HEZA: A GIS-based Method for Improved Approximate Flood Risk Analyses

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Abstract: A large percentage of flood hazard areas in Texas that are mapped as part of the National Flood Insurance Program (NFIP) have been studied using approximate methods. Areas where the 1-percent annual chance flood hazard has been approximated are identified on Flood Insurance Rate Maps (FIRMs) with a "Zone A." In the past, the methods used to map these areas were not well documented. In Texas, much of the current Zone A mapping is based on historical reporting and engineering judgement. The availability of countywide digital topographic datasets and Geographic Information Systems (GIS) provides a framework for more consistent mapping of these areas using recognized and documented hydrology and hydraulic methods. Halff Associates, Inc. has developed a GIS-based program, the Halff Easy Zone A (HEZA) mapping tool, that is being used to prepare reliable and consistent approximate flood hazard mapping in a timely and cost-efficient manner.

HEZA requires digital topographic data as a basis. In many areas, the United States Geological Survey (USGS) digital quadrangle hypsography is the best available topographic information. In more developed areas, five-foot, and two-foot contour interval data is often available. HEZA estimates the 1-percent annual chance peak discharge using the USGS regression equations for Texas. Calculations of the 1-percent annual chance water surface elevation, the Base Flood Elevation (BFE), are made using a standard normal depth (slope-area method) calculation.

Results of HEZA have been compared against other Zone A mapping approaches and existing Zone A mapping. Experience to date suggests that the results are consistent with other methods and the available topographic data. The resulting floodplain delineations will provide a good starting point for future detailed flood risk analyses. Development of HEZA in a standard ArcGIS™ format allows for possible future enhancements such as web-based information systems and tools designed to serve engineers, planners, floodplain administrators, and the public.

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Introduction

The National Flood Insurance Program (NFIP) was established to provide flood insurance as an alternative to disaster assistance in exchange for communities adopting and enforcing floodplain management regulations. The NFIP is managed by the Federal Emergency Management Agency (FEMA). FEMA publishes Flood Insurance Rate Maps (FIRMs) that define flood hazard areas for two levels of risk: the 1-percent annual chance flood, commonly known as the 100-year flood, and the 0.2-percent annual chance flood, or 500-year flood. NFIP regulations are based on the 1-percent annual chance flood, also known as the Base Flood.

Until recently, FIRMs were only published in a paper format. In 2003, FEMA began the Map Modernization program with a goal of preparing Digital Flood Insurance Rate Maps (DFIRMs) for the country. Map Modernization will increase the quality and availability of flood hazard maps and data, allowing communities to more effectively manage the flood risks in their area. The intent of the Map Modernization program is not only to transition from paper to digital FIRMs, but also to update and improve the flood hazard assessments as well. To the extent that funding allows, flood risks identified on the new DFIRMs are to be based on the most current information available.

Approximate (Zone A) Flood Hazard Areas

FEMA has traditionally defined the 1-percent annual chance flood hazard area for riverine flooding using two types of study: detailed and approximate. Flood hazard areas that are mapped using approximate study methods are designated on FIRMs as "Zone A." Existing Zone A mapping has several limitations. Often, there is no record of the methods that were used to calculate and map the Zone A floodplains. Many of the flood hazard areas are based on older topographic and base map data, sometimes dating back 30 to 50 years. Over time, Zone A areas may have been distorted or shifted as revisions were made to the paper FIRMs. Zone A flood hazard mapping is only partially available in digital format. The existing digital files (known as "Q3" files) are only available in certain areas and are not necessarily updated as revisions are made to the official FIRMs.

Where flood hazard areas are based on detailed study methods, Base Flood Elevations (BFEs) are called out on the FIRM. The BFE indicates the water surface elevation of the 1-percent annual chance flood, giving property owners and developers an easy reference to assess the likely severity of flooding and to elevate new construction above the flood stage. Traditionally, BFEs are not included in Zone A flood hazard areas because of the lack of detail in the calculation and documentation of the original approximate analyses. Floodplain management requirements still apply to these flood hazard areas; however, and communities are responsible for enforcing regulations based on the BFE. Activities such as new development, flood proofing an existing building, or submitting Letters of Map Change (LOMC) all require that the BFE be determined at the proposed site.

Appropriate methods for conducting approximate flood hazard analyses are outlined in Appendix C of FEMA's Guidelines and Specifications for Flood Hazard Mapping Partners. Options for the calculation of approximate flood discharges include hydrograph transfer methods, the rational formula, the National Resource Conservation Services' TR-55 procedures, and regional regression equations. Options presented for water surface computations include using nomographs from the Federal Highway Administration, FEMA's Quick-2 computer program, and normal depth calculations using Manning's equation.

FEMA 265, "Managing Floodplain Development in Approximate Zone A Areas," provides methods for determining approximate BFEs in existing Zone A areas. These methods include contour interpolation, extrapolation from detailed study data, and the calculations outlined in Appendix C of the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners. Attempts to identify BFEs based on the contour interpolation method are often inconsistent, and are limited to the vertical accuracy of the source topographic data, typically USGS quadrangle 10-foot contours. Extrapolation from detailed study data is only appropriate within a short distance upstream of a detailed study reach. For best results, the BFE may be evaluated using new calculations, but this may introduce inconsistency with regard to the original calculations and the existing mapping upstream and downstream of the proposed site.

The Map Modernization program has introduced new methods for mapping Zone A flood hazard areas that take advantage of developments in Geographic Information Systems (GIS) and hydrology and hydraulic modeling applications over the last decade. In addition to the traditional methods defined above, FEMA now defines three new study types: enhanced approximate type 1, enhanced approximate type 2, and automated H&H studies. Enhanced approximate type 1 studies are prepared, mapped, and documented in nearly the same manner as a detailed study. The floodplain is designated as "Zone AE" with BFEs shown, and a hydraulic model based on limited traditional survey data is provided along with published flood profiles and a summary of discharges. Type 2 studies result in a Zone A designated floodplain and are supported by a hydraulic model containing only approximate measurements for any structures. BFEs and profiles are not published for public use, but the models are made available to floodplain managers. Automated H&H studies are typically run in a GIS environment using standard hydrology and hydraulic computations based on the best available digital datasets. The Halff Easy Zone A (HEZA) mapping tool has been developed to perform automated H&H studies.

GIS-based Flood Hazard Mapping Approaches

GIS provides an excellent platform for preparing flood hazard mapping in a consistent and cost-effective manner. Flood hazard mapping prepared in a GIS format can easily be integrated into other GIS-based applications to assist with emergency management and community planning. Environmental Systems Research Institute, Inc. (ESRI) distributes the industry standard ArcGIS™ software package. Many existing floodplain mapping and management tools have been developed in the ArcGIS™ environment.

Flooded areas are calculated by comparing a water surface representing the peak flood stage on the river or stream to the ground surface. In GIS, these surfaces may be represented digitally either as a triangulated irregular network (TIN) or as a digital elevation model (DEM). A TIN represents elevations as a continuous three-dimensional surface, while a DEM breaks the surface into a grid of equal-area cells, with each cell representing a discrete elevation. ArcGIS™ provides standard routines to compare surfaces and evaluate their differences. Flood hazard areas are determined by subtracting the ground surface from the water surface. Positive differences, where the water surface elevation is higher than the ground, represent flooded areas.

GIS can be used to support both automated H&H and enhanced approximate studies. For enhanced approximate studies, The United States Army Corps of Engineers' (USACE) Hydraulic Engineering Center (HEC) has produced the HEC-GeoRAS program to provide an interface between GIS datasets and the HEC-RAS hydraulic model. Automated H&H applications may be developed using custom programs that are either embedded in the GIS or interface with it. HEZA has been developed in Visual Basic and produced as a dynamic link library (DLL) file that can be imported into ArcGIS™ and run from within the application.

Available Data Sources

Two types of data are needed in order to map flood hazard areas digitally: base mapping and topography. Base map datasets typically consist of aerial orthophotography and planimetrics. At a minimum, base map data consists of stream centerlines and transportation features. Other useful datasets include political boundaries and open-water shorelines. The horizontal accuracy and currency of the data is important so that floodplain boundaries are correctly located in relation to properties and structures subject to flooding. Existing datasets that are available at the national and state levels include the Environmental Protection Agency's Reach Files Version 3 (RF3) and transportation layers available from the Texas Department of Transportation (TxDOT). Wherever possible, it is desirable to obtain data directly from the communities in which the study is being conducted. Typically, but not always, community-supplied data is more recent and more accurate than the national and state datasets.

Recent aerial photography is useful to validate the vector base map datasets. In Texas, recent aerial photography may be obtained through the Texas Natural Resources Information System's (TNRIS) Strategic Mapping Program, the United States Department of Agriculture's National Agricultural Imagery Program, and from local sources. In lieu of any more recent or accurate base map data, FEMA recognizes the United States Geological Survey's (USGS) Digital Orthophoto Quarter Quadrangles (DOQQ) as a default source of base mapping.

It is beneficial to obtain the most recent flood hazard mapping for the area that is being studied so comparisons can be made between the existing and proposed delineations. The existing FIRMs are either obtained directly as digital image files or the paper maps are scanned into digital format. The FIRM images are georeferenced to the study coordinate system using landmarks such as major road intersections in the best available base map data.

There are several sources for topographic information with varying degrees of accuracy and cost. In Texas, the USGS quadrangle contours, or hypsography, are available in digital format through TNRIS. In many rural areas this is the best available data. In developed areas more recent and accurate topographic information is often available through local sources. Other sources of topographic data include traditional aerial orthophotogrammetry, Light Detection and Ranging (LIDAR), and Interferometric Synthetic Aperture Radar (IFSAR). If this data does not already exist, the cost of obtaining the data solely for the purpose of preparing approximate flood mapping is typically very large relative to the availability of existing USGS hypsography. In addition, when mapping Zone A areas using automated H&H techniques, the benefit of additional detail in the topographic data may not be realized due to the approximate nature of the analyses.

Halff Easy Zone A (HEZA) Mapping Tool

HEZA has been developed in order to map approximate flood hazard areas efficiently and effectively using automated H&H methods within ArcGIS™. The tool is based on standard hydrology and hydraulic formulas. Engineers set-up and review the input datasets and evaluate the output. The user must prepare input datasets for hydrology, cross-section layouts for mapping, and specify default parameters. Options are made available to adjust the calculations to conditions specific to individual study areas. Figure 1 shows the HEZA user interface.

Hydrology calculations are based on the regional regression equations for Texas developed by the USGS and TxDOT (Asquith and Slade). Regional regression equations in Texas take the form of:

$$Q_T = aA^b\, SH^c\, SL^d$$

where:

Q_T = expected peak discharge (cfs) at the T-year recurrence interval
A = contributing drainage area (sq. miles)
SH = basin shape factor defined as the ratio of main channel length squared to contributing drainage area (sq. mi./sq mi.)
SL = mean channel slope defined as the ratio of headwater elevation of longest channel minus main channel elevation at site to main channel length (ft./mi.)
a,b,c,d = multiple linear regression coefficients dependent on region number and event frequency

The parameters A, SH, and SL are computed automatically based on raster datasets prepared by the user. For the FEMA Map Modernization studies, it is most efficient to prepare these datasets at the county scale. Parameter calculations are based on a digital elevation model (DEM). Typically the National Elevation Dataset (NED) 30-meter DEMs are used. The NED dataset is available across Texas, and the vertical accuracy of the dataset is consistent with the mapping of current approximate flood hazard areas. The basic NED DEM is hydro-enforced to match the vector stream centerline network. The resulting grid is processed using a standard eight-direction pour point model to produce flow direction, flow accumulation, and flow length grids. These grids are used to calculate drainage area, shape factor, and channel slope at each cross-section. The regression coefficients are determined by locating each cross-section within a polygon coverage of the Texas regression equation regions.

Water surface calculations are based on the discharge formulation of Manning's equation:

$$Q = 1.49\, A\, R^{2/3}\, S^{1/2} / n$$

where:

Q = discharge (cfs)
A = cross-sectional area of discharge ($ft.^2$)
R = hydraulic radius as area divided by wetted perimeter (ft.)
S = hydraulic slope (ft./ft.)
n = Manning's roughness coefficient (dimensionless)

Normal depth is calculated at each cross section by solving Manning's equation using a sequence of increasing depths until the result, Q, equals or exceeds the peak discharge determined for that cross-section from the regression equations. The geometric parameters A, R, and S are calculated based on station and elevation points taken from a ground surface TIN supplied by the user. A default roughness coefficient, n, is specified by the user and applied at all cross-sections.

Defaults are built into the mapping tool to avoid calculations based on supercritical flow or adverse slope. A critical depth is calculated for each cross-section based on minimum specific energy. The resulting normal depth from Manning's equation is compared to the critical depth. If the normal depth is less than critical, the water surface elevation at the cross-section defaults to critical depth. The user supplies a default hydraulic slope that is applied to any cross-section where an adverse slope is calculated from the ground surface TIN.

Comparisons of Zone A Mapping Methods

As a contractor to FEMA, Halff Associates is currently studying over ten counties in the State of Texas as part of the Map Modernization program. In the course of these studies, Halff Associates has applied both enhanced approximate study methods and HEZA in order to refine existing Zone A flood hazard areas. The results of both study types are more consistent with available topographic and base map data as compared to the current Zone A mapping. Figure 2 shows a Zone A floodplain boundary that has been refined using HEZA against the effective Zone A mapping from the Q3 files. In addition, especially where the accuracy of topographic data is limited to 10-foot contour intervals or greater, the results of the automated H&H studies made using HEZA appear to match mapping created using more costly enhanced approximate study methods. Figure 3 compares the results of applying HEZA against the results of an enhanced approximate type 2 study.

Conclusions

The application of automated H&H methods to map approximate flood hazard areas using HEZA results in an improved product as compared to current Zone A mapping. For areas where the USGS quadrangle hypsography is the best available topographic data, typical of rural areas in Texas, the additional cost of preparing enhanced approximate studies is probably not justified. The digital flood hazard mapping created with HEZA is based on documented hydrology and hydraulic calculations and base map data. The USGS regression equations and Manning's equation are simple and tested formulas for hydrology and hydraulic calculations. The typical base map sources are widely available at little or no expense. As the base map and topographic datasets are updated, mapping can be revised with a minimum level of effort.

While HEZA uses the same GIS-based mapping techniques as interfaces for detailed hydraulic models such as HEC-GeoRAS, it must be remembered that the hydrology and hydraulic calculations are approximate in nature. The mapping results are an improvement over existing Zone A mapping, but the fact that the mapping is consistent with the topographic data should not mislead users to assume a greater level of detail in determining the BFE. Figure 4 is shown to illustrate the need for detailed studies in order to obtain the most accurate assessment of flood risks. By basing approximate flood hazard mapping on the best currently available topographic data, it will be easier for future detailed studies to tie-in at the limits of study.

Development of HEZA in a format compatible with ArcGIS™ ensures compatibility with the next several generations of ESRI software, and will allow for the tool to be integrated into larger flood hazard (or all-hazard) management applications. Possible future enhancements could include the accurate determination of BFEs within Zone A flood hazard areas on a community's DFIRMs. In this case, the HEZA interface could be extended to allow users to query the BFE at any point in a Zone A floodplain based on the original datasets that were used to map the floodplain. The availability of these tools and applications could be extended to larger user groups using internet-based GIS interfaces.

Figures

Figure 1. HEZA User Interface.

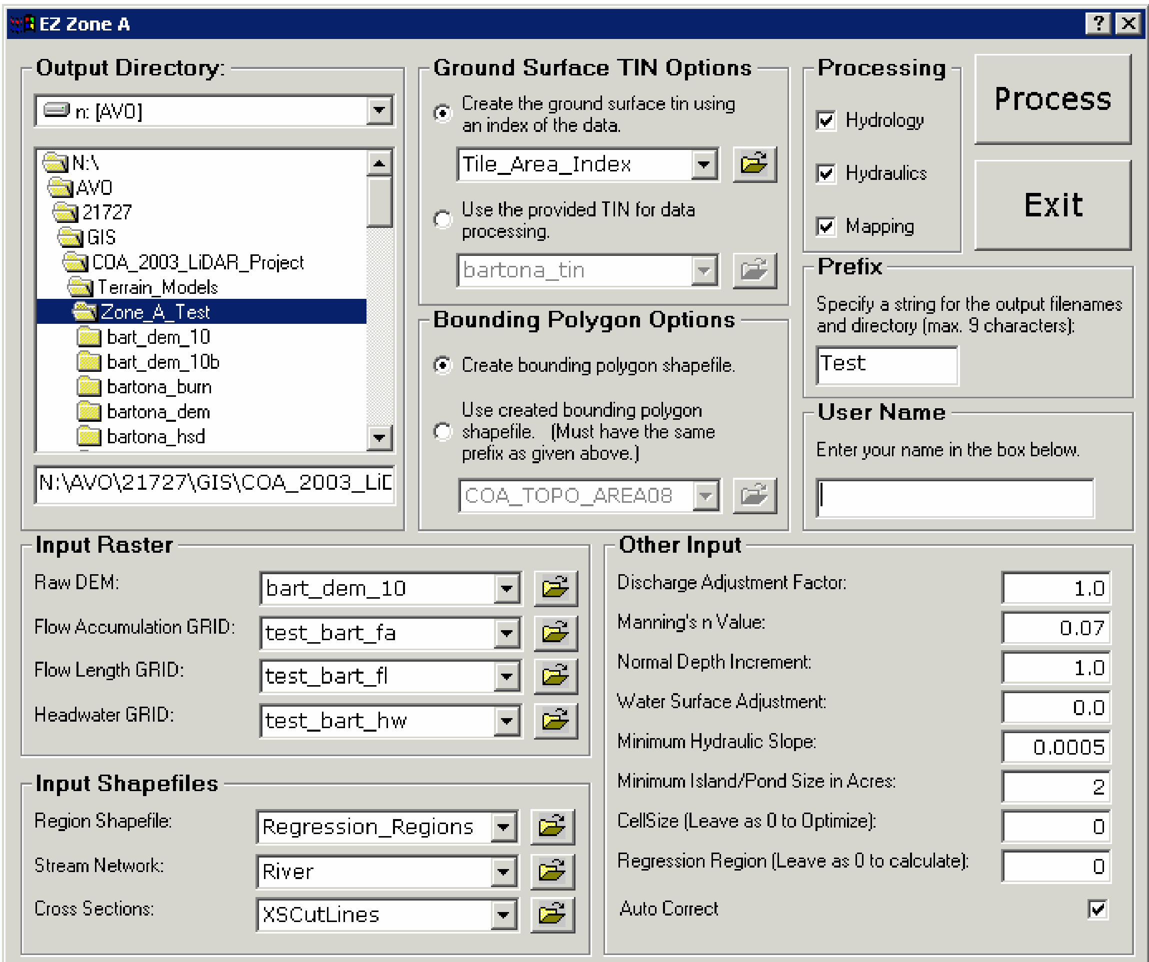


Figure 2. Comparison of HEZA Results against Effective Zone A (Q3).

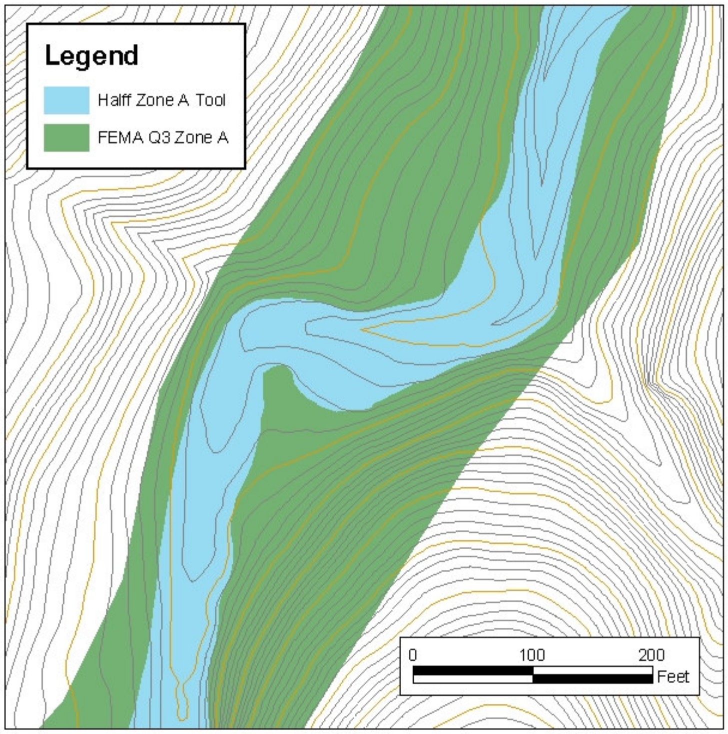


Figure 3. Comparison of HEZA Results against Enhanced Approximate Type 2 Study.

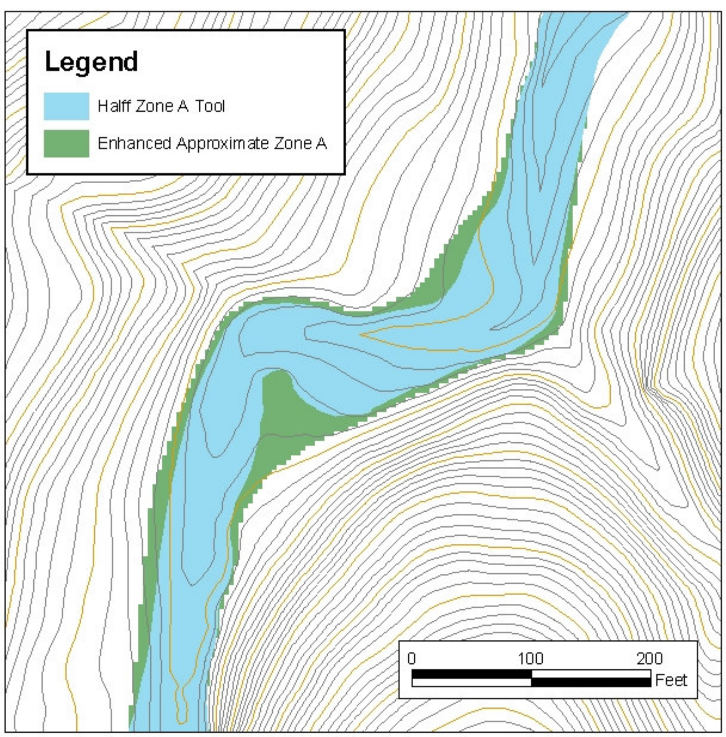
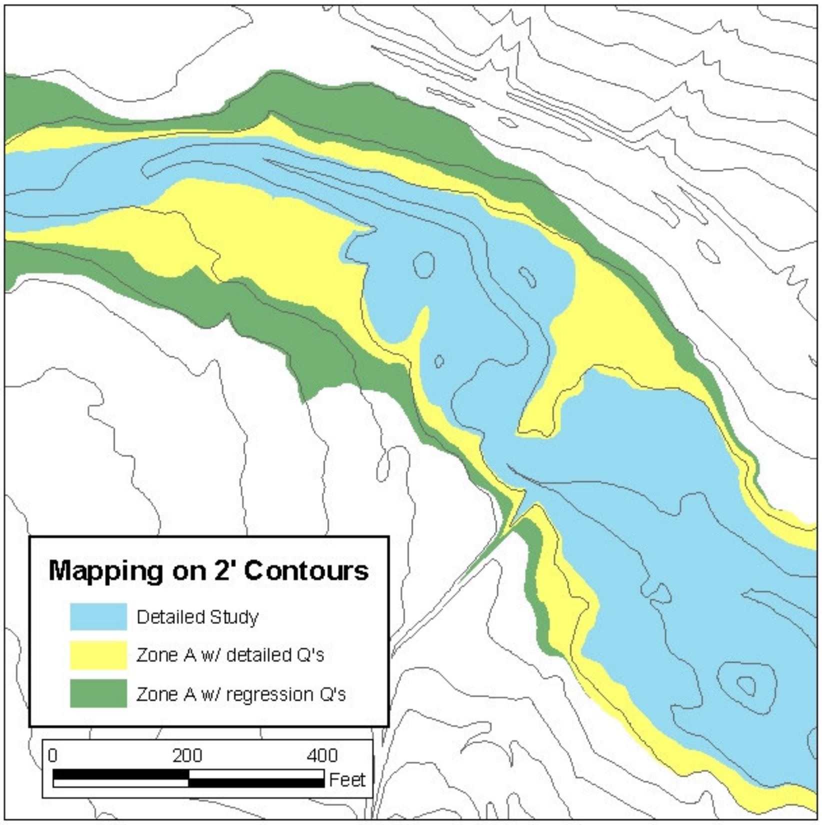


Figure 4. Comparison of HEZA Mapping against Detailed Study Results.



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