

Geo-Enabling Mountain Bike Trail Maintenance:

Enhanced Stewardship of the Fountainhead Mountain Bike Trail through GIS Technology

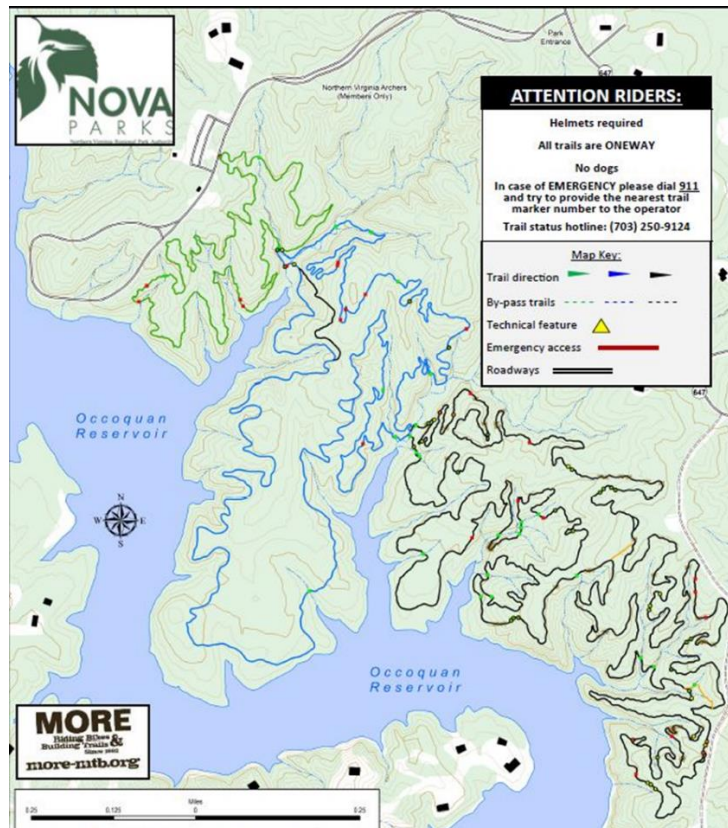
Introduction

Fountainhead Mountain Bike Trail

The Fountainhead Mountain Bike Trail is a single track mountain bike trail located in Fountainhead Regional Park. The popular trail is open year-around and endures heavy usage. Maintenance on the trail is essential to keep it safe and fun for riders while also protecting the environment. With fifteen miles of trail, maintenance is an arduous and time consuming task for volunteer trail crews.

The purpose of this project is to improve the trail maintenance process using GIS technology. The original trail maintenance process consisted of trail liaisons recording their observations for trail maintenance using pencil and paper maps with notes scribbled in the marginalia. The maps were used on multiple rides to transcribe relative locations, descriptions about observations, proposed solutions, and lists of tools. Trail liaisons would compare notes and try to develop a plan for making trail repairs; however, with inexact and piecemeal information, planning for trail work days was challenging. Additionally, the note taking strategy did not include a record keeping component so there were no data to evaluate the effectiveness of the trail maintenance. The Fountainhead Mountain Bike Trail Maintenance GIS was designed to alleviate these challenges to the data collection process and provide tools for planning and assessing trail repairs.

Figure 1. Fountainhead Mountain Bike Trail, October 2015

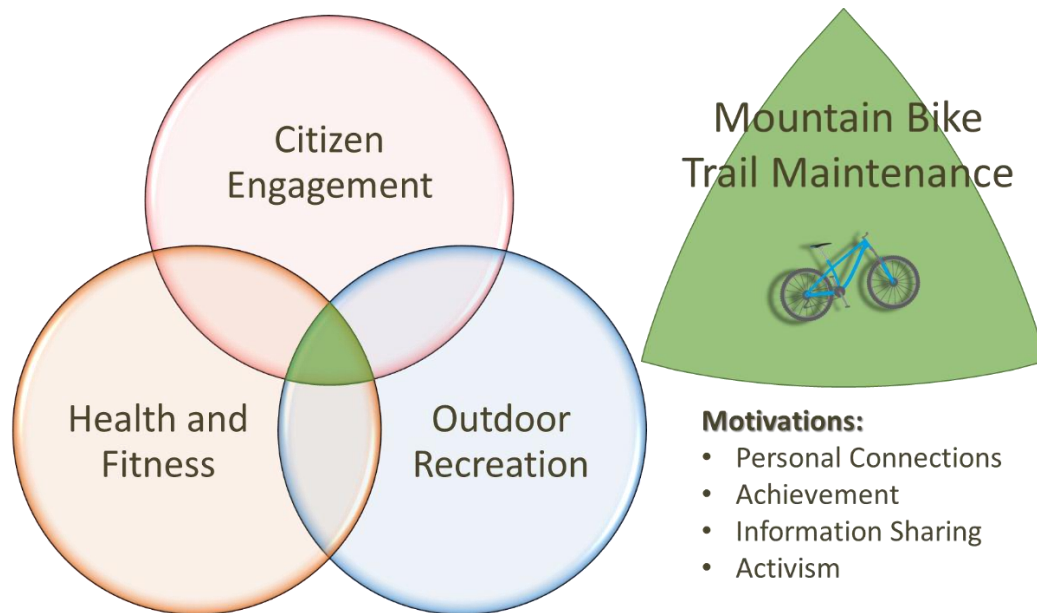


Application Design Overview

The Fountainhead Trail Maintenance GIS solution consists of a mobile application for field data collection of observations that require maintenance and a web application for data analysis and record keeping. The objective of the solution is to improve the efficiency of data collection; make it easier to share information; provide a mechanism for planning and tracking changes to the trail; as well as improve the trail crews' ability to implement trail maintenance during a work day.

Research for the design of the GIS solution revealed three trends in applications that incorporated volunteered geographic information (VGI) in the outdoors. The category of applications that most commonly used VGI were applications for health and fitness (Kessler, 2011; Navarro, et al., 2013; Parker et al. 2013). Also popular were applications that supported discovery in the outdoors for tourism or natural observations (Goodchild, 2007; Kashian et al. 2014, Parker et al. 2013). Lastly, there were applications that were designed to engage citizens where they live or for monitoring and reporting on the environment or in disaster situations (Song and Sun, 2010; Connors, Lei, & Kelly, 2012; Haworth and Bruce, 2015; Paudyal et al., 2012). Although there were no examples of applications for trail maintenance, the design of this GIS solution combines the motivations for recreation and activism that define applications that use VGI in the outdoors.

Figure 2. Mountain Bike Trail Maintenance in the Venn diagram of VGI Applications



One of the most important decisions in designing the GIS was what technology to use. The foremost requirement for the technology was tool integration. In order to realize the GIS design and accommodate the essential features, the technology needed to support tool integration with a web and mobile application as well as data storage and management. The project was constrained by the time and cost to implement the complete GIS with considerations towards developing a sustainable solution and accommodating future development. The following table outlines the technology tested for the GIS. The rows highlighted in green represent the technology that was used in the final solution.

Table 1: GIS Technology

Technology Name	Function	Description
QGIS Desktop 2.8.2	Data collection	QGIS was used as an alternative to ArcMap for georeferencing the paper map from Knobby Tires, LLC and comparing it with data from Open Street map and a GPS track collected with a Garmin GPSMap 60CSx.
ArcMap 10.3.1	Data collection Publishing baseline data	ArcMap was used to organize the data into a file geodatabase and then publish it as a service. Once the data had been published, it was available for consumption by web and mobile applications.
Web AppBuilder	Web application development	Web AppBuilder supported the web application development with templates for the layout of the web application and widgets to provide editing and analytical functionality.
Collector for ArcGIS	Mobile application framework	Collector is a mobile application designed by Esri to enable field data collection. The application provides a framework for hosting a published web map. The web map provides geographic context while the Collector application facilitates data collection.
ArcGIS Online (AGOL)	Cloud platform	AGOL is a cloud platform for hosting data, publishing applications, and conducting analysis.
ArcServer and Portal	Server Internet gateway	ArcServer provides data storage and management capabilities. Portal makes the data accessible on a network or over the internet. ArcServer and Portal were setup on AWS.
Amazon Web Services (AWS) Elastic Compute Cloud (EC2)	Cloud platform with web service for hosting virtual servers	AWS provides a cloud platform web services for information technology infrastructure. The EC2 service provides a compute and hosting service for ArcServer.

Methodology

Database Design

The databases were designed specifically for trail maintenance. They include information for planning and assessing how environmentally sustainable the trail is. The design of the databases were based on conversations with the trail liaisons who are subject matter experts on trail design and maintenance. Other components of the design were generated from considerations about how the data would be used. Since data analysis factored heavily into the planning process for trail work days, database values were constrained using domains and coded values with only one free text field available.

Since field data collection was a major component of the trail maintenance process, the database design needed to ensure that enough information was collected in the field so that riders did not have to go back out to the trail. This requirement was balanced with the need to collect data efficiently. To make the data collection process efficient, the fields were design with drop-down menus based on the coded values.

The database design was also based on principles that would be the data easier to analyze during the planning process. This included restricted values and categories and time and location information. In addition to the free text notes field for ancillary information, there is an option to attach a photo. The picture field was a requirement from MORE (Tom Crotty & Paul Hardy, MORE Trail Liaisons, project communications). The picture added significant information for the planning process as it helped to verify the requirement for maintenance, prioritizing the repair, and other information that was not immediately captured in the fields of the database.

The Mid-Atlantic Off-Road Enthusiasts (MORE) worked with the Northern Virginia Regional Park Authority (NVRPA) to map the trails. They contracted with the Knobby Tires Mapping, LLC to collect the trail and trail features, such as bridges, technical features, and rock gardens. The original plan for collecting the baseline data for the map was to use the data that had been collected by Knobby Tires Mapping; however, the NVRPA was unable to locate the data. As a result, the initial collection of data was digitized from the published map produced and distributed by Knobby Tires Mapping. The map was georeferenced and features were digitized by hand as shapefiles using QGIS Desktop 2.8.2. Two other sources were considered for the baseline data, Open Street Map (OSM) and data collected with a personal GPS. Although the Fountainhead Mountain Bike trail had been collected in OSM, the trail was incomplete and did not show the newest additions. The GPS track was fairly accurate but it was not as clean as the digitized data. After the trail and trail features were collected, they were imported into a single file geodatabase (FGDB). A FGDB was chosen so that all of the data would be together when it was uploaded to ArcGIS Online (AGOL). The FGDB was designed in ArcGIS for Desktop 10.3.1.

To support mapping functionality in the web and mobile applications, the data was entered into two databases. The first database captured all of the baseline data in two features classes. The database design also considered the likelihood and frequency of features changing. The trail was collected as one feature dataset and the trail features were collected as another feature dataset in the baseline database. Another database was setup to capture the observations from riders on the trail. Data for the observations' database was added using the Collector mobile application during the field data collection process.

A separate database for the observations allowed for testing and modifying the data schema without affecting the baseline data. Initially, the observations feature class included a field for report status. This field was designed to assure the quality of VGI data by providing a check by the trail liaisons; however, the crowd-sourced strategy for data collection was eliminated based on the physical constraints of the trail. As a result the field was removed in the second design process. Also the descriptions for repair status were refined to include only four possibilities:

- Investigate - feature requires additional investigation before planning maintenance;
- In-work – feature is currently undergoing maintenance for multiple field work days;
- Maintained – feature has been repaired;
- Watch – feature may be susceptible to damage, so continue to monitor its status.

The final observations database included fields for the date, category of the repair, status of the repair, notes, location, and a photo. This is the essential information for planning trail maintenance.

Table 2: Final Database Designs

Feature	FGDB	Feature Class	Geometry	Attribution
Bike Trail	FH_Track_Features	Track	Line	Loop: green, blue, black Section Name Difficulty Ranking: easier, intermediate, hard
Trail Features	FH_Track_Features	Features	Point	Type: bridge, mileage sign, technical feature, rock garden, entrance, exit ID: alpha-numeric code Mileage (only for mileage sign)
Maintenance Observations	FH_Observations	Observations	Point	Date Category: drainage, erosion, feature repair, fallen tree Repair Status: investigate, in-work, maintained, watch Notes: 250 characters Photo Attachment

Mobile Application Design

The objective of the mobile application is to provide a means to record observations on the trail. The mobile application makes use of Esri's Collector for ArcGIS. The Collector application provides a framework designed for field data collection and consumes the web map object published on AGOL which uses the data from the Track Features and Observations databases. The Collector framework provides the ability for mobile data collection, including taking photos, uploading data, visualizing the map, among other capabilities and uses the built-in functionality of a smart phone for data collection (Esri). Since there is cellular data available along the Fountainhead trail, the field data is sent back to the database, making it immediately available for visualization and analysis in the mobile and web applications; however, offline caching and later uploading is also possible.

Figure 3. Collector for the Fountainhead Trail



Created with Balsamiq - www.balsamiq.com

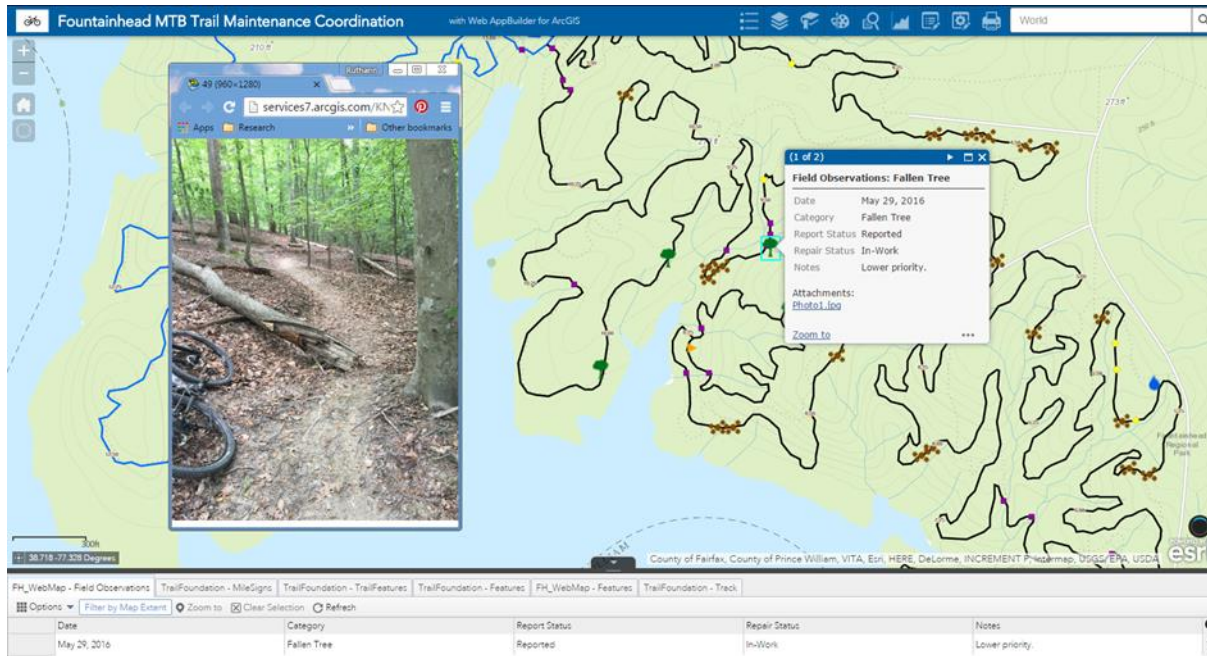
Web Application Design

The web application was designed to support data visualization and analysis for planning for trail work days and for evaluating the effectiveness of the maintenance. Once data has been collected in the field, it is upload to the observations database that is visible to the web application as well as the mobile application.

The web application was designed using the online version of Esri's Web AppBuilder. Web AppBuilder is a wizard-driven application for building web applications (Esri). Web AppBuilder provides templates that control the appearance of the application. Functionality, such as querying or filtering data, is provided through a library of customizable widgets. Data for the web application is provided by a web map that has been published in AGOL.

The approach to designing the web application started with talking to the trail liaisons about what tasks and operations were carried out in trail maintenance. That list was converted to a list of data analysis functions that would support those operations (Tom Crotty & Paul Hardy, MORE Trail Liaisons, project communications). For example, trail liaisons remove fallen trees from the trail in order to keep it clear for riding. This task required that the trail liaisons were able to identify fallen trees and their locations in the data. The functions in the web application that allowed them to do this included sorting the data by type; filtering the data spatially; and querying the data by type.

Figure 4. The Fountainhead MTB Trail Maintenance Coordination Web Application



Solution Testing

The project included two main branches of testing, technology and fit-for-use. Since there were numerous technology options, one part of the project dealt with which technology to use. This assessment was based on ease of use; cost; expectations for maintenance and future development; and tool integration. The other branch of testing was concerned with fit-for-use in the design of the GIS. The principal test for the design of the GIS solution was the satisfaction of the customer. The design and assessment of the application were evaluated by the trail liaisons who support the Fountainhead Mountain Bike trail. They provided feedback throughout the project about the usefulness of the solution, the capabilities, and the implementation.

Technology Testing

Technology testing for the GIS was completed in three parts that reflected the use of different technology options to serve data into the mobile and web applications. The first possibility for the setup of the GIS used AGOL for publishing and serving the web map into the mobile and web applications. The second option was a hybrid approach in which the data was managed in ArcServer and published on AGOL. In the last option, the web map was served by ArcServer and published by Portal, which were hosted on an Elastic Cloud Compute (EC2) instance on Amazon Web Services (AWS). Although these differences are not visible to the end user, the underlining design of the platform is changed with each option. These changes represent different levels of ownership for the platform and the ability to interact with the data. All of these changes affect the cost of the model and the level of expertise required to develop and maintain the GIS. The options were evaluated using the criteria outlined in Table 3.

Table 3: Evaluation Criteria for the Technology

Testing	Criterion	Explanation
Technology	Tool Integration	Integrated database, web application, mobile application to support field data collection for planning and analysis
	Access to Tools	Availability of a solution for database design, web and mobile application development that persists beyond the school project
	Maintenance of GIS	The level of expertise and intensity of development to maintain the solution
	Future Development	Accommodation for modifications and enhancements beyond the original solution
	Scalability	The ability for the solution to be made available on more trails
	Cost	The expense to create and maintain the GIS
	Time to Develop	The period of time to develop the initial solution and the expectation for maintenance

Option 1: ArcGIS Online

ArcGIS Online (AGOL) is Esri’s cloud environment for data storage, visualization, analytics, and development. Through this platform Esri provides an easy to use, collaborative environment for storing, publishing, and serving data. Since AGOL is Esri’s cloud platform, Esri manages the system maintenance, updates, and security. The hosted cloud environment significantly reduces the burden of maintenance and security for the user and allows the user to focus on designing and building the GIS solution. Additionally, the integrated tools allow for the user to design and then build the complete GIS solution.

The drawbacks to the AGOL solution regard cost and data management. The cost for using AGOL tools is significant. The user pays for the convenience, ease of use, and well-designed tools. Despite the high price point, Esri does provide discount programs to make the tools accessible to various user groups such as education and not-for-profit organizations. With the AGOL platform, the user’s primary responsibility is for the data. The only data management tool available on the platform is filtering by values. As a result the user must incorporate this requirement into the database design and consider a data management strategy to support editing and versioning of the database.

Table 4: AGOL Evaluation

Criterion	Rating
Tool Integration	Using ArcMap, FGDBs, Web AppBuilder, Collector, and AGOL fit the design pattern constructed by Esri. The tools were integrated through the AGOL platform.
Access to Tools	Esri provided Web AppBuilder and Collector which integrated with AGOL to consume data supplied to a web map. Tools incorporated an intuitive user interface and were well-documented with a large user community.
Maintenance of GIS	Esri maintains and supports the platform. Many aspects are in continuous development with the periodic release of stable versions. This means that the AGOL user only needs to maintain the data.
Future Development	Esri releases stable and beta versions of the tools and supports user contributions and forums for using and developing on the platform. The platform does not support developing custom geoprocessing services.
Scalability	AGOL is a scalable cloud platform that will accommodate additional data storage. The tools are stable and in active development at Esri and in the user community.
Cost	Esri supports multiple programs to provide a more accessible pricing solution, such as the non-profit program.
Time to Develop	Since the web and mobile applications were integrated with AGOL, the platform supported a quick and agile development strategy.

Option 2: Hybrid Solution

The hybrid solution attempted to take advantage of the hosted cloud platform of AGOL and the integrated tools while also incorporating the data management capabilities of ArcServer on an EC2 instance. In the hybrid solution, data was stored and managed by ArcServer. This allowed for data versioning and editing with multiple editors. AGOL served as a gateway to the web and mobile applications to support field data collection and analysis. To make this solution work, data from the field was downloaded periodically and moved to ArcServer for data management. Once the data had been edited, it was moved back to AGOL and added to the web map, which the web and mobile applications consumed.

The strength of the hybrid solution design was that it incorporated the data management capabilities of ArcServer as well as the system maintenance, security, and tool integration offered by AGOL. The biggest challenges; however, was in moving the data back and forth between the two platforms. This required focused attention, scheduling, and record keeping to ensure that the data was up-to-date on both platforms. Additionally, the AWS platform still required system and security maintenance. This solution is not a supported design pattern from Esri so there is limited documentation and assistance from the user community. Lastly, the cost for ArcServer is not trivial. It is a tool that is not included in many of Esri's discount programs so it has limited accessibility. Although the data management capabilities offered by ArcServer showed potential, the complicated and multi-step process for publishing data made this a difficult solution to maintain for non-experts.

Table 5: Hybrid Evaluation

Criterion	Rating
Tool Integration	Utilized the integrated tools and format of AGOL with a multi-step process to publish data to the web map and for data management in ArcServer. The data management process relied entirely on user maintenance.
Access to Tools	ArcServer is a more complicated tool to use. Using ArcServer with AGOL in this pattern is not supported by Esri which made it difficult to integrate the tools.
Maintenance of GIS	Although all of the maintenance and security for AGOL was managed by Esri, the user must maintain the EC2 instance and storage options as well as the ArcServer software.
Future Development	ArcServer requires software updates. The configuration of the design is not user-friendly.
Scalability	The solution will scale to incorporate additional trails. In AGOL and the AWS environment will scale to support more trails and users.
Cost	The cost for this solution includes the use of two environments and software maintenance.
Time to Develop	Since this is not a typical design pattern, more time was invested in setting up AWS and ArcServer. Additionally, since the web and mobile tools are available through AGOL, a strategy was required to support sharing data between the platforms and keeping the data current.

Option 3: ArcServer and Portal

The third technology design was driven by the opportunity to own the entire platform. With ArcServer and Portal hosted on an EC2 instance, the user is able to implement a complete data management solution. It is also possible to design and publish geoprocessing services to support future development for tools. These capabilities, however, did not outweigh the challenges for this solution design. Without AGOL, the user no longer has access to the integrated tools and fully supported environment. Now the user must consider how to maintain the platform and keep it secure rather than working on the solution design, data collection, or analysis. Additionally, there more challenges in getting Web AppBuilder and Collector to work with the data. Since many of these tools are not fully mature, they did not accommodate the solution design and the documentation for developing the design is limited. As a result a majority of the time was spent on system maintenance, security, and development. The development process was so time consuming that it made communicating with the stakeholders challenging because of the delays between conversations and prototypes. This solution posed more challenges than potential gains so it was eliminated after researching and testing the option.

Table 6: ArcServer and Portal Evaluation

Criterion	Rating
Tool Integration	Required additional licenses for desktop versions of Web AppBuilder and AppStudio. Since this is not a documented design pattern, it was challenging to figure out how to make the tools work together. In some cases, the tools did not support the functionality.
Access to Tools	It is difficult to obtain licenses for ArcServer and Portal. It was challenging to understand how to make them work with Web AppBuilder and Collector.
Maintenance of GIS	This solution required that the platform and software be maintained and secured. Although there is no requirement to maintain hardware with AWS, there are still billing charges, new tools, and design components to consider.
Future Development	This solution was discarded in the research phase before fully transitioning from the hybrid solution because of the challenges to development.
Scalability	The platform should support scaling because ArcServer and Portal are designed as enterprise tools.
Cost	The cost for this solution is higher than the others because the user is fully supporting the server platform on AWS and the GIS software.
Time to Develop	This solution was discarded in the research phase before fully transitioning from the hybrid solution because of the challenges to development. Researching for this solution suggested that it would take a considerable amount of time and custom development to put together the complete GIS solution.

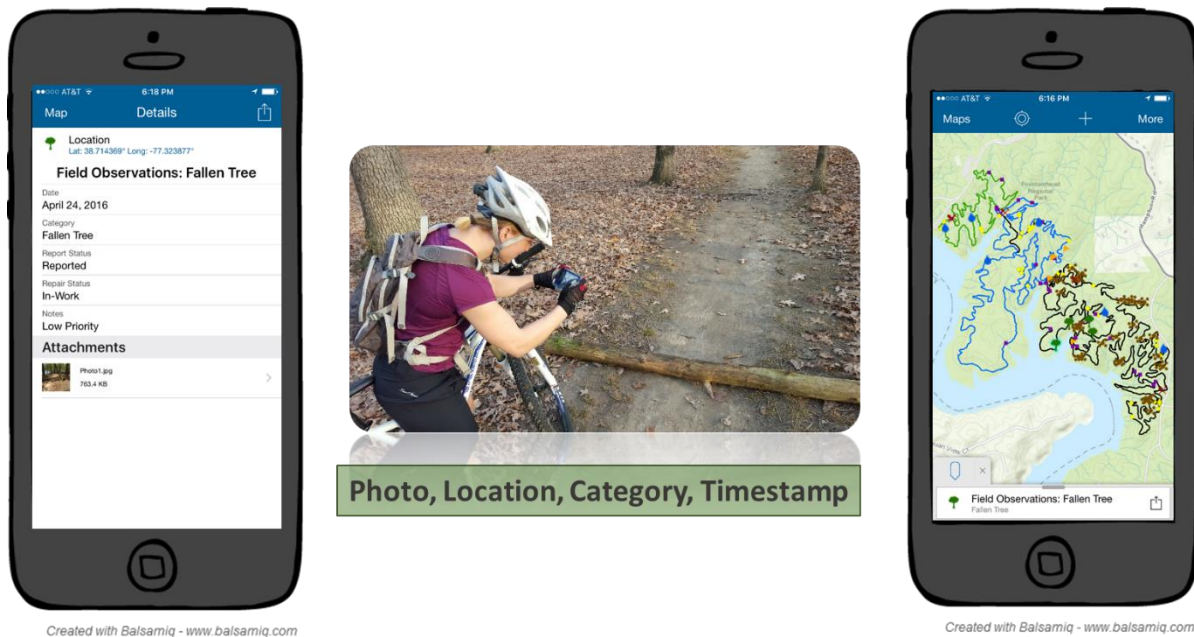
Fit-for-Use Testing

Fit-for-use testing was completed in multiple stages that reflected the major activities in the trail maintenance process, namely field data collection, planning and analysis, trail work, and trail assessment and evaluation.

Trail Monitoring

Field data collection consists of a rider marking observations during a trail ride. The rider opens the Collector application to the trail map and selects a button to add a trail report. The trail report is a menu with prepopulated drop-down menus. The most common values have been set as defaults. The report consists of the category of the observation, repair status, date, and notes. The user also has the option to add a photo to the report. The position of the report is geolocated to the location of the rider. After the report has been completed, a symbol representing the category is displayed on the map.

Figure 5. Field Data Collection with the Collector App



The foremost consideration in the design of the field report was the safe and fast submission of high quality data. The data entry values and data types were constrained by the coded values in the database. This method supported the drop-down menus which ensured accurate and fast data collection. Additionally, only the data that had to be captured in the field was required for submitting a report. For example, the user may add notes from the photo while reviewing the field observations in the web application from the comfort of home rather than entering that information on the trail.

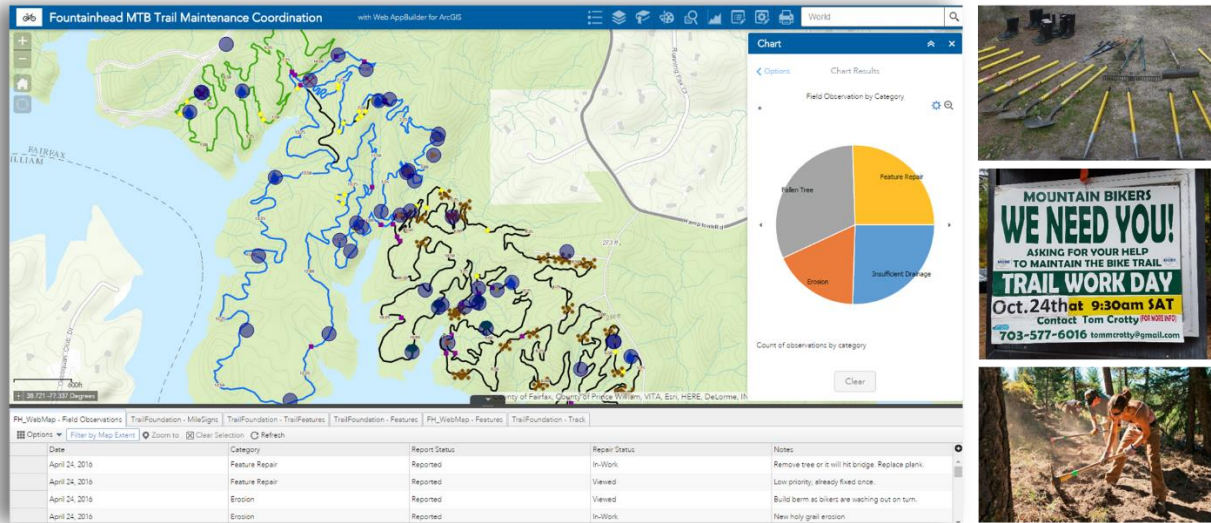
Originally, the GIS design proposed crowd-sourcing the field data collection process. After using the first prototype of the mobile application, it became readily apparent that the Fountainhead Trail did not support crowd-sourcing for safety and logistical reasons. As a result, the data collection process was limited to the trail liaisons and a select set of volunteers. Although restricting the population of data collectors did limit the data collection opportunities, it did not significantly decrease the efficacy or efficiency of the data collection process because only one report is necessary to record an observation and the observation report is designed to maximize the efficiency of the data collection process. In fact, there were benefits to this modification in that there were no duplicate reports, which would have resulted in a high data volume and significant data processing, as well as an assurance of high quality data, reducing the need a robust quality control process. The database fields and values were modified after the first stage of testing based on comments from the trail liaisons.

Planning for Trail Maintenance

A few weeks prior to a trail work day, the trail liaisons got together and looked at the data that had been collected on the trial. With the GIS, they used the web application to view the data and plan for the trail maintenance. Trail liaisons looked for what type of observations have been collected in order to figure out what tools to bring for the trial work. They also looked at how the observations were distributed in order to decide how to divide up the work.

The web application included widgets that supported querying and filtering the data by attribution and location. These tools helped the trail liaisons identify what types of observations were collected and where. Once the trail liaisons had allocated work to the different trail crews, they printed maps that showed the work. On some occasions, the trail liaisons added annotations electronically or by hand. These annotations helped to explain the work to the trail crew or denote changes based on the participants and materials on the work day.

Figure 6. Fountainhead MTB Trail Maintenance Coordination Web Application Supporting the Planning for a Trail Work Day



The tools supported the querying and planning work for the trail liaisons. The web application offered a visualization with active query that was not available to the trail liaisons prior to the development of this GIS. The most common critiques from the trail liaisons referred to the refinement of the querying tools and the editing capabilities (Tom Crotty & Paul Hardy, MORE Trail Liaisons, project communications). In the web application, there were multiple ways to filter the data, including creating a custom filter based on the database fields, sorting and restricting values in the attribute table, or creating an interactive spatial query. Most of the queries could be combined in multiple steps; however, it was not possible to save a query. In order to support the planning process, the trail liaisons wanted to design and save queries that persisted during and between planning sessions. The web application did support some saved queries but it did not support the interactive method of analysis employed by the trail liaisons in the planning process. Over time, the trail liaisons will become more accustomed to the tools and understand how they work. Additionally the tools will improve as Esri and the user community build new widgets to support the web applications.

Editing is a cumbersome task in the web application. The widgets that supported editing were not as well developed as the other tools. Editing required multiple steps to select and set an editing tool and then the interactions with the map were clumsy. For more complex editing, ArcMap is an alternative solution. For these operations, ArcMap connects to the web map published in AGOL. Data is able to be edited in ArcMap and saved in AGOL. Using ArcMap is not a suitable approach for non-expert users

because of its complexity; however, since data editing is primarily through the addition of new reports the web tools are sufficient.

Trail Work

Prior to the development of the Fountainhead Trail Maintenance GIS, the process for completing trail work consisted of gathering a number of volunteers for a trail day. The trail liaisons and volunteers would hike down the trail with all of the tools that they could carry. The trail liaisons would point out locations for trail maintenance and a small group of volunteers would remain in that location to complete the work. The trail liaisons only divided the volunteers into a couple of groups and tried to keep them all in eye contact so that no one would get lost or injured.

With the development of the trail maintenance GIS, the trail liaisons provided groups of volunteers with maps denoting the planned trail maintenance. Each group was led by a trail liaison or a select volunteer who had access to the Collector application. The Collector application provided enhanced navigation through the woods by geolocating the position of the phone and displaying it on the map. With Collector, groups were able to navigate off-trail between trail maintenance locations. During the planning process, the trail liaisons selected trail repairs that required similar tools, expertise, and were located in areas that were easily accessed.

As a result of the new planning tools and techniques, it is possible to complete more trail maintenance in a shorter period of time and with fewer volunteers. The planning that the trail liaison completed prior to the trail work day, allows for volunteers to carry only the tools that they need for the specific repairs so smaller, faster moving groups can make the repairs. The biggest advantage is the ability to navigate between observations rather than walking the entire trail, which significantly reduced the time required to access and then complete a repair.

Evaluating Trail Maintenance

This stage of testing is not complete because there were not enough data to support the analyses. The plan is to use the one-year trail period granted by MORE to analyze the type, cost, and amount of trail maintenance conducted. Since records about trail maintenance from previous years were not kept, making a quantitative comparison about the efficacy of the solution will be challenging; however, there is substantial qualitative evidence from the trail liaisons who have been in charge of the trail for more than ten years. The evidence will focus on descriptions about the level of effort for to monitor and conducting maintenance. The goal of this analysis on the Fountainhead Trail is to support decisions that will improve trail sustainability.

Discussion of the Results

Successes and Challenges

A quick and agile development process was one of the biggest advantages to choosing Esri's tools. Being able to rapidly create prototypes for testing by the trail liaisons and the ability to readily implement their recommendations made it much easier to communicate with the trail liaisons, who were not familiar with the concepts of GIS, application development, or data management. The ability to put a tangible, usable tool into their hands for testing was invaluable. For the trail liaisons, using the GIS in the field revealed the potential and possibilities of trail maintenance when supported by GIS. As a result, they quickly became advocates for its use and continued development. At times, this relationship

was challenging to manage because of the time commitment; however, it was motivating to see reactions of the trail liaisons and their growing awareness of the capabilities of GIS.

Technology

Esri's technology has an extensive and responsive user community. Initially it was challenging to search through the potential technology options for the ideal components to support a trail maintenance GIS. With numerous desktop, server, web, and mobile options, Esri has a wide variety of tools and programs for funding. After designing and implementing three technology options to support the GIS and evaluating them, the first option using ArcGIS Online was the optimal solution for the Fountainhead Mountain Bike Trail GIS. The primary reasons for choosing ArcGIS Online were the integrated tools that provide technical components for monitoring the trail as well as planning and evaluating the trail maintenance. Additionally this solution supports continued development of the GIS at an accessible price point.

The Fountainhead Mountain Bike Trail is a functioning GIS. As a result of the addition of technical tools to the trail maintenance process, the trail liaisons have changed the manner in which they approach trail maintenance from the data collection to the data analysis process. The GIS has fundamentally altered the way in which they understand trail maintenance and consider the scope of what can be accomplished. So far, the GIS has been used to support five trail maintenance days over the spring, summer, and fall. In August of 2016, MORE approved funding for three ArcMap licenses through Esri's Non-Profit program. These licenses include access to the ArcGIS Online platform as an organization.

Fit-for-Use

With the use of the Fountainhead Mountain Bike Trail GIS, the trail liaisons saw a significant reduction in the level of effort and time investment required to maintain the trail (Tom Crotty & Paul Hardy, MORE Trail Liaisons, project communications). The GIS increased their ability to assess trail maintenance through the accurate and timely collection of data which included precise locations and photos for reference. The GIS improved trail maintenance by providing tools for planning and visualization which supported targeted trail maintenance efforts, improving the efficiency of the trail maintenance process and the use of volunteers and equipment. The GIS substantially modified the strategy for conducting trail maintenance of the Fountainhead Mountain Bike Trail.

An unanticipated benefit of the mobile application was the ability to navigate off-trail through the woods to reach the locations for trail work. The result was the trail liaisons were able to divide area occupied by the trail into sections and then send out volunteers to work in those areas. Previously volunteers stayed together in one or two groups and moved along the trail because of the challenges to navigation and communicating the locations of the maintenance. With the mobile application, users were able to see their locations on the map along with the locations of the trail maintenance.

Conclusions

Directing and following through the complete design process from identifying a problem; proposing and designing a solution; testing and modifying the solution until it meets the stakeholder's expectations was very informative and gratifying. The opportunity to go through this process was very rewarding because it was possible to see an idea become a tangible, usable implementation. Going through the

design process provided a deeper understanding of how ideas, technology, funding, and expectations affect the implementation of GIS solutions.

The basic components of the Fountainhead Trail Maintenance GIS are all in place. The major focus of this project was implement a GIS design that would improve the process of trail maintenance through the use of technology. The subsequent efforts will be on refining some of the tools, improving the quality of the baseline data, and collecting data, not from the field, but about the use of the GIS solution to support trail maintenance efforts. The next steps in tool development will be incorporate a survey for the trail workers to provide information about completed trail work. The trail liaisons have already collected additional baseline data using the field data collection tool Collector. This data needs to be relocated due to reduced positional accuracy. The main objective will be to collect qualitative and quantitative data about the GIS to demonstrate its value for trail maintenance. The data will include:

- information about the level of effort for monitoring and implementing trail maintenance;
- understanding the types of repairs and costs as well as defining strategies to reduce cost;
- demonstrating the ability to advocate with data.

By collecting this information, the trail liaisons will have a better understanding about how sustainable the Fountainhead Mountain Bike trail is. This will prompt discussions about improvements to the trail which may be supported by additional GIS development, such as the development of geoprocessing services for land analysis for relocating parts of the trail or creating new trail and skills areas.

This project met the objectives outlined through the creation of a GIS to support trail maintenance. The GIS consists of web and mobile applications that consume data hosted and published through Esri's cloud platform, ArcGIS Online. The solution has improved the ability of the trail liaisons to monitor the trail by using the mobile application for field data collection. With the web application they are able to plan for trail work days and evaluate the quality of the repairs. The GIS has provided tools so that the trail liaisons are able to know more about the trail and understand the impact that they are having on its sustainability.

References

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