Open Source GIS Software

A Guide for Understanding Current GIS Software Solutions

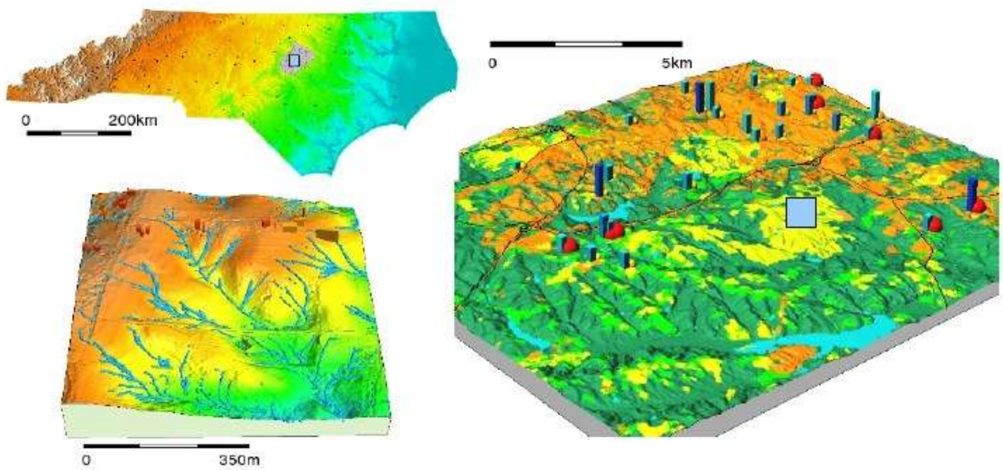

Image from: *Open Source GIS: A GRASS GIS Approach* by Markus Neteler and Helena Mitasova Springer Press

North Carolina Geographic Information Coordinating Council
GIS Technical Advisory Committee

December 2017

Preface

This document was created for the NC Geographic Information and Coordinating Council (GICC) (https://it.nc.gov/gicc) by the GIS Technical Advisory Committee (TAC) for the purpose of summarizing the functionality of commonly used open source GIS software packages and tools.

The target audience for this document includes small or large organizations that are considering implementing open source GIS software solutions but need to confirm functionality to meet their specific requirements.

Acknowledgements

Thank you to the many people that helped draft this document. It relied on the following key participants:

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Daniel Madding - NCDA&CS
Professor Scott Madry - UNC-CH
Ed Shipman - NCDOT
Jeff Essic - NCSU
Helena Mitasova - NCSU
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Overview

This guidance document evaluates open source GIS software solutions as full solutions, or as partial solutions in combination with proprietary software. Solutions include desktop GIS, geospatial database, geospatial server, and mobile data collection functions.

This document is intended to inform state and local government and non-governmental organizations to support decisions about GIS software solutions. It is a snapshot based on research, observations, experience, judgments and opinions of volunteer advisors to the TAC. It is not intended to be comprehensive and should not be the only source for informed decisions about GIS software solutions. The observations and statements in this document do not represent endorsement of any specific product or vendor.

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Glossary of Terms and Acronyms

Commercial-off-the-shelf (COTS) COTS software and services are built and delivered from a vendor. They are standard products that can be purchased, licensed, or leased by the public.

Open Source Software (OSS) is computer software with its source code made available with a license in which the copyright holder provides the rights to study, change, and distribute the software to anyone and for any purpose. Open source software is often developed in a collaborative public manner.

Open Source Geospatial Foundation (OSGeo) is a non-profit and non-governmental organization whose mission is to support and promote the collaborative development of open geospatial technologies, data, education and training. QGIS, GRASS, PostGIS, GDAL, and GeoServer (and others) are projects of OSGeo (osgeo.org).

General Public License (**GPL**) is a free and widely used software license standard, which guarantees end users the freedom to run, study, share, and modify the software. The license was originally written by the Free Software Foundation (FSF) for the GNU Project and grants the recipients of a computer program the rights of the Free Software Definition. The GPL is a copyleft license, which means that derivative work can only be distributed under the same license terms.

Understanding the Advantages of Open Source

There are multiple considerations when evaluating and implementing geospatial tools, including the organization’s mission, support needs, level of technical capabilities, information technology (IT) policies, budget, and more. Open source tools can provide excellent capabilities, stable operation, a quick learning curve, and support options. Each organization should consider its specific requirements and capabilities before implementing any such tools.

There are multiple advantages in using open source geospatial software and tools. The primary benefits are lower cost and access to source code. Open source software is generally licensed under GNU or Creative Commons license structures, which allow for the free sharing of the software with certain restrictions on the inclusion of fees or other charges. There is no initial or recurring cost of use, and the user is free to share, alter, improve, and distribute the code but cannot charge a fee for doing so.

Commercial geospatial software can be expensive and can require annual license fees. Furthermore, it rarely allows end users to acquire or view the source code. This could limit users' understanding of what the code and/or tools are doing. Open source makes source code available, and the community can contribute and share without the financial and strict licensing requirements of commercial software. Open source also allows for free knowledge and technology sharing and puts the end user communities in charge of development if they wish to do so. Individual user communities such as transportation, engineering, archaeology, and others can develop specific tools that are not of broad commercial interest and that are not generally developed or supported by commercial vendors.

Open source also allows additional security capabilities, as the source code can be viewed, and concerns such as malware and trap doors are easier to locate. Open source geospatial tools are now comparable to commercial systems in many regards and exceed them in several specific capabilities, such as voxel and true 3-D capabilities. Software support, training, and other services are now widely available.

Another benefit is that additional users beyond trained GIS specialists can now benefit from using geospatial data and tools. Workers within agencies can begin using these tools, and many open source GIS software packages are smaller (in terms of MB on a computer), easier to learn, and can be easily configured for specific users and tasks, including tablets and field data collection.

Users must be aware that open source and commercial software providers have somewhat different perspectives on technical support. Commercial software support is a service for licensed users. The open community takes more responsibility for involvement in issues such as submitting bug reports and participating in guiding the development of the open source tools themselves. Reliance on an open community for technical support may not be suitable for all end users. Options are available to engage a service provider for technical support for an open source solution.

Case Studies

This paper describes two use cases as examples of implementing open source GIS software.

Use Case #1
State Government
North Carolina State Board of Elections

The North Carolina State Board of Elections (NCSBE) has decided to move to an open source platform for their GIS applications. There were three factors that contributed to that decision: cost, functionality, and maintenance. Initially, when most think of open source versus vendor solutions, they think free vs. paid, but that is not typically the case. For an open source solution, while there might not be a cost to acquire software (front-end), there may be costs to implement the solution (back-end). For NCSBE, the cost of supporting an open source software solution is less than the cost of the current vendor GIS software solution.

The next factor is functionality. Many vendors offer a wide variety of functionality in their GIS offerings that may be driven by commercial factors more than user preferences. The open source community typically drives functionality based on user needs, desires, and preferences in ways that can result in feature-rich platforms.

Finally, NCSBE is looking at maintenance options. Open source platforms typically offer a wide variety of paid and community support. These support options are great for all sizes of organizations from large to small, and typically even the paid support vendors offer some limited software health options for free. NCSBE decided to migrate from Esri software with a Microsoft SQL Server database to a PostgreSQL database. The decision came about due to the complexity of the database structure Esri uses to store their data and tables in the database system; the table layout is very cryptic and widespread for those who want to access the data layer for added functionality. Storing the data in PostgreSQL while using QGIS on the front-end has streamlined the data dictionary, allowing for non-GIS database administrators to help with data maintenance, recovery, and reporting.

Use Case #2
Federal Government
The National Geospatial-Intelligence Agency

Cost is not always the main factor in choosing an open source solution. Some large, well-funded, organizations such as Monsanto, New York City's Department of Information Technology & Telecommunications (NYC DoITT), and the National Geospatial-Intelligence Agency (NGA) have strict procedures on what software can be installed on their IT infrastructure. In the case of NGA, a system security breach could be devastating not only to the organization but also to the Nation's security.

Software security is of primary concern to NGA. By policy, NGA must thoroughly review all software for adherence to stringent security policies. This can be very resource intensive and time consuming.

Commercial software packages typically have frequent update cycles. These can create significant workload and delays for the reviewing agencies, especially when access to source code is impeded. Additionally, commercial vendors are normally hesitant to release their proprietary information for review. Open source software code is freely available for review and security auditing, thus providing a much easier path for security policy driven code review. To organizations like the National Geospatial-Intelligence Agency, these combined issues are frequently of higher consideration than simple cost comparisons.

NGA's approach was to engage a vendor for implementation of open source GIS software solutions. In April 2017, NGA awarded Boundless Spatial Inc. a contract to support their GEOINT mission. For more details on the contract visit:

Sources:
https://boundlessgeo.com/press_releases/national-geospatial-intelligence-agency-awards-boundless-36m-contract

Open Source Geospatial Software Packages

The Technical Advisory Committee reviewed and evaluated the most commonly used open source geospatial software packages: QGIS including a semi-automatic classification plugin, the Geographic Research Analysis Support System (GRASS), GeoNode, GeoServer, PostgreSQL, and PostGIS.

QGIS

QGIS, previously known as Quantum GIS, is an open source desktop GIS application that supports viewing, editing, and analysis of geospatial data (http://qgis.org). It functions as GIS software, allowing users to analyze and edit spatial information in addition to composing and exporting graphical maps. QGIS is comparable to Esri's ArcMap. QGIS supports both raster and vector datasets, GPS data, and remote sensing imagery such as LiDAR and satellite images. Also, QGIS is cross-platform, meaning it can be installed on different operating systems, including Windows, Mac, and Linux. This gives QGIS an advantage over ArcGIS, which can only be installed on Windows OS. Vector data formats supported include Esri shapefiles and coverages, personal geodatabases (with a plugin), DXF, MapInfo, PostGIS, and other formats. QGIS can generate and consume web services, including Web Map Service (WMS) and Web Feature Service (WFS).

Integration with other open source GIS packages, including PostGIS, GRASS GIS, SAGA, and MapServer is easy and a common configuration. QGIS also has an extensive set of plugins, which extend its core capabilities. These plugins can geocode using the Google Geocoding API and can perform geoprocessing functions, which are similar to the standard tools found in ArcGIS. QGIS also interfaces with PostgreSQL/PostGIS and MySQL databases.

Concerning user comments and lessons learned, QGIS contains a very powerful suite of desktop geospatial tools that can be easy to learn. Use can be expanded by increasing the number of occasional or non-specialist users due to its ease of use and lack of cost.

The primary advantages of QGIS are no-cost acquisition, open architecture, simplicity of learning and using, expandability using plugins, a vibrant user and development community, and the ability to develop specific tools for different applications. Disadvantages include uncertainty about the cost of technical support, uncertainty that the free software does not offer functionality and quality equivalent to commercial products, and fear that the software is 'buggy' or will frequently crash. However, these concerns are generally unfounded.

For users with limited or no GIS experience, QGIS may be easier to learn and start using than commercial equivalents. Many QGIS training options are available, including books, YouTube videos, and QGIS tutorials and materials from the qgis.org website. Many universities around the country teach classes using QGIS and offer periodic short courses; commercial training options also exist. For example, UNC Chapel Hill offers QGIS and GRASS short courses each semester, which are offered for free and are open to all.

QGIS - Semi-Automatic Classification Plugin

The Semi-Automatic Classification Plugin (SCP) is a free open source plugin for QGIS that allows for the supervised classification of remote sensing image data. It provides several tools for the download of free image data, the processing and analytics of image data, post-processing of thematic data, and raster band calculation. The SCP for QGIS is developed and managed by Luca Congedo, who is a PhD. student in Landscape and Environment at Sapienza University in Rome, Italy. The SCP for QGIS is used globally and in NASA training related to remote sensing. Similar to other open source software systems and tools, the SCP encourages community participation in open source online forums for software support and development. Several online forums are available for SCP on FaceBook, Google+, and YouTube.

The overall objective of SCP is to provide a set of software tools for raster processing to create a workflow for land cover classification that can be used by both experienced and casual users of remote sensing data. The SCP for QGIS includes tools for collecting training data, batch downloading imagery, pre-processing of image data, post-processing of raster data, band calculation, batch processing, and customized scripting. The online support documentation includes a community forum, user manual in fourteen languages, tutorial, video demonstrations, and support.

Sources:
www.qgis.org/en/site/
Congedo Luca (2016).
Semi-Automatic Classification Plugin User Manual.
http://dx.doi.org/10.13140/RG.2.1.1219.3524

GRASS

GRASS GIS, commonly referred to as GRASS (Geographic Resources Analysis Support System), is a free and open source GIS software suite used for geospatial data management and analysis, image processing, graphics and maps production, spatial modeling, and data visualization. It has been under continuous development since 1982 and supports native 64-bit, cross platform implementation of computational tools for raster and vector data. GRASS is currently used in academic and commercial settings around the world as well as by many governmental agencies and environmental consulting companies. It is a founding member of the Open Source Geospatial Foundation (OSGeo) (https://grass.osgeo.org). GRASS is a comparative product to Esri's ArcMap desktop software, but is more focused on raster data analysis.

GRASS includes modules to perform basic and advanced raster data functions such as raster algebra, terrain analysis, optimization using cost surfaces and least cost path tracing, watershed and stream extraction from large DEMs, and viewshed analysis. More specialized tools include solar irradiation modeling, regression analysis between raster layers, landscape pattern metrics, surface water flow, and erosion modeling. Many analyses can be performed using a voxel (3D) raster data model as well as the standard pixel (2D) raster data model.

For image analysis, GRASS GIS can perform supervised classification, unsupervised classification via object segmentation, atmospheric correction of satellite imagery, principal components analysis, and several common vegetation index analyses.

Vector data in GRASS GIS supports full topology and attribute management. Specific modules provide tools for basic vector data operations such as buffers, clipping and overlays, spatial interpolations, proximity analysis, and network analysis. LiDAR data can also be processed as point data or converted to raster data via binning.

Both raster and vector data can be managed as temporal datasets for analyzing data changes over time or interpolating missing data.

See a table showing a comparison of the GIS functionalities available in QGIS, ArcGIS, and GRASS, in Appendix A below.

Sources:
https://grass.osgeo.org/

GeoNode

GeoNode is a geospatial content management system and web platform that enables the creation, management, sharing, and publication of geospatial data and interactive maps. It brings together mature and stable open source software under one interface and can be installed on a user system or subscribed to as a cloud-hosted service at AcuGIS (https://www.acugis.com/geonode-hosting.html). GeoNode is a comparative product to Esri's ArcGIS Online.

Geonode can be installed on either Linux or Windows servers, but there are some differences in installation requirements. The current and stable version of GeoNode is version 2.6 (May 2017). GeoNode is written in Django, https://www.djangoproject.com, a Python-based web framework.

Installation on Linux currently uses 64-bit technology; the current Windows installation differs by requiring the 32-bit version of the Java 8 JRE. Detailed installation instructions for Ubuntu Linux, CentOS Linux, and Windows can be found at http://docs.geonode.org/en/master/tutorials/install_and_admin/index.html.

Applications/Examples:

- http://demo.geonode.org
- http://geoportal.trinity.duke.edu
- http://worldmap.harvard.edu/boston

Sources:
www.geonode.org

GeoServer

GeoServer is a powerful map and feature server for sharing, analyzing, and editing geospatial data. Designed for interoperability, it publishes data from a wide variety of spatial data sources using open standards. GeoServer forms a core component of the Geospatial Web.

Geoserver is a comparative product to Esri's ArcGIS Server and will run on Windows, Linux, MacOS, or any platform that supports a Java 8 environment.

GeoServer is the reference implementation of the Open Geospatial Consortium (OGC), Web Feature Service (WFS), and Web Coverage Service (WCS) standards as well as a high performance certified compliant Web Map Service (WMS). By leveraging open standards, GeoServer ensures interoperability with a wide array of open source and proprietary software products as well as online services such as Google Maps. It is simple to integrate with both new and existing desktop, mobile, and web applications.

Features of GeoServer include:

- Support for many back-end data formats (ArcSDE, Oracle Spatial, DB2, Microsoft SQL Server, Shapefile, GeoTIFF, and many more).
- Multiple output formats (Esri Shapefiles, KML, GML, GeoJSON, PNG, JPEG, TIFF, SVG, PDF, GeoRSS).
- Fully-featured web administration interface and REST API for easy configuration.
- Configurable role-based security subsystem based on Spring Security.
- Java J2EE application works with Jetty, Tomcat, JBoss, and others.
- A robust community that has developed many extensions for GeoServer, including MBTiles support, Mapbox Vector Tile output, WPS, and DXF output, among many others.

PostgreSQL

PostgreSQL is a powerful open source object-relational database system. It has more than 15 years of active development and a proven architecture that has earned a reputation for reliability, data integrity, and correctness. It runs on all major operating systems, including Linux, UNIX (AIX, BSD, HP-UX, SGI IRIX, macOS, Solaris, Tru64), and Windows. It is fully ACID compliant (Atomicity, Consistency, Isolation, Durability), has full support for foreign keys, joins, views, triggers, and stored procedures (in multiple languages). It has native programming interfaces for C/C++, Java, .Net, Perl, Python, Ruby, Tcl, ODBC, among others, and exceptional documentation.

An enterprise class database, PostgreSQL features include Multi-Version Concurrency Control (MVCC), parallel queries, logical replication, point in time recovery, tablespaces, asynchronous replication, nested transactions (save points), online/hot backups, a sophisticated query planner/optimizer, and write-ahead logging for fault tolerance. It supports international character sets, multibyte character encodings, Unicode, and it is locale-aware for sorting, case-sensitivity, and formatting. It is highly scalable both in the quantity of data it can manage and in the number of concurrent users it can accommodate. There are active PostgreSQL systems in production environments that manage more than 4 terabytes of data.

The PostgreSQL SQL implementation conforms to the ANSI-SQL:2008 standard. It has full support for subqueries (including sub-selects in the FROM clause) and read-committed and serializable transaction isolation levels. While PostgreSQL has a fully relational system catalog which supports multiple schemas per database, its catalog is also accessible through the Information Schema as defined in the SQL standard. By being compliant with open standards, PostgreSQL is much easier to integrate with both open source and proprietary software.

PostgreSQL provides full text search support for JSON and JSONB (binary JSON) data, and its Foreign Data Wrappers (FWD) allow PostgreSQL to attach to external data tables (CSV, MySQL, Oracle, MSSQL Server, MongoDB, etc.). PostgreSQL's Hstore extension allows it to store and query NoSQL key-value data, which is very useful in cases such as semi-structured data or rows with many attributes that are rarely queried.

Sources:
www.postgresql.org
https://wiki.postgresql.org/wiki/Foreign_data_wrappers

PostGIS

While Microsoft SQL Server (MSSS) and Oracle have native spatial capacity, PostgreSQL derives its spatial capability from an extension, PostGIS. PostGIS is the most complete implementation of the Simple Features (officially Simple Feature Access), which is both an Open Geospatial Consortium (OGC) and International Organization for Standardization (ISO) standard ISO 19125.[1] MSSS also implements this standard. The syntax for a spatial query is very similar between PostGIS and MSSS. PostgreSQL is supported and used by many GIS softwares, including QGIS, ArcMap, ArcGIS Server, Manifold, Grass, and GeoServer, to name a very few.[2] Esri deploys PostgreSQL with its GeoEvent Server product and recommends the use of PostgreSQL as the back-end for the temporal storage. PostgreSQL/PostGIS are mature products with long-term support.

Similar to SQL Spatial, PostGIS adds spatial data types (geometry, geography, raster, and others) to the PostgreSQL database. It also adds functions, operators, and index enhancements that apply to these spatial types. These functions, operators, index bindings, and types augment the power of the core PostgreSQL DBMS, making it a fast, feature-plenty, and robust spatial database management system. PostGIS offers features rarely found in other competing spatial databases such as Oracle Locator/Spatial and SQL Server.

PostGIS follows the Open Geospatial Consortium Simple Features for SQL Specification and has been certified as compliant with the "Types and Functions" profile. PostGIS is open source software, released under the GNU General Public License.

PostGIS is a spatial database extender for PostgreSQL object-relational databases. It adds support for geographic objects allowing location queries to be run in SQL.

Key features PostGIS provides:

- Processing and analytic functions for both vector and raster data for splicing, dicing, morphing, reclassifying, and collecting/unioning with the power of SQL raster map algebra for fine-grained raster processing
- Storage of GIS data (vector and raster) in an RDBMS
- Supports both geography as well as geometry (planer)
- Spatial query of both vector and raster [3]
- In addition to X and Y being spatial, M and Z are also spatial
- Extensive time capabilities that can be used as M values
- Runs on Windows and Unix-like OS's (Linux, Mac, etc.)
- Free Software (GNU 2 license or later)
- Available with vendor support
- Available as a hosted solution in the cloud
- Spatial reprojection SQL callable functions for both vector and raster data
- Support for importing/exporting Esri shapefiles via both command line and GUI packaged tools and support for more formats via other 3rd-party open source tools
- Packaged command-line for importing raster data from many standard formats: GeoTiff, NetCDF, PNG, JPG, to name a few
- Rendering and importing vector data support functions for standard textual formats such as KML, GML, GeoJSON, GeoHash, and WKT using SQL
- Rendering raster data in various standard formats GeoTIFF, PNG, JPG, NetCDF, to name a few, using SQL
- Seamless raster/vector SQL callable functions for extrusion of pixel values by geometric region, running stats by region, clipping rasters by a geometry, and vectorizing rasters
- 3D object support, spatial index, and functions
- Network topology support
- Packaged Tiger loader/geocoder/reverse geocoder/utilizing US Census Tiger data

PostGIS-related PostgreSQL optional extensions include:

- **pgRouting** (http://pgrouting.org): extends PostGIS to support geospatial routing such as driving distance, shortest path distance, and traveling salesman, which can take into consideration various costs such as speed and turn restrictions.
- **ogrfdw** (https://github.com/pramsey/pgsql-ogr-fdw): is a PostgreSQL foreign data wrapper built on GDAL/OGR. It allows reading other spatial and non-spatial data sources as tables in PostgreSQL. Vector data gets translated to PostGIS geometry type.

Also, **pgpointcloud** (https://github.com/pgpointcloud/pointcloud) is a PostgreSQL extension and loader for storing point cloud data in PostgreSQL; it includes an extension for casting between point cloud data type and PostGIS geometry.

Sources:

1. Wikipedia, Simple Features, https://en.wikipedia.org/wiki/Simple_Features
2. Wikipedia, PostGIS, https://en.wikipedia.org/wiki/PostGIS
3. PostGIS, Chapter 8, https://postgis.net/docs/reference.html

Geospatial Tools

The committee reviewed one geospatial tool related to mobile GIS. Other resources of interest to open source application developers are described in Appendix B.

IntraMaps Roam

IntraMaps Roam is a simple data collection application built using QGIS. Roam is built as a stand-alone, fully packaged Python application with everything included. QGIS is not required to be installed on the users' machines. It is a free and open source application for tablet use and provides a field-friendly interface on top of QGIS. Similar to ArcGIS Collector, it offers a 100 percent offline solution for data collection and general field use. It currently runs on Windows devices and can run from source on Linux; Android tablets can be supported once QGIS is ported to Qt5. Point, line, and polygon geometries are supported. It has simple-to-use forms for field use, configurable displays, GPS capture, logging, and tracking capabilities.

The link below is an example ROAM site for Los Angeles County, CA: http://egis3.lacounty.gov/eGIS/county-gis-projects/open-source-gis

The site includes:

- Free software downloads
- Tutorials
- Sample scripts for updating tablet basemap layers from the Los Angeles County GIS Data Portal
- Utilities for synchronizing edits from multiple tablet users Github code: http://roam-docs.readthedocs.io/en/latest

Web References

Comparing ArcGIS to QGIS in 27 areas
http://gisgeography.com/qgis-arcgis-differences

Comparing ArcGIS Desktop to QGIS
http://monde-geospatial.com/arcgis-vs-qgis-10-most-important-differences-between-arcgis-and-qgis/

ArcMap Functionality matrix
https://www.esri.com/~/media/Files/Pdfs/library/whitepapers/pdfs/arcmap-functionality-matrix.pdf

NGA Contract with Boundless
https://boundlessgeo.com/press_releases/national-geospatial-intelligence-agency-awards-boundless-36m-contract

FOSS4G, Free and Open Source Software for Geospatial
https://wiki.osgeo.org/wiki/FOSS4G

Appendix A
Desktop GIS Functionality Matrix

GIS Functionality	QGIS	ArcGIS Desktop (Advanced)	GRASS
Display Earth Resources Laboratory Applications Software (ELAS) datasets	Yes, with GDAL	Yes	Unknown
Consume Enhanced Compression Wavelet (ECW)	Yes	Yes	Yes
Geospatial Data Abstraction Library (GDAL)	Yes	Yes	Yes
Display LAS (Lidar Data Files)	Yes, with Plugin	Yes, with Extension	No
Import LAS data as points	Yes, with Plugin	Yes, with Extension	Yes
Import LAS data and bin to raster	Yes, with Plugin	Yes, with Extension	Yes
Directly import LAZ compressed LAS	Yes, with Plugin	Yes, with Extension	Yes
Reshape existing features	Yes	Yes	Yes
Cut polygon features	Yes, with Plugin	Yes	Unknown
Buffer features	Yes	Yes	Yes
Create new features	Yes	Yes	Yes

GIS Functionality	QGIS	ArcGIS Desktop (Advanced)	GRASS
Create new features from the buffer	Yes	Yes	Yes
Create new polygons	Yes	Yes	Yes
Modify each selected row individually or as a group (Attributes Dialog)	Yes	Yes	Yes
Split lines	Yes	Yes	Yes
Explode (multipart) features	Yes	Yes	Yes
Simplify features	Yes	Yes	Yes
Can create topology rules	Yes	Yes	Unknown
Report topology errors	Yes, with Plugin	Yes	Yes
Add rule to topology	Yes, with Plugin	Yes	Yes
Create topology	Yes	Yes	Yes
Validate topology	Yes	Yes	Yes
Snapping geometry	Yes	Yes	Yes
Create a Database View	Yes	Yes	Yes
Add Web Map Service to a data view	Yes	Yes	Yes
Add Web Feature Service to a data view	Yes	Yes	No

GIS Functionality	QGIS	ArcGIS Desktop (Advanced)	GRASS
Read/display/consume shapefiles	Yes	Yes	Yes
Read/display/consume geopackage	Yes	Yes	Yes
Read/display/consume spatial database	Yes	Yes	Yes
Read/display/consume file geodatabase	Yes, with Plugin	Yes	Yes, with Plugin
Read MS Excel file format	Yes, with Plugin	Yes	Yes, with Plugin
Read DBF file format	Yes	Yes	Yes
Layout and symbolize a map to display data	Yes	Yes	Yes
Create multiple layouts for one map document	Yes	Yes	Yes
Insert an inset map in the layout	Yes	Yes	No
Export a map (optional formats)	Yes	Yes	Yes
Advanced cartography tools (e.g., annotation)	Yes	Yes	Unknown
Export a data window in optional formats	Yes	Yes	Yes
Export data layer in multiple formats	Yes	Unknown	Yes

GIS Functionality	QGIS	ArcGIS Desktop (Advanced)	GRASS
Select records by a query of attributes	Yes	Yes	Yes
Select records by location	Yes	Yes	Yes
Select records interactively in a table	Yes	Yes	Yes
Select records interactively in a map with Plugin	Yes	Yes	Unknown
Export a selection of records	Yes	Yes	Yes
Bookmark a map extent	Yes	Yes	Yes
Change the map scale of a data window	Yes	Yes	Unknown
Define the projection of a data layer	Yes	Yes	Yes, with Plugin
Re-project a dataset	Yes	Yes	Yes
Join a table to a data layer	Yes	Yes	Yes
Join the table of a polygon data layer to a point data layer based on point location within a polygon	Yes	Yes	No
Buffer a feature or selected features	Yes	Yes	Yes
Clip one dataset based on another dataset	Yes	Yes	Yes

GIS Functionality	QGIS	ArcGIS Desktop (Advanced)	GRASS
Intersect features	Yes	Yes	Yes
Union features	Yes	Yes	Yes
Merge features	Yes	Yes	Yes
Dissolve features	Yes	Yes	Yes
Manage datasets in a catalog	Yes	Yes	Yes
Create and edit features	Yes	Yes	Yes
Interactively edit raster cell values	No	No	Yes
Snap to base map layers when editing	Yes	Yes	No
Snap to feature service layers when editing	Unknown	Yes	No
Build a model of processes and output	Yes	Yes	Yes
Read raster formats (MrSID, TIFF, GIF, JPEG2000)	Yes	Yes	Yes
Spatial analysis	Yes	Yes	Yes
3D analysis	Yes, with Plugin	Yes, with extension	Yes
Extract, overlay, with proximity, statistics	Yes	Yes	Yes
Generalize data	Yes	Yes	Yes

GIS Functionality	QGIS	ArcGIS Desktop (Advanced)	GRASS
Convert vector to raster	Yes	Yes	Yes
Convert raster to vector	Yes	Yes	Yes
Raster processing	Yes	Yes	Yes
Classify a raster dataset	Yes, with Plugin	Yes	Yes
Create a mosaic dataset	Yes	Yes	Yes
Create LAS dataset	Yes, with Plugin	Yes	No
Metadata editing, import, export	Yes, with Plugin	Yes	Yes, with Plugin
Generate tile cache tiling scheme	Yes	Yes	Yes
Geocode addresses	Yes	Yes	Unknown
Reverse geocode	Yes, with Plugin	Yes	Unknown
Spatial statistics	Yes	Yes	Yes
Analyze a (road) line network	Unknown	Yes	Yes
Linear referencing tools	Yes, with Plugin	Yes	Yes
Create and edit metadata templates	Yes, with Plugin	Yes	Unknown
Create and edit valid metadata records	Yes, with Plugin	Yes	Unknown

GIS Functionality	QGIS	ArcGIS Desktop (Advanced)	GRASS
Validate metadata records	No	Yes	No
Voxel (3D raster) Data structure	Yes, with Plugin	No	Yes
Vector temporal analysis	No	Yes, with Extension	Yes
Raster temporal analysis	No	Unknown	Yes
Python interface for geoprocessing	Yes	Yes	Yes
Hydrologic analysis	Yes, with Plugin	Yes	Yes
Solar Irradiation analysis	Yes, with Plugin	Yes	Yes
(software) code freely available for customizations?	Yes	No	Yes
Raster profiling	Yes, with Plugin	Yes	Yes
Can raster operations be masked with vector data?	Yes	Unknown	Yes

Appendix B
Other Resources for Open Source Application Developers

Leaflet

Leaflet is a common open source JavaScript library for mobile-friendly interactive maps. Its 38 KB of Java Script provides mapping features for developers (http://leafletjs.com/index.html#features).
Leaflet works efficiently across all major desktop and mobile platforms, can be extended with many plugins (http://leafletjs.com/plugins.html), has an easy-to-use, well-documented API (http://leafletjs.com/reference.html) and a simple, readable source code. See (https://github.com/Leaflet/Leaflet) and (https://github.com/Leaflet/Leaflet/blob/master/CONTRIBUTING.md).
For ArcGIS users, Esri has created a lightweight set of tools for working with ArcGIS services in Leaflet (https://esri.github.io/esri-leaflet).

GDAL

Geospatial Data Abstraction Library (GDAL) is a set of tools and libraries for manipulating and translating geospatial data. Currently, GDAL has drivers for 142 raster formats and 84 vector formats. There are Python, C#, C, and C++ APIs available, and GDAL is used by most commercial geographic software for raster access, including Esri ArcGIS products and Google Earth. GDAL can also be used as an Extract, Transfer, and Load (ETL) tool for vector data, allowing the user to query, project, and reformat data. GDAL is embedded in QGIS.

For more information on GDAL and raster compression see the TAC report:
https://it.nc.gov/document/understanding-compression-geospatial-raster-imagery