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A Cartographic Workflow Manual for Endangered Species Conservation

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A CARTOGRAPHIC WORKFLOW MANUAL FOR ENDANGERED SPECIES
CONSERVATION

By

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A Cartographic Workflow Manual for Endangered Species Conservation

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ABSTRACT:

  In response to global consumer demand for rare and exotic wildlife products, poaching of endangered species has become pervasive around the world (Eliason 1999). Despite the enactment of CITES, and other international efforts to protect vulnerable species from overexploitation, the global market for illegal wildlife products is estimated as high as $20-billion a year industry (Wyler 2008). Within important wildlife habitat sites, law enforcement struggle to curb rampant poaching that threatens the ultimate survival of many endangered species (Jachmann 2008; Rowcliffe 2004). Law-enforcement agencies responsible for protecting wildlife from poachers often lack geospatial tools that could greatly improve the effectiveness of their efforts. These tools include accurate topographic maps with the appropriate scale and the level of detail necessary for navigating in difficult and dangerous terrain, and GIS base data needed to monitor and evaluate the effectiveness of patrols (Pickles 2015).
  Recently, collaborations between the University of Montana (UM) and the large cat advocacy group Panthera, have enabled the production of geospatial packages for four protected areas of concern. These packages include printed topographic map series, GPS base-maps and comprehensive GIS base data. Throughout the creation of these packages, UM faculty and students have developed a nuanced workflow for this process using GIS and graphic design software. Until 2018, this workflow had yet to be fully documented. This document presents this workflow in the form of a cartographic manual, including step-by-step methods for creating appropriate geospatial packages. The goal of this document is to increase the efficiency of future cartographic collaborations between UM and conservation-minded groups, while providing valuable educational resources for UM students in GIS and cartography.

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Background

Part 1: Global Species Exploitation and Commercial Poaching

In the last century, land use conversion and development across the world has diminished the habitat of many of the world's vertebrate wildlife species to a fraction of the area they once were (Ceballos et al. 2015, McCallum 2015, Walston et al. 2010, and Seabloom et al. 2002). As a result, levels of species extinction have risen to unprecedented rates, and vulnerable wildlife populations are more isolated than ever before (Ceballos et al. 2015, Newmark 2008). Today, many species that once thrived across vast ranges are confined to small isolated fragments of habitat, in many cases within formally protected parks and reserves. These areas often serve as last strongholds for species facing the threat of extinction (Stokes 2010).

Driven by increasing demand for rare wildlife commodities, the overexploitation of many plant and animal species exacerbates issues of habitat loss and degradation (Hall 2008, Rosen 2010). To address overexploitation of global wildlife and plant species, in 1963 The International Union for Conservation of Nature (IUCN) drafted a treaty entitled The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The language of the treaty was agreed upon a decade later and finally came into force July 1st 1975. CITES was established with the goal of "(ensuring) that international trade in specimens of wild animals and plants does not threaten their survival" (CITES 1973). Despite 183 nations agreeing to enact

domestic laws that adhere to the mission of CITES, the trade of species protected under the treaty remains profitable (Wyler et al. 2008).

The global trade in illegal wildlife products includes the trade in live mammals, birds and reptiles, as well as animal products like elephant ivory, rhino horn, big cat skins and bones, bear gallbladders and exotic meats and fish (Warchol 2007, CITES.org). These products are consumed as delicacy food items, traditional medicinal products, or used as decorative objects (Warchol 2007). Unsustainable harvest of these commodities is a major threat to biodiversity across the world, and can push already vulnerable wildlife populations to the brink of extinction (Rosen 2010). Further compounding this issue, formal designation of species "threat status" can increase the perceived rarity of such commodities (Hall 2008). Which in turn can increase consumer demand for endangered wildlife products, creating a dangerous feedback loop for targeted species (Courchamp 2006, Hall 2008).

Diverse motivations for the illegal killing of wildlife documented in the literature include food, exhilaration, tradition, acts of rebellion, self-protection, and protection of property (Forsyth et al 1998; Muth et al. 1998). However, the greatest contributing factors for poaching today are economic motivations driven by intense demand. In fact, a study conducted by Warchol et al. (2008) estimated that the illegal trade of wildlife is the second largest illicit economy, ahead of the illegal trade of arms, and behind illicit drug trafficking. The high ranking of illegal wildlife trade is the result of increasing rarity of wildlife products that has inflated black market values to extreme rates (Hall 2008; Anderson 2014). For example, 2013 black market prices for elephant ivory were as high as US$ 3,000 per kilogram (Anderson 2014). Similarly, a kilogram of rhinoceros horn could fetch as much as US$ 50,000, a set of tiger bones as much as US$ 7,000 and a tiger pelt can be worth up to US$ 20,000 (Graham-Rowe 2011). While these prices can

seem extreme to those living in affluent nations, they are astronomical in many poverty-stricken portions of the world. Accordingly, the literature describes commercial poaching efforts of varying levels of sophistication, from poor villagers who supplement their livelihoods by illegally harvesting wildlife, to organized crime networks with advanced technology and diverse resources (Moyle 2009; Ayling 2013).

While international agreements have paved the way for domestic regulations guarding vulnerable species from exploitation around the world, those laws remain difficult to enforce in in the field as they often lack the necessary law enforcement infrastructure to do so (Critchlow 2016). Studies have shown that laws aimed at protecting wildlife show little success without mechanisms to enforce them on a regional scale (Rowcliffe et al. 2004). Therefore, successful protection of vulnerable wildlife species depends on appropriate law-enforcement actions being taken at the local level. According to Critchlow, such actions include "ranger patrols, intelligence gathering, and effective criminal justice systems" (2016). Protected areas where robust law-enforcement actions have been implemented have successfully deterred poaching and have in some cases managed to secure wildlife populations (Jachmann 2008, Rowcliffe 2004). Alternatively, poaching-levels are likely to remain high where the probability of being arrested is low (Hofer 2000). For this reason, better enforcement of wildlife laws is likely the best way to address poaching.

However, law-enforcement efforts are expensive, and budgetary limitations often prevent adequate allocation of anti-poaching patrols within protected areas (Jachmann 2008; Plumptre et al 2014). Additionally, in protected areas where law enforcement is active, they can be hindered by inefficient patrol practices, and lack necessary mechanisms for self-evaluation (Stokes 2010). By addressing patrol efficiency, it is possible to reduce cost and improve the effectiveness of

anti-poaching efforts. Recent studies have shown that this is possible using a variety of geospatial tools (Stokes 2010, Critchlow 2016). However, such tools may be unavailable to law-enforcement (Pickles 2015). This study aims to address this limitation by identifying appropriate geospatial solutions and formalizing a framework for their construction.

Part 2: Geospatial Solutions to Poaching

According to Critchlow (2016), law enforcement can be the most expensive aspect of protected area management. For this reason, efficiency is a key consideration in anti-poaching law-enforcement efforts (Jachmann 2008). Because threatened wildlife species are often isolated to remote terrain, inefficiency in anti-poaching law enforcement efforts is often a result of navigational limitations. Anti-poaching patrol efforts can squander significant resources by getting lost or by patrolling in the wrong locations (Pickles 2015). To effectively patrol and enforce laws that protect wildlife, law-enforcement must first, be able to find their way.

One vital tool for navigating wild landscapes are accurate, up-to-date, high resolution topographic maps. Whether they come in the form of large printed maps or GPS base maps, they can be vital to navigational efficiency. Many of the world's developed nations have government agencies whose sole purpose is to create domestic maps and geospatial data. However, the production of topographic maps can be prohibitively expensive (Rhind 1999). As a result, many nations in the developing world do not have available topographic map series at an appropriate scale, or they have not been updated in decades. For example, the United States Geological Survey has mapped the entire United States at a scale of 1:24,000, while in contrast, David Rhind estimated that in 1999, 1:50,000 scale maps were available for only about half of the world, and much of them were totally out-of-date (Rhind 1999).

Similar to accurate maps, another important means of increasing efficiency in anti-poaching law-enforcement practices, is the use of geographic information systems and technologies (GIS). GIS methods have been used in a number of ways to monitor and improve the efficiency of anti-poaching patrols. These methods include assessing spatial bias in patrol distribution, tracking locations of poachers in the field, and predicting poaching hotspots using species distribution models (Stokes 2010; Plumptre et al 2014; Linkie et al. 2015; Hotte et al. 2016; Critchlow et al. 2016). GIS data collection and monitoring efforts requires accurate and comprehensive base data. Data relevant to anti-poaching efforts can include the features of the human environment as well as the physical environment. Important features include transportation networks, buildings, points of interest, political boundaries, hydrological features, land cover, relief and elevation above sea level. Similar to topographic maps, geospatial base-data is expensive to create and update, and it requires proper training to effectively use.

The technological and navigational limitations discussed above are especially relevant in to the current state of tiger conservation. Demand for tiger Parts in traditional Asian medicine has made tiger hunting an extremely profitable pursuit (Moyle 2009,). Poachers are willing to trek into some of the world's densest jungle terrain to hunt and trap tigers. Poachers are heavily armed and are willing to fight in the event that they are ambushed by law-enforcement. In pursuit of these poachers, patrols require accurate methods for identifying their own position, where they need to go, and the best way to get there. In many cases, the necessary tools are out of date, inaccurate, or simply do not exist.

In accord with concepts regarding the importance of tiger source sites summarized in Walston et al. 2010, big cat advocacy group Panthera dramatically shifted their approach to tiger conservation in 2009 by introducing the Tigers Forever program. This program was designed to

focus exclusively on the greatest threats facing the world's remaining tigers, by offering support on a site-by-site basis. Accordingly, this program provides law-enforcement, at key habitat sites, with the technology and training they need to be effective. As part of the Tigers Forever program, in 2014, Panthera collaborated with the department of Geography at the University of Montana to construct a package of geospatial tools that could be used by patrol rangers in Parsa National Park, Nepal. This package included a series of 12, 1:25,000 scale, 7.5-minute map sheets, corresponding GPS base maps, and all relevant GIS base data. Today, these geospatial products are available to park rangers as they plan and carry out patrols.

From the success of the Parsa mapping project came a series of subsequent projects to provide crucial geospatial tools to other regions key to the survival of threatened species. In 2016, student cartographers led by Kevin McManigal and Hugh Robinson completed a series of maps and GIS data for another region containing important tiger habitat, Manas National Park, India. In the summer of 2017, the mapping collaborative set their sights on protecting an endangered sub-population of Senegalese lions. In January of 2018, a comprehensive geospatial package was delivered to officials in Niokolo-Koba National Park, Senegal. In the spring of 2018 students began work on yet another mapping project. This time, in peninsular Malaysia, where the success of tiger populations depends on habitat connectivity between Teman Negara National Park in the south, and vast tracts of national forest land in the north.

While these projects have successfully provided important geospatial packages for three crucial pieces of big cat habitat (with Malaysian maps currently under construction at the time of publication), they have hardly scratched the surface of what is required to protect the world's remaining tiger populations. In fact, there are at least 15 additional Panthera Tigers Forever sites that lack comprehensive maps and GIS base data. Additionally, much of Africa's remaining lion

habitat is unmapped or out of date. Certainly, other anti-poaching initiatives could benefit from similar geospatial packages, including efforts to protect elephants, rhinos, gorillas and a host of other species targeted for their black market value. Furthermore, the same packages could be applied to any conservation that simply requires good maps and up to date geospatial data. Examples of potential conservation efforts where these tools could be applied are only limited by the imagination of the wildlife specialists who implement them.

While there may be a seemingly unlimited number of conservation efforts that could benefit from robust geospatial tools, the construction of topographic maps and GIS base data for large conservation areas has its own set of limitations. First, these products require a specific set of GIS and cartography skills that is not standard at most universities across the U.S. Also, the specifics of the workflow required to construct these products have yet to be comprehensively documented. Second, such projects are extremely time and labor intensive. For this reason, a pool of talented cartographers as well as significant funding is required in order to embark on a given project. Furthermore, these projects take time. Data preparation and map construction have spanned anywhere from 3-6 months for previous projects at UM. These long construction periods represent a significant limitation to the number of maps that can be created each year, time when wildlife law-enforcement agencies will not be able to protect wildlife to their full capacity.

To address these limitations, a step-by-step workflow manual has been created by combining existing documentation and technical expertise from educators and students at the University of Montana. This manual discusses all required steps for creating the geospatial packages discussed above using the Environmental Systems Research Systems (ESRI) GIS products and Adobe design software products (ESRI 2018, Adobe Systems 2017). The intention

of this manual is to greatly improve the efficiency of all aspects of future production while also

serving as a valuable educational tool. Increased efficiency will lead to decreased time

requirements, cost, and therefore the opportunity to create more maps. More maps can mean

more tigers, and hopefully other species. A secondary goal of this manual is to facilitate the

application of these geospatial tools to numerous other species conservation efforts.

The following section provides historical context for the topographic mapping techniques

covered in Chapter 2 of this document.

Part 3: Historical Context for Modern Cartographic Workflows

In the last century, many nations have made it a priority to survey and catalog the

physical aspects of their contained landscapes in the form of topographic maps. These efforts

stem from planning and development reasons, resource extraction and military purposes. In fact,

many nations' federal governments or military branches have independent divisions in charge of

surveying and constructing topographic maps. Examples of such agencies include the United

States Geological Survey (USGS), the Topographical Survey of Switzerland, and the United

Kingdom's Ordnance Survey. These mapping divisions are charged with systematically

surveying and mapping their nations using multi-sheet map series. Map series are sets of maps

that use consistent scale, size and symbols to exhaustively map regions of interest. The first

topographic map sheet series of an entire nation was completed in 1789 for the nation of France,

it is known as the Carte géométrique de la France (Library of Congress).

The USGS began a systematic effort to survey and make topographic maps for the entire

United States beginning in 1884 (Lynne et al. 2009). At this time elevation was mapped using

the process of field surveying, where elevation is determined at individual control points, using

an aneroid barometer (Lynne et al. 2009). Next, terrain was drawn in the field by inferring incremental contours of equal elevation. Field sketching later employed trigonometric techniques to improve the speed of control point collection (Lynne et al. 2009). The original USGS topographic maps from this period were at scale of 1:250,000 and 1:125,000, covering 1-degree and 30-minutes of longitude and latitude respectively (Lynne et al. 2009). Aerial photogrammetry techniques developed during World War I, were eventually employed in USGS mapping efforts and increased both efficiency and the accuracy of resulting maps (Bagley 1917; Lynne et al. 2009). Furthermore, the development of stereo-pair tracing methods that allowed terrain to be drawn quickly based on overlapping aerial photographs without being in the field were important developments (Bagley 1917; Lynne et al. 2009). Demand and methodological cartographic improvements paved the way for the development of the finer scale maps with greater detail. These 7.5 minute, 1: 24,000 scale map sheets soon became the standard map product of the USGS (Lynne et al, 2009). Today, USGS 7.5 minute maps are available for the entire United States in print and digital formats.

According to Lynn et al. USGS 2009, "the development of computers may represent the greatest technological innovation to change the mapping process". Cartographers and surveyors were quick to adapt computer technologies for cartographic workflows. These technologies eventually developed into what is known today as geographic information systems (GIS). GIS is defined as any "system designed to capture, store, manipulate, analyze, manage and present spatial or geographic data (UW Research Guides 2017). These systems have fundamentally changed the way that cartography is practiced, while reimagining the way modern society uses geographic information.

The most widely used software platform for conducting GIS analysis and cartography is suite of products produced by ESRI. Their programs (and others like it) allow the integration of geographic data in both vector and raster data formats (ESRI 2018). This software allows the quick analysis of geographic data, including projection, orthorectification, data creation, data manipulation, and analysis. It also allows users to create detailed maps much quicker and with greater accuracy than was ever possible before. Advancements in data retrieval, like airplane and satellite-based remote sensing techniques have also increased the availability of GIS data sources and made it more affordable (O'sullivan 2014). Advancements in the geographic information sciences (the study of how geographic information systems are applied to address scientific questions) have paved the way for the use of traditional statistical methods with spatial components (Goodchild 2009). These geospatial statistical methods have been applied in diverse fields of study, from projects concerning large-scale demographic phenomena, natural resource extraction, to crime distribution analysis and everything in between (O'sullivan 2014).

Modern GIS data types like high resolution orthoimagery and digital elevation models allow users to generate maps with diverse themes and purposes quickly without ever setting foot in the region to be mapped. Through GPS data acquisition, online GIS data sharing capabilities, and publicly available GIS data, topographic workflows have changed dramatically since the days of field surveys and stereographic contouring techniques. Today, cartographers can conduct the entire map production process using one GIS software platform. This includes the compilation of data, processing of data, data creation (digitizing), generation of derived map features (e.g. contours and hillshading), creation of labels, symbolization, and styling.

Despite these broad capabilities, today's advanced cartographic workflows often employ some form of design software to increase map aesthetics, and workflow efficiency. Tools like

Adobe Photoshop allow cartographers to optimize raster data, by modifying and blending

features like hill-shading and hypsometric tint to create better representations of physical

landscape features (Adobe Systems 2017). Adobe Illustrator is used to efficiently manage vector

features (points, lines, and polygons) by creating templates to quickly apply graphic styles to

map features, facilitating consistency between map sheets (Adobe Systems 2017). While these

programs have vastly improved modern cartographic products, it should be noted that care must

be taken to ensure the geographic accuracy by maintaining original size and scale of map

features derived using GIS software.

Discussion

The aim of this cartographic workflow manual is to guide student cartographers through

the process of creating multi-sheet topographic map series at specific dimensions and scale. The

processes outlined in Chapter 2 are optimized using these specifications for a few reasons. The

first reason for the size and scale chosen for this manual and its associated projects is that 7.5

minutes maps at a 1:25,000 scale are optimized for navigating in the field. At this resolution it is

possible to include features as small as individual buildings and huts while displaying significant

areas on a manageable size page. This balance of scale and physical map size helps limit the

number of maps needed in the field at a given time, while providing detailed enough information

to navigate effectively. Second, these specifications are similar to the USGS standard 1:24,000

topographic maps that have become an important standard. However, the scale was modified

slightly (decreased to 1:25,000) to facilitate on-the-fly calculations.

While the workflow outlined in Chapter 2 is optimized for the specifications discussed

above, it is possible to apply many of the same methods to mapping projects of different scales

and size. It should be noted however, that accuracy is a function of scale. For this reason, it is important to use map features and symbols that are appropriate for the scale of the final map product. This means limiting the inclusion of map features to those that are relevant at the chosen scale, and also digitizing or creating features with the final scale in mind.

Similarly, it should be noted that this workflow manual advises the use of a 30-meter pixel resolution DEM to generate topographic contours at an interval of 10-meters. While some might argue that a 30-meter resolution DEM is insufficient for generating such contours, the decision to do so was based a number of factors. Two such factors, are the availability and cost of high resolution DEMs. While 30-meter resolution DEMs are widely available through the National Aeronautical Space Administration's (NASA) Shuttle Radar Topography Mission (SRTM) at no cost, higher resolution DEMs are much less available (NASA 2018). In fact, high resolution DEMs available through private companies can be extremely expensive.

Additionally, DEMs at resolutions greater than 30-meters, contain information regarding unwanted features. While these extraneous details are easily identified with the human eye, such information can be difficult to account for within GIS software. For example, features like crop edges, forest canopy, anthropogenic infrastructure, or open water are often evident in 10-meter DEMs. However, topographic contours derived from a DEM are meant to represent the land surface, not the surface of features like buildings and vegetation. To avoid having to assess such features in the generation of topographic contours, the DEM must be processed to smooth out those features, which effectively reduces the resolution of the DEM. In contrast, 30-meter SRTM DEMs provided by NASA require little preprocessing and produce smooth and accurate contours (USGS 2018). To address concerns regarding contour accuracy, it would be necessary to ground truth contours generated at both resolutions. It is beyond the scope of this project to do so.

Like many aspects of cartography, the distinction between different land cover classifications can be difficult. However, these distinctions can be one of the most useful aspects of topographic maps. Agencies around the world use different classification systems to categorize land cover using remotely sensed data. For example, the USGS adheres to a multi-level classification system developed by Anderson et al. 1976. Alternatively, organizations like the Food and Agriculture Organization of the United Nations, and the European Commission have developed their own systems for making such distinctions. While many alternative systems exist, none have been universally adopted. Yang et al. (2017) attributes the heterogeneity of land cover classification systems to diverse purposes and users. Certainly, land cover distinctions focused on understanding sustainable development and agricultural production will be organized differently from those used for navigation or law enforcement. Chapter 2 discusses the use of supervised classification methods to classify remotely sensed imagery, however it does not discuss a system for defining those classes. The system used by a given mapping project must be determined collaboratively by the cartographer and the contracting agency, to create a system suited for the purpose of the maps and the landscape they represent.

Finally, it is important to note that this workflow manual is optimized for use with specific commercial software programs. Those programs include ESRI ArcInfo 10.5 GIS products, Adobe Illustrator CC 2017, Adobe Photoshop CC 2017, and MapTiler software (ESRI 2018, Adobe CC 2017, and Koklan 2018). Steps included in the manual are for the Windows 10 operating system and may not be as effective with other operating systems. While this manual does provide step-by-step cartographic instruction, it assumes that the user has basic knowledge of cartographic conventions as well as prior experience using the programs listed above. Users of this manual should be resourceful. It is crucial to supplement this document using online

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documentation regarding cartographic conventions, as well as ESRI and Adobe software products.

Additionally, while this manual was written in a way that facilitates its adaptation to mapping projects with diverse specifications, it does have limitations in regards to its adaptability to rapidly changing software programs and operating systems. In order to maintain the usefulness of this manual as a guide for creating state-of-the-art topographic mapping products, the steps within this manual must be updated often. Notably, ESRI has made clear its intentions to conclude support for their ArcMap products in the near future, with ArcGIS pro replacing it as their flagship mapping software. Because so much of this workflow is devoted to software-specific steps, this migration would mean much of this manual would have to be completely retooled. While this represents a significant obstacle to using this guide in the future, the existence of this workflow manual in its current form can only aid in the inevitable adaptation process.

Conclusion

Due to habitat loss, commercial poaching, and a host of other factors, the likelihood of extinction for many of the world's most charismatic wildlife species is on the rise (Ceballos 2002). In recent decades, global efforts to stabilize population levels for many of the world's most vulnerable wildlife species have failed to live up to expectations (Walston et al. 2010). Their shortcomings can often be attributed to a lack of regional and site-specific efforts that address the greatest threats to vulnerable species, most notably commercial poaching.

These limitations are especially relevant in the realm of tiger conservation, where years of landscape-level protection efforts have made only incremental progress against organized poaching. To reverse this trend, recent tiger conservation efforts (including the Panthera Tigers

Forever program) have resolved to focus their efforts on small regions that contain disproportionately large numbers of tigers. This regional approach is more cost effective, and its value has been demonstrated (Walston et al. 2010).

In accord with this shift towards protecting tiger source habitat, the Tigers Forever Program seeks to meet the technological and financial needs of local agencies responsible for apprehending poachers in the field. More often than not, those technological needs include navigational tools like topographic maps and GIS base data. In collaboration with Panthera, the Department of Geography at UM has produced those geospatial tools for three Tigers Forever sites to date. The continued demand for similar packages from other Tigers Forever and big cat conservation sites with ties to Panthera, as well as examples from other protection programs in the literature, exemplifies the necessity of relevant geospatial tools in species conservation efforts.

While crucial to anti-poaching efforts, these navigational tools are expensive and time-consuming to produce. The production of future geospatial packages depends on adequate funding and proper training for the groups who produce them. To help reduce production cost, and serve as an educational resource to species conservation projects, a cartographic workflow manual was created and is presented in Chapter 2. It is the goal of this workflow manual to ease the creation of important geospatial packages for many tiger conservation sites in the future by reducing cost, increasing efficiency, increasing quality, and by strengthening the relationship between UM and conservation minded groups like Panthera. Furthermore, the recent application of this workflow to African lion protection efforts has demonstrated that this manual can be employed by diverse species conservation efforts.

Finally, while the goals of this document have been clearly defined throughout the development of this project and are discussed in Chapter 1, it should be noted that a secondary goal of this manual has emerged throughout its creation. This goal is to demonstrate the importance of print cartography as a viable tool in the world of species conservation. Throughout the process of researching and writing this manual, the lack of published material regarding the use of high-end print maps in conservation efforts was startling. While the literature contained many examples of spatial monitoring and GIS methods for improving patrol efficiencies, there were few mentions of the importance of accurate print maps and GIS base data. Hopefully, future UM students will take it upon themselves to demonstrate the importance of such tools by studying their role in on-the-ground species conservation efforts.

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CHAPTER 2:

The Cartographic Workflow Manual

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List of Figures

Part 1: Map Sheet Setup and Indexing

Large scale topographic mapping projects can require hundreds of hours of labor by experienced cartographers. However, each project has its own unique requirements that affect the total amount of time and resources necessary to successfully complete them in a timely manner. For this reason, it is important to assess the factors that affect time requirements and make an estimate of budgetary needs early on. While it is impossible to determine the exact amount of time and resources necessary to complete each project, knowing the number of map sheets that will be required to completely cover the area of interest at a given scale is crucial for planning a timeline and acquiring funds. Part 1 covers the steps for defining the total extent of the area to be mapped as well as determining the number of map sheets that will be required for a project. This section covers the steps for:

- Creating a feature class for the total extent of the area to be mapped.
- Generating a feature class for a 7.5 minute longitude by 7.5 minute latitude grid of the all map sheets to be produced.
- Using an alphanumeric system to assign index values to each map sheet. And labeling the map sheet grid in ArcMap.
- Creating a point feature class with XY coordinates of each map sheet corner point in decimal degrees.

When creating a feature class for the total map extent, it is crucial to have a clear understanding of the total extent of the final maps. For maps of National parks with defined boundaries this can be simple, but it can be potentially complicated for regions with less formal boundaries. It is crucial to discuss this with the agency contracting the maps before moving

forward. Once the extent is formalized it should be digitized in GIS software. This is done by creating a rectangular polygon that completely encompasses the area of interest in an ArcMap (.mxd) document. Because of the abovementioned dimensions of each map sheet, it is important that the each map sheet's border (top and bottom) are at a longitude or latitude at a multiple of 7.5 minutes (0.125 decimal degrees).

1.1 Creating the Total Map Extent Feature Class

1. Create a new Geodatabase. Include "Master" somewhere in its name. This geodatabase will contain master-level data spanning the entire map area (see Appendix I for more information of project folder organization).

2. Open a blank ArcMap document.

3. Add the necessary base map and relevant base data needed to define the total area to be mapped.

4. Confirm that the data frame is in WGS 84 and is unprojected (WGS 84). This can be done by right-clicking **Layers** in the **Table of Contents**, clicking **Properties**, selecting the **Coordinate System** tab and searching for WGS 84. Confirm that there is nothing listed under "**Projection:".**

5. Next, Confirm the cursor on screen XY coordinates are listed in decimal degrees. If they are not, right-click **Layers**, then **Properties**, then select the **General** tab and under **Units** change **Display** to **Decimal Degrees**.

6. To find the westernmost edge of the total map extent, hover the cursor on the western edge of the map area and slowly move it west until the cursor on screen X coordinate

(listed first) shows a multiple of 0.125 decimal degrees. It may be helpful to zoom in slightly for this task. Make note of that X coordinate value.

7. Repeat this process to find the easternmost edge of the total map extent by moving the cursor east from the eastern edge of the park boundary, noting the first X coordinate with a multiple of 0.125 decimal degrees.

8. To find the northernmost and southernmost borders repeat this process, this time noting the first multiple of 0.125 for the on screen cursor Y coordinate. XY Coordinates that are multiples of 0.125 will end in one of the decimals listed in the table 1.

.000	.125	.250	.375	.500	.625	0.750	.875

Table 1. Decimal coordinates on the 7.5 minute grid.

9. Determine the coordinates of each corner point for the total map extent based on the coordinates noted in steps 6 and 7.

10. Find and select the **Go to XY Tool** XY on the **Tools toolbar**. Change units to decimal degrees and enter the coordinates of the northwest corner point of the total map extent.
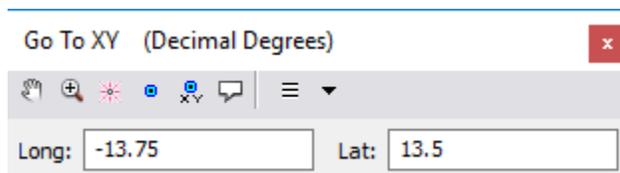
Figure 1. The ArcGIS "Go To XY Tool".

11. Select **add point**.

12. Repeat Steps 9 and 10 for each corner point.
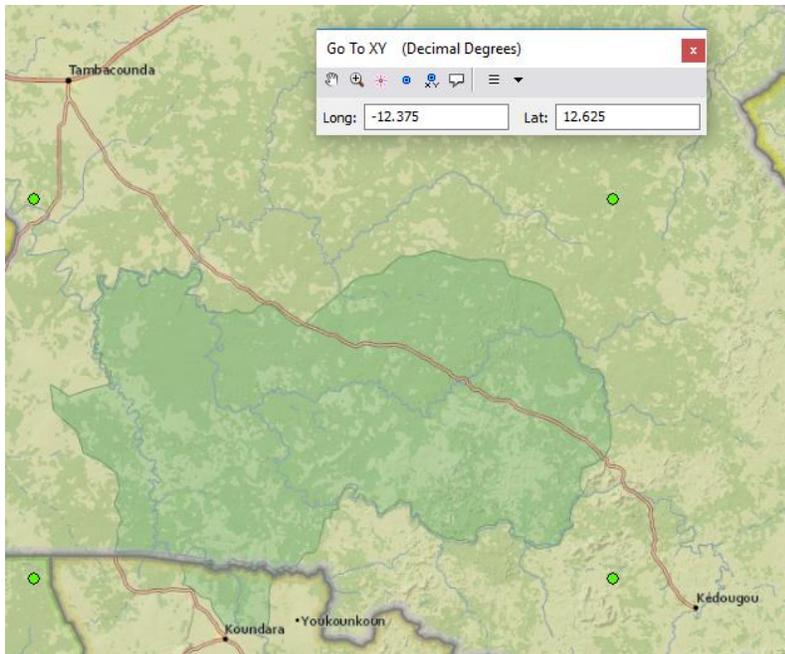
Figure 2. An example of total map area extent corner points.

13. Once each corner point has been added as a graphic feature, they must now be converted into map features. To do so, select all corner points at once using the shift key. In the **Draw Toolbar** find the drop-down and select **Convert Graphics to Features.** Convert the points to a feature class and save it in the master geodatabase, choose the option to use the same coordinate system as the data frame, name the new feature class **Corner_Points**, and check the box to automatically delete graphics after conversion.

14. Create a blank feature class in the master geodatabase, and choose **Polygon** for feature class type. This feature class will represent the total extent of the area to be mapped, name it accordingly. Add the new feature class to the ArcMap document.

15. Begin an editing session. Choose to enable snapping by selecting **Use Snapping** under the drop-down on the **Snapping Toolbar**. Select the create features icon ▣ on the **Editor Toolbar**. In the **Create features** window select the empty map extent feature

class, then, select **Polygon** in the **Construction Tools** window. Draw a rectangle with each point in the **Corner_Points** feature class created in step 13, as its corner points. Save edits, and Stop editing.
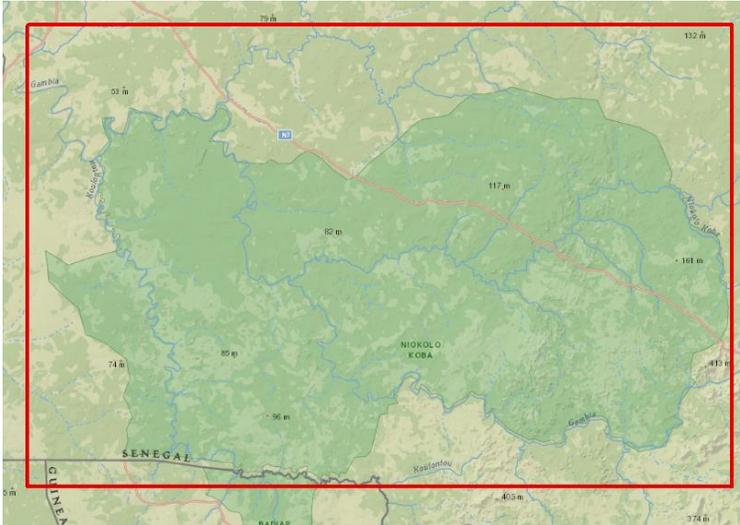
Figure 3. The total map sheet extent feature class for Niokolo-Koba National Park, Senegal.

1.2 Creating the Map Sheet Grid

1. Now, determine the number of 7.5 minute maps contained in the map extent feature that was just created. This can be done by subtracting the westernmost X coordinate determined earlier by the easternmost X coordinate and dividing by 0.125. Ignore negative signs in the result.

   Example:

   (-13.75 degrees E - -12.375 degrees E) / 0.125 per map sheet = 11 map sheets

   The result is the number of individual map sheets that fit across the map extent. Repeat this step for the northernmost and southernmost points in the Y direction. The result is the

number of individual map sheets that will fit vertically in the total map extent. Multiply

these numbers to determine the total number of map sheets within the total map extent.

2. Next, open the **Create Fishnet** tool. Name the layer "Map_Sheet_Index" or something

with a similar meaning. Add the total extent layer that was just created as the **Template**

Extent, enter the number of map sheets previously determined in the North-South

direction in the **Number of Rows**, and the number of map sheets determined for the East-

West in the **Number of Columns**. Uncheck the box for **Create Label Points**, and choose

Polygon as the **Geometry Type**. Select **Run**.
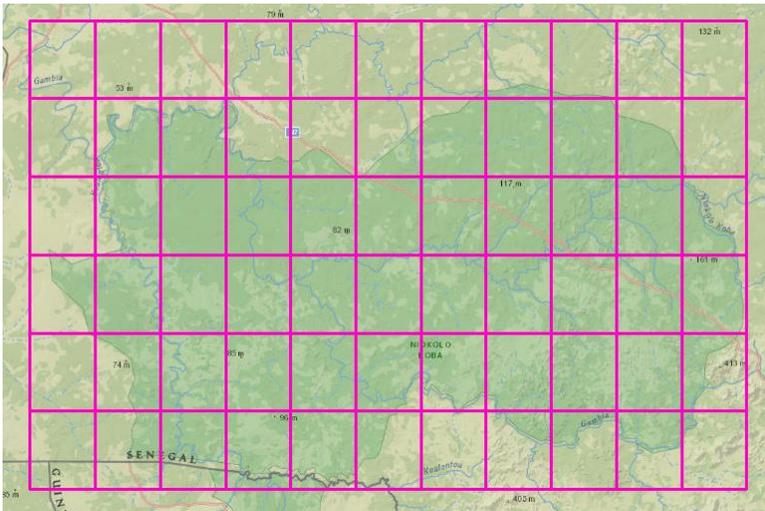
Figure 4. The total map sheet extent feature class divided into individual map sheets using the fishnet tool.

3. Each cell in the fishnet, shown in Figure 4, represents one 7.5 minute map sheet. Now,

each cell should be assigned a name using an alphanumeric index system, where rows are

assigned letters (alphabetically from north to south) and columns are assigned numbers

(in order from west to east). To do so, open the attribute table for the newly created map

index feature class. Under the attribute table drop-down menu ⊟ ▾ , select **Add Field** and

name it Map_Index, choose **Text** for data type. Begin an editing session, select the cell in

the northwest corner on screen and in the newly created **Map_Index** field name it A1. It

is important to select each cell on screen during this process as they are not automatically

ordered in this way within the attribute table. Once each cell has been assigned an index

value, save the edits and stop editing. To confirm the correct index was assigned to each

cell, right click the **Map_Index** layer in the **Table of Contents**, select the **Labels** tab,

check the box next to **Label Features in this Layer** and under **Label Field:**, select

Index, **Apply** and **OK**.
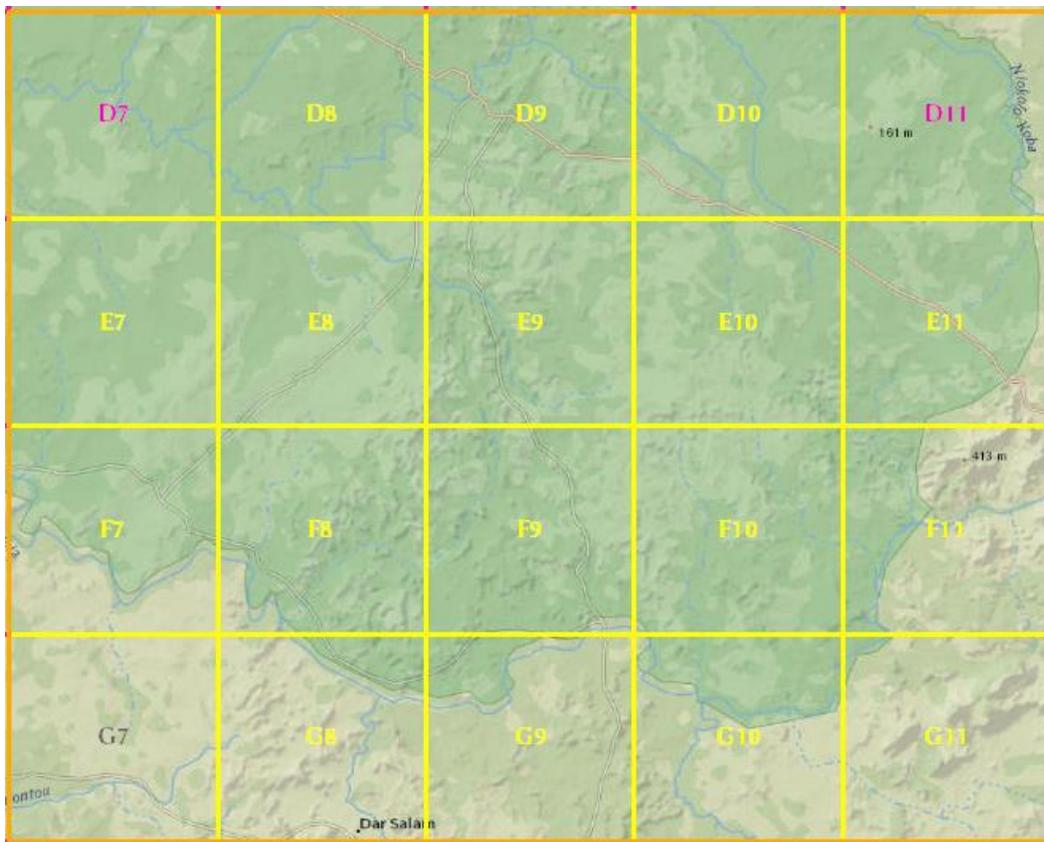
Figure 5. Map sheets with assigned alphanumeric index values.

1.3 Generating Corner Points

4. Finally, it can be useful to have access the XY coordinates of each map sheet's corner points, when georeferencing the final maps. Open the **Create Grid Corner Points** tool (This is a third-party tool available for download online) (Broad 2015). Add the Map_Index layer as the input feature class, name the output point layer and select **No** under the **Add Midpoints** option. Open the attribute table for the output feature class, add a new field named X and a field named Y with **Float** as the data type. Right-click the X field and select calculate geometry, under **Property** select **X Coordinate of Point**, and for **Units** select **Decimal Degrees**, and select **OK.** Repeat this for the Y field. To confirm that this process was successful, open the attribute table of the new corner point features class. Each corner point should be a multiple of 0.125 decimal degrees, as shown in Table 1.

Part 2: Obtaining and Organizing Geospatial Data

Useful topographic maps contain very detailed information regarding both physical and human landscape features. For the cartographer, this means large amounts of data to obtain, and generate using GIS software. It also means, that organization of relevant data is crucial from the beginning of the project to the end. Part 2 of the cartographic manual covers the most important data types needed to create detailed topographic maps, and different sources where this data might be obtained. It will also cover a system for organizing all spatial data using ArcGIS mapping software. Understanding what data is available for a project, and what data needs to be created can also aid the in the budgeting process discussed in Part 1. Throughout Part 2 refer to Appendix I for information on organizing GIS data, and Appendix II for information on features that should be included in a topographic map series.

2.1 Assessing Available Data

1. The first step of this process is to assess all important map features that must be included in the final topographic map series. The features included will be completely dependent on the unique landscape and the specifications of the contracting agency.
   It can be helpful to assess the map area in Google Earth, Openstreetmap, and other free mapping services to gain an idea of the overall complexity of these features within the map area.

2. Create a comprehensive list of all the map features that must be included in final maps. Use this list of possible map features as a guideline. However, do not limit possible features to the ones included in this list (refer to Appendix II when creating this list).

2.2 Organizing Raw Vector Datasets

1. First, assess the vector data provided by the agency contracting the mapping project. In

   most cases, anti-poaching patrol efforts will have some kind of GIS base data for the area

   that will be mapped. It is crucial to obtain data regarding features to which only law-

   enforcement or park rangers will have access. Features like ranger camps, patrol stations

   or river fords will not be easy to find via publicly hosted geodata web pages. If GIS data

   for such features is unavailable, it is important to request GPS coordinates for such

   features. Once data is obtained from the contracting agency, add that data to an ArcMap

   document and determine whether it covers the entire extent of the map area. Data for

   features not provided by the contracting agency will likely be digitized using

   orthorectified imagery or available topographic maps as a reference. Check the Natural

   Earth Data website for vector data regarding international and state boundaries, national

   parks, and wildlife reserves (Natural Earth Data).

2. As GIS data is obtained and assessed for its accuracy and coverage of the map area, it is

   important to have a defined system of organization from the beginning. As data is

   obtained it should be saved within a raw data geodatabase . Any changes to raw data

   should be made to copies of the original raw data, this way changes to raw data are never

   destructive.

3. In the data creation stages of this workflow, vector data will be saved as feature classes

   within feature datasets based on the feature types listed Part 2.1. These feature datasets

   will be saved in a master geodatabase (refer to Appendix I for the organization structure

   and Appendix II for a list of possible feature datasets). Master-level data is a distinction

   between map-sheet level data, which includes all the same map features, organized in the

same manner, but clipped to the extent of each individual map sheet (See figure 14 for a

graphic representation of this organization strategy). All data creation (besides spot

height generation) will occur at the master-level, then the ArcGIS Model-Builder module

or a Python script can be utilized to automate the process of clipping data to the extent of

each map sheet (see Part 6). This system of organization is useful for ensuring that

features that span multiple map sheets will match across map sheet borders (refer to

figure 6).
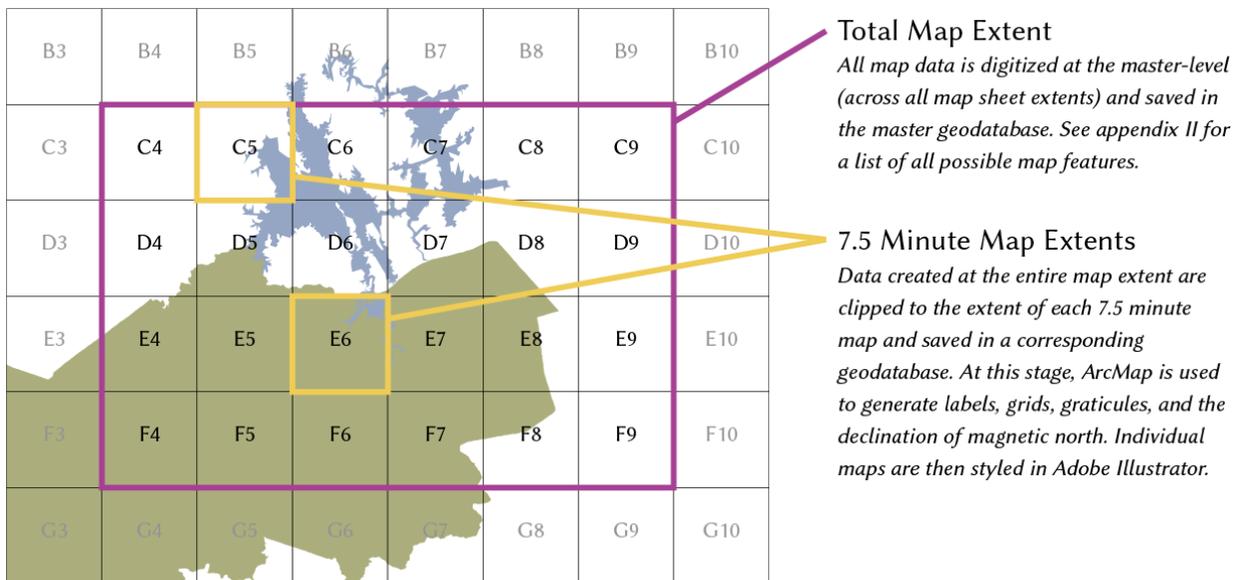
Figure 6. Master data vs. map sheet data organization.

4. Within **ArcCatalog**, navigate to the server and folder where the master geodatabase was

   created in Part 1.1. Open the **master geodatabas**e and **right-click** into white space,

   select **New** and **Feature Dataset** . Name it for the feature type it will contain (for

   example, transportation, hydrology etc.), and click **Next**, in the menu for the XY

   coordinate system find and select **WGS 1984**. By defining the coordinate system for a

   feature dataset, it guarantees that all feature classes saved within will assume the same

coordinate system. Select **Next,** and do not choose a coordinate system for Z coordinates,

select **Next**, and **Finish**. Repeat this step to create a feature dataset for each broad

category of vector feature types to be included in the final maps.

5. Now, within each feature dataset, create empty feature classes for all appropriate map

    features identified in step 2. Use Appendix II as a reference. For example, the *hydrology*

    feature dataset would contain an empty feature class for *oceans* , *rivers* , *lakes*

    , *streams* , *intermittent streams* , *ponds* , *rapids* , *waterfalls* , *irrigation*

    ditches , *wells* , *water towers* , *etc.* However, not every map sheet will contain

    actual features for each of these categories. If no features are found to populate a feature

    class during the digitization process (discussed in Part 3) that feature class can be deleted

    later.

2.3 Organizing Raw Raster Datasets

1. Now, consider map features that must be generated using raster data types (georeferenced

    images or digital elevation models (DEM)). These features include:

    ● Elevational Relief (represented with hypsometric tint and contours of equal

      elevation), generated using a DEM (see Part 4).

    ● Hill-shading and texture, generated using a DEM (see Part 4).

    ● Land cover classes generated using satellite or aerial imagery (forest, grass, urban,

      cultivated, etc.).

2. Proper creation of the above features requires adequate pixel-resolution. In most cases, a

    30-meter resolution DEM, and 10-meter resolution imagery are adequate for generating

    features at this scale. These raster datasets are available free of charge for many Parts of

    the world via the USGS, however in some cases higher quality datasets may be

necessary. If this is the case, companies like Airbus, DigitalGlobe, TanDEMx and Planet

Imagery will often donate imagery to academic or conservation projects.

3. In most cases, it will take multiple DEMs to comprehensively cover the map area. To

generate features using multiple DEMs, they must first be combined into a single mosaic

dataset (refer to 4.1 for mosaicking DEMs). This process must be repeated for

orthoimagery, simply repeat the same process detailed in Part 4.1.

4. Note that raster datasets cannot be saved within a feature dataset. For this reason, the

coordinate system must be redefined manually for each raster dataset. This is done using

the project raster tool (found in the data management toolbox in ArcMap). Open the tool,

add the mosaicked DEM, choose to save the output raster dataset in the master-level

geodatabase, and name it. Choose **WGS 1984** as the output coordinate system, choose

Bilinear as the resampling method, and select **OK**. Repeat this step for any imagery to be

used in the digitizing process.

Part 3: Digitizing Vector Map Features

All data that cannot be obtained via the contracting agency or downloaded from the web, must be digitized using ArcGIS software. This process represents one of the most time-consuming and therefore expensive aspects of the entire workflow. For that reason, it is crucial to have thorough documentation of the tools used in ArcGIS for digitizing vector map features. In addition to the editing tools discussed in Part 3, ESRI's online documentation for the **Editor Toolbar** can also be helpful in determining the most efficient methods for digitizing map features.

Because final maps will be printed at a scale of 1:25,000, many features will have to be generalized. Not every feature visible in high-resolution imagery can be digitized. In fact, digitizing features at too fine a scale can be an inefficient use of time, as overly detailed features will have to be simplified in the end. Depending on the available reference imagery, it may be useful to use the "5, 10, 25 zoom rule". To follow this rule, search for noteworthy features at a zoom-level of 1:25,000, zoom to about 1:10,000 to digitize features, and never zoom below 1:5,000 to decipher a feature. However, for some difficult-to-see features like foot trails or intermittent streams it may be necessary to zoom to 1:2,000. Zooming to this level should only be done as a last resort.

Additionally, it is best practice to name features within the corresponding attribute table as features are edited and created. Be sure each feature class has an attribute field in which a name can be added. Use ESRI base maps, reference imagery, Google Earth, Openstreetmap, or web maps that host multiple map services as sources for naming information. Be sure to enter feature names using the language in which they will appear in the final maps with proper capitalization. These features can be labelled automatically in an ArcMap document.

The process described below is dependent on the unique requirements of the land scape to be mapped. It is crucial to keep these requirements in mind throughout the entire digitizing process. For example, in regions with pronounced wet and dry seasons, vegetative and hydrological features will change significantly from one piece of reference data to another. Be aware of subtle changes between different satellite images. It is also important to use clues to identify features that may not be visible because of limitation in image resolution or because they are obscured by forest canopy. For example, dense vegetation can be an indication of running water at least part of the year.

Throughout the digitizing process be aware of the needs of the agency using the maps. Determine features of importance and develop methods for identifying in the imagery. For example, rangers in Niokolo-Koba National Park, Senegal use the location of intermittent water holes or ponds to identify likely locations of lions in the field. For this reason, the inclusion of a these features in maps for that area was particularly important. In maps for the Kenyir region of Peninsular Malaysia, the availability of cell phone service can be important information for law-enforcement. To address this, the identification of cellphone towers was an important priority when identifying points of interest. These unique requirements should be determined early on in any mapping project.

Because there are different requirements for digitizing vector data types in ArcGIS, Part 3 is divided into steps for setting up an editing session, digitizing point features, digitizing line features and digitizing polygon features. These broad steps for digitizing vector features discussed in Parts 3.1-3.4 should be applied to specific feature types discussed in Part 3.5-3.7. The symbolization of features during the digitization process is a matter of personal preference. All map features will be re-symbolized when they are exported as Adobe Illustrator files.

3.1 Edit Session Set Up

1. The first few steps when digitizing any type of map feature are the same. Set up an ArcMap (.mxd file) named for the features you will be editing. Using the ArcCatalog window in your ArcMap document, navigate to the feature class you would like to edit. Add that feature class to your ArcMap document. It can be helpful to work on all feature classes within a feature dataset at once. For example, to edit hydrology map features, create a new ArcMap file, name that file *HydrologyV1.mxd*, and add all the feature classes within the *Hydrology feature dataset*. Modify the symbology of all feature classes so they are easy to distinguish. This is done under **Layer Preferences**, **Symbology**. By creating a separate ArcMap document for editing each general category of map features, it is possible to maintain an organized workspace without an overly cluttered **Table of Contents**, and optimize the symbology and order of reference layers for different types of map features.

2. Next, make sure the ArcMap document is in **Data View**. Confirm this under the **View drop down** on the main toolbar.

3. Then, add reference maps and imagery. The most recent imagery with the greatest spatial resolution will be the most useful for digitizing, however, make do with the best imagery available. Using the ArcCatalog window in your ArcMap document, navigate to the master level geodatabase and add these raster datasets to the **Table of Contents** of the .mxd file. Additionally, ESRI's proprietary base maps can be great reference layers. To add these, select the drop-down on the **add data** icon , select **base maps,** and choose an appropriate base map. Transparency of reference layers can be changed under **Layer Preferences** and **Display**.

4. Additionally, add the total map extent and map sheet index feature classes. Only digitize features within the total map extent. It is a good idea to digitize features for only one map sheet at a time. This makes it easy to assess your progress as you go.

5. If you haven't already, dock the **Editor Toolbar** on your main toolbar in ArcMap. This can be done by selecting **Customize**, **Toolbars** and **Editor.**

6. Follow the same steps to dock the **Snapping Toolbar.** Under the **Snapping** drop-down make sure **Use Snapping** is checked, and check all categories of snapping. These can be toggled on and off to aid in different types of feature creation.

7. Under the **Editor** drop-down menu, select start editing.

8. Under the Editor drop-down, select **Editing Windows,** and select **Create Features.** This window will be important throughout your editing session.

3.2 Digitizing Point Features

Map features that will appear very small when represented at a scale of 1:25,000 will be digitized as point features . Examples of potential point features are; individual buildings, ponds, ranger camps, patrol stations, factories, schools, etc. It is relatively simple to create point features in ArcGIS.

1. Select the point feature class you would like to edit by highlighting it at the top of the **Create Features** window. Below this window is the **Constructions Tools** window. This is where you choose how to create a feature in a feature class. For most point features you can simply choose the **Point Construction** tool . Simply click a point on screen where a point feature should be added and it will be added to that feature class.

2. If possible, name all new point features so that they can be labeled later. Open the attribute table of the feature class you are editing and type in the name field. You can also use the select features tool to select a point feature and edit any of its attribute information. Alternatively, to save screen space, editing of attribute information can be done using the **Attribute Editing Window**. To open this window select the **Editor** drop-down menu, select **Editing Windows,** and select **Attributes**. Now, when an editable feature is selected all attribute information for that feature will show in the **Edit Attributes** window, where it can be edited without opening the full attribute table.

3.3 Digitizing Line Features

Map features that extend across the landscape but are too thin to be represented using a polygon, should be digitized as line features . Examples of potential line features are; rivers, streams, roads, trails, political boundaries and airstrips etc. To create line features highlight a **Line** feature class in the **Create Features** window. In the **Construction Tools** window there will be two main options, the **Line Construction** tool ╱ Line , and the **Freehand Construction** tool
↷ Freehand .

1. To use the **Line Construction Tool**, click to add vertices, and double click to end a line segment. Because this tool requires lots of clicking to construct complex shapes it is better suited for straight simple features, usually man made, like roads.

2. To create features using the **Freehand Construction Tool**, click once to begin a line segment, vertices will be automatically added wherever you move the cursor. To pan without ending a line segment, hold down the toggle wheel on your mouse and drag. Because **Freehand Construction Tool** adds many vertices with minimal clicks, it **is** well suited for natural features with smooth curves.

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3. It can also be useful to edit line features that you just created or ones that already existed. This is done by selecting **Edit Vertices** . This allows you to select one or many vertices and change their position. Additionally, the **Reshape Feature Tool** allows you to reshape a selected feature by creating a sketch over it. The sketch will replace the feature from the first point of overlap to the last point of overlap. **Either Freehand Construction** or **Line Construction** can be used while reshaping a line feature.

4. While constructing line features for features like roads and rivers, it is important to confirm that line segment endpoints are coincident, make sure **Snapping** is enabled. It is also important join line segments that are meant to be one continuous feature. This is helpful when applying styles to map features when they have been exported into Adobe Illustrator. To merge two line segments, select them both at once using the shift key, and under the **Editor Drop-Down** select **Merge**. To split one line segment into two, select the **Split** tool , located on the **Editor Toolbar** and simply click where you would like to split a line feature. Try to keep line work as organized as possible. Additionally, avoid merging line segments that aren't continuous, this will complicate matters when features are exported to Adobe Illustrator.

3.4 Digitizing Polygon Features

Features that are too large or too wide to be represented as point or line features, should be digitized as polygons . Examples of potential polygon features are rivers, lakes, and land cover. (However, digitizing land cover classifications can be very time consuming. Supervised classification of satellite imagery is the preferred method for classifying land cover.)

1. Highlight a polygon feature class in the **Create Features** window. This will reveal a handful of new options in the **Construction Tool** window. Most of these options for

creating polygon features are relatively straightforward. However, options like the

Ellipse and **Rectangle** are not especially useful for representing natural features. The

Freehand Construction Tool ⌒ Freehand is the most useful for digitizing complex

curved features. It is used in the same way as for line features, except when you double-

click it closes the polygon by connecting the two nearest endpoints. It is prone to creating

errors or "broken shapes" when overly complex features are digitized. This can be

avoided by creating multiple overlapping polygons, and merging those shapes. Two or

more shapes in the same feature class can be merged by choosing those features (hold the

shift key to select multiple features), and selecting **Merge** under the **Editor Drop-down**

Menu.

2. For more angular features, use the **Polygon Construction Tool** ◈ Polygon . Click to

begin a polygon, click to add vertices, and double-click to complete a shape.

3. To modify polygon features, use the **Edit Vertices Tool** ⬠ or the **Reshape Features**

Tool . These tools work with polygons just as described in 3.3.

4. Remember to **Save Edits** every few minutes to avoid losing work to computer crashes or

other software malfunctions.

5. To create a polygon with a coincident boundary to a polygon of a different feature class

use the **Trace** tool . When this tool is selected, the cursor will automatically snap to

the shape of any other selectable feature.

6. Another useful editing tool for all feature types is the **Cut** ✂ / **Copy** 🖹 and **Paste** 📋

options. **Cut** can be used to remove a selected feature from one editable layer and add it

to another editable layer of the same feature type. **Copy** can be used to create an identical

feature to paste into another feature class. The pasted feature can then be edited in its new

feature class. This is especially useful for quickly creating features in different feature

classes with coincident borders. When selecting **Paste** 📋**,** simply choose the feature

class you would like to paste the selected feature into.
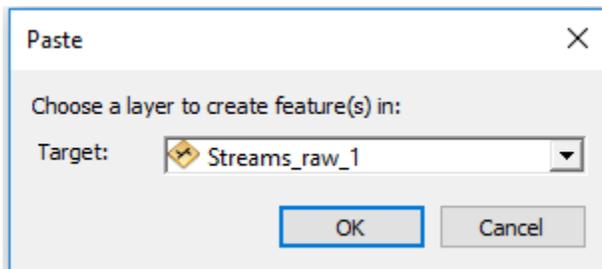
3.5 Notes for Digitizing Buildings and Other Points of Interest

Depending on the amount of urban development in your map area, digitizing buildings

can be very time consuming. Urban areas can have hundreds of individual houses and huts.

However, not every structure can be digitized and included in a final map. Apply the 5, 10, 25

rule mentioned in the beginning of Part 3 when creating features for buildings and other points of

interest.

Areas with many buildings in close proximity may have to be generalized and individual

features should be organized into broad symbolization categories. Use features listed under

"points of interest" in Appendix II as a guide for categorizing different building types. If a

structure fits into one of the listed categories, add a point feature within that feature class, all

other buildings can be created as features in the general "buildings" feature class. Name features

within the corresponding attribute table as you go. Refer to 3.1 and 3.2 for steps for creating

point features.

3.6 Notes for Digitizing Hydrology Features

Depending on the aridity of the landscape, digitizing hydrologic features can also be a time-consuming process. Add fords, ferries, ponds, wells, weirs, waterfalls, water holes, and water towers as point features where they exist in the imagery. Small streams, intermittent streams, and rivers should be digitized as line features using steps discussed in 3.3. Most stream features will be symbolized using a tapered line in the design portion of this workflow. To facilitate this symbolization, it is best to add anchor points to stream features starting downstream and moving upstream. Doing so for all stream features will indicate the direction of flow and reduce time in future workflow steps.

With hydrologic map features, it can be helpful to use topographic contours and shaded relief layers to guarantee that rivers and streams never flow uphill. In arid areas, features can be difficult to identify using reference imagery. However thick vegetation can be a good indication of stream locations, especially when streams are seasonally intermittent (present during wet seasons and dry other times of the year). Get a feel for the landscape by studying the imagery in reference to known stream and river features.

Lakes and rivers large enough to be represented as polygon features at this scale should be digitized as polygons. Refer to 3.4. These features should be easy to identify using imagery. Avoid "over-digitizing" these features as well, as their edges will be simplified later in the workflow.

3.7 Notes for Digitizing Transportation Features

Refer to Appendix I for important transportation map feature subcategories. If transportation network information is not available for the map area, the cartographer must decide in which feature class each road feature must be created. Highways are large paved roads

that will likely extend across multiple map sheets. Feeder roads can be paved or improved. They connect to highways and continue out across map sheets. Smaller roads that do not extend great distances should be defined as other roads. Other roads should can be paved or unpaved, however if there are many unpaved roads these features should be given their own feature class and symbolized differently on final map sheets. Foot trails may be very difficult to distinguish. Include features that are evident in the reference imagery and clearly too small for 4-wheel travel. Other transportation features should be found using other reference maps and data as was described throughout this tutorial. Remember to merge continuous road features of the same category. Most transportation features like roads will be digitized as line features. However, things like railway stations and tunnels may be better suited as point features.

Part 4: Blending Shaded Relief and Hypsometric Tint

In high-end cartography, physical terrain is represented using a number of raster datasets. Useful raster datasets include shaded relief, aerial perspective relief, hypsometric tint, surface texture, and more. There are many methods for generating such raster datasets, however, to avoid getting too complicated, Part 4 will discuss a simple method for representing physical terrain by blending a single hillshade dataset with a hypsometric tint dataset.

Shaded relief, or hillshading is a representation of the shape of the landscape if it were illuminated from a given light source. Traditionally, shaded relief was created by hand-shading with charcoal or pencil. Now it can be generated quickly using a DEM and GIS software. In cartography, it is the convention for the main light source to be placed in the top right corner of the page. However, some methods for generating shaded relief combine multiple light sources to increase contrast throughout the map.

Hypsometric tint uses color gradients to represent changing elevation across the landscape. Appropriate colors are different for every map site, but shades of green are often used to represent low elevation areas where vegetation is abundant, tans and browns for semi-arid grassland areas, and shades of grey can be used to represent alpine areas. These colors are easily assigned to different elevation values in a DEM using GIS software. ArcGIS has many built-in color ramps, however it also allows the creation of custom ones.

The color ramp you choose and how you blend it with shaded relief is based largely on personal preference. It is possible to blend these datasets using ArcMap without ever opening Photoshop. This can be done by simply setting the transparency of the hillshade so that the

hypsometric tint will show through (Buckley 2009). This is adequate for many maps, however the result can be a little uninspiring. Conversely, the methods discussed here produce really aesthetically pleasing results.

The blending process discussed in this tutorial requires a lot of experimentation with different colors, levels of transparency, and Photoshop blending modes (Huffman 2014). For this reason, the final result is largely dependent on the personal preference of the cartographer.

Part 4 covers the steps for downloading DEMs from the USGS Earth Explorer web map, mosaicking DEMs, and generating shaded relief and hypsometric tint with ArcGIS. Layers are then exported as high-resolution images to be edited using Adobe Photoshop blending techniques. Finally, Photoshop will be used to clip the resulting image to the extent of each individual map sheet.

4.1 Downloading and Mosaicking DEMs

1. In ArcCatalog, navigate to the total map extent feature class in the master geodatabase. Right-click and choose to export that feature class as a shapefile.

2. Open a web browser and navigate to the USGS earth explorer web page (USGS 2018). If you don't already have an account create one and log in.

3. In the second window under **Search Criteria**, select the **Shapefile** tab. Navigate to the map extent shapefile you just exported and choose to upload it. Now, you can search for datasets that are within the area to be mapped. It may take multiple datasets to cover the entire map extent. Navigate to **Data Sets.**

4. Choose the option for 1-Arc Second SRTM DEM dataset by checking the box to its left. Select **Results**.

5. Select the footprint icon ![footprint] to see the extent covered by each image. Confirm the resulting datasets cover the entire map extent area and download all necessary files.

6. Unzip each DEM dataset downloaded in the last step. Navigate to the raw data geodatabase using ArcCatalog. **Right-Click** inside the raw data geodatabase and select **New Raster** to create a new blank raster dataset. Name it and assign it the appropriate bit depth (SRTM DEMs are stored with 16-bit depth).

7. In ArcCatalog create a new mosaic raster dataset in the raw data geodatabase and name it **master_DEM_Raw**. In the resulting dialog choose to leave the spatial reference blank (it will assume the coordinate system of the imported DEMs).

8. **Right-click** the new mosaic dataset, and select **Load**. This will open the **Mosaic to New Raster** tool. In the tool's dialog add each DEMs as an input raster, under **Number of Bands** enter "**1**". Leave all other defaults and select **OK**.

9. Open a new ArcMap document, and add the **master_DEM_Raw** as a layer.

10. Search for the **Extract by Mask** tool. Add **master_DEM_Raw** as an input raster and the use the total map extent layer as the input mask. Name the output **DEM_clipped** and save it to the raw geodatabase.

4.2 Projecting, Aligning the DEM, and Setting the Scale

1. Navigate to the **project raster** tool. Add **DEM_clipped** as the input raster and WGS 84 UTM and the appropriate UTM zone as the output projection. Name it **DEM_UTM** with a suffix for the zone in which it was projected. Select **Run**.

2. Now that the DEM is projected in WGS and its UTM zone, it may need to be rotated slightly so that the middle of the dataset is parallel to true north. To do so, go to **View**, and choose **Layout View**. Make sure the DEM is centered in the layout. This can be done

quickly by right-clicking the layer in the **Table of Contents** and selecting **Zoom to**

Layer. Next, select **Insert** and **North Arrow**. Choose any north arrow and select **OK**.

Right-click the north arrow, and select **Properties**. In the north arrow properties window

make sure the **Align To** option is set to **True North**. Next, note the angle listed under

Calculated Angle. Subtract that number from 360 and take note of the result.

You can delete the north arrow now.

3. Under **Customize**, and **Toolbars**, select **Data Frame**. Dock this toolbar on the main
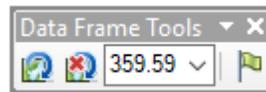
toolbar. In the **Data Frame Rotation Angle** box enter the number

determined in the last step and select hit the **Enter** key.

4. Now, set the appropriate page dimensions. To do so, go to **File**, **Page and Print Setup**

and uncheck the box that says **Use Printer Paper Settings**. Now set the dimensions so

they are greater than those of the total map area at 1:25,000 scale and select **OK**. To

determine those dimensions assume that each map sheet is 20 inches wide by 30 inches

tall and multiply those dimensions by the number of maps in each direction. Map sheet

dimensions do vary depending on the latitude of the map area. But for the purpose of this

tutorial, an estimate of total dimensions is sufficient.

5. Navigate to **Layout View** and set the scale to 1:25,000. Right-click on the DEM layer

and select **Zoom to Layer** (this will center the page on the DEM).

6. Navigate to **Data Frame Properties** and under the **Data Frame** tab set the **Extent** to

Fixed Extent. This locks the extent of the map area so it cannot be accidentally modified.

4.3 Generating Shaded Relief

1. Search for the **Hillshade** tool in the **Spatial Analyst Toolset**.

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2. Add the projected DEM as the **Input Raste**r and name the **Output Raster** something with Hillshade in the name. Leave options for **Azimuth** and **Altitude** as they are. Under **Z Factor** the value of 1 is the default, there may appear a warning icon ⚠.
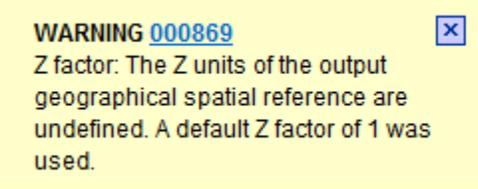
WARNING 000869 ☒
Z factor: The Z units of the output geographical spatial reference are undefined. A default Z factor of 1 was used.

Figure 7. The Z-factor error warning in ArcGIS.

If this warning is present the linear units (X, Y distance) used by the DEM dataset may use different units than those for Z-factor (vertical distance). To address this, you may need to enter a conversion factor, refer to ESRI's online documentation for determining the appropriate Z-factor conversion factor (Frye 2007). **Run** the tool.

4.4 Generating Hypsometric Tint

1. Explore available imagery of the map region to get an idea of how colors change with elevation in the map area. Are low land areas highly vegetated? Are high elevation areas desolate? Pay attention to the timing of the imagery. Is there snow in the mountains throughout the warm season? What color is the soil? Form an idea of the color palette you would like to use. It may be useful to turn on the hillshade layer with 50 percent transparency to get an idea of how everything will look after it is blended (Buckley 2009).

2. Open the layer properties for the DEM_UTM dataset. Under **Display** choose **Bilinear Interpolation**. In the **Symbology** tab choose **Stretched** under the **Show:** option. Explore the different color ramps available under the drop bar. Depending on the landscape you

are trying to represent choose something that loosely matches the color palette you have

envisioned. Select **Apply** to apply that color ramp to your DEM.

3. To customize the color ramp, right-click the color ramp drop-down in the **Symbology** tab

and select **Properties**. This will bring up a window that shows multiple "algorithmic

color ramps" that fade from one color to another. Double-click each color ramp to edit

the colors in the ramp. To add more colors, simply select **Add** and edit the colors in each

ramp. Each ramp should begin with the color chosen for the end of the previous ramp and

fade to the same color chosen for the next ramp. This will prevent abrupt shifts in color

within the gradient.
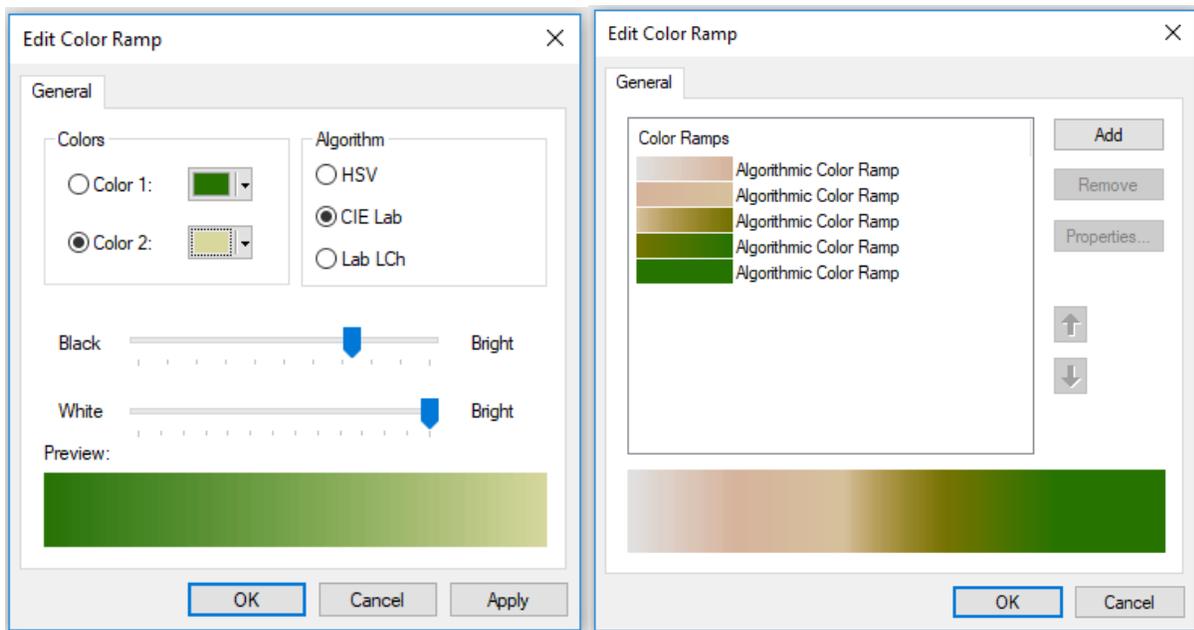
Figure 8. The ArcGIS color ramp design dialog windows.

4. When choosing which colors to include in the hypsometric gradient, flip back and forth

between imagery and your color ramp, by checking the DEM layer on and off in the

Table of Contents.

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5. Additionally, the appearance of the color ramp can be adjusted by changing the way it is "stretched" across elevation values. In the Symbology window for the DEM layer, locate **Stretch Type**. For this option, try **Standard Deviations**. Adjust the **n** value and observe how this affects the color ramp. Custom color ramps can be saved by right-clicking the ramp in the drop-down menu under **Symbology**, and selecting save to style.

4.5 Exporting Raster Datasets and Loading in Photoshop

1. Once you are happy with your shaded relief and hypsometric tint, turn off all transparency. Transparency is adjusted under the **Display** tab in the **Layer Properties** window.

2. Raster datasets must be exported one at a time. To do so, turn off all layers (including any ESRI base maps) except the layer to be exported.

3. Navigate to **File** and **Export Map**. Save it as a TIFF file at 300 dpi, and name it for the feature it includes. Repeat this step for both hypsometric tint and hillshading.

4. Open Photoshop and go to **File** and **New**. In the resulting window name the file, choose **RGB** as the **Color Mode** and give the document the same page dimensions used in step 4.2.4.

5. Next, go to **File**, **Scripts**, and **Load Files into Stack**. **Browse** for and select the TIFF files for shaded relief and hypsometric tint. Select **OK**. This will load both files exactly as they were in your ArcMap document.

4.6 Blending Raster Datasets in Photoshop

In addition to the following steps for blending raster datasets in Photoshop, see online documentation for blending shaded relief and hypsometric tint using Photoshop (Huffman 2014).

1. In the **Layers Panel** of your Photoshop window, place the hypsometric tint at the bottom with the shaded relief above it. Rename layers so they are easy to identify.

2. In the **Layers Panel** change the blending mode to **Linear Burn**. This can be found under the drop-down menu for blending modes, the default blending mode is **Normal** (or no blending). The **Linear Burn** blending mode darkens the hypsometric tint based on the darkness of the overlying shaded relief layer. Effectively adding the deep shadows from the shaded relief layer to the hypsometric tint layer without blending in any of the gray tones. However, the result is too dark. This is because **Linear Burn** darkens the hypsometric tint based on the darkness of the shaded relief.

3. To lighten up the image, adjust the **Levels** of the shaded relief layer. In the **Layers Panel** go to **Layer, New Adjustment Layer, Levels**. Name the new adjustment layer **Shadows**. In the layers panel, hold the **Alt** key and hover your mouse between the new adjustment layer and the shaded relief layer. An arrow should appear, click between the two layers. This ensures that the new adjustment layer only affects the shaded relief layer.

4. With the new levels adjustment layer added, a histogram will appear in the **Properties** window. Drag the center slider in histogram to the left, this will brighten some of the mid-level dark pixel values in the shaded relief. Now, drag the far right slider towards the center of the histogram. This should add a little contrast within the darkest shadows in the shaded relief. Adjust these sliders until you are satisfied with the results.

5. Next, to add highlights to slopes receiving direct light, create a copy of the shaded relief layer. Rename it something like highlights. Apply the blending mode **Screen**, to the highlight layer. This will brighten the hypsometric tint by the corresponding value from the shaded relief.

6. However, this brightens the entire image. To maintain some of the mid-level values of the shaded relief add another **Levels** adjustment layer. Now, in the histogram for the new **Levels** adjustment layer, drag the far-left slider towards the center until only the brightest highlights are still visible.

7. **Alt-click** between the new adjustment layer and the **highlights layer** so that it is only applied to that layer.

8. Now, the darkest and the lightest values in the shaded relief have been blended into the hypsometric tint without adding the unwanted gray values. The overall look of the image can still be adjusted in a few ways. To modify the contribution of each layer to the overall image adjust its opacity (everything is set to 100% currently). To change the effect of each blending mode, adjust the opacity of the **Levels** adjustment layers or experiment with the histograms until you get the results you are looking for. It is important to remember that many vector features and labels will sit on top of this raster dataset in the final maps. For this reason, it may be best keep the overall image on the lighter side with less saturated colors. This will aid in the readability of the final maps.

4.7 Dividing Relief for Individual Map sheets

1. Now, this raster datasets needs to be clipped to fit the extent of each individual map sheet. To do so, go back to the ArcMap document. Turn of all layers except the map sheet index layer. Without changing the scale or layout of the map document, export this layer as an Adobe Illustrator (AI) file.

2. Open the new AI document. Refer to Appendix II to delete the clipping mask for this layer and ungroup all features in this layer.

3. Select all map index features without selecting the layer itself, and hit **Ctrl-c** to copy those features to the clipboard.

4. Back in the Photoshop environment, hit **Ctrl-Shift-v** to paste the map index features into that document. Photoshop will prompt you on how you would like the vector features to be added. Choose to **Paste As:** a **Path** for this option, and select **OK**.

5. On the **Tools** window, usually docked on the left side of the Photoshop environment, select the **Path Selection** tool . Select the map sheet rectangle in the northwest corner. With just one map sheet selected find the **Load Path as a Selection** option at the bottom of the **Paths** window.

6. Now, use this selection to export this portion of the image to a Photoshop document of its own. This is done by simply by hitting **Ctrl-Shift-c** (which copies the image and merges all layers into one) then, **Ctrl-n** (which will create a new PS document with dimensions of whatever is in the clipboard) and finaly, **Ctrl-v** (which will paste the merged image into the new PS document).

7. This process sometimes leaves very small gaps of white space at the edge of the image. To fill these in use the **Magic Wand** selection tool to select those white pixels. Go to **Edit** then select **Fill**. Select the option for **Content Aware** fill and select **OK**. This fills the white space based on nearby pixel-values, and it does a really nice job. It should be noted that to maintain the accuracy of the map, **Content Aware** fill should only be used for very small portions of the image.

8. **Ctrl-s** will save the new PS document. Do so as a tiff with no compression and 300 dpi in a new folder named for its corresponding map index value. Repeat steps 5-7 for all map

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sheets, giving them each their own folder. Later these folders will be used to house all AI

versions of map features for each map sheet (Refer to Appendix I).

Part 5: Generating Contour Lines

Equal-interval contour lines have been used in maps to represent change in elevation for centuries. Contour lines were historically generated based on measurements made in the field using an aneroid barometer or by sketching based on stereopair photographs. Today, GIS programs are able to generate accurate contours quickly using information stored in a digital elevation model (DEM). This tutorial covers the steps for generating 10-meter-interval contour lines for the entire map area using ArcGIS software and a 30-meter DEM. Raw contours will be smoothed to improve their appearance and contour layers will be divided into index contours and intermediate contours.

5.1 Generating Smooth Contours

1. Open an ArcMap document containing the clipped and projected DEM from Part 4.

2. Open the **Contour** tool.

3. For **Input raster** add the DEM. Under **Output polyline features**, name the contour layer something like "Master_Contours10m" and save it in the Master GDB. Under **Contour Interval** enter 10. Assuming your DEM is scaled in meters above sea-level this will result in a contour line every 10-meters. Leave the option for **Base contour** at 0 and **Z-factor** at 1 and run the tool.
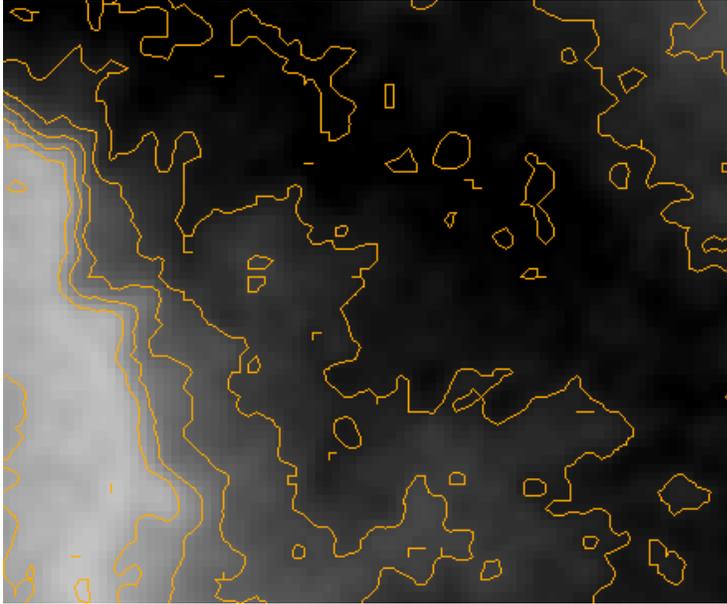
Figure 9. An example of topographic contours derived from a raw DEM.

4. You should notice that the results are not ideal. Zoom in and it should be possible to see many artifacts of the pixels in the DEM. There may stair-step like edges and perhaps areas with incomplete geometry. To fix this we must smooth the DEM to account for abrupt changes and errors in the data.

5. To do so, open the **Focal Statistics** tool. This tool examines and modifies each pixel in a raster dataset using its "neighborhood" of surrounding pixels. In this case, we want to smooth our DEM so that it generates better contour lines. For this reason we will choose "**MEAN**" for the statistic type. Name the output DEM, and start with the default neighborhood of 3 cells by 3 cells (increase the size of the neighborhood if the results are still filled with errors). Name the output and run the tool. The resulting DEM should contain less artifacts from the pixel edges in the DEM.

6. Run the contour tool again, this time using the smoothed DEM as the input. Examine the resulting contours. See figure 10 for an example of the desired results.
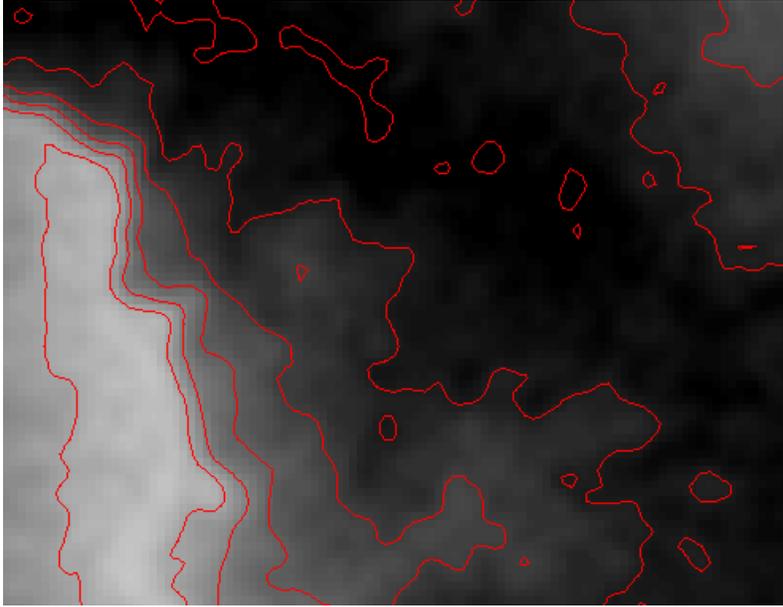
Figure 10. An example of topographic contours derived from a smoothed DEM.

7. Now, to remove sharp corners from our contours lines, open the **Smooth Line** tool found in the **Cartography Toolbox**. Add the new contour layer and name the output. Choose "**PAEK**" as the **Smoothing Algorithm**. For **Smoothing Tolerance**, experiment with values less than, or right around the contour interval of 10-meters (be sure to change the unit to meters). Leave the default for **Handling Topological Errors** and run the tool.

8. Assess the results. Contour lines should have smooth curves and should follow the shifting values of the DEM. If you are not happy with the results repeat the steps listed in this tutorial, changing the size of the focal statistic neighborhood and the smoothing tolerance. Contours do not have to be perfect at this stage (they can still be simplified in Illustrator), but they should look a lot better than the results in shown in Figure 6.

5.2 Isolating Index Contours

Because the final maps will symbolize index contours (elevations that are multiples of 100) differently than all other contours, these features should be separated into two feature classes.

1. Open the attribute table for your contour layer. **Right-click** the **Contour** field heading and choose to **Sort Descending**. Take note of the highest contour value.

2. Under **Table Options** , choose **Select by Attributes**. Create an SQL Query statement to select all index contours. Something like this: "Contour IN (100, 200, 300)". Include every multiple of one hundred that exists in the contour feature class. Select **Apply** to make the selection.

3. Right-click the contour layer in the table of contents, and select **Export Data**. Save the output feature class in the **Geology feature dataset** in the master geodatabase, and name them Master_Index_Contours.

4. Reverse the selection made above so that all intermediate contours are selected. Simply click the Switch Selection icon .

5. Right-click the master contour layer in the **Table of Contents**, and choose to export data. This time name the output Master_Intermediate_Contours and save it in the master geodatabase within the **Geology feature dataset**. See Part 10 for generating contour labels.

Part 6: Processing Land Cover Data

One important feature included in topographic maps are the distinctions between different land cover types (forest, grass, water, bare ground, etc.). These distinctions can be helpful for understanding one's surroundings while navigating. Land cover is shown in final maps as a series of coincident (non-overlapping) polygon features exhaustively covering the map area. Land cover information is most commonly obtained by classifying pixels in aerial or satellite imagery based on spectral value. While it is possible to digitize land cover classifications manually, it is not recommended as it can be extremely time-consuming and prone to miss-classification and error. It is important to communicate with the contracting agency to determine the classification system to be used. With each land cover class defined, have the contracting agency provide waypoints in the field of examples of that classification. Identify those waypoints in a GIS, confirm their accuracy, and use those waypoints to create training sites for a supervised classification. Supervised classifications can be conducted using a number of different programs. Google Earth Engine has been used in previous topographic mapping projects at UM. Be cognizant of inherent error in classification algorithms, resulting from low quality imagery, cloud cover, or seasonal change in vegetation. Make sure the contracting agency is aware that classifications are never one-hundred percent correct.

Part 6 covers the steps for converting raster land cover information to individual polygon feature classes for each land cover distinction. Next, each land cover class will be smoothed to remove stair-step like effects, and insignificant polygons will be removed based on a size threshold. As a result of this process, borders between land cover polygons will no longer be coincident, causing overlap in some places and gaps in others. To address this issue, a series of feature ArcGIS tools (Erase and Append) will be used to regain the intended topology.

This portion of the manual will not cover the steps for conducting a land cover classification of raster imagery, but rather discuss methods for processing the output of such a classification, removing errors and extraneous details, and preparing data for use in this workflow.

6.1 Converting Raster Land Cover Data to Polygon Features

1. At this point the distinctions between land cover classes should already be determined using the ArcGIS image classification toolbar or using Google Earth Engine. Consult the contracting agency when determining these distinctions. Load the land cover classification in an ArcMap document. At this point, these features should be stored as in a single raster dataset.

2. Use the **Raster to Polygon** tool to convert that layer to a polygon feature class. Name the output, and save it to a new data geodatabase for processing (all intermediate data can be saved here).

3. Open the attribute table for the polygon land cover layer. Add a new field named "Category". Create a selection for all polygons in a given class and using the field calculator name that class. Repeat this step to name each land cover class in the attribute table (forest, cultivation, bare ground, etc.).

4. Now, export each land cover class into its own feature class by creating a new selection in the land cover polygon layer. Save each feature class to the raw data geodatabase.

5. Start an editing session. For each land cover feature class, open the attribute table, find the **Shape Area** field, right-click that field and choose to **Sort Ascending**. Select all features with a shape area of zero, select those features, and delete them. This removes unnecessary features with no shape area. **Save Edits** and **Stop Editing**.

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6.2 Aggregating and Smoothing Land Cover Polygons

1. Open the **Aggregate Polygons** tool. This tool removes features below a given threshold in a polygon features class.

2. Add one of the land cover features classes as the input layer. Set the **Aggregation Distance** to 100 meters, the **Minimum Area** to 1 square meter, and **Minimum Hole Size** to 500 square meters. Check the results. If things look too generalized experiment by decreasing input values for **Aggregation Distance** and **Minimum Hole Size.**

3. Once you are satisfied with the polygon aggregation it is time to smooth the polygons. Open the **Smooth Polygon** tool. Input the aggregated land cover polygon feature class, set **Smoothing Tolerance** to 200 meters and choose **PAEK** as the smoothing algorithm. Leave the other defaults. Check the results, when you are satisfied move on the next land cover polygon feature class.

6.3 Cutting Land Cover Polygons

Coincident boundaries are crucial for land cover polygons. This is because land cover is symbolized using semi-transparent polygons in the final maps. After all land cover features are cleaned up and smoothed, steps must be taken to regain coincident boundaries between these features. This process involves starting with a rectangle feature, punching out a land cover feature class (using the erase tool) and merging that feature class. This process requires many intermediate processing feature classes.

1. Put the land cover vector layers in order of total coverage, from greatest to smallest.

2. Make a copy of the total map area extent feature class, save it to the raw data geodatabase and rename it for the land cover class that is most dominant throughout the map area,

forest, for example. This will serve as the base layer from which all features will be

punched out and merged.

3. Open the **Erase** tool. Add the new base land cover features class as the **Input Feature**

   and add another land cover feature class as the **Erase Feature**. Run the tool.

4. *Now open the **Append** tool. Add the land cover dataset that was just used to erase areas*

   from the rectangle base layer as the input dataset and add the output from the erase tool

   as the Target dataset. Run the tool. The result is one dataset with coincident boundaries.

Figure 11. A graphic representation of the process for erasing and appending multiple land cover class feature classes.

5. Open the **Erase** tool again. Add the dataset created in step 6.3.3 as the **Input Features**

   and add the next land cover layer as the **Erase Features**.

6. Again, append the land cover layer that was just used as the erase feature to the output

   from the erase tool.

7. Repeat this process to punch out and append each land cover data set. The final result is

   one dataset with perfectly coincident boundaries.
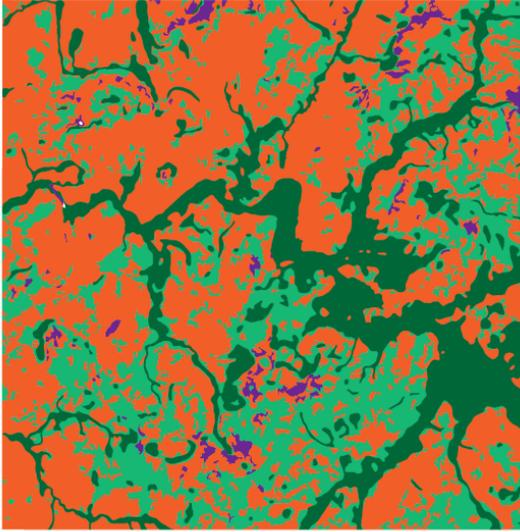
Figure 12. Land cover features class with coincident boundaries.

Part 7: Clipping Map Vector Data to Map Sheet Extent

Once all map data is processed and created at the master-level (the entire map extent), that data must then be subdivided to the map-sheet level (individual map extents). In GIS, this process is called clipping. Clipping is a relatively simple process in most GIS programs, and can be completed quickly by defining a clipping extent. However, due to the high number of map features spanning many map extents, this process can become quite time-consuming. The automation of the clipping process can greatly improve its efficiency. Part 7 is an overview of different methods for clipping master-level data to the map sheet-level in a topographic map series workflow.
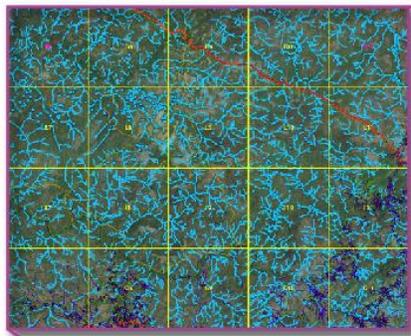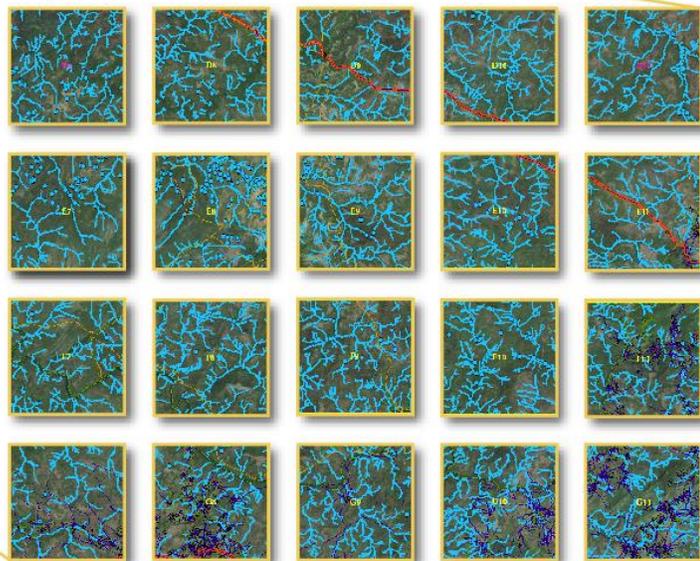
Figure 13. Master data sets clipped to individual map sheet extents.

7.1 Model Builder

One way to automate this process, is to use the ArcGIS Model Builder module. Model builder allows the user to specify ArcGIS tools, input datasets, outputs datasets, and where they are saved.

1. First, create a new blank geodatabase for each 7.5 minute map sheet extent and name it after its alphanumeric index value. Within each geodatabase, include a blank feature dataset for the each one within the master geodatabase (transportation, hydrology etc.). This can be done quickly by creating a copy of a blank template geodatabase.

2. In each map sheet geodatabase, save a feature class for the extent of that map in the map elements feature dataset (see Appendix I for more on folder organization). This can be done in ArcMap by selecting a map sheet in the map sheet index layer, right clicking that layer in the **Table of Contents** and choosing to **Export data**. Name the new feature class after the alphanumeric index value for that extent.

3. In ArcMap, select the model builder icon to open that window.

4. Create a model to clip all master map data to the extent of each map sheet extent. This will require defining the input datasets once, the output extent once for each map sheet, and the output geodatabase once for each map sheet. Refer to ESRI's online documentation for Model Builder. Figure 14 shows an example of a simplified model for doing clipping feature classes to map sheet extent. In practice, the model would include a clip for every feature class stored in the master geodatabase. Such a model could be used for each map sheet by replacing the first input for each clip (shown in blue in figure 14) with the appropriate map sheet extent. The output for each clip (shown in green) would

have to be renamed, and the output geodatabase (shown in green on the far right) would

be modified as well.

Figure 14. A simplified model for clipping five feature classes and storing them in the appropriate geodatabase. In practice, this model would contain a yellow clip tool for each feature class stored in the master geodatabase.

7.2 Creating a Script

Another possible method for automating the clipping process, is to use a script (possibly using the python scripting language and the Arcpy site package). Depending on the project, this may be preferable to using Model Builder because a script can also be used to create the necessary file folders and blank geodatabases. This manual will not discuss the process of writing a python script. To do so, refer to ESRI's online documentation for the Arcpy site package.

Part 8: Map Sheet MXDs, Projection, Data Frame Rotation, and Grids

Now that master-level data has been clipped to the extent of each map sheet, map sheet-level data must be loaded into individual ArcMap documents. Within each map sheet MXD, the data will be projected, rotated to align with true north, and a 1 km^2 UTM grid and 2.5 minute graticule will be generated. Additionally, north arrows will be created to show true north and magnetic north. Before these steps can be taken however, an MXD template should be created so individual map sheet MXDs can be prepared quickly.

Part 8 includes steps for preparing an MXD map sheet template, adding and centering data in that MXD, projecting the data frame, adding two north arrows, rotating the date frame to align it to true north, and adding the UTM grid and labels and graticule crosshatches and labels. Parts 8.2-8.5 should be repeated for each individual map sheet.

8.1 Setting up the Map Sheet MXD Template

1. Open ArcMap, under templates choose ISO A1 Portrait for the page size. Maps of this size and scale usually fit well on this standard poster page size, however 7.5 minute map sheets will get wider the nearer they are to the equator. Some projects may require a wider page size. Save the new MXD file and name it something like mapsheet_template.mxd and save it in the map sheet project folder.

2. Make sure the document is in **Layout View**.

3. Add horizontal guides at 5 inches and 30 inches, and a vertical guides at .5 and 22.9 inches (disregard these guides if your project requires a different page size).

4. Drag the data frame so it snaps to the newly placed guides.

5. Under data frame properties choose **No Color** for the data frame stroke.

6. Save the template.

8.2 Adding Map Sheet Data

1. Open the MXD template you just created. Under **File** choose to **Save as**, and name it after the map sheet you will be working on in the corresponding map sheet folder (ex. Kenyir_C4.mxd).

2. Under **File**, navigate to **Map Document Properties**. Change the default GDB to the corresponding map sheet GDB (ex. Kenyir_C4.GDB).

3. Add all data from the connected Geodatabase. Change the symbology of each layer to bright, contrasting colors.

4. Set the scale to **1:25,000**.

5. Right-click one of the newly added data layers in the **Table of Contents** and select **Zoom to Layer**. This will center the data within the data frame.

6. To avoid accidental changes in the scale or extent, lock the data frame. This is done under **Data Frame Properties**, **Data Frame**, and **Extent**. Select **Fixed Extent**.

8.3 Projecting the data frame

1. Under **Data Frame Properties**, navigate to **Coordinate System**.

2. Navigate to the correct projection (the final projection chosen for this project) in the **Projected Coordinate Systems** folder (ex. WGS 1984 UTM Zone 28N). Right-click on the projection and select **Add To Favorites**. This will make it easier to navigate to this projection for future map sheets. Select **OK**, to apply this projection.

8.4 Rotating the Data Frame

1. Under **Insert**, choose **North Arrow**. This will not be the north arrow used in the final layout.

2. Add the first north arrow in the list. Double-click the north arrow to bring up **North Arrow Properties**. Under **Angle**, select **True North**. Note the value under **Calculated Angle**.

3. Subtract the value for **Calculated Angle** from 360 (ex. 360 - 359.11 = 0.89).

4. Enter the result as the **Data Frame Rotation Value** in the **Data Frame Toolbar**.
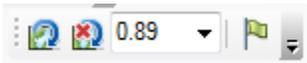
   Press enter to apply this rotation value to the data frame.

5. Delete the north arrow.

8.5 Creating the North Arrow

1. Under **Insert**, choose **North Arrow**. Under the option for **More Styles**, choose **Survey**.

2. Find the **Survey North 20 Arrow** and a select **OK** to add it to the layout. This arrow will represent true north.

3. Double-click the new north arrow and select **True North** under **Angle**.

4. Find the **Survey North 19 Arrow** and a select **OK** to add it to the layout. This arrow will represent magnetic north. However, there is no way to align a north arrow to magnetic north automatically in ArcMap. Refer to online tools for determining magnetic declination (NOAA).

5. Switch to data view and using the **Identify Tool** click the center of the map sheet to determine the latitude and longitude at the center of the map sheet. Switch back to **Layout View**.

6. Enter the longitude and latitude in NOAA's magnetic declination calculator and choose the WMM model, add today's date.

7. A new google maps window will appear showing the location you entered. It will also show declination information (ex. 5.83° W ± 0.29° changing by 0.11° E per year). Take note of this information.

8. Back in the ArcMap document double-click your second north arrow. Under **Calibration Angle** enter the value determined above (ex. 5.83).

9. Move both north arrows to the bottom of the layout, outside of the data frame.
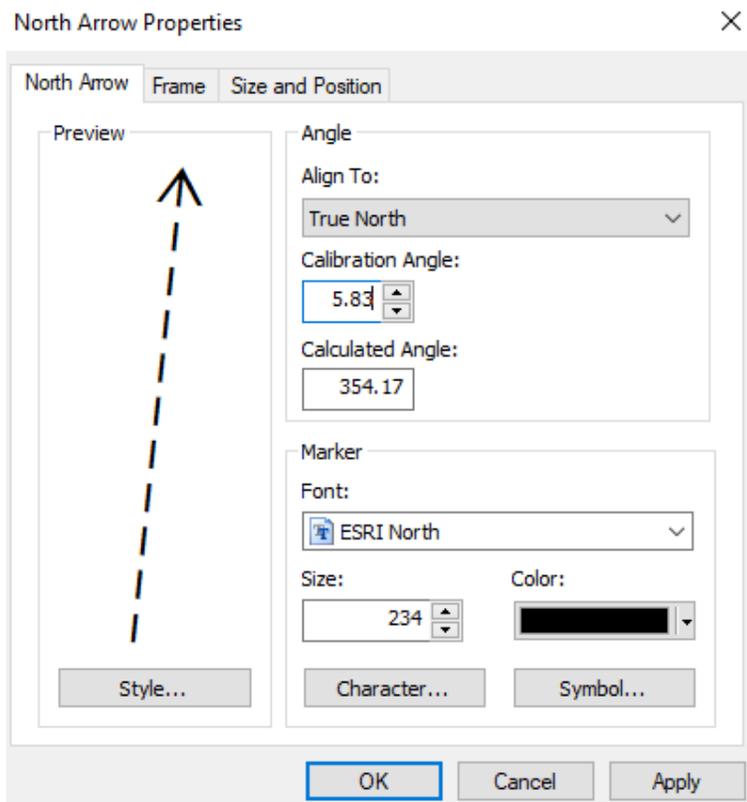
Figure 15. North arrow creation dialog in ArcGIS.

8.6 Graticules and UTM Grid

1. Open the **Data Frame Properties** window. Under the grids tab select **New Grid**.

2. Select the option to create a new **Graticule**. This will create lines of latitude and longitude with corresponding labels. You can rename this grid if you choose, however the default name works fine. Select **Next**.

3. In the next window, select **Tick Marks and Labels** under **Appearance**, and set the intervals of **0º 2' 30"** for both longitude and latitude. Select **Next** and **Next** again.

4. In the last window choose to **Place a Simple Border at Edge of Graticule**. Select the symbol (currently a horizontal black line) to adjust its symbology. Select **No Color** and **OK** so that only the graticule labels, ticks and cross hatches show in the resulting grid. Select **Finish**.
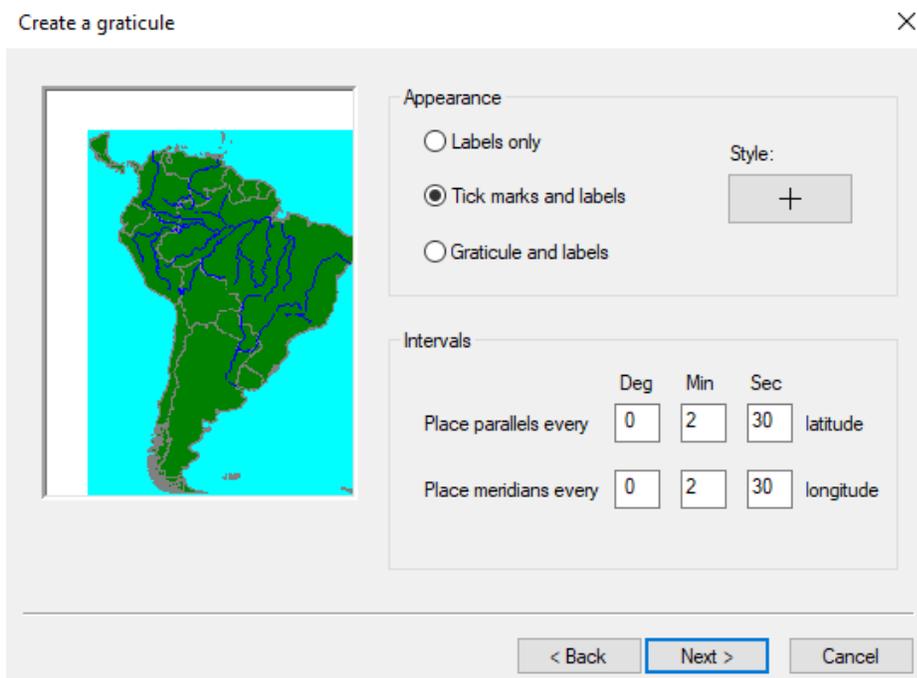
Figure 16. Grid and graticule creation dialog window in ArcGIS.

5. Open the **Data Frame Properties** window. Under the grids tab select **New Grid**. This time, choose **Measured Grid**. This will create a grid of UTM coordinate lines with corresponding labels.

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6. Under **Appearance** choose **Grid and Labels**. Leave the default coordinate system and under **Intervals** enter 1000 Meters for both the **X Axis** and the **Y Axis**. Select **Next**, **Next** again and **Finish**.

7. Now to further customize the UTM grid, make sure it is highlighted in the **Data Frame Window** and select **Properties**.

8. In the next window, under **Major Division Ticks** make sure options for **Top**, **Left**, **Bottom**, and **Right** are all checked. Under **Symbol** click the horizontal black line and change its symbology to a 2 point hot-pink stroke. This will be changed after export.

9. Under the **Labels** tabs make sure **Top**, **Left**, **Bottom**, and **Right** are all checked for the **Label Axes**. For **Label Style** Choose **Corner Label** change the font size to 11, the font color to pink to match the grid and set the **Label Offset** to 14 pts.
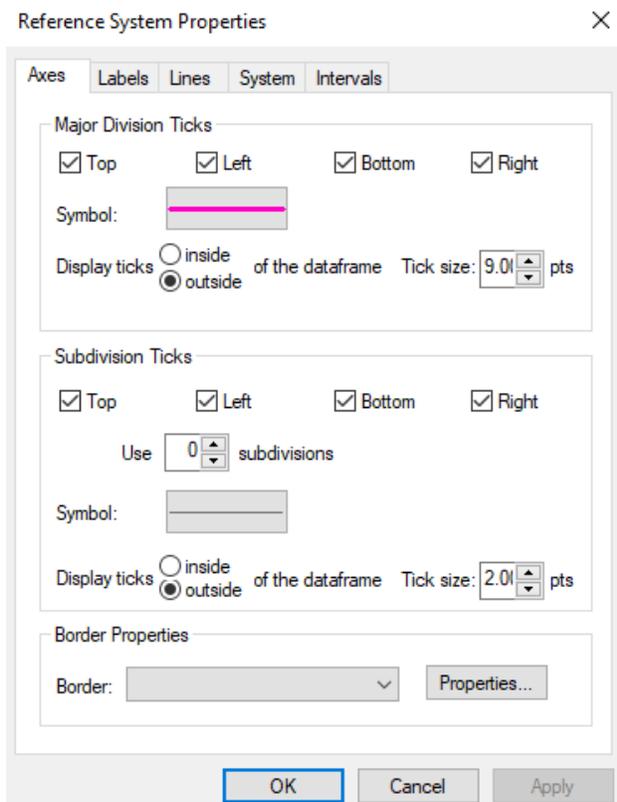
Figure 17. Grid and graticule properties dialog window.

10. In the same window select **Additional Properties**. Under the **Corner Labels** tab, check the boxes for **Top**, **Left**, **Bottom**, and **Right** and set the font to 11. Under the **Principal Digits** tab, change the **Secondary Font** size to 5.25, set the **Number of Principal Digits** to 2, and **Base Digits** to 4. Make sure the **Unit Suffix** is set to "m." the E**asting Suffix** is set to "E" and the **Northing Suffix** is set to "N". Select **OK** and **Apply**. See figure 19.
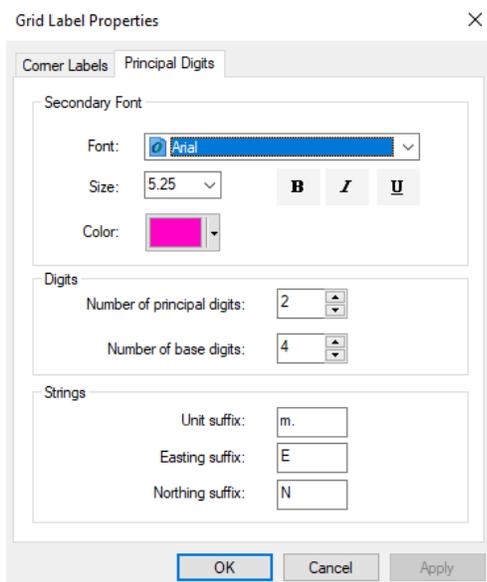
Figure 18. Grid and graticule label properties dialog window in ArcGIS.
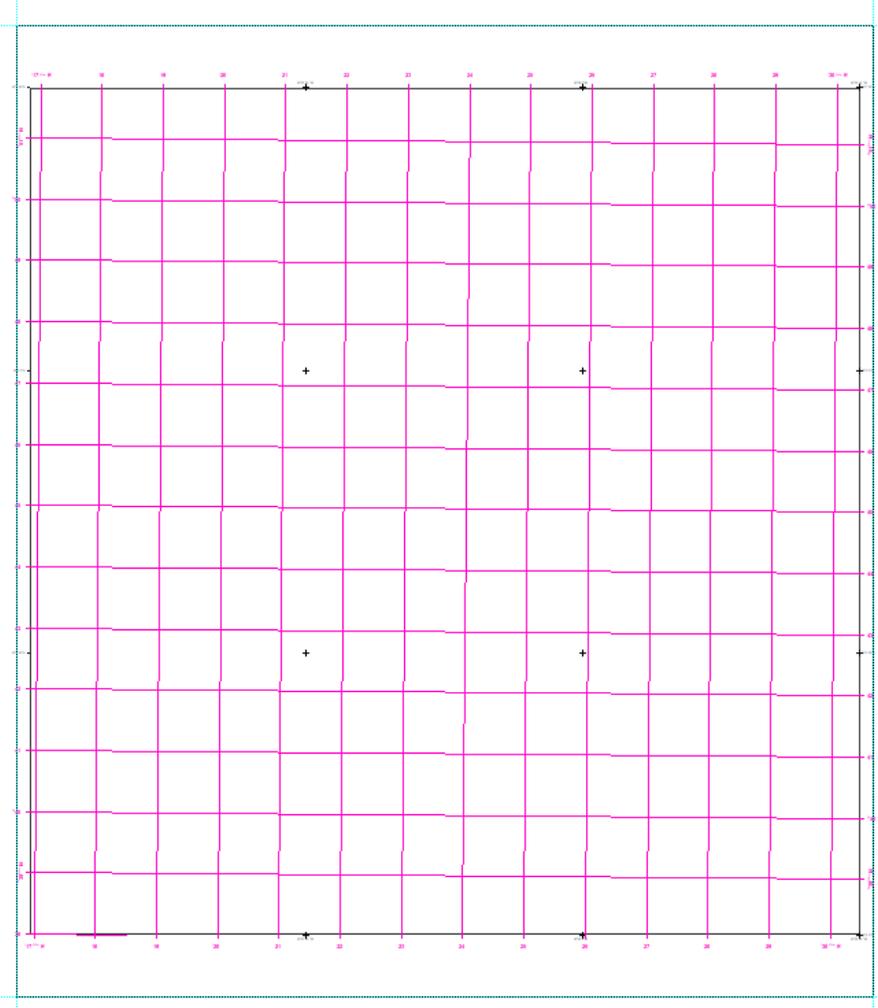
Figure 19. The map grid and graticule in ArcGIS.

Part 9: Generating Spot Heights

A common feature in most topographic maps are spot heights. Spot heights are points features labeled based on their elevation (meters) above sea-level. Spot height points are placed evenly throughout a map so that elevation can be found quickly at any location. Part 7 includes steps for creating a spot height feature class for each map sheet, editing that feature class to add points, and generating elevation for the created point features. Spot heights should be placed near important physical locations or points of interest. This could be anything from a ranger station to a mountain pass. A general rule used in previous mapping projects is to place about one spot height point per square kilometer. Use the UTM grid created in Part 8 for this purpose. Also, use other important map features as a reference when placing points.

1. In ArcCatalog, create a new point feature class within the map sheet geodatabase for the map sheet you are working on, in the **Surveying** feature class. Name it **Spot_Heights**.

2. Add that feature class to the **Table of Contents** in the ArcMap document for that map sheet.

3. Adjust the symbology of map features so that important features are visible for reference when placing new spot height points. Shaded relief, contours, imagery and points of interest can be helpful when deciding where to place spot height points.

4. Start an editing session and begin placing spot heights. It can be helpful to work systematically from starting in one corner of the map and working your way across it. Place spot heights on mountain passes, peaks, where streams and rivers meet, at patrol camps and ranger stations, major transportation intersections. Never place a spot height point on top of a contour line. Each map should contain about 150-200 spot heights depending on the complexity of the terrain.

5. Once you have placed spot heights throughout the entire map, make one last visual assessment to make sure points are spread throughout the entire map and no areas were completely missed. **Save** your edits and stop the editing session.

6. Open the **Extract Values to Points tool**. This tool takes a point feature class and extracts the cell values from an underlying raster dataset. For **Input point features**, add the newly created spot heights layer, and for **Input raster** add the DEM. For **Output point features**, name the new feature class **Final_Spot_Heights**. Make sure you have set geoprocessing options to allow geoprocessing outputs to be overwritten. If you have not done this, you will get an error.

7. Under the **Labels** tab for the new feature class, check the box for **Label features in this layer**, and make sure the **Label String** is set to "**RASTERVALU**". For now, don't worry about the placement of the spot height labels, this will be adjusted with the rest of the labels in Part 10.

Part 10: Feature Labels in ArcMap

The final step before exporting maps from ArcMap is to label all features that will be included in the final maps. Label placement is crucial for the usability and clarity of final maps. Labels are formatted, placed, and spaced using the ArcMap Maplex label engine. The Maplex label engine is a set of labelling tools that allow the cartographer to customize label position, density, and style within ArcMap. However, because Adobe Illustrator provides a lot more freedom in label placement and style, ArcMap will only be used for generating labels, and spacing labels for features that must be labeled multiple times. Applying fonts to and styling labels will be covered in Part 13.

Part 10 will cover steps for turning on the Maplex Label engine, generating labels for map features and finding the optimal spacing for features that are labelled more than once. In addition to labeling general map features, this tutorial will cover specific methods for labeling spot heights and topographic contours.

10.1 Turning on Maplex Label Engine and labeling General Map Features

1. In **Data Frame Properties**, find the option for **Label Engine** and set it to **Maplex Label Engine**. Select **OK**.

2. Confirm that all map features from the corresponding map sheet geodatabase are added to the map sheet MXD you are working on.

3. Dock the **Labeling Toolbar** to your ArcMap workspace. Under **Placement Quality** change **Fast** to **Best.**

4. Begin by labeling all map features that will be included in the final map sheet. Layer by layer, open layer preferences by double clicking that layer in the **Table of Contents**. Under the **Labels** tab, check the box next to **Label features in this layer**. Make sure the

Label Field option is set to the appropriate attribute field for that feature class. It is not important to change fonts or font size at this point.

5. Some features that span across significant portions of a map sheet should be labeled multiple times so they can be identified quickly in final maps. This includes long hydrologic features like rivers and streams, and transportation features like highways and feeder roads. To add repeat labels, select **Placement Properties** under the **Labels** tab. Under the **Label Density** tab check the box next to **Repeat Label**, and select **Options**. Here you can set the repeat interval, the smaller the value entered here, the more labels will be placed on a given map sheet. Experiment with different values for repeat interval until it places an appropriate number of labels (a given feature should not be labelled more than 2-3 times per map sheet).

6. When labeling, overlap between labels and features should be avoided as much as possible. However, some overlap is acceptable, and even inevitable. The Maplex Label Engine gives the cartographer some control in determining what kind of overlap is acceptable. This is controlled using the **Labels Toolbar**. Select the **Label Weights** icon , and each map feature can be given a weight 1-1000**.** Features with higher weights take precedent, will be overlapped the least. For now, give both contour layers weights of 700 and experiment with giving other features weights in this dialog. Remember, labels will never look perfect at this stage, so don't spend too much time adjusting feature weights and label density. This process will be more straightforward using Adobe Illustrator software.

10.2 Spot Height Labels

1. Spot height labels were already generated in Part 9. Confirm that spot heights are labeled by checking the **Layer Properties** for the spot heights layer. **RASTERVALU** should be listed under label field.

2. Under the **Symbology** for the Spot Height layer, change the symbol size to **3 pts** and the font size to **6 pts**.

3. In the **Symbology** window, select **Placement Properties**. In the next window check the box next to **User-Defined Zones** and select **Options**. We want to prioritize certain label placement positions for spot heights. To do so, copy the values from the following image.
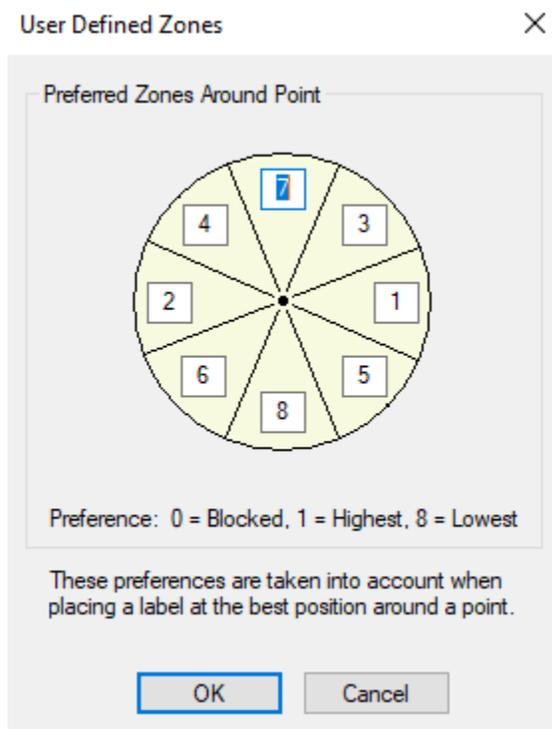
Figure 20. Label placement conflict preference.

4. Check the labels. If many spot height labels are overlapping important features, adjust the weight of that feature using the process described in in step 6 of 10.1.

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10.3 Contour labels

The placement and spacing of contour labels is more time-consuming than the steps described above for labeling other feature types. There are many possible preferences for labeling contours in topographic maps. The following steps are for adding evenly spaced contours that are never upside-down and that do not ladder. See the image below for examples of the contour placement preferences used in this workflow.
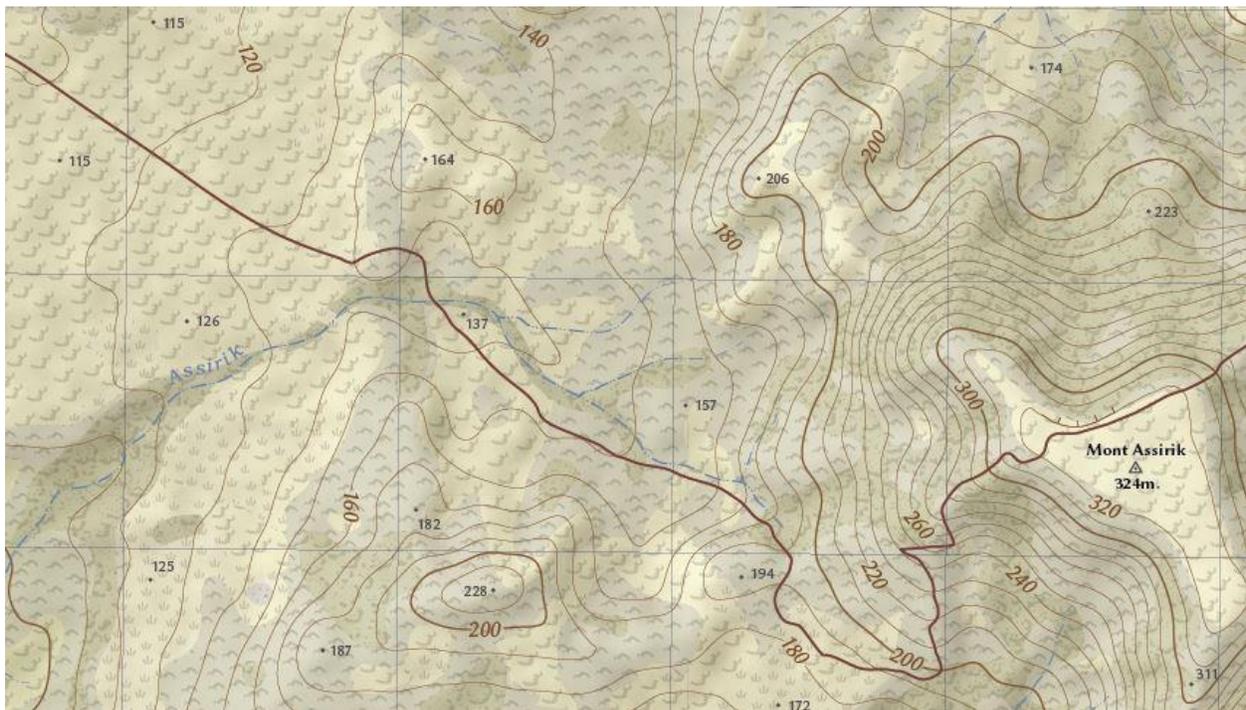
Figure 21. Contour label placement.

1. If you haven't already, check boxes to **Label Features** in the index and intermediate contour layers. Make sure **Contour** is selected as the label field for both.

2. Under the **Labels** tab for the index contour layer, select **Placement Properties**. Under the **Label Position** tab, choose **Contour Placement**, and select **Options**.

3. Under **Label Alignment**, select **Page Alignment** and enter **85** under the **Maximum Label Angle**.

4. Under **Laddering** select **No Laddering**. Select **OK**.

5. Under the **Label Density** tab, check the box for **Repeat Labels** and select **Options**. Under **Minimum Repetition Interval**, enter 4000 map units. Select **OK**, **OK**, and **Apply**.

6. Repeat these steps for the intermediate contour labels.

7. Assess the spacing of the contour labels. Are there enough labels? Are there too many? Experiment with different **Minimum Repetition Intervals** to get a reasonable amount of labels. Remember, contour labels can be added or deleted in Illustrator.

8. Again, don't worry too much about the overall appearance of these labels, they're style and placement will be significantly changed in Illustrator.

Part 11: Data Export from ArcGIS

As discussed throughout this workflow document, the final placement of map labels and application of graphic styles and symbols is conducted in Adobe Illustrator software. This software provides the cartographer with significantly more control than ArcMap, and allows styles to be applied quickly for all map features. To load map features into Illustrator, they must first be exported as .AI files from their ArcMap documents. This process is conducted separately for the map graticule layer. Part 11 covers the steps needed for preparing a map sheet for export, and for exporting map features as .AI files.

11.1 Exporting Map Features from ArcMap

1. Uncheck any raster datasets in the **Table of Contents**.

2. Uncheck the graticules under the **Grids** tab in **Data Frame Preferences**.

3. Make sure all other map features are turned on in the **Table of Contents**, and turn off any transparency applied to those features under **Display** in the **Layer Preferences**. Layers with transparency applied won't be exported.

4. Confirm that both north arrows are still visible.

5. Remove outlines for any polygon features so they have a solid fill and no stroke.

6. Make sure your map sheet extent layer is on, this layer will be important for lining things up in the new Illustrator document.

7. Go to **File** and select **Export Map**. Name the map after the map sheet with "Export" in its name (ex. Kenyir_C4_Export), save the map as an Illustrator file (.AI) in its Illustrator map sheet folder (see Appendix I). Set the resolution to **720** and the color space to **RGB**. Make sure the box for **Clip Output to Graphics Extent** is not checked. Under the format tab check the box for **Convert Marker Symbols to Polygons**. Select **Save**.

11.2 Exporting the Graticule

The process for exporting the graticule is the same, however it must be done separately from the other vector features to avoid losing labels to labeling conflicts in ArcMap.

1. Turn the graticule back on by checking it under **Grids** in **Data Frame Preferences**. Turn off all other layers, except the map sheet extent layer (This layer is needed to realign the graticule in Illustrator), by unchecking them in the **Table of Contents**.

2. Go to **File** and select **Export Map**. Save it as an .AI file in the corresponding Illustrator map sheet folder (see Appendix I). Add "graticule" to the document name. Set the resolution to **720** and the color space to **RGB**.

Part 12: Legend Design and Map Template Setup in Illustrator

Before map features exported from ArcMap can be edited in Illustrator, a legend containing all symbols for map features can be designed and organized as an Illustrator document. Additionally, a map template document featuring all map features that do not change from one map sheet to another should be designed at this stage. The map template contains a neat line, scale and projection information, data service credits, cartographer credits, a map legend as discussed above, as well as place-holder text for map sheet indexes and titles. Illustrator documents also have the ability to store graphic styles and symbols which can be applied to all map features, aiding in consistency throughout all map sheets. Once the legend and map templates are complete, data exported from ArcMap can quickly be pasted into the template document, symbols can be applied to point features and graphic styles can be applied to polygons and text.

Part 12 covers basic steps for saving symbols, patterns, and graphic styles to an Illustrator document that can be used to represent map features. This section will also discuss the creation of a map template document, to aid in the applications of styles. See Appendix V for a chart showing the different Parts of the map template and legend. Also, remember to utilize online resources for learning to create symbols, patterns and graphic styles using Adobe Illustrator.

12.1 Setting up an Illustrator Workspace

1. Open Adobe Illustrator.

2. Dock important windows that will be used throughout this workflow. This is done by selecting items under the **Window** drop down. Windows that will be referred to

throughout this manual include: **Layers**, **Character Styles**, **Character**, **Paragraph**, **Pathfinder**, **Symbols**, **Graphic Styles**, **Swatches**, **Appearance**, and **Stroke**. If you are working on a PC has dual monitors it can be helpful to drag these windows to the secondary monitor and leave the primary monitor for the main document window.

3. Drag the corner of the **Layers** window to expand it. This workflow requires diligent use of layers to prevent important features from being edited accidentally. The use of layers also facilitates quick selections of many features.

4. Familiarize yourself with the layers panel options for locking layers , turning them on and off , as well as confirming on-screen selections .

5. Illustrator will save the layout of your workspace on your PC, so these steps won't need to be repeated unless you use a different PC.

12.2 Creating a new Map Template Document Neatline and Map Frame

1. Go to **File**, **New** to create a new Illustrator document. Set the page size to the dimensions of the ISO standard A1 poster size (23.4 x 33.1 inches). As discussed in Part 8, if you have chosen other dimensions for the map page size use these dimensions. Choose to save the new document in the project's master illustrator document folder. Name it "Master_Template".

2. Open the Illustrator document for the exported features of any map sheet. See Appendix III for steps to ungroup features and remove clipping masks. Within that document select the map sheet extent feature only, and hit **Ctrl-C** to copy that feature. Close the map sheet extent document.

3. In the master template, paste the copied extent layer. In the layers panel name the layer for this feature "Neatline". See Appendix IV for graphics related to map sheet template layout.

4. Go to **View**, **Rulers**, **Show Rulers**, then **View**, **Guides**, **Show Guides**. Select the new layer icon ▣ at the bottom of the layers panel and name the new layer "Guides". Create new horizontal guides at 5 inches and 30 inches, and a single vertical guide at the center of the page at 11.7 inches.

5. Center the neatline based on the new guide, and drag the guide until it snaps to the horizontal guide at 30 inches.

6. Select the neatline. Under the **Appearance**, increase the stroke to 5 pts (a thick neatline is used to cover the edges of map features that have minor inconsistencies). Select the icon to add a new stroke▣. Set the new stroke to 3 pts and drag it above the other stroke in the **Appearance** window. Change the color of the new stroke to add contrast.
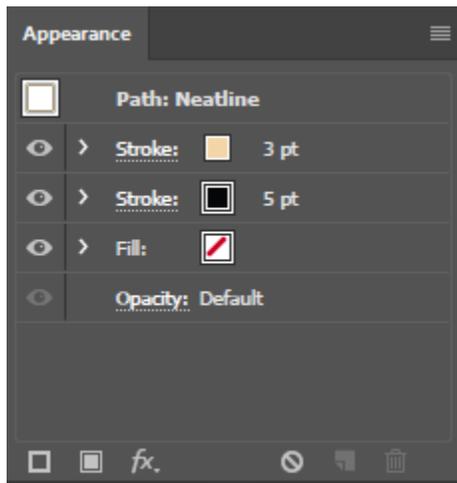
Figure 22. The appearance window in Adobe Illustrator.

7. Now create a new layer called "Map border". This layer will act as border that will contain all map information. Add guides a quarter inch from the margin on all sides of

the artboard. Use the rectangle tool to create a box that snaps to the new grid. Give the new rectangle a 1 pt. black stroke.

12.3 Adding Marginal Information and Creating Character Styles

1. Choose a typeface that can be used for all marginal information within all map sheets. This font should be legible, attractive, and should include special characters like accents that will be used in a map series.

2. Place a title that describes the overall region for the topographic map series (ex. Parc National du Niokolo-Koba). Center the title above the neatline. Using the **Character** window apply the chosen font and adjust the font to an appropriate size. Under the options drop-down in that window select **Small Caps**. Now, with the title selected, under the character styles window, select the options drop down and select **New Character Style**. This saves the character preferences chosen for that text. Character styles will be used throughout this portion of the workflow to increase efficiency in applying styles and to maintain consistency between all map sheets.

3. Repeat step 12.3.2 to create placeholder text for the map index, map sheet names, country information, projection information, and cartographer credits. Again, see Appendix IV for more layout information.

4. Now, using cartographic conventions to new create character styles for labeling all maps features.

12.4 Creating the Scale Bar

1. Open an ArcMap document for a map sheet towards the center of the total map extent (scale bar size will differ depending on longitude). Create a new document and set the scale to 1:25,000.

2. In layout view choose **Insert** and insert an appropriate **Scale Bar**. Right-click on the new scale bar and make sure the units are set to **kilometers**, and that there are four division and no subdivisions.

3. Insert another scale bar. This time, set the scale to meters, the number of divisions to four, and the number of subdivisions to three. Drag the corner of the scale bar to until it shows 4 kilometers (this is a good size for map documents at this scale).

4. Export the map as an Illustrator document at 300 dpi and name it master scale bar.

5. Open the new AI document. Follow the steps discussed in Appendix III to ungroup features and delete clipping groups.

6. Copy the scale bar features and paste them into the map template document.

7. Reverse the direction of the scale information for the scale bar in shown in meters so that zero is on the right and 1000 meters is on the left. Now, combine the scale bars into one at the zero point.

8. Make sure the scale bars line up seamlessly. Change the typeface to match the chosen font and add text with scale information.

9. Center the new scale bar to the center of the document using the center guide. The final scale bar should look something like the one below.

Scale 1:25,000

Meters 1000   500   250   0   1   2   3   4 Kilometers

CONTOUR INTERVAL 10 METERS

Figure 23. An example scale bar.

12.5 Creating the North Arrow Placeholder

1. Now, use Illustrator tools to create a placeholder north arrow for magnetic north and true north. The example below also includes an arrow for grid north, this is optional.
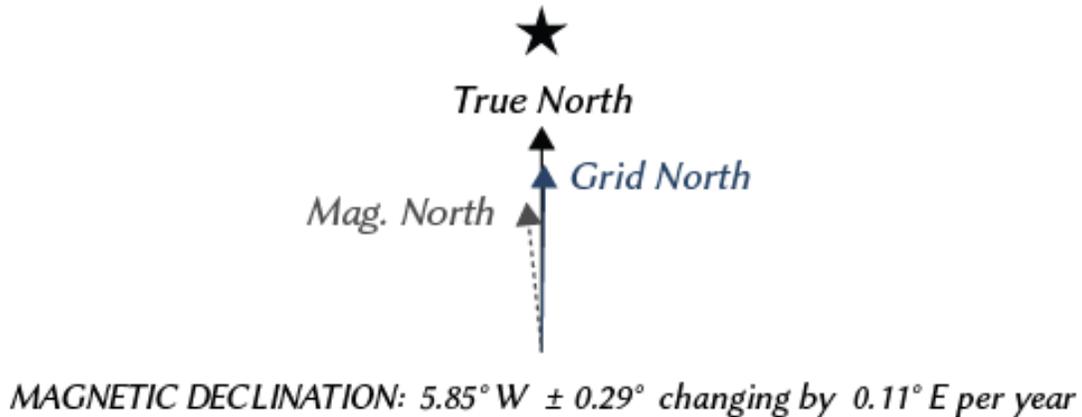
Figure 24. North arrow and magnetic declination.

2. Because map sheets are already aligned to true north, the line for true north will be perfectly vertical. However, the arrow for magnetic north will have to be modified for each map sheet. This will be covered in Part 13 of this guide.

3. Also, include filler text for magnetic declination and rate of change. Actual declination values will be edited for each map sheet.

12.6 Creating the Map Symbols, Graphic Styles and Patterns

Before a map legend can be created, symbols (for point features), graphic styles (for line and polygon features) and repeating pattern swatches (a different type of graphic style used to represent land cover polygons) must be designed to represent all map feature types that will be included in the final maps. Use cartographic conventions to design your own symbols and patterns. Use online resources for ideas and inspiration.

1. Open a new Illustrator document with the same dimensions used for the map template document created in 12.2.

2. For each point feature, save a map symbol as a new Illustrator Symbol by selecting it on screen. Then, under the drop down menu ≡ for **Symbols**, select **New Symbol**. In the next window, name the symbol appropriately.

Figure 25. Examples of mosque symbols used for two different regions.

3. Save symbols for line or polygon features by selecting one on screen. Under the drop down menu ≡ for **Graphic Styles**, select **New Graphic Style**. In the next window, name the graphic style appropriately.

Intermittent Stream

Stream

River

Figure 26. Examples of graphic styles for Hydrologic features.

4. The steps for creating repeating patterns is more difficult. Use online documentation to aid in this process. Custom patterns will also be saved as **Graphic Styles**.

Figure 27. Examples of land cover swatch patterns.

12.7 Creating the Map Legend

With symbols, styles, and patterns created for all map features, the legend can now be created. The final map legend will be linked to the map template. By linking the legend instead of embedding it, broad changes can be made to the legend and included symbols and styles in many documents at once. This also prevents the legend from being unintentionally modified.

1. Open a new Illustrator document, and give it dimensions that will allow it to fit in the bottom portion of the map template. See Appendix IV for details on legend size and placement.

2. In the new legend document, import all symbols from the template document. This can be done under the symbol options drop-menu ▤, **Open Symbol Library**, **Other Library**, and navigate to the master template Illustrator document created in 12.1. Repeat these steps for graphic styles.

3. Place instances of all symbols, styles and patterns in the legend document. Label symbols based on their feature types and arrange them to create a comprehensive and legible map legend. Save the Illustrator file.

4. Now, to link the legend file to the master template, open that document, go to **File**, and **Place**. Navigate to the legend file and click to place it. Center the legend at the bottom of the template page. Save the master template file. As discussed earlier, changes made to the legend file will be applied wherever that file is linked at any point in the workflow.

Part 13: Importing Maps features and Applying Feature Styles

To apply symbols, graphic styles and character styles to map features and labels, map sheets (exported as .AI files in Part 11) are added to the map sheet template document and saved accordingly. With symbols, graphic styles, and character styles already save in the map sheet template document, map features can be symbolized quickly in a systematic way. However, some complex features like streams stream labels and contour labels require extra work to be properly symbolized. Additionally, shaded relief created in Part 4 of this manual is added to each map sheet illustrator file at this time.

Part 13 covers steps for pasting map features and shaded relief into the template document, and applying all necessary styles and symbols to map features. Part 13 also includes specific steps for placing most feature labels and for applying correct styling to tapered stream features. The steps described here must be repeated for each map sheet.

13.1 Pasting Features into the Map Template

1. Open the master map template document created in Part 12.

2. Now, open the Illustrator document containing the raw vector files for a map sheet. Follow the steps discussed in Appendix III for ungrouping features and deleting clipping masks.

3. Under the **Layers** menu ≡, confirm that **Paste Remembers Layers** is checked.

4. With all layers unlocked, drag a selection box across the entire screen. Double-check that all features were selected.

5. Hit **Ctrl-C** to copy those features.

6. In the master template document, make sure all layers are visible and locked. Hit **Ctrl-Shift-V** to paste the map features in place. With all pasted items still selected, use the arrow keys to align the map to the neatline.

7. Confirm that the pasted map features line up with the neatline. Drag the neatline above the map features in the **Layers Panel**. The neatline should cover the edges of all map features. At this point, make sure each map feature is placed in the correct order within the layers panel.

8. Go to **File**, **Save As**. Rename the template document after the map sheet you will be working on, and add "working" to the document name. Save it in the Illustrator folder for that map sheet (see Appendix I).

9. Save changes to the raw map sheet export file and close it.

13.2 Adding the Graticule

1. Open the document containing the exported graticule from the same map sheet.

2. Follow the steps discussed in Appendix III for ungrouping features and deleting clipping masks.

3. Drag a selection box across the whole screen to select the graticule, graticule labels and map sheet extent layer. Hit **Ctrl-C** to copy those features.

4. Back in the map sheet working document hit **Ctrl-Shift-V** to paste. With the newly pasted features still selected, use the arrow keys to align them with the other features (it may be helpful to turn off the neatline during this).

5. This process places graticule labels well above and below the actual graticule hash marks. Use the arrow keys to move them to a more appropriate distance.

13.3 Applying Styles to the Grid and Graticule

At this point all map features have been imported into the working map sheet document. It is now time to apply the graphics styles, character styles, and symbols designed in Part 12 to their corresponding map features. We'll start with the grid and graticules.

1. Lock all layers except the graticule.

2. Select one of the graticule labels.

3. Go to **Select**, **Same**, **Appearance**. This will select all graticule labels.

4. In the **Character Styles** panel select the style for graticule labels (you may have to click the style twice in the character styles window). This will apply that style to all selected text.

5. With the text still selected, click the **New Sublayer** icon in the layers panel. Name the new sublayer "Text". Drag all selected layers into the text sublayer (tip: **Ctrl** + **Shift** +]) will move all selected features to the top of their layer in the layers panel).

6. Repeat the steps above to select graticule hash marks, graticule tick marks, grid labels, grid tick marks and grid lines, apply appropriate styles and move them to a new sublayer within their current layers.

13.4 Applying Other Styles to Features and Feature Labels

1. To apply styles to a given map feature, lock all layers except the one you would like to edit.

2. Drag a selection box across the entire map.

3. With those features selected, find the appropriate style in the graphic styles panel and select it.

4. Confirm that styles were successfully applied. Repeat these steps for all features and feature labels (note: character styles for feature labels will be found in the **Character Styles panel**).

13.5 Placing Symbols

Replacing point symbols exported from ArcMap is not as simple as selecting features and applying a graphic style. Adobe Illustrator does not have built-in functionality to do so. To manually replace raw symbols with graphic symbols in Illustrator could take hours for a single topographic map. Luckily, there are third-Party script available online that do so. One such script, is available for free download online through the cartography blog, Kelso Cartography (Vaughn 2008). Below are the steps for using this script to apply graphic symbols to point features in Illustrator.

1. Lock all layers except the layer containing the point features you would like to edit.

2. Under symbols, locate the corresponding symbol for that feature. Place one instance of that symbol anywhere on the map.

3. Drag a selection box across the screen to select all points for that feature.

4. Under **File** go to **Scripts**, and select the name of the script discussed above. This will replace every point feature with an instance of the chosen symbol.

5. Check each symbol to guarantee all symbols were correctly placed with now overlapping features.

13.6 Label Placement

At this point, all features have been given the appropriate style for the final maps. However, there will still be some label conflicts. For now, don't worry about the placement of contour labels, this is discussed in depth in Part 14 of this manual. Because of the number of spot height

labels per map sheet (about 150-200) these labels will require the most time. Take time during this step to ensure that no labels are crashing with each other or important map features.

1. Scan the map to find label conflicts or misplaced labels.

2. Move labels that conflict with others. Prioritize more important map features.

3. River and stream labels should match the curve of their corresponding feature. Use the **Curvature Tool** to draw a curved line the matches the curve where you would like to place a label. Select the **Type on a Path Tool** and click on the curved line, retype or paste the label text on the line.

4. Certain labels may require greater spacing between all letters. This is called tracking and can be adjusted in the **Character Panel**. Similarly, kerning, the space between two letters can be adjusted in the same window. For multi-line text, use leading to adjust the space between lines.

13.7 Placing Shaded Relief

1. In the layers panels of the Illustrator document create a new layer and name it "relief".

2. Lock all other layers and highlight the relief layer in the layers panel.

3. Go to **File** and choose **Place**. Navigate to the folder where the shaded relief for this map sheet is stored (it should be the same folder the current illustrator document is stored, see Appendix I for more on folder organization). Choose the relief file.

4. Now, click the top left corner of the neatline to place the image there. To fine-tune the placement of the relief image, hide the neatline in the layers panel, and use the arrow keys to make adjustments.

5. Drag the relief layer below the land cover features in the layers panel.

13.8 Applying Correct Stream Taper

To add to the aesthetic appearance of hydrological features in topographic maps, many

stream features can be symbolized using a subtly tapered line. This style can be employed by

changing the stroke profile in the stroke window [Profile: ▶]. By saving the profile

to a graphic style (along with the appropriate line width and color) this style can be applied

quickly to all stream features.
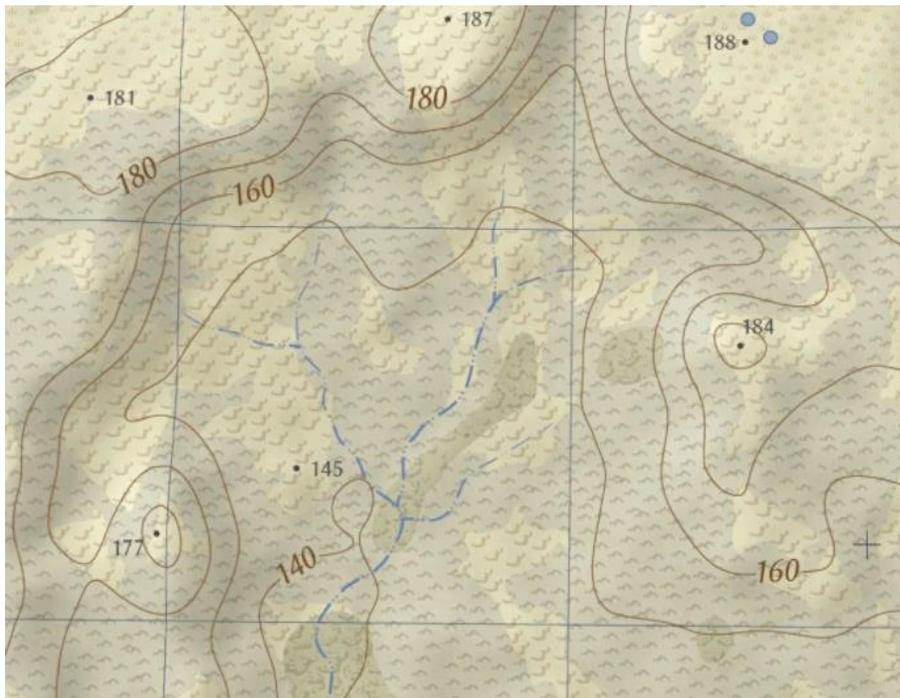
Figure 28. An example of correct stream taper.

However, when this style is applied to many features at once it may inappropriately taper streams

that are contained within a network of streams. Additionally, depending on the anchor direction

streams may taper the wrong way. The following are steps for applying the correct taper

direction for all stream features.

1. First, lock all other layers in the Illustrator **Layers** panel.

2. Make sure the graphic styles have been applied to all stream types. Sometimes it may be useful to hide all map feature layers except tapering streams (leave the neatline on as well).

3. Pan the document. When a stream tapers in the wrong direction, select that feature, and reverse the anchor direction in the stroke panel ▷◁.

Figure 29. An example of incorrect stream taper.

4. Streams that connect to other streams, hydrologic features or leave the page should not taper. For such features, simply change the stroke profile to **Uniform** in the stroke panel.
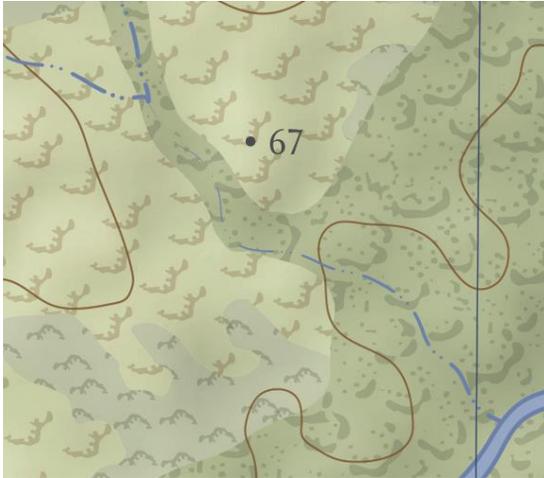
Figure 30. An example of a stream that should not taper.

5. Complex stream networks can require that the upper portion of a stream tapers but the lower Part is uniform. To fix this use the **Scissors** tool to divide a line into two segments. Now, apply a taper to the upper segment and uniform stroke to the lower segment.

Figure 31. A stream feature that must be sliced to apply multiple stroke taper profiles.

Figure 32. A stream feature that has been sliced and given different stroke taper profiles.

Part 14: Contour Labels and Masks

In Part 10 we took steps to optimize the placement of contour labels in ArcMap. However, due to inevitable conflicts with other map labels and features, contour labels may still need to be moved to increase legibility. This workflow adheres to set of guidelines in the placement of contour labels.

1. Contour labels should always face uphill.

2. Contour labels should never be placed upside down

3. Contour labels should not "ladder" up terrain features.

4. Sufficient contour labels should be placed to easily determine elevation anywhere on the map.

5. Contour lines are masked where contour labels are present to increase legibility.

Use the above rules to move contours labels for each map sheet in Illustrator. Once contour label placement is finalized for a map sheet, they can be used to create an offset mask for the underlying contour line (McManigal 2010). Below is an example of contour labels before and after the contour line masks were created.

Figure 33. Unmasked contour lines.
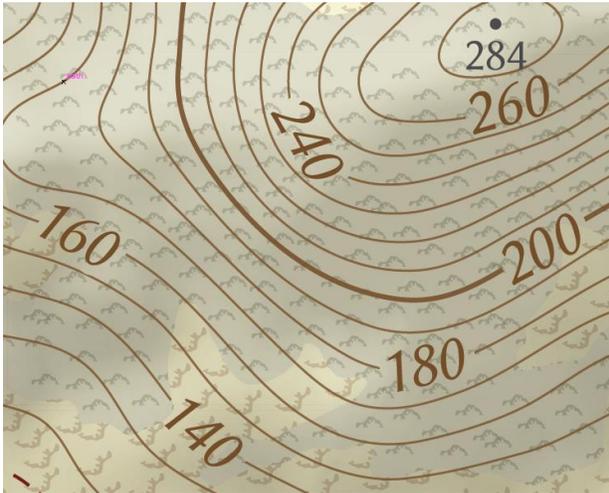
Figure 34. Masked contour lines.

Part 14 covers the steps for creating contour label masks. This process will have to be completed twice per map sheet. Once, for index contours and again for intermediate contours.

1. Finalize the placement of all contours labels before beginning this tutorial

2. Lock all layers except the contour label layer for which you are creating the masks.

3. Create a duplicate of the contour label layer by selecting it in the layers panel, going to layer options ☰ and selecting **Duplicate Layer**. Lock the original layer, and select the **Eyeball** 👁 icon to hide it.

4. Drag a selection box across the screen to select all contour labels

5. Go to **Type** and select **Create Outlines**. This converts text labels into vector features.

6. Zoom in to an area with a few contour labels. With the all text outlines still selected, go to **Object**, **Path**, and **Offset Path**. In the **Offset Path** window, enter a value somewhere around .**015 inches** (check **Preview** to get a preview of the size of the offset). Select **OK** when you are happy with the offset. Inspect the results of this offset throughout the map, make sure there are no significant gaps where a contour line might show through. This will be the size of the final contour line mask. Is it big enough to completely mask the underlying contour? Is it so big that it masks portions of surrounding contours? Experiment with values between .012 inches and .020 inches for these offsets. The example below shows adequate size for an offset.

The example below shows a contour mask that is not big enough.

7. Once you are happy with the size of the offset, zoom all the way out (**Ctrl + 0**). Drag a new selection box to reselect all offset features (and the underlying text vectors).

8. In the **Pathfinder** panel, hold the **ALT** key and select the **Unite** Icon. Now click the **Expand** Icon. Click anywhere on screen to release the selection.
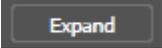
9. Now, find the extent layer for the map sheet you are working on. Unlock it. Highlight that path in the layers panel. Under the layers panel options choose the **Duplicate** the selected path.

10. Drag the duplicate layer into the Contour label layer and place it at the top of that layer (above all other mask features). Lock the original extent layer again. Add a fill to the newly duplicated extent layer so it becomes an opaque rectangle covering the entire map extent.

11. Drag a new selection over the entire screen to select the type offset vectors and the extent rectangle. Go to **Path**, **Compound Path**, and select **Make**.

12. Unlock the contour line layer you are masking in the layers panel. Drag the compound path you just created from the contour label layer, to the top of the contour line layer that you will mask.

13. With no selections, click to highlight the contour line layer in the layers panel. Under layer panel options , choose **Make Clipping Mask**. The clipping mask is now complete.

14. Unhide the original contour label layer by selecting the **Eyeball** icon next to that

layer. Lock the contour labels and lines layers.

Part 15: Creating Index Locator Maps

Because of the fine-scale and size of the topographic maps constructed in this workflow, effective navigation will often require utilizing multiple maps. To ease in the use of multiple topographic maps, each map sheet should include a locator map showing the 8 surrounding map sheets. These locator maps should also include the most important map features like national park boundaries, international boundaries, or large bodies of water.
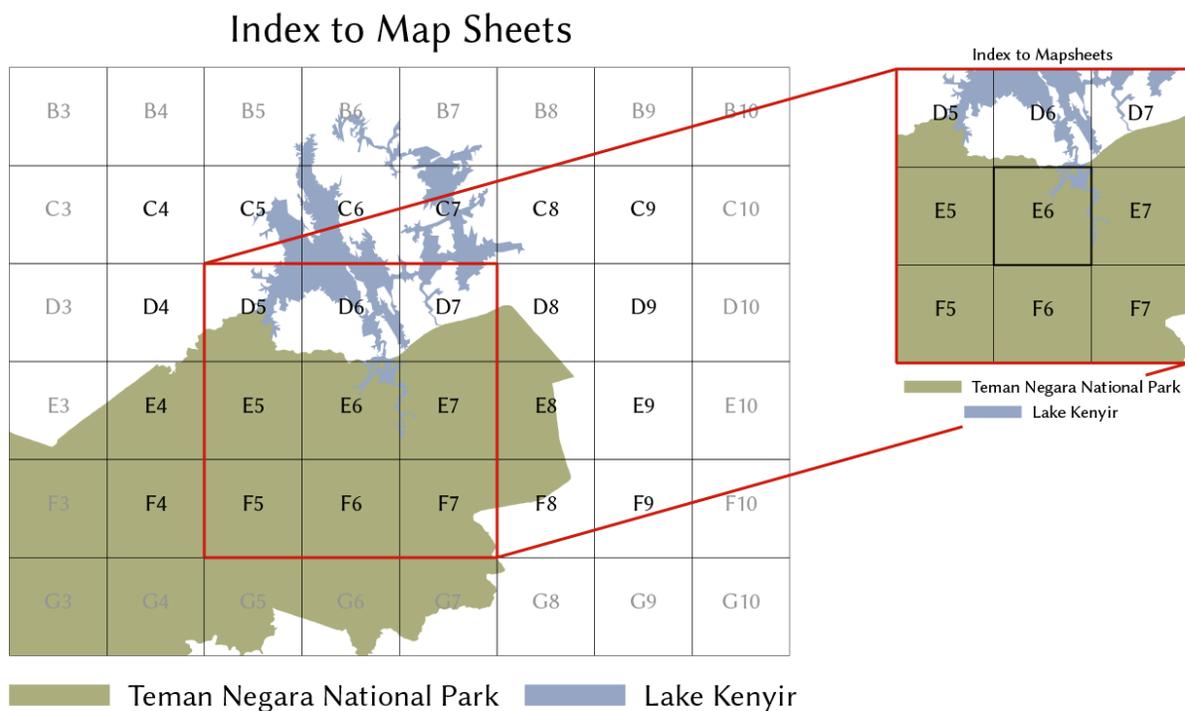
Figure 35. The master index of map sheets for a Malaysian map series and example of an individual index map.

Part 15 covers the steps to construct a master locator map using ArcMap and Adobe Illustrator. The master locator map will be subdivided and included in the corresponding map sheet document.

15.1 Master Index Map

1. Open a new ArcMap document. Add data for the master map sheet index and for any important vector features that should be included in the index maps.

2. Under Layer Preferences for the map sheet index layer, choose to Label Features, and under Field choose the alphanumeric field.

3. Turn off all layers except those to be exported. Remove any transparencies that were applied to layers. Export the map as an AI file.

4. Open the AI file that was just created. Follow the steps discussed in Appendix III to delete clipping masks and ungroup features.

5. Create a new layer and name it **"Master Index"**. Place all features in the master index layer and organize features within appropriate sublayers (ex. grid labels, grid, parks etc.).

6. Symbolize features with appropriate colors, and apply typeface to text labels.

7. Select the map polygon features. Go to **Object**, **Path**, **Simplify**. In the next window drag the slider to adjust the **Curve Precision**. Check the **Preview** option to experiment with different values. Remember, the final index maps included with each map will only take up a couple of inches, so simpler is better.

15.2 Individual Index Maps

1. To create individual map sheet index maps, create a new illustrator layer and name it for its corresponding map sheet.

2. Create a selection containing that map sheet rectangle, the 8 surrounding map sheet rectangles, all corresponding labels, polygon map features. Hit **Ctrl + C** to copy those features.

3. Highlight the map sheet layer created in step 15.2.1, and paste those features in blank space anywhere on the page. The result will look like this.
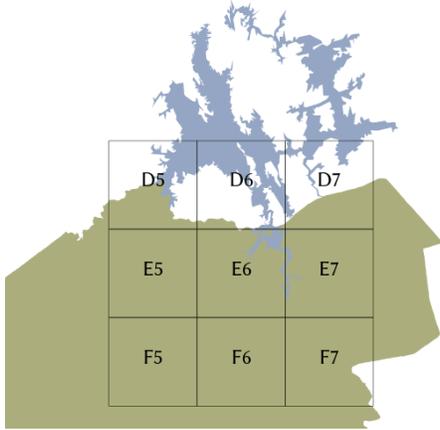
Figure 36. An example of an untrimmed map sheet index.

4. Now, to trim the polygon map features to the extent of these six map sheets, choose the **Line Segment** tool. Click and drag to draw a line segment where you want to trim a polygon. Like below. Note: this must be completed separately for each polygon.
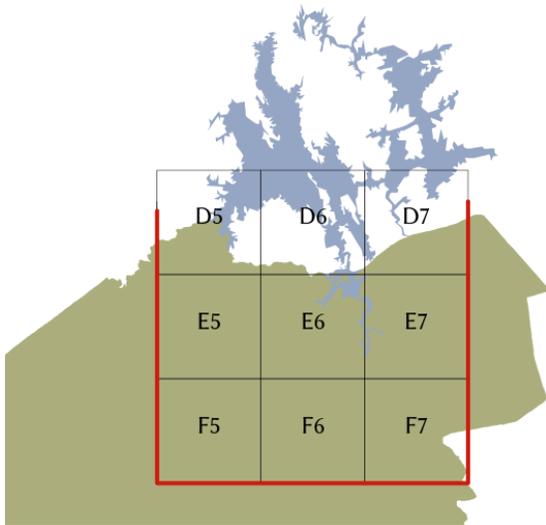
Figure 37. Line segments used to trim extraneous park border features.

5. Select both the new line and the polygon you want to trim. While they are both selected click the **Divide** tool located in the **Pathfinder** panel.

6. Select the polygon, **right-click**, and choose to **Ungroup**. Now, select the portion of the polygon that is outside the map grid (there may be many pieces), and delete it.
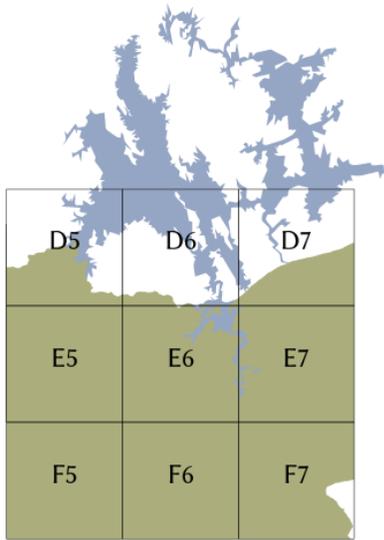
Figure 38. Line segments used to trim extraneous lake features.

7. Repeat these steps, to trim any other polygon features to map grid.
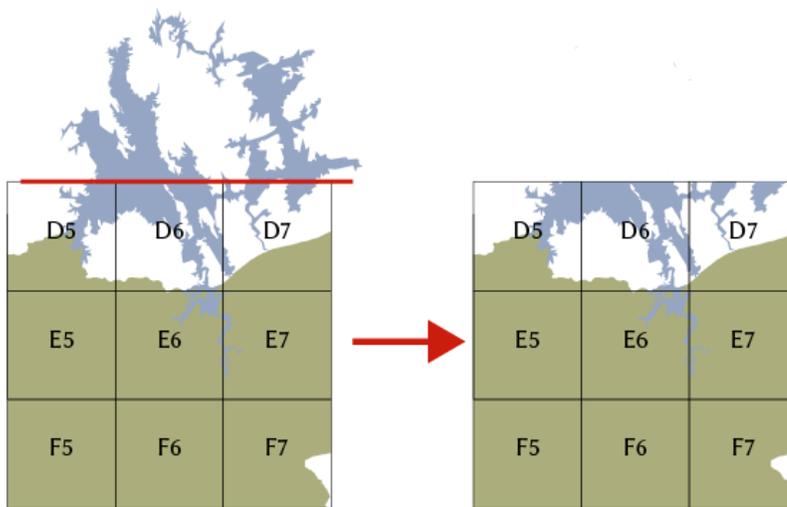
Figure 39. Repeat "divide" process to clip extraneous lake features.

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8. Select the center rectangle in each map sheet and increase its stroke to show it is the map sheet of interest.

9. Repeat these steps to create a map index for each map sheet.

10. Add a small title and legend for each index map. See figure IV for final map layout.

11. Save the Illustrator document containing one master index map and all individual index maps for each map sheet so index maps can be accessed easily.
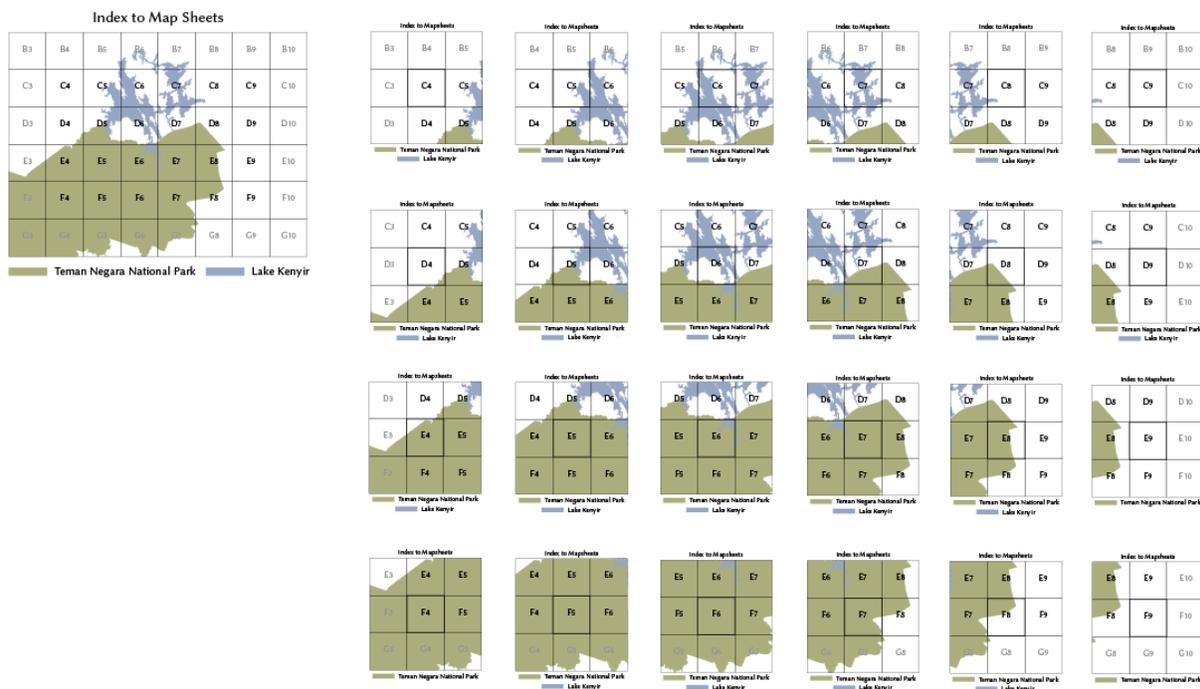
Figure 40. Example Illustrator document for master map index and individual map indices.

12. One at a time, paste each index map into the corresponding map sheet Illustrator document (consult Appendix IV for map sheet layout information). Save each document and close it.

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Part 16: Exporting Final Proofs and Printing Maps

With all maps complete, it is time to export each map sheet illustrator file as an image file, and print proofs. It is a good idea to print one proof for each map sheet on cheaper poster paper to make one last check for errors. Afterwards, maps can be printed on waterproof paper and sent off along with digital copies of the contained GIS data.

Part 16 covers the final steps for exporting maps, printing proofs, making corrections and printing final maps.

16.1 Exporting Maps Sheets as Tiffs

1. Open the Illustrator document for the map sheet you are exporting.

2. Make sure all layers are visible.

3. Go to **File**, and choose **Export**.

4. Change **Color Model** to **RGB**. For **Resolution** choose **300 ppi**. Check the box for **Embed ICC Profile**.

5. Repeat this for all finished map sheets.

6. Print full size proofs for each map.

16.2 Map proofing

With printed proofs for each map, scan each one for mistakes. It's often much easier to identify errors and inconsistencies in printed maps. Line maps up side-by-side, on the floor, or on a large table. Keep detailed notes on the location of mistakes so they can easily be found in Illustrator documents.

1. Check that every map feature is correctly styled.

2. Check for inconsistencies between features that span multiple map sheets. Confirm that stream labels are correct and consistent across maps.

3. Double-check label placement and spelling. Contour labels are especially prone to misplacements, make sure all contour labels follow the guidelines discussed in Part 14.

4. Double-check grid and graticule labels for mistakes. These labels will be used to make measurements in the field, so it is crucial to catch any errors now.

5. Confirm the appropriate title, alphanumeric index, and index maps have been added to each map sheet.

6. Once all corrections are made in the Illustrator map sheet documents, repeat the steps in 16.1 to export final map proofs. At this point, maps are ready to be printed on waterproof paper and used in the field.

Part 17: Stitching Map Sheets, Georeferencing, and Creating Digital Deliverables

The final step in the mapping process is to create GIS data that can be shared with contracting agency to be used for any purpose they see fit. These digital outputs include all vector data saved as shapefiles that can be easily loaded into GIS software, and a comprehensive base map saved as a georeferenced image. The base map can also be used in GIS or loaded into GPS units and used to navigate in the field.

Part 17 covers the steps for georeferencing final map sheets using ArcMap. It will also cover the process for stitching final map sheets into a composite image using Adobe Photoshop, and georeferencing the composite image. This section will also discuss the steps for using MapTiler Software to prepare zoomable raster images that can be loaded into Google Earth and other GIS platforms.

Figure 41. Georeferenced map sheet composite of 20 map sheets in Niokolo-Koba National Park, Senegal.

17.1 Sharing Vector Data

There are a variety of formats for saving vector data to be shared for use in GIS software. The main project geodatabase could be compressed and shared in a zipped file, or feature classes could be exported as shapefiles, compressed, and emailed. ArcMap also supports the conversion of feature classes to kml and gpx files (google earth and common GPS file types). Consult with the contracting agency on their preference for GIS file types.

17.2 Georeferencing Individual Map Sheets

To be used as GPS base maps or loaded in GIS software final map files must first be georeferenced. Once raster maps are georeferenced in ArcMap, they can be exported in a variety of file types including kmzs (google earth rasters), geotiffs (high-resolution georeferenced images), and geojpegs (medium-resolution georeferenced images).

1. Open the Illustrator document for the map sheet you want to georeference.

2. In the layers panel unlock the neatline.

3. Select the neatline on screen. In the **Appearance** panel, change the stroke of the neatline to a neutral color that blends well with the rest of the map. This border color will be used in all georeferenced map sheets so choose a color that works well across all map sheets. Lock the neatline in the layers panel.
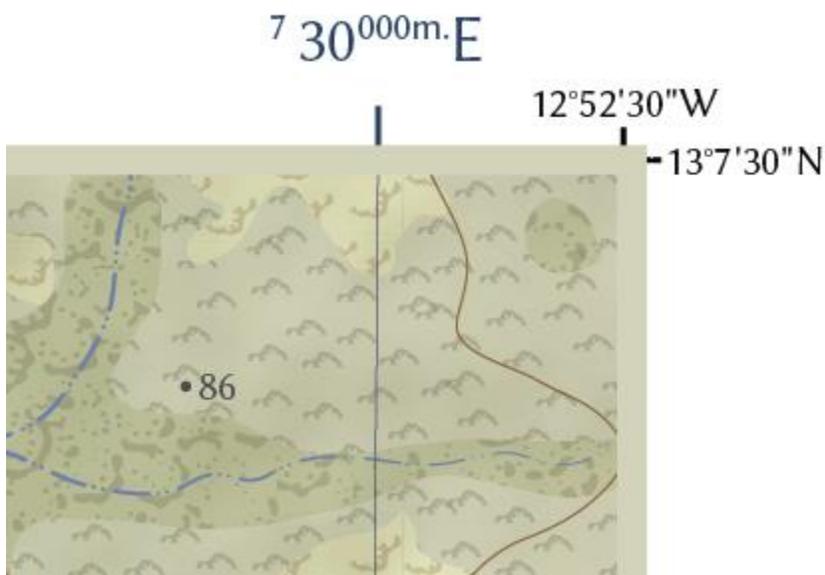
Figure 42. A neutral map sheet border color.

4. Find the layer for the graticule crosshatches. Drag it above the neatline in the **Layers** panel.
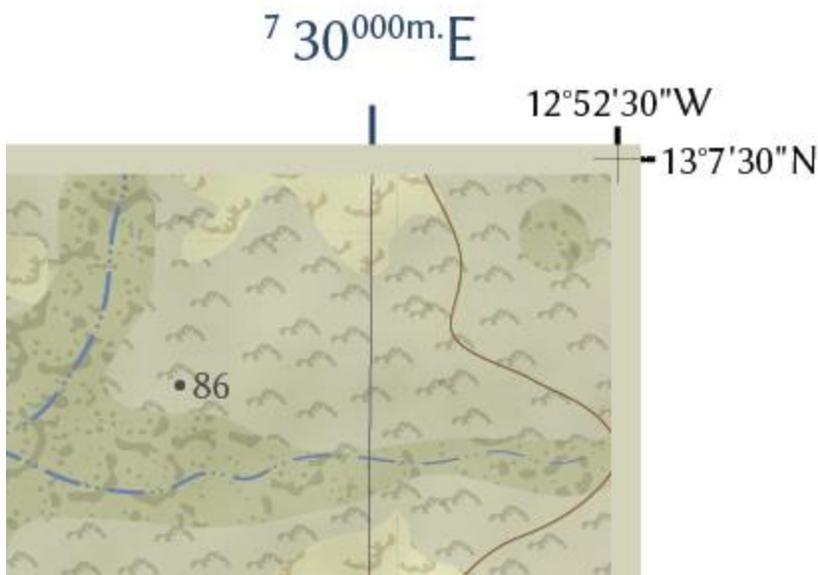
Figure 43. Using graticule crosshatches to georeference map images.

5. Go to **File**, and choose **Export**.

6. Change **Color Model** to **RGB**. For **Resolution** choose **300 ppi**. Check the box for

   Embed ICC Profile.

7. Right-click the file name for the high resolution tiff file you just created. Choose to **Open**

   With Photoshop.

8. With the tiff open in Photoshop, use the **Marquee** tool to make a selection from the cross

   hatch in the top left corner of the map to the bottom right. Zoom to each corner to

   confirm the selection lines up perfectly with the center of the cross hatches.
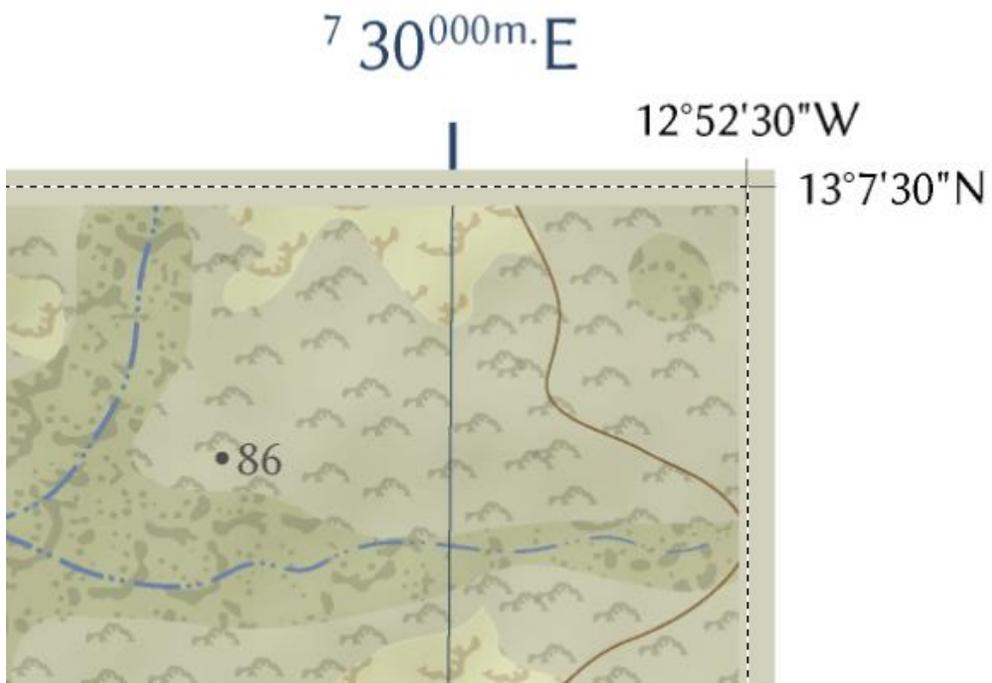
Figure 44. Marquee selection to crop map sheet in Photoshop.

9. Go to **Image** and select **Crop**.
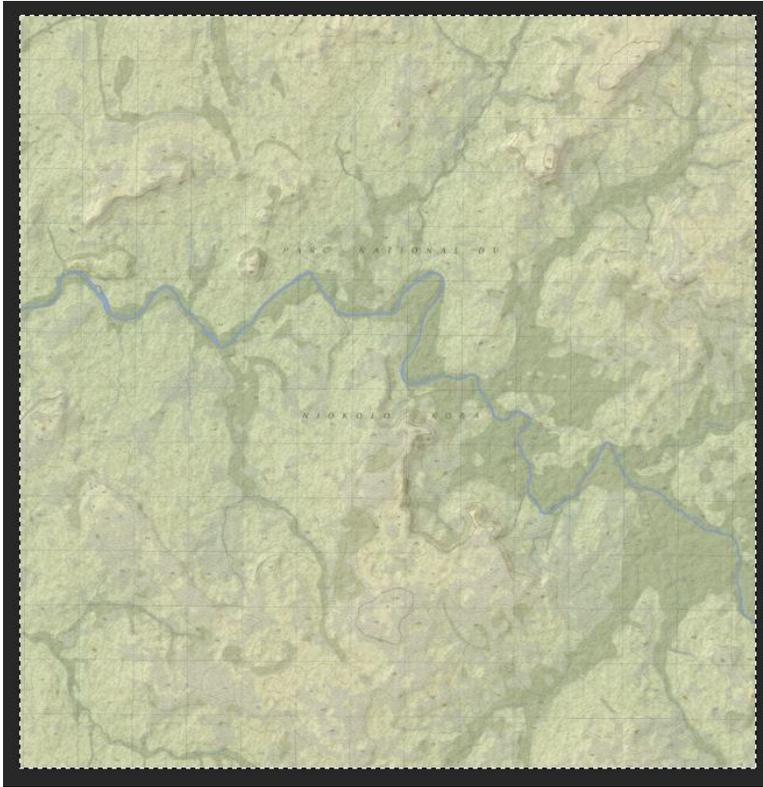
Figure 45. A cropped map sheet in Photoshop.

10. Hit **Ctrl** + **D** to remove the selection. Save the cropped map image.

11. Open a blank ArcMap document.

12. Go to **Customize**, **Toolbars**, and add the georeferencing toolbar to your ArcMap layout.

13. Find the **Add Data** ⬦ ˅ icon in ArcMap and navigate to the un-georeferenced cropped

    map image. Choose to add it to your map document and choose to **Build Pyramids** and

    under **Interpolation Method** choose **Bilinear Interpolation**. At this point the maps

    colors may appear distorted. To fix this, go to the symbology tab for map sheet layer and

    set **Stretch** to **None**.

14. In Part 1 we discussed methods for extracting corner points for the map sheet grid using a

    third-party ArcGIS toolbox. If you have already done so open that table now. If you have

    not created such a table refer to Part 1.3 to do so, or create one manually using excel or

google sheets (remember, map corners were set at increments of 7.5 minutes or .125 decimal degrees). Corner point information will be especially important in Part 17.3.

15. In ArcMap zoom in the upper left corner of the unreferenced map image.

16. On the georeferencing toolbar select the **Add Control Points** ⚲ icon. Zoom in close to the upper left corner, and click right at the corner. Now, right-click and select **Input X and Y**. Enter the coordinate in decimal degrees and select **OK**. Do not forget to include negative signs if your coordinates require them.
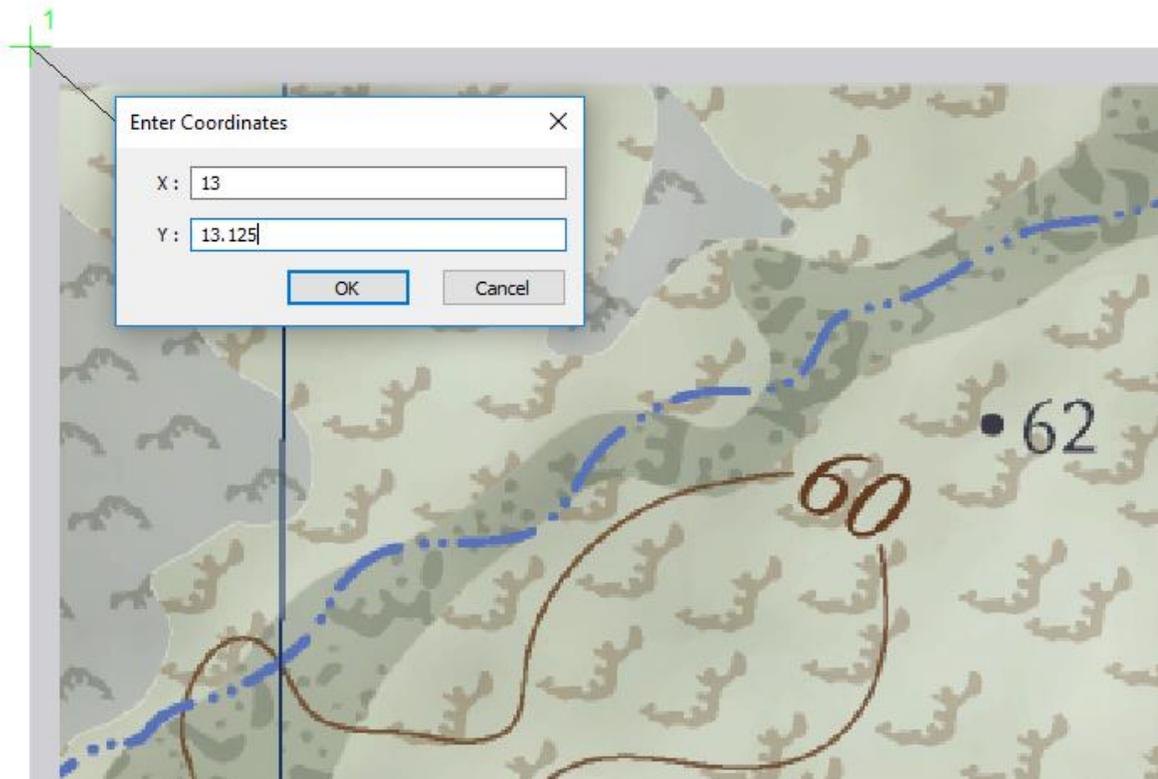
Figure 46. Georeferencing map corner points.

17. **Right-click** the map image in the **Table of Contents** and choose to **Zoom to Layer**. Repeat these steps for each corner point.

18. With all four corner points entered, go to **Georeferencing**, and choose **Rectify** (do not

    choose **Update Georeferencing** as you will need un-georeferenced images for Part 17.3).

    This option allows you to save the referenced map as a geotiff. Save it at the highest

    resolution available (the resolution can be decreased later if need be).

19. Repeat Part 17.2 to georeference each map sheet.

20. Use ArcMap options to export the file types required by the contracting agency, such as

    geotiff or geojpeg.

17.3 Stitching Maps Sheets and Georeferencing

With final maps cropped, they can now be stitched using Adobe Photoshop. Note that the

product created in the steps below will contain subtle lines between map sheet borders.

1. Open a new Photoshop document, and name it something like "MapStitch".

2. Give it page dimensions that are larger than the total map area at a scale of 1:25,000.

    These dimensions were estimated in part 4.2.4.

3. Go to **File**, and select **Place Embedded**. Choose the cropped un-georeferenced map sheet

    for the northwest corner of the map area. Do the same to place another adjacent map

    sheet image.

4. Use the **Move** tool to drag the second map so it lines up perfectly with the first map.

5. Repeat the above steps to place the rest of the map sheets in the Photoshop document

    using the map sheet cross hatches as a guide.

6. Use the **Marquee** tool to make a selection containing all map images. In the **Layers**

    panel go to **Options** , and select **Merge Down** to merge all images into one layer. Go

    to **Image**, and choose **Crop**, to remove any whitespace in the margins of the maps.

7. Go to **File**, **Export As**, and export the image a high-resolution tiff file.

Repeat the steps in 17.2 to georeference the file in ArcMap. This will require adding a control point at every corner point. Consult the corner point spread sheet for this process.

17.4 Creating a Google Earth Superoverlay Using MapTiler

Georeferenced images can be overlayed in google earth using Klokan's MapTiler software (Koklan Technologies). With the composite maps rendered as a "super overlay", the map can be viewed in a 3D environment while enjoying all the GIS functionality of Google Earth (See figure 47).

Figure 47. An example of a composite map image overlayed in google earth.

1. Open MapTiler.

2. Click the option for **Google Earth Kml Superoverlay**.

3. Drag and drop the georeferenced tif into the window.

4. The image's geographic reference will automatically be read by the program.

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5. Select **Continue**. On the next page leave the defaults and select **Render**. In the next window create a new folder and name it accordingly. Select **OK**.

6. In the new folder, double-click the kmz file to open the tiled map in Google Earth.

17.4 Creating a Garmin Base Maps Using MapTiler

1. With MapTiler open, drag and drop your georeferenced image into the map tiler window. The program will automatically recognize the images georeference.

2. Select **Continue**. Check the box next to **Garmin GPS Devices**, and choose **Render**. Name the file for the map sheet or map sheets it pertains to.

Figure 48. A topographic GPS base map in the field in Manas National Park, India (Photo via Pickles 2017).

This concludes the cartographic workflow manual. While this document is intended to be a comprehensive guide for topographic map construction, steps may differ depending on the unique requirements and challenges of a given landscape and the map's purpose. Good luck!

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Appendix I: Folder Organization

To maintain efficiency throughout a mapping project it is crucial to have a plan for data organization from the beginning of such a project. Appendix I is a summary of one potential method for folder organization designed for the workflow described in this manual. See the flowchart on the following page for a depiction of this organization method.

The main project folder should be stored on a server so that multiple cartographers can access it at once. Using a server in this way allows cartographers to edit or generate different map features simultaneously, increasing the efficiency of a mapping project. Note that ArcGIS will not allow a feature class to be edited if that feature class is open on another computer. This prevents two cartographers from editing the same feature class at once.

Within the main folder are two subfolders. One is designated for master-level data (raw data, map features that cover the entire map area, and Illustrator templates), and another for map sheet-level data (data that has been clipped to fit the extent of a single map sheet and Illustrator documents for individual, styled map sheets).

Folder Organization and Structure
Appendix I

Raw Data GDB — Contains all raw geospatial data. This data should remain unchanged. Edits should be made to copies of raw data in the Master GDB.

Master GDB — Contains features datasets for all broad map feature categories spanning the entire map area (i.e. Hydrology, Transportation, Boundaries, etc.) Also contains raster datasets (DEMs, Imagery) See Appendix II.

Feature Creation MXDs — ArcMap Documents are an efficient way to organize the data creation process. Create an MXD for each broad feature type. See Appendix II.

Master GIS Folder

Master Illustrator Folder

Master Illustrator (Template) files — Master-level adobe Illustrator files include map sheet templates, style templates, graphic styles templates, symbol templates and the map sheet legend file.

Master Shaded Relief Doc — Blended shaded relief for the entire map area. See Manual part 7.

Master-Level Folder

Main Project Folder

Mapsheet-Level Folder

Map Sheet GIS Folder

Map Sheet GIS Folders

Map Sheet GDBs — All features in the Master GDB clipped to the extent of each map sheet.

Map Sheet MXDs — All features in the Master GDB, clipped to the extent of each map sheet.

Map Sheet Illustrator (AI) Folder

Map Sheet AI Folders

Map Sheet Illustrator files — Map sheet documents containing all map features

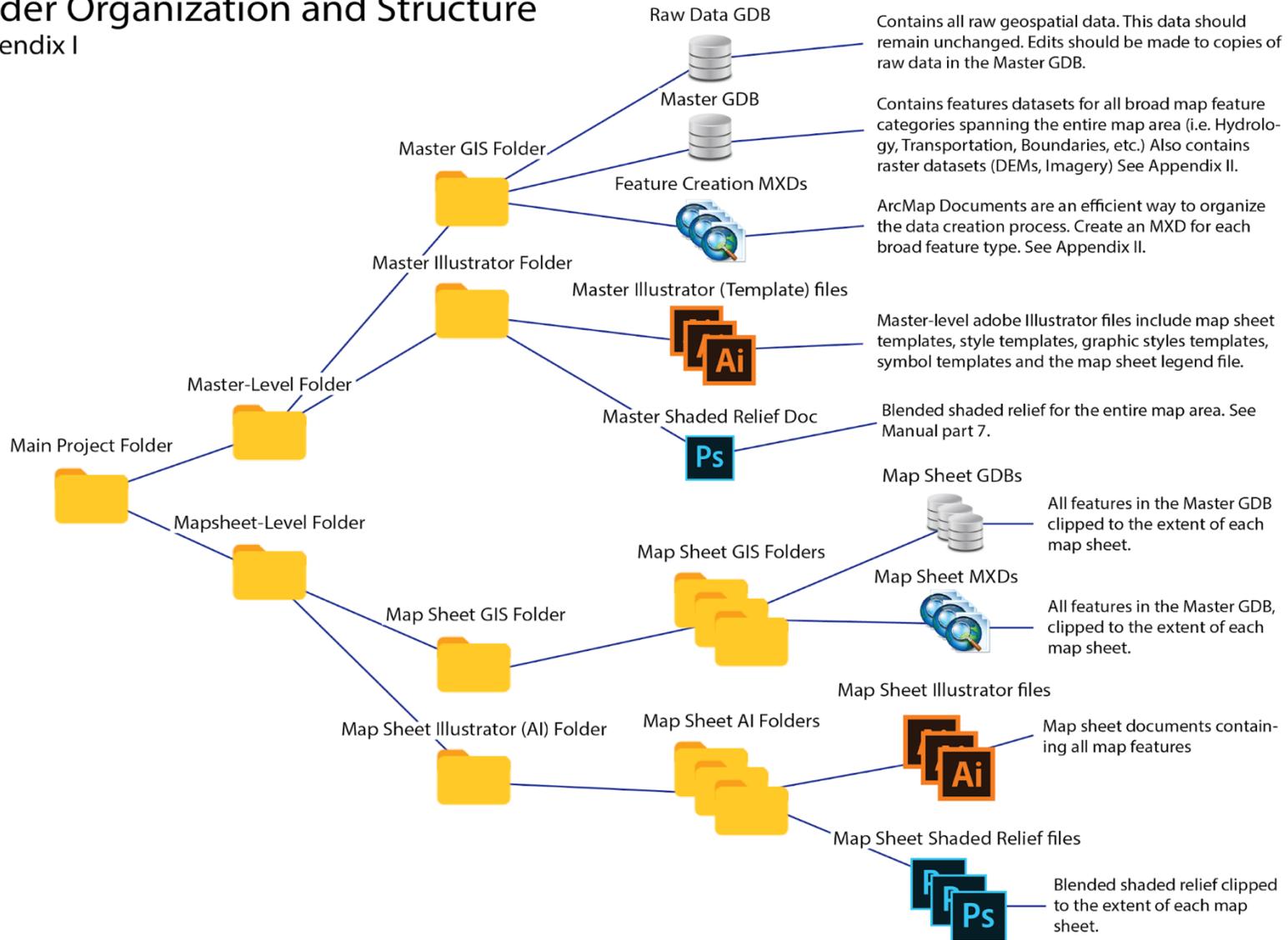**Map Sheet Shaded Relief files** — Blended shaded relief clipped to the extent of each map sheet.

Figure 49. Project folder and file types organized in a file tree.

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Appendix II: List of Map Features

The following Appendix should serve as a reference for possible map features included in a topographic mapping series. It will also provide insight on the GIS data organization structure. Map features listed here should be included in a topographic map series if they are present in the map area. Map series and individual sheets will not contain all features listed below and may include other features not listed.

Organization Structure for Map Features

Vector features (points, lines, and polygons) should be stored as individual feature classes within the appropriate feature dataset. Those feature datasets should be stored in the master geodatabase (separately from raw data files). When master feature datasets are clipped for individual map sheets they will be stored within a new geodatabase for that corresponding map sheet. This organization structure applies to both the master geodatabase and individual map sheet geodatabases as well. Raster datasets should be stored within the master geodatabase. Refer to Part 2 of this manual for more information on data organization.

File Geodatabase (Master or Map Sheet-Level)..……….

- Raster Datasets………………………….……….
- Feature Dataset………………………….……….
    - Point Feature Class……………….……...
    - Line Feature Class……………….....…..
    - Polygon Feature Class…………….…..

Example Raster Datasets (Stored in Geodatabase):

- Georeferenced topographic maps (used for reference)

- Digital elevation model (used for hypsometric tint and generation of other relief features)

- Hill shade and other relief features(used for terrain representation)

- Imagery (used for reference and/or land cover classification)

Example Vector Datasets (stored in geodatabase as feature datasets):

- **Boundary features**

    - District boundary

    - Fence of wall

    - International boundary

    - National park boundary

    - Other park boundary

    - Park sectors

    - Municipal boundaries

- **Geological features**

    - Topographic contours(intermediate contours)

    - Topographic contours (index contours)

    - Road cuts

    - Embankments

    - Pits

    - Quarries

    - Rock cliffs

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- ○ Soil cliffs ⊟
- ○ Large rocks ⊡

- **Land cover** (classifications are dependent on landscape, refer to Part 6) ⊡
  - ○ Dense Forest ⊠
  - ○ Low density forest ⊠
  - ○ Bush ⊠
  - ○ Cultivation ⊠
  - ○ Nursery ⊠
  - ○ Orchard ⊠
  - ○ Scrub ⊠
  - ○ Swamp ⊠
  - ○ Plantation ⊠
  - ○ Grassland/savanna ⊠
  - ○ Bare ground ⊠
  - ○ Exposed rock ⊠
  - ○ Sand/gravel ⊠

- **Hydrological features** ⊡
  - ○ Aqueducts ⊟
  - ○ Canals ⊟
  - ○ Dams ⊡
  - ○ Ditches ⊟

- ○ Ferries
- ○ Lakes
- ○ Streams
- ○ Intermittent streams
- ○ waterholes/ponds
- ○ Water towers
- ○ Waterfalls
- ○ Water tanks
- ○ Weir
- ○ Well
- **Map Elements**
  - ○ Full map-area extent
  - ○ Map sheet grid (map index)
- **Transportation features**
  - ○ Airstrips
  - ○ Bridges
  - ○ Causeways
  - ○ Feeder roads
  - ○ Foot trails
  - ○ Fords
  - ○ Highways

- ○ Other roads
- ○ Railway line
- ○ Railway station
- ○ Road construction
- ○ Ropeway line
- ○ Ropeway station
- ○ Tunnel
- **Points of Interest**
  - ○ Buildings
  - ○ Built up areas
  - ○ Bus terminal
  - ○ Cave
  - ○ Cemetery
  - ○ Chimney
  - ○ Church
  - ○ Factory
  - ○ Fire station
  - ○ Health post
  - ○ Hospital
  - ○ Hotels
  - ○ Huts

- ○ Mines
- ○ Monument
- ○ Mosque
- ○ Open sheds ,
- ○ Gas/petroleum station
- ○ Police station
- ○ Populated place
- ○ Post office
- ○ Ranger camp
- ○ Revetment ,
- ○ Ruins
- ○ Schools Temples
- ○ Town
- ○ View tower
- ○ Villages
- ○ Other points of interest

- **Surveying features**
  - ○ Elevational benchmark
  - ○ Mountain pass
  - ○ Spot height
  - ○ Summit

- ○ Triangulation point
- **Utility features**
  - ○ Transformer station
  - ○ Transmission line
  - ○ Transmission tower

Contents	Preview	Description

Name	Type
Boundaries	File Geodatabase Feature Dataset
Geology	File Geodatabase Feature Dataset
Hydro	File Geodatabase Feature Dataset
Hydro_processing	File Geodatabase Feature Dataset
LandCover	File Geodatabase Feature Dataset
MapElements	File Geodatabase Feature Dataset
POIs	File Geodatabase Feature Dataset
Surveying	File Geodatabase Feature Dataset
Transpo	File Geodatabase Feature Dataset
Utilities	File Geodatabase Feature Dataset
Full_NK_Topos	File Geodatabase Raster Dataset
NK_30mDEM	File Geodatabase Raster Dataset
NK_Aerial_Perspective	File Geodatabase Raster Dataset
NK_Hillshade	File Geodatabase Raster Dataset
NK_IZ_Topos	File Geodatabase Raster Dataset
SenegalTopos	File Geodatabase Raster Dataset

Figure 50. An example of feature datasets and raster datasets within the master geodatabase.

Aqueduct	File Geodatabase Feature Class
Canal	File Geodatabase Feature Class
Dam	File Geodatabase Feature Class
Ditch	File Geodatabase Feature Class
Ferry	File Geodatabase Feature Class
forested_islands	File Geodatabase Feature Class
Lake	File Geodatabase Feature Class
Ooze_away_place	File Geodatabase Feature Class
Rapids	File Geodatabase Feature Class
River	File Geodatabase Feature Class
Saline	File Geodatabase Feature Class
Sand_gravel	File Geodatabase Feature Class
Sluice_gate	File Geodatabase Feature Class
Spring	File Geodatabase Feature Class
Streams	File Geodatabase Feature Class
Streams_Intermittent	File Geodatabase Feature Class
Twine_service	File Geodatabase Feature Class
Water_tower	File Geodatabase Feature Class
Waterfall	File Geodatabase Feature Class
Waterholes	File Geodatabase Feature Class
WaterHolesRaw	File Geodatabase Feature Class
WaterTank_Pond	File Geodatabase Feature Class
Weir	File Geodatabase Feature Class
Well	File Geodatabase Feature Class

Figure 51. An example of feature classes within the hydrology feature dataset.

Appendix III: Ungrouping and Deleting Clipping Masks

When exporting map features from ArcMap as an adobe Illustrator file, a certain process must be followed to remove features that will prevent the editing of other features. When ArcMap features are exported as an AI document, vector are automatically placed in groups. Groups prevent individual features from being selected on their own in Illustrator. Clipping masks are also applied to such features upon export from ArcMap. Clipping masks clip unwanted features that exist outside the map extent however, they also prevent the editing of features. Appendix III covers the steps for opening an AI file that contains vector features exported from ArcMap, deleting any clipping masks, and ungrouping map features.

1. Open an Illustrator file containing map features exported from an ArcMap document.

2. If you receive a warning regarding legacy text, choose the option to **Update** the text.

3. Now, navigate to **Select**, **Object**, and **Clipping Masks**. If there are any clipping masks in the document (and there will be if this is the first time that document is opened) a new selection should appear.

4. With the Clipping Mask selected hit the **Delete** key.

5. Now, to ungroup all features within their layers, select all layers by holding **Shift** and clicking the radio button to the right of that layer in the layers panel. So that the layers panels looks like the image below.

6. Go to **Object** and select **Ungroup**. To confirm that this worked simply select the arrow next to any layer to open it. If it is still grouped it will only contain one feature named

Group. If there are no groups the layer will contain many features named **<Path>** or a

label.

7. With all features ungrouped, and clipping masks deleted, features can now be selected

individually. Importantly this allows the cartographer to lock all but the layer they intend

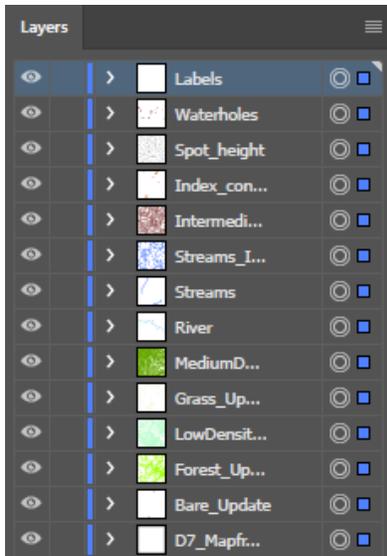to edit and make selections quickly by dragging a selection box across the entire screen.

Figure 52. Using the layers panel to confirm an on-screen selection.

Appendix IV: Map Sheet Template Document Layout

In Part 12 of this manual, the map sheet template document is created to facilitate the creation of map sheets with different extents, and the application of styles to map features. Appendix IV contains an example of the ideal layer order for map features in an adobe illustrator document. Appendix IV is an example of the map sheet template document and its layout for reference.
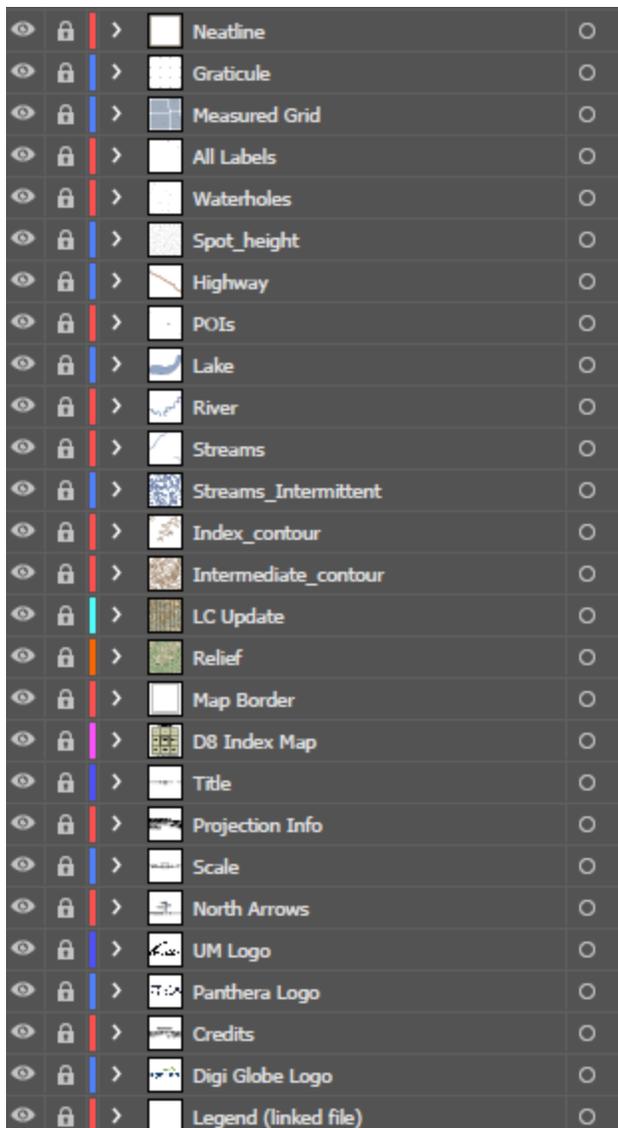
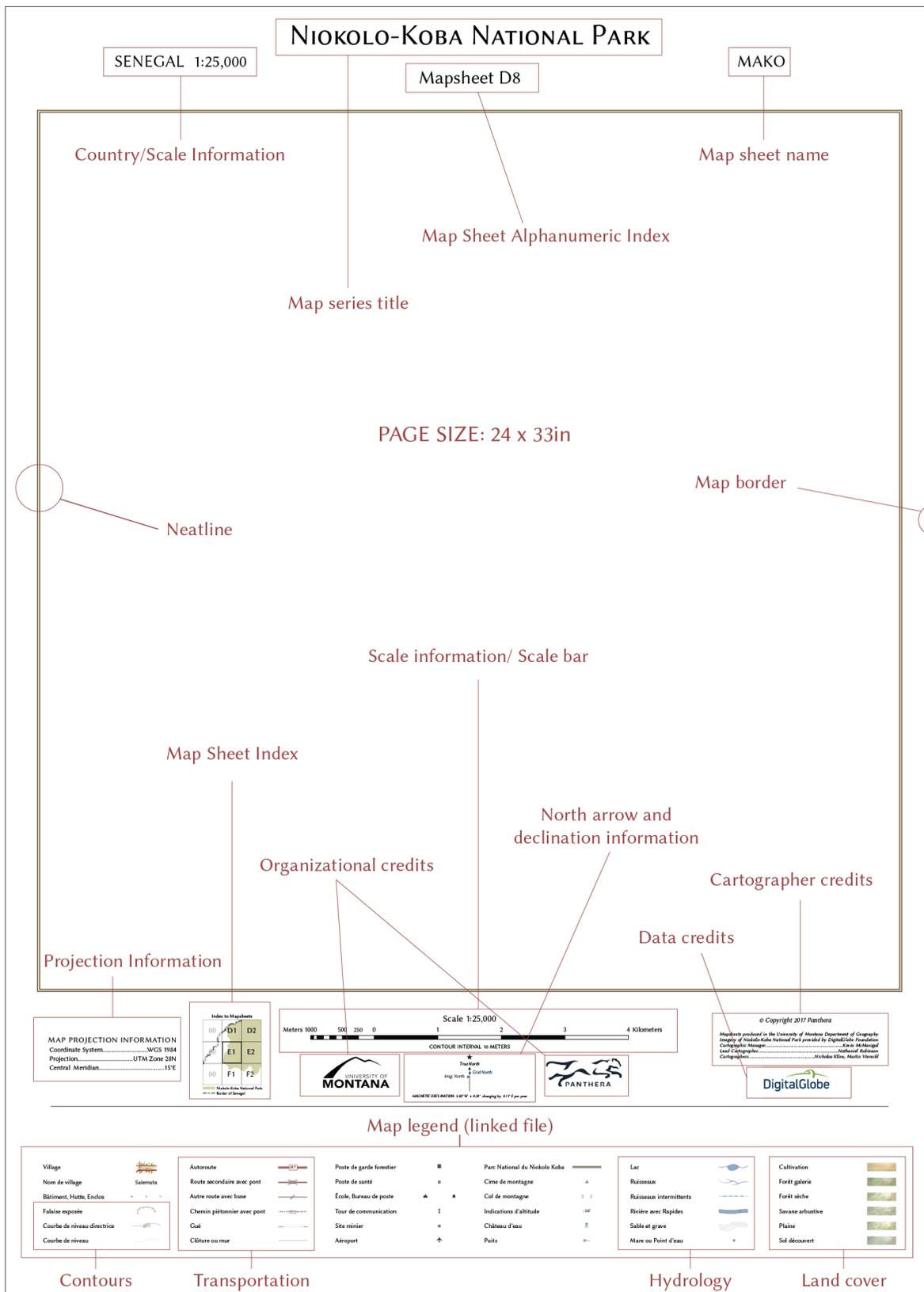*Figure 53. An example of appropriate layer order for features in Illustrator.*

Figure 54. An example of map sheet template layout with important items labeled in red.