MAppFx:
Southern Guam
Ugum Watershed
Streamflow Duration Curves

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WATER AND ENVIRONMENTAL RESEARCH INSTITUTE
OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM

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The UOG Web Team helped WERI bring GHS and WERI websites on the UOG domain, and keep our web pages secured, backed up, and running.

Abstract

The prediction of streamflow variability is essential in many different water resources evaluation studies. Defining long term flow variability is essential in studies such as hydropower feasibility, evaluating surface water resources for water supply studies, low and high flow studies such as in-stream flow requirements, and other studies where it is required to define the variability of flows in a stream.

Predicting flow variability is normally accomplished by direct analyses of streamflow data for the stream in question or by applying a hydrologic inferential technique from a gaged to an ungaged stream or from a gaged location on a stream to an ungaged location on that same stream. Of course, the most reliable means is to use actual stream flow data measured at the point of interest. In 2015, WERI hydrologists developed a means of predicting flow variability at ungaged sites in Southern Guam, applying streamflow duration curve analysis.

However, the information developed in the streamflow studies was not readily available to everyone making studies that rely on predicting long term streamflow variability at ungaged sections of a river. With MAppFx, making flow variability information easily available to those making future water resources studies is now accessible to everyone. The MAppFx platform is an online interactive map and graph interface. The user of MAppFx will have an interactive map like Google® Earth. Various controls, and map features (line, point, polygon), upon selection, provide the option of viewing an interactive graph of a dataset associated with the map feature. The result is an effective and modern means of hydrologic information transfer.

MAppFx, an online interactive map and graph application, applies JavaScript codes and libraries, to build the platform for the worldwide access of Guam's flow duration analysis. MAppFx has recently been applied to make production well water quality history available worldwide. The Ugum River flow duration curve dataset is used as a manageable sized set in the first phase of the project. A second phase of this project will apply the MAppFx platform to the entire Southern Guam group of flow duration curves.

Key Words: southern Guam, Ugum watershed, flow variability, streamflow duration curve analysis, WERI MAppFx, online information transfer, data visualization, web application

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Chapter 1

INTRODUCTION

The prediction of streamflow variability is essential in many different water resources evaluation and protection studies. Defining long term stream/river flow variability is essential for determining hydropower feasibility, evaluating surface water resources for water supply, and predicting low and high flow rates (e.g., in-stream flow requirements). Predicting streamflow variability at gaged and ungaged streamflow sites is essential for determining capacities, sustainability, and potential power of a river/stream. It was determined that this valuable hydrologic information for Guam must be made available on the Guam Hydrologic Survey website as an online data visualization interface, such as MAppFx, which is described in WERI Technical Report 180.

1.1 Flow Duration Curve Availability

WERI researchers developed a means of predicting flow variability at ungaged sites using geo-statistical streamflow duration curve analysis, WERI Technical Report 154 (Heitz and Khosrowpanah 2015). Flow duration curves (FDC) were developed for various stream reaches (segments) in Southern Guam. The flow variability data was developed in GIS format shape files. A crude method of distributing the data was developed using digital compact disks (CDs) to disseminate the shape file data. This proved to be an unsatisfactory means of delivering the data. In recent years, web application methodologies were developed to disseminate GIS type data directly on the web. This project used these techniques to develop a web application to disseminate the previously developed geographically distributed flow variation data. The Ugum watershed was used as a test watershed for developing these techniques. Figure 1.1 (next page) shows the location and extent of the watershed and included streams. The locations of adjacent stream gage sites are also provided. It is planned to use the techniques developed in this project to disseminate the flow variability data that was developed for all the other streams in Southern Guam.

1.2 Water Resource Information Transfer Concern

Researchers at WERI were aware that even though FDCs had been developed for all segments of streams in Southern Guam, this data was not readily available to local water resources agency personnel and to others interested in the variability of flows in Guam's streams. This project developed a web application that makes the flow variability of streams in the Ugum river watershed available to anyone with Internet access. The data is easily selectable from a map interface and duration curve plots and raw duration data are available for stream gages and stream reaches of selected streams in the watershed. It is envisioned that a follow up project will be undertaken to add the rest of Southern Guam streams to the map application that was developed.

1.3 Goals, Purpose, and Specific Objectives

The goal of this project is to develop a means of providing online data visualization using an interactive map and graphing system for stream FDCs. The purpose is to make a portion of the results of the project described in WERI Technical Report 154 available online.

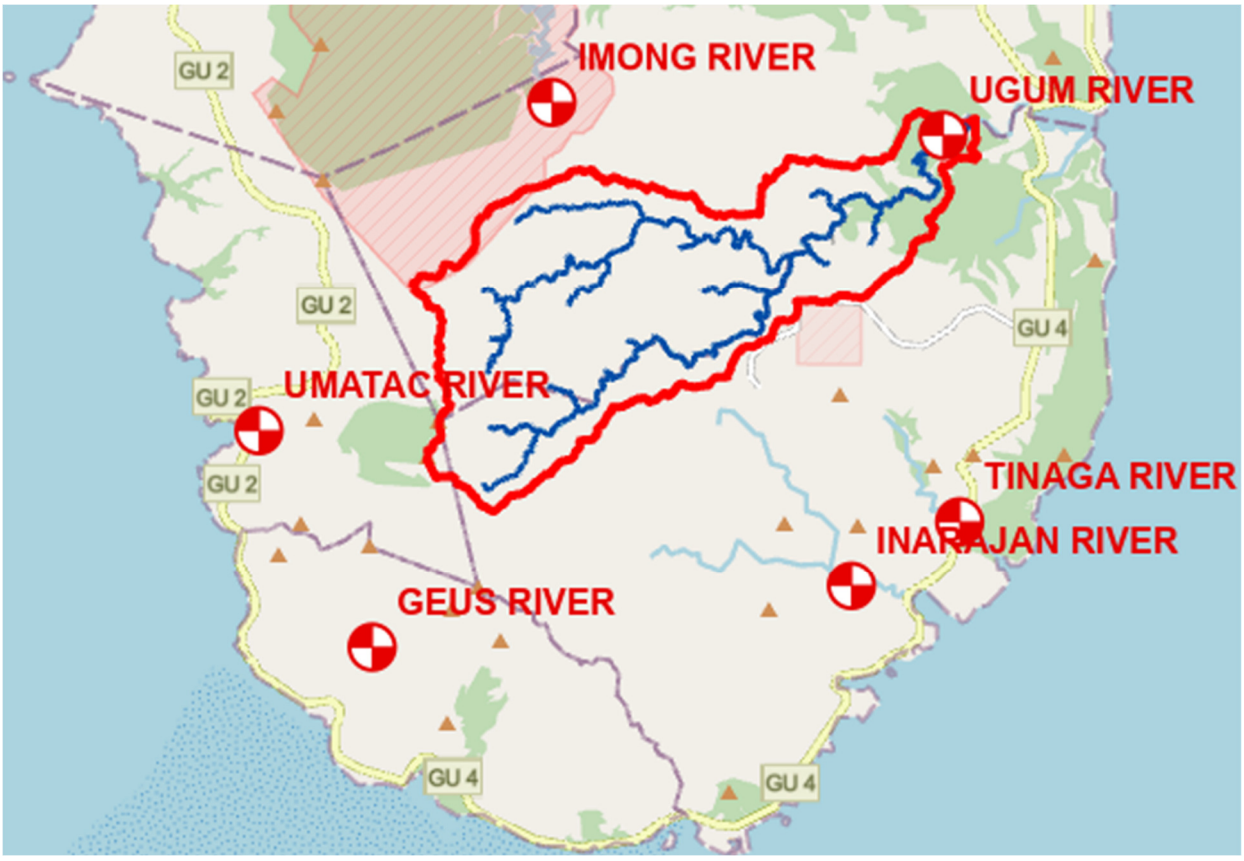

Figure 1.1. Ugum Watershed Streams and Stream Gage Locations in Southern Guam.

This will make it easy to visualize flow variability differences within and between streams in Southern Guam. Specific objectives of the study were to:

1. Organize the original stream reach GIS datasets for conversion into JavaScript Object Notation (JSON) files
2. Develop the concept and code for an interactive data visualization system
3. Provide workshop(s) for recommended use and online access to maps
4. Provide training for regulating agencies (Guam EPA, GWA, and Guam Land Management)

The map and graph products were developed using JavaScript code, charts, maps, and a database system on a static web page. The resulting map and graph products will be accessible on the Guam Hydrologic Survey website.

1.4 Scope, Limitations, and Delimitations

Scope:

This project covers providing Internet accessible flow duration data for the major stream sections in the Ugum watershed (see Figure 1.1). The product is stream section/segment maps and associated data files for retrieving the stream segment flow duration values and graphs.

Limitations:

MAppFx in this stage can process one graph at a time for a selected stream segment. For the hydrologic information, Ugum Watershed has one stream gage; however, a method exists for estimating the ungaged reaches.

Delimitations:

Estimates are based on methods of predicting the likelihood of streamflow rates at ungaged stream sites. The prediction methodologies and statistical parameters of the predictions are described in the original duration curve study for South Guam (Heitz and Khosrowpanah, 2015). This methodology was used in a previous study to predict low head hydroelectric potential in the Pacific Northwest, USA (Gladwell et al. 1979).

The FDCs provided in this study are particularly useful in preliminary water resources site evaluations and for comparing sites between streams in different watersheds. If projects warrant further evaluation, detailed watershed modeling might be useful to provide more information.

1.5 Benefits

The greatest benefit of this study was to provide a means of providing easily accessible stream flow variability information for the Ugum watershed. It is planned that future studies will provide this accessibility to all the streams of Southern Guam. Federal and local agencies will have a common geographically oriented and easily accessible database to use when making studies that involve steam flow variability.

Chapter 2

BACKGROUND AND RELATED RESEARCH

Southern Guam's Ugum Watershed is a major southern municipal utility water source. In the past, hydrologic flow duration analyses for stream sections (reaches) were produced using existing stream gage and rainfall data mapped into stream segments. Now, a new online data visualization application, called MAppFx, is available to make Southern Guam flow duration data available to interagency partners and anyone worldwide.

2.1 Guam and the Ugum Watershed

The Island of Guam is a United States Territory located in the Western Pacific approximately 1,560 miles southeast of Narita, Japan and 1,600 miles east of Manila, Philippines (Figure 2.1). As of 2023, the population of the island is more than 173,000[1]. Guam (210 sq mi) can be divided into two physiographic regions which include the land areas north and south of the Pågu-Adilok Fault. The northern area is an uplifted karst plateau that contains a freshwater lens identified hydrogeologically as the Northern Guam Lens Aquifer (102 sq mi). Southern Guam (108 sq mi) lies South of the Pågu-Adilok Fault. This area is mostly made up of volcanic terrain, with several watersheds, rivers, and streams. Southern Guam Watersheds (Figure 2.2, next page) shows the major drainage basins, highlighted on the map. For data management and first phase development, the focus of this study was the Ugum River and its watershed (7.1 sq mi). This watershed is currently a utility water source (2-3 MGD).

Figure 2.1 Southern Guam, south of the Pågu-Adilok Fault.

[1] https://www.worldometers.info/world-population/guam-population/

Figure 2.2 Southern Guam watersheds. The Ugum Watershed (peach) and its river is a municipal utility water source.

2.1.1 Flow Variability in Southern Guam Streams

The prediction of streamflow variability is essential in many different water resources evaluation studies. Defining long term flow variability is most useful for determining hydropower

feasibility, evaluating surface water resources for water supply studies, and low/high flow studies such as in-stream flow requirements.

Flow variability can be defined using a hydrologic statistical method that computes the flow variability distribution expressed as a flow duration curve of a stream's flow at a particular location on a stream. In 2015, Heitz and Khosrowpanah produced average daily flow duration curves (FDCs) for stream reaches in selected streams in watersheds throughout Southern Guam, including the Ugum river and its tributaries (Figure 2.3) (WERI Technical Report 154, Heitz and Khosrowpanah 2015).

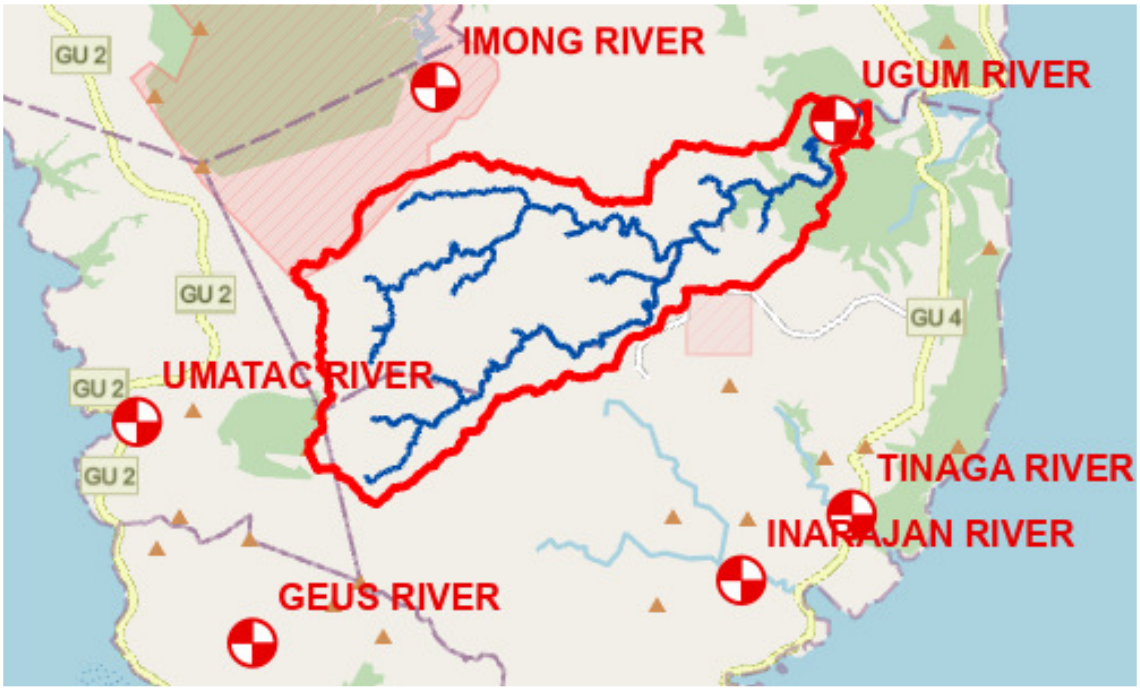

Figure 2.3 Ugum watershed (red bounded area) river and tributaries. From the 2015 research, each river segment upstream (blue) from the stream gage (red circle-cross-checker marker) near the outlet has a predicted hydrologic FDC.

2.1.2 Flow Duration Curves and Methods Applied

The FDC provides a means of representing the long-term variability of flow at a stream site in a concise graphical fashion. FDCs are basically a form of hydrologic statistical distribution of percent probability of a streamflow rate equal to or greater than a particular flow value. A sample curve (e.g., Figure 2.4, next page) was generated from average daily flow data at a U.S. Geological Survey (USGS) stream gage (Figure 2.3) located on the Umatac River. Flow duration is plotted with the exceedance percentage on the horizonal axis. The exceedance value is the percentage of time that a particular flow rate (vertical axis) is equaled or exceeded. For the example in Figure 2.4, shown in red, a daily average flow of 2 CFS is equaled or exceeded 66% of the time.

The 2015 study applied a Geographic Information System (GIS) spatial analysis technique to predict the average flow along all the streams in Southern Guam. The starting points for these average flow computations were based on average rainfall maps and a LiDAR based digital elevation model of Southern Guam. Average annual rainfall input to the streams were computed

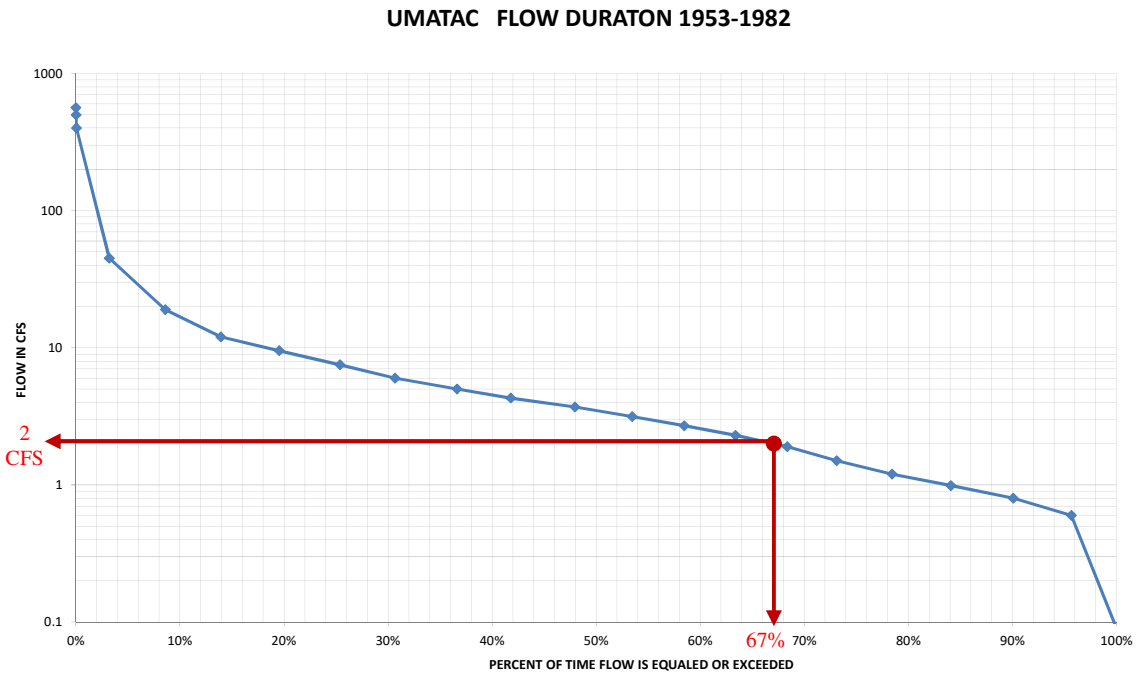

Figure 2.4 Sample FDC generated from the Umatac River stream gage data (1953-1982). Shown in red, for example, reads 67% of the time the (volume) average daily flow rate (ft^3/s or cfs) at the gage is greater than or equal to 2 cfs (ft^3/s).

by applying the GIS accumulation function to the average annual rainfall maps based on the flow directions computed from the digital elevation model. An average annual rainfall accumulation vs. average annual flow correlation was developed and applied to the accumulated average annual rainfall input to the stream segments resulting in a map of average annual flow for the Southern Guam streams. Duration curve values for the stream segments were computed by applying the average annual flow values in the streams to a set of parametric curves. The results were a set of GIS based stream segments with attributes that include average flow and flow duration values for each stream/river segment.

A complete detailed description of the hydrologic methods applied and data used is available in WERI Technical Report 154 (Heitz and Khosrowpanah 2015).

2.2 Online Data Visualization

For decades, WERI and interagency partners on island and abroad have longed for useful and easy ways for WERI to share research analysis results. In 2021, WERI and Brigham Young University (BYU) collaborated to explore information transfer through the means of web applications. BYU presented a worldwide database platform called Tethys Portal that can house regional and site data. BYU's Tethys Portal is a hydroinformatics system that applies a collection of interactive map applications to hydrologic and water quality datasets to achieve hydrologic data visualization. In a first product successful collaboration endeavor, WERI set sight and interest on a particular Tethys Portal web application that applied an interactive map and graph interface. In the summer of 2022, BYU trained WERI researchers to develop its first interactive map and graph application with production well nitrates and the Ugum stream FDCs. In the fall of 2022, WERI hosted the Guam Water Resources Forum, and presented and demonstrated its two new online information transfer products. These products received interest and positive

remarks from attendees. In early 2023, the first **MAppFx** product was described in WERI Technical Report 180, *MAppFx: Production Well Nitrates Northern Guam Lens Aquifer*. The report and web application were published and posted on the Guam Hydrologic Survey website.

Online interactive map(s) and graphs, as web pages, are now possible and made easy using JavaScript codes. The code begins as a common web page document (HTML5, or hypertext markup language document). In the HTML document are the application of JavaScript (JS) codes, JS libraries from Leaflet® (interactive map) and Plotly® (interactive graph), and JavaScript Object Notation (JSON) file (map and graph data). The JS codes in the HTML document, prepare variables, and call and execute subroutines from the JS libraries and access the JSON files. JavaScript makes the web page interactive, and MAppFx (Valerio et al. 2023) was designed to be manageable; easy to update; have a simple and intuitive interface; and become a quick reliable source of hydrologic and water quality information reference.

Chapter 3

METHODOLOGY

The goal of this project (Chapter 1) was to build MAppFx for the calculated flow duration curves (FDCs) of the Ugum river. The first two specific objectives are the methods, and this chapter provides details.

3.1 Data Organization and GeoJSON files

The FDC project described in Chapter 2 produced a GIS polyline shapefile that represents the stream datasets in the Ugum watershed. Each polyline has segments of two main attributes (a GIS feature database and table of values). These include vertex coordinates and the computed average flow (cfs, ft^3/s) and flow duration values (cfs, ft^3/s) for particular percent exceedance values.

The core of the MAppFx application, the interactive map and graph, utilizes a database in either JSON (JavaScript object notation) or GeoJSON format. Both are essentially text files of a specified bracketing format database for MAppFx JavaScript libraries to display. GeoJSON is used for data describing geographically distributed data for maps. GeoJSON files can be made from common geographic file type (e.g., KML, CSV, shapefile) and a converter such as the online version, mapshaper (mapshaper.org). Figure 3.1 (next page) shows the GeoJSON data structure, converted from the Ugum river/stream shapefile. The mapshaper web application is quite intuitive, and the shapefile can be converted to GeoJSON in three steps:

1. Create a ZIP (compressed file) of the GIS file sets for the Ugum FDC river/stream. The file set must have at least the three required files of file extensions .shp, .dbf and .shx.
2. On mapshaper, import the GIS shapefile (step 1), either drop/paste/select from folder.
3. Press the export tab, on the dialog box, select "GeoJSON" format, and select Export.

3.2 Programming Concept

The MAppFx online application is built on an HTML web page file and JavaScript code files. Figure 3.2 (next two pages) shows the program flow diagram. The HTML document head section (<head>…</head>) references the scripts, which includes the map and graph libraries (Leaflet and Plotly, respectively). This section also contains the main JavaScript code that accesses the GeoJSON file and creates the Leaflet map and Plotly graph in the body section (<body>…</body>) of the HTML file. Other user interface features not mentioned are customized specifically to make the MAppFx web application, documented in Valerio et al., 2022 (WERI TR 180 or Guam Hydrologic Survey website). The MAppFx web page and script components are managed in the Guam Hydrologic Survey website domain.

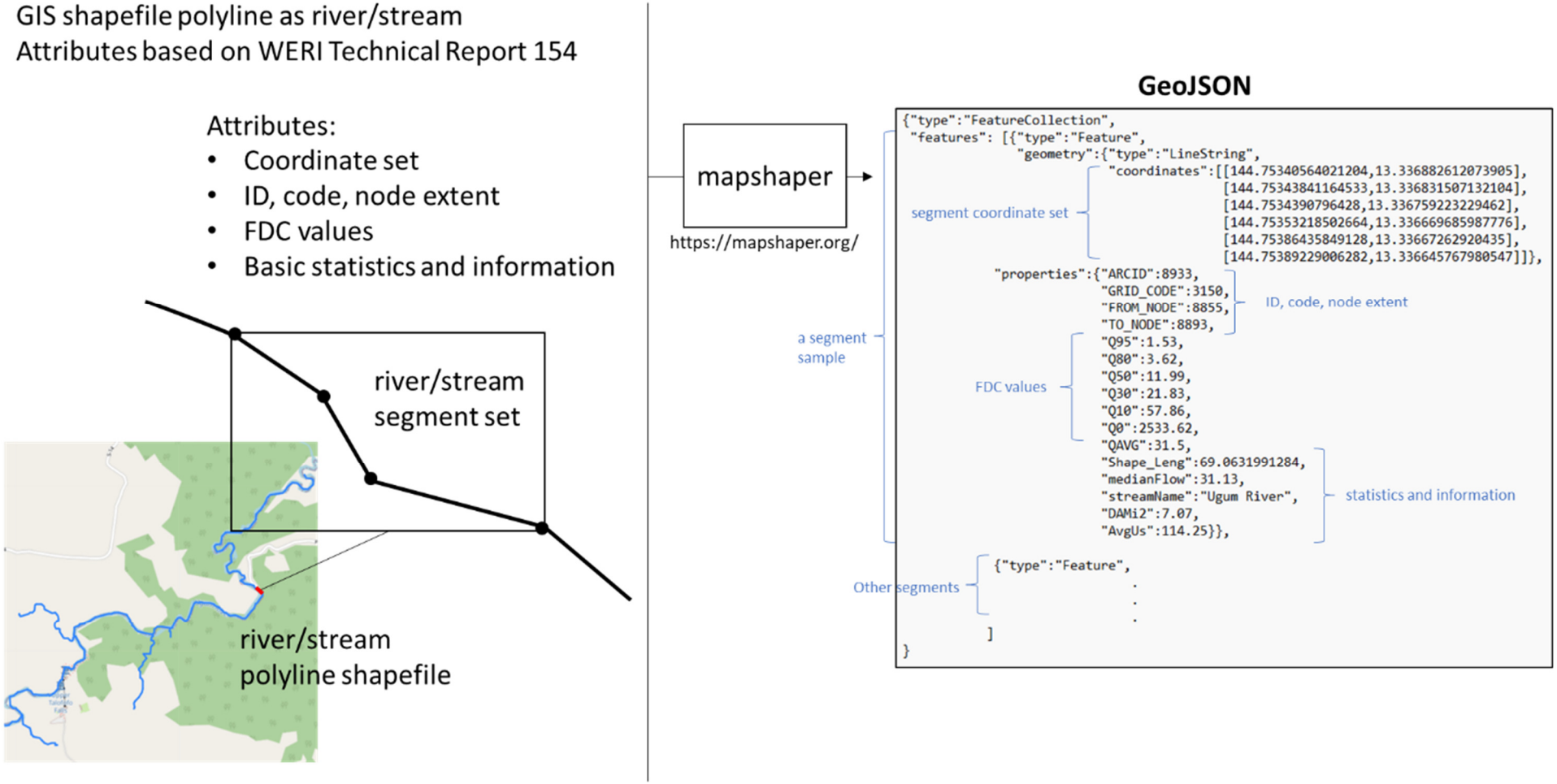

Figure 3.1 FDC shapefile converter to GeoJSON.

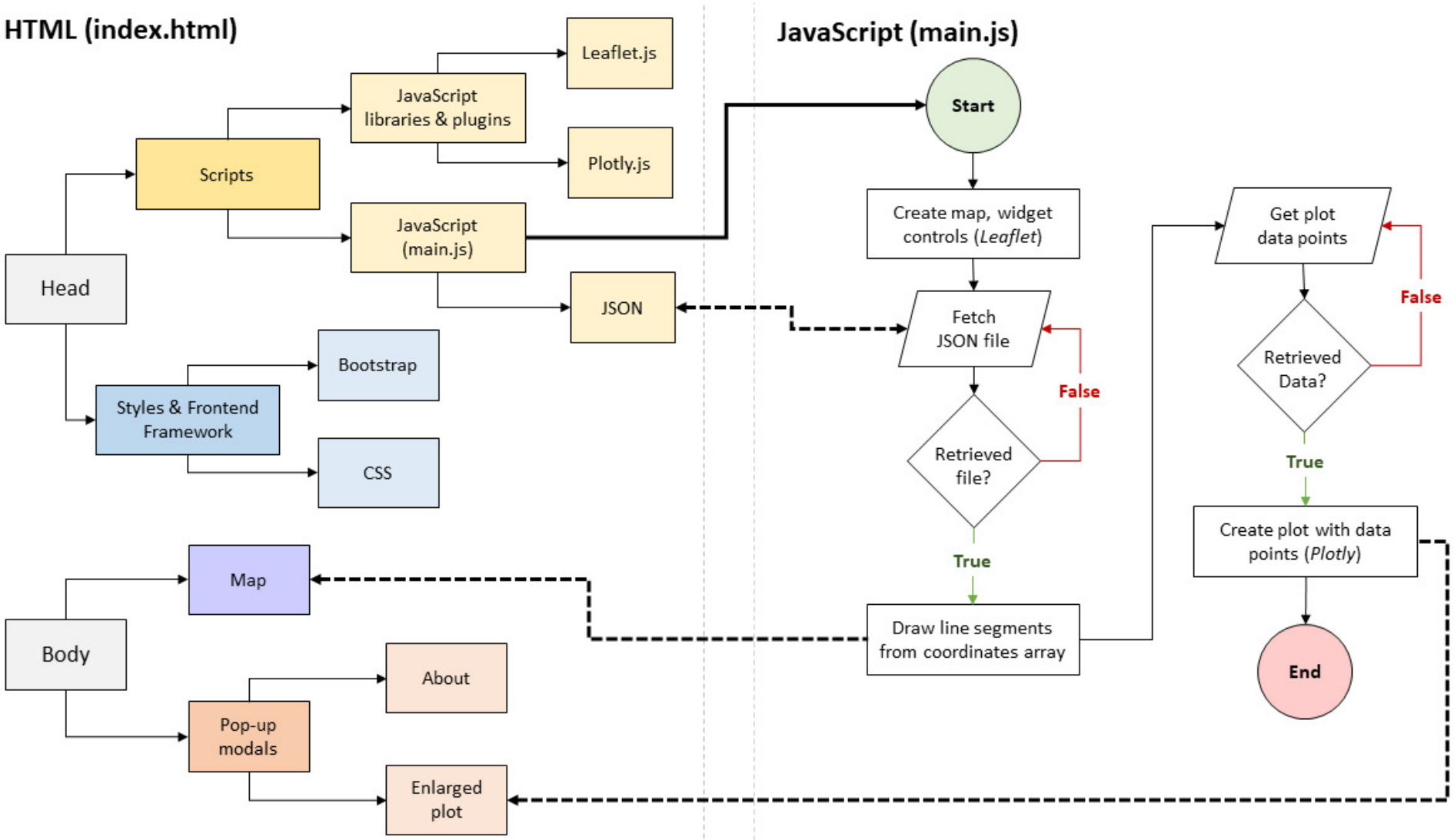

Figure 3.2 Programming flow diagram for the MAppFx Package.

Chapter 4

RESULTS AND DISCUSSION

The result is an online MAppFx product of gaged and ungaged (computational) stream flow duration curves (FDCs) of the river/streams of the Ugum Watershed, available online on the Guam Hydrologic Survey website (GHS), (guamhydrologicsurvey.uog.edu). GHS hosts a collection of maps, reports, databases, and web applications as WERI Web MApps and MAppFx. The resulting online product, access, and guide to the user interface are covered here.

4.1 Flow Duration Curves Online

The first interactive map and graph for Southern Guam as FDCs is now available online. This MAppFx product resides in the GHS website and is available in the following link:

GHS/Library: MAppFx: Ugum River FDCs

Selection of the link above opens a web page containing a project summary report. This report may also be accessed on the GHS website homepage, listed in the Library dropdown menu (Figure 4.1), also available under the Hydrology menu. On the summary page, selecting the large imagery of the application opens the MAppFx interface, which is an online interactive map of Guam's Ugum River, a layer of blue stream/river polyline (Figure 4.2). The MAppFx interface includes a product header and widgets (interactive web-app buttons and options). The widgets are located on the top and bottom right corners. These app widgets provide access to information, links, and map tools. The polyline has segments that may be selected, and upon selection, a segment caption appears. The next section is a guide to the interactive user interface.

Figure 4.1 GHS website homepage and Library drop-down menu. MAppFx products currently reside in the Library menu. Boxed in red is the MAppFx Ugum FDC's summary page.

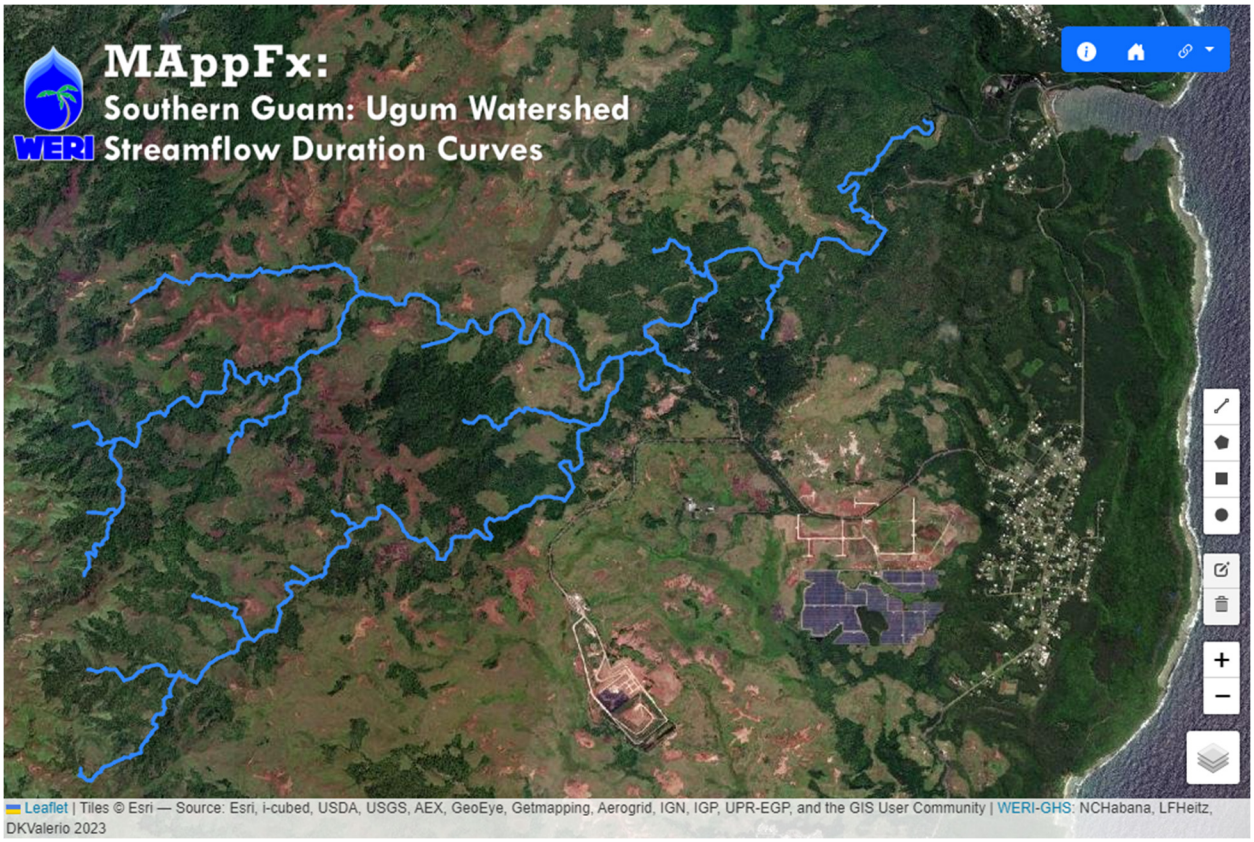

Figure 4.2 MAppFx: stream/river FDCs, Ugum Watershed.

4.2 User Interface

The MAppFx interface is intuitive and can provide streamflow curves and data upon selecting sections of the stream. Figure 4.3 shows steps to obtaining information from stream sections. The online map interface is interactive that allows the user to "zoom" (magnify), in and out. The map has two groups of buttons (widgets and plugins) for map tools, information, and control options. The top right set is the navigation "widgets" for information and links. The bottom right set are Leaflet® plugin controls for drawings, zoom, and background map layer options. The background map may be changed upon preference between street map or imagery. The bottom left item is also a plugin to an interactive mini map. To access the FDCs from stream segments, the user would select the stream segment of interest that would activate a "pop-up", which is a caption dialog. The pop-up will contain a Reach ID, exceedance probability (Q-percent) and respective flow rate (cfs) values, and two buttons: (1, blue) labeled "Plot FDC" and (2, green) "Download CSV" file. The blue button opens an interactive graph of the FDC (Figure 4.4), and the green button downloads the graph data as a comma space value (csv) file.

MAppFx is a new way to store and access a large collection of spatial and graphical data. Interactive data visualization is a modern means of data sharing with interagency partners and researchers, available through an Internet browser. This product may also replace report appendixes, projects that refer to a large collection of data with a simple reference link.

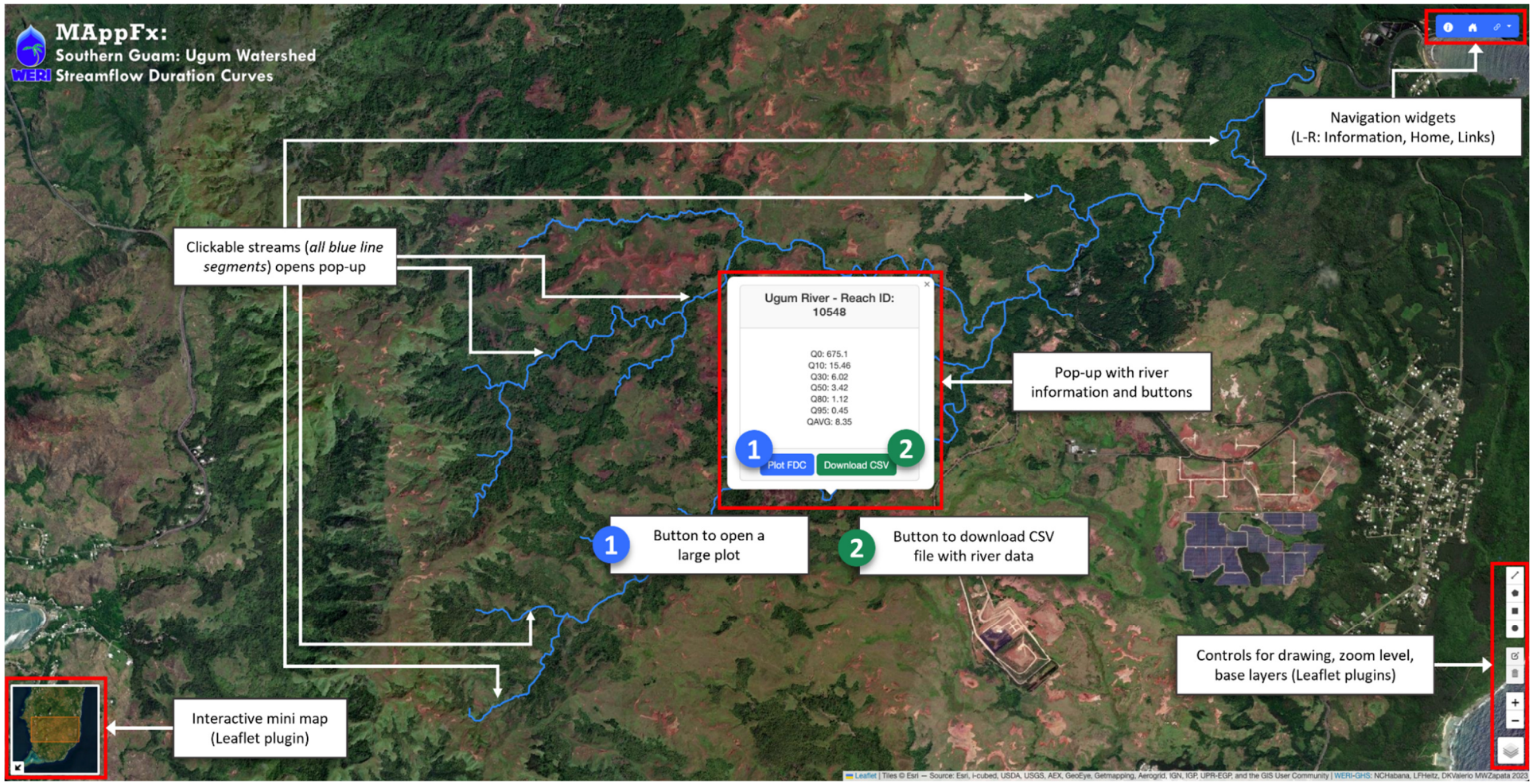

Figure 4.3 MAppFx, an intuitive user interface for data visualization of FDCs.

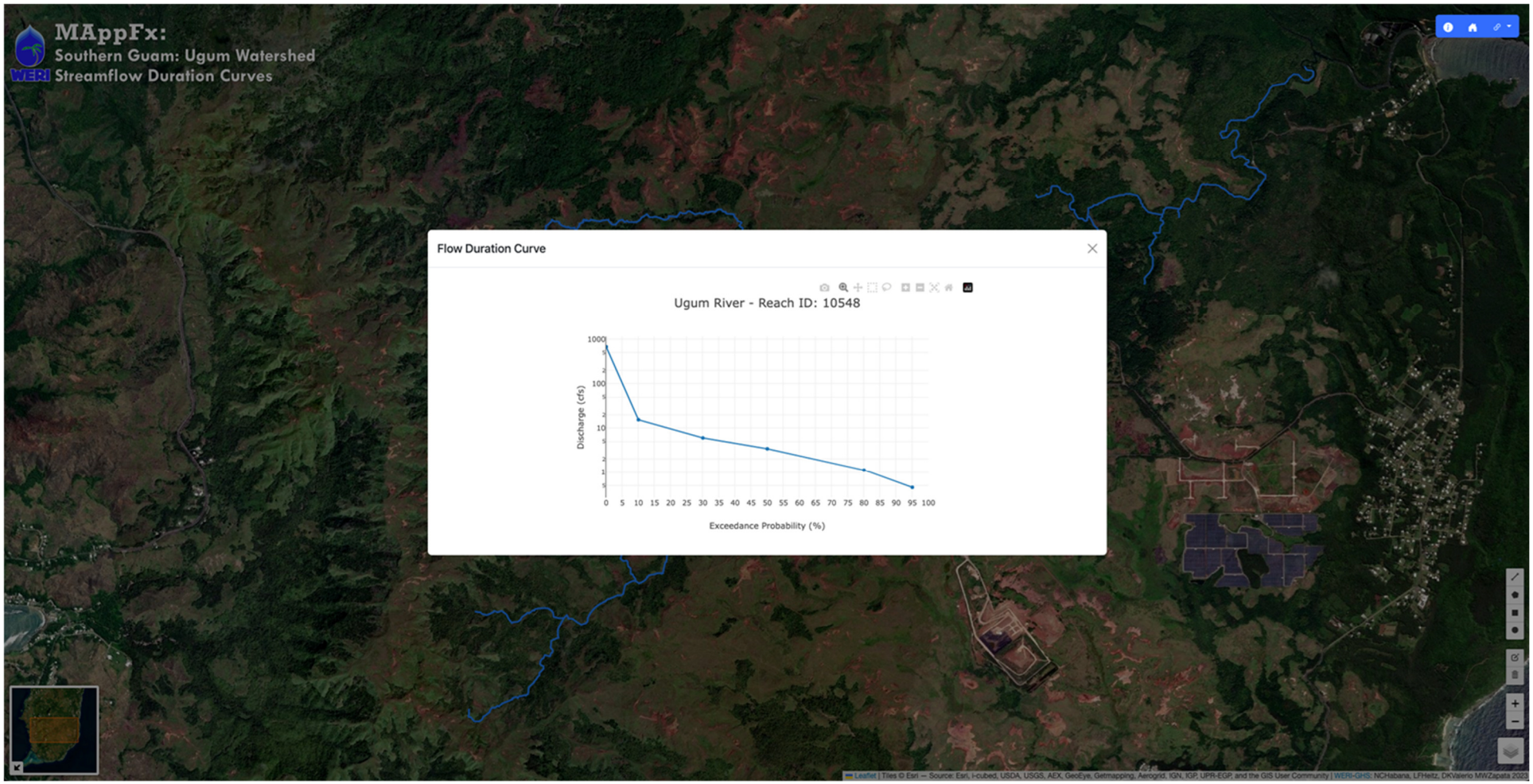

Figure 4.4 Interactive FDC of selected stream segment. Upon selection of the blue button in the caption dialog (Figure 4.3), an interactive FDC appears before the background map. To close the plot, select the "x", close button, on the top right corner of the graph, which returns the user to the map interface.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Modern means of water resource research information transfer is through online data visualization. WERI develops MAppFx products, particularly in this project, the Ugum streamflow duration curve (FDC) at sections of the stream/river, based on WERI Technical Report 154. This project accomplished its goals, purpose, and proceeded with the specific objectives (Chapter 1) to develop a useful data visualization product, MAppFx.

5.1 Summary Conclusion

Guam hydrologic information of FDCs is the second WERI online data visualization interface, a MAppFx product. The FDCs of the Ugum River in the Ugum Watershed, Southern Guam, are the first phase of FDCs that are available online. The FDCs are based on WERI analysis research (Heitz and Khosrowpanah 2015). MAppFx is an intuitive data visualization interface that features a map of the Ugum River, as polyline of segments that upon selection, opens the section of the river's FDC (graph). This means of information transfer makes quick hydrologic reference of a select site along the river. The next phase updates the map to include all the FDCs segments from every mapped stream/river in Southern Guam.

5.2 Recommendations

While online data visualization is gaining popularity in the earth sciences, outreach is key to ensure interagency partners and researchers have access, familiarization, and utility training for complete product success. WERI has already introduced an early development introduction of this product in a WERI Guam Hydrologic Forum, hosted in November 2022, which received feedback of amazement and gratitude. Other upcoming WERI-Zhosted venues will bring this product on stage to gain popularity and familiarization as a valuable data source for determining feasibility of watershed development.

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