Abstract

Harris County, and especially the City of Houston, Texas, have continuously battled flooding problems due to urbanization since the first subdivisions were developed. Due to the combination of flat terrain, impervious clay soils and subtropical annual rainfall average exceeding 48-inches, Houston has earned the moniker "The Bayou City". Regular flooding from the great flood of 1929 to Tropical Storm Allison in 2001 have caused significant flood related damages to the City of Houston, resulting in both economic and human losses.

To combat the continued flood related losses, the State of Texas established the Harris County Flood Control District (HCFCD) in 1937, with the prime responsibility of overseeing the streams, rivers and bayous for residential and agricultural beneficial uses. As Harris County developed, increasingly complex watershed management issues developed, and HCFCD's role expanded to include cooperation with the US Army Corps of Engineers to complete watershed master plan studies and implement regional flood control and flood relief projects.

As technology develops, traditional hydraulic and hydrologic methodologies are incorporated into geographic information systems (GIS), creating a more useful method to both manage and develop planning tools to address watershed development issues. While GIS integrated watershed concepts are still maturing, many regulatory agencies, such as the HCFCD, are beginning to reap the benefits of GIS as a means to manage, update and track watershed development status and the hydrologic (flooding) aspects of that development. This paper describes the benefits realized by utilizing GIS to manage several digital data sources and hydrology and hydraulics applications in the watershed master planning process.

Background

Harris County, Texas is home to more than 3 million residents. The county spans more than 1,756 square miles, and encompasses 22 major watersheds. The HCFCD is responsible for maintaining more than 2,500 miles of channel, and identifying infrastructure improvements that reduce flood damages in the 22 major watersheds.

On Tuesday June 5th, 2001, Tropical Storm Allison settled over Harris County and its surrounding communities. In just a few short days, Tropical Storm Allison dropped more than 80% of the average annual rainfall over the City of Houston, resulting in 22 fatalities, 73,000 damaged residences, and more than $5 billion in property damage. In response, HCFCD organized a joint study with the Federal Emergency Management Agency (FEMA). Together, they initiated the Tropical Storm Allison Recovery Project (TSARP). One advantage of this project was to use a portion of the federal money made available as a result of the flood damages to update the Flood Insurance Rate Maps (FIRM).

TSARP provided updated hydrology and hydraulics models of the main channel segments in the 22 watersheds. Additionally, the TSARP hydrology and hydraulics models were developed using a comprehensive detailed LIDAR data set. The LIDAR data is the cornerstone datasets for the watershed master plan.

In addition, to address the future drainage needs of ongoing development, as well as historical flooding problems in developed areas, the HCFCD initiated a countywide watershed master plan (WMP) study. The WMP builds upon updated hydrology and hydraulics established in the TSARP effort to confirm and address historical flooding problems. Based on projections of future development, the WMP also serves as a planning tool, a roadmap for development of the future drainage systems.

Lockwood, Andrews, & Newnam, Inc. (LAN) is developing the WMP for the Addicks Reservoir Watershed, a 138 square mile watershed, and is providing program management services for the Barker Reservoir and Cypress Creek Watersheds WMP efforts. The Addicks, Barker and Cypress watersheds are unique compared to the other 19 Harris County watersheds because their large percentage of undeveloped land is experiencing rapid growth. This development growth has intensified the need for an up-to-date master plan.

The WMP project is a multi-phase endeavor, with each subsequent phase designed to build on the previous phase. This paper presents LAN's efforts in the GIS phase, just one major phase of the WMP. The following tasks summarize the GIS components of the project.

TABLE 1—GIS PHASE TASKS

Task	Description
1	Data Collection and Organization
2	Initial Layouts of Future Channels
3	Level of Service Analysis for Existing Channels
4	Determination of Future ROW Needs

Data Collection and Organization

Aside from the LIDAR data that was readily available, considerable effort was invested to locate and collect the most reliable and up-to-date data available for the project. Like most major metropolitan areas, the Houston/Harris County area is in the process of developing digital sets, such as parcel polygon shapefiles. The community as a whole has done a tremendous job gathering, organizing and making available many useful data sources that are beneficial to watershed master planning. The following table lists the data used in the drainage master plan and the source that provided the data.

DATA	SOURCE
Parcels Land Use Right of Way	Harris County Appraisal District
Major Thoroughfares Existing Roads	City of Houston
Energy Easements Transmission Lines	Centerpoint Energy
TSARP Watershed Maps Detention Basin Locations Channel and Water Body Locations Purchased Property City Limits FEMA Floodplain Data	Harris County Flood Control District
Gauging Stations Parks Potential Wetlands Stream Wildlife Habitat Water Quality Benchmarks LIDAR Hydrologic and Hydraulic Models Municipal Utility Districts	Harris County Flood Control District
Roughness Data Aerial Photography (MrSID)	Houston-Galveston Area Council
Threatened and Endangered Species Threatened and Endangered Species Areas	Texas Parks and Wildlife Department
NWI Wetlands	USFWS
STATSGO – Soil Associations SSURGO – Soil Classifications	Natural Resource Conservation Service
Hazardous Materials	Environmental Site Assessment
Oil and Gas Wells Oil and Gas Pipelines	Railroad Commission of Texas

The data collection process was a crucial component of the WMP project, because this information provided the digital foundation for the entire project. To optimize data use, an organization system was implemented to standardize working files and deliverables. Support data, such as those listed above were organized by their source and left in their original format, which primarily consisted of shapefiles.

Watershed specific data was organized into a geodatabase system based on the emerging industry standard ArcHydro repository. Two levels of geodatabases were established, a Watershed level and a Subwatershed or Plan area level database. All geodatabases were designed so that at any time throughout the project, they can be merged together to form one comprehensive database for all of Harris County.

The main project deliverable for the WMP was to provide HCFCD an organizational tool that standardizes:

1. The general characteristics of each watershed and subwatershed
2. The data required to perform various hydrologic and hydraulic analyses
3. The results of the analyses

Initial Layouts of Future Channels

The development of a "Drainage Road Map" for future main and lateral channel locations within the undeveloped areas of the county is the first step to identify future right-of-way (ROW) needs for HCFCD. As undeveloped regions of Harris County continue to develop, the future channel location map gives HCFCD a tool to guide drainage plans and ROW dedication proposed by developers. This process is of particular importance for the Addicks, Barker and Cypress watersheds due to their large portions of undeveloped area. The following items outline the necessary steps to accomplish the future channel layouts:

1. Develop stream files with ArcHydro pre-processing tools to identify natural flow patterns.
2. Prepare working exhibits for each subwatershed and its surrounding area with overlaid layers including:
    a. ArcHydro pre-processing stream files
    b. ArcHydro pre-processing catchment files
    c. HCAD boundary files
    d. Municipal Utility Districts (MUD)
    e. Existing and future thoroughfares
    f. Existing HCFCD channels
    g. Recent aerial photographs
    h. Pipeline location files
    i. Two foot contours
3. Delineate catchment areas of approximately 200 acres based on working (maps)
4. Identify proposed drainage network

Engineering judgment was used when performing tasks C and D. The following is a list of general guidelines used to develop the future channel locations (tasks C and D):

1. Contain flow within watershed
2. Minimize the number of proposed channel crossings at pipelines
3. Contain flow within major tributaries
4. Provide outfall for 200-acre (+/-)groups of parcels
5. Use contours to take advantage of the natural grade
6. Offset 300, 600 or 900-feet from roadways to allow for development
7. Follow ArcHydro pre-processing stream files using engineering judgment
8. Provide outfall for major thoroughfares at regular intervals for storm sewers

9. Align proposed channels to cross perpendicular to roadways and pipelines
10. Consider MUD boundaries for catchment areas

Exhibit 1 is an example of a working map used to develop the Drainage Road Map. **Exhibit 2** is an example of the final product for this phase of the project. It includes the proposed catchments and the future channel locations.

As a final check of the future channels, the natural ground (or future bank elevation) profile was compared to the future minimum invert elevation (as discussed in a the 'Determination of Future ROW Needs' section of this paper). To make this comparison, 3D point files were created from future channel centerlines with points spaced at 15-foot intervals. The x, y, and z coordinates were populated for each point, and the ground profile was then plotted against the minimum channel invert profile. Through this process, watershed teams identified potential depth problems with the future channel network early in the planning process, saving valuable time and resources. **Exhibit 3** is an example of a 1st tier (connecting directly to the main channel) future channel profile plotted against the minimum invert.

Level of Service Analysis for Existing Channels

One tasks to be accomplished as part of the WMP was to quantify existing channel capacity, or Level of Service (LOS), for HCFCD studied streams. A visual representation of LOS for the streams allows HCFCD to identify channel segments that do not meet a minimum or desired LOS and are in need of improvement. Determining the LOS for each stream also identifies potential areas for concern in developing the WMP. The following items outline the steps necessary to accomplish this task:

1. Divide studied channel centerlines based on bridges, culverts, hydraulic structures, and HEC-RAS modeled cross-sections
    a. Generate cross-sections using HEC-GeoRAS
    b. Split channel shapefile at cross-sections
2. Develop floodplain Triangulated Irregular Networks (TIN) for the 2, 5, 10, 25, 50, 100 and 500-year events using HEC-GeoRAS
3. Establish and evaluate initial LOS based on HEC-RAS output files
    a. Populate stream segment shapefile with initial LOS results
    b. Overlay color coded stream segment shapefile with aerial, ROW and floodplain shapefiles
    c. Compare LOS results with floodplain shapefile and HCFCD ROW limits

4. Investigate problem area bank elevations and assign appropriate service elevation (see service elevation definition below)
    a. Use HEC-RAS cross sections, LIDAR DEM, and aerial
5. Run final LOS calculations
6. Assign final LOS to previously identified channel segments

The service elevation is the maximum elevation at which the channel is able to convey flow without flooding overbank areas. Engineering judgment was used in assigning service elevations to each stream segment. Bank elevations assigned in HEC-RAS are not necessarily the appropriate service elevation to use in this LOS analysis. The following guidelines were used in assigning service elevations to each cross-section:

1. In agricultural areas consisting mainly of rice fields, watershed teams chose the ground elevation of the rice field as the service elevation.
2. In undeveloped areas where the surrounding terrain was at an elevation lower than the banks of the channel, the channel service elevation was defined as the elevation of the surrounding terrain.
3. In developed areas where streets are allowed to channel and discharge runoff into the stream, the street elevation was considered and sometimes chosen as the service elevation of the channel.

Exhibit 4 is an example of the color-coded channel segment LOS results. **Exhibit 5** details an example of a service elevation profile plot.

A structural, or building, inventory for each studied stream completes the LOS analysis and is a second method to determine LOS of each stream within the watershed. The structural inventory gives HCFCD a graphical display of structures in an area that will be flooded during a given event. The following steps outline this task:

1. Create a structural inventory centroid/point shapefile from based on the Harris County Appraisal District (HCAD) parcels polygon shapefile
2. Assign elevations to structural inventory shapefile from the LIDAR bare earth DEM using 3D Analyst
3. Adjust assigned elevations to reflect slab elevations by adding 8 in. to the natural ground elevation
4. Assign water surface elevations to the structural shapefile based on the previously created water surface TINs

The HCAD parcel shapefile contains the latest assessed valuations (AV) for both land and improvements. Flood damage losses were compiled for each LOS stream segment to assist in prioritizing flood damage prevention measures. Comparing the results of the structural inventory with the LOS analysis provided verification of both analysis methods. This is an example of special analysis methods that would not be practical without GIS.

Determination of Future ROW Needs

Required ROW for future channels is a vital planning tool for a regulatory agency such as HCFCD. Future ROW needs are dictated by several factors including channel cross-section, channel depth and peak discharge information.

Several channel templates have been developed by other consultant for the county-wide WMP project to help define future ROW needs. The channel templates were designed to be functional, aesthetically pleasing, and ultimately reduce maintenance costs.

Ensuring adequate depth of the future HCFCD channels to accommodate future stormsewer outfalls is accomplished by checking the minimum and maximum invert of each channel. The minimum invert is determined by applying the minimum allowable 0.05% slope from an established downstream elevation that likely cannot change. The first step in accomplishing this task is populating a field in the geodatabase with cross-sections that have immovable invert elevations, such as concrete lined channel sections and environmentally sensitive areas. The maximum invert is based on the natural ground of contributing catchments, and allowing sufficient outfall depth at the channel for a storm sewer outfall. This process ensures that either the lowest point in a catchment or the point with the longest flow path will have adequate outfall depth. The network feature of ArcHydro enables this process through its upstream and downstream connection identification. This is another example of how automated engineering techniques and time savings are achieved with GIS applications. Manual calculations to determine the maximum and minimum invert would be prohibitively time consuming and resource intensive.

Several approaches are available to determine peak discharge rates. For this project, the Kinematic Wave (KW) hydrograph for each catchment was initially selected, but was eventually determined not to be applicable for several reasons. The KW calculation requires detailed information such as flowpath lengths, slopes and percent impervious values. An automated tool was developed (by others) to incorporate these parameters into the geodatabase based on the LIDAR DEM and the land use grid. The tool then interfaces the geodatabase with HEC-HMS to ultimately produce flows for each catchment.

Initial KW tool results returned relatively high flows, particularly for flat, undeveloped areas, versus flow rates estimated during the TSARP effort, and time constraints prevented final adjustments to the KW tool. Therefore, the watershed teams used HCFCD developed site runoff curves. The site runoff curves are a simple method based on historical data, requiring only area (acres) and percent impervious as inputs. Watershed teams are currently calculating peak discharge rates for each catchment.

The final, still remaining effort to complete the ROW determination is to apply the appropriate channel template to define the future cross section based on the calculated peak flow and the maximum and minimum channel invert. The channel cross-section will then be incorporated into the HEC-RAS model of the future stream to verify the channel capacity. The base HEC-RAS models were developed using HEC-GeoRAS utilizing the LIDAR DEM data. Any deficiencies in channel capacity will be addressed by modifying the initial channel.

The KW tool was one of a handful of automated operations or tools that were attempted on this project with limited success. Problems identified with some of the automated tools include:

- Tool development and application time can equal or exceed a similar manual method.
- May provide the planner with a false sense of confidence in the tool results.
- May discourage the planner from becoming familiar with the details of the watershed.

The benefits of specialized tools, however, do outweigh the difficulties of automation in watershed master planning. Many more automated tools were implemented with great success, specifically the ArcHydro and HEC-GeoRAS tool sets.

Conclusion

The goal of the project is to provide HCFCD a high-quality planning tool to guide future watershed development. In addition, problems areas and potential solutions are identified for existing channels in the developed portions of the watershed. The use of GIS on the WMP project had a dramatic impact on the quality, accuracy and timely delivery of the final product. Additionally, GIS assimilated large amounts of data within a short time frame, allowing more effort to be spent on engineering tasks.

Exhibit 1: Future Channels and Catchment Working Map

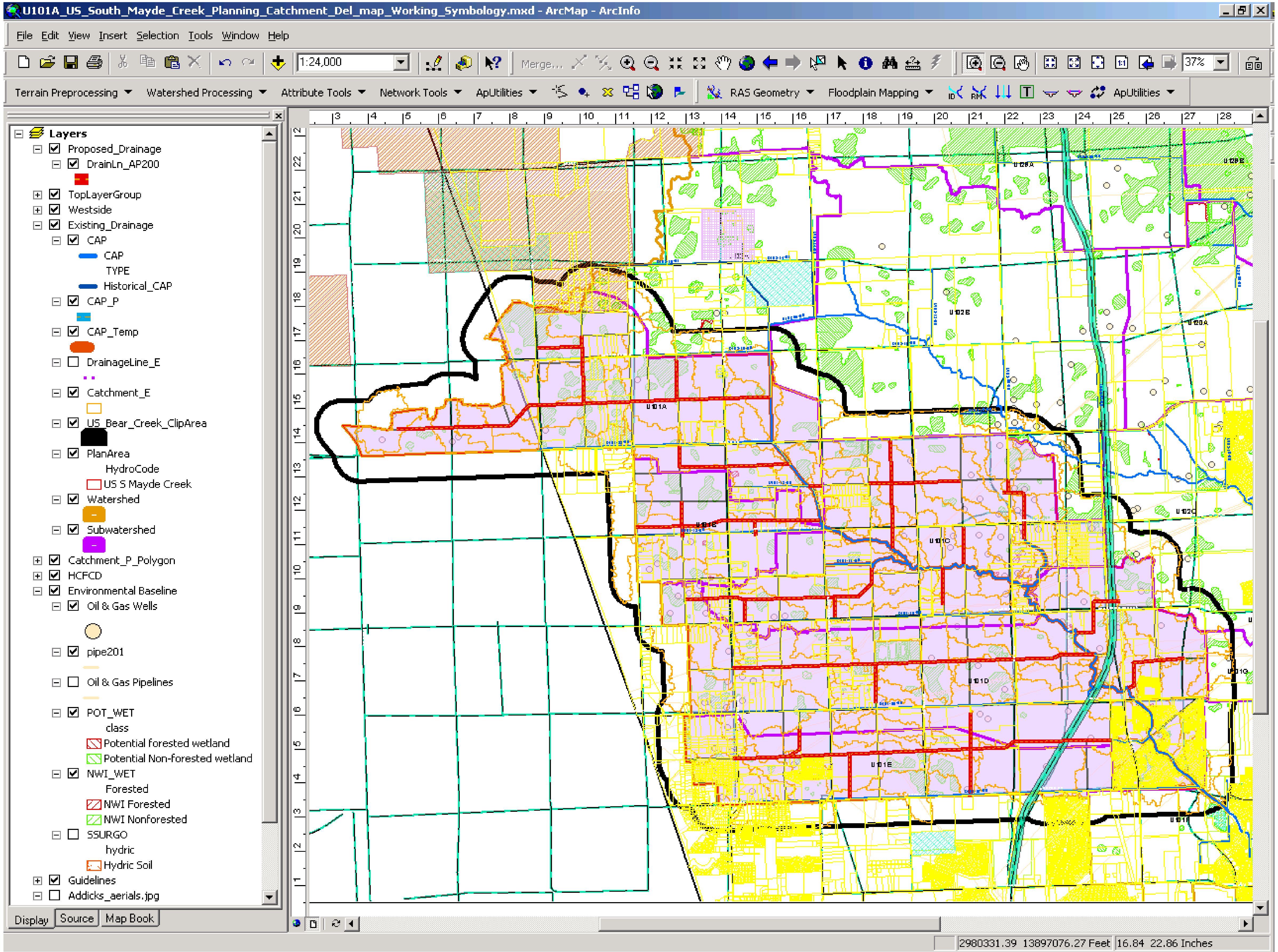
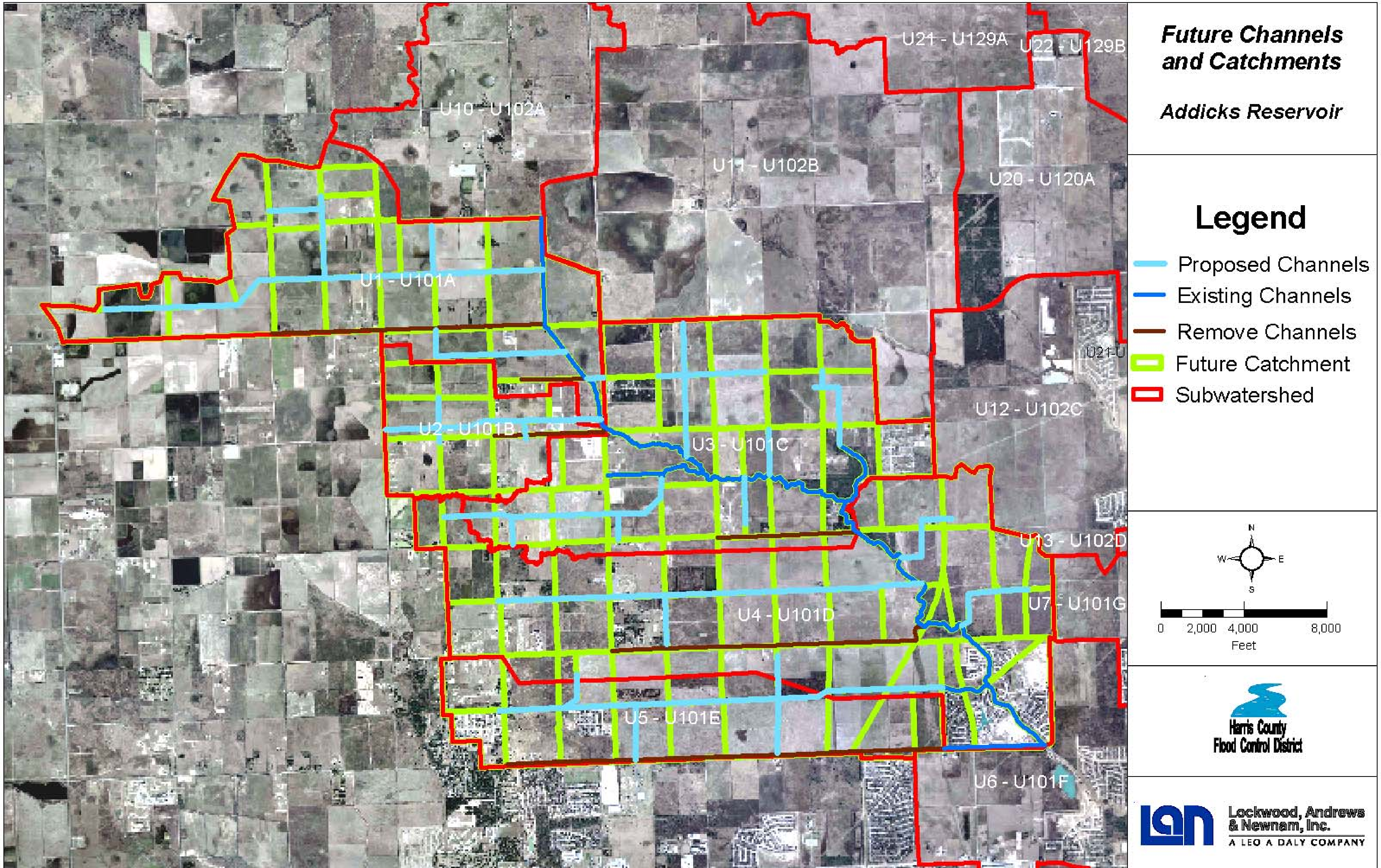


Exhibit 2: Future Channels and Catchment Results



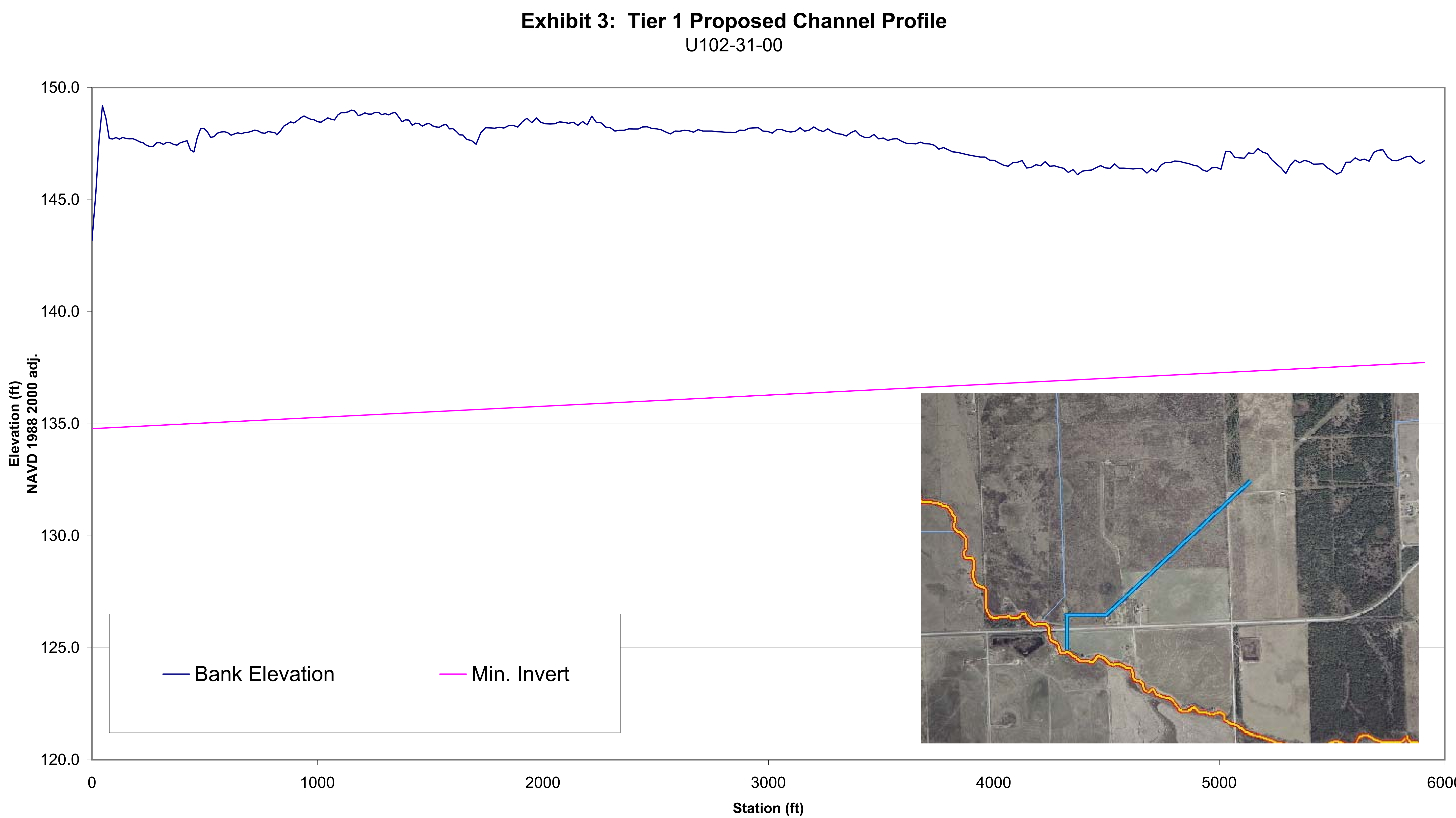


Exhibit 3: Tier 1 Proposed Channel Profile
U102-31-00
150.0
145.0
140.0
135.0
130.0
125.0
120.0
Elevation (ft)
NAVD 1988 2000 adj.
0
1000
2000
3000
4000
5000
6000
Station (ft)
Bank Elevation
Min. Invert

Exhibit 4: Level of Service

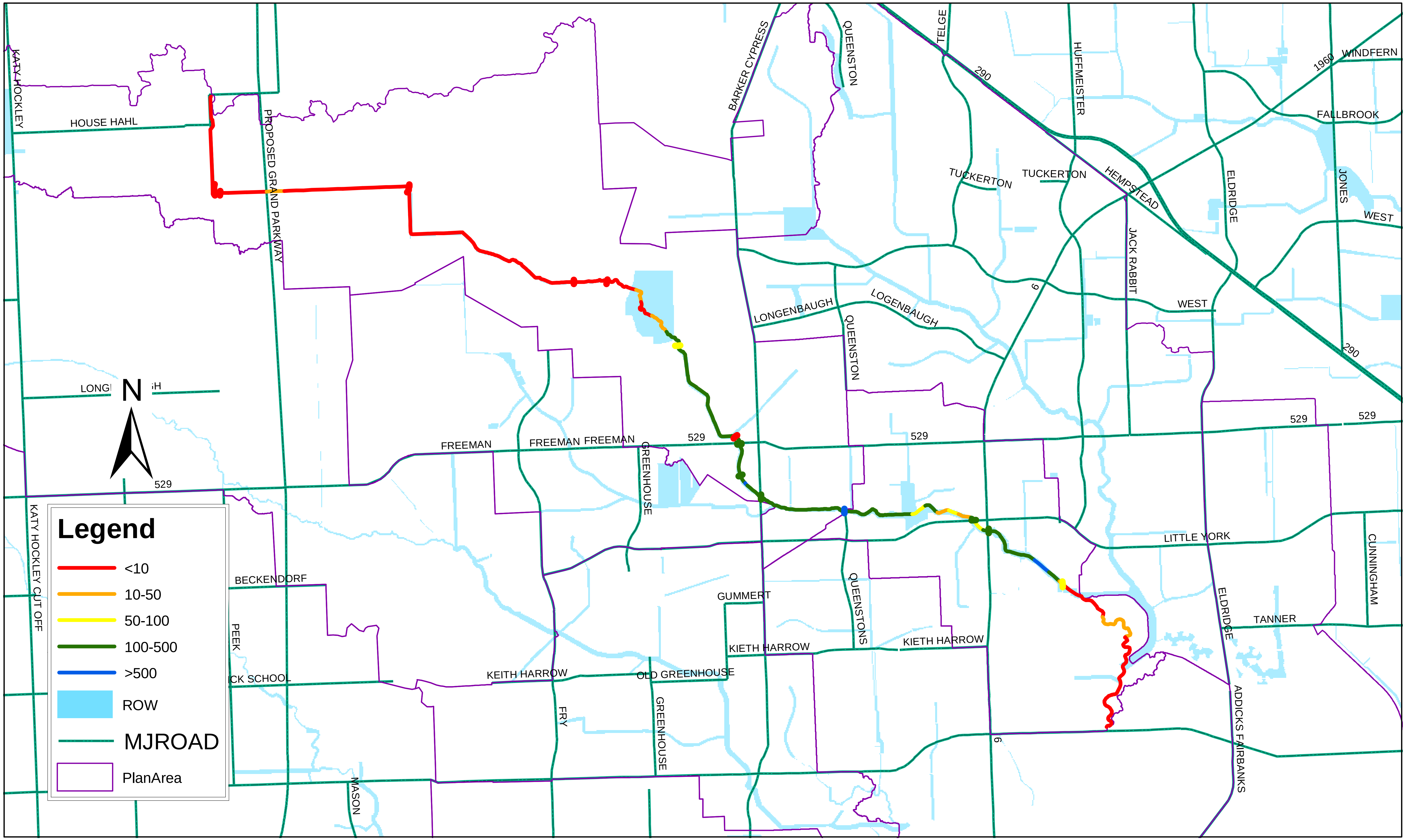


Exhibit 5: Service Elevation Profile
Langam Creek U100-00-00