

# USING INTEGRATED DOCUMENT AND GIS DATABASES FOR GEOTECHNICAL LEVEE EVALUATION

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## ABSTRACT

The California Department of Water Resources (DWR) Urban Levee Geotechnical Evaluations (ULE) and Non-Urban Levee Evaluations (NULE) Programs are evaluating approximately 1,950 miles of urban and non-urban levees in California's Central Valley. The amount of historical data associated with these levees (historical performance, design, maintenance) is staggering.

Similarly, the collection of program-generated site-specific data like subsurface exploration logs, laboratory test results, light detection and ranging (LiDAR) survey data, bathymetric data, and helicopter-borne electromagnetic (HEM) survey data is voluminous and will continue to grow in size as the levee evaluations continue. Collected historical and program-generated data needed to be cataloged and formatted in such a way that data are readily available to geotechnical evaluation teams and program stakeholders. This paper discusses how existing and program-generated data are handled in the Levee Evaluations Database, an integrated documents database. It also discusses how the database works in association with geographical information systems (GIS) to efficiently respond to ULE and NULE Program needs.

ULE and NULE Program teams developed the Levee Evaluations Database to identify and catalog collected historical and site investigation information. This information is also compiled in a GIS database. Database integration allows GIS specialists to create data layers of site-specific information into specialized maps that can be overlaid with other relevant levee information. Resulting maps can show geotechnical conditions in a specific levee reach and help analysis teams assess existing conditions, prepare analysis cross sections and correlate analysis results with historical performance information.

The combined Levee Evaluations and GIS databases also facilitate retrieval of collected information. These combined databases helped ULE and NULE teams catalog, manage and organize terabytes of information and knowledge. They also promote consistency and uniformity of available information, and improve communication across the levee evaluation teams. These databases have already proven indispensable when generating levee profiles and the cross sections required for geotechnical evaluations and analysis.

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## INTRODUCTION

Over the years, major storms and flooding have caused significant personal and property losses and resulted in extensive damage to public infrastructure. Moreover, a combination of factors has put public safety and the California's financial stability at risk for an even greater calamity in the future.

To meet these challenges, the DWR launched *FloodSAFE California* a multi-faceted program to improve public safety through integrated flood management. FloodSAFE's goal is to improve integrated flood management in California using a system-wide approach while reducing flood risk at regional and local levels. FloodSAFE is funded by almost \$5 billion in approved bond measures.

### **Urban Levee Geotechnical Evaluations (ULE) Program**

About 450 miles of project and appurtenant non-project levees comprise urban levee systems in the Central Valley. Senate Bill 5 mandates that communities with populations of 10,000 people or more must be protected by levees providing a minimum of 200-year flood protection. As a result, urban levees are being evaluated in phases. These phases include data collection, field investigations, preliminary analysis, supplemental field investigations, final analyses and an evaluation report on the levees' existing conditions (California Levee Evaluation Program, Mike Inamine et. al, USSD 2010).

### **Non-Urban Levee Evaluation (NULE) Project**

About 1,650 miles of Project and appurtenant Non-Project levees comprise the non-urban levee system in the Central Valley. Unlike the more detailed ULE Program's approach, non-urban levees require a different approach for analysis; the extent of non-urban levees under study and limited funding drive evaluation strategy on the whole.

The NULE Project first evaluates levees using existing data collected during the research phase. Selected levees were then assessed during subsequent phases by conducting field investigations and performing more detailed analyses. This phased, risk-based approach is tactically dissimilar from the ULE Program's approach, in which all urban levees are evaluated to the same standard. Since non-urban levees will be evaluated at different levels of detail, local stakeholders will be included in the decision-making process. This evaluation approach demands time and process, and uses original design hydraulic loading conditions (California Levee Evaluation Program, Mike Inamine et. al, USSD 2010).

## COLLECTING DATA

One of the first steps of levee evaluation is to collect and review existing relevant data. This data may include both existing historical documents and program-generated data. Existing historical data pertaining to levees varies, and can include recorded levee performance history, hydraulics and hydrology (H&H) studies, geomorphology reports, records of geotechnical explorations, levee design documents and as-built drawings,

operations and maintenance (O&M) manuals and levee maintenance records. These kinds of information were available from various organizations across the Central Valley and needed to be gathered into a single, comprehensive database.

Program-generated information also varies and can include transcribed site reconnaissance records, personal interviews with levee maintenance personnel, geotechnical exploration records, laboratory test results, LiDAR survey results, bathymetric survey results, collections of geomorphologic data, reports, maps and HEM survey data.

### **Organizing Existing Data**

Existing documents containing any information related to the California levee system were reviewed to understand levee history, past performance and current levee conditions. Parallel, efforts were launched to collect primarily existing geotechnical data from various organizations. A total of over 7,000 documents (totaling approximately 140 GB in electronic form) have been gathered to date, and the process continues as levee evaluations move forward and new information becomes available.

The ULE and NULE teams then created the Levee Evaluations Database, which is a portable, easily-searchable document database designed to help teams perform efficient document reviews. Microsoft Access was selected as the software platform, as it is ubiquitous, portable and is compatible with DWR's California Levee Database (CLD), which uses Oracle-based software.

The Levee Evaluations Database was designed to integrate with the CLD at the end of the ULE and NULE evaluations programs. DWR's CLD serves multiple purposes, and to supplement the CLD, the Levee Evaluations Database adopted the CLD's structure, further customizing to CLD requirements and including additional fields to suit both ULE and NULE Project requirements.

Non-urban levees in the Central Valley are divided into segments that range in size from a few thousand feet to several miles long. These segments were originally defined by the U.S. Army Corps of Engineers' (USACE's) O&M manuals. Each O&M manual describes one or more levee segments and gives a brief introduction to the construction history of the segment(s) and local operations and maintenance procedures. These segments are unique, and in turn act as the building blocks of the Levee Evaluations Database. These segments serve as geographical locators for Levee Evaluations Database documents. Upon entry to the database, each catalogued document was assigned a unique system-generated identification number that acts as its primary key. Level 1 data collection during Phase 1 NULE Project activities relied heavily on the Levee Evaluations Database.

## Levee Evaluations Database Document Entry

When creating records in the Levee Evaluations Database, the existence of eligible documents were initially checked against the database itself to avoid the entry of duplicate records. Before creating a record, documents were preliminarily reviewed. Users populated several fields in a document's database entry, such as the description of document, its author, its published year, whom the document was prepared for, a filename and path to the location of the document on its local hard drive, and other relevant information and keywords.

Subsequently, the document was associated with the appropriate levee segment(s) based on geographic relevance. As soon as a record is created in the Levee Evaluations Database, it is assigned a unique identification number. All populated information is then saved in the databases' many relational tables using primary keys.

To control accuracy, the database is regularly updated and assigned a new version number. Figure 1 below shows the database document entry initial screen and Figure 2 shows the entry and editing panel for detailed document and data information.

Levee Evaluations Project Database

Version 3.6.2 BETA - Click for Version Information  
August 21, 2009

Your Initials (for data entry):  
WNH

Search by Criteria

Author [dropdown]  
Year (yyyy) [text]  
Document Type [dropdown]  
File Type [dropdown]  
Clear Criteria

Search by Document Number:  
[text]

Search by Keyword  
Search Field [dropdown]  
[text]  
Perform Search

Matching Documents (Double-Click to view document)

- Incident Report, RD 2113, Fay Island Levee Breach, Incident No. 2006-012-0101
- Lower American River, Ratio of Applied to Critical Vegetated Shear Stress (0.5) Plots 145,000 cfs
- Phase III Final Emergency Levee Repair, Sacramento River Basin, MA9 Sacramento County, California
- Proposed Extension to Existing Drainage Culvert West Sutter Levee By-Pass 50-4-1880-1.
- RD1500 (Sutter Bypass) Boring Logs
- Status Incident, San Joaquin River, RD 2091 Levee Boils, Incident No. DWR98-099-0216
- (Topography) San Joaquin River, Old River to Skaggs Bridge, Kings River, San Joaquin River to Hardwick
- (Topography) San Joaquin River, Old River to Skaggs Bridge, Kings River, San Joaquin River to Hardwick
- (Topography) San Joaquin River, Sacramento District Office, Sacramento, Ca.
- 00000000\_1907, 1909, 1911 Flood Effects\_Historical
- 00000000\_Boring Logs, CPT Probes, and Laboratory Data, San Joaquin River Delta Risk Management Strategy
- 00000000\_Brookside Aerial\_RD 2074
- 00000000\_Historical Map Wathall Slough Levee\_RD 17
- 00000000\_King Island - n.d.
- 00000000\_Profile of Levee RD 404\_n.d
- 00000000\_RD 1608\_Levee Sections
- 00000000\_RD 17 Historical Map
- 00000000\_RD 17 New Head Levee Profile\_Historical
- 00000000\_RD 2074 Base Map\_Levee Stations
- 00000000\_RD 2074 Display Map\_Levee Stations

Add New Find by Segment Preview Report Export to Excel Document Count: 6825

Figure 1. Database First Screen for Document Entry and Search

Figure 2. Document Detail Entry

### **Levee Evaluations Database Search**

The Levee Evaluations Database is a searchable database. Search routines enable identification of documents by geographic location (segments), document unique identification number, author, published year of document, type of report and other keywords as entered by users. Report generation capabilities enable the user to export searched and short-listed information. Reports about segment information can also be generated and saved. Figure 3 shows a sample record search.

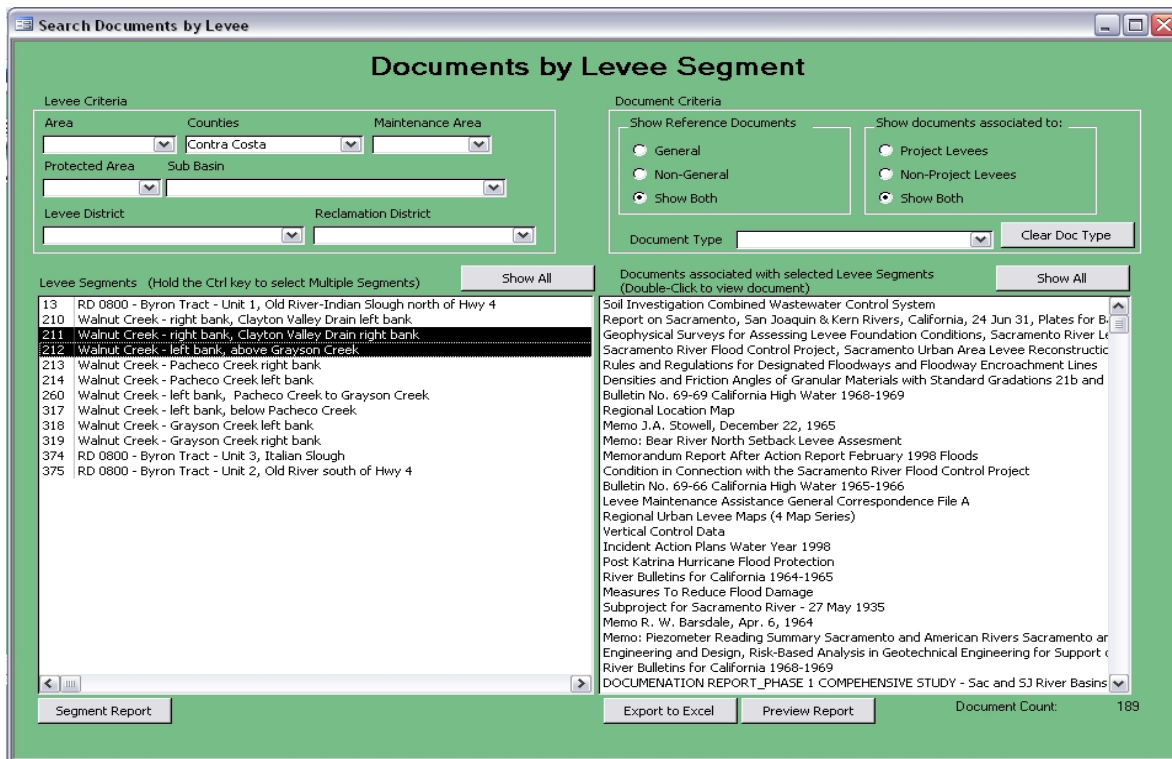


Figure 3. Document Search by Segment

### **Levee Evaluations Database Additional Features**

Database developers use a systematic quality control process to maintain the quality of catalogued information based on end user feedback. Access to the database and permissions to edit or delete records are part of the database's features.. The Levee Evaluations Database also controls records modification via user permissions, controlling modifications to segment detail information or the addition of new segments. Features were also added to the database so users can modify or add dropdown menus (e.g., author, prepared for, etc.) Figure 4 shows a screen shot of the information editing administrative screen.

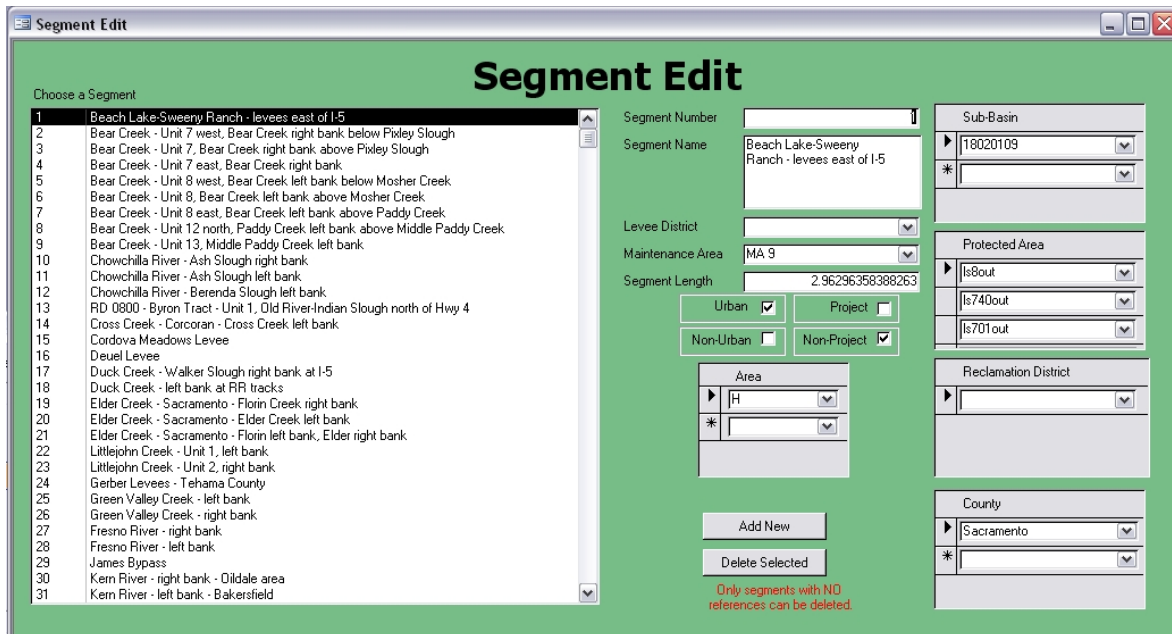


Figure 4. Document Administrative Screen

### **Document Hyperlinking**

The Levee Evaluations Database has document hyperlinking capabilities. When users need more detail than shown in summarized entries onscreen, they can have immediate access to the full electronic copy of a document. Relative paths of documents populated in the local archived location fields are used to access full electronic copies of resident documents from external storage devices.

### **Organization of Program-Generated Documents**

Program-generated data such as site reconnaissance records, transcripts of personal interviews, reports, geotechnical explorations, laboratory test results, LiDAR survey data, bathymetric and HEM survey data were organized in several ways. Documents gathered during site reconnaissance and completed personal interview questionnaires were digitally scanned and distilled to Adobe Acrobat's portable document (pdf) format before being added to the Levee Evaluations Database. Other levee data added to the Levee Evaluations Database includes boring logs integrated from a gINT database and GIS-generated, idealized levee three-dimensional geometry.

### **gINT Database Integration**

gINT is geotechnical data management and reporting software. Geotechnical information was collected and cataloged in a gINT database as part of levee evaluations data integration.

After a review of existing historical levee documents, data gaps were identified and further information was gathered by performing additional explorations in the field.

These field explorations were documented in drill logs, cone penetration test (CPT) records and other in situ test logs. Soil classifications on drill logs were adjusted based on information from appropriate soil sample laboratory test results.

This log and test result information was cataloged into a gINT database that allowed project templates to be automatically applied to boring logs. gINT also, assigned log numbers. gINT promotes helps promote overall consistency of data presentation and information management.

The gINT database exports boring logs directly into computer-aided drafting (CAD) programs to create generalized subsurface profiles. These profiles correlate with physical test locations, and include information about laboratory test results and existing improvements at exploration locations. Ultimately, supplemental boring logs and subsurface investigation results will be gathered into the same searchable database on a GIS platform to provide all collected historical and geographic information at the click of a mouse.

## **LiDAR, BATHYMETRY AND HEM SURVEYS**

### **Topographic Data Collection**

The ULE Program conducted low altitude helicopter-based light detection and ranging (LiDAR) topographic surveys along 400 miles of urban levees. LiDAR survey data was supplemented with bathymetric data to produce complete models of the levee's prism and channel.

The ULE Program collected bathymetry using multi-beam sonar technology, which allowed data to be collected in shallow water. LiDAR and bathymetric survey data was then modeled in GIS, developing a triangulated irregular network (TIN) mapping surface. This information was then used to generate three-dimensional terrain models of the levees.

A key aspect of LiDAR and bathymetric surveys is the seasonal timing of data collection. LiDAR data was collected in early spring to minimize impact on new leaf growth from vegetation and during low water levels in the levees prior to spring melt. Bathymetric survey data was collected during fall when levees have high enough water levels to ensure sufficient overlap between LiDAR survey and bathymetric survey data. This way, respective survey data can help prevent gaps between survey information on levee waterside slopes and create a complete topographic profile.

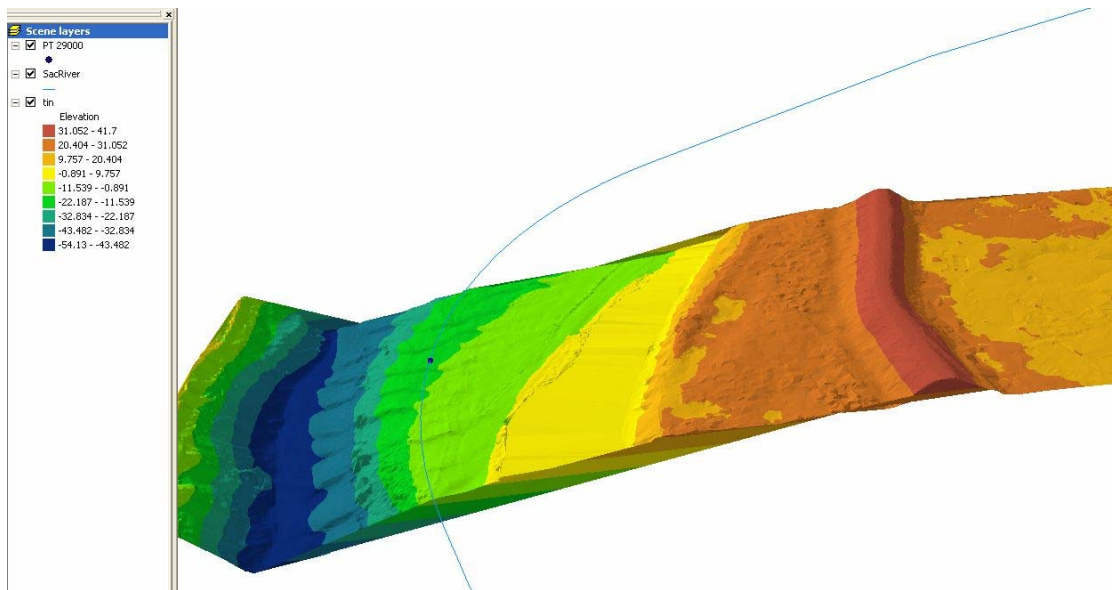


Figure 5. Topographic Data Collection from LiDAR and Bathymetric Surveys

### **Geomorphology Maps**

Geomorphic levee mapping is accomplished by conducting surveys to develop an initial understanding of their geologic setting and identifying the potential locations of geological anomalies. Geomorphic studies' ultimate product is a surficial geologic map (Figure 5) of site-specific conditions in a reach. This information provides a framework for understanding geomorphic processes in a particular segment. The steps for developing a surficial geologic map include analyses of vintage aerial photography (1937, 1958), reviewing historical topographic, surficial geologic, and soil survey maps, and reviewing field reconnaissance reports.

A stratigraphic model is then produced from available field investigation data. The model is evaluated for stratigraphic discontinuities, particularly with respect to buried subsurface channels that might significantly increase a levee's susceptibility to underseepage.

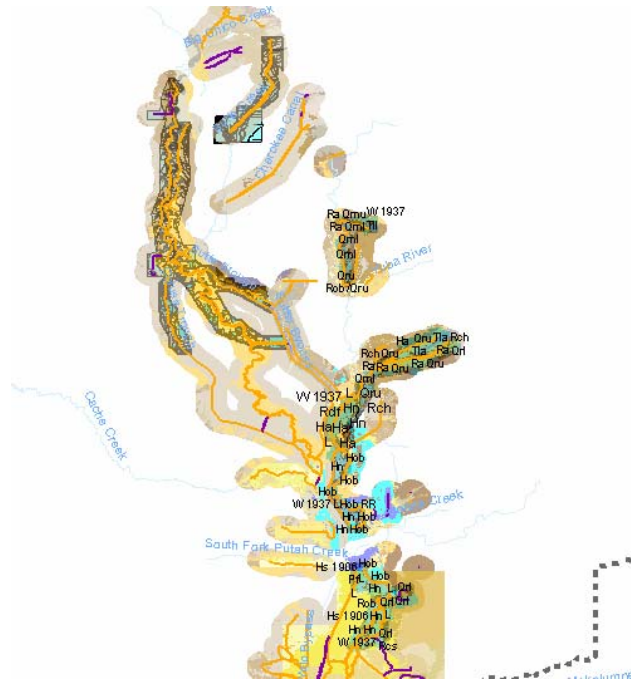


Figure 6. Geomorphologic Maps Generated for This Project

### Geophysical Surveys

Geophysical studies consisted of HEM and ground-based galvanic surveys. ULE Program HEM surveys provided a rapid assessment of subsurface conditions at a macro scale. As these HEM studies involved a helicopter carrying a large sensor, Federal Aviation Administration (FAA) and other safety restrictions constrained the extent of survey coverage to about 300 of the 450 total miles of urban levee. Areas not covered by HEM survey were supplemented by surface galvanic studies. Figure 7 presents sample results from the ULE Program’s HEM and galvanic studies.

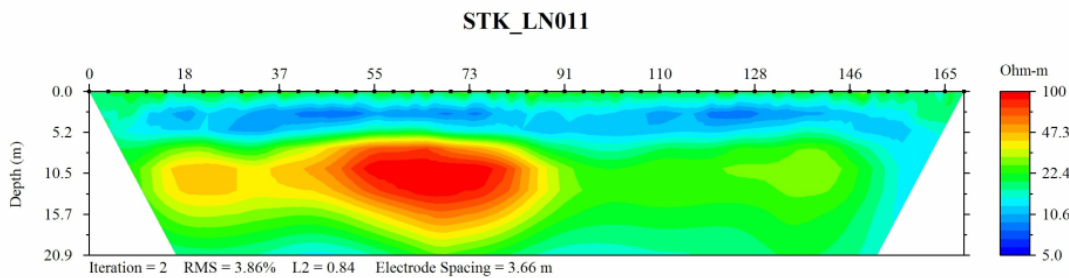


Figure 7. Galvanic Study Results

### **USING GIS TO INTEGRATE MULTIPLE DATABASES**

Geotechnical evaluation of urban and non-urban levees first involves assessing available data. GIS serves the purpose of integrating information residing in multiple databases. ULE Program and NULE Project GIS teams organized available survey and other data in topographic layers. In the final on-screen maps, these layers can be turned on and off,

allowing users to create multiple views of available information in a particular location simply by activating selected layers.

### **Generating Points of Interest**

Historical information, events and other pertinent data are shown as points of interest (POI) in resulting GIS maps. These points may be related to levee performance, maintenance or the presence of any existing structures that could impact levee performance. During the document review phase of study, a description of each POI and its geographical extent was documented in the Levee Evaluations Database. GIS developed symbology for representing each POI, which were then organized into layers and overlaid on a map. A key or information table for POIs provides a description, a document unique identification number (for documents in the Levee Evaluations Database) and details citing source information for each POI. POIs were also hyperlinked to an electronic copy of Levee Evaluations Database items stored on an external hard drive, allowing users immediate document access.

The gINT database georeferences and catalogs both historical and program-generated subsurface exploration information. This information is then mapped into a layer on a resulting GIS-based map. Users can identify relevant exploration information about any segment, and retrieve boring logs directly from the gINT database.

### **Cross Section Analysis Using GIS-Rendered Information**

As mentioned above, GIS renders three-dimensional models of levee ground surface from LiDAR and bathymetry survey data. As analysts selected cross sections for study, these locations were cut from TIN mapped surfaces. GIS hyperlinked these cross sections and their location on the levee's alignment map for easy access and review. This information helped analysts verify levee geometry and compare it to ULE Program standards. It also helps analysts compare a levee's crest elevation against USACE design water elevations to verify freeboard requirements.

### **Geomorphology Maps**

Geomorphology maps were prepared to scales of 1:24000 and 1:62500. These maps identify features like abandoned channels which might cross underneath a levees and influence its performance. Surficial deposits information, along with abandoned channel information, were gathered and mapped in separate layers in the GIS database. Analysts can quickly understand the geomorphology of a segment under review. Geomorphology studies also helped create underseepage susceptibility maps, which were later added to GIS as another layer.

### **Erosion**

GIS helps perform levee erosion and levee geometry analyses. These analyses are based on a comparison of USACE design levee geometry with a levee's existing geometry.

Criteria determining design levee geometry included the levee's design water surface elevation, freeboard, waterside slope angle, landside slope and, and crest width. In GIS, these design parameters rendered a model of an idealized, three-dimensional levee. GIS facilitated continuous comparison of the idealized model levee to actual ground surfaces in existing levees. Continuous characterizations of potential levee geometry deficiencies, as well as potential erosion sites, were identified.

## **CONCLUSION**

The ULE Program's and NULE Project's GIS systems act as an innovative, value-adding vehicle for data management, integrating enormous amounts of information to facilitate the organization, classification, sorting, grouping and updating of critical geotechnical information about the levees under study.

GIS increased information access speed and efficiency, helping geotechnical assessment teams achieve efficiencies of scale and scope, and minimizing the time required to become familiar with hundreds of miles of levees. The GIS and database tools created by the NULE and ULE programs render detailed information about the levees including their construction, composition, flood history, previous documented distress issues, anomalies, vegetation, animal activity records and other data. This information is vital to the assessment teams to produce high quality meaningful assessments.