

# Notes on GPS, GNSS, and GIS for Cavers

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## Overview

Here are some notes on tablets, cell phones, GPS (Global Positioning System), and apps that cavers might use for cave projects, especially apps that are free or not too pricey. GPS and GIS (Geographic Information System) are my sub-hobby within caving. I recently experimented with the Bad Elf GPS Pro and a Windows tablet among other things. The procedures to make these things work together are not completely spelled out in the user manuals, so I had to figure things out by testing. New devices are coming on the market. Maybe this article will save readers some time, and I welcome discussion of these topics.

## GPS, GNSS, and GLONASS

Cavers use all sorts of GPS devices to record cave locations. Your iPhone or iPad will work, but your accuracy may be limited to  $\pm 10$  m, that is within a radius of 10 m or 33 ft., but you can improve on that. Since the iPhone 4S model your iPhone can use both GPS (American) and GLONASS (Russian) satellite signals, both of which are part of the GNSS (Global Navigation Satellite System). You just need an app that gives you the best precision your phone can achieve. See more below.

Nowadays a cell phone or handheld “GPS” receiver may achieve about  $\pm 3$  m accuracy with WAAS (Wide Area Augmentation System) correction and “waypoint averaging.” Some units now display basic topographic maps on a small screen. See Other Apps below for details.

For a project where you are accurately locating cave and karst features, it’s nice to be able to see where you are on a standard topographic map while you are away from internet networks. In the USA that is usually a USGS 1:24,000 quad with 10 or 20-ft. contours, or in Mexico a 1:50,000 quad with 10 or 20-m contours. These maps show elevation contours, streams, roads, trails, fences, and houses, while small devices may only show a simplified view of contours and streams.

## Windows, WallsMap, QGIS

I have used many devices and apps to map cave, karst, and species locations. Now you can use a low-cost Windows tablet to track your position in the field in real time on a digital topographic map with a linked GPS receiver. No wifi or network is needed in the field. This will allow you to use WallsMap (free from the Texas Speleological Survey) for fieldwork, or QGIS (also free). Both are a good GIS apps that use topographic and other maps. It’s nice to have a 10 or 12-in. screen too. Both apps can link to a Bluetooth GPS receiver and show your exact location.

## Getting Equipped

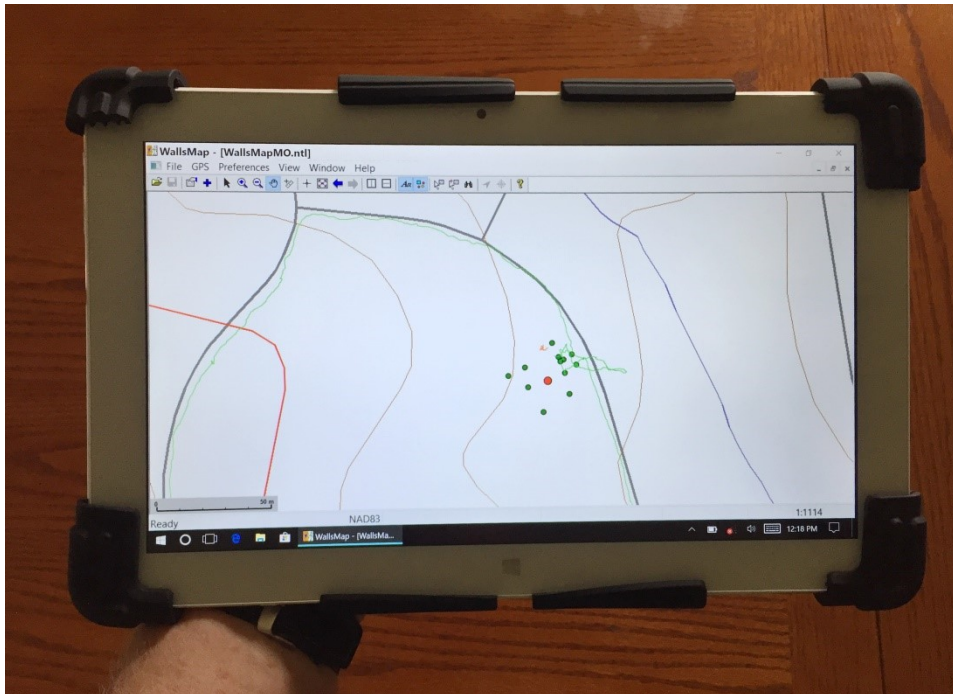
WallsMap is free and fairly simple to learn, but it runs only under Windows. QGIS is an open-source (free) program for several platforms (Windows, Linux, OS X, Android) that gives you advanced tools like the pricey ArcGIS, but it requires time to learn. You might even run QGIS on a good Android tablet, which has a built-in GPS sensor, but you need a bigger screen to see all the tools. The Apple Macbook and the Modbook probably can run QGIS under Mac OS X (10.8 and newer). Refurbished MacBooks can be found for \$100 and up, but the new Modbook 2-in-1 tablet costs \$2,000-3,000.

In June 2018 I bought an inexpensive Windows 10, 2-in-1 tablet/laptop with detachable 11.6-inch touchscreen for writing and experimenting with GIS and GPS. It is a vitalASC made in China as the JME X512BS, and available through Amazon and eBay. It is sort of a Microsoft Surface clone (see photos on next page). It costs about \$175, has an intel Atom X5 8350 processor, 64-bit Windows 10, 4 GB RAM, and 32 GB EMMC onboard storage. I bumped up the storage with a 128-GB microSD card installed as drive D: The system

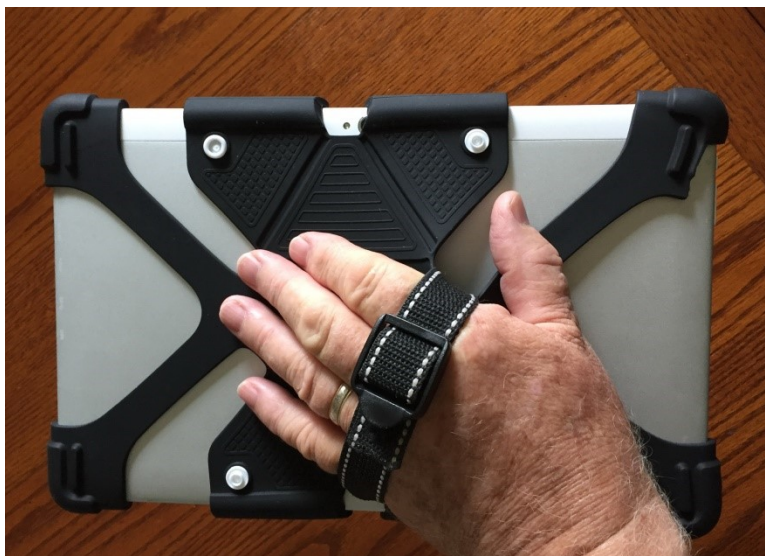
can install most software on D:, saving drive C: for Windows. This tablet has a detachable, somewhat mediocre keyboard, and an internal GNSS receiver, which currently does not talk to many Windows mapping apps.

I downloaded the app, “Windows Maps,” for free from the Microsoft Store, and it can read my tablet’s internal GNSS sensor and provide the current position and free, offline street maps, but it cannot do serious mapping. Another app, “GPS-GPX Logger Pro,” costs \$1.09, and it can read the GNSS data and show your location. You can download free street maps for offline use, but there are no topo maps.

QGIS can use an external GPS very well, and it can read the internal GNSS sensor in its “GPS Information panel.” Use the View menu, then Panels, then click on Autodetect to get the GNSS or Bad Elf signal. QGIS does not say how many GNSS satellites are locked in, but it uses them to draw your location and/or a track on your screen. I am currently using QGIS 3.2 “Bonn,” but QGIS versions have had this GPS panel for years. One can also import a .gmx (Garmin track file) or a .kml or .kmz file via its “GPS Tools” (see Vector menu, then GPS).



My vitalASC 2-in-1 tablet with Windows 10 and WallsMap. This is a view of my neighborhood in Jefferson City, Missouri, with streets (gray lines), topographic contours (red and brown), and points I took using the Bad Elf GPS Pro (green and red). The short orange track was from the Bad Elf for two minutes. The green track was a walk around the block (the line is crooked from satellite signal dithering, not me.)

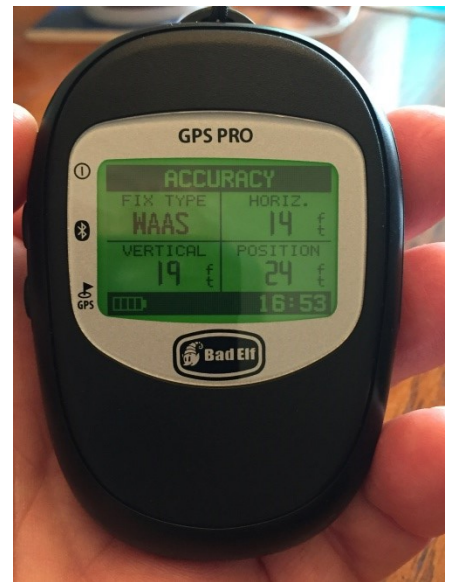


I bought a silicone rubber tablet cradle from eBay for \$11, and added an adjustable strap to hold the unit.



Since WallsMap couldn't read the GNSS sensor, I bought a Bad Elf GPS Pro receiver from [mypilotstore.com](http://mypilotstore.com) for about \$150. This unit is popular with pilots and outdoorsmen, providing a claimed  $\pm 2.5\text{-m}$  accuracy, better than most tablet and phone internal sensors. It can connect wirelessly via Bluetooth to five devices simultaneously, and as far away as 10 m. This allows you to carry a Windows tablet to mark the Bad Elf location as a point in your Windows app, or log a track. Optionally, you can carry an iPhone/iPad running the free Bad Elf app to check the GPS receiver's status and to download a track logged by the GPS (there is no Bad Elf app for Windows yet). Or you can use the iPhone/iPad later to email the .gpx or .kml data from your iPad to your Windows tablet, or connect with a USB cable. Qstarz does not work with iPhone/iPad, but Bad Elf does.

The Bad Elf is an independent GPS receiver, with all the location and other information visible on the LCD screen, and independent data logging as well. You can use the Bad Elf alone anytime. WallsMap and QGIS can both "pair with" the Bad Elf and start drawing a track as soon as the receiver connects via Bluetooth. You do not have to turn on the Bad Elf's internal logger to see the track, but you can do that and save it later. QGIS also can log the incoming data if needed without using the Bad Elf's own logger. See the Bad Elf photos below.

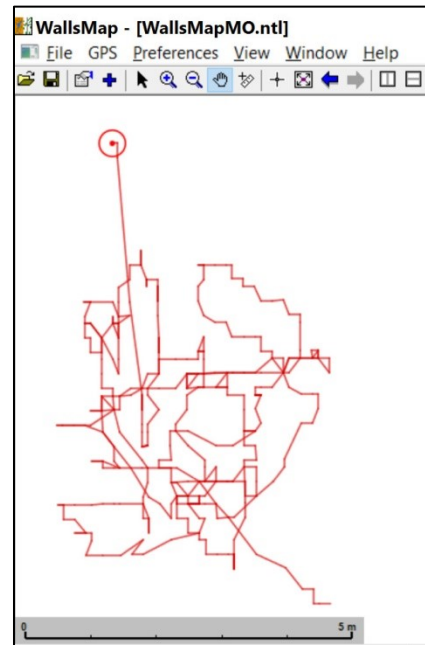
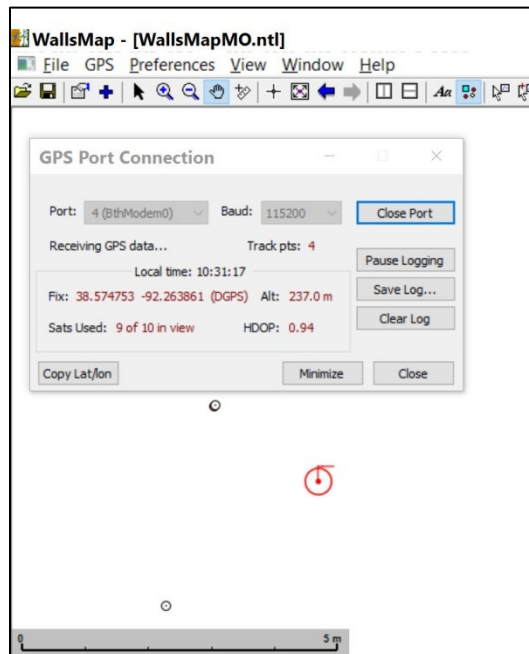


Views of the Bad Elf GPS Pro, with different screens showing satellites, location, accuracy, speed, track, altitude, and Bluetooth status. Another screen turns GPS logging on/off. The GPS Pro + model has GNSS and slightly increased accuracy, but for \$100 more.

Both WallsMap and QGIS connected to the Bad Elf via serial port COM4, but this could differ with other tablets. I have been able to connect at 115,200 baud (speed), although one source recommended 9600. QGIS pairs with the Bad Elf without giving you data rate information. With both apps, it is best to use the WGS84 datum with decimal latitude/longitude as the Bad Elf outputs decimal degree data, which gives you good precision if you record five decimal places. One second of latitude is about  $\pm 30.8$  m, but 0.00001 degree is  $\pm 1$  m precision (but you may do not really get  $\pm 1$  m).

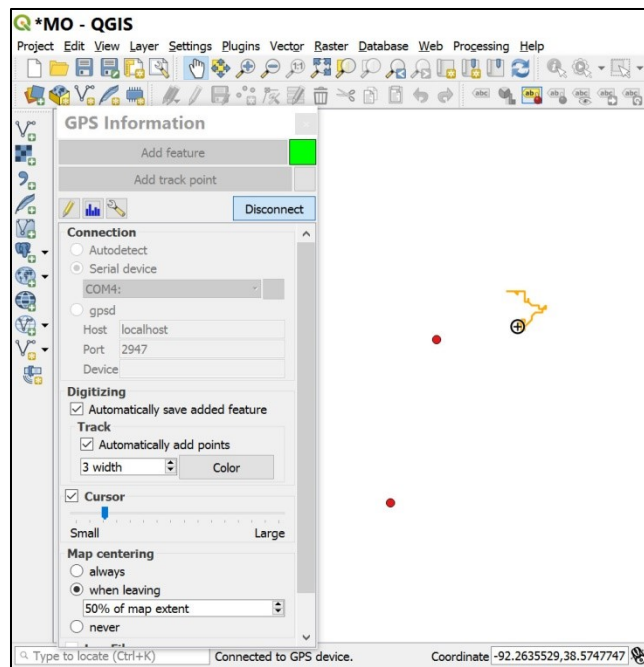
If the Bad Elf does not connect right away, make sure the app is set on the right COM port and try again. If that does not work, try turning off Bluetooth in your tablet, then on again. Sometimes a reboot of the tablet helps. For some reason when I streamed music via wifi simultaneously, it interfered with connecting to the Bad Elf. It connected after I shut off the music.

Below are screenshots of WallsMap and QGIS. The first one shows the WallsMap screen and the “GPS Port Connection” tool already connected to the GPS (click on Open Port). The red circle is the current location of the GPS, and the lines are the track. The track is caused by moving the receiver and/or by the shifting location caused by dithering satellite signals. The second image shows WallsMap after two hours of the Bad Elf sitting in one spot on my dining table and drawing a track on the screen, within a 4 or 5-m radius. If I had been outside it would have made a tighter pattern as more satellites would be in view.



The image below shows QGIS and its “GPS Information” tool, available in the View/Panels menu. There is no baud (speed) option, it does that automatically. The track is shown with a circle and crosshairs for the current GPS position. The separate “GPS Tools” (a standard QGIS plug-in) enables downloading tracks logged in the Bad Elf as .gpx or .kml files (go to Vectors menu, then GPS Tools).

In WallsMap and QGIS you must start a point layer (shapefile) to mark GPS locations and name them. To increase the precision of the location you can visually mark the centroid of a track from the Bad Elf sitting in one spot for a few minutes. With the tablet you can use your finger or an active (battery-powered) stylus to mark points in a point layer or move them.



## Field Use

As with any GPS receiver, to decrease the location error you should maximize the number of satellites locked in. This can be difficult near entrances when you are down in a sinkhole, against a bluff, or under trees. It may help to “do an offset” by shooting a few survey vectors from an open area with compass, clinometer, and tape to the entrance. Pick an area where you can “see” more satellites. Survey to the entrance and pick the datum, if known, or a place that appears to be the best point of beginning (POB or datum) for a cave survey, and draw a sketch to locate it.

Watch the number of satellites on the Bad Elf and record the horizontal and positional error. Later, use Walls or another app to plot the location of the GPS unit and the total offset (x, y, z coordinates) to the cave entrance. This can be used to tie cave surveys together, but remember the error may be  $\pm 2.5$  to 4 m with the Bad Elf. It might help to also shoot to a landmark visible on the topo as a check, like a fence corner or some prominent point.

In an open area I was able to lock in 9 or 10 out of 11 satellites with the Bad Elf, but you might get more. In this case the horizontal error was  $\pm 3.8$  m, vertical error  $\pm 5.2$  m, overall positional error  $\pm 6.6$  m (the hypotenuse between the previous two). So, the horizontal error often is  $\pm 4$  m, and the claimed error of  $\pm 2.5$  m is under ideal conditions. Bad Elf uses WAAS correction, like most good GPS receivers.

Waypoint averaging can be done with some Garmin and Magellan handheld units to maximize accuracy and precision, but with the Bad Elf app just write down the displayed errors or record a track for a few minutes, then visually pick a centroid and mark a point. If you wait 30 to 60 minutes, the satellite constellation may improve. If you are near trees it might be worth hanging the Bad Elf on the tip of a 6-m bamboo or composite fishing pole, lashed to a tripod for a while, to get one or two more satellites.

## Other Apps

I have an iPhone 6, an iPad mini 2, and an old Hisense Android tablet, so I was curious about GPS/GIS apps that work without an internet connection. The popular iPhone/iPad “Compass” app displays your location only in degrees, minutes, seconds, so you can only achieve  $\pm 30$  m accuracy at best. Discard that and download “Compass 55” (free), which can use decimal degrees, UTM, or MGRS (military grid). I tested the app and got  $\pm 10$  m accuracy with the device’s receiver only, but achieved  $\pm 5$  m accuracy paired with Bad Elf. By itself Bad Elf gave me  $\pm 4$  m.

Avenza Maps, Compass 55, and Gaia GPS use the Bad Elf, but they require the iPhone/iPad to have “location services” (internal GPS) turned on too. Most of these simple apps are designed to look first for an internet signal and cell towers, then look for an external GPS. The table below sums up what I learned about these apps.

My old Android tablet has “Polaris GPS Navigation,” a free app with many good features such as different street and simplified topo maps, including Mexico. It has different coordinate systems and displays the position error,  $\pm 6$  m at best. The newest version can use raster maps, such as geotiffs, but I have not tested that. It did not work with Bad Elf, using only the internal GPS sensor. There are many Android GPS apps.

Some handheld Garmin and Magellan GPS units have built-in topo maps that provide GIS-like capability. “GPSFileDepot” offers free Garmin Maps of most US states, but they have almost none for Mexico. Garmin and some companies provide Mexican topo maps on a microSD card for \$80 and up. My guess is that they are medium-resolution maps, coarser than 1:50,000 scale. A new iOS app, “Map E32,” with Mexican topos, may appear soon in Apple’s App Store.

The best source of Mexican maps is INEGI, the government mapping agency (see my article on how to obtain Mexican maps, available online and cited below). All topo and geologic maps are available online for free at INEGI, and they may be used in QGIS or be prepared for use in WallsMap with QGIS, Global Mapper, or ArcGIS. INEGI offers geotiffs, geogiffs, geopdfs, shapefiles, and other formats. The Mexican ITRF92 datum can be interpreted as WGS84 (same as NAD83) to make the maps work in your GIS. American topo maps are available online from USGS and various state mapping agencies, like TNRIS (Texas Natural Resources Information System). See Sources below.

Google Earth Pro can be used offline if you prepare your tablet by zooming up and down over the area of interest. Then when you go offline that area will be in memory, and you can track your location when you open it again. GE on my Windows tablet cannot read the internal nor the external GPS, and the iOS and Android versions can only read the internal GPS. There are no topo maps in GE, but at least you can see towns, roads, and fences. Beware of water tanks that look like deep, black pits on Google Earth, but some of those black spots really are deep sótanos!

Accuracy of  $\pm 1$  m or better requires expensive GPS receivers, like the Bad Elf Surveyor or EOS Arrow lite for \$600, or \$2,000-5,000 for more advanced receivers. A new Android phone, the Xiaomi Mi 8, uses dual channel positioning with L1 + L5 dual frequency, which can effectively correct signal delays caused by the ionosphere. This phone may achieve decimeter (10 cm) accuracy.

For cavers who want to map cave and karst locations fairly accurately, I recommend getting a Windows tablet (even an older one) and a Bad Elf GPS Pro or a Qstarz, and work with TSS or AMCS in Texas or Mexico. Or if you have a Garmin or other unit with a microSD card slot, you could buy digital topo maps and still have  $\pm 3$  m accuracy. The future will bring better accuracy to your phone’s GNSS, but you are still limited by a small screen and simplified maps.

If you already have an iPhone/iPad or Android, and you want a quick and convenient app, try the free version of Avenza Maps, Gaia, Compass 55 (iOS only), or Polaris GPS Navigation (Android only). In the free Avenza Maps you can have up to three topos (including Mexico) available in your tablet for offline use. Most other capable apps cost money, but WallsMap and QGIS are free.

## Acknowledgments

Thanks to the late David McKenzie for creating Walls (cave mapping program) and WallsMap, a Windows GIS program used for serious mapping of cave locations and cave footprints on the landscape. The worldwide QGIS community is thanked for their wonderful software too. I am grateful to three cavers for reviewing this article: Peter Sprouse provided information on using WallsMap with a QStarz GPS Bluetooth receiver and the new Xiaomi Mi 8 phone. Jim Kennedy and Jean Louis Lacaille Múzquiz provided information on Garmin units.

**Table of GIS/GPS apps that cavers might consider.**

<b>App</b>	<b>OS</b>	<b>Bad Elf Compatible</b>	<b>Cost</b>	<b>Features</b>	<b>Remarks</b>
QGIS	Windows, Linux, OS X (Mac), not iOS (iPhone/iPad)	yes	free	Complete GIS, nearly unlimited. Can draw points, polylines, polygons.	Any geotiffs, shp, pdf, etc.
WallsMap	Windows	yes	free	GIS viewer, draws points, kml/kmz export. Can view but not draw polylines, polygons.	Any geotiffs, shp, pdf, etc.
Avenza Maps	iOS, Android	picks best signal	free-\$130/yr.	Free: up to 3 geopdfs, free-\$4 each. Plus: \$30/yr. unlimited maps from MapStore. Pro: \$130/yr. shapefiles, kml, gpx.	Many countries' topo maps including Mexico 1:50,000 geopdfs. Requires internal location services to be on to use Bad Elf.
Compass 55	iOS	picks best signal	free-\$3.99	Good GPS and map viewer, 3 coordinate systems, $\pm 5$ or 10 m accuracy. Can navigate, show speed, etc.	Export kml/kmz or gps track. Download Google and offline maps in \$3.99 version.
Gaia	iOS, Android	picks best signal	\$20-40/yr.	Member or Premium Member	Many countries' topos, but no Mexican maps.
GeoJot+	iOS	yes	\$329/yr.	Pro Member	Geared toward data collection to their servers.
GIS4Mobile-X	Windows Mobile, Mac, iOS, Android	yes	free to expensive	From Denmark. Uses shapefiles, satellite, and street maps worldwide.	Geared toward data collection to their servers or yours. Free vers. has no coordinates on screen.
Google Earth Pro	most platforms	no	free	Satellite views, boundaries, many pois (points of interest), distance tool.	No topo maps, but can work offline if an area is in memory. Canopy obscures terrain.
Polaris GPS Navigation	Android	no	free	Multiple coordinate systems, offline maps.	Simplified Mexican topos, raster maps.
Other apps →	iOS	yes	free to expensive	CarryMap, Collector for ArcGIS, Cartomobile, Fluidsurveys, Fulcrum, GIS Cloud, GIS Kit-Garafa, iCMTGIS II, iGeoTrak, NeoTreks Cartapro, SuperSurv Pro, Survey123 for ArcGIS, TerraGo Edge, Theodolite HD, Wolf-GIS Pro.	Many of these are expensive pro apps. It takes time to get details for the free ones.

## Sources

<https://texasspeleologicalsurvey.org/> [download Walls and WallsMap free, see digital TSS menu]

<https://qgis.org/en/site/forusers/download.html> [download QGIS free]

<https://bad-elf.com/> [all the models of Bad Elf]

<http://www.mypilotstore.com/mypilotstore/> [good price on Bad Elf GPS Pro]

<http://www.inegi.org.mx/> [Mexican topo and geologic maps]

<https://tnris.org/data-catalog/entry/usgs-quad-grid/> [Texas topo and geologic maps]

<https://www.gpsfiledepot.com/> [GPSFileDepot, free Garmin Maps, most US states but not Mexico]

<https://buy.garmin.com/en-US/US/p/127966#devices> [Garmin Topo Mexico on microSD card, \$80]

Elliott, William R. 2018. "How to obtain Mexican maps." Appendix 5 in *The Astyanax Caves of Mexico*. AMCS Bulletin 26, 426 pp. <http://cavelife.info/Astyanax/19%20appendix%205.pdf>

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