This choice was made because of the data's availability and hiking features. The clients provided positive feedback that, in turn, informed the next iteration of changes that the application should include. Feedback from the clients determined that the application should contain localized descriptions of features and places within the study region. For example, the new rails to trail data and maps should be shown in the application. Additionally, features such as searching for points of interest, such as restaurants and amenities should be included, as well as the addition of real time wildfire data. The clients concluded that the application should be unique and should feature local amenities, while the most important feature of the application remains the visibility and usability of the trail features.

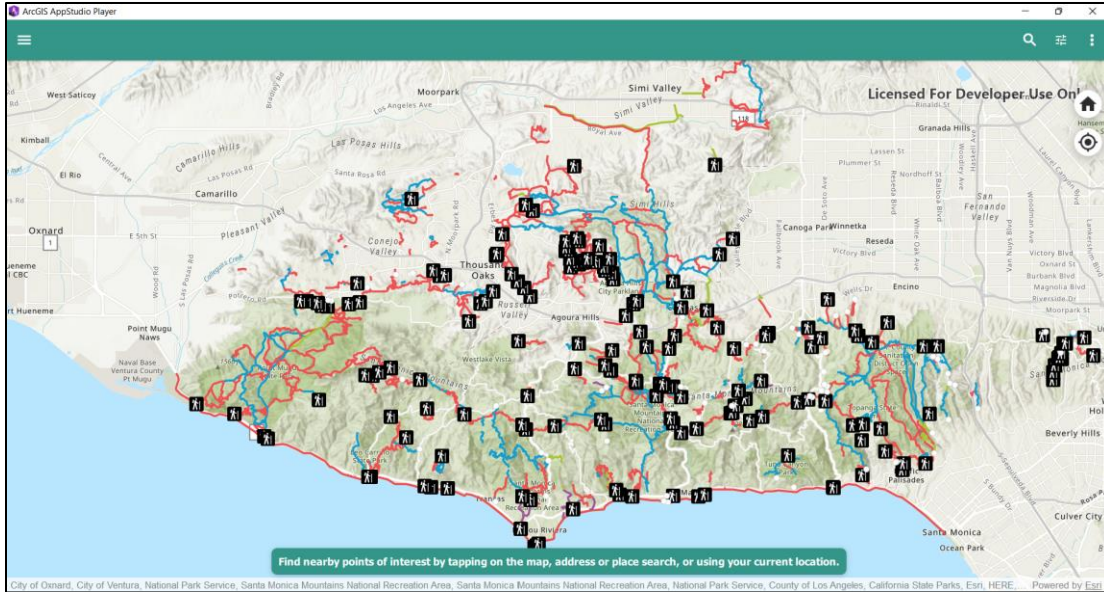


Figure 3 Mock trail application to understand the visualization aspect of trail data

3.1.1. GRT User

The client’s emphasis on the importance of the trails and local amenities influenced the design of the GRT app. According to the clients, a typical GRT user, in particular those unfamiliar with a given area, will consist of a hiker that utilizes a mobile device during a hiking event. Additionally, the clients stipulated that users should have the option to access local weather conditions and wildfire events in order to aid in their decision about where best to hike in real time or near-real time. Therefore, weather and wildfire information were added to the web map, to be accessed using customized widgets. The web map was designed so that only selected, specific layers are automatically turned on, to keep the web map initially loaded clean and not cluttered. These choices were made with the hiker GRT app user in mind.

3.1.2. App Design

The preliminary discussion with the GRTA clients provided a general basis for the GRT app’s web map design. Based on these requirements, the prioritized layers and their symbology

were developed into the web map. Additional decisions about the final web map design were influenced by the literature and current hiking app reviews that included best practice guidelines for web GIS app developers. These practices focused on who the application user is and what their needs are, the design of the map itself and its key functions, and the importance of creating an enjoyable interactive experience for users. It is important that the components are positioned in the application in an appropriate, easy to view and use way.

Since a mobile application was the GRTA end goal, it was important to have each widget, layer, or feature viewed and utilized in a simple to use design for users. Additionally, minimal future maintenance of the GRT app was part of the development process emphasized by the GRTA team since it would be fully transitioned to the GRTA team at the end of the project. Also, the client requested that the application software be low cost and require minimal software development skills to maintain.

The main goal of the GRTA was to create an application that included all of the relevant spatial data and was fully mobile, multi-user, real time, and fast. Another requirement was that users did not have to be GIS experts to effectively use the GRT app. The application from the study has an extremely low cost because everything is free or cheap for the developers. The mobile cloud computing uses mobile and cloud computing and solves problems with limited computing, storage, and energy resources in mobile devices (Neene et al. 2017). The GRT app was developed to be easy to maintain and not require a software developer to update and deploy it. This is a crucial factor for the development of the application for the GRT and stakeholders.

3.2. Esri Software Requirements

The Esri platform offered the most appropriate web and mobile GIS application functionality, application development tools, and easiest long-term maintenance, so therefore it

was the best choice for the GRT app. Each step in the development process involved utilizing various Esri platforms, including cloud-based GIS, online mapping tools. The Esri software utilized to build the various components of the GRT app are described in the following sections.

3.2.1. ArcGIS Pro

Esri ArcGIS Pro provided a platform to create an appropriate spatial database, the Esri File Geodatabase, for this project. In Pro, the data provided by the GRTA team were stored in a single project database, referred to as the GRT database, that serves as the foundation for hosting all the data used in the application. With the GRT database created, attribute relationships were established based on a unique entity relationship diagram created as a data structure design for this project. These relationships helped to connect and validate the attribute data within the tables in this spatial database. Additionally, Pro's ModelBuilder tool provided an easy-to-use geoprocessing environment to develop multiple repetitive workflows to support data manipulation and decrease the potential for human error in completing geoprocessing tasks. Three unique ModelBuilder workflows were created to support semi-automated data additions or updates in the spatial database, deletion of data from the database, and an option for amending existing data in the GRT database.

3.2.2. ArcGIS Online

After the map from Pro was shared, the map layers required editing and updating on ArcGIS Online (AGOL). AGOL is Esri's software as a service (SaaS) platform that runs through internet access. It integrates with desktop platforms, such as ArcMap and ArcCatalog and ArcGIS Pro. A key feature is the sharing capabilities of AGOL. The simple functionality of the AGOL platform makes sharing maps with the public extremely easy. The Living Atlas feature in AGOL allows for creators to select various basemaps to include in the map. Additionally,

ArcGIS Online contains a lot of data from Esri, Esri partners and the Esri user community. This data allows access to authoritative data sources and layers to be included in a web map. For example, the wildfire data, weather data, and highway data were all found through AGOL's extensive authoritative datasets. The layers were added to the web map, as well as the cited sources for each layer. Having the ability to access data from credible sources, such as the California Department of Transportation or the National Weather Service ensures all the web map layers are reflecting accurate and legitimate data. Through AGOL's web mapping services, content creators can use their existing web maps to create applications through Esri's ready-to-use apps.

3.2.3. ArcGIS Web AppBuilder

Esri's Web AppBuilder provided a platform for the GRT app and its widgets to be developed on. This decision was made because of the customization of widgets and template theme for the application. Web AppBuilder allows for an easy transition from the creation of a web map in AGOL to developing an application. There are many built-in widgets included in Web AppBuilder that developers can utilize. Additionally, there are premade templates to display the web map and widgets. There exist ways to create custom widgets and templates in the developer's edition of Web AppBuilder that the online version does not contain. The developer's edition contains custom widgets tools for the application.

3.2.4. ArcGIS Web AppBuilder Developers Edition

In addition to the templates offered by Web AppBuilder, the depth of custom features offered through the developer edition of Web AppBuilder allowed for further customization and development of the application (Create your first app-ArcGIS Web AppBuilder | Documentation. n.d.). The developer downloaded the software node.js. This software download was necessary

because Web AppBuilder runs on top of node.js, so it had to be installed on the computer.

The ArcGIS Web AppBuilder download package contains the Windows version of Node.js that allows for the developer edition to be downloaded and edited.

Once the developer edition was downloaded various folders were contained within the argiswebappbuilder developer edition download. The folder contained data and code on all the ready-to-use widgets, templates, and developer guidelines. Additionally, there were sample widgets and templates that could be utilized to create custom widgets or themes.

The development process in **Error! Reference source not found.** specifies sections of the workflow further by describing coding libraries. These libraries are vital in creating any interactivity a developer wishes to be available on their map. For the creation of the Great Redwood Trail application, the development environment was Esri's Web AppBuilder Developers Edition platform. The folder containing all the preliminary code was opened through sublime text editor. Sublime text editor was used to ensure any additional programming could be performed then reflected in the developer's console. The data for the application was formatted as shapefiles, map packages, map exchange documents, and live layers. Esri's ArcGIS Pro hosted the data in a geodatabase. Once the symbology for the datasets was determined, the web map was then shared to ArcGIS Online to be integrated into the GRT app. The coding and interface creation for the application was done utilizing JavaScript. JavaScript was utilized to generate content that is regularly updated. Once the application was created, it was deployed onto USC's web server.

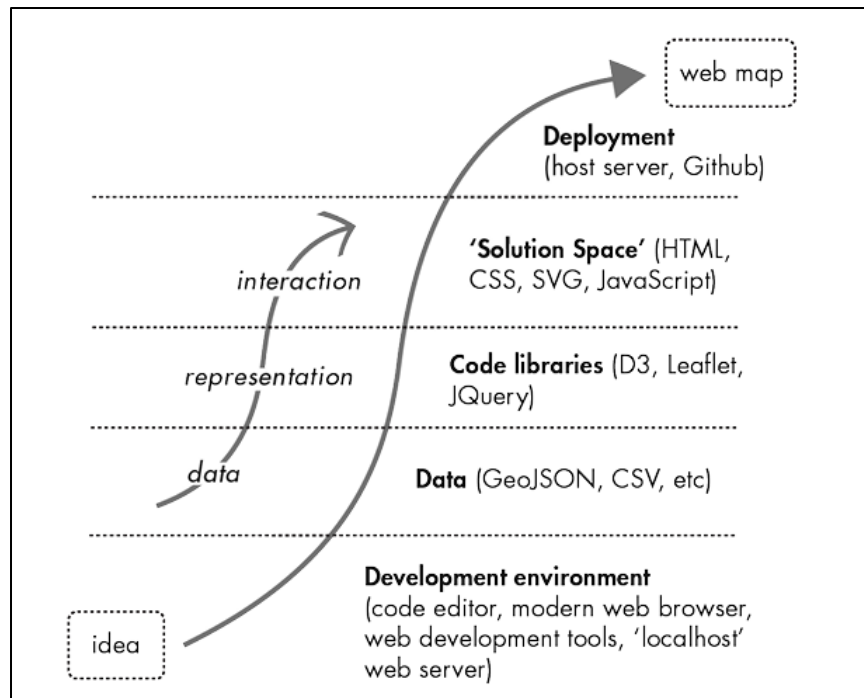


Figure 4 GRT app Development Process

Next, a sign in portal appears to access the development platform homepage. The sign in consists of having an ArcGIS organizational account or an ArcGIS Developer account. Then, the URL for the ArcGIS organizational account that Web AppBuilder will access must be specified.

After log in credentials are used, then the app had to be added to ArcGIS Online to obtain an app id. This meant going to the developer's AGOL account and adding the app. First, one must navigate to the My Content tab then click add item. The following parameters had to be specified, type of app, purpose, API, and URL. For the GRT app, the type of app selected was Web Mapping, the purpose was Ready to Use, JavaScript API selected. These steps ensured the app was registered and ready to be developed.

3.2.5. Tech Transfer/Web Server

Esri's ArcGIS API for JavaScript is laid out to support custom Esri tools, and for developed applications to be registered then rehosted on another web server. USC web server

hosted the app. Uploading the application to the server required the code in the config.json file had to include code that added a proxy to the proxy property in the application. Next, the application had to be registered through Esri. The application's ID had to be included and updated in the config.json file. After all the programming edits were completed, the application was ready to be transferred to the USC web server. To do so, FileZilla was utilized to upload the folder to the personal USC account directory. The folders were able to be transferred to the USC web server, but the GRT app would not load on a web browser. So, a new way of transferring the app had to be developed. For this, the GRT app was downloaded and saved to a shared google drive. There, the GRT app can be downloaded with five widgets. Rather than uploading the entire GRT app into a WebApp Builder, the five widget folders were copied over to a new app template. Once the five widgets were added to the new app's widget page, they were added to the web app and placed around the web map. The web map was kept the same and selected to be included in this new version of the GRT app web app. Once the widgets were uploaded and the original web map selected the web app was able to be transferred to the clients.

3.3. Data

The data used in the GRT app is described in the following sections. This data contained datasets that were incorporated into the GRT database. The GRTA provided key datasets on trailhead points, bike lanes, counties, and other project area features. Additionally, live fire and weather events datasets were incorporated into the GRT app to allow users access to more information. All the datasets used in the GRT app provided users with key information, such as county boundaries, trailhead points, hiking segments, live fire locations, and weather patterns.

3.3.1. Counties Layer

The counties layer was shared from the GRTA team via google drive. In google drive, the counties layer was downloaded as a shapefile then uploaded as a feature class into the GRT database. The layer was in the NAD 1983 (2011) State Plane California projection. These attributes gave identifiers to each county. The data author is stated as GRT since the GRTA team provided the datasets that did not contain metadata with the origin source. However, through research, the attributes in the table matched the data from the California County Boundaries feature layer by the California Department of Forestry and Fire Protection. This authoritative source containing the same data as the GRT key counties layer, ensured the information's legitimacy and was added to the map.

3.3.2. Trailhead Layer

The trailhead data was used in the GRT app to represent the trailhead points of the hiking trails. The trailhead layer was shared from the GRTA team via google drive. In google drive, the trailhead layer was downloaded as a shapefile then uploaded as a feature class into the GRT database. The trailhead layer was in the NAD 1983 (2011) State Plane California projection. The attribute table contained the following columns on the gps coordinates of the trailheads, the name of the trailheads, and their elevation. The author of the layer is the GRTA team. Since this data was created by the GRTA, they are credited for its creation and the primary data source. Unlike the Counties layer, the trailhead layer did not have an authoritative source to check it against. It was still added to the map because of its vital information on trailhead location.

3.3.3. Hiking Trails Layer

The hiking trails layer was utilized in the GRT app so that users could view the location of the trails. The trails layer was shared from the GRTA team via google drive. In google drive,

the trails layer was downloaded as map packages then uploaded as a feature class into the GRT database. The trails layer was in the NAD 1983 (2011) State Plane California projection. The attribute table contained the following columns on the length of the trails, the location of the trails, and their specific ID. Similarly, to the trailhead layer, the hiking trails layer attributed the GRTA as its author. This was because of its creation by the GRTA members to create trail segments. These segments are characterized by the type of trail, existing trails, and bike lanes, proposed hike and bike trails, and different type of trail classifications. This layer was important for GRT users to have access to because of the trail segments. This layer gives users information on trail routes and future trail routes.

3.3.4. Wildfire Layer

The next dataset of use involved real-time fire data so that users could have real-time updates as to where wildfires occur. Through ArcGIS Online's layers, Esri had an authoritative layer of fire data. The fire data is updated regularly, according to the description of the feature layer. Since the fire information is regularly updated and comes from the Federal government's Integrated Reporting of Wildland-Fire Information (IRWIN) and National Interagency Fire Center (NIFC) initiatives, it was deemed sufficiently authoritative and added to the map in Figure 5. For the live-fire data, Esri's live fire data stream was used which sources its data from Integrated Reporting of Wildland-Fire Information (IRWIN) and National Interagency Fire Center (NIFC). These are collaborative reporting ventures from several Federal agencies, including the Bureau of Land Management, the National Parks Service, and the US Fish and Wildlife Service. To ensure this data was accurate and legitimate, researching both entities' websites provided the authoritative, trustworthy data needed to ensure the fire streaming was reflective of real time updates.

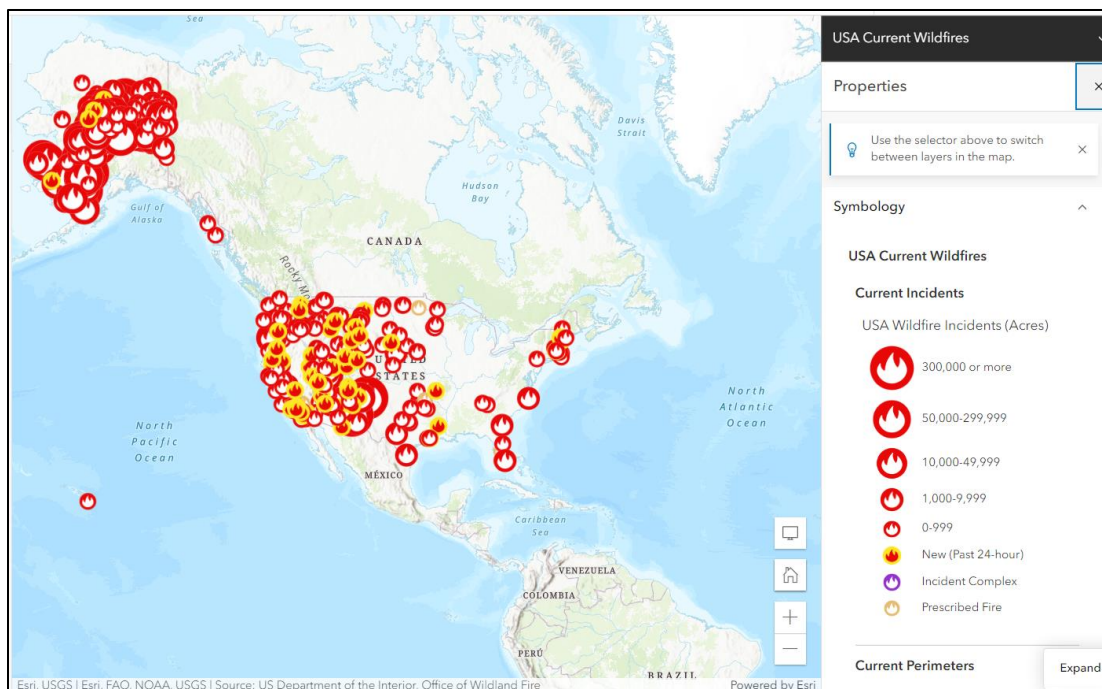


Figure 5 Fire Data from the GRT Geodatabase

The live streamed data was created by the California Governor’s Office of Emergency Services that was projected in WGS 1984. The fire data from this layer was divided into two categories, wildfires, and wildfire perimeters. The current incidents or wildfire points were obtained from Integrated Reporting of Wildland-Fire Information (IRWIN). While the current perimeters or wildfire perimeter were obtained from National Interagency Fire Center (NIFC). The data from the IRWIN provided users with information of wildfire points on the map. These wildfire points were categorized by acreage, 300,000 or more, 50,000-299,999, 10,000-49,999, 1,000-9,999, 0-9,999, New (Past 24-hours), Incident Complex, and Prescribed Fire. The NIFC displayed fire perimeters to show users the boundary encompassed by a wildfire. These were included in the web map to give users access to wildfire information. The legitimacy of the wildfire data sources ensured that users were streaming accurate information.

3.3.5. Weather Events Layer

The National Weather Service layer provides users information on the type of weather event occurring and where it is occurring. The National Weather Service was the source for weather data that was projected in WGS 1984. This weather data was visualized as polygons showing the area of a weather event, which was organized by event type. This feature layer was created by Esri but sourced its data from the National Weather Service. This layer was added to the web map to show users where extreme weather events were occurring.

3.3.6. Data from other WebMap Layers

The additional layers included are the national highway layer, weather conditions layer, campgrounds, and recreational routes. The inclusion of the highway layer provides users with some geographic reference. Highways are easily distinguishable and provide a solid frame of reference when trying to understand one's location. The highway layer is a way of linking the built environment, such as highways, with the natural environment, such as the trails. The highway layer serves as a source of navigation for the users to utilize. Similarly, the weather forecast layer provides users with valuable information. The weather conditions of a particular area influence one's decision to hike in that area. The layer helps serve the users in a way that allows them to make decisions that pertain to their safety. The weather conditions layers make it easy for individuals to access weather-forecasting information that impacts users' decision making. With use of the additional layers, users can determine the safest route to take to access campgrounds.

Overall, these additional layers feed information to the users. With the inclusion of the highway and recreational routes data, users have a frame of reference and a geographic source. These layers serve as an overview for users to understand the layout and landscape of the area

shown in Figure 6 **Error! Reference source not found.** Without the additional data layers, users would simply have a map showing trail landscape lacking roadways that are commonly utilized. Mapping out highways and roadways is vital in displaying a publicly used source of transportation and movement. Similarly, campground areas are important for the user to plan out visits. Combining road status information along with campsite locations gives users the most relevant information when making decisions. The importance of weather data is similar in providing users with valuable information as the inclusion of highway and campground data. The decision to include weather patterns is to provide users with information that can impact their decision on where to hike. Delivering weather data to users not only impacts their decision making but helps ensure their safety. A hiking application provides users with information on trails, but an application, such as the Great Redwood Trails application, goes further and provides users with information to help orient themselves and make safe decisions. These layers are visualized in ArcGIS Online as shown in Figure 6.

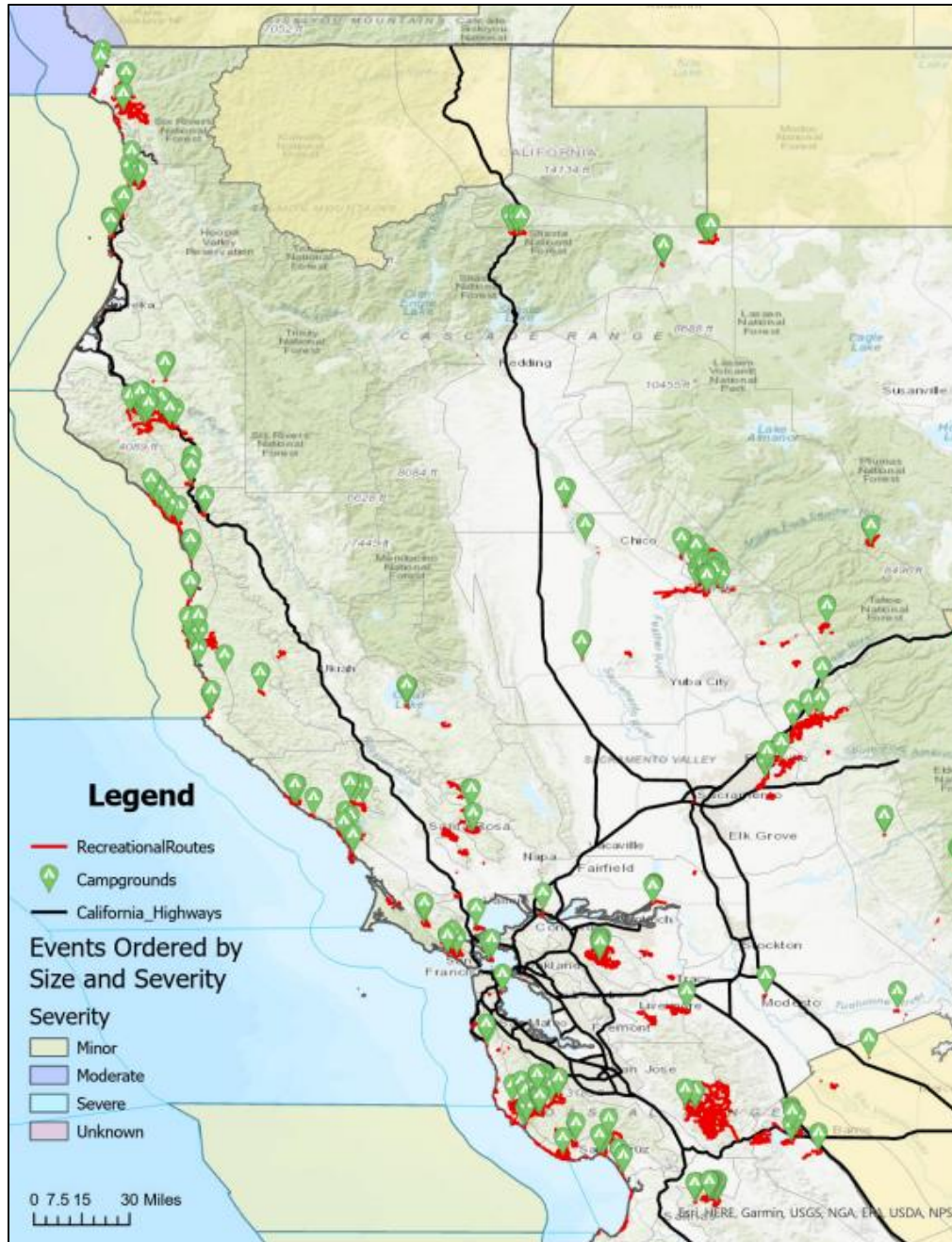


Figure 6 Additional Layers Visualized: The National Highway Layer, Weather Conditions Layer, Campgrounds Layer, and Recreational Routes

3.3.7. Yelp Data from Widget

The restaurant data was gathered through a token requesting information on restaurants from Yelp’s API. This source was legitimized through Yelp’s extensive data resource guidelines.

The moderators for Yelp evaluate the accuracy, eligibility, and formatting of all business information submissions. The accuracy of business information is checked against the primary business website, business presence on social media outlets, and relevant user-generated content (UGC) (Yelp Developers n.d.).

Table 1 Primary Datasets Utilized in Application

Data Name	Data Type Acquired	Original Projection	Source
Key Counties	Shapefile	NAD 1983 (2011) State Plane California	GRT
Yelp	Yelp API	WGS 1984 Web Mercator (auxiliary sphere)	Yelp API
Fire	Feature Layer	WGS 1984 Web Mercator (auxiliary sphere)	Esri Authoritative Source- Integrated Reporting of Wildland-Fire Information (IRWIN) and National Interagency Fire Center (NIFC); initially NASA’s data was going to be used
Weather Events	Feature Layer	WGS 1984 Web Mercator (auxiliary sphere)	National Weather Service
Hiking Trails	Map package	NAD 1983 (2011) State Plane California	GRT
Trailhead Points	Shapefile	NAD 1983 (2011) State Plane California	GRT

3.4. Great Redwood Trail Agency (GRTA) Data Prep

The datasets provided by the GRTA were shared through a Google Drive containing Esri legacy formats including shapefiles and map packages that were to be explored and uploaded to the GRT database. These datasets were initially visualized using ArcGIS Pro to better understand

their purpose and functionality for the web map. The datasets were used in the beginning stages of the database creation. The datasets were cleaned up to reduce any duplicates, had attributes defined, and used to create relationships with each other. The datasets were transferred as shapefiles in the WGS 1984 Web Mercator (auxiliary sphere) projection. The shapefiles included key counties information, trailhead points, and hiking trails.

To utilize the key counties dataset, preliminary preparation was required. The key counties dataset was in the NAD 1983 (2011) State Plane California projection and had to be reprojected to WGS 1984 Web Mercator (auxiliary sphere) projection. The dataset was uploaded into the database in its original format, a shapefile. This consisted of selecting the GRT database then importing the shapefile. Once the key counties shapefile was uploaded, it was then analyzed. The attribute table was opened, and missing attribute definitions were noted and sent over to the GRTA team for clarification. The dataset did not contain a credit source, but through research, the key counties dataset matched county data information from the State of California's GIS database. The key counties layer shared from the GRTA seemed to be a clipped version of the State of California's overall county shapefile. Therefore, the key counties layer was added to the web map.

For the trailhead points data, it was uploaded to ArcGIS Pro in its original projection, NAD 1983 (2011) State Plane California. Then, the attribute table was opened to better understand what the trailhead points represent. At this step, it was understood that this data layer was point data that showed the location of the trailheads for each trail. The table contained latitude and longitude points that, when searched in Google Maps, gave the point location of a trailhead. So, this data created by the GRTA was included in the web map to show users where

the trailheads were located. This layer worked alongside the hiking line segments layer to provide both a starting point for the trails, as well as highlighting the actual trails.

The second set of data that was shared from the GRTA team contained data on trails projected in NAD 1983 (2011) State Plane California that would later be reprojected to WGS 1984 Web Mercator (auxiliary sphere) projection. The bike facilities data was divided into two-point categories showing bike parking and bike shops. The bike routes dataset contained bike routes in Arcata, Blue Lake, Eureka, Ferndale, Fortuna, HC, Multiregional Facilities, PCBR Humboldt Co, Rio Dell, and Trinidad. The bike shapes dataset contained existing bike shapes in Arcata, Blue Lake, County, Eureka, Fortuna, Rio Dell, and Trinidad. The existing bike lanes dataset contained a single layer that contained existing bike lanes from 2017-2018.

The infrastructure dataset contained layers on Amtrak lines, bus routes, and other transit routes. The major destinations dataset showed destinations that included commercial and business centers, major destinations for all jurisdictions, major destinations for Fortuna, and major destinations for Rio Dell. Lastly, the trails data contained a layer labelled HP3 Routes. This should contain all the hiking trail line segments. However, to ensure the trails were accurately depicted through the HP3 Routes layer, the mdx and mpk files were uploaded to Pro and analyzed.

To bring the ArcMap .mdx data into ArcGIS Pro, it consisted of clicking the Import Map on the Insert tab to view the new map. Next, the data path sources were corrected, and updated path files were saved and refreshed to be reflected on the map. This final display included the bike lanes and trails in the project region.

To import the Esri ArcGIS Desktop legacy map packages (mpk) in Pro, using the import map function to select all the map packaged to be imported into the project. The map packages

were not imported directly to the database, they were viewed in Pro as various map layouts.

Figure 7 shows an imported map package originally provided by the GRTA team. Each layout contained a legend, symbology, and trail lines. The map packages confirmed that the HP3_Routes layer was in fact the trail layer. The only layer imported into the GRT geodatabase was the HP3_Routes layer. This layer contained the hiking trail segments. This was the prioritized layer to be included in the GRT app.

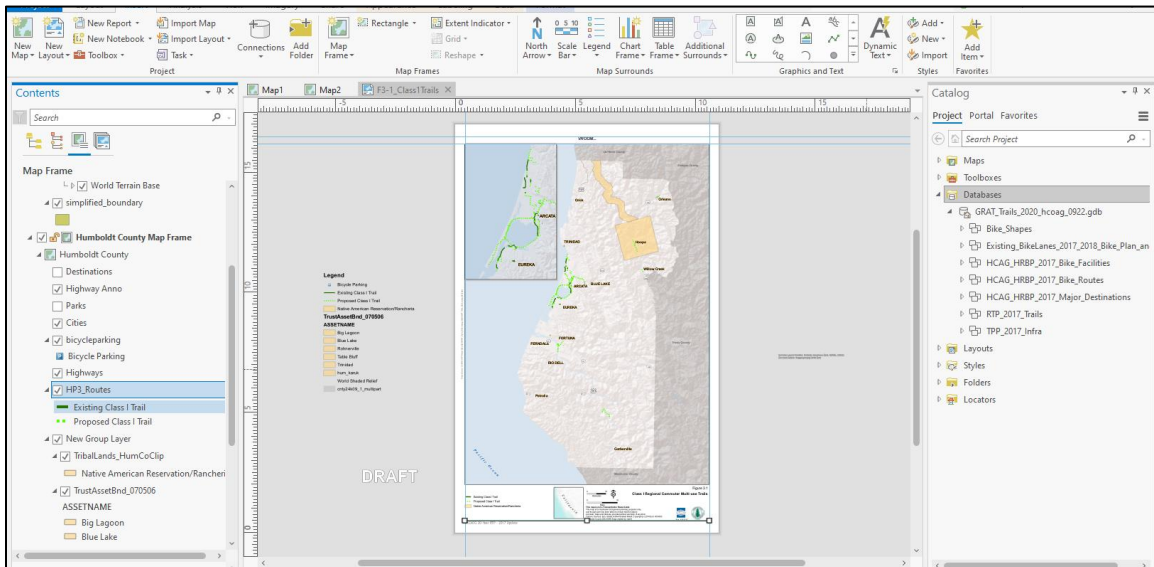


Figure 7 Imported Esri Legacy Map Package with Trail Data

The HP3_routes data layer was added to the web map because of its hiking trails created by the GRTA team. The legitimacy of the data stems from the GRTA team creating these line segments of current and future trail development. The HP3_Routes layer was checked to ensure that all the necessary lines segments were included through the cross reference of the HP3_Routes layer and the map packages that showed localized or zoomed in areas of the trail segments. Since the map packages already symbolized the line segments in a particular format, this symbology was transferred over to the HP3_Routes layer that would be used in the web app.

The next three datasets analyzed were the Major Rivers GRT layer, Major Lake and Reservoirs GRT, and the Major River and Creeks GRT. These datasets were shared as shapefiles in the NAD 1983 (2011) State Plane California projection. Similarly, to the other datasets, they were uploaded to Pro, and each attribute table was analyzed. The source for these datasets was unknown, so checking their attributes against attributes USGS's Content Standard for Digital Geospatial Metadata (CSDGM) ensured that the three datasets being analyzed were actual river, reservoir, and creek locations. The datasets were confirmed to be legitimate rivers, reservoirs, and creeks, but they were specific rivers, reservoirs, and creeks to the project area. Therefore, they were reprojected to WGS 1984 Web Mercator (auxiliary sphere) projection and uploaded to the GRT database.

The Key Cities and Cities GRT shapefiles were shared in the NAD 1983 (2011) State Plane California projection. These datasets were represented as polygons showing the boundaries of cities rather than points. To ensure the city boundaries layer shared from the GRTA were correct, they were checked against the State of California's city boundary layer. Once the GRTA datasets and the State of California's city boundary layer were uploaded to Pro, it showed the overlap between city boundaries. So, the city layer was just specific cities that were pulled from the overall California City boundary layer. It was then reprojected to the WGS 1984 Web Mercator (auxiliary sphere) projection and uploaded to the GRT database.

The Subwatershed GRT and Subbasins GRT were shared similarly to the other datasets in that they were shared via Google Drive as shapefiles in the NAD 1983 (2011) State Plane California projection. Similarly, to the other datasets, once the attribute tables were opened the attributes were not defined or understood. So, researching the attribute definitions from the USGS's website allowed for clarification. This led to the realization that the two datasets were

the boundaries or watersheds and basins in the GRT project area. A quick search of the location of the subwatersheds and subbasins showed that they were legitimate locations of active watersheds and basins. Therefore, the two datasets were reprojected to the WGS 1984 Web Mercator (auxiliary sphere) projection and uploaded to the GRT database.

The Bioregions dataset was shared through Google Drive as a shapefile in the NAD 1983 (2011) State Plane California projection. This dataset was easier to analyze because of its broad attributes. Rather than being a specific subset of data focused on the GRT project area, the Bioregions layer was an overarching dataset of ecological makeup. This dataset was much easier to overlay over the Environmental Protection Agency's Ecoregions of the US since they were the same. Therefore, its legitimacy was confirmed through overlaying with an authoritative bioregion layer. It was then reprojected to the WGS 1984 Web Mercator (auxiliary sphere) projection and uploaded to the GRT database.

The Bays dataset functioned like the Bioregions dataset. It was also shared through Google Drive as a shapefile in the NAD 1983 (2011) State Plane California projection. Similarly, to the Bioregions layer, the Bays layer was not specific to the GRT project area. The Bays layer encompassed a greater scale. To ensure the Bays layer represented the actual location of bays, it was overlaid with National Oceanic and Atmospheric Administration's (NOAA) data layer on bays. Once both datasets were uploaded to Pro and analyzed for overlap, it was confirmed that the Bays dataset shared from the GRTA was legitimate. Then the Bays layer was reprojected to the WGS 1984 Web Mercator (auxiliary sphere) projection and uploaded to the GRT database.

The GRT 5-Mile Points is like the Trailhead layer, discussed in the previous sections, in that it represents Trailhead locations but splits the points to show them at a frequency of five miles. The GRT 5-Mile Points layer is a duplicate of the trailhead layer but lacks detailed

information from the trailhead layer. The realization of the similarities between 5-Mile Points and the Trailhead layer was realized when comparing their attribute tables. Both shapefiles share similar attributes and point locations on the map, however, the frequency of points differs between the two. The GRT-5 Mile Points layer was reprojected to the WGS 1984 Web Mercator (auxiliary sphere) projection and uploaded to the GRT database, but it was not prioritized to represent the trailhead locations as the Trailhead layer was.

The Rail Mile Posts GRT layer was shared similarly to the other datasets in that it was shared via Google Drive as shapefiles in the NAD 1983 (2011) State Plane California projection. Its attribute table was opened and analyzed to understand the shapefile better. Once opened, the attribute table contained information of rail station locations and names. So, this layer represented the points of where rail stations are located. To be sure that the rail stations were represented correctly in the Rail Mile Posts GRT layer, the rail station was searched in Google Maps for legitimacy. Once the rail stations were searched and existed in the correct county and district as shown in the attribute table and Google Maps, it was confirmed that the rail stations were correct and able to be used. The Rail Mile Posts GRT layer was reprojected to the WGS 1984 Web Mercator (auxiliary sphere) projection and uploaded to the GRT database.

3.5. Entity-Relationship Diagram

Once all the initial data from the GRTA team was prepped, an entity-relationship diagram was created to establish relationships between datasets that would eventually be transferred to the GRT database. To begin, the data that was acquired from the GRT team was downloaded from the google drive then uploaded to ArcGIS Pro to be visualized. Once visualized, each layer's attribute table was opened to fully understand the purpose of each dataset. Some of the attributes did not have clear meanings. So, it was decided to start a data dictionary defining what

attributes were known and asking the clients for the definitions of the unknown attributes. This step was vital to begin the next step, creating an entity-relationship diagram. An entity-relationship diagram serves to establish relationships between the datasets that will later be created in the Pro database. The entity-relationship diagram (ERD) shows the datasets that were established to be relational to another dataset depicted below in Figure 8. The ERD consists of all the GRTA layers and their attributes from each dataset. In black text are the data attributes that were able to be defined, while in red text are the attributes that no definition was able to be found. Each dataset is in a three-column chart. The first column determines which attribute is the primary key. The second column lists all the given attributes of the dataset. The third column describes the type of data of the attribute. The relationships established were five relationships between datasets. The first relationship was a one-to-many relationship between Major Rivers GRT and Major Rivers and Creeks GRT. Next, there was a one-to-many relationship between GRT 5-mile points and GRT points. Then, another one-to-many relationship between Key Cities GRT and Cities GRT. Key Counties and Rail Mile Posts GRT had a one-to-many relationship. Key Counties and GRT counties had a one-to-many relationship.

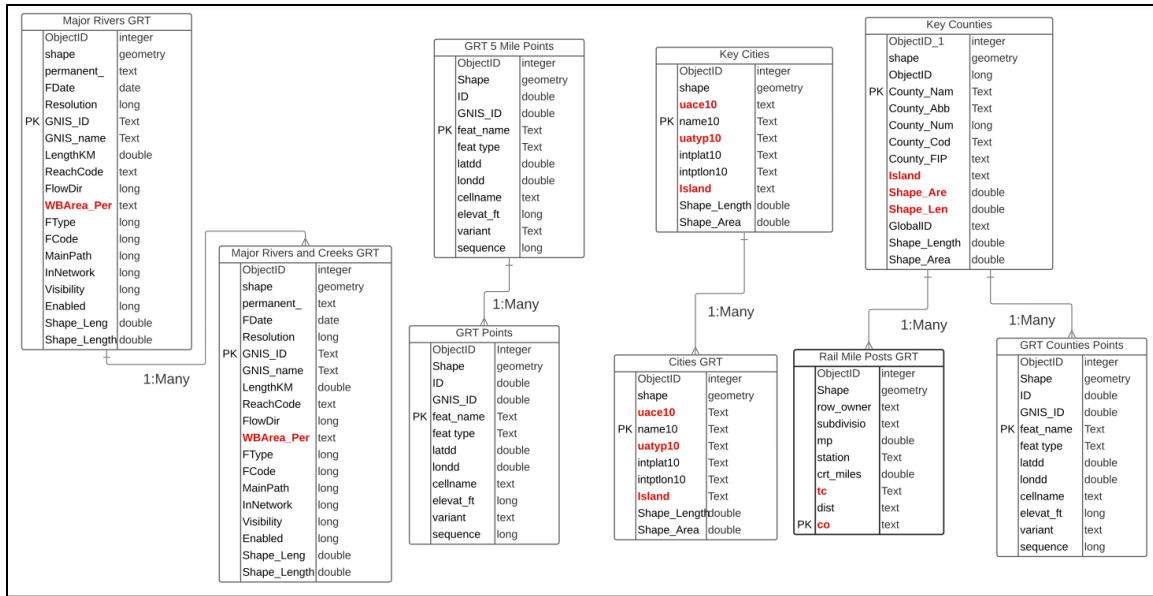


Figure 8 Entity-Relationship Diagram

3.6. Database Creation and Set-Up

After the entity-relationship diagram was constructed, the creation of the ArcGIS Pro geodatabase began. Section 3.4 discusses the data prep steps that were taken to ensure the relevant layers were added to the map. The shared GRTA datasets were uploaded into the geodatabase. This was done by adding the shapefiles directly into the database rather than just adding data to the map. If the data was simply added to the map, then the datasets would not exist in the actual database. After all the datasets were uploaded into the database, the relationships from the ERD were created in Pro. To create the relationships in the database, one right clicks on the dataset on interest in the database. Then navigate to manage and click on the relationships tab. Here, the relationship between datasets is established, as well as primary keys, and the cardinality of the relationships. The first relationship was a one-to-many relationship between Major Rivers GRT and Major Rivers and Creeks GRT. Next, there was a one-to-many relationship between GRT 5-mile points and GRT points. Then, another one-to-many

relationship between Key Cities GRT and Cities GRT. Key Counties and Rail Mile Posts GRT had a one-to-many relationship. Key Counties and GRT counties had a one-to-many relationship. The rest of the datasets that did not contain relationships were added to the database as well. They were included separately from the ERD tables, but still included in both the geodatabase and the data dictionary. Figure 9 below shows the non-relational datasets. After the datasets were uploaded to the geodatabase, the map in Pro was shared as a web map. The web map's title had to be stated as well as the summary of the map and any tags. This map from Pro had to be shared as a web map to be accessed in ArcGIS Online because the only way to select the base web map for the app was to select a web map from AGOL.

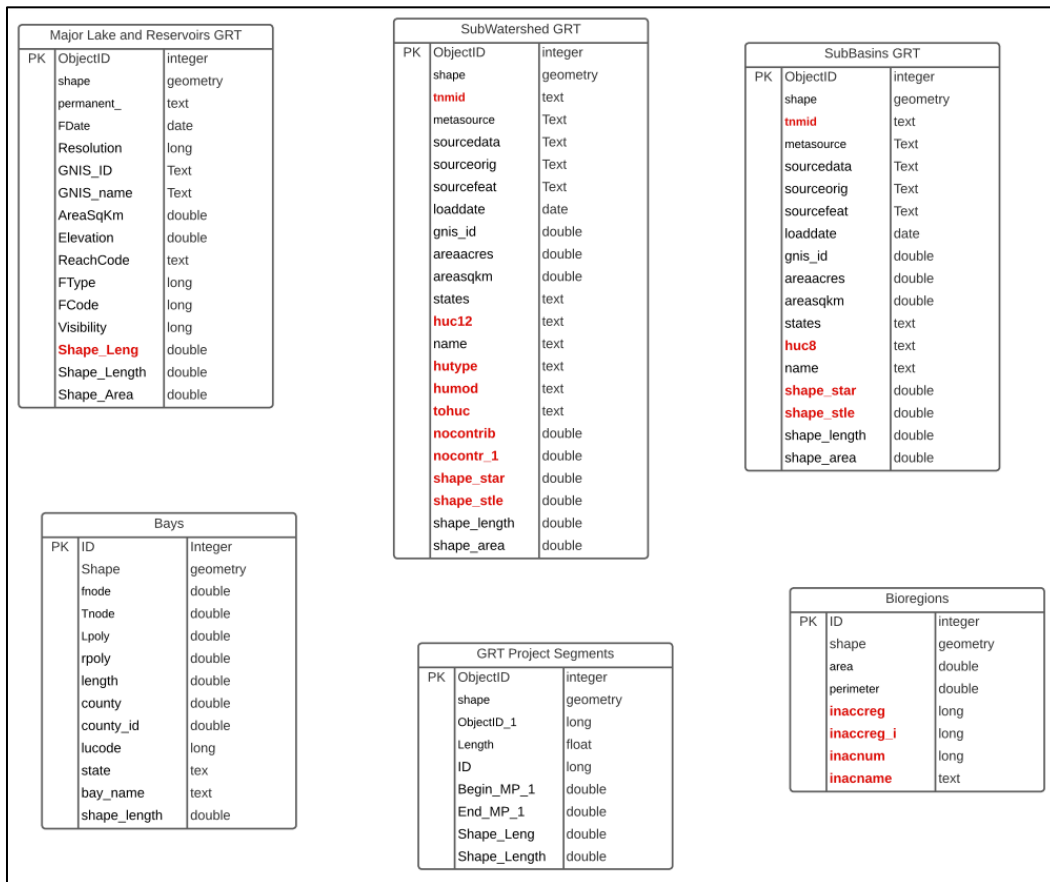


Figure 9 Datasets Without Relationships

3.7. ModelBuilder Workflows

The next step was creating a ModelBuilder that will update the database with data. First, the developer must navigate to the Analysis tab of the ArcGIS Pro ribbon. Then, ModelBuilder is selected. Once selected a new window opens with an empty ModelBuilder workflow. The developer can select any geoprocessing tool to include. For the GRT ModelBuilder, the ‘Create Feature Class’s geoprocessing tool was selected first. This tool requires a database for the new feature class to be created into, so the GRT database was selected. The feature class name is left open for any developer to add in any data that then gets uploaded to the database. The next workflow consisted of selecting the ‘Append’ geoprocessing tool. Developers can select the edit existing datasets they wish to update then the updates are reflected into the existing GRT database. The developer can upload the updated data that will replace an existing dataset. The last workflow involved using the ‘Delete Rows’ geoprocessing tool. This tool allows developers to select the targeted rows from a particular dataset in the GRT database that will be removed. The removal of rows is then reflected in the GRT database. These three workflows allow any future data amendments to be done with minimal steps when utilizing one of the workflows.

To summarize chapter 3, an initial meeting with the GRTA team set the stage for important components of the GRT app, such as identifying the GRT user, discussing the design of the app, and sharing key datasets. Once the datasets were shared, initial data preparation steps were taken. This involved creating a data dictionary and building an entity-relationship diagram with the datasets provided by the GRTA team was vital in ensuring the integrity and legitimacy of the data. Once the data was cleaned and the relationships were established, then the database was created on ArcGIS Pro. In ArcGIS Pro, the relationships from the entity-relationship diagram were transferred over, three ModelBuilder workflows were created, and the GRT map

was finalized. These steps were crucial for the next series of development to occur. In the next chapter, the development of the web map and widgets for the app are described.

Chapter 4 Development Process

The development of the GRT app consisted of creating a web map, selecting appropriate symbology, and developing widgets to allow user interactivity. Section 4.1 discusses the process of web map development. Next, section 4.2 describes the symbology for all layers. It was important that the layers did not overlap causing layers to be hidden or obscured. Therefore, making symbology choices that created an easy to digest map was key. The next step involved the development of the five custom widgets. Section 4.3 discusses how the widgets were all developed. Each customization of all five widgets is described in the following sections. Section 4.4 describes the user design of the GRT app. This chapter discusses the creation of the web and GRT app in great detail in order to explain the developmental choices made in regard to the GRT app.

4.1. WebMap Development

The web map consisted of the shared GRTA data layers that were uploaded to the database in ArcGIS Pro (Pro) then shared to ArcGIS Online (AGOL). The process of sharing the web map from Pro to AGOL involved using the share function in the Pro ribbon. This share function provides options for the type of package or formatting a project will be shared as. The preliminary Pro map was shared as a web map. The web map formatting was decided so that the map could then be selected and consumed in the app. Once this setting was chosen, the title of the map, any additional tags, and the summary of the project were added in. Then, the map was shared to ArcGIS Online (AGOL). This was to ensure that the datasets and their relationships were shared in AGOL. To access a web map for an application, it had to be shared to Esri's AGOL platform. Then, the map for the application could be selected to serve as the base web map for the application.

Once the map from Pro was shared to AGOL the base web map for the application was developed. The layers were prioritized in order of the most relevant to the least useful layers needed to be displayed depicted in **Error! Reference source not found.**. The layers that were automatically turned on when a user accesses the web app were: current wildfires, trailhead points, wildfire perimeters, key counties, the national highway layer, weather conditions layer, campgrounds, and recreational routes. These layers were symbolized in ways that allowed users to easily view and access them shown below in **Error! Reference source not found.**.



Figure 10 Web Map on AGOL

4.2. Symbology

The GRT app consisted of specific layers that shared information on hiking trails, wildfires, and weather events that had to be symbolized appropriately to convey each layer's meaning. The select layers, hiking trails, wildfire, trailheads, weather events, counties, highways, campgrounds, and recreational routes that were chosen to be displayed on the initial startup of the web map. Each symbology choice reflects the data most accurately, so that the user can see the data in the most accurate way. Since each layer represents a different concept, it was important to display those characteristics on the map. Similarly, ensuring all the data is visualized in the map was a key factor when making symbology decisions.

4.2.1. Hiking Trails Symbology

The trails for the GRT app were shared as a layer called the "HP3_Routes" and symbolized according to trail type. The HP3_Routes or hiking trails were line segments of several types of sidewalks, trails, and future trail development. These line segments consisted of both existing and proposed boardwalks, existing and proposed bike trails, existing and proposed trails. These categories were symbolized through the selection of a color ramp that showed each line segment in a distinct color. The color ramp allows users to view line segments at the same time but know that they are not the same line segment. The width of the trail segments was all five points so they would not distract one another. This was to ensure that users could click on a line segment and a legend would tell them the type of trail it was.

4.2.2. Wildfire Symbology

The Currents Incidents layer is symbolized as a red-colored fire symbol showing the distinct categories of fire incidents. These categories symbolize the severity of a fire by acreage burned, if the fire is a new fire, the incident is complex, and the fire is prescribed. Point

symbology was chosen since the data reflects on the map as points of active wildfires. The Current Perimeters layer is a polygon that shows the area the fire is encompassing and burning. It was vital to use a red outline with light red fill as the polygon symbology to show a wildfire perimeter as well as correlate with the red coloring from the current wildfire incidents.

4.2.3. Trailhead Symbology

The trailhead symbology is shown as a circle filled with a dark purple. This decision was made after testing out other symbology, such as a hiker, which was not visible on the map. The dark purple point acts as points on the map that users can click on to obtain directions to and from. These dark purple points display the locations of trailheads on the map.

4.2.4. USA Weather and Warnings Symbology

The USA Weather and Warnings symbology is categorized by varying polygons. These classes are broken down by weather event type and shown as a differing color polygon. The differing colors represent different weather events. Some weather events include air pollution, flooding, or hurricanes that are represented on the map as a distinct color of the red, blue, green color ramp. Additionally, the area that the weather event occurs in is encompassed in a polygon. The user can identify what type of weather event is occurring and where it is occurring, by the area of the weather event and the color it is symbolized in.

4.2.5. Counties Symbology

The symbology for the key counties was a black border around each county. This ensured that the boundary for each county was clearly defined. Additionally, each county contained a label. This label showed the user what the name of the county was. A county name label helps users know which county they are accessing.

4.2.6. Highways Symbology

The highway layer contained information on all highways in the US. This layer was clipped to show highways only in the state of California. At first, it seemed useful to symbolize each California highway in a distinct color to show that they are different from each other. However, different colored line segments representing highways distracted from the top priority hiking trails. So, the highways were represented as a thin, black line that displays the locations of major highways without distracting from other line symbology.

4.2.7. Recreational Routes Symbology

The recreational routes are symbolized in blue to show the distinct line segment. Since there already exists line segments, a blue line stands out and does not become hidden amongst the other line segments.

4.2.8. Campground Symbology

The campground data reflects points on the map where campgrounds are located. The campground symbology reflects points that are symbolized by a basic shape that displays a tent. This allows users to understand that the point reflects a campground. Because of the point symbology, users can direct themselves to and from that point.

4.3. Widget Development

Through various tutorials, FAQ sheets, and documentation assistance, the vital components of the app were created. Utilizing Esri's "Get Started" guide allowed for the steps and process to develop widgets to be constructed (Get started - ArcGIS Web AppBuilder | ArcGIS Developers n.d.). The guide was through Esri's ArcGIS Developers site, in which, a zip folder containing the files to launch Web AppBuilder locally. Then, the guide provided steps on

how to link a blank app to the new browser where the widget would be deployed. Additionally, the guide contained tips and outsourced links for any issues faced. Similarly, the “Get Started with the Yelp Fusion API” documentation provided key steps in understanding what data was available (Get Started - Yelp Fusion API n.d.). Through Yelp, there were instructions on how to create and manage an app, which would have been utilized in case the app development on Web AppBuilder did not launch. Additionally, the business points were linked to the developer’s guidance page, which provided a description of the data being accessed. The API key was vital in incorporating into the custom widget. This was so that when a user opens and searches on the widget, it calls on the Yelp API, then, producing restaurant information.

The next step in the application development process involved creating widgets through AGOL’s Web AppBuilder Developer Edition tools. The web map met the design requirements for the application, however, there were more components that needed to be included. To do so, the Developer Edition folder of Web AppBuilder was downloaded to a local machine. From custom widget building, to editing existing widgets to creating new template themes, the Developer Edition folder contained the foundational coding to begin customizing the application. The process for accessing the folders and subfolders consisted of various steps. First, the Web AppBuilder Developer Edition program folder had to be downloaded to the local machine alongside a developer’s license and Esri credentials. Then, the startup batch file within the Web AppBuilder Developer folder, was launched to start the program. Next, the AGOL account associated with the Developer Edition usage had to be authenticated. In addition, the App ID and the Web AppBuilder developer machine’s address, the name of the local computer where the Web AppBuilder Developer was downloaded, were both registered. After the registration steps,

the Web AppBuilder Developer Edition folders were available to use and edit so that the customization of the application could begin.

4.3.1. Restaurant Locator Widget Creation

The 'Restaurant Locator' widget was created through the utilization of Yelp's API. However, before an API Key was requested, the environment for the widget had to be set. First, the 'Sample Widget' subfolder in the widgets folder was copied into the main widget folder, containing the pre-designed (built-in) widgets that are installed with Web AppBuilder. After the 'Sample Widget' folder was copied over, it was renamed 'Find Restaurants' to distinguish the widget. In the 'Find Restaurants' folder, there were an images subfolder, manifest.json file, and widget.JavaScript file. The name of the widget and author of the widget were both changed and updated in the manifest.json file depicted in Figure 11 **Error! Reference source not found.**, containing the core programming comprising a widget. Next, in the main branch, the server folder contained a config.json file with code that was copied into the config.json file of the Find Restaurants so that the widget will be loaded from the widgets folder that contains all the Web AppBuilder widgets (Youtube - Extending the Web AppBuilder for Arcgis 2018). Then the nls folder was created. This folder contained translations for the manifest.json to utilize. After the nls folder was created, the manifest.json file was updated to show the line of code that states "hasLocale" was switched from false to true. Then, new folders were created. The config.json which is the settings for the widget that contains the Yelp API key. A css folder was created to add styling to the widget to edit the appearance. A widget.html file was created to serve as the html template for Web AppBuilder to load in the widget with. Next, the widget.JavaScript file was updated in order to add some functionality. In the widget.JavaScript file, dependencies for the widget were added and the pre-rendered html template string was removed, because the

widget.html file was created to replace it. The RestaurantsNearAction.JavaScript file was created to add feature action coding for the widget. In the manifest.json file, lines of code were added to inform over the use of the feature action file, RestaurantsNearAction.JavaScript. Then, a settings folder was created to extend the settings capacity in order to have Web AppBuilder populate restaurant information for the Yelp API key. Lastly, in the images folder, Yelp stars and the Yelp icon were added to add some graphics to the widget.

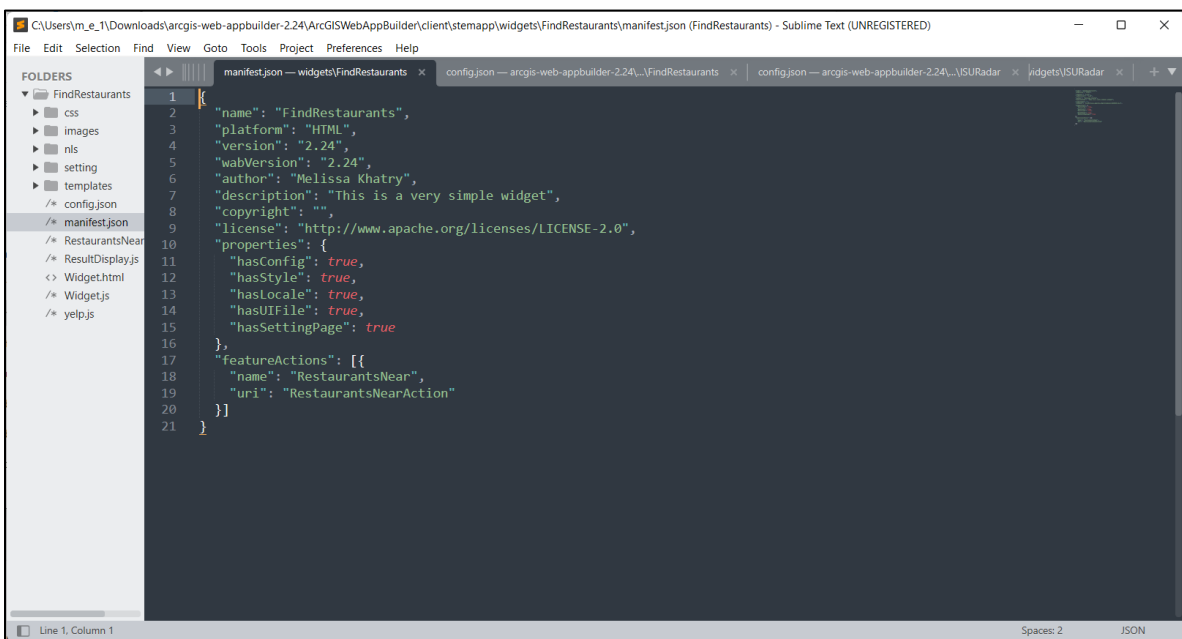


Figure 11 Manifest.JSON file

4.3.2. Radar Widget Creation

NEXRAD data was used in the Radar Widget that provided a live radar forecast for the United States (National Centers for Environmental Information n.d.). The Radar Widget shows users a live radar of weather patterns across the United States that the user can turn off or keep on. For the creation of the widget, the 'Sample Widget' was copied and pasted in the main widgets folder. Then, the manifest.json file was edited as new files and folders were created. The config.json file contained the code to run the widget by obtaining data from NEXRAD.

Additionally, a css folder contained the styling code to customize the widget. The nls folder contained many subfolders within it that had translations for the manifest.json file to utilize to run the widget. A widget.html file was created to serve as the html template for Web AppBuilder to load in the widget with. Next, the widget.JavaScript file was updated in order to add some functionality. In the widget.JavaScript file, functions for the widget were added that loaded or ran the data, as well as stopped the data from running. Similarly, the setting folder contained JavaScript files that extended the configuration of the widget (Esri Community 2016).

4.3.3. Layers List Widget Creation

The list of all layer's toolbox was configured to display accurate information for the GRT app. First, the title and legend were selected so that users can see the title name of all the available layers. Next, specific actions that the users can make were selected. These actions included: zooming, changing the transparency of a layer, enabling, or disabling pop ups for layers, reordering the list of layers, accessing a layer's attribute table, and looking at the metadata of a layer. From the developers' side, not all the layers had to be shown on the list widget. However, the decision was made to allow users access to all the layers.

4.3.4. Wildfire and Weather Information Widget Creation

The wildfire and weather information widget provides two lists of occurring weather events and wildfires. These lists are populated through active wildfire and weather events. Meaning, no user input is required since the layers in the web map feed into the lists. The developers view shows the layer that had to be selected, each layer's information symbology, and the additional display features. The configuration of the information widget allowed two key information on two separate layers to be displayed simultaneously. The first layer shown was the current incident layer. It was shown to generate a list of the wildfire events. The symbology for

the wildfires remained the same as in the original web map. The next layer was the weather events layer which displayed the weather events ordered by type of event. These weather events kept their original symbology but generated a list of the weather events taking place. These weather events were further categorized by type and each type of weather event could be expanded to show the number of events for a specific weather type occurring.

4.3.5. Wildfire Filtering Widget Creation

The filtering widget was configured to utilize the current incidents layer that displayed the wildfire events. The label was set as Current Incidents with the symbology icon remaining the same as in the original web map. Two expressions were generated to allow for filtering. The first expression allows for users to select the point of origin state from the current incidents attributes and ensure that it is equal to a state which is all the unique values to the field. The next expression used the attribute from current incidents point of origin county to filter by county. Then, the expression ensures that all the point of origin county values are equal to counties in the field. These two expressions created allowed for the wildfire filtering enabled by users.

4.4. UX/UI Design

Once all of functionality components were complete, then the application design began. The user interface design of the application had already been discussed and thought out. But, once the custom widgets, layers, and database were all complete, they were added to the map.

When an app developer opens the developer portal of Web AppBuilder, there are four main categories on the ribbon bar to customize. The first is the theme category. In the theme section, ten different themes to choose from. These themes consist of several types of layouts such as dashboards, pocket, tab, and more to determine the appearance of the app. Each theme has a distinct layout that determines choices such as widget placement and map placement. Next,

the style choices in the theme tab allow developers to choose the color of the title or header of the app. The title of the app may be filled with any color the developer chooses. The default color is gray, but developers can change it and even import custom colors. The last section of the theme tab is the layout section. This layout section allows developers to organize the layout of the widgets. The widgets can be grouped together on one side of the app or spread out. The layout allows developers to organize where and how users access widgets.

The next tab in the ribbon customization is the map tab. In the map tab, developers can select the web map for their app. There are options to select custom web maps or web maps from AGOL's map portal. Developers can set the extent for their web map. The existing web map view is the default choice, but developers can further customize the view of the map to their preference so that users have a specific extent when starting the app. Next, developers can customize the visible scales of the map. This means that developers can control how much a user zooms in or out of the map. The last section involves setting a refresh interval. Developers can set their map to refresh at whatever cadency they prefer. Developers can refresh the map at a to honor the rate each layer is refreshed or use a single interval for all non-static layers.

Next, the widget customization tab allows the sequence of widgets to be set. Additionally, to widget layout, built-in widgets can be searched and edited. For example, in the GRT app, the existing filter widget was edited to allow for specific filtering. An expression was created to filter wildfires by county and state so users could view current wildfires in a specific area. In the widgets tab there are fifty-three existing widgets that can be used and edited by developers. Also, once developers download the developer's edition folder, developers can create their own widgets that are then searchable in the master list of widgets.

The last tab is the attribute configuration tab. There, developers can add branding to their app. The type of branding available includes logos, titles, and subtitles for the app. Additionally, any external links can be added to the app in this section. Also, the state of the app can be set in this section which allows the map extent and layers visibility to remain the same while exiting the app. Lastly, developers can configure data sources for the app that are not including already in the layers of the web map.

For the Great Redwood Trails application, a dashboard theme was chosen. The dashboard theme was selected formatting of widgets around the web map. Therefore, the dashboard template displayed the web map and five widgets that conveyed restaurant, fire, weather, and layer information for the users. The color of the dashboard theme was white color so that the map stands out. Additionally, a splash screen was added so that when users first access the application, they are welcomed to it as well as read a disclaimer in the formatting. The splash screen was a built-in widget in Web AppBuilder. The splash screen widget was turned on with a disclaimer. The disclaimer is simply to notify the users that the data might not be updated as quickly as needed. Therefore, there are links to up-to-date wildfire and weather pattern information.

In summary, this chapter discussed the development of two key components: the web map and the widgets. For the development of the web map, each key layer had to be symbolized accordingly. The eight key layers symbology choices were made with the user in mind to ensure that a user can understand the meaning of each layer. The next component involved the development of the widgets that are included in the GRT app. Each widget had a different development process that ultimately produced a Restaurant Locator Widget, Radar Widget,

Layers List Widget, Wildfire and Weather Information Widget, and Wildfire Filtering Widget. In Chapter 5 the results of the database and widget development are assessed.

Chapter 5 Results

The GRT app consisted of creating the GRT database on ArcGIS Pro and the development of the GRT app on Web AppBuilder with the key results building from each other. The database had to be created first to host the data for the app. Then, once the database was finished, the GRT app and its five widgets were developed. The following sections discuss the results of both the database and the GRT app and each of its widgets.

5.1. Database Results

The ArcGIS database provides a centralized location for hiking layers, whether focused on trailheads, bike lanes, or roadways. The input data for the application consists of existing GRT layers, which are viewed by users in the web map, being fed or streamed from the Geodatabase. When users are viewing the GRT app, they can toggle on or off data layers at their discretion. This is to ensure users can view relevant layers, while still being provided all available layers. The database also acts as the source of information for the layers list widget. The same symbology and naming convention from the database appear in the layers list widget for users to manipulate. The database serves as a base for future developers to add, amend, or remove data from the web app. Developers can access the database through Pro and make any dataset amendments. To reflect these changes in the web app, the Pro map must be shared as a web map to AGOL. Then, in Web AppBuilder the updated web map must be selected to serve as the map for the app.

5.2. ModelBuilder Results

The ModelBuilder workflow helps to ensure that the database can be maintained over time. The ModelBuilder has three different functionalities for manipulating data. The database

engineer can add new data through the add new dataset in the 1st workflow by using the add dataset function and naming the new dataset. Next, one can delete existing datasets in the database by using the delete rows in existing dataset function and then updating dataset the dataset from the 2nd workflow in **Error! Reference source not found.** The 3rd workflow in **Error! Reference source not found.** allows the database maintainer to amend existing datasets or update them and publish them as new datasets in the database through the amend function then creating a new feature class and naming the output. These three workflows were chosen and created because of the commonly needed tools to maintain a database: add new data, delete data, and amend existing data.

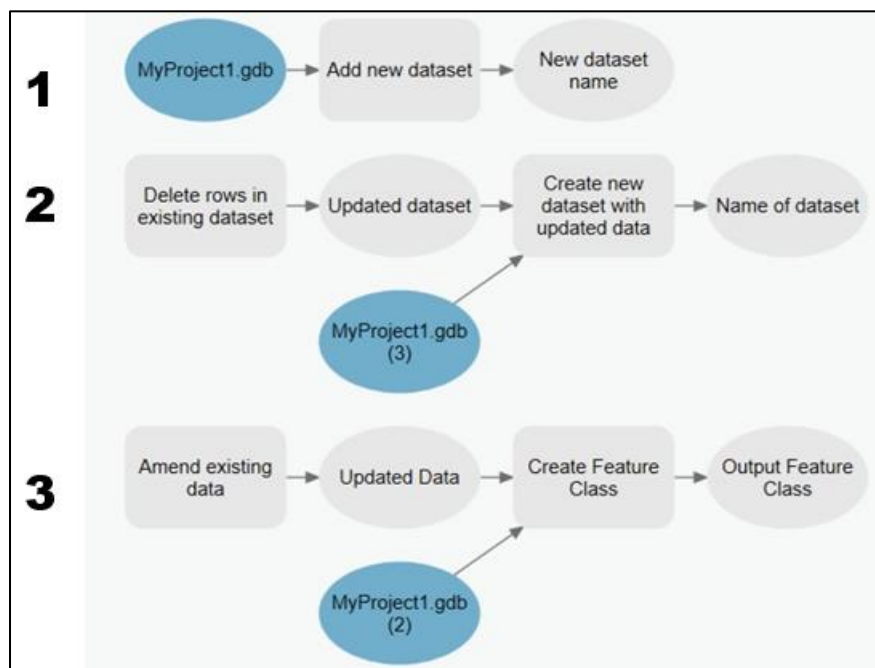


Figure 12 Esri ModelBuilder Workflows

5.3. Widget Customization Results

The widgets in the GRT app allow users to filter information that populates onto the web map or in a widget. Each widget provides users with more access to information that can be tailored to each user's preference. When a user first accessed the GRT app, the first thing that appears is a splash screen message shown below in Figure 13. The message welcomes the user to the app as well as provides a disclaimer about the frequency of data updates and provides users with websites with the most up to date information. In the mobile version of the GRT app, the user is presented with the web map and the first widget, the restaurant locator widget. This widget appears first because of the clients request to highlight local restaurants. Here, the user can type in an address or choose a point on the map to populate a list of restaurants near their proximity. If a user desires to use another widget, they simply click the next arrow button to scroll to the next widget, the radar widget, as well as continue to view the web map. With the radar widget on, users can view weather patterns. They can turn it off and clear the radar forecast off the web map. Next, the user can click the next arrow to scroll to the following widget, the layers list widget, the users also can scroll back to the previous widget. The layers list widget allows users to filter which layers are visible on the map. With the web map above the widget, users can see in real-time the layers turning off and on. Next, users click to the subsequent widget, the wildfire and weather information widget. Here users view a list of active wildfires as well as a list of weather events that are categorized by the type of weather event. The last widget users can scroll to is the wildfire filtering widget. This widget allows users to select the state and the county they wish to filter by. Then, the filter populates the desired area of wildfire locations on the web map.

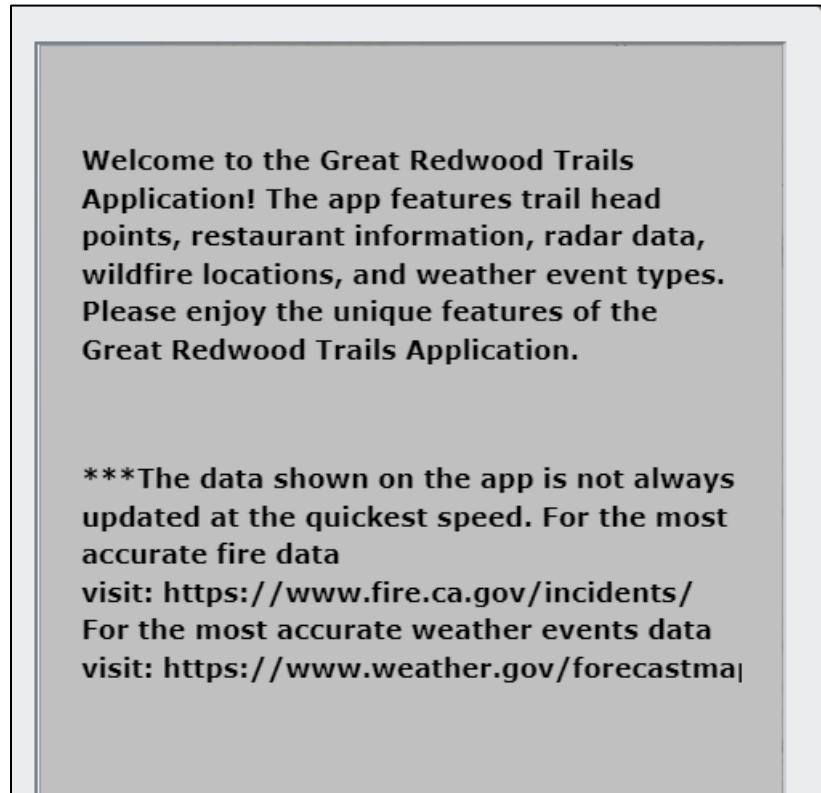


Figure 13 Splash Screen Message Mobile Version

The web view of the GRT app consists of the same splash screen message and widget functions as the mobile version. The layout of the web map and widgets is the only difference shown below in Figure 14. The web view has the web map on the upper right corner of the web page with the five widgets bordering around the web map. The following subsections describe the results of each widget of the GRT app.

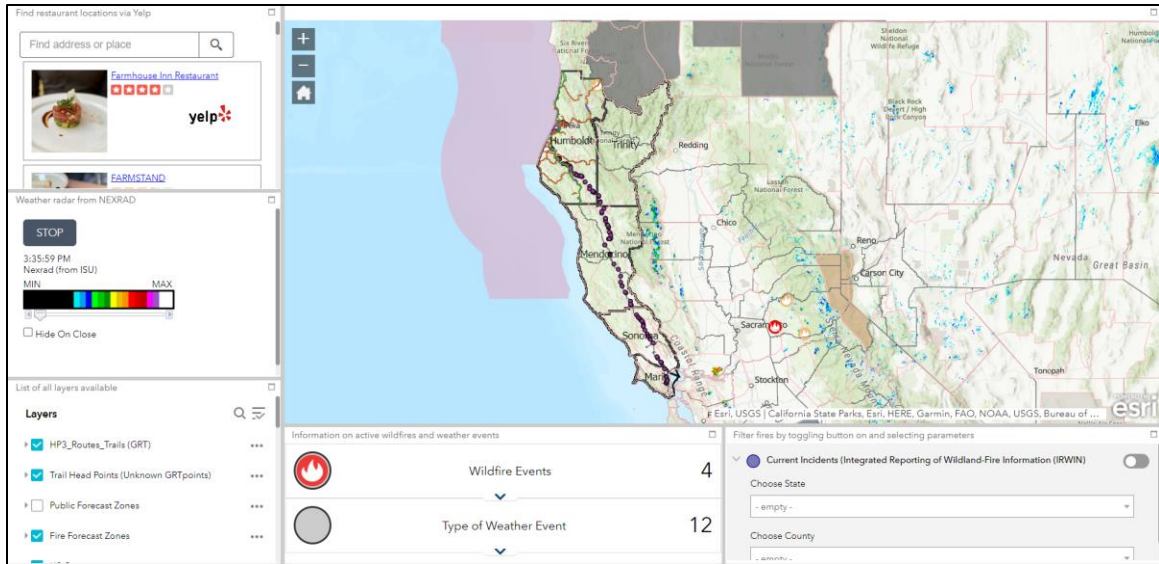


Figure 14 Desktop Version of GRT App

5.3.1. Restaurant Locator Widget

To include local restaurants, the Yelp API allows for restaurant information to be pulled and added to the map. The custom widget included some coding to ensure that the Yelp API is being requested and then is generating restaurant search results. The widget was further customized to include a feature action tool. This tool allows users to select a point on the map then populate a list of restaurants in the point's proximity. In the mobile version, the GRT user can scroll and find the Restaurant Locator widget below the web map shown in Figure 15. Then, the user can input an address or use the feature action tool to populate a list of restaurants. Figure 16 then shows the generated list of restaurants users can access. This list allows users to select a restaurant and be navigated to the Yelp page of the business. Additionally, users can navigate to the selected restaurant.

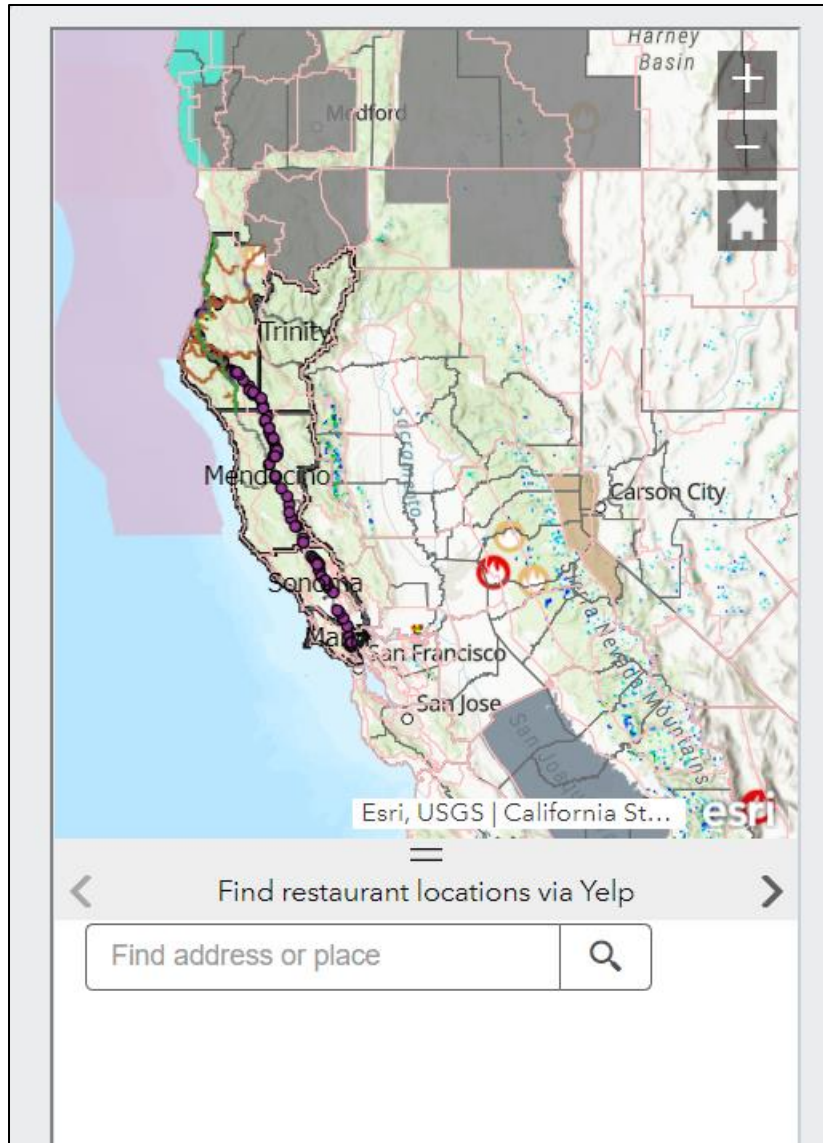


Figure 15 Restaurant Locator Mobile Version

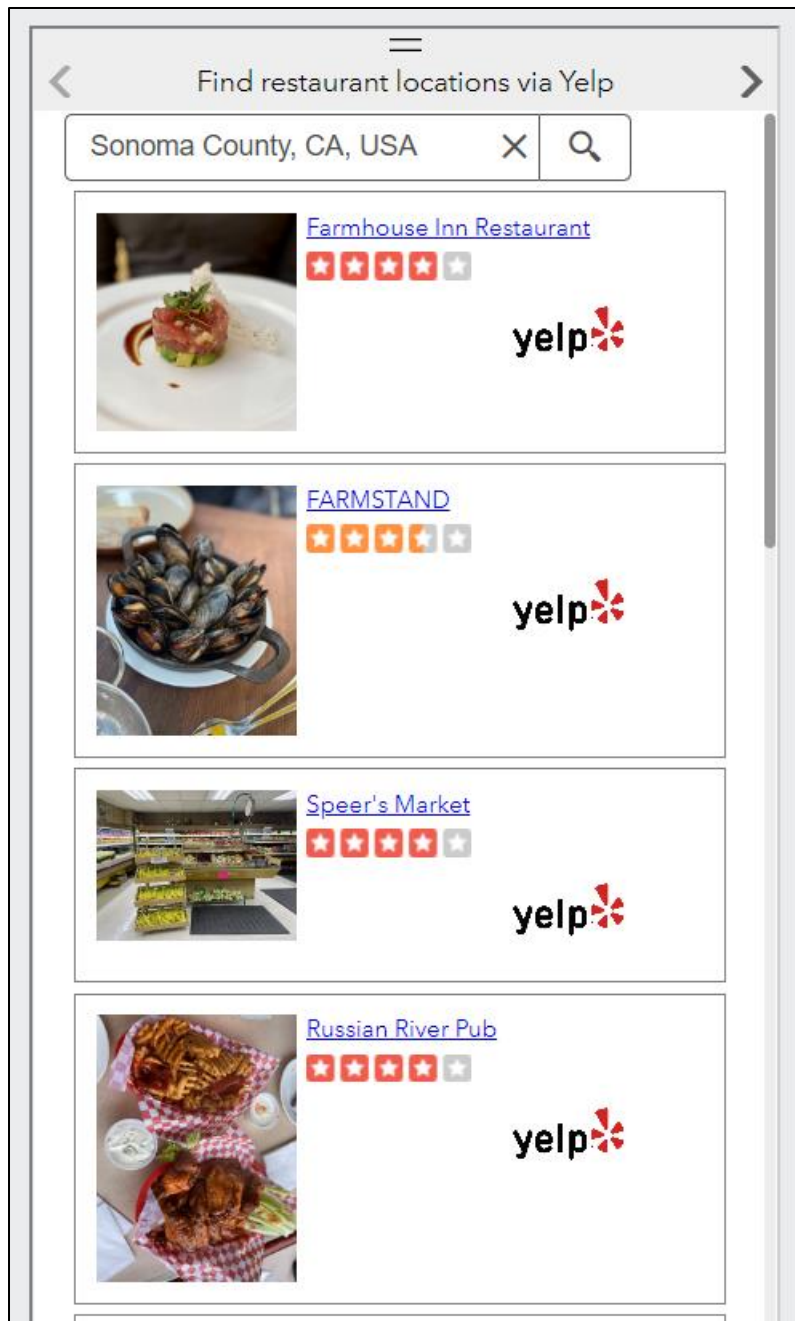


Figure 16 Widget with Populated Restaurants

5.3.2. Radar Widget

The radar widget shows the type of weather patterns occurring in a certain area. The legend within the widget displays colors. The radar is depicted as a color spectrum. The green in the radar signifies light or moderate rainfall (Ahrens 2023). The yellow, orange, and red colors

represent moderate to heavy rainfall and may represent hail. The white and blue indicate snowfall while the pink indicates freezing rain, sleet, or a wintry mix.

Additionally, users can track the movement of a weather event type as visualized in Figure 17. This allows users to be better informed and visually observe where a weather event is occurring and how to best avoid it. This widget provides users with the ability to see weather patterns and track their movements throughout the US depicted in Figure 17. This mobile version shows how users can scroll to the radar widget. Additionally, the radar widget contains a stop button which will turn off the radar information on the map.

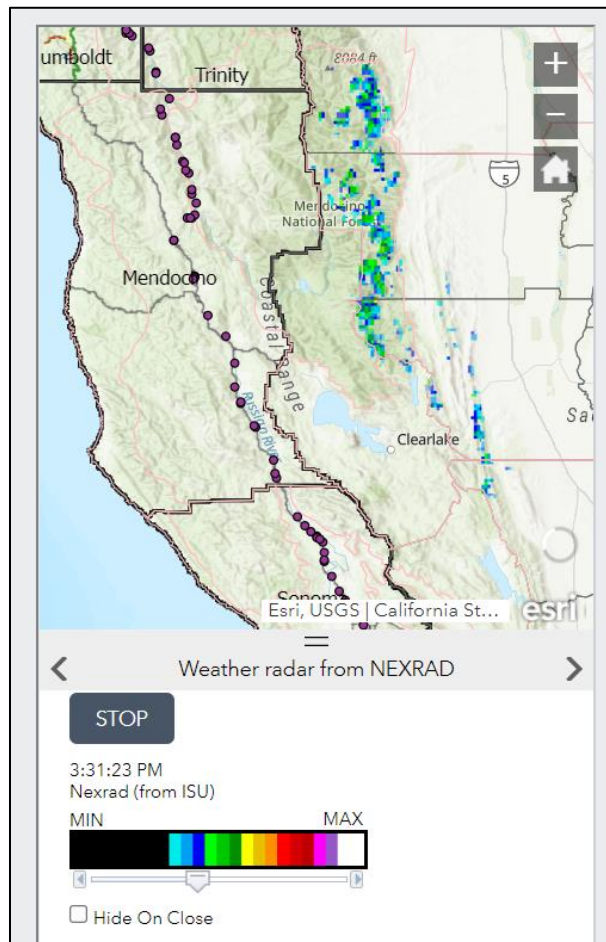


Figure 17 Radar Widget Mobile Version

5.3.3. Layers List Widget

The Layer List widget provides a clear list of all the layers included in the web map and their default symbols. Additionally, the widget allows developers and users the ability to turn individual layers on and off. Each of the layers in the list contains a check box on the side of each layer's title that allows for viewing individual or collective layers (ArcGIS Online Resources n.d.). Some of the layers even contain sublayers within them. For the GRT app, the HP3_Routes_Tails, Current Incidents, Current Perimeters, weather events, counties, highways, campgrounds, and recreational routes layers were selected for the default view.

5.3.4. Wildfire and Weather Information Widget

The Info Summary widget allows developers to provide counts of features in a specified layer, as well as a collapsible list of information of the layer or layers selected. The list of layers produced in the widget panel can be grouped by a specified field (ArcGIS Online Resources n.d.). The layers added to this widget were the USA wildfire and USA weather current condition layers. For each layer, the attribute was selected at the top of the menu and extract data source was selected. Then, the layers selected, USA wildfires and USA weather conditions, were both selected. From the wildfire layer, the current conditions sub layer was chosen. For the current weather conditions, the events ordered by size and severity were chosen. Then, the title of the widget was updated.

5.3.5. Wildfire Filtering Widget

The Filter widget allows developers to offer limits or filters for users to select to limit the visibility of features in a layer (ArcGIS Online Resources n.d.). When the criterion for the filter is selected, the map reflects the filtering and displays the selected data. For the GRT app, a new filter was selected, and the layer chosen to be filtered was the USA wildfire layer. Then, two

expressions were added: Point of Origin State (string) is Unique and Point of Origin County (string) is Unique. Then, the box for ‘Ask for values’ was selected. The prompts were Select State and Select County shown in Figure 18. The list of values able to be selected was ‘All unique values of this field’. This was to ensure that users would select states and counties that pertain to the layer and project area (Using Web AppBuilder’s Dashboard Theme – Esri n.d.). Then, the feature being filtered, for the GRT app being wildfires, generates onto the map. So, wildfires for a specific state and county are filtered to only display the fires in the selected state and county. Figure 18 shows this process visualized on the map.

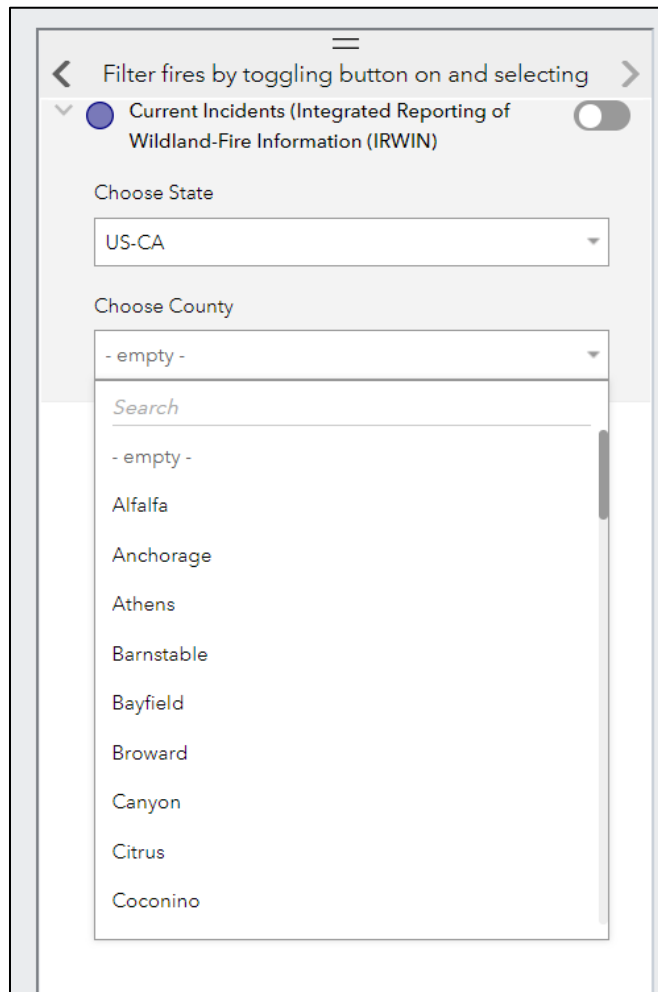


Figure 18 Mobile Version of Wildfire Filtering Widget

To summarize Chapter 5, the creation of the geodatabase, ModelBuilder Workflows, and widgets all resulted in the GRT app. The database resulted in a centralized location for all the datasets that were consumed by the GRT app. The ModelBuilder Workflows assisted in allowing database manipulation that would then be reflected in the app. The widgets allowed users to search, query, and manipulate the existing information and layers in the GRT app in order to populate additional or user-specific information. In all, these creations, database, ModelBuilder, and widgets, built off one another to produce the GRT app. In the final chapter, limitations and future work are discussed in order to propose alternative methods for improving and furthering the GRT app.

Chapter 6 Conclusions

The following sections describe challenges faced with the GRT app data, software, and symbology. Section 6.1 and its subsequent subsections discuss the issues with working with the data given by the GRTA team and the challenge in uploading the GRT app onto the USC web server. Section 6.2 discusses the results of the widget creation, symbology choices, and limitations with the GRT app itself. Section 6.3 proposes future research on furthering the GRT app.

6.1. Issues Faced with Data and Software

The following subsections describe at length some of the data and software challenges faced when developing the GRT app. One of the biggest challenges to overcome was working with data provided by the GRTA team. Section 6.1.1 discusses the data inconsistencies as well as the extensive data cleanup that had to be conducted. Another challenge faced involved the deployment of the app on the USC web server that caused issues with a smooth deployment of the GRT app onto the server, which is discussed in section 6.1.2.

6.1.1. Data Issues

The biggest challenge with the data used in the GRT app was the integrity of data given by the GRTA team that did not include metadata or sources of the data. The GRTA team initially provided shapefile layers via google drive. These layers included data on: Major Rivers, Major Rivers and Creeks, GRT 5 Mile Points, GRT Points, Bays, Key Cities, Cities GRT, Key Counties, Rail Mile Posts GRT, Major Lake and Reservoirs GRT, GRT Counties Points, Subwatershed GRT, Subbasins GRT, and Bioregions. These layers were uploaded onto ArcGIS Pro to understand their symbology and visualize them. Once these layers were visualized, their

attribute tables were opened to understand what each layer was symbolizing. These attribute tables contained attributes that were shortened and not defined. So, it was realized that the metadata was incomplete and the GRTA team did not know the origin source for the data layers. Then, what attributes could be defined were and used to establish an entity-relationship diagram. This diagram would establish relationships that would be created in the geodatabase as well. The defined and missing attributes for all the data layers are available on appendix a.

The biggest challenge faced with these two live layers is ensuring the data reflects the most up-to-date information. Since the app might not have refreshed in a timely manner, a splash screen was created with a message that warned about the live layers and re-directed users to websites that could provide more current information.

6.1.2. USC Web Server Issues

The web app was created on a local computer to eventually be transferred to USC's web server to host the app. First, some programming edits were completed, so that the application was ready to be transferred to the USC web server. To do so, FileZilla was utilized to upload the folder to the personal USC account directory. Once it was uploaded, the application loaded on the USC account. However, the layers would not load on the web version of that app. It was through discussions with the USC IT lead that the discovery that the USC web server did not have the configuration to support the download of Web AppBuilder Developer Edition to then deploy the GRT app was made. So, the pivot was made to share the app's folders and data until the USC web server was configured to support Web AppBuilder Developer Edition.

6.2. Application Results Discussion

Throughout the development of the GRT app, there were successes, challenges, and pivots that led to the final pilot app. The development process consisted of three main

components. These included, creating a geodatabase to be passed onto the GRTA team which contained the necessary data for the app, the symbology choices made in creating a web map, and the construction of the widgets that went into adding interactivity to the app. The following subsections discuss the results of each component of the GRT app, as well as any limitations in the GRT app.

6.2.1. Database

The geodatabase was created through data obtained from the GRTA team. As discussed in previous sections, there were challenges with working with the given datasets. The missing data dictionary and attribute definitions made it difficult to establish relationships amongst the datasets. Additionally, the prioritization of particular datasets was a strenuous process without timely feedback from the clients. Since the clients preferred the database to be hosted and created on Esri's software platform, ArcGIS Pro, there were limitations with the capabilities of Pro itself. For example, it was not possible to view all the tables of each dataset at the same time. Meaning, a simultaneous view of all the data's attribute tables could not be possible. This was a challenge because it meant opening a single table up a time and noting the attributes in it. A solution to this issue would be to create the database on a different platform. MS Access was used to obtain an overall view of the attribute tables. On MS Access, the ability to generate relationships through attributes is possible. So, furthering the GRT app would involve hosting the database on a different software platform to have access to database manipulation and maintenance tools that are not available on ArcGIS Pro.

6.2.2. Web Map Symbology

The symbology choices of the web map were a great challenge because of three factors, fulfilling the user requirements for designing a web map and ensuring the multiple layers were

easily visible, and the use of a cell phone for accessing the GRT app. These factors influenced how each layer appeared on the map while always prioritizing what a GRT app user needs to view.

In the GRT app, users can filter the location of wildfires. The user filters the state and county they would like to view wildfires in, then the map populates active wildfires in the specified area. The web map design process consists of components, such as user-friendliness, cartographic choices, and interactivity that all shape a web map's effect on users. With each component in mind, the GRT app's web map was developed to allow user to interact with the web map, and then manipulate the information populated on the map itself. This interaction adds to a user's experience by connecting two sources of information, the information from the data layers and the user's specified widget filtering and searches. The web map design process consists of components, such zooming abilities, symbology choices for each data layer, and widgets that allow users to input specific requirements or parameters. With each component created, the GRT app's web map was developed to allow user to interact with the web map, and then manipulating the information populated on the map itself.

The GRT app's web map was created to ensure that layers do not overlay each other and are visible to users. Since a phone would be the primary source for accessing the GRT app, the layout of features of the web map was critical. From displaying hiking trails to describing the wildfire and weather conditions, the symbology choices were made with both a web and mobile design in mind. However, ensuring the best layout of each data layer proved to be a challenge. For example, many of the layers were line segments that represented different types of trails, such as pedestrian trails and future pedestrian trail development. So, attempting to symbolize these lines while also maintaining their meaning involved ensuring each line segment was shown

in distinct colors. These distinct colors allowed users to know that each line represented a different type of trail and to know what it represented meant clicking on the line segment that would show a pop-up with information on the line. Similarly, the weather events symbology was difficult to decide and work with. The weather events were symbolized by weather event type that was represented as differing colored polygons. So, that the area the weather event was occurring would be obvious. However, the colored polygons hid some of the layers and parts of the project area. A way to overcome this solution was trying to discover a method of symbolization that allowed for the layer to be hidden, but when a user hovers above a certain area, the weather event polygon would appear. This type of symbology would have been ideal for the weather events layer but was not possible to do. The ability to hide then show the layer in accordance with the area a user hovers over was not a capability of ArcGIS Pro. So, the layer remained on but had a 25% transparency so that the additional layers were not hidden.

To elevate the symbology choices in the GRT app, it would be beneficial if layers had been prioritized since the start of development by the clients. This is to ensure that some unnecessary layers are not included in the app. Rather than choosing symbology for each layer, the clients could have discussed the appropriate symbology for the layers. Additionally, custom symbology, such as GRT trail head points or wildfire icons, could add uniqueness to the app and ensure users are fully aware of the meaning of the layer. These symbology suggestions could one day be made to further the development of the GRT app that would allow the layers to be eventually available offline.

6.2.3. Widget Construction

The construction of the five widgets was done on Esri's Web AppBuilder Developers Edition platform that would then be deployed onto USC's web server. The biggest challenge

faced with the web app was deploying the GRT app that contained the five widgets. As previously discussed, the USC web server was not properly configured to download and maintain Web AppBuilder Developer Edition's environment. So, the GRT app was not properly launched. The workaround involved sharing the GRT app and its folders that contained the custom programming for each widget. Once the web server could support Web AppBuilder, the GRT app will be launched. This web server technicality could not have been foreseen and alternatives have been extensively thought out. Therefore, sharing widget folders, app folders, the datasets, and the geodatabase until the GRT app can be properly launched has become the temporary solution.

6.2.4. Application Limitations

The two main limitations in the GRT app include the lack of full trail line segments and the inability to deploy the app on the USC web server. Since the trails are still being developed from previous rail lines, not all the trail lines are accessible as datasets to include in the GRT app. This limits the accessibility users have to hiking routes. However, as more of the trail becomes developed and mapped out, these trail segments will be added to the GRT app.

6.3. Future Development

The further development of the GRT app includes adding newly developed trails to the web map and creating additional widgets, while hosting the app development on a different software platform. Adding additional trail layers can disrupt the current layout of the web map. Therefore, rethinking the web map design may be a key component in furthering the GRT app. Also, including new layers may require new widgets to populate specific information onto the map. Along with these web map and widget developments, looking at other software platforms to host and develop the GRT app may serve to create a better setting for it.

6.3.1. Future Design

As new hiking trails become developed, they will be included in the web map of the GRT app. The inclusion of new trails may lead to a redesign of the web map to better illustrate the trails and other layers. The original symbology ensures that all the layers in the web map are displayed clearly and do not overlap. However, with more trail segments being included, these symbolized layers may require new symbology to ensure users can view each layer clearly. These new symbology choices can include using dotted line segments, custom line segments, trail type specific colors, or creating out of the box symbology.

Along with additional layers being added to the web map, new widgets may become necessary for the GRT app to best serve users. Widgets that show condition, type, or classification of trails may need to be developed to not only improve user experience but add to the functionality of the app. Currently, trail characteristics do not exist in the GRT app. But, in the future the trails may contain information about their conditions that could be conveyed to users through a widget. Additionally, existing widgets may need updating to ensure information being displayed reflects any changes. The existing widgets may be configured to reflect any new data that has been included in the GRT app.

The Radar Widget could be improved by including a legend of what the colors in the radar spectrum symbolize. The spectrum is a standard spectrum and reflects the same meaning as other radars. However, the user may not have prior knowledge as to what the colors of the spectrum signify. The inclusion of a legend on the radar widget would help the user better understand the weather patterns occurring.

6.3.2. Other Software Available

The GRT app was developed on Esri's Web AppBuilder platform. As discussed in previous sections there were challenges with app development and with app deployment. So, to combat these issues in the future, developers could look to other platforms to further the GRT app. Through Esri's platform, there are two alternatives to Web AppBuilder, StoryMaps and Dashboards. StoryMaps is a platform that allows developers to add text alongside a web map, so that users can read information that the developers wish to convey to users alongside a map. It does not allow for widgets to be included, but, if in the future, the GRT app requires a lot of text to give a contextual background to users alongside the web map, then StoryMaps would be the ideal option. The second alternative is Esri's Dashboards platform. Dashboards is a platform that allows developers to have multiple widgets and windows alongside the web map. It is ideal for showing statistics, text, and widgets with a web map. However, it is not like an app in which developers can deploy it and users can access it through their phone. Dashboards would be ideal if in the future the GRT app requires more widgets that contain charts and statistics to convey the data.

An alternative to Esri's platforms would be to look into developing the GRT app completely from scratch. This would mean obtaining software development programs and tools that would create an environment to create every component. Visual Studio and Firebase are two examples of software programs that allow for database development and user interface development. The challenges with re-creating the GRT app out of Esri's platform would be the time constraint and all the necessary troubleshooting. It would be very time consuming to create the app all over but could allow for further customizations that were not possible through Esri.

References

- Ahrens, D.C. 2023. *Essentials of Meteorology: An Invitation to the Atmosphere*. Pacific Grove: Brooks/Cole, 2023.
- AllTrails. 2010. "AllTrails: Trail Guides & Maps for Hiking, Camping, and Running." Accessed November 10, 2022. AllTrails.com. <https://www.alltrails.com/>.
- Anderson, Z., and Jones, M. 1970. "Rethinking the Role of a Mobile Computing in Recreational Hiking." SpringerLink. Springer International Publishing, https://link.springer.com/chapter/10.1007/978-3-030-45289-6_16.
- ArcGIS Online Resources. n.d. "Web Appbuilder." Accessed July 31, 2022. <https://dlac.grinnell.edu/arcgisonline/web-appbuilder/>.
- ArcGIS Solutions Web AppBuilder Widgets | ArcGIS Solutions. n.d. "Solutions Web Appbuilder Widgets." Accessed October 6, 2022. <https://solutions.arcgis.com/shared/help/solutions-webappbuilder-widgets/>.
- Barnett, M. 2016. *Precipitation Triggered Landslide Risk Assessment and Relative Risk Modeling Using Cached and Real-Time Data* (dissertation).
- Blake, M.C., Jones, D.C., and Graymer, R.W. 2000. "Geologic Map and Map Database of Parts of Marin, San Francisco, Alameda, Contra Costa, and Sonoma Counties, California." Geologic map and map database of parts of Marin, San Francisco, Alameda, Contra Costa, and Sonoma Counties, California, 2000. <https://doi.org/10.3133/mf2337>.
- California Department of Forestry and Fire Protection (CAL FIRE). n.d. "Fire Hazard Severity Zones Maps." Cal Fire Department of Forestry and Fire Protection. Accessed July 14, 2022. <https://osfm.fire.ca.gov/divisions/community-wildfire-preparedness-and-mitigation/wildland-hazards-building-codes/fire-hazard-severity-zones-maps/>.
- California Senate - Open States. 2021-2022. "SB 69." Accessed July 14, 2022. <https://openstates.org/ca/bills/20212022/SB69/>.
- Create your first app-ArcGIS Web AppBuilder | Documentation. n.d. "ArcGIS Web AppBuilder" Accessed June 9, 2022. <https://doc.arcgis.com/en/web-appbuilder/create-apps/makefirstapp.htm#:~:text=Create%20an%20app,Create%20D%20and&text=On%20the%20My%20Content%20tab,click%20Create%20a%20Web%20App>.

- Cybulski, P., and Horbinski, T. 2020. User Experience in Using Graphical User Interfaces of Web Maps. *ISPRS international journal of geoinformation*;9(7):412.doi:10.3390/ijgi9070412
- Esri Community. 2016. "Isuradar Nexrad Weather Radar Widget." <https://community.esri.com/t5/web-appbuilder-custom-widgets-documents/isuradar-nexrad-weather-radar-widget/ta-p/914966>.
- FarOut. n.d. "Farout." Accessed October 27, 2022. <https://faroutguides.com/>.
- Ferguson, J. 2022. "Marin County, California." *Marin County, California: History and Information*. Accessed September 15, 2022. <https://www.ereferencedesk.com/resources/counties/california/marin.html>.
- Fire Season | Humboldt County, CA - Official Website. 2021 "Fire Season - Humboldt County." Accessed September 15, 2022. <https://humboldt.gov/2874/Fire-Season>.
- Fit Club LLC. 2019. "Cairn: Hiking & Outdoor Trail." Google Play Store, Vers. 1.3.1 (2019) https://play.google.com/store/apps/details?id=com.cairnapp.cairn&hl=en_US&gl=US
- Fleming, J. 1998. *Web navigation: designing the user experience*. O'Reilly & Associates, Inc., USA.
- Fritz, E. 1931. The role of fire in the redwood region. *Journal of Forestry* 29:939–950
- Frontline. 2022. "The Mendocino Complex Fire - Causes, History & Statistics." <https://www.frontlinewildfire.com/wildfire-news-and-resources/mendocino-complex-fire/>.
- Gaia GPS: Hiking Trail Maps, Ski Touring, 4x4 Offroad App. 2021. "Gaia GPS: Hiking Trail Maps, Ski Touring, 4x4 Offroad App." Accessed November 10, 2022. <https://www.gaiagps.com/>.
- Get started - ArcGIS Web AppBuilder | ArcGIS Developers. n.d."Get Started." Accessed July 17, 2022. <https://developers.arcgis.com/web-appbuilder/guide/getstarted.htm>.
- Get Started – Yelp Fusion. n.d. "Get Started with the Yelp Fusion API." Accessed June 9, 2022. https://www.yelp.com/developers/documentation/v3/get_started.
- Great Redwood Trail. n.d. "Great Redwood Trail: The Great Redwood Trail Agency." Accessed January 25, 2023. <https://thegreatredwoodtrail.org/great-redwood-trail/>.
- Guilfoil, J. 2022. California Coastal Conservancy to manage the Great Redwood Trail project. *The Ukiah Daily Journal*.

- Haklay, M. 2010. *Interacting with Geospatial Technologies*; Wiley-Blackwell: Hoboken, NJ, USA; ISBN 978-0470998243.
- Hansen, W. J. 1972. User engineering principles for interactive systems, Proc. Fall Joint Computer Conference, 39, AFIPS Press, Montvale, NJ (1971),523-532
- Hiking Project. 2016. "Hiking Trail Maps." Accessed November 10, 2022. <https://www.hikingproject.com/>.
- Humboldt. n.d. "Visit Humboldt- California's Redwood Coast." Accessed September 15, 2022. <https://visithumboldt.com/>.
- Kraak, M.J., and Brown, A. 2001. *Web Cartography, developments and prospects*.
- Maizlish, N., English, P., Dervin, K., Chan, J., and English, D. 2021. "CDPH Climate Change and Health Profile Reports." CDPH Climate Change and Health Profile Reports, December 2, 2021. <https://www.cdph.ca.gov/Programs/OHE/Pages/ClimateHealthProfileReports.aspx>.
- Marin Magazine. n.d. "About Marin County." Accessed January 21, 2022. <https://marinmagazine.com/about-marin-county/>.
- Muehlenhaus, I. 2013. *Web Cartography: Map Design for Interactive and Mobile Devices*. United Kingdom: CRC Press, 2013.
- National Centers for Environmental Information. n.d. "Next Generation Weather Radar (NEXRAD)." Accessed May 2, 2022., <https://www.ncei.noaa.gov/products/radar/next-generation-weather-radar>.
- Neene, V., and Kabemba, M. 2017. "Development of a Mobile GIS Property Mapping Application Using Mobile Cloud Computing." *International Journal of Advanced Computer Science and Applications* 8, no. 10. <https://doi.org/10.14569/ijacsa.2017.081008>.
- Norman, D. A. 2013. *The Design of Everyday Things*. New York, NY: Basic Books
- Olson, D., and Sawyer, J. 2019. "Northern California Coastal Forests." WWF. World Wildlife Fund, 2019. <https://www.worldwildlife.org/ecoregions/na0519>.
- PeakVisor App. 2017. "Peakvisor App" Accessed November 10, 2022. PeakVisor App. <https://peakvisor.com/>.

- Permit Sonoma. n.d. "Sonoma County Historic Overview." Accessed September 15, 2022. <https://permitsonoma.org/divisions/planning/historicresources/sonomacountyhistory/sonomacountyhistoricoverview>.
- Recreation.gov. 2022. "Camping, Cabins, Rvs, Permits, Passes & More." Accessed November 10, 2022. Recreation.gov. <https://www.recreation.gov/>.
- Rosson, M.B., and Carroll, J.M. 2001. Usability Engineering: Scenario-Based Development of Human-Computer Interaction. Elsevier
- Roth, R. 2017. User Interface and User Experience (UI/UX) Design. Geographic Information Science & Technology Body of Knowledge. 2017. 10.22224/gistbok/2017.2.5.
- Teodoro, A.C., and L. Duarte. 2013. "Forest Fire Risk Maps: A GIS Open Source Application – a Case Study in Norwest of Portugal." International Journal of Geographical Information Science 27 (4): 699–720.
- Tourism Official Site | SonomaCounty.com. n.d. "Sonoma County Tourism Official Site." Accessed September 15, 2022. Sonoma County. <https://www.sonomacounty.com/>.
- Tsou, M.H. 2011. "Revisiting web cartography in the United States: The rise of user-centered design." Cartography and Geographic Information Science 38, no. 3: 250-257.
- U.S. Census Bureau Quickfacts: Humboldt County, California. n.d. "U.S. Census Bureau Quickfacts: Humboldt County, California." 2020-2022. Accessed November 3, 2022. <https://www.census.gov/quickfacts/humboldtcountycalifornia>.
- U.S. Census Bureau Quickfacts: Marin County, California. n.d "U.S. Census Bureau Quickfacts: Marin County, California." 2020-2022. Accessed November 3, 2022. <https://www.census.gov/quickfacts/marincountycalifornia>.
- U.S. Census Bureau Quickfacts: Mendocino County, California. n.d "U.S. Census Bureau Quickfacts: Mendocino County, California." 2020-2022. Accessed November 3, 2022. <https://www.census.gov/quickfacts/mendocinocountycalifornia>.
- U.S. Census Bureau Quickfacts: Sonoma County, California. n.d "U.S. Census Bureau Quickfacts: Sonoma County, California." 2020-2022. Accessed November 3, 2022. <https://www.census.gov/quickfacts/sonomacountycalifornia>.
- U.S. Census Bureau Quickfacts: Trinity County, California. n.d "U.S. Census Bureau Quickfacts: Trinity County, California." 2020-2022. Accessed November 3, 2022. <https://www.census.gov/quickfacts/trinitycountycalifornia>.

- “Using Web AppBuilder’s Dashboard Theme - ESRI.” n.d. Accessed July 31, 2022.
<https://downloads.esri.com/learnarcgis/educators/app-builder-dashboard.pdf>.
- Visit Mendocino County – Room to Roam. n.d. “Visit Mendocino County.” Accessed September 15, 2022. <https://www.visitmendocino.com/>
- Wang et Al. 2011. “The Role of Smartphones in Mediating the Touristic Experience.” Accessed July 15, 2022. <https://journals.sagepub.com/doi/10.1177/0047287511426341>.
- Welcome to the Visit California Homepage. n.d. “Trinity County.” Accessed October 20, 2022. <https://www.visitcalifornia.com/experience/trinity-county/>.
- Wiley, B. 2018. "Tracking Santa Barbara County Wildfires: A Web Mapping Application." Order No. 11016999, University of Southern California.
<http://libproxy.usc.edu/login?url=https://www-proquest-com.libproxy1.usc.edu/dissertations-theses/tracking-santa-barbara-county-wildfires-web/docview/2179993356/se-2?accountid=14749>.
- Yelp Developers. n.d. “Yelp Data Quality Guidelines.” Accessed July 29, 2022.
<https://docs.developer.yelp.com/docs/yelp-data-quality-guidelines>.
- YouTube- Extending the Web AppBuilder for Arcgis. 2018. “Extending the Web AppBuilder for Arcgis.” January 23, 2018. YouTube
<https://www.youtube.com/watch?t=12m52s&v=CgLFkDogAN0&feature=youtu.be>.

Appendix A Existing Hiking Apps

Appendix A below shows a table that was presented to the GRTA to show initial research on existing hiking applications. The key features, likes, and dislikes of each hiking app was added to the table.

App Name	Key Features	Website	Likes	Dislikes
AllTrails	<ul style="list-style-type: none"> -Browse 300,000+ trails with hand-curated trail maps -Access 8 different map types -Export files from trails, activities, and maps on AllTrails.com -Import files to your AllTrails activities and maps lists -Read and leave reviews -Create custom lists and favorites lists of trails -Create custom maps on AllTrails.com -Use Navigator to keep track of your adventures and log your activities -Use map details to get more information on trails -Be an active member in the AllTrails community 	https://www.alltrails.com/	<ul style="list-style-type: none"> -search bar -different filters/categories -description of trail types/level 	<ul style="list-style-type: none"> -busy home page -no easy to use/access widgets
Gaia GPS	<ul style="list-style-type: none"> -Navigate offline even without cell service. -Print Custom Maps. -Always have a backup map. -Access All Maps. -The best maps for any adventure. -Layer Maps Together. -Discover even more terrain details. 	https://www.gaiagsps.com/	<ul style="list-style-type: none"> -3D maps -Peaks are all clearly pointed out -Import photos -Elevation and cardinality shown -Zoomed in insert of current location 	<ul style="list-style-type: none"> -Two maps on one screen might be confusing -App specifically for mountain peaks -Base map hard to replicate
Peak Visor	<ul style="list-style-type: none"> -The cutting-edge technology with high-precision terrain 	https://peakvisor.com/panora	<ul style="list-style-type: none"> -3D maps 	<ul style="list-style-type: none"> -Two maps on one screen

	<p>modeling allows simple yet effective insight into the landscape of the mountains.</p> <ul style="list-style-type: none"> -It is the most convenient way to explore a mountainous area, its trails, summits, passes, viewpoints, and even parking areas. 	ma.html?lat=45.9420159&lng=7.8699421&alt=4598	<ul style="list-style-type: none"> -Peaks are all clearly pointed out -Import photos -Elevation and cardinality shown -Zoomed in insert of current location 	<ul style="list-style-type: none"> might be confusing -App specifically for mountain peaks -Base map hard to replicate
Hiking Project	<ul style="list-style-type: none"> -Hiking Project provides detailed information on trails near you, including GPS route info, elevation profiles, interactive features and more. -It is a core gathering place for the hiking community. 	https://www.hikingproject.com/	<ul style="list-style-type: none"> -Uses MapBox basemap -Widget bar with hiking categories -Clear/visible search bar -Trail directory: States then subregions -Crowdsourced map data 	<ul style="list-style-type: none"> -When you use search bar no map but search list -List not map is the first thing shown
Recreation.gov	<ul style="list-style-type: none"> -book a weekend getaway -plan a cross-country road trip -helps you find and reserve campsites -review location details for your trip -quickly access information on past and upcoming reservations. 	https://www.recreation.gov/	<ul style="list-style-type: none"> -MapBox base map -Map alongside lists are populated -Search bar for locating trails -More features not about trails 	<ul style="list-style-type: none"> -Must scroll to find trail map locator -Too many other activities included
Far Out	<ul style="list-style-type: none"> -detailed trail information like: -distance -elevation -waypoints -water sources -campsites, -all viewable on topographic or satellite maps 		<ul style="list-style-type: none"> -app actively tracks your location on the map, making sure you're always on trail. -All of this works offline without cell reception. 	<ul style="list-style-type: none"> -each trail is purchased individually
Cairn	<ul style="list-style-type: none"> -Record your hikes, climbs, and outdoor runs, and then analyze your trips' stats -Share your progress and location for safety -See where others have found cell coverage on the trail 	https://www.cairnme.com/	<ul style="list-style-type: none"> -Extensive offline capabilities -Send time specific messages -Allow others to track you 	<ul style="list-style-type: none"> -Focuses more on safety than searching for trails -Offline abilities are

	-Focused on safety			primary features -Might be too difficult to replicate
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Appendix B Attributes of GRT datasets defined

Bays

- Id- identification
- fnode- FNODE# is the internal number of the from-node.
- Tnode- TNODE# is the internal number of the to-node.
- Lpoly- LPOLY# is the left polygon number (cover# in polygon attribute table).
- Rpoly- RPOLY# is the right polygon number (cover# in polygon attribute table).
- Length- length
- County- county
- county id- unique county identification
- **lucode**
- state- state
- bay name- name of bay

Bioregions

- id- identification
- area- area of bioregion
- perimeter- perimeter of bioregion
- **inaccreg**
- **inaccreg_i**
- **inacnum**
- **inacname**

Boundaries

- id- identification
- objectid- identification of object
- county_nam- county name
- county_abb- abbreviated county name
- county_num- number for identifying county
- county_cod- code for identifying county
- county_fip- county fip code, Federal Information Processing Standards (FIPS), now known as Federal Information Processing Series, are numeric codes assigned by the National Institute of Standards and Technology (NIST)
- island- island
- shape_are- area of the shape
- shape_length- length of the shape
- globalid- global identifier

Cities

- id- identification
- **uace10**
- name10- name of city
- **uatyp10**

- intptlat10- latitude
- intptlon10- longitude

GRT Points

- FID
- Shape- shape
- Gns_id- Geographic Names Server identifier
- Feat_name- name of feature
- Feat_type- type of feature
- Latdd- latitude
- Londd- longitude
- Cell name- name of the cell or point
- Elevat_ft- elevation in ft
- Variant- variant
- Sequence- sequence

Major rivers and creeks

- Id – identification
- Permanent- permanent
- Fdate
- Resolution- resolution
- Gnis id- Geographic Names Server identifier
- Gnis name- Geographic Names Server name
- Length km- length of river in km
- reachCode
- FlowDir- direction of river flow
- WBArea_Per
- FType
- FCode

Major rivers grt

- Id- identification
- Permanent- permanent
- Fdate
- Resolution- resolution
- GNIS_ID- Geographic Names Server identifier
- GNIS_Name- Geographic Names Server name
- LengthKM- length or river in km
- ReachCode
- FlowDir- direction of river
- WBArea_Per
- FType
- FCode
- MainPath
- InNetwork
- Visibility

- Enabled
- Shape_Length- length of river

Rail Mile Posts GRT

- FID
- Shape- shape
- Row_owner
- Subdivision
- Mp
- Station- rail station
- Crt_miles
- Tc
- Dist- district of station
- Co- county of station

SubBasins GRT

- ID- identification
- Tnmid
- Metasource- metadata source
- Sourcedata- source of data
- Sourceorig- origin source
- Sourcefeat- feature source
- Loaddate- date of data being uploaded
- Gnis_id- Geographic Names Server identifier
- Areaacres- are in acres
- Areasqkm- area in sqkm
- States- states
- Huc8
- Name- name of subbasins
- Shape_star
- Shape_stle

SubWatershed GRT

- Id- identification
- Tnmid
- Metasource- metadata source
- Sourcedata- source of data
- Sourceorig- origin source
- Sourcefeat- feature source
- Loaddate- date of data being uploaded
- Gnis_id- Geographic Names Server identifier
- Areaacres- area in acres
- Areasqkm- area in sqkm
- States- states
- Huc12