Hydrologic Map of Guam Watersheds

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

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Intentional Page

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Guam Forest System / Watersheds Planning Committee

The development of the Hydrologic Map of Guam Watershed was initiated in response to the strategic needs of the Guam Forest System's (GFS) Watershed Planning Committee (WPC). In June 2024, WERI served as an invited panelist and speaker for Session I of the WPC at the Guam Forest System Plan Summit, hosted at the Hyatt Regency in Tumon. Anticipating critical inquiries regarding watershed management and planning, the necessity for a high-resolution, accurate hydrologic map became immediately apparent. Consequently, WERI introduced sample high-detail maps of foundational watersheds, developed utilizing advanced surface hydrology and terrain analysis methodologies (WERI TR 175). Progress on the map's development was formally presented at several subsequent engagements, including WPC meetings (March and June 2025), the Guam Educators Conservation Summit (April 2025), the BSP and GCMP Planners Symposium (August 2025), and the WERI-GLE Guam Hydrologic Survey Workshop (September 2025).

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Mr. Reyes and BSP/GCMP team reached out to WERI with great interest in the production of this map.

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A great source for Island History and Wisdom. Dr. Underwood directed WERI to a great team, Kumisión I Na’an Lugåt, to determine the proper assignments, spelling, of Guam place names.

Abstract

The strategic protection and sustainable development of southern and central Guam's water resources necessitate a comprehensive, high-resolution surface hydrology map. The hydrologic regime across these regions is inherently complex, defined by a stark contrast between heavily dissected, low-permeability volcanic watersheds and transitional argillaceous clastic wedges featuring plateau basins and doline merokarst. Historically, spatial data was fragmented and constrained by coarse-resolution basemaps, hindering interagency collaboration and comprehensive watershed management. To resolve these limitations, this project executed advanced geographic information systems (GIS) spatial analysis on the 2020 1-meter LiDAR-derived Digital Elevation Model (DEM). A rigorous algorithmic methodology was deployed to iteratively process fill area mechanics, precisely routing flow accumulation and resolving internal runoff pathways within nested surface depressions down to a strictly defined 50 sqm threshold. The resulting high-fidelity geodatabase precisely delineates 90 individual watersheds and 13 watershed groups, capturing classic river-valley boundaries, internal drainage basins, and refined tributary divides. Place names and hydrologic features have been integrated with indigenous nomenclature, currently undergoing final authentication by the Kumisión i Fino' CHamoru's Kumisión i Na'an Lugåt Guahan (Guam Place Name Commission). Ultimately, this definitive 1:12,000-scale spatial framework and its accompanying GIS datasets are deployed online via the Guam Hydrologic Survey. This product directly equips local and federal stakeholders, planners, and water resource managers with the essential infrastructure required to execute strategic development, utility operations, and rigorous environmental conservation protocols.

Key Words: Guam watersheds, rivers, streams, tributaries, plateau basins, runoff paths, surface depressions, and CHamoru place names

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1 INTRODUCTION

Effective water resource management and watershed protection demand highly accurate surface hydrology mapping. Historically, these efforts were heavily constrained by low-resolution basemaps and the inherent complexities of operating Geographic Information Systems (GIS). To resolve these limitations, this project executed advanced GIS spatial analysis and hydrology geoprocessing on the latest 1-meter Light Detection and Ranging (LiDAR)-derived Digital Elevation Model (DEM). The resulting high-resolution map provides stakeholders with a visually definitive, highly accessible spatial tool for development planning and resource conservation.

1.1 Statement of State Water Problem

Current maps of southern Guam lack the resolution and detail required for comprehensive watershed protection and management. Researchers, developers, and water resource stakeholders frequently require higher-resolution maps that maintain clarity at finer scales to support their operational and environmental objectives. Furthermore, because advanced Geographic Information Systems (GIS) spatial analysis is often restricted by a user's technical expertise and software access, there is a critical need for a readily accessible, high-resolution surface hydrology map. This updated geospatial framework will significantly enhance the assessment, management, and protection of Guam's watersheds while streamlining the transfer of vital hydrologic data across agencies and the public.

1.2 Goal, Purpose, and Specific Objectives

The goal is to produce a high-resolution hydrologic map detailing the precise watershed boundaries and fine surface runoff paths of Guam. The purpose of this map is to deploy a definitive spatial framework that guides/aides in determining sustainable development plans, environmental protection strategies, and technical training.

The specific objectives were:

1. Prepare and refine the Southern and Central Guam GIS raster and shapefiles
2. Execute GIS hydrologic spatial analysis to delineate high-resolution watershed boundaries and precise runoff networks
3. Analyze and interpret the resulting hydrogeologic terrain features
4. Provide technical training to stakeholders for map access, spatial interpretation, and resource planning.

This technical report accompanies the finalized map product, accessible via the Guam Hydrologic Survey website:

https://guamhydrologicsurvey.uog.edu/index.php/2025/08/01/hydrologic-map-of-guam-watersheds/

1.3 Scope, Limitations, and Delimitations

Scope: The spatial domain encompasses the Southern and Central Guam Watersheds, explicitly capturing enclosed plateau basins (Otdot and Pågu) situated within the argillaceous terrain. All geospatial hydrologic features were generated using the 2020 NOAA Topobathy DEM.

Limitations: The 1-meter bare-earth DEM inherently omits surface structures—such as buildings and dense forest canopy—and lacks the capacity to resolve subterranean flow routing, specifically culverts and municipal storm drain networks. Ground-truthing and field investigations were not conducted to manually rectify these digital omissions; therefore, these spatial constraints serve as a strict caveat for end-users. Consequently, specific rendered flow paths depict simulated bare-earth runoff trajectories rather than the actual hydrodynamics of structurally altered urban or vegetated environments. Despite these localized artifacts, this fine-resolution raster fundamentally remains the absolute best baseline spatial data available for executing regional hydrologic analysis across Guam.

Delimitations: To optimize spatial clarity and computational performance, fill area (surface depression) watersheds were explicitly delimited to areas greater than or equal to 300 sqm. The final cartographic product is locked to a 1:12,000 scale and formatted for an 8' x 6' portrait layout.

1.4 Benefits

This high-resolution surface hydrology framework provides immediate, actionable insight for watershed management, strategic planning, and environmental protection. The map directly equips local and federal entities, including the Guam Forest System/Watershed Planning Committee, Guam EPA, Bureau of Statistics and Plans, Coastal Management Program, Guam Waterworks Authority, military engineers, and the Kumisión I Fino' CHamoru. The map product explicitly incorporates a disclaimer regarding spatial limitations and recommendations for its proper application.

2 BACKGROUND AND RELATED LITERATURE

The southern and central regions of Guam are defined by complex volcanic and argillaceous limestone landforms, comprising distinct mountain and hill-valley watersheds that discharge directly into coastal bays and reef channels. This project rigorously delineated these terrains to establish a high-resolution spatial framework of the island's river-valley watersheds.

In stark contrast to the highly permeable northern limestone plateau, southern Guam—situated south of the Pågu-Adilok Fault—is geologically dominated by weathered volcanic features that form heavily incised river watersheds with significantly lower permeability. Immediately north of this fault lies central Guam: an uplifted argillaceous clastic wedge exhibiting a horst-and-graben structural profile. This transitional argillaceous terrain uniquely demonstrates both surface fluvial river-valley characteristics and subsurface aquifer capacity.

To execute the hydrologic and terrain analysis, advanced Geographic Information System (GIS) geoprocessing tools were applied directly to the 2020 Light Detection and Ranging (LiDAR) bare-earth Digital Elevation Model (DEM) (NOAA 2020). The conceptual model driving this spatial analysis focused heavily on depression fill mechanics, drainage flow routing, and surface runoff accumulation. Iterative algorithms were applied to precisely define internal basin boundaries, large fill area watersheds, and internal surface depression runoff paths. Ultimately, this refined geoprocessing methodology represents a significant technical upgrade over the earlier spatial analysis conducted for the northern plateau, *Surface Hydrology of the Northern Guam Lens Aquifer (NGLA)* (Habana et al. 2022).

2.1 Watershed Geology and Hydrology

Guam comprises three distinct hydrologic and geologic terrains: volcanic, argillaceous limestone, and limestone plateau. The limestone plateau features internal basins that drain into their respective focal watersheds and into the NGLA (Habana et al. 2022). Southern Guam is dominated by mountain and hill river-valley watersheds that flow into coastal bays and reef channels. These are broadly recognized as the watersheds of Guam. The Hagåtña Argillaceous region in central Guam also contains fluvial landforms that drain into the Hagåtña Swamp and Bay, while simultaneously serving as a utility aquifer.

2.1.1 Geology and hydrologic terrain

The southern volcanic landforms are the remnant foothills of collapsed volcanoes located west of the island (Reagan and Meijer 1984; Tracey et al. 1964). These submarine and water-laid volcanic structures were followed by Miocene-Pliocene reef-building events (Tracey et al. 1964; Stark 1963; Carroll and Hathaway 1963). Guam has undergone tectonic uplift since the Pleistocene (c.f. Miklavic et al. 2021; Siegrist and Randall 1992; Siegrist et al. 1998; Tracey et al. 1964), exposing the terrain to significant pluvial weathering. The central section is a merokarst composed of Mariana Limestone deposits and Alutom Formation erosion, which forms an uplifted argillaceous clastic wedge (Siegrist 1995).

The watersheds are a direct product of pluvial and fluvial erosion. The most intensely weathered materials are clays, tuffaceous sands, and shales (Stark 1964; Carroll and Hathaway 1963). This significant weathering results in mass wasting, rills, gullies, and sheet erosion (c.f. Siegrist 1992; Scheman et al. 2002; Park et al. 2007; Kottermair et al. 2011). Watershed development is driven by tropical rains, acting most effectively during prolonged, intense rainfall and subsequent flash floods. Siegrist et al. (1998) observed that stream and river networks, alongside erosion patterns, are also controlled by weak geologic substructures like faults and joints. The south features alluvial valleys along rivers and in coastal lowlands, which generally form flat wetland areas (Siegrist et al. 1997). The Talo'fo'fo' River valley contains the largest wetland-alluvial basin, extending furthest inland. These volcanic watershed valleys are heavily vegetated, with the hills densely covered by *Miscanthus floridulus* (sword grass). Of primary concern is the resulting badland erosion in these hills. Satellite imagery reveals badlands throughout the south, with the Talo'fo'fo', Ugum, and Inalåhan watersheds being the most severely impacted.

Southern Guam can be divided into three primary watershed aspects: east-, west-, and south-facing. A north-south ridgeline along the length of the southern mountains delineates the eastern and western slopes. These slopes exhibit a foothill profile, with the dividing ridge situated closer to the west coast. Generally, smaller watersheds are found on the western and southern sides, while much larger watersheds dominate the eastern side. The largest is the Talo'fo'fo' watershed, which encompasses several tributaries that feed the main river before discharging into Talo'fo'fo' Bay. At the southern end, the Malesso' Watershed Group contains basins and river outlets that drain into the southern bays and Cocos Lagoon. The central argillaceous watersheds span the eastern side and parts south of the Pågu-Adilok Fault—characterized by a north-south horst-and-graben profile—as well as the Hagåtña Swamp and the river that empties westward into Hagåtña Bay.

Although much of the limestone in the south has dissolved, remnant caps and patches still exist. The Geologic Map of Guam (Siegrist et al. 2007; Tracey et al. 1964) identifies Alifan limestone caps on the crests of the island's highest mountains. These caps store groundwater, producing springs at several peripheral locations. Alifan limestone is also found near the west coast. Additionally, Bonya, Maemong, and Alifan limestones are present within the Talo'fo'fo' valley. The Bonya limestone near the Maagas River forms a cockpit karst that hosts a subterranean "lost" river, the Tolaeyu'us.

The southeastern coastal flank consists of an Argillaceous-Mariana Limestone terrace that continues into the central section, forming a perimeter of uplifted, younger reef limestone. These argillaceous limestones contain plateau basins and small, marginal-edge watersheds. Guam's larger watersheds and rivers—such as the Talo'fo'fo', Ylig, and Pågu—discharge into the sea through reef channels. These channels occur where limestone has subsided (Siegrist and Randall 1992), forming drowned river mouths. This morphology is further shaped by riverine discharge (fresh and turbid water) inhibiting reef growth, sunlight attenuation, and sea-level changes (Emery 1962). Argillaceous limestone is also present in the Apra Harbor and Hågat areas. Apra Harbor, the Orote Peninsula, and Santa Rita feature Mariana Limestone, alongside a patch of argillaceous limestone and a small area of Alifan

Limestone. The oldest limestone unit is the Geus River member (Siegrist et al. 2007), located mostly in the south, appearing as a strip of outcrop between the Facpi Formation and the Bolanos Member within the Anaguan and Cetti watersheds. It is also found within the Humåtak, Toguan, Bile, and Geus watersheds.

The subsequent weathering of these clay-rich limestone formations has produced distinct stream and river-valley features. This mixed rock formation exhibits characteristics of both lens aquifers and hilly river valleys. Additionally, some argillaceous limestones form plateau basins, such as the Pågu and Otdot Plateau Basins (Habana et al. 2022). This clay-rich limestone is less pervious, featuring lower hydraulic conductivity and porosity compared to the northern karst. The Pågu plateau basin (Habana et al. 2022) uniquely features a river-like terrain (a dry valley) as its focal watershed.

These watersheds receive seasonal tropical rainfall, driven by Guam's distinct annual dry and wet seasons. Annual rainfall totals vary significantly—often notably wetter or drier due to the El Niño-Southern Oscillation (ENSO) (Lander 1994; PEAC 2016) — the historical average is 100 inches per year. Consequently, streamflow may reduce to a trickle during the dry season or cease entirely at parts during a prolonged drought. Both the central and southern sections provide sources for utility water. The Hagåtña Aquifer Basin contains deep utility wells equipped with vertical pumps that produce up to 8 million gallons per day (MGD) (Zapata et al. 2025); the Hagåtña Spring also contributes to this utility water production. In the south, water sources primarily consist of surface water and springs. Utility water is collected and treated from the Fena Reservoir and the Ugum River, while spring water is captured at the Santa Rita Spring. Furthermore, the argillaceous limestones in the south hosted two production wells (Malojloj wells MJ-1 and MJ-5; Guam Waterworks Authority, GWA, 2015), which are now inactive.

2.1.2 Previous hydrologic maps

Previous efforts to map Guam's watershed terrain provided a useful foundational framework for land use planning and resource management. These early iterations generalized the landscape into 14 major watersheds with delineated river networks, and the resulting GIS shapefiles served as standard baseline references for local agencies and researchers. However, these initial versions—often approximate sketches derived from manual contour delineations—exhibited significant spatial limitations.

Even with the introduction of earlier DEM technology and GIS spatial analysis, legacy maps relied on basic polygons and polylines that lacked internal terrain resolution. Consequently, they failed to capture critical micro-terrain features observable at finer scales, such as localized runoff paths, complex surface depressions, and precise tributary organization. While recent studies have incorporated hillshade or elevation data, their scopes are typically restricted to small, localized study areas. Processing high-resolution, island-wide surface hydrology is inherently data-intensive and computationally demanding. The map produced in this project explicitly overcomes these historical deficiencies by coupling the latest 1-meter DEM with upgraded computational capacity. This critical hardware advancement enabled the execution of intensive spatial algorithms across massive raster datasets, successfully generating the most comprehensive and improved surface hydrologic map of Guam's watersheds to date.

2.1.3 Name selection of hydrologic features

In alignment with the University of Guam's initiative to promote Island Wisdom in research, this project is actively integrating indigenous nomenclature. Ongoing collaboration with the Kumisión i Fino' CHamoru (Commission on CHamoru Language) and the Kumisión i Na'an Lugåt Guåhan (Guam Place Name Commission) ensures the precise authentication of place names across the map's hydrologic features. These commissions are currently determining official CHamoru spellings and recovering historical designations for specific watersheds, basins, and critical geographic landmarks.

While this formal authentication process remains ongoing, the provisional nomenclature utilized in the current hydrologic map version relies on established historical basemaps—primarily the 1954 Army Service Map and the 2007 Geologic Map of Guam—supplemented by contemporary geospatial datasets from ESRI® and Google Earth. The spatial geodatabase and final map product will be updated to reflect the Kumisión's official place name resolutions immediately upon their finalization.

2.2 Data

Data Sources & Terrain Analysis Hydrologic and terrain analysis features are derived directly from the 2020 LiDAR-based Topobathy Digital Elevation Model (DEM) (NOAA 2020) and supplemented by contemporary basemap imagery (ESRI et al. 2025). The primary dataset (DEM2020) is a bare-earth, squared-cell raster featuring a precise 1-meter spatial resolution.

While this 1-meter DEM represents the absolute current standard for accurate elevation modeling, the bare-earth methodology possesses inherent limitations regarding exact runoff simulation. The digital removal of surface structures—including buildings, physical infrastructure, and dense forest canopy—prevents the model from fully resolving the flow-altering hydrodynamics of roofs, walls, curbs, or vegetative undergrowth. Furthermore, subterranean culverts remain unresolved within the DEM, although localized deep fill areas adjacent to roadway embankments frequently indicate their physical presence. Despite these inherent digital artifacts, the derived 1-meter flow paths deliver vastly superior analytical insight into watershed hydrology compared to traditional manual contour delineations.

Hydrologic Monitoring Network The spatial framework integrates active stations from the Comprehensive Water Monitoring Program (Guam P.L. 24-161), jointly managed by WERI and the USGS.

- **South of the Pågu-Adilok Fault**: The physical monitoring network comprises 9 stream/river flow gages and 5 continuous rain gages.
- **North of the Pågu-Adilok Fault**: Monitoring strictly focuses on groundwater aquifer dynamics utilizing Deep Observation Wells (DOWs EX-1, EX-4) and Observation Water Levels (OWLs A-20, A-16), with datasets accessible online.

- **Southern mountains**: The Southern Mountain Rain Gage, jointly maintained by WERI and the NWS (established 2023; initiated by Lander in 2021), operates at the topographic peak intersecting the Humåtak, Ugum, Sadok, and La Sa Fua watersheds.

Real-time telemetric data and precise instrumental parameters are available via the USGS National Water Information System (https://maps.waterdata.usgs.gov/mapper/index.html). Additionally, WERI deployed *MAppFx: Streamflow Duration Curves* (Habana et al. 2024), an interactive spatial visualization interface that executes flow duration algorithms and river flow analyses leveraging this exact gage network (Heitz and Khosrowpanah 2015; Habana et al. 2024).

2.3 GIS Tools

Spatial analyses were executed utilizing ESRI® ArcGIS Pro® (version 3.7). The coordinate reference system across all geospatial files was strictly standardized to UTM, WGS 1984, Zone 55 North. Core geoprocessing relied heavily on the Spatial Analyst toolkit—specifically Hydrology, Map Algebra (Raster Calculator), Extraction, and Zonal Statistics—supplemented by necessary Conversion, Data Management, and Analysis tools. Table 2.1 details the specific geoprocessing tools deployed.

Table 2.1 ArcGIS Pro geoprocessing tools.

Category	Subcategory	Specific Tool
Spatial Analysis Tools	Extraction	*Extract by Mask*
	Hydrology	*Basin*
		Fill
		Flow Accumulation
		Flow Direction
		Stream Order
		Watershed
	Map Algebra	*Raster Calculator*
	Surface	*Contour*
		Hillshade
		Slope
	Zonal	*Zonal Statistics*
Conversion Tools	From Raster	*Raster to Point*
		Raster to Polygon
		Raster to Polyline
	To Raster	*Feature to Raster*
		Polygon to Raster
Data Management Tools	Features	*Feature to Line*
	General	*Merge*
	Generalization	*Dissolve*
Analysis Tools	Overlay	*Erase*

https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/an-overview-of-the-hydrology-tools.htm

Manual feature refinement, spatial preparation, and topological construction were conducted using the Edit tab suite, predominantly leveraging Create, Selection, Edit Vertices, Reshape, Merge, Split, and Clip functionalities. Comprehensive algorithmic documentation for these workflows is provided via the official ESRI ArcGIS Pro Hydrology and Geoprocessing online tool references.

https://pro.arcgis.com/en/pro-app/latest/tool-reference/main/arcgis-pro-tool-reference.htm

To guarantee strict spatial fidelity, rigid raster output parameters were enforced within the Geoprocessing Environments tab. This execution protocol ensured absolute cell size preservation and perfect alignment (snapping) with the baseline DEM throughout all analytical iterations. The mandated environment settings were:

- **Raster Analysis Cell Size**: DEM2020 (1 m)
- **Cell Size Projection Method**: Preserve Resolution
- **Mask**: Domain DEM, Fill Areas, and Fill Areas with low point cell left null
- **Snap Raster**: DEM2020

2.4 Conceptual Model and Process

To achieve a highly detailed hydrologic analysis, this project established a specialized conceptual model specifically engineered to resolve runoff pathways within complex surface depressions—a spatial metric previously unavailable in the *Surface Hydrology of the Northern Guam Lens Aquifer* study. Because a unified, automated script for this specific iteration does not yet exist, mapping nested surface depressions requires a rigorous algorithmic approach incorporating intermediate manual inspections and refinements. Figures 2.1 and 2.2 illustrate the conceptual cross-section and plan view for determining both overflow runoff and internal runoff trajectories within these filled areas.

The initial iteration executes a standard fill-and-accumulation analysis on the DEM to establish the primary overflow runoff paths, tracing the lowest adjacent raster cells continuously down to the coastal river outlets. However, highly permeable, deep limestone dolines do not physically fill to overflow capacity. To accurately model this hydrogeologic reality, fill areas exhibiting a depth greater than 15 feet are assumed completely closed; these were manually delineated and mapped as internal watershed boundaries.

For nested depressions (e.g., FA3 situated within FA2, both contained entirely within FA1), the model forces localized runoff calculations directly into the sinks. This is technically executed by converting the lowest-elevation raster cell (Ls) of a specific fill area DEM into a null value (NoData) "hole". This iterative voiding and filling process is repeated for successive nested depressions until the resulting internal fill area strictly falls below a 50 sqm threshold. This specific 50 sqm stop-condition is enforced because the 1-meter DEM resolution yields crude, overly pixelated runoff paths at smaller scales. Finally, consistent with the spatial parameters established for northern Guam's plateau basins, tributary and fill area watersheds are strictly delimited to areas greater than or equal to 300 sqm.

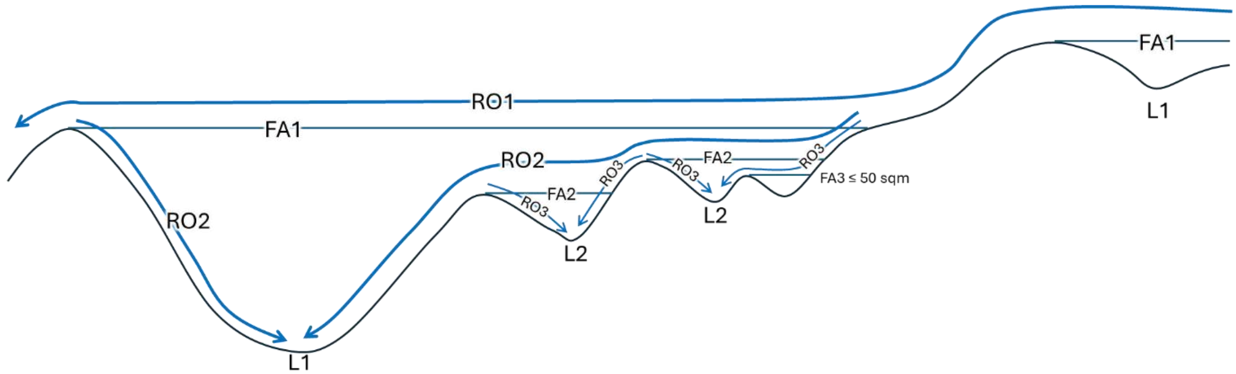


Figure 2.1 Concept cross-section and index of fill areas within a fill area, index lowest points of fill areas, and index runoff path. The algorithm is delimited to fill areas greater than or equal to 50 sqm.

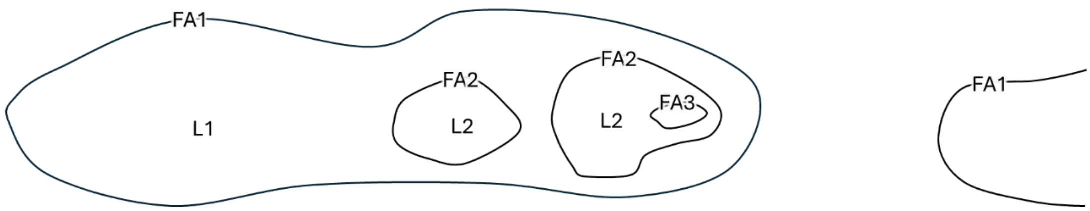


Figure 2.2 Top view concept example of fill areas within fill area (FA1 and FA2). The fill area is limited fill area polygons ≥ 50 sqm.

Comprehensive procedural details regarding these GIS tools, iterations, and delimitations are documented in the Methods section.

3 METHODS

This section details the geospatial methodologies applied to the latest 1-meter DEM to execute a high-resolution hydrologic and terrain analysis of Guam's watersheds. The following GIS analytical workflows generate a refined, high-fidelity suite of hydrologically relevant features and rasters within defined watersheds and surface depressions.

3.1 Initial Domain DEM

To optimize computational processing times and constrain file sizes, an initial DEM domain boundary was established and extracted. This domain explicitly captures the southern watersheds and extends north of the Pågu-Adilok Fault to encompass the central argillaceous plateau basins (Habana et al. 2022). A coastal boundary polygon was manually digitized utilizing DEM hillshade and 50% transparent satellite imagery overlays. The northern boundary is drawn just beyond the Sesonyan Watershed and Pågu Bay to capture inland plateau basins (see Figure 3.1). The *Extract by Mask* tool was then applied using this polygon to isolate the initial processing DEM.

3.2 Initial hydrologic analysis

The preliminary hydrologic and terrain analysis adopts the established methodology from Habana et al. (2022) to further refine the working DEM domain. This sequential geoprocessing workflow comprises the following primary outputs (product | *tools*):

1. Fill area and fill depth | *Fill* and *Raster to Polygon*
2. Fill area watersheds | *Watersheds* (use fill area ≥ 300 sqm)
3. Primary watershed boundaries | *Flow Direction (*filled*) and Basins*
4. Runoff/stream paths | *Flow Accumulation and Stream Order (Strahler)*
5. Tributary watershed divides | *Selection of polyline watershed*
6. Fena Reservoir, Maagas River | *Edit tools (manual refinements)*

All geoprocesses converting rasters to polygon or polyline features enforce the "simplify" parameter to eliminate artificial squared-cell edges.

3.2.1 Fill area and fill depth

Surface depressions were isolated by applying the *Fill* tool to the initial DEM. Map algebra (*Raster Calculator*) was utilized to subtract the initial DEM from the filled DEM, generating the Fill Area Depth (FAD1) raster. Raster cells exhibiting depth values greater than zero were conditioned to a value of 1 and subsequently converted into the initial Fill Area (FA1) polygon features. Polygons exceeding the 300 sqm threshold (FA1GE300) were extracted to serve as the baseline for subsequent fill area watershed delineation.

3.2.2 Fill area watersheds

Fill Area Watersheds (FAW) were delineated around the FA1GE300 polygons. This execution required a standard D8 flow direction raster derived from the initial DEM, utilizing the FA1GE300 features as input pour points. These resulting FAW polygons are

Figure 3.1 Initial domain DEM boundary/area (red line). Above the Pågu-Adilok Fault are the Argillaceous member (blue-white hash area) and Plateau Basins. The polygon is drawn along the coast and above Sesonyan watershed and Mangilao Plateau Basin.

converted into polylines to explicitly determine tributary watershed divides in subsequent steps.

3.2.3 Delineation of plateau basins and watersheds

The *Basin* hydrology tool was selected over the Watershed tool to delineate major parent watersheds and plateau basins, requiring only the filled DEM and its associated flow direction raster. Following generation, basin polygon boundaries were scaled using a graduated line thickness symbology based on defined area classifications (ranging from ≥ 2 sq km down to 2.5K sqm).

- ≥ 2 sqkm
- [1, 2) sqkm
- [0.5,1) sqkm
- [0.25, 0.5) sqkm
- [0.1, 0.25) sqkm
- [50K, 100K) sqm
- [20K, 50K) sqm
- [2.5K, 20K) sqm

Polygons smaller than 2,500 sqm—predominantly isolated coastal fragments—were deemed hydrogeologically insignificant at the 1:12,000 map scale and explicitly excluded from display to prevent visual clutter. Finally, the dataset was manually inspected to delete anomalous plateau basins and fill area watersheds located north of the established Sesonyan and Pågu boundaries, cementing the finalized spatial domain for central and southern Guam (Figure 3.2).

3.2.4 Runoff (or rivers, or streams) paths to fill areas

This geoprocessing step identifies the primary overflow runoff paths flowing into and out of the initial fill areas across the filled DEM. The *Flow Accumulation* tool was applied to the flow direction raster of the finalized DEM domain. Because selecting appropriate flow accumulation thresholds is inherently subjective and dictates map density, iterative threshold testing was required to determine a density suitable for a 1:12,000 scale without overwhelming the cartography.

Once an optimal accumulation threshold was established, values meeting the criteria were converted to binary (1 and 0), and the *Stream Order (Strahler)* tool was executed to generate polyline networks. Because accumulation algorithms artificially route flow perfectly across filled depression surfaces, these synthetic traverse lines were strictly erased from the final dataset using the FA1GE300 polygons as an *Erase* feature.

3.2.5 Tributary watershed divides

Tributary Watershed Divides (TWD) were delineated by leveraging the previously generated fill area watersheds. The FAW polygon features were converted into polylines, which naturally terminate at the connecting intersections of the fill area watershed series. To isolate the true divides, a spatial selection was executed where the FAW polylines intersected the runoff paths and fill area polygons. By switching this selection, the

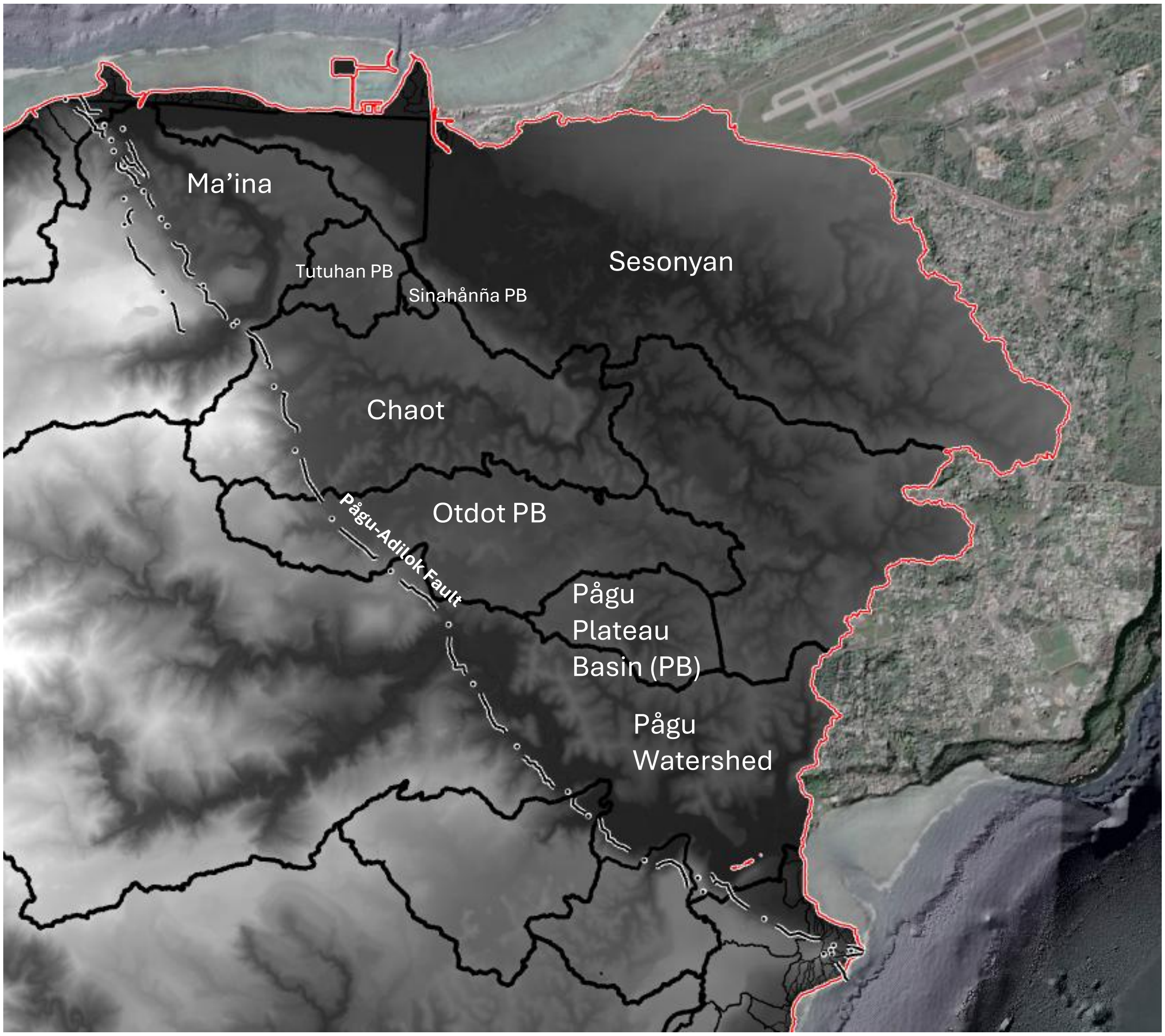


Figure 3.2 Final Guam Watershed DEM Domain for hydrologic analysis. Basin refines the final DEM and scope boundary, north of the Pågu-Adilok Fault. This captures watersheds that continue north of the fault, up to the Sesonyan Watershed, its adjacent boundaries inland, and plateau basins. Pågu, Chaot, and Ma'ina Watersheds also have parts of its areas north of the fault, and Otdot Plateau Basin south of the fault.

remaining independent segments were extracted as the final TWD polyline features, followed by rigorous manual inspection and refinement at the terminal nodes.

3.2.6 Fena reservoir surface

The raw bare-earth DEM generates an irregular, triangulated surface profile over the Fena Reservoir, producing severe digital artifacts during runoff simulation. To correct this, a precise maximum fill area was established by determining the exact elevation of the reservoir's lowest spillway point. A bounding polygon was then digitized along the maximum fill boundary using high-resolution aerial imagery (ESRI et al. 2025). This definitive water surface polygon was subsequently utilized to erase and override the erroneous initial runoff paths generated over the reservoir extent.

3.3 Runoff Paths within the Initial Fill Area

To resolve the complex hydrodynamics within surface depressions, a rigorous iterative geoprocessing workflow was executed on the Fill Area DEMs. The primary objective is to delineate internal runoff paths within the first fill area (FA1) and recursively process all nested depressions down to a strictly defined 50 sqm threshold. Runoff paths mathematically modeled skimming over filled surfaces are systematically erased. For example, referencing the conceptual model, ROP1 is trimmed by FA1, and ROP2 is erased by the FA2 polygon, repeating sequentially until the remaining nested fill area is less than 50 sqm.

3.3.1 Fill Area 1 (FA1), runoff and overflow runoff paths

This process will use a suggested naming convention of files produced for the ease of keeping track of the complex management of files. File naming must be well managed especially in the iteration process. Also, raster files have limited name lengths. The first fill area (FA1) was determined by subtracting the DEM from the filled DEM, step 1, which result in a fill area depth (FAD). Raster calculator converts the FAD for rasters greater than zero, set to 1, produces FA1. Then the FA1 is converted to a simplified polygon (FA1Pol). Then the area of the polygon is calculated, extracting the polygons greater than or equal to 300 sqm (FA1GE300). Step 2, use FA1GE300 as the mask form to extract the fill area DEM from the original DEM (FA1DEM). Step 3, determine the lowest point (L1) of each FA1DEM, using Zone Stat, min, to create the FA1 minimum value (FA1Min). Step 4, set the L1 raster point to zero and the rest of FA1 to 1, using raster calculator. This is done with the conditional function, such as true that FA1Min is equal to FA1DEM set the cell to zero, and false set the cell value to 1. Step 5, set the lowest point to null where the raster cell is the lowest value in the FA1DEM. This can be done with map algebra (raster calculator), where FA1DEM has a null at L1 (FA1DEML1), set conditional to FA1L1 is equal to one, set equal to FA1DEM, other case (0 or null) is null. This will bring the runoff path within FA1 increased accumulation towards the L1, null cell. Step 6, create a filled DEM from using Fill, thus FiFA1DML1 from FA1DEML1.

Next steps will create the runoff paths over FiFA1DML1. Step 7, apply flow direction to FiFA1DML1, producing FDFA1DML1. Then, Step 8, use flow accumulation to FDFA1DML1, resulting in AccFDFA1L1. The flow accumulation file is examined for selecting values that would present a runoff path that has enough detail when map is zoomed into. Thus, symbology inspected using two color conditional value, accumulation greater than or equal to 300 was converted to 1 and less than that set to 0, floacc1-300. Flowacc1-300 raster and input flow direction are used to produce stream order, output as Strahler1. Next, FA2 is used to erase runoff paths that skim over the fill areas. Also, all L1s are converted to points.

In summary, strict file naming conventions are mandatory during this sequence to manage the complex geodatabase and accommodate rigid raster name length limitations. The foundational execution requires isolating the lowest raster cell elevation (L1) within the FA1 DEM, converting it to a null value (NoData), and forcing accumulation algorithms toward this localized sink. The simplified GIS geoprocessing notation is as follows:

1. **FillDEM**, obtained the Fill Area 1 to obtain a filled DEM | (FA1) *Fill Analysis (Fill):*
   - Fill Area Depth (FAD), *Raster Calculator* (RC): **FAD** = **FillDEM** - **DEM**
   - FA1, RC: **FA1** = **FAD** > 0
   - FA1 to polygon (FA1Pol), *Raster to Polygon*: **FA1** → **FA1Pol**
   - Extract FA1Pols ≥ 300 sqm; attribute table (create real number field for area) *Calculate Geometry* (area sqm); *Select by Attribute* area ≥ 300 sqm; *Data, Export Features*: **FA1GE300**
2. **FA1DEM**, obtain fill area DEMs (≥ 300 sqm); *Extract by Mask* (FA1GE300)
3. **FA1Min**, find lowest elevation in FA1DEM; *Zonal Statistics* (minimum) (ZS-min)
4. **FA1L1**, set FA1DEM minimum elevation raster cell (L1) to 0 and other FA1DEM to 1, *RC-conditional* (RC con): **FA1L1** = Con(**FA1Min** == **FA1DEM**, 0,1)
5. **FA1DEML1**, create a null raster cell at L1 in FA1DEM, RC-con:

   FA1DEML1 = Con(**FA1L1** == 1, FA1DEM)
6. **FiFADML1** | *Fill* FA1DEML1 → **FiFA1DML1**
7. **FA2GE50**, obtain FA2 as raster and polygon:
   - RC-con: **FA2** = Con(FiFA1DML1 - FA1DEML1 > 0, 1)
   - *Raster to Polygon* (RtoP): FA2 -> **FA2Pol**
   - FA2 ≥ 50 sqm → **FA2GE50** (see step 1, 3-4 bullets)
8. **FDFA1DML1**, produce flow direction raster of FiFA1DML1 | *Flow Direction* → **FDFA1DML1**
9. **AccFDFA1L1**, produce runoff paths from FDFA1DML1 | *Flow Accumulation* → **AccFDFA1L1**
10. **ROP2**, produce stream order (Strahler) of runoff paths:
    - Determine accumulation to convert, e.g. cell values of AccFDFA1L1 ≥ 300, convert those cells into ones, and lesser values to either null (NoData) or any value less than 1; RC-con: **Acc110** = Con(AccFDFA1L1 ≥ 300, 1) or Con(AccFDFA1L1 ≥ 300, 0)
    - Produce runoff path with *Stream Order* (Acc110, FDFA1DML1) → **SOFA1**
    - Convert SOFA1 to polyline, *Raster to Polyline* (StrFA1): **ROP2**
    - Erase the runoff paths lines that go over the internal fill areas of FA1, *Erase FA2GE50*
11. **L1Pnt**, create an L1 Raster and convert to Point: **L1** = Con(FA1L1 == 0, 1), L1 → **L1Pnt**

ROP2 and L1 will later be merged with all ROPs and Ls after all processes are completed.

3.3.2 FAx subsequent fill areas and runoff path iterations

Polygons within FA1, will be {FA2, FA3, ..., FAn}, where FAn is the last fill area greater than or equal to 50 sqm. The following is the note process, similar to the steps above. The process within are repeated to further obtain the minimum FA within the first FAs. The file naming here are indexed as x and y, iteration integers. are the file name progress iteration (e.g., FAxDEM, FA2DEM as 2nd iteration on Fill Area 2).

The second fill areas (FA2), the process begins with extraction of FA2 DEM. For the iteration indexes, consider x = 2 and y = 1 to start this iterative process. Next iteration will be x = x+1 and y = y+1, and so forth. The following is a simplified notation for the internal fill area.

1. **FAxDEM** | *Extract by mask*: **FAxDEM** = **FAxGE50** (DEM, from Sect. 3.4.1, Step 7)
2. **FAxMin**, determine lowest elevation | *ZS-min* → **FAxMin**
3. **FAxLx**, convert Lx to 0 and FAx to 1 – FaxLx | *RC*: **FAxLx** = Con(FAxMin == FAxDEM, 0,1)
4. **FAxDEMLx**, create a Null cell at Lx with FAxDEM | *RC*:
   FAxDEMLx = Con(FAxLx == 1, FAxDEM)
5. **FilFAxLx**, fill FAxDEMLx | *Fill* → **FilFAxLx**
6. **FDFFAxLx** | *Flow Direction to* FilFAxLx → **FDFFAxLx**
7. **AccFDFFAxLx** | *Flow Accumulation* to FDFAxLx → **AccFDFFAxLx** | AcFDFFAxLx01 (GE100)
8. **SOx** | Stream Order, *SO (Strahler)*
   - convert accumulation to 1 and 0 (similar to previous section, Step 10)
   - using rasters FDFFAxLx and AcFDFFAxLx01 | SOFAxLx; Convert raster to line → SOx
9. **SOxE50** | *Erase* SOx with FAyGE50 → SOxE50
10. **FAyGE50** | *RC* FAy = Con(FilFAx - FAxDEMLx > 0, 1); Convert *raster to polygon*, FAy → FAyPol
11. **Lx** and **LxPnt**, create Lx Raster and Point: RC | Lx = Con(FAxLx == 0, 1); Lx → LxPnt

Next iteration, x = 3 and y = 2, repeat steps 1 to 11.

Six iterations were made successfully, maintaining FAs ≥ 50 sqm. On the seventh iteration, there were no FAs ≥ 50 sqm. For data management and result inspection, each iteration was done in a new map tab, and each tab indexed by successive step. The next step were feature final processes.

3.3.3 Feature clean-up and final processes

All terminal sink points (L1Pnt to LnPnt) and Stream Order polylines generated across the iterative loops were consolidated using the *Merge* tool. To optimize ArcGIS Pro rendering performance, both resulting feature classes were simplified into multipart features and applied *Dissolve* geoprocess.

3.3.4 Other features included in the Map

To maximize cartographic utility, supplemental GIS features were created or modified from local sources and included in the map. The features created were contours (shapefile feature type - polylines), watershed groups (polylines), Internal basin/watershed boundary (polylines), highlight plateau basin boundaries (polygons), surface water visible in imagery (polylines and polygons), some wetland areas (polygons). Highways (source: Guam BSP 2012) were included and labeled. For the raster fill area depth (FAD), a color symbology was decided.

The contour features were processed using *Contour* and the initial DEM. Two files of contour intervals (100’ and 50’) were generated. The hundred feet interval contours were labeled, and the 50’ contours were less thick and ghostly. Certainly, this could have been done with a single file. The two files were just simple to activate separately. The two contours were dissolved for faster display.

The groups, internal plateau basin/watershed boundary, highlighted plateau basins, surface water visible in imagery, and some of the wetlands were created manually using edit tools and create. Groups, internal plateau basin/watershed boundary, and highlighted plateau basins/watershed boundaries were based on the boundaries of fill area watershed. Polylines used fill area watershed boundaries using either create-trace of copying and pasting from the polyline version of the fill area watershed boundary.

3.4 Improved Method for Runoff Paths

An optimized methodology for delineating runoff paths was subsequently developed. Rather than isolating sinks progressively, this refined approach simultaneously extracts all fill area low points from the primary and nested fills while adhering to established area delimitations. This streamlined technique requires significantly fewer geoprocessing steps and was successfully deployed for the concurrent northern terrain update (currently in progress).

3.5 Place Names of Hydrologic Feature and Select Landmarks

A couple of hydrologic watershed maps with place names were submitted to Kumisión I Na’an Lugåt Guåhan (Guam Place Name Commission), for determining CHamorro place names and spelling of plateau basins, watersheds, rivers, mountains, landmarks, bays, points, and historic places/areas. Interim watershed boundaries and feature nomenclature were established using georeferenced overlays of the 1954 AMS (AFFE) Edition 1 Guam, Quadrangles, Mariana Islands-Island of Guam (USGS 1968, 1975), ESRI (2025), and Google Earth™. Several interim maps were submitted to the Guam Place Name Commission; their recommendations will be used to update the map.

3.6 Hydrologic Map, and GIS Files

The final map layout is formatted to an $8' \times 6'$ (portrait) locked to a 1:12,000 scale. The geospatial hierarchy is strictly ordered to prioritize hydrologic clarity, stacking FAD point data, surface waters, watershed divides, internal basins, and finalized Strahler runoff paths over the topographic basemap and contour networks.

The map layers (features and rasters) were organized:

1. Fill area depth point
2. Surface water seen in imagery
3. Tributary watershed divide
4. Watershed group boundary
5. Watershed/plateau basin
6. Springs
7. Plateau basin highlight
8. Internal basin boundary
9. Watershed of fill area ≥ 300 sqm
10. Fena max fill
11. Runoff path (Strahler)
12. River Fill area
13. 50’ and 100’ contour

The place names were ordered:

- Places
- Coastal names
- Site landmark
- Point
- Bay
- Plateau basins and watersheds

The next section exhibit the results.

4 RESULTS AND DISCUSSION

This section presents the finalized spatial datasets, hydrologic topography, and distinctive features of the Hydrologic Map of Guam Watersheds and its accompanying terrain analysis.

Derived from the 2020 bare-earth DEM, the primary mapping results establish a ≥ 300 sqm spatial threshold for large fill areas. This optimizes GIS rendering performance while capturing the distinct terrain features of karst surface depressions and alluvial wetlands. The hydrologic analysis resolves complex overflow scenarios and multi-iteration runoff pathways across Guam's argillaceous limestone and cockpit karst topographies. It explicitly identifies internal drainage basins, low points in sinkholes and surface depressions, and artificial depression artifacts caused by roadway embankments. The analysis also refines the classic river-valley watershed and tributary boundaries of the volcanic terrains.

Finally, these derived features delineate 90 individual watersheds and 13 watershed groups with provisional place names. The distribution of the 2026 GIS layers and digital map is detailed and accessible via the Guam Hydrologic Survey website.

4.1 Initial Hydrologic and Terrain Analysis

The following datasets were generated during the initial hydrologic and terrain analysis and incorporated into the final map layout. Except for the FAD raster, all datasets are vector shapefiles:

- Fill Area (FA1) – Polygon
- Fill Area ≥ 300 sqm (FA1GE300) – Polygon
- FA1 < 300 sqm and internal Fill Areas (2-6) ≥ 50 sqm (FALT300GTE50) – Polygon
- FA1 Depth (FAD, ft) – Raster (1 m spatial resolution)
- Low Point 1 (LP1) – Point
- Fill Area Watershed (FAW) – Polygon
- Overflow runoff path (Run Off Path 1) – Polyline
- Tributary Watershed Divide (TWD) – Polyline
- Basin (as plateau basins and watersheds) – Polygon

The FA1 polygon features represent areas ranging from the base 1 sqm DEM spatial resolution (simplified to polygon triangles at half-resolution) to continuous areas exceeding 0.6 km^2, excluding the Fena Reservoir. Small, densely clustered FA1 polygons (Figure 4.1) within alluvial valleys spatially coincide with known wetlands. While this clustering serves as a wetland indicator, caution is required, as similar terrain features occur over low-slope karst topography. Instructions for accessing the complete feature list are provided in Section 4.5.

The FA1GE300 dataset (Figure 4.2) was delineated using criteria from Habana et al. (2022). A spatial threshold of ≥ 300 sqm was established to delimit "large" fill areas. This threshold also ensures the generation of Fill Area Watersheds (FAW) at a mappable scale

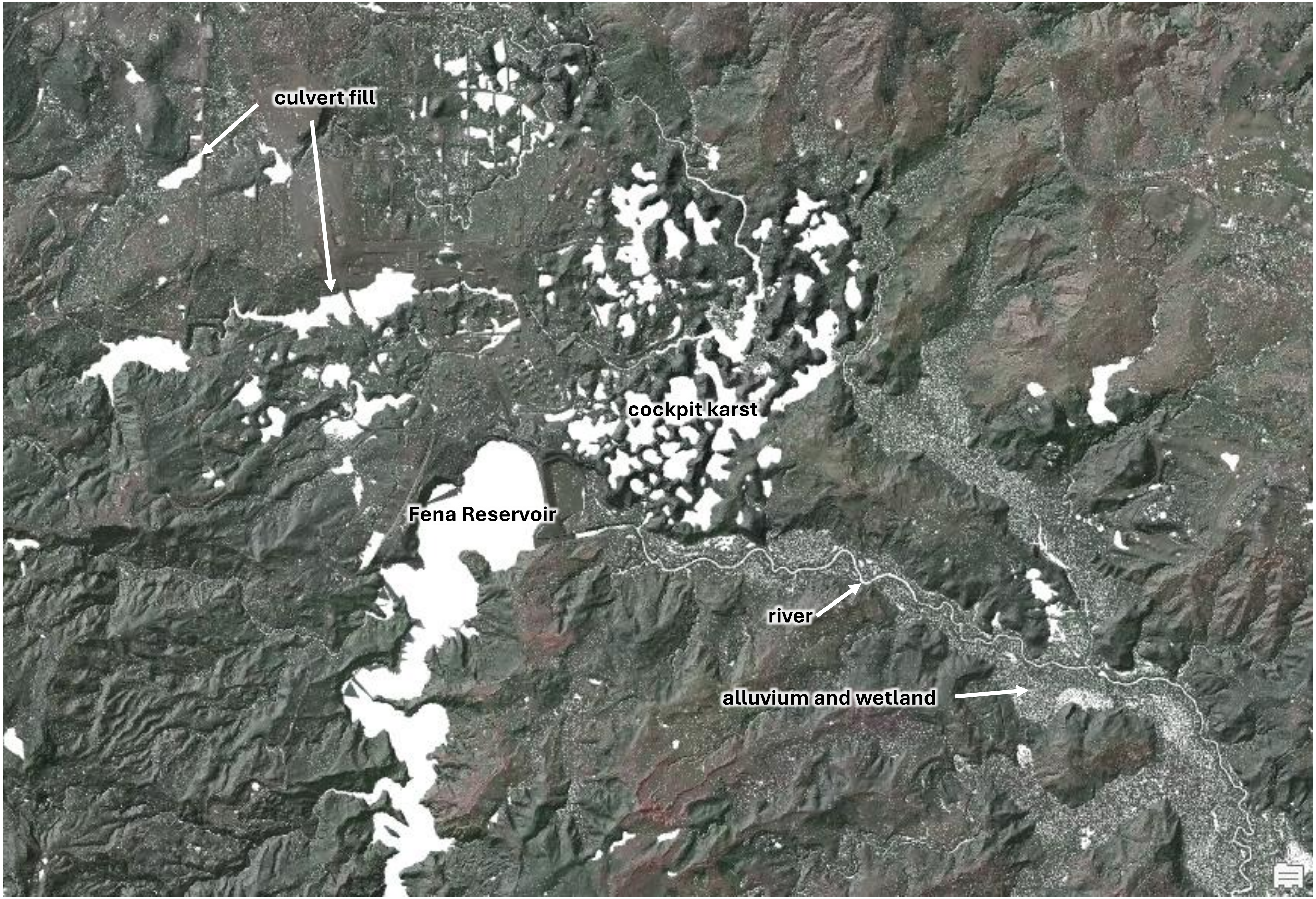


Figure 4.1 Sample of FA1.

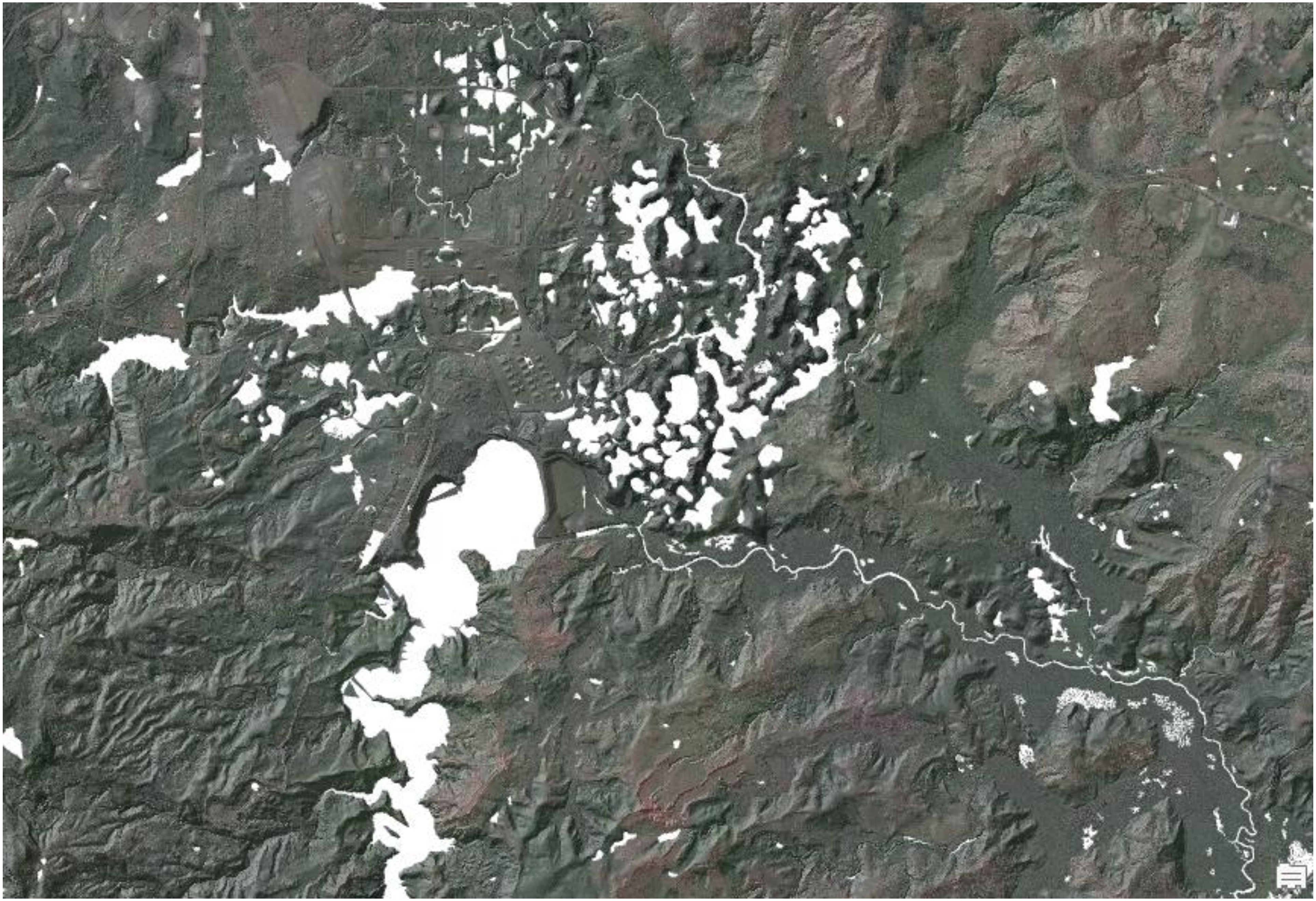


Figure 4.2 Sample of FA1GE300.

(Figure 4.3), optimizing file management and reducing polygon clutter in the final map layout.

Raster pixelation becomes noticeable at display scales of 1:1,200 and below; consequently, smaller fill areas exhibit cruder geometric shapes and less precise area calculations. To optimize rendering performance in ArcGIS Pro, the final map utilizes two fill area shapefiles. The FALT300LT50 polygons were processed using the Dissolve tool to create a single multipart feature, significantly improving rendering times. For context, the undissolved FALT300GT50 dataset contains over 10 million individual polygons, whereas FA1GE300 contains approximately 300,000.

FAD raster values were extracted using a mask limited to the FA1GE300 areas. Figure 4.4 illustrates the FAD raster symbology, classified into a 10-interval depth color scheme:

- (0-0.5]' | white
- (0.5-1]' | light blue
- (1-5]' | blue
- (5-10]' | green
- (10-15]' | yellow
- (15-20]' | orange
- (20-25]' | red
- (25-30]' | purple
- (30-40] | violet
- > 40' | black

The maximum calculated fill depth is 134 ft, located within the La Sa Fua Watershed. This extreme value likely represents a bare-earth DEM artifact requiring future field verification.

Subsequent analysis delineates the overarching basins encompassing the fill area watersheds, which combine to form tributary watersheds. This hierarchical approach defines both classic river-valley watersheds and plateau basins, and establishes the refined inland boundary north of the Pågu-Adilok Fault (Figure 4.5). Although this geoprocessing iteration generated numerous small coastal basins, features under 2,500 sqm were excluded from the display to preserve clarity. The remaining watershed and plateau basin boundaries utilize graduated line thicknesses to represent distinct area size classes.

The bare-earth DEM was extracted by mask to the refined domain boundary, followed by flow accumulation geoprocessing to derive runoff pathways. The initial runoff network was modeled across a filled DEM; grid cells with flow accumulation values ≥ 300 were selected and classified using the Strahler stream ordering method. Because this step utilized a filled surface, flow accumulation across simulated depressions produced artificial linear stream segments traversing low-gradient terrain (Figure 4.6). These synthetic traverse lines were removed using the Erase tool—with the FA1GE300 polygons (Figure 4.2) and the Fena Reservoir boundary serving as erase features—yielding the finalized overflow runoff paths (Figure 4.7).

The filled DEM served as the baseline for determining plateau basins and river-valley watersheds. Raw basin features (Figure 4.5) derived from the initial fill analysis underwent manual refinement via visual inspection of river networks, ridgelines, and FAW delineations. Based on regional precipitation extremes, fill areas with depths exceeding 15 ft were deemed incapable of overflowing during maximum-intensity rainfall; thus, they

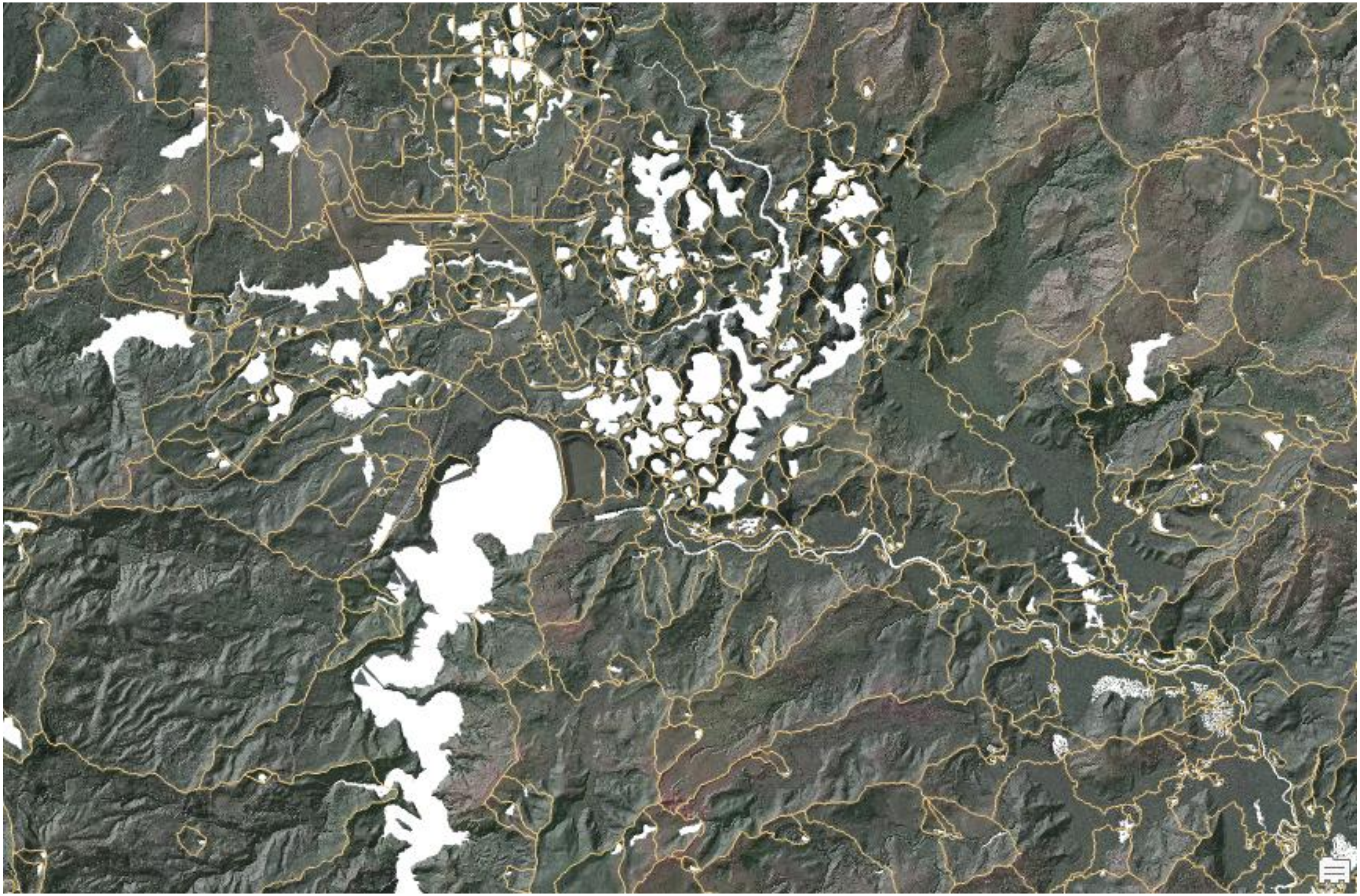


Figure 4.3 Sample of FAWs, yellow polygon area boundary.

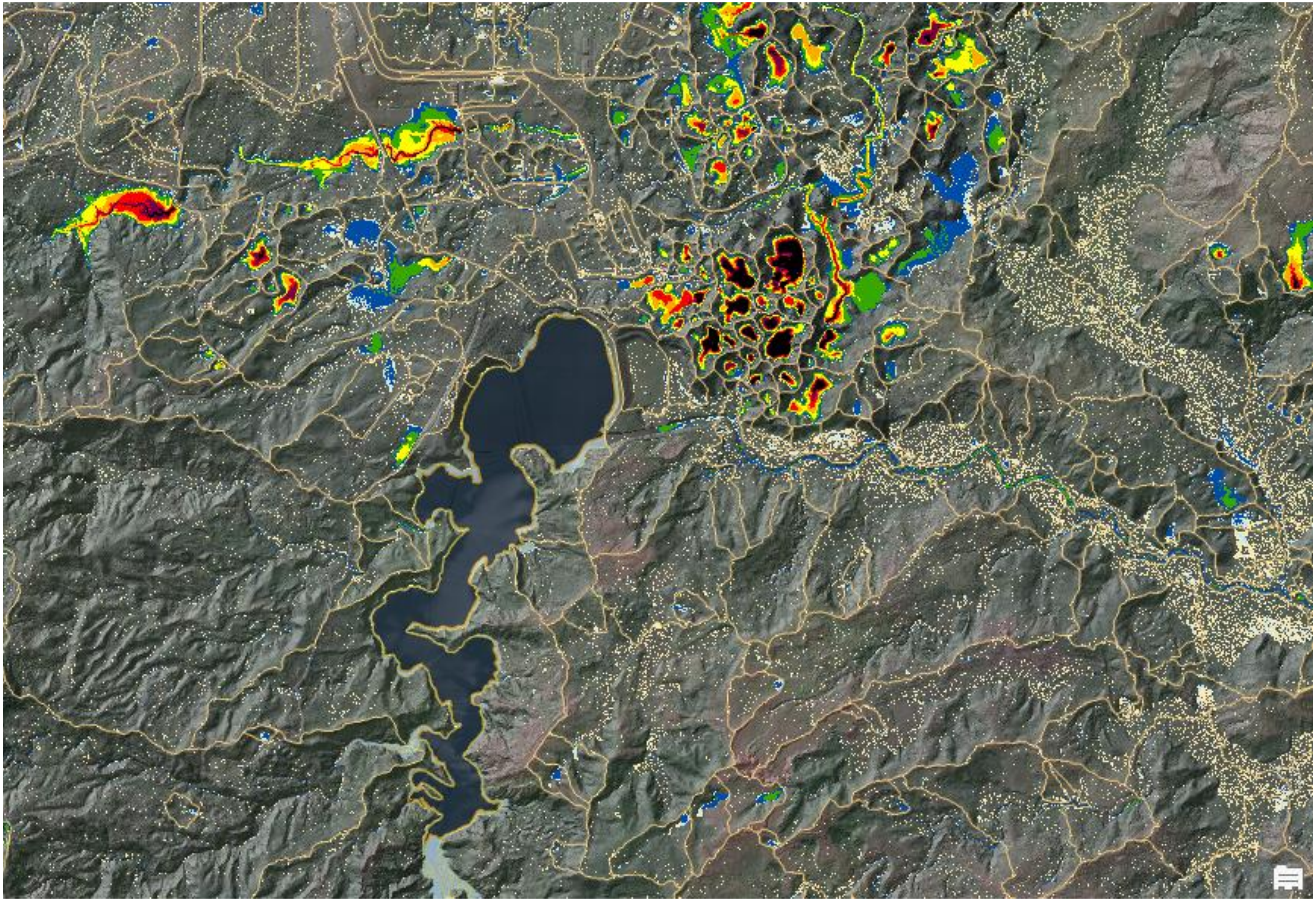


Figure 4.4 Sample of FAD, Maemong limestones, cockpit karst.

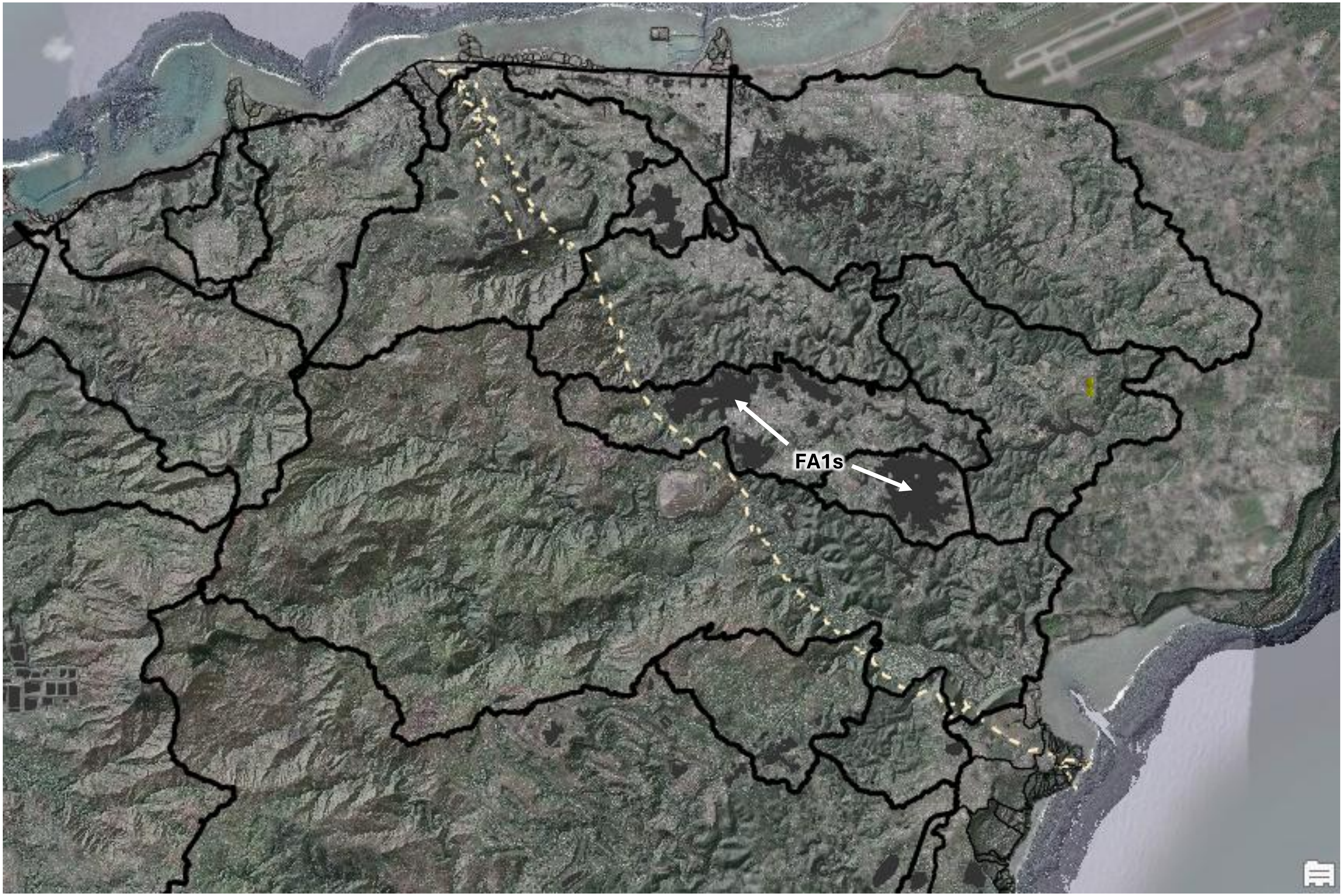


Figure 4.5 Sample of basins (classic watershed and plateau basins) and refined domain. North of Pågu-Adilok Fault (dashed line) refined inland boundary of watersheds. Notice the thin lines set for small coastal basins.

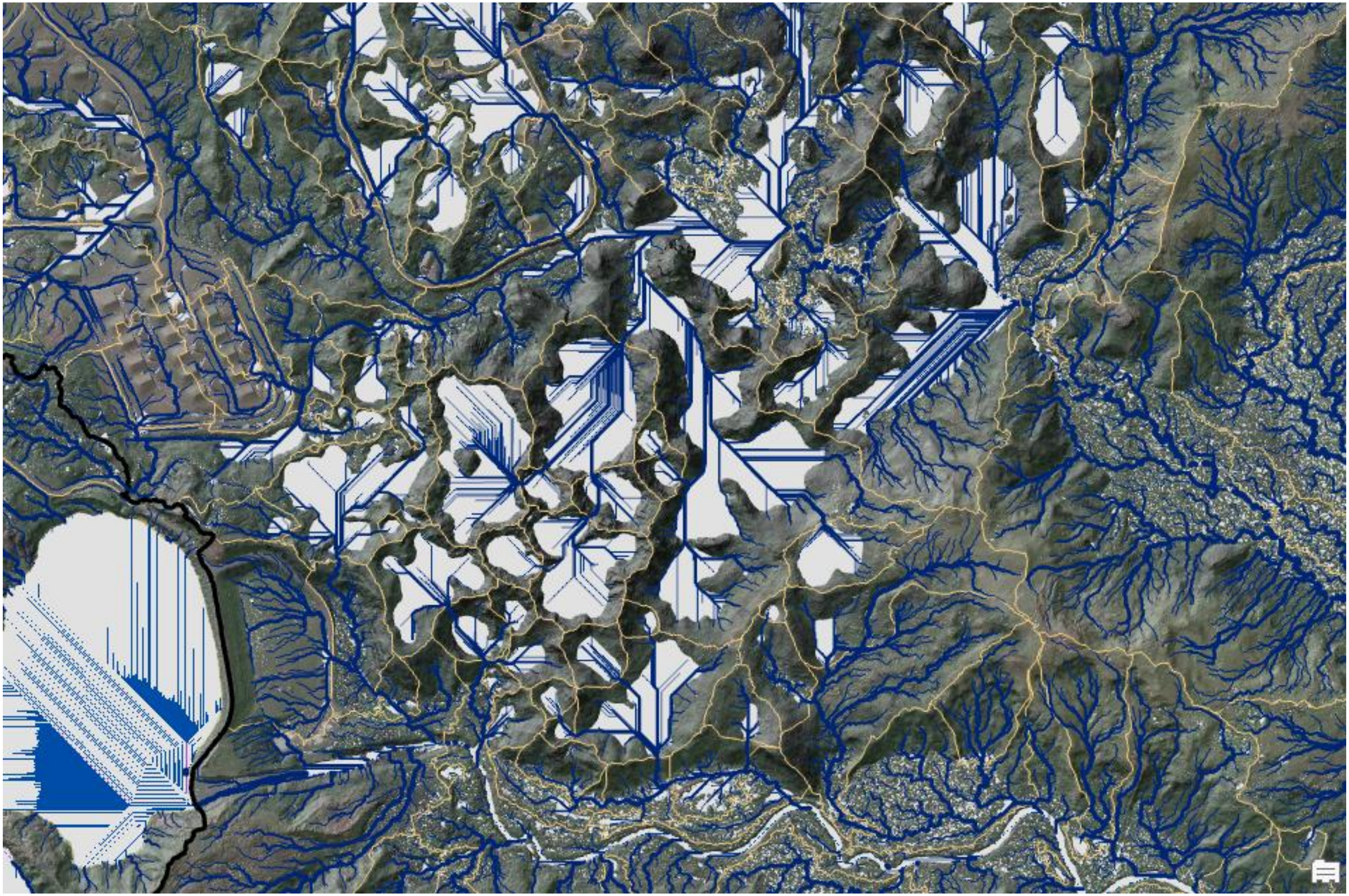


Figure 4.6 Sample of first runoff paths, accumulation. Accumulation lines skim across filled areas and are later deleted using fill area and Fena polygons. The results for overflow runoff paths.

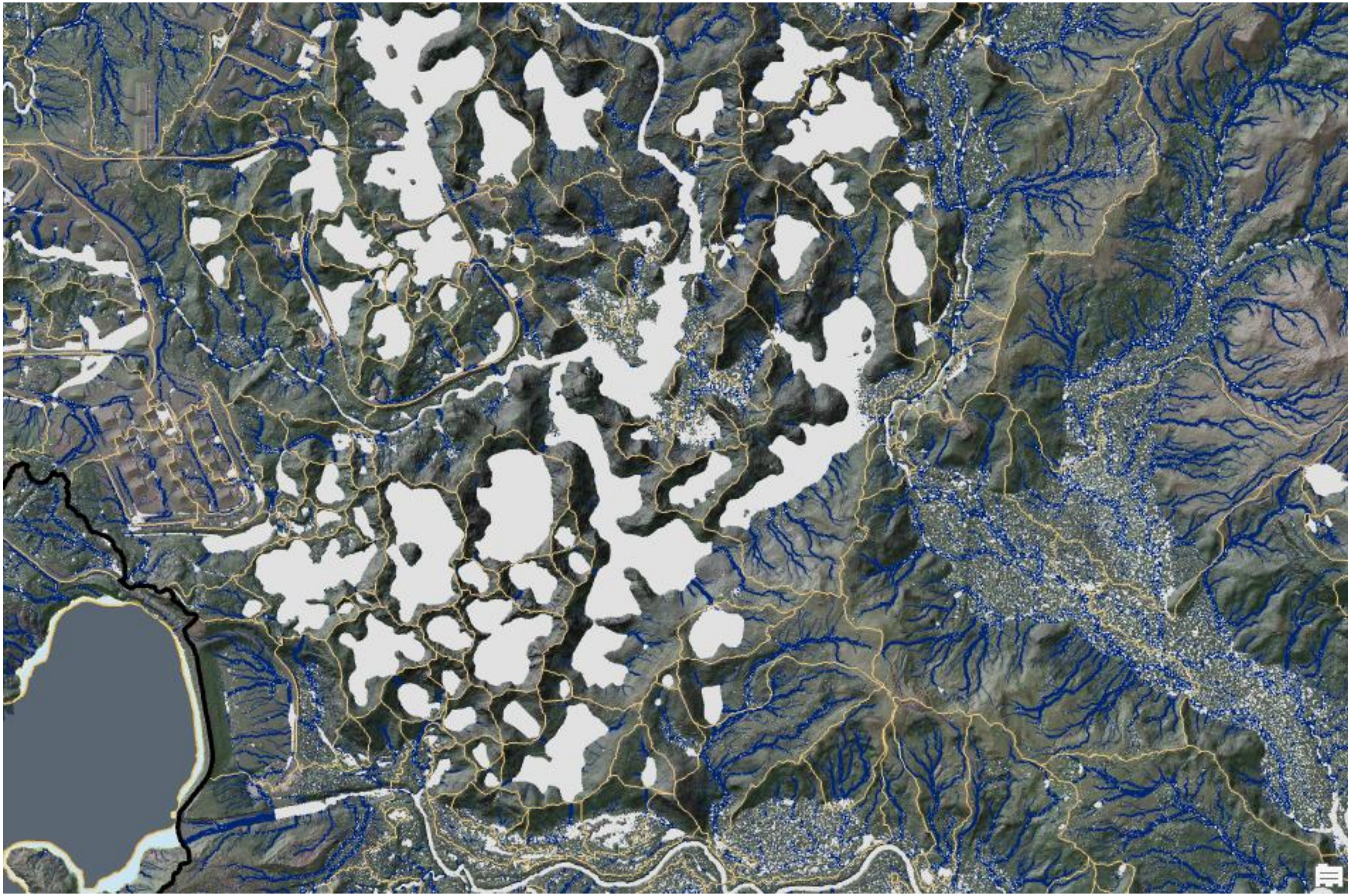


Figure 4.7 Sample of first runoff paths, outside of fill area (≥ 50 sqm), accumulation. Selecting first run accumulation, then erased with fill area (≥ 50 sqm) and Fena polygons.

were designated as closed internal basin boundaries. Figures 4.3 through 4.6 illustrate the analyses and runoff paths used to establish these internal boundaries and their tributary divides. The resulting tributary divides and corresponding fill area sub-watersheds are displayed in Figure 4.8.

Finally, major surface water bodies were delineated as polygon features. The Fena Reservoir boundary was defined through a composite tri-layer approach: traced satellite imagery, the spillway overflow point elevation (maximum fill capacity), and a DEM-derived triangulated surface area trace (Figure 4.9). This maximum-fill elevation polygon served as a clip feature to extract all intersecting vector shapefiles. Secondary surface water bodies were digitized directly from basemap satellite imagery (Figure 4.10). Note that future aerial imagery may not align perfectly with these static polygons due to seasonal water level fluctuations, vegetative changes, or minor georeferencing shifts in basemaps.

Additional internal basin boundaries were manually delineated via visual inspection of fill areas with depths ≥ 15 ft. The finalized watershed boundaries, overflow runoff paths, and tributary watershed series dictate the internal basin boundaries, comprising:

- Internal fill area
- Internal Fill Areas ≥ 50 sqm
- Tributary watershed divide
- Fena Reservoir

Features within the "Internal Fill Areas ≥ 50 sqm" dataset were derived from the second and third fill area geoprocessing iterations. The geoprocessed Fena Reservoir fill area was ultimately replaced with a manually edited polygon digitized directly over ArcGIS Pro basemap imagery.

4.2 Fill Area Runoff Path, Accumulation

A significant technical advancement in this study—unprecedented in the northern Guam hydrologic analysis—is the delineation of internal runoff paths within fill areas. The geoprocessing workflow applied six successive iterations until no internal fill areas ≥ 50 sqm remained; representative samples are illustrated in Figures 4.11 through 4.13. The majority of these internal fill areas coincide spatially with argillaceous limestone formations. By the sixth iteration, only a single fill area remained. In each referenced figure, the displayed elevation contours derive directly from the bare-earth DEM. The resulting runoff paths across all iterations were merged into a single consolidated shapefile, as shown in Figure 4.14 within the Maagas River basin.

Other notable features captured include roadway culvert crossings and refined internal basin boundaries. Figure 4.15 depicts a culvert crossing that generated an artificially deep fill area on the upstream side of the roadway. This localized deep fill is a classic geoprocessing artifact: executing the fill algorithm across a bare-earth DEM where a road embankment bisects a natural drainage path creates an artificial depression. Because bare-earth DEMs do not account for subterranean culvert pipes, the simulated water surface artificially backs up to the crest of the road embankment.

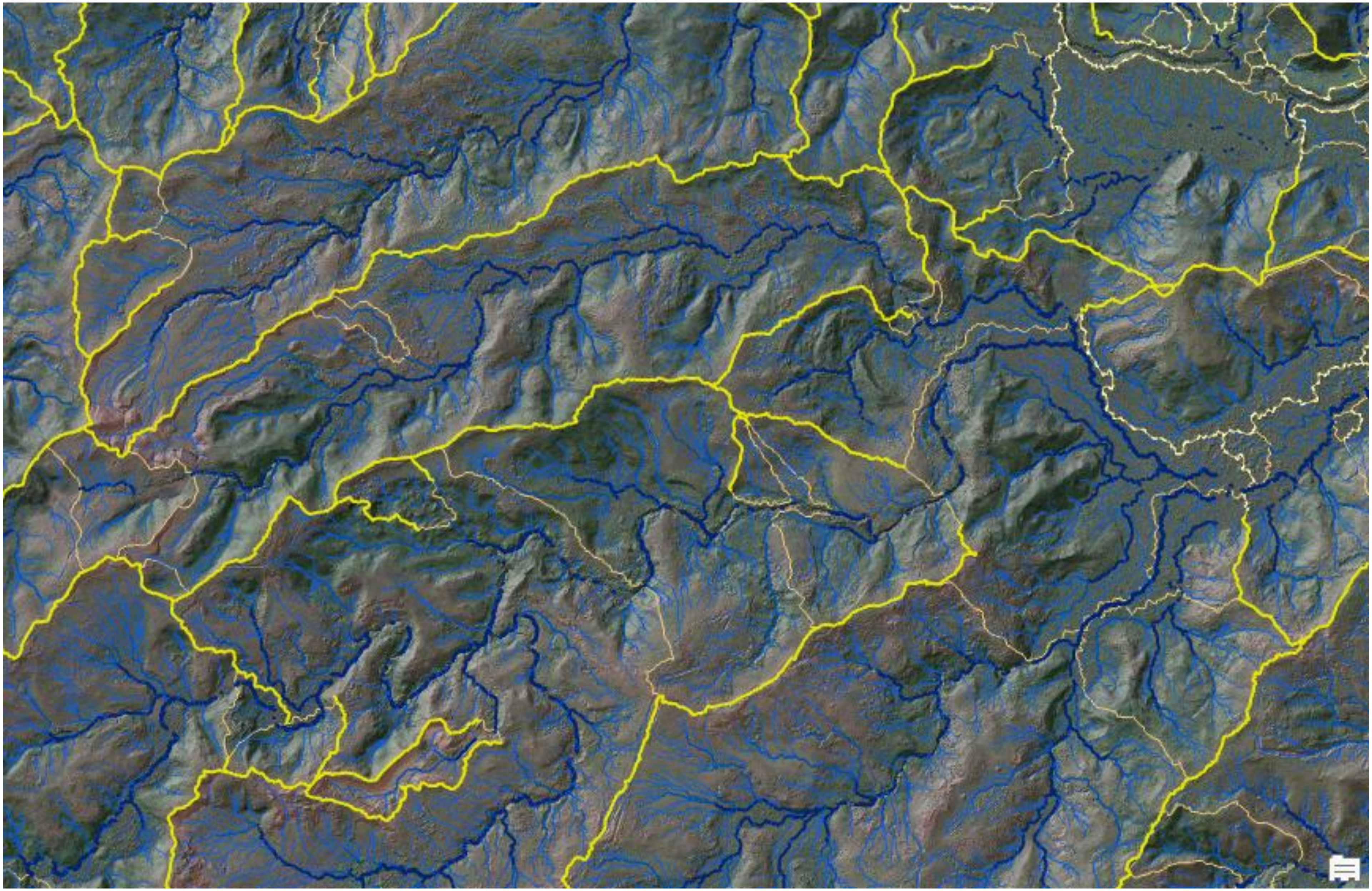


Figure 4.8 Sample of tributary watershed divide (yellow). Tributary watershed divide (TWD, see Chapter 2) is first derived from a deselection technique with fill area watersheds (thin lined polygons), runoff paths, and fill area (≥ 300 sqm). TWD are further refined with manual edits at terminal or intersecting streams.

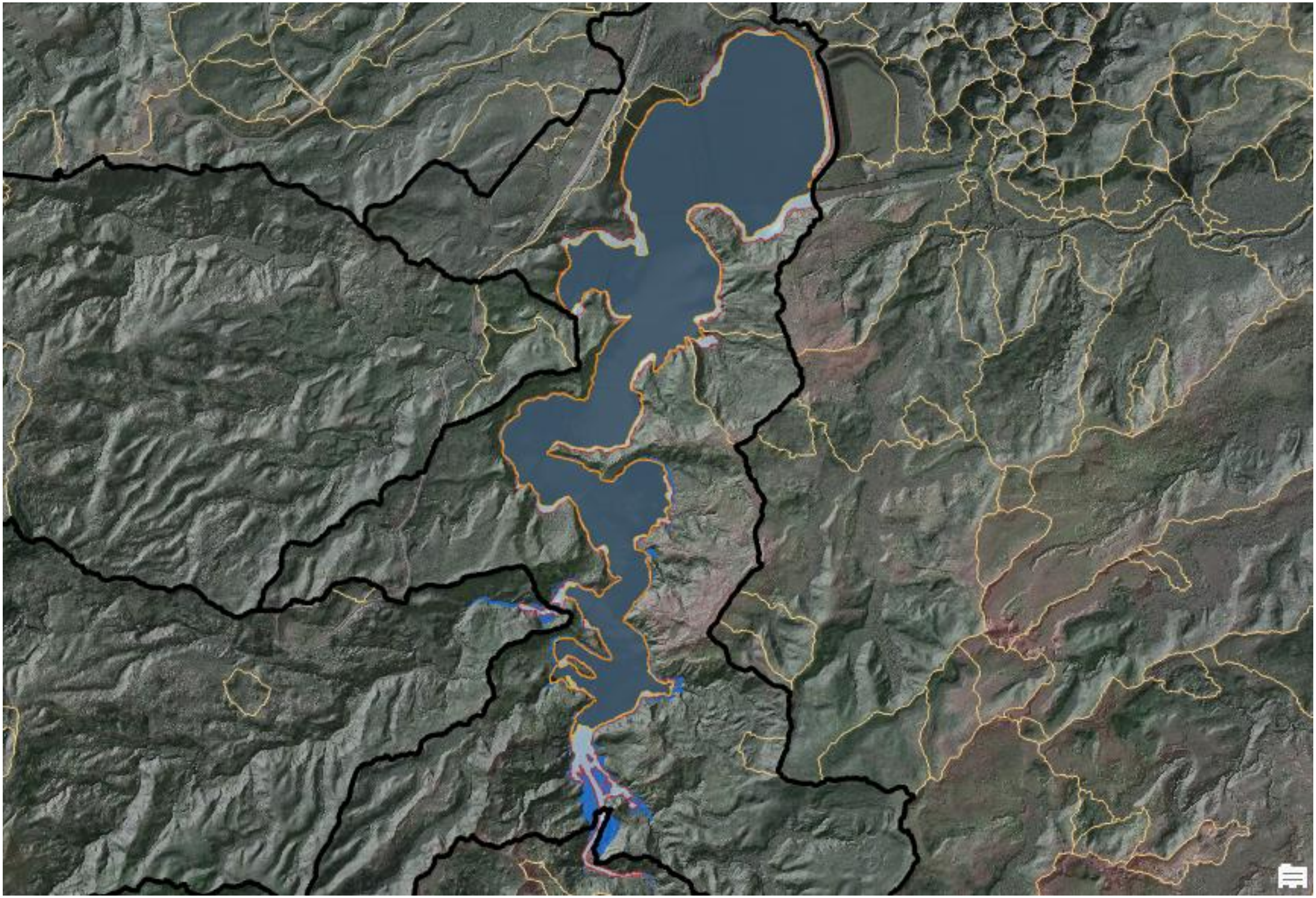


Figure 4.9 Fena reservoir. Fena reservoir has three layers; max fill, satellite image filled, and DEM triangular-surface boundary.

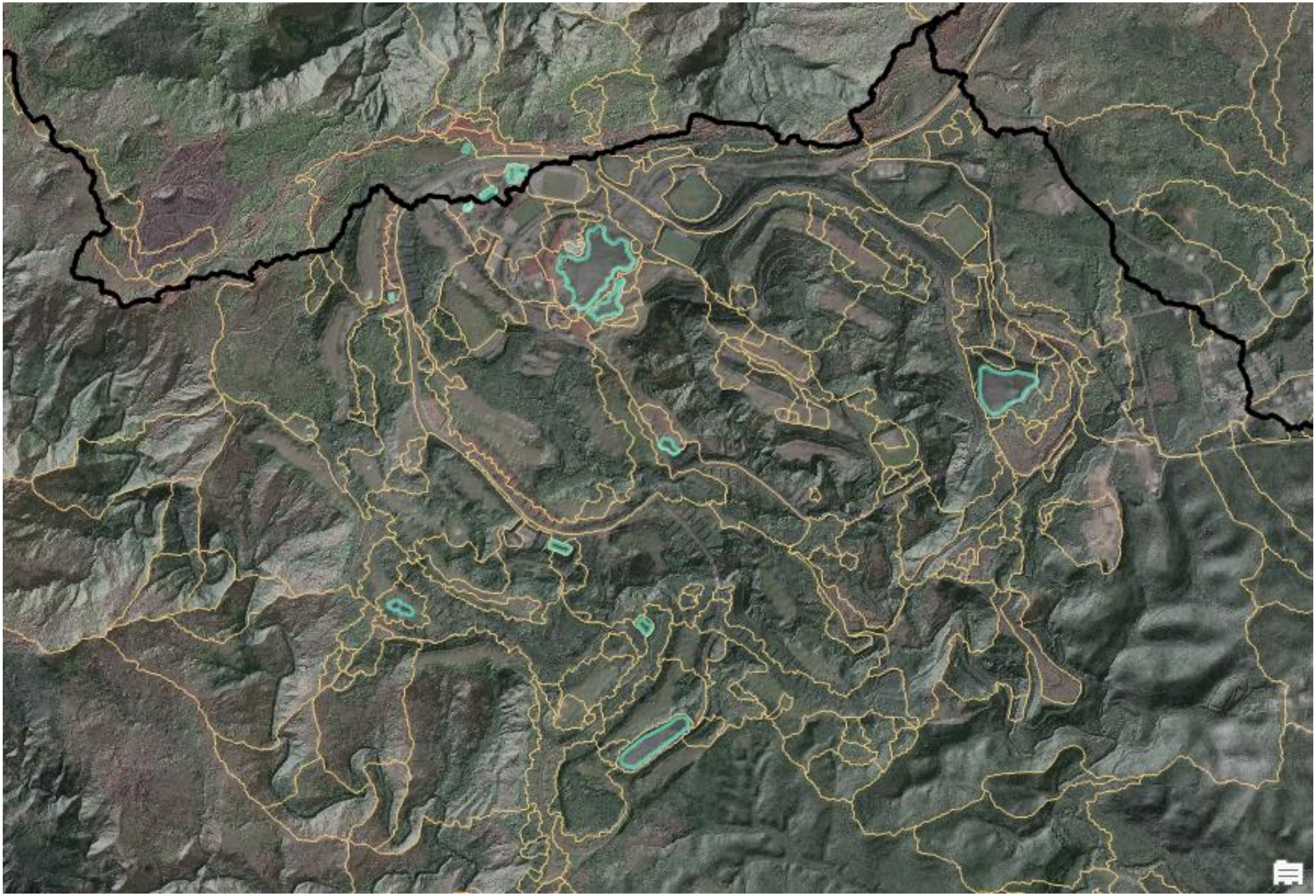


Figure 4.10 Sample surface waters (green line boundary), found from satellite imagery (ESRI 2024 and 2025).

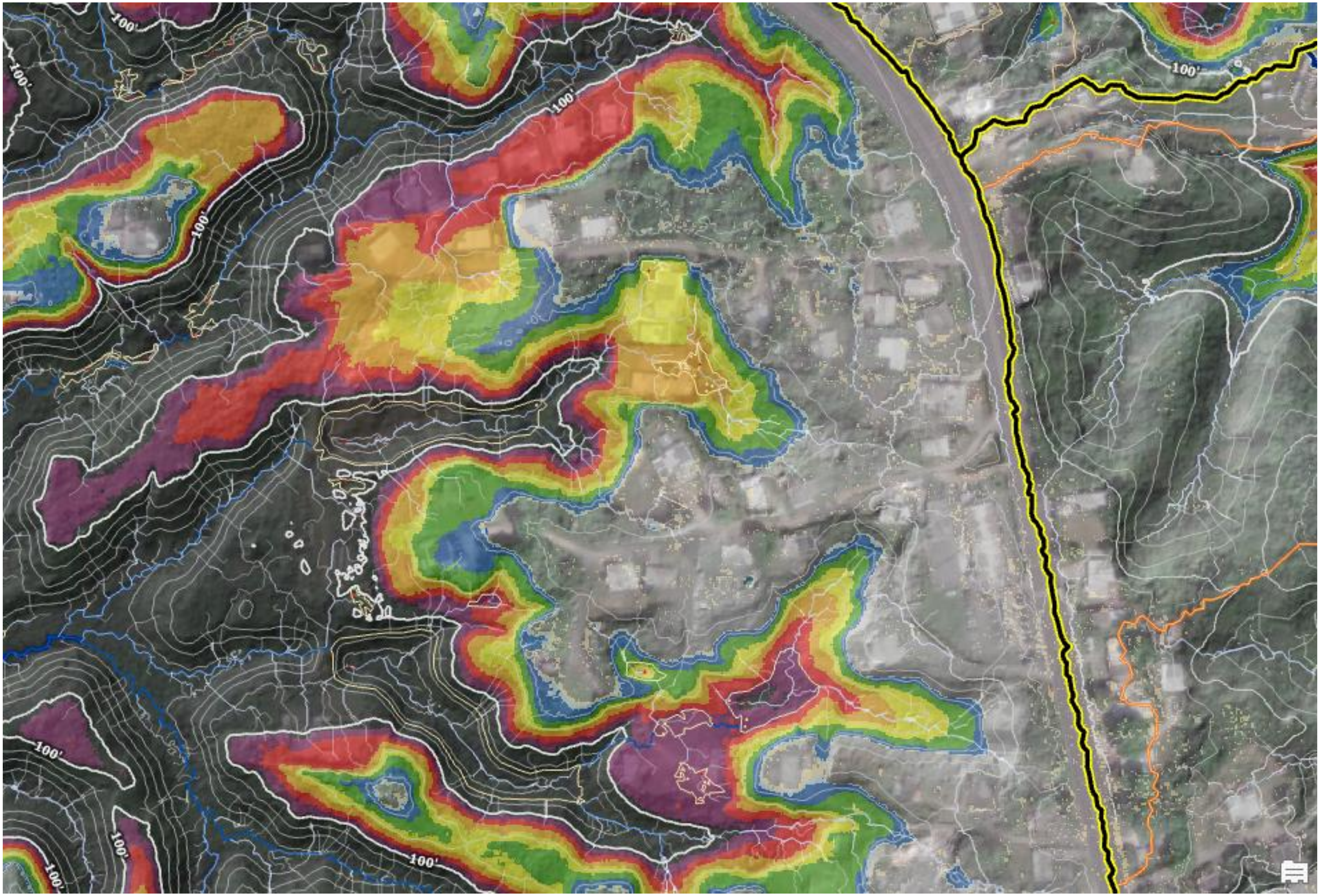


Figure 4.11 Sample, final runoff paths within fill areas, plateau basin, dry valley, argillaceous. Black area is more than 40 feet deep from max fill area elevation.

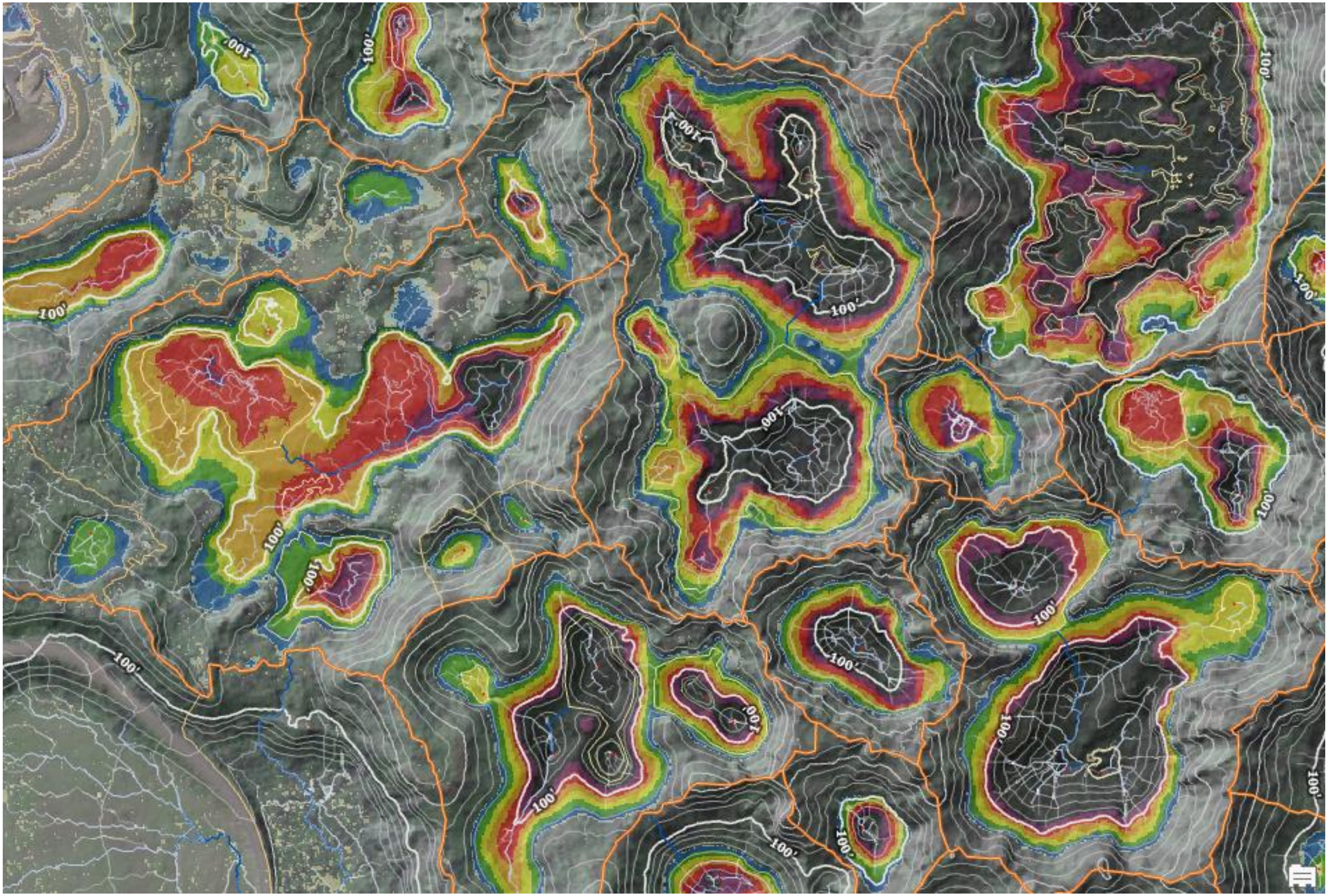


Figure 4.12 Sample, final runoff paths (including overflow runoff paths) within fill areas and low points (red dots), cockpit karst. FAD > 15 feet were delineated with internal basin boundaries (orange lines).

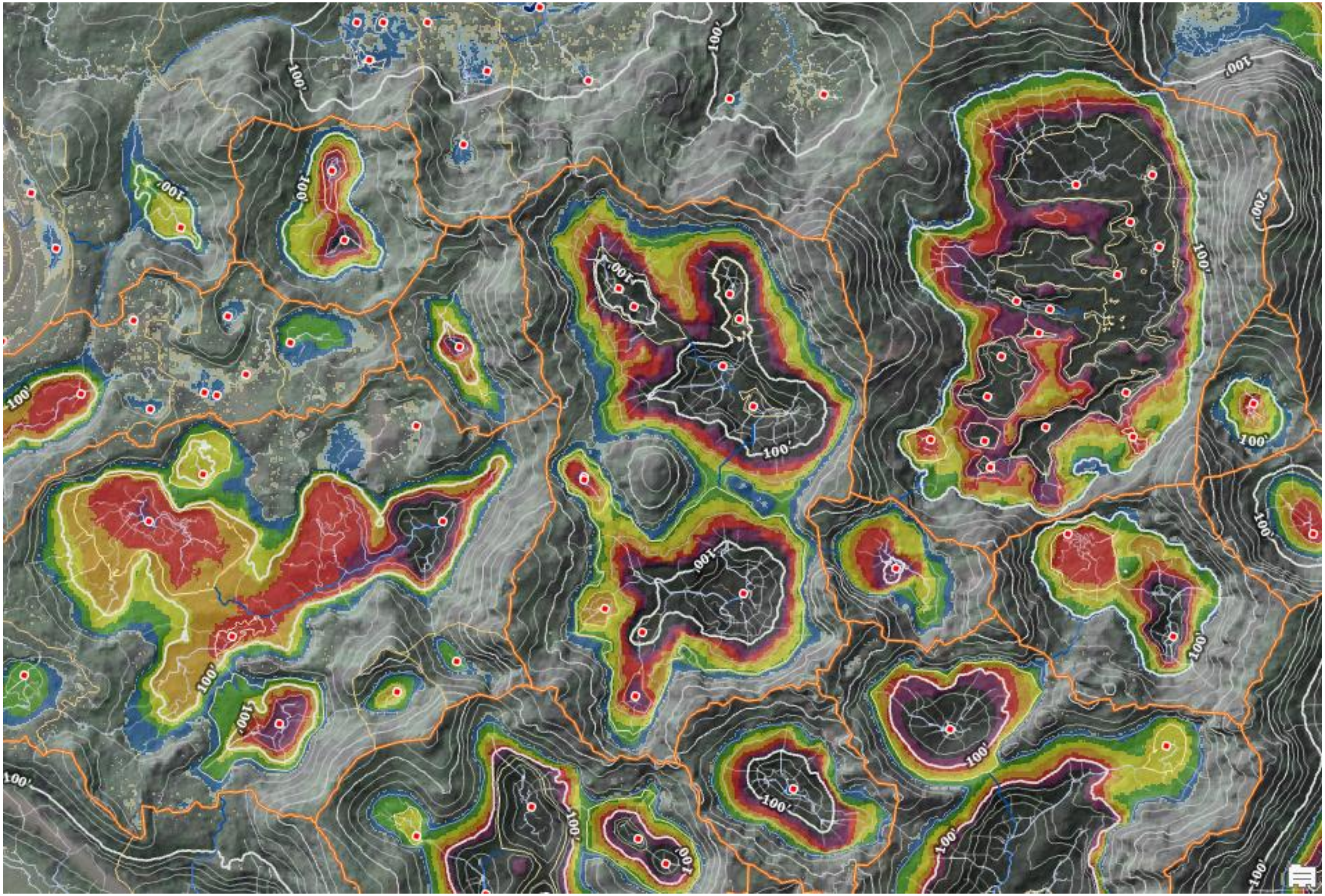


Figure 4.13 Sample, low points (red) within fill areas.

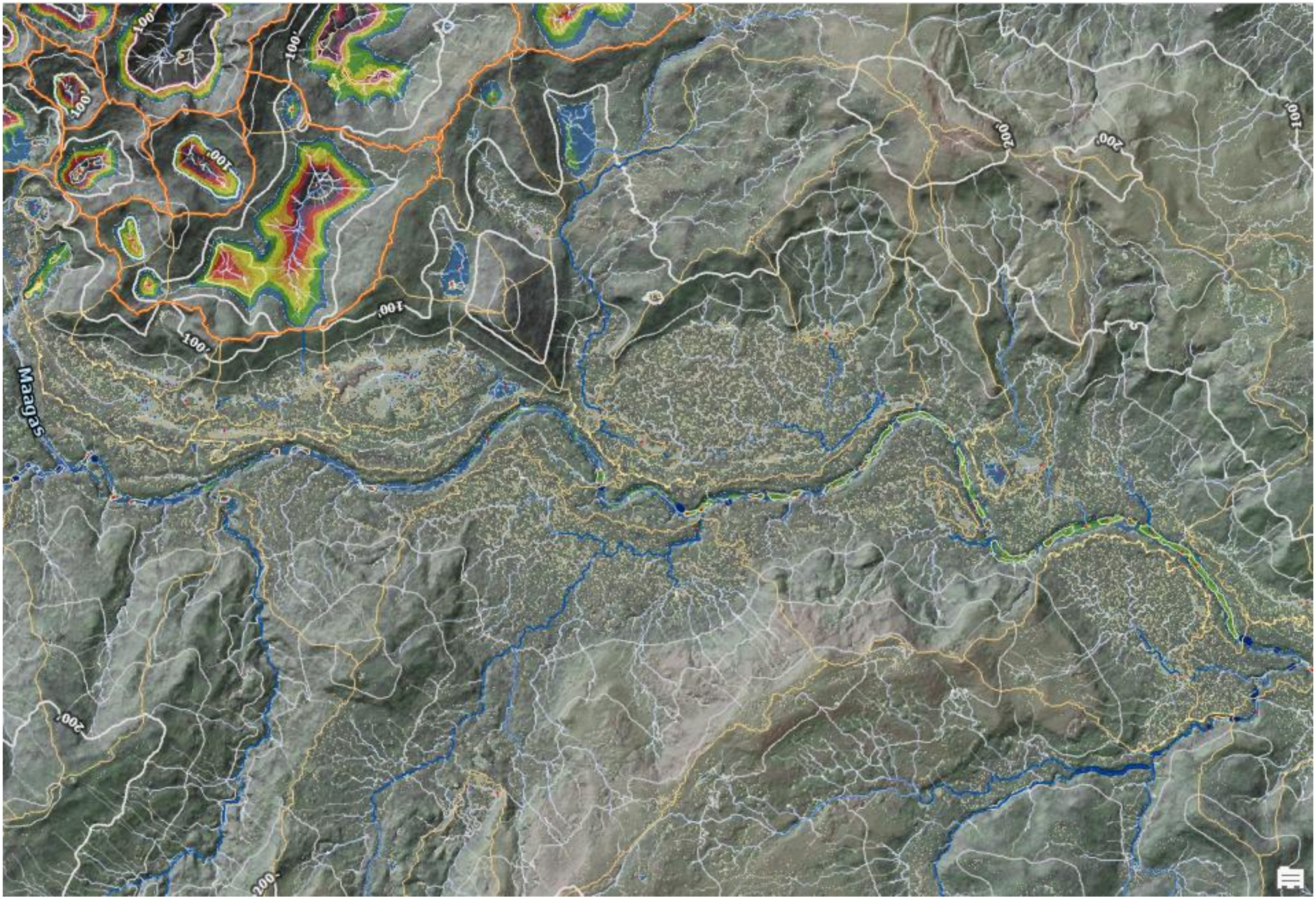


Figure 4.14 Maagas River, fill area and runoff path.

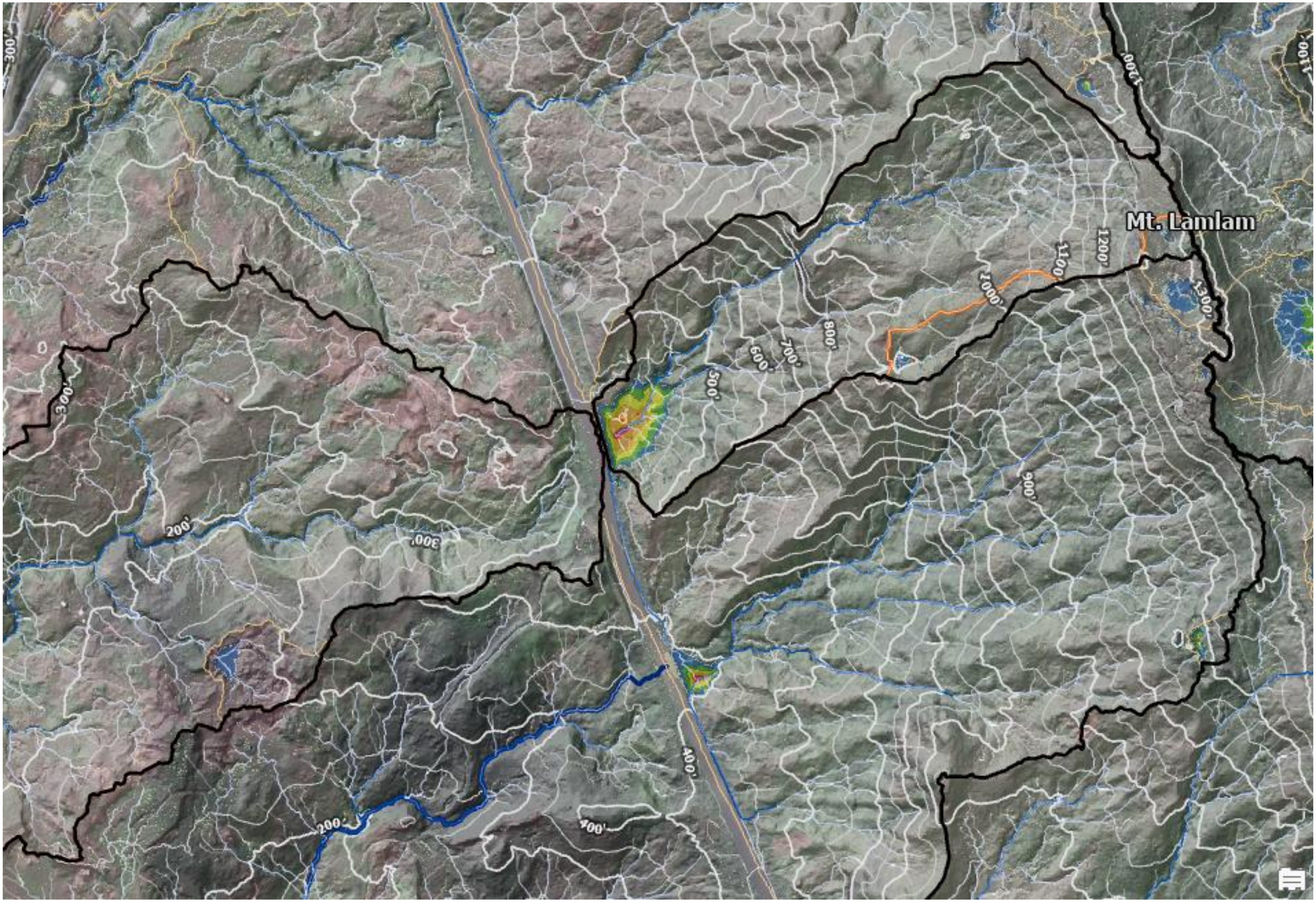


Figure 4.15 Culvert case, watershed area pinches at the road and fill area. Notice that there is no internal basin boundary for this case.

Other notable features captured include roadway culvert crossings and refined internal basin boundaries. Figure 4.15 depicts a culvert crossing that generated an artificially deep fill area on the upstream side of the roadway. This localized deep fill is a classic geoprocessing artifact: executing the fill algorithm across a bare-earth DEM where a road embankment bisects a natural drainage path creates an artificial depression. Because bare-earth DEMs do not account for subterranean culvert pipes, the simulated water surface artificially backs up to the crest of the road embankment.

A second notable case involves internal basin boundaries incorporating watershed lines routed across overflow runoff path boundaries. Figure 4.16 demonstrates these boundaries within the Pågu plateau basin. These internal boundaries are similarly delineated across the sample mapping extents (represented by orange lines in Figures 4.11 through 4.15). Because the initial basins and watersheds were derived using the standard Basin tool on the primary filled DEM, they required manual refinement along the perimeters of watershed fill areas to accurately delimit these specialized overflow scenarios.

4.3 Watershed Name Place

Watershed and place names are currently provisional. The majority derive from the 1954 Army Map of Guam and the 2006 Geologic Map of Guam, with supplemental nomenclature from Google Earth and ESRI basemaps. Figure 4.17 displays a georeferenced sample of the 1954 Army Map used to determine watershed names. Table 4.1 lists the 13 watershed groups and 90 individual watersheds alongside their calculated areas. The map layout also incorporates geographic place names, including bays, points, local regions, national landmarks, memorials, and highways. The current map draft has been submitted to the Kumisión i Fino' CHamoru, Na'an Lugåt team; attribute tables and labels will be updated upon receipt of their official recommendations.

4.4 Watershed Groups

Watershed groups are delineated based on their discharge into specific bays, location between major coastal points, and outlet orientation. This section utilizes sample map clips scaled to fit the page; thus, they may not reflect the true 8' x 6' dimensions of the 1:12,000 scale final map. The intent is to illustrate watershed groups and hydrologic features, rather than provide an exhaustive discussion of each individual watershed.

In the following figures, major ridgelines are highlighted in red. Figure 4.18 shows the north-to-south ridge dividing the east and west slopes. West-facing mountain and hill slope groups include Asan, Piti, Apra, Hågat, and Humåtak. East-facing groups include Yona, Talo'fo'fo', and Inalåhan, which notably exhibit larger surface areas. The northern watershed groups flowing into north-central bays are Piti, Asan, Hagåtña, and Sesonyan (Figure 4.19). The Hagåtña Group contains two plateau basins (Tutuhan and Sinahånña), while the Sesonyan Group contains the Otdot Plateau Basin. At the island's southern end, the Malesso' Group comprises small watersheds flowing into Cocos Lagoon (Figure 4.20).

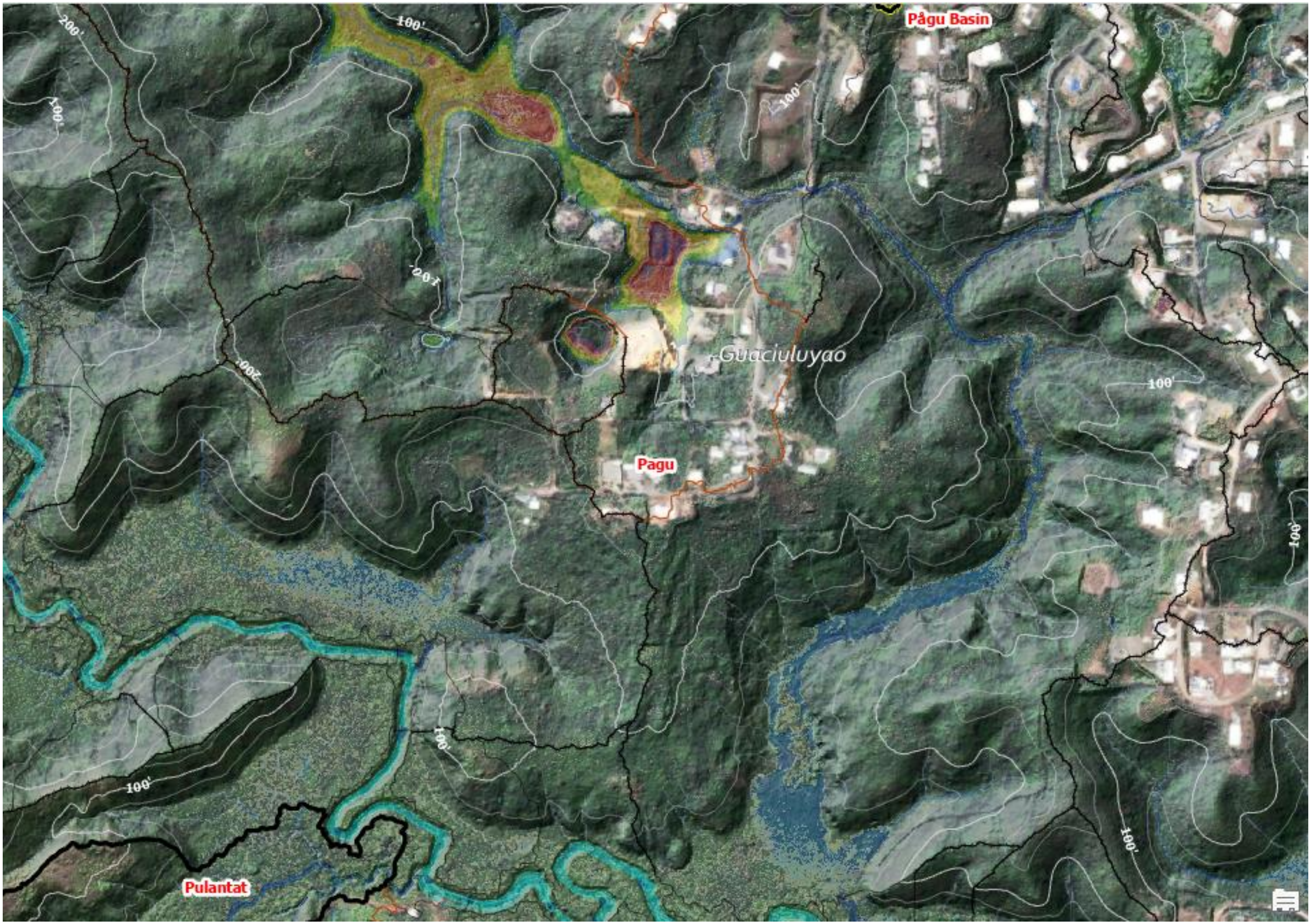


Figure 4.16 Internal Basin Boundary of fill area depths ≥ 15 ft (thin dark orange line).

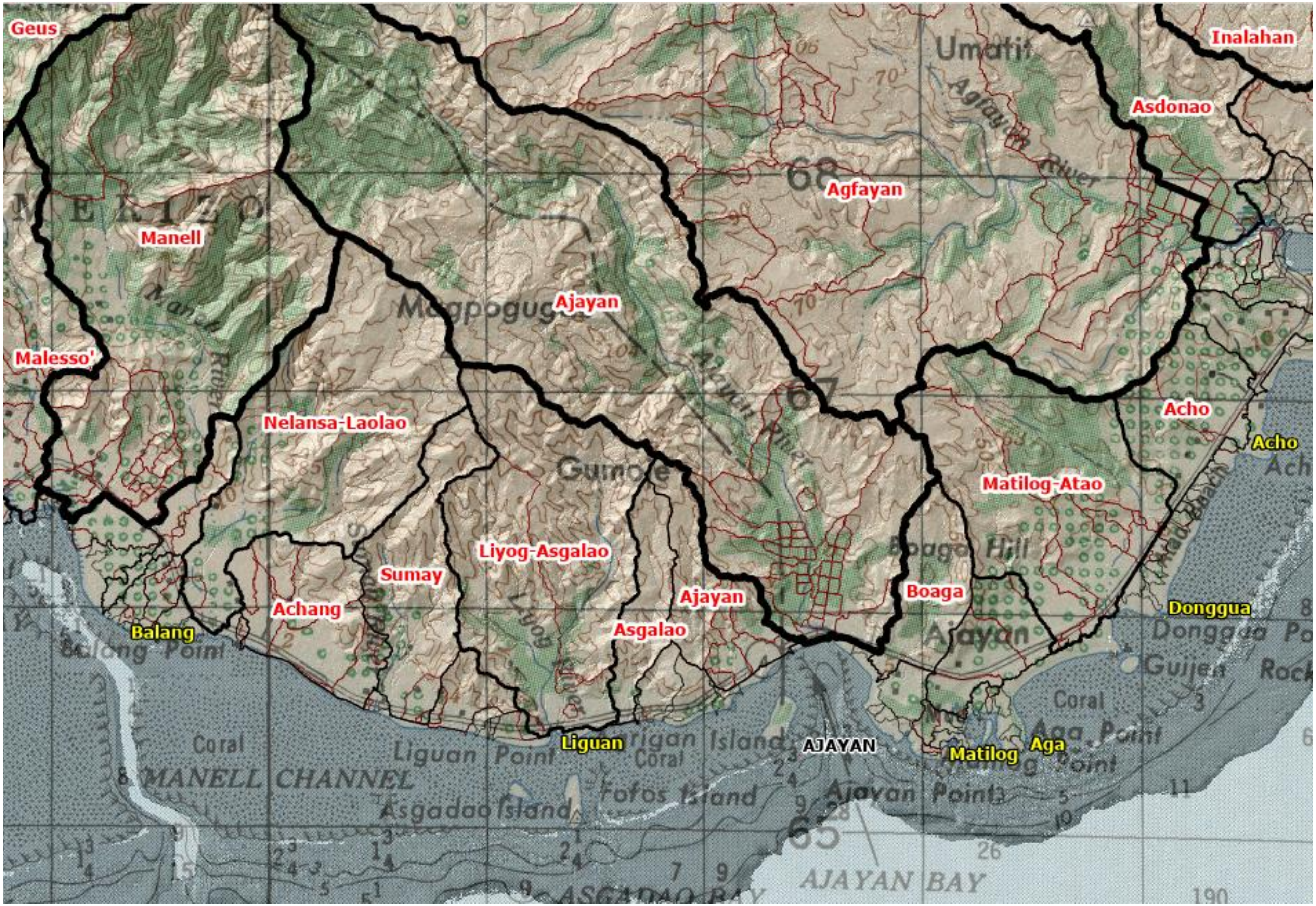


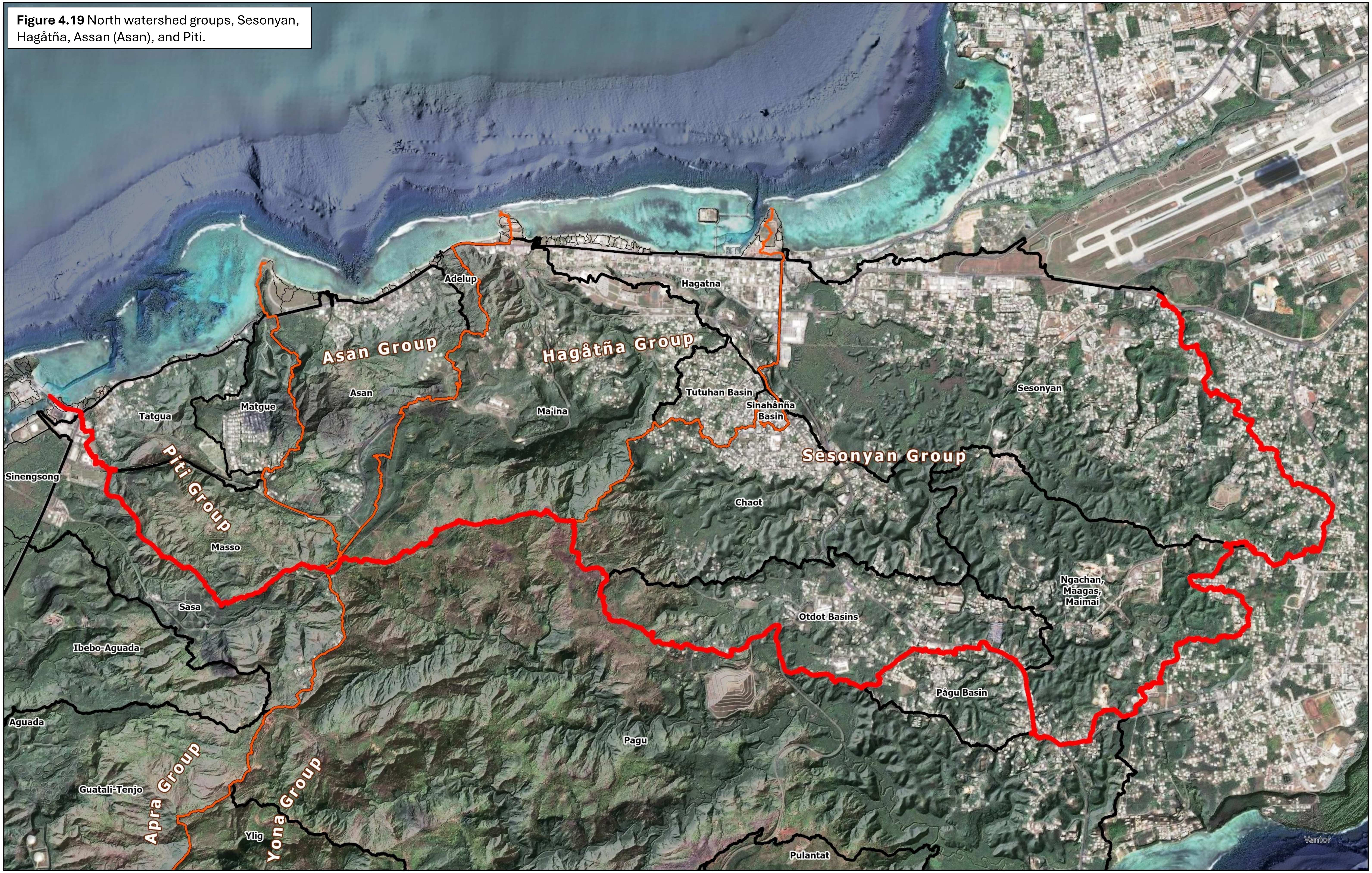
Figure 4.17 Sample georeferenced Map of Guam (AMS 1954), first pass watershed name.

Table 4.1 Watershed and Group area.

Group	Watershed Name	m^2	Km^2	mi^2	Km^2	mi^2
Sesonyan	Chaot	4,394,898	4.39	1.70	21.8	8.40
	Ngachan, Maagas, Maimai	4,297,300	4.30	1.66		
	Otdot Basins	3,242,730	3.24	1.25		
	Sesonyan	9,821,807	9.82	3.79		
Hagåtna	Hagåtña	1,196,414	1.20	0.462	7.88	3.04
	Ma'ina	5,962,655	5.96	2.30		
	Sinahåña Basin	77,614	0.078	0.030		
	Tutuhan Basin	647,746	0.648	0.250		
Assan	Adilok	175,618	0.176	0.0678	3.20	1.24
	Assan	3,025,181	3.03	1.17		
Piti	Masso	1,771,352	1.77	0.684	3.97	1.53
	Matgui	904,906	0.905	0.349		
	Tatgua	1,294,072	1.29	0.500		
Apra	Aguada	465,356	0.465	0.180	24.1	9.31
	Apalacha	530,298	0.530	0.205		
	Apra	375,239	0.375	0.145		
	Apra (Camp Bright)	485,538	0.486	0.187		
	Gabgab	644,699	0.645	0.249		
	Guatali - Tenho	11,521,553	11.5	4.45		
	Ibebo - Aguada	3,033,737	3.03	1.17		
	Sasa	2,577,089	2.58	0.995		
	Sinengsong	332,948	0.333	0.129		
	Sumai	312,133	0.312	0.121		
	Tantapalo	3,842,958	3.84	1.48		
Hågat	Alifan	1,735,571	1.74	0.670	19.1	7.36
	Anaguan	4,678,837	4.68	1.81		
	Anai	591,402	0.591	0.228		
	Dadi	1,386,173	1.39	0.535		
	Ga'an	195,523	0.196	0.075		
	Ga'an (thin, E)	219,169	0.219	0.085		
	Hågat	1,137,169	1.14	0.439		
	Lengga	1,019,294	1.02	0.394		
	Namo - Ayuga	3,735,433	3.74	1.44		
	Roxas	1,510,977	1.51	0.583		
	Sagua	549,721	0.550	0.212		
	Umang	993,639	0.994	0.384		
	Urote	1,311,593	1.31	0.506		
Humåtak	Achugao	602,383	0.602	0.233	18.2	7.02
	As Måfnas	881,056	0.881	0.340		
	Bile	566,384	0.566	0.219		
	Humåtak	5,296,302	5.30	2.04		
	Iledigao	1,009,377	1.01	0.390		
	Lasso' Fu'a	3,083,928	3.08	1.19		
	Ogasan	1,046,110	1.05	0.404		
	Sella	1,593,916	1.59	0.615		
	Setti	1,979,971	1.98	0.764		
	Setti-Fouha	622,442	0.622	0.240		
	Toguan	1,508,378	1.51	0.582		
Malesso'	Achang	373,046	0.373	0.144	14.2	5.47
	Ahåyan	3,555,485	3.56	1.37		
	As Gådao	185,191	0.185	0.072		
	As Male-Atot	288,183	0.288	0.111		
	Buaga	244,062	0.244	0.0942		
	Geus	3,290,773	3.29	1.27		
	Gumohe	1,539,893	1.54	0.595		
	Laolao	1,099,747	1.10	0.425		
	Malesso'	768,254	0.768	0.297		
	Manell	2,444,075	2.44	0.944		
	Sumai	386,080	0.386	0.149		
Inalåhan	Acho'	309,874	0.310	0.120	31.1	12.0
	Agfayan	4,892,896	4.89	1.89		
	As Donao	650,437	0.650	0.251		
	Asiga	733,288	0.733	0.283		
	Dandan - Tinagu	8,754,830	8.75	3.38		
	Inalåhan	13,065,913	13.1	5.04		
	Malolos	923,218	0.923	0.356		
	Matilog - Atao	988,603	0.989	0.382		
	Nomna	425,698	0.426	0.164		
	Ulomnia-Mulona	361,239	0.361	0.139		
Talo'fo'fo	Almagosa	3,487,017	3.49	1.35	113.7	43.9
	Gago-Imong	5,029,055	5.03	1.94		
	Maulap	3,224,406	3.22	1.24		
	Talo'fo'fo'	72,572,304	72.6	28.0		
	As Alonso	4,660,489	4.66	1.80		
	Fena Reservoir	3,058,974	3.06	1.18		
	Mata	3,426,333	3.43	1.32		
	Ugum	18,288,444	18.3	7.06		
Ipan	Anaga	1,130,596	1.13	0.437	1.72	0.664
	Ipan	589,349	0.589	0.228		
Yo'ña	Dagua	432,339	0.432	0.167	65.1	25.1
	Ilig	28,674,096	28.7	11.1		
	Manapu	1,233,371	1.23	0.476		
	Pågu	23,254,679	23.3	8.98		
	Pågu Basin	1,071,607	1.07	0.414		
	Pulantat	2,140,399	2.14	0.826		
	Tagachang	483,020	0.483	0.186		
	Togcha	5,705,457	5.71	2.20		
	Witek	832,896	0.833	0.322		
	Yo'ña (Nasgan)	335,009	0.335	0.129		
	Yo'ña	513,679	0.514	0.198		
	Yo'ña Hill	405,409	0.405	0.157		

Figure 4.18 North-to-south ridge line (thick red) divide the west-east slopes, from Adilok to Malesso' Pier Park. The east-side watersheds, Yo'ña (Yona), Talo'fo'fo', and Inalåhan Groups, are much larger than the west-side.

Figure 4.19 North watershed groups, Sesonyan, Hagåtña, Assan (Asan), and Piti.



Note that the final map does not highlight these major ridgelines, displaying only the watershed group boundaries.

The Sesonyan Group contains watersheds flowing into East Hagåtña Bay, east of the Paseo Peninsula (Figure 4.21). The Sesonyan and Chaot watersheds distinctly illustrate unique argillaceous, merokarst, and fluvial river valleys. The Otdot Plateau Basin presents rigid doline karst west of Route 4 and fluvial merokarst east of the highway. The Hagåtña Group features both merokarst and classic river valleys. Figure 4.22 illustrates this bedding shift from the Alutom Formation to the argillaceous valley in the Ma'ina Watershed along the Fonte' River. The Fonte' River's headwaters originate in the Alutom Formation, flow across the Pågu-Adilok Fault over argillaceous limestone, and discharge into West Hagåtña Bay near Adilok Point. This group also contains the Tutuhan and Sinahånña plateau basins, which may contribute baseflow to the Chaot, Hagåtña, and Fonte Rivers (supported by a northward hydraulic gradient in a 2013 Gingerich groundwater model). The Hagåtña Watershed functions atypically due to a municipal storm drain system; however, heavy rainfall and storm surges still cause coastal flooding.

Assan (Asan) and Piti Groups watersheds discharge into Asan Bay and Piti Bay, respectively. Figure 4.23 illustrates the boundaries and river valleys for these groups.

The Assan Group contains two watersheds with rivers flowing into the Asan Channel, which discharges into Assan Bay adjacent to Assan Park. Southeast of the urban area lies a patch of argillaceous limestone hills. The Assan Spring houses an inactive utility production station (owners: US Navy 1916; GWA 2004). A small argillaceous watershed within this group, Adilok Hill, features a minor runoff valley discharging into Asan Bay. Additionally, the urban storm drain system empties into Asan Bay through the reef cut.

The Piti Group features three main rivers flowing into Piti Bay: Matgue River (Matgue Watershed), Tatgua River (Tatgua Watershed), and Masso River. The Masso Watershed, located south of Route 6 (Spruance Drive), contains the Masso Reservoir.

Apra Group comprises watersheds discharging into Apra Harbor. The primary watersheds (Figure 4.24) are Sasa, Ibebo-Aguada, and Guatali-Tenho, alongside smaller coastal watersheds like Aguada and Apalacha. The peninsular watersheds—Apra, Tantapalo, Sumai, and Gabgab—are located on a limestone flat and exhibit plateau basin characteristics. The Urote (Orote) Basin appears to contain a series of dolines. Apra Harbor's coastal area features wetlands and mangroves, consisting primarily of alluvium deposits and Alifan limestone.

Hågat Group includes watersheds discharging into Hågat and Talaifak Bays, spanning from Åpaka' (Apaka) Point to Fakpi Point. Originating from the peninsula, the Dadi and Roxas wetland watersheds feature argillaceous, Alifan, and alluvium geology (Figure 4.25). Standard river-valley watersheds continue south, including Namo-Ayuga, Alifan, Ga'an, Hågat, Lengga, Umang, Anaguan, Anae, and Sagua. Watersheds extending from Namo-Ayuga to Anaguan reach the north-to-south ridgeline. The Alifan limestone cap of this ridgeline features numerous boundary springs, including Sånta Rita, Fa'åta, Asu'su', and

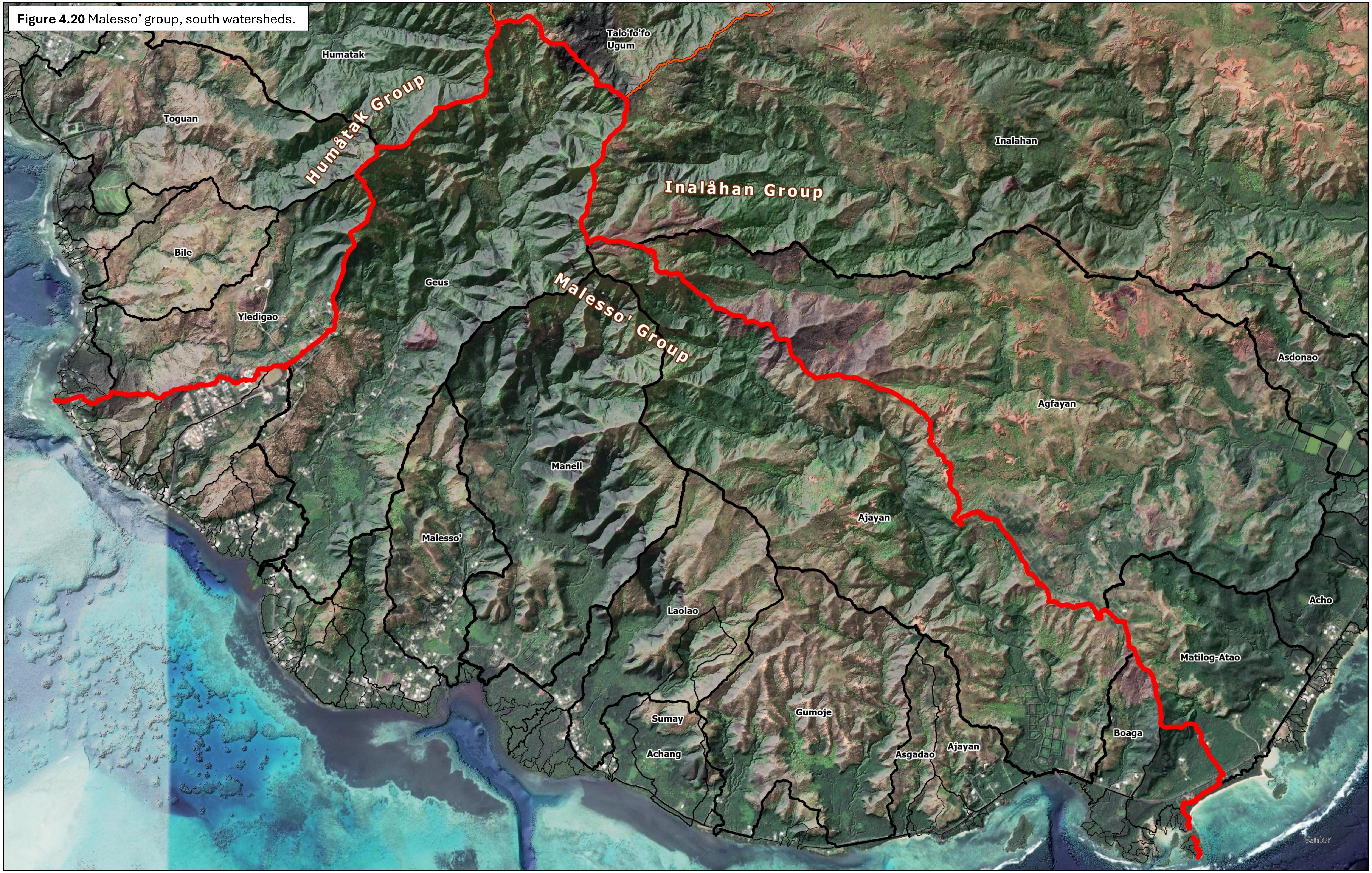


Figure 4.20 Malesso' group, south watersheds.

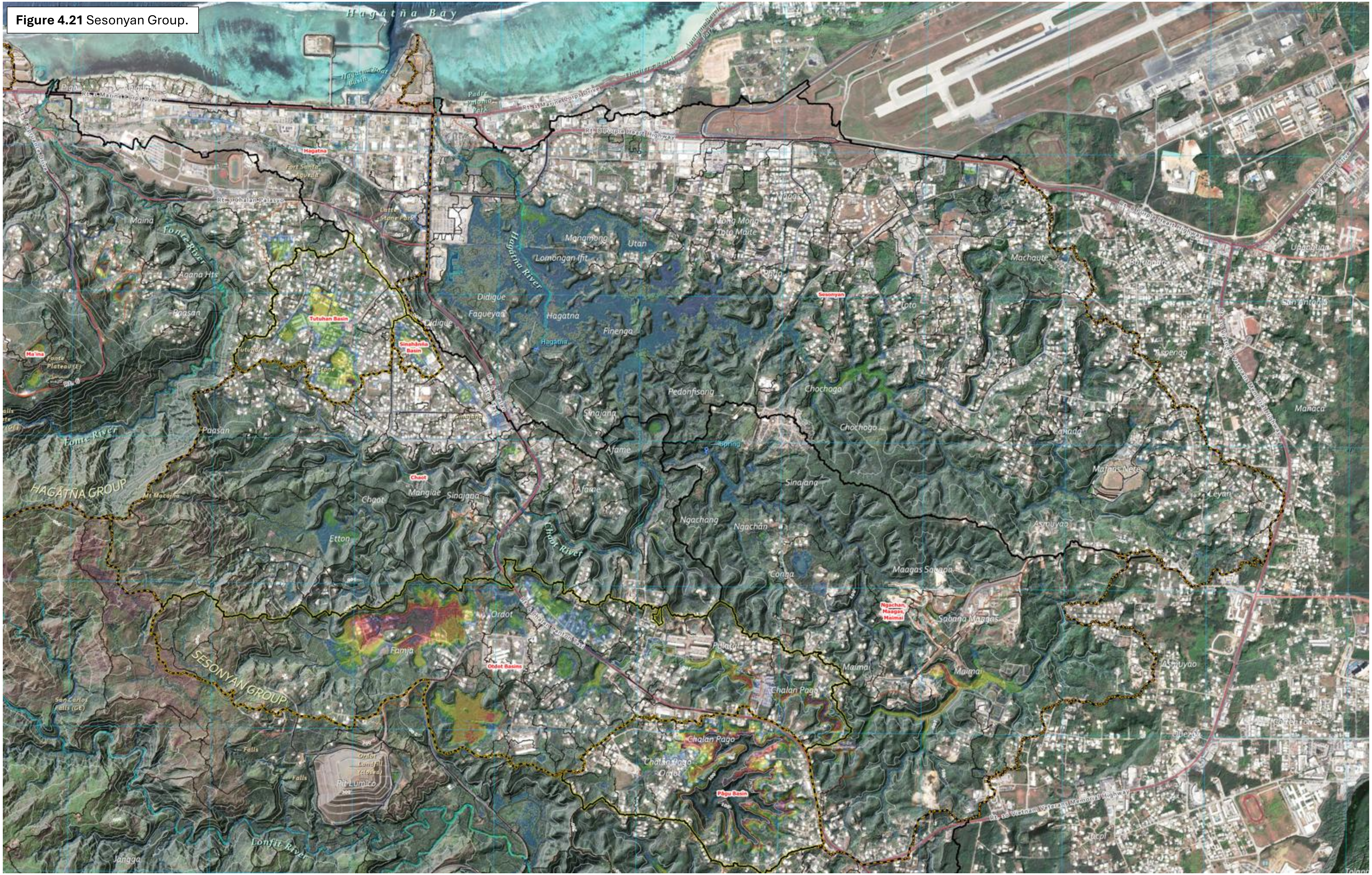


Figure 4.21 Sesonyan Group.

Figure 4.22 Hagåtña Group.

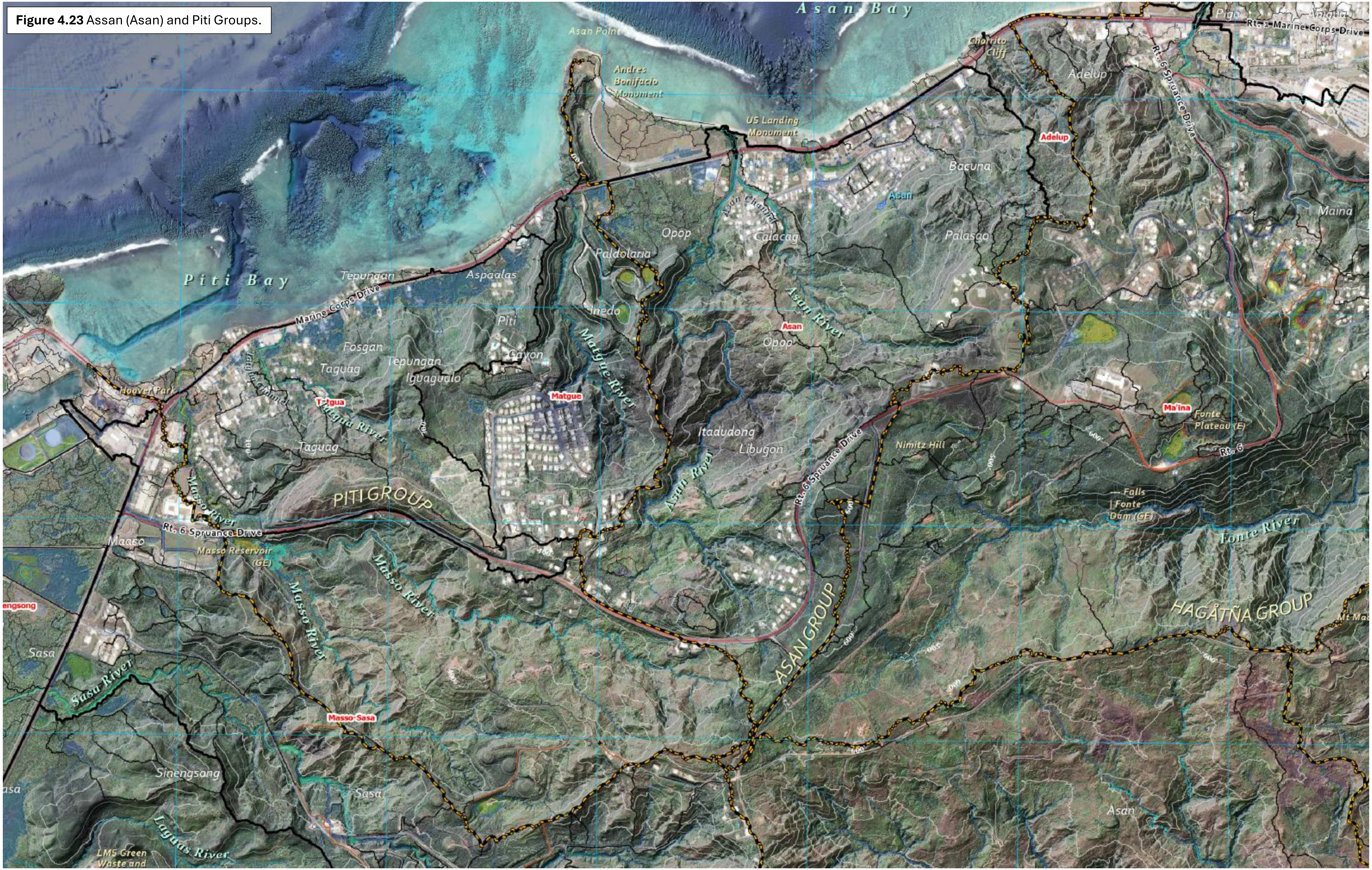


Figure 4.23 Assan (Asan) and Piti Groups.

Figure 4.24 Apra Group.

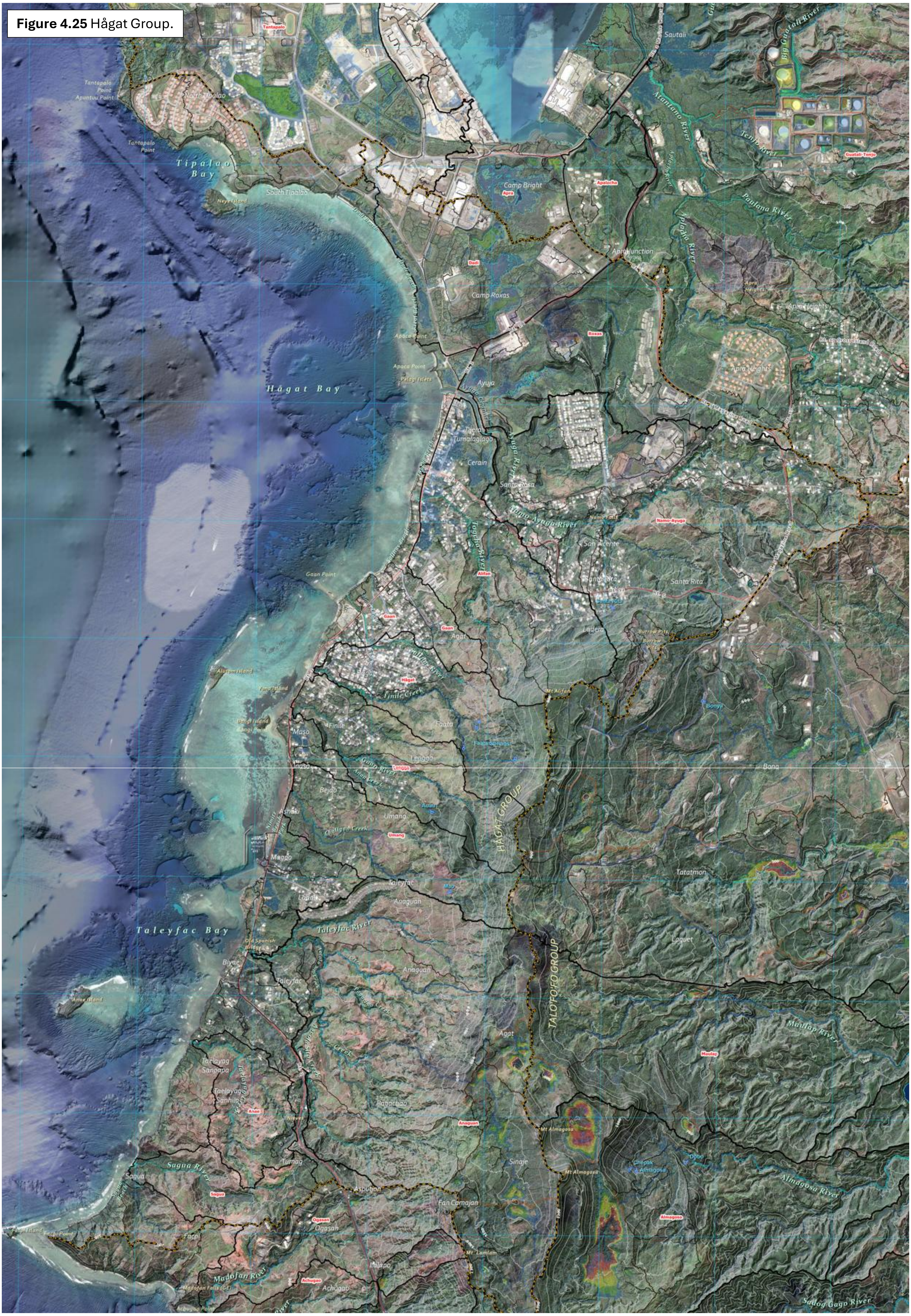


Figure 4.25 Hågat Group.

Må'o. The Anaguan boundary follows a ridgeline passing through Mount Lamlam. South and west of Anåguat lie the smaller Ånae, Sagua', and Fakpi Point watersheds.

Humåtak Group comprises a collection of southwestern watersheds. Route 2 bisects several of these, including Ogasan, Achugao, Asmafines (As Mafnas), Sella, Setti (Cetti), and Lasso’ Fu’a (Figure 4.26). Achugao and Lasso’ Fu’a feature high road culverts containing limestone-type surface depressions. Between Fakpi Point and Jaotan Point lie six river outlet bays. Sella and Setti Bays each receive two rivers from their respective watersheds: Asmafines (As Mafnas) and Sella flow into Sella Bay, while Setti and Fu'a flow into Setti Bay. South of Setti Bay are Fu'a, Humåtak, Toguan, and Bile Bays.

The Humåtak Watershed contains the Humåtak, Laelae, As Taban, and Saddok rivers, marking the transition between Routes 2 and 4. The Toguan Watershed houses the Humåtak-Malesso' Wastewater Treatment Plant (Guam Waterworks Authority). South of Toguan Bay, the Bile (Bile River) and Iledigao (Pigua River) watersheds both flow into Bile Bay.

Malesso’ Group encompasses watersheds discharging into Cocos Lagoon (Figure 4.27). Because these watersheds are relatively small, a 1:12,000 map scale was necessary to accurately capture their detailed features. This group includes the Geus, Malesso', Manell, Laolao, Gumohe, Asgadao, and Ajayan watersheds, alongside the smaller Sumai and Achang watersheds.

The Malesso' and Manell watersheds discharge into Achang Bay via the Manell River. The Sumai River (Gumohe Watershed) flows into Sumai Bay. The Leyog River (also in Gumohe) and As Gådao Creek (As Gådao Watershed) both flow into As Gådao Bay.

Inalåhan Group, the island's third-largest watershed group, generally slopes eastward, discharging into southeastern bays (Figure 4.28). It contains ten watersheds: Matilog-Atao, Acho', Agfayan, As Donao, Asiga, Dandan-Tinago, Inalåhan, Malolos, Nomna, and Ulomnia-Mulona. The Inalåhan Watershed is the largest (13.1 km^2), containing eight rivers that feed the Inalåhan River before discharging into Inalåhan Bay. To the south, the Agfayan River (Agfayan Watershed) discharges into Agfayan Bay.

Dandan-Tinago is the second-largest watershed in the group (nearly 9 Km^2). It contains the Tinago and Aslinget Rivers, which merge with the Pauliluc River before discharging into Pauliluc Bay. This watershed also hosts a solar farm (Guam Power Authority, completed in 2015), capacity 36 megawatts, more than 150 acres, generating 6% of Guam's total power. The group's northwest section contains the Asiga, Malolos, and Nomna watersheds, characterized by argillaceous limestone.

Talo’fo’fo’ Group is the largest watershed group on Guam (114 km^2). Figure 4.29 illustrates this area, which hosts the island's primary surface water source (producing up to 14 MGD). The group contains seven watersheds with several rivers as tributaries to the Talo'fo'fo' River, ultimately discharging into Talo'fo'fo' Bay. The river within the As Alonso Watershed independently discharges into Talo'fo'fo' Bay without merging into the Talo'fo'fo' River. The Talo’fo’fo’ Watershed contains the Fena Reservoir—identified on Google Earth™ as Maagas River and Fena Valley Reservoir—which provides up to 11 MGD (less during drought conditions) of utility surface water. Constructed in 1951, an 85-foot earthen dam

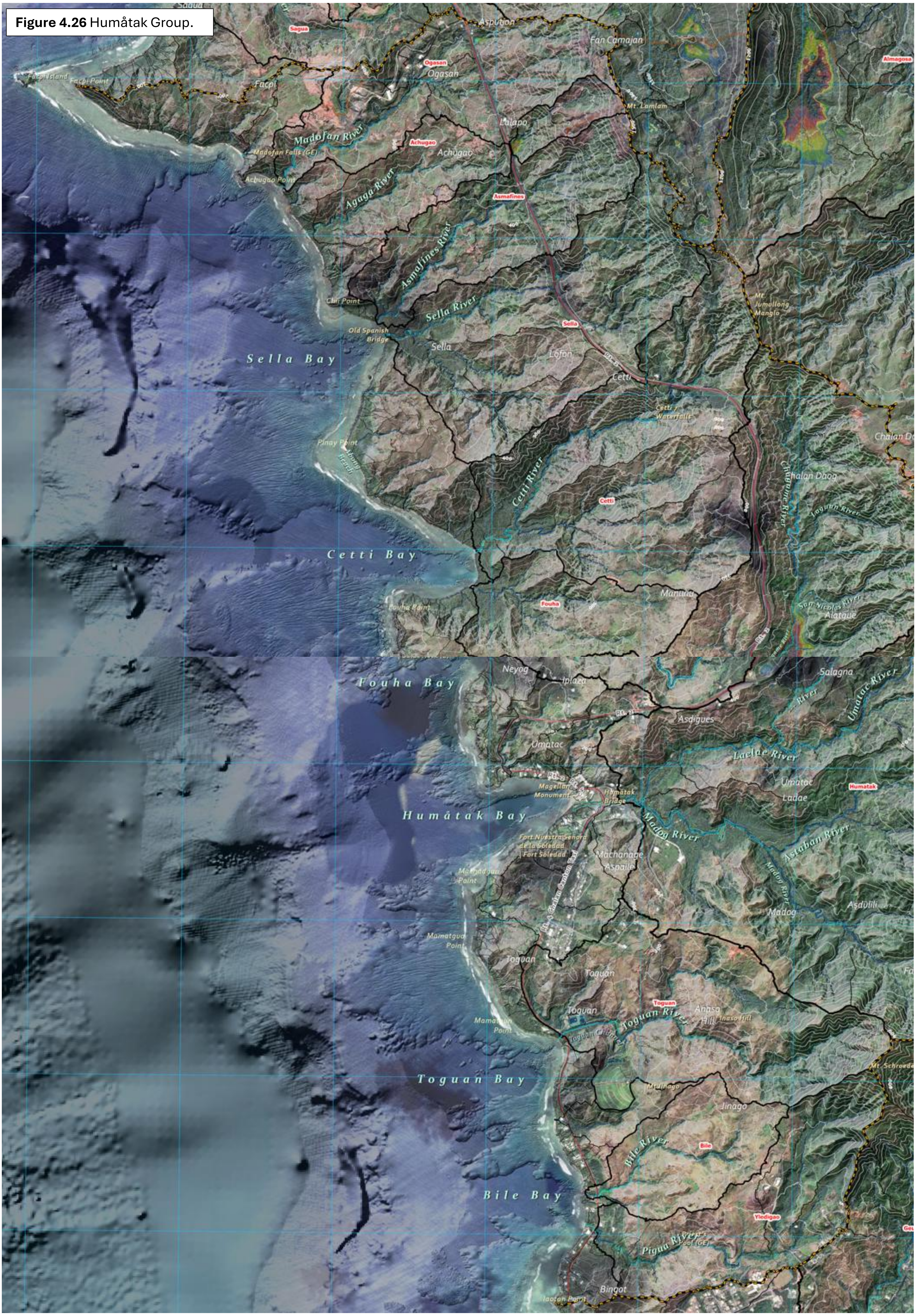


Figure 4.26 Humåtak Group.

Toguan Bay
Bile Bay
Achang Bay
Sumay Bay
Asgadao Bay
Aga Bay
Ajayan Bay
MALESSO' GROUP
Toguan River
Bile River
Pigua River
Geus River
Manell River
Laolao River
Sayafe River
Sumay River
Liyog River
Ajayan River
Dante River
Pasamano River
Inalåhan River
Ylig River
Toguan
Bile
Geus
Manell
Malesso'
Talona
Laolao
Sumay
Achang
Gumoje
Asgadao
Ajayan
Aglayan
Enalahan
Asdonao
Acho
Boaga
Matilog-Atao
Merizo
Geus Valley
Pigua
Bingot
Talona
Palalo
Guague
Julog
Sagualao
Sumay Maleso
Liyog
Asmaile
Atot
Gagas
Tongan
Aga
Magpogugae
Gugae
Namo
Somnao
Nagan
Umatit
Guasaon
Asquede
Machecho
Sinenjaya
Guenyon
Dongua
Socogna
Sinagoso
Atate
Fane
Jinago
Mt Schroeder
Mt Finasantos
Mt Sasalaguan
Manell Point
Jaotan Point
Balang Point
Aga Point
Liguan Point
Asmaile Point
Ajayan Point
Tongan Rock
Asgadao Island
Fofos Island
Gaijen Point
Gaijen Rock
Boaga Hill
Figure 4.27 Malesso' Group.

Figure 4.28 Inalåhan Group.

was built at the gorge to back up the water and form the reservoir's current size. Water is drawn to the U.S. Navy Fena Water Treatment Plant. Up to 4 MGD of this water is purchased by the Guam Waterworks Authority (GWA), while the remaining 7 MGD is utilized by the Navy.

The Saddok, Almagosa, and Maulap watersheds are tributaries to the reservoir. The Saddok Watershed contains the Saddok Gago and Imong Rivers, while the Almagosa and Maulap watersheds contain their respective namesake rivers. The Almagosa River may also receive spring flows (specifically Chopak, Almagosa, and Dobo' Springs) from the base contact of the Alifan limestone cap.

The reservoir overflows via a spillway into the Ma'ågas River, a primary tributary of the Talo'fo'fo' River. Northwestern tributaries of the Talo'fo'fo' River include the Mahlac and Tolai Yu'us Rivers. The Tolai Yu'us River is fed by the Maemong and Bonya Rivers, while the Talisay River (a tributary of the Maemong) may receive water from Bonya Spring. Notably, the Tolai Yu'us is a subterranean river flowing through the Bonya Limestone, a nest of cockpit karst.

Southwestern tributaries of the Talo'fo'fo' River include the Sågge', Sarasa, and Ugum Rivers. The Sågge' River is fed by the Tinechong River, and the Salasa River is fed by the Malaja River. The Ugum River's tributaries are the Bubulao and Atate Rivers, with the latter fed by the Liyog River. The Ugum River features an intake atrium for a surface water treatment plant (GWA, producing up to 2.4 MGD) and hosts the Talo'fo'fo' Falls recreation site and (WWII) historical site Yokoi's Cave.

The area south of the Maagas and Talo'fo'fo' main rivers exhibits badland erosion. The main river valley contains the system's largest alluvium deposits and most extensive wetlands. North of the river outlet lies the Mata Watershed, consisting of an uplifted argillaceous limestone plateau and a dry river valley that likely contributes runoff and baseflow into an agricultural pond.

Yo'ña (Yona) Group, is the second-largest watershed group (30 km^2). Figure 4.30 displays its three river outlet bays: Pågu, Ilig, and Togcha'. This figure also includes the Ipan Group, a set of coastal limestone watersheds.

The Pågu Watershed contains the Pågu River, fed by two primary upstream tributaries: the Lonfit and Sigua Rivers. The Lonfit River has multiple tributaries flowing over waterfalls, including San Carlos Falls and two unnamed falls. It flows past the closed and capped Otdot Landfill before meeting the Sigua River, which originates from a southwestern tributary watershed. The Sigua River extends upstream into a southern valley near Mount Alutom featuring four named waterfalls: Alutom, Upper Sigua, Lower Sigua, and Little Sigua Falls. These tributaries merge to form the Pågu River, passing under Route 4 to discharge into Pågu Bay. Two argillaceous watersheds, Pulantat and Manapu, may provide runoff to the Pågu River during intense storms. Additionally, the Pågu Basin (a plateau basin) features an argillaceous limestone dry valley that may contribute baseflow to the river. South of Pågu lies the Ilig (Ylig) Watershed, containing the Ilig River—one of the long rivers on the island. The river extends to the Managua area, flows through Manenggon, continues

Figure 4.29 Talo'fo'fo' Group.

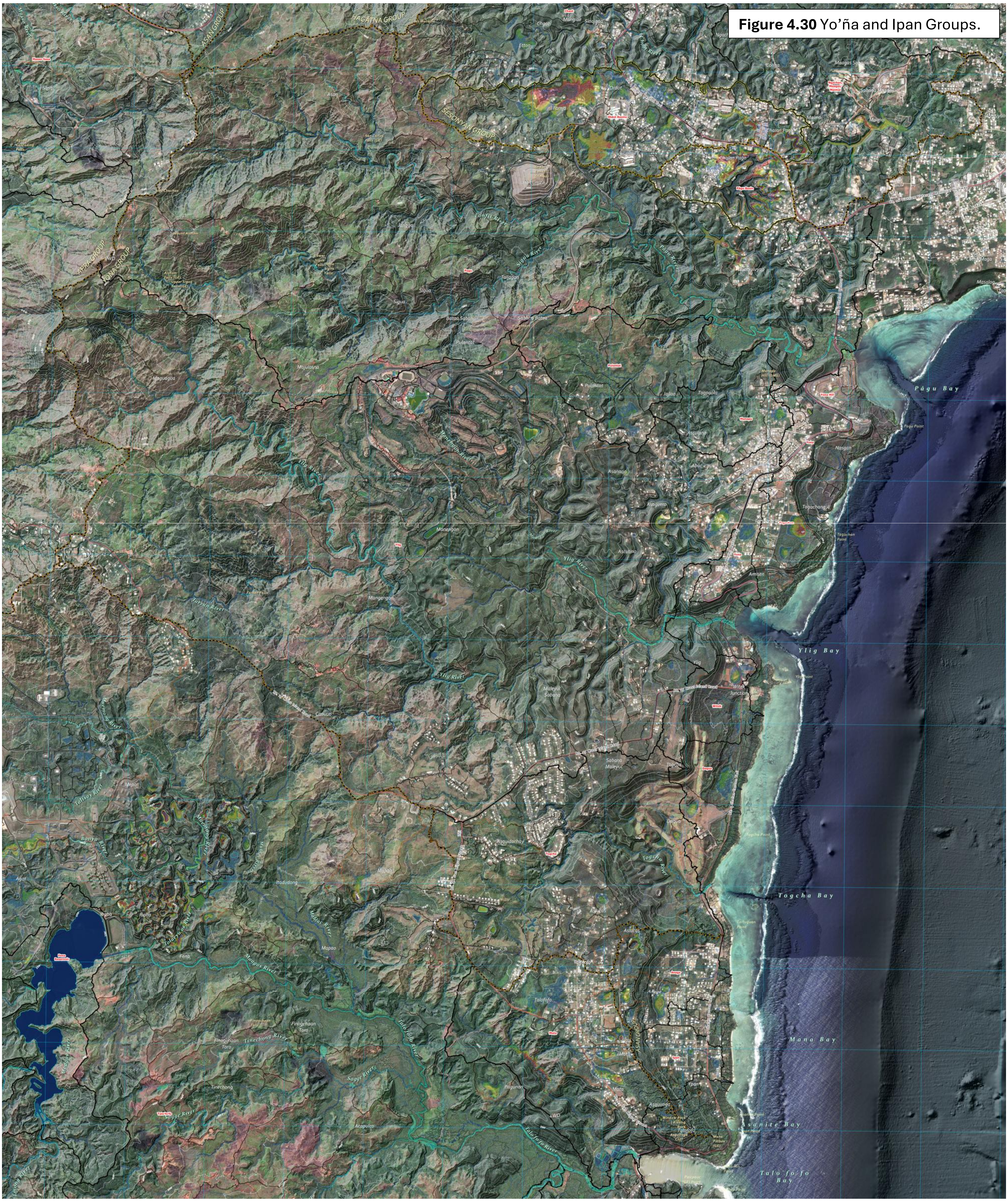


Figure 4.30 Yo'ña and Ipan Groups.

through an alluvium valley, and passes under Ilig Bridge, along Route 4, before discharging into Ilig Bay. Its main tributaries are the Manenggon and Tarzan Rivers. The Tarzan River features Tarzan Falls, while the Manenggon River flows through the LeoPalace Resort Guam.

South of Ilig is the Togcha Watershed. It contains the Togcha River, which flows adjacent to the Country Club of the Pacific golf course and under a culvert in Route 4 before discharging into Togcha Bay.

Ipan Group, located south of the Togcha Watershed, contains the Anaga and Ipan argillaceous limestone coastal valley watersheds. Characterized by coastal limestone with karst surface depressions, this area lacks true rivers but features surface runoff paths and possibly flow into dolines or karst surface depressions.

4.5 Hydrologic Map of Guam Watersheds, Available Online

The 2026 map is currently available on the Guam Hydrologic Survey website (guamhydrologicsurvey.uog.edu), Guam Public Law 24-247. Figure 4.31 displays the web page interface where an image can be selected to access the PDF map file. The map is available in vector PDF, flattened PDF, PNG, and JPEG formats. To navigate from the GHS homepage: select the Library menu, click WERI Web MApps, scroll down to Browse Maps by Agency, open the WERI tab, and select "Hydrologic Map of Guam Watersheds." The direct link is:

https://guamhydrologicsurvey.uog.edu/2025/09/12/hydrologic-map-of-guam-watersheds/

The contents are as follows:

- FADMaxPnt (Fill Area Depth, depth max, point)
- FAD1NF1 (Fill Area Depth > 130 feet, raster)
- HiwayLabel1 (Highway label, line)
- Places (Place name, point)
- CoastalNames (Coastal name, line)
- SiteLandmark (Landmark, point)
- Point (Geographic point name, point)
- Bay (Bay name, point)
- SW1 (Surface water from imagery, polygon)
- Tributary Watershed Divide (line)
- Watershed group boundary (line)
- Watershed/Basin (polygon)
- Spring (point)
- Plateau Basin (polygon)
- Internal basin boundary (polygon)
- Watershed of fill area ≥ 300 sqm (polygon)
- FenaMaxFill2 (polygon)
- Surface depression low point (point)
- Runoff path (Strahler, line)
- River fill area (polygon)
- SGContour100' (100 feet contour, line)
- SGContour50' (50 feet contour, polyline)
- FAD1NF1 (Fill Area Depth first iteration, feet, raster)
- highways (polyline)

Drag and drop the layer package file directly into the ArcGIS Pro Contents pane or map view to load the hydrologic features. This watershed map will be continuously updated and

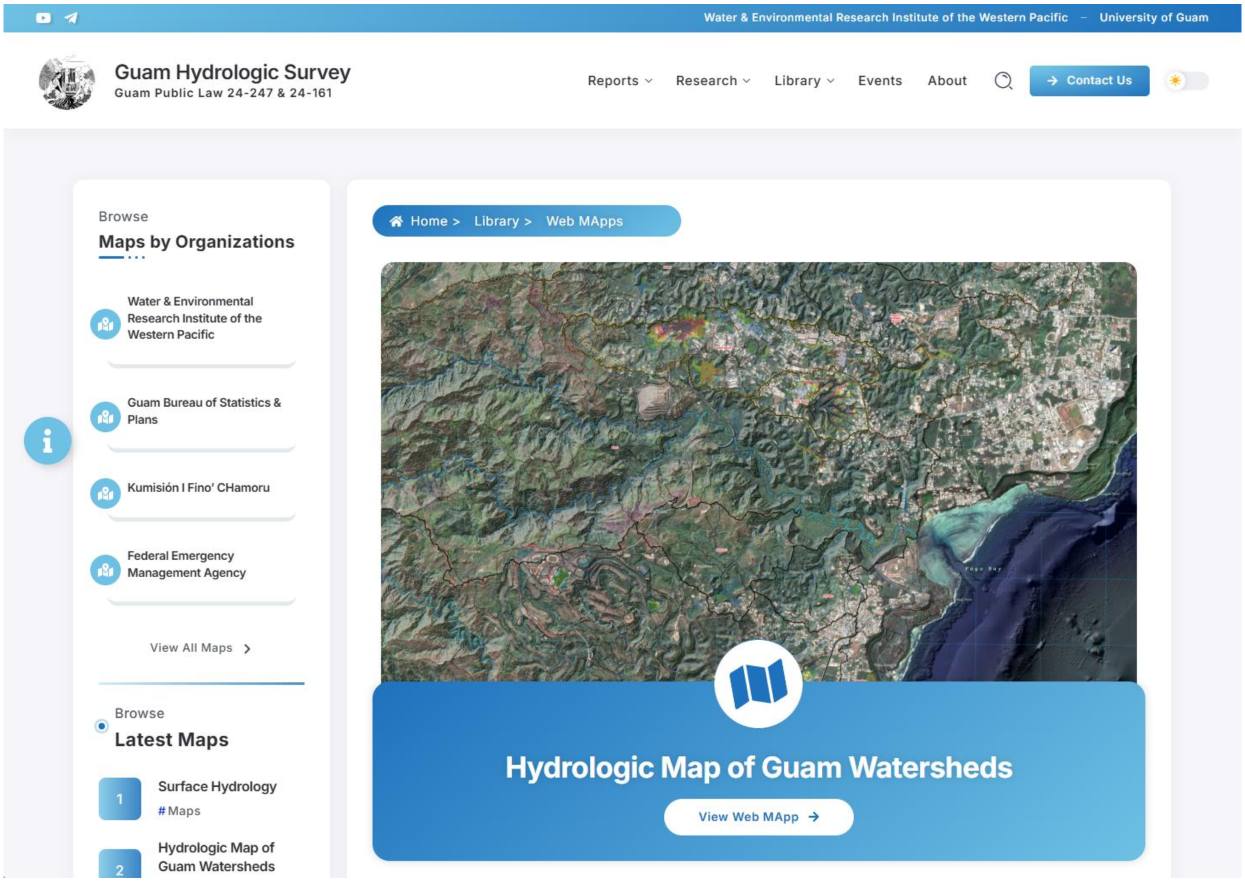


Figure 4.31 Hydrologic Map of Guam Watersheds, WERI Web MApps, on the GHS website. Included in the website are shapefiles and rasters in a GIS layer package. Scroll down the page (Figure 4.31) and find the downloadable features.

posted on the WERI-GHS website as new edits, place names, or spatial refinements are made.

5 CONCLUSION AND RECOMMENDATIONS

The 2026 Hydrologic Map of Guam Watersheds establishes an updated, high-fidelity geospatial framework essential for island-wide water resource management. This concluding section documents the successful execution of the project's technical objectives, summarizes the rigorous GIS methodologies utilized, reviews stakeholder outreach initiatives, and outlines targeted recommendations for advancing future spatial modeling.

5.1 Objectives Accomplished, Method, and Outreach

All primary project goals and specific analytical objectives outlined in Section 1.2 were successfully achieved. The GIS methodologies executed to generate these hydrologic features are thoroughly documented in Section 3, while Section 4 details the final organization of the spatial geodatabase. The high-resolution cartographic product and complete GIS feature files are now actively deployed on the Guam Hydrologic Survey (GHS) website. This technical report serves as the definitive reference document for the map product, with any future spatial updates posted directly to the GHS portal.

To facilitate end-user application and operational transition, a GHS-Global Learning and Engagement (GLE) Workshop is scheduled for late September 2026, focusing on spatial data access, map interpretation, and resource planning. This capstone training follows a robust series of preliminary outreach engagements conducted throughout 2025:

- WERI-GLE Guam Hydrologic Survey Workshop 2025: September 2025
- Guam Bureau of Statistics and Plans and Guam Coastal Management Program Planners Symposium: August 2025
- Guam Educators Conservation Summit: April 2025
- Guam Forest System/Watershed Planning Committee: March and June 2025

5.2 Summary Conclusion

The 2026 Hydrologic Map of Guam Watersheds was engineered utilizing advanced hydrologic spatial analysis tools within ArcGIS Pro. By leveraging high-resolution, LiDAR-derived Digital Elevation Models (DEMs), this geospatial analysis rigorously delineated complex surface flow routing, accumulation pathways, and highly precise stream networks. Crucially, the modeling successfully accounts for the stark hydrogeologic contrast between the highly permeable karst limestone plateau of northern Guam—which governs the recharge dynamics of the Northern Guam Lens Aquifer—and the heavily dissected, less pervious volcanic terrain of the south.

This effort yields a refined, high-fidelity spatial framework defining the island's drainage basins, internal sub-watershed divides, and stream morphologies. Ultimately, this comprehensive geodatabase functions as an essential, practical tool for hydrogeologic research and utility operations. It directly equips resource managers, planners, and environmental agencies with the robust geospatial infrastructure required to execute sustainable groundwater management, surface water allocation, and comprehensive island-wide environmental planning.

5.3 Recommendations for Further Study

To further advance this regional spatial analysis, future modeling efforts must process the updated high-resolution northern DEM and seamlessly couple it with the existing southern terrain data to establish a unified, island-wide topographic framework. To optimize computational efficiency, the current sequential spatial algorithms and geoprocessing workflows should be translated into a dedicated, automated GIS script or program. Finally, subsequent models must actively incorporate critical localized geologic features—specifically the highly permeable northern limestones, the Alifan limestone caps, and the Mariana argillaceous facies. Achieving this integration will require developing advanced methodologies that accurately balance these subsurface hydrogeologic variables without distorting the surface-level hydrologic delineations.

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