Rebuilding the Levees with GIS

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Abstract

The USACE New Orleans District has historically segregated its levee data into individual survey files, CADD design drawings, and overview GIS layers. Although each dataset addresses a different niche of levee data management, no single comprehensive data source yet existed. Following Hurricane Katrina, requests for maps displaying levee designs and construction project locations were met by duplicating levee features for each new use. By associating surveyed traverse stationing to centerline reaches and surveyed elevations to centerline vertices, the District created a reusable ESRI measure-based levee data set. This dataset forms a comprehensive foundation that meets numerous levee management needs and supports an extensive array of decision-making requirements. Rather than redrawing levees, users can simply provide an event table for each attribution of the levees, such as construction, inspection, and design, using the official stationing. The new levee design eliminates time-consuming cartographic work and ensures consistent geometries across all attributions.

Introduction to the Problem:

In the aftermath of Hurricane Katrina, the GIS team for the United States Army Corps of Engineers New Orleans District (CEMVN) was tasked with numerous requests to calculate and map attributes of Southeast Louisiana's hurricane protection system. Simply acquiring the data was, in many cases, a challenge in itself. The New Orleans District levee data management lifecycle begins in CAD, where engineers draft the design aspects of individual project sections of levee and floodwall to be fit within the larger hurricane and river and protection systems. After the design phase, levee data management moves into the domain of surveying. Surveys are periodically conducted on individual levee reaches, generating an updated record of the horizontal and vertical positions along the centerline profile of the levee. GIS has traditionally stood at the end of this levee data management pipeline, contenting itself with storing the horizontal location of levee segments to be used in regional-scale mapping work.

As part of the Interagency Performance Evaluation Team (IPET) [1] study of the weaknesses in the hurricane protection system that contributed to Hurricane Katrina failures, the GIS team generated a new levees data set by digitizing levee features from 1-foot imagery. Distinct linear features were created to represent segments that share the same jurisdictional authority (federal or local), the same design criteria (hurricane or river protection system) and the same construction method (levee, levee and floodwall, or floodwall). Although this data set (figure 1) was far more accurate than the previous regional-scale levees GIS feature class, it was still unable to answer many of the questions that were being asked. When the IPET team requested to see deficiencies in existing levee and floodwall heights based on authorized design grades, the analysis had to be performed outside of the GIS system and reported as specific sampling points along the levees. When project managers asked to see new construction project reaches on maps, the GIS team started to generate copies of its levee features, breaking and combining linear segments to create new features that represented the individual construction projects.

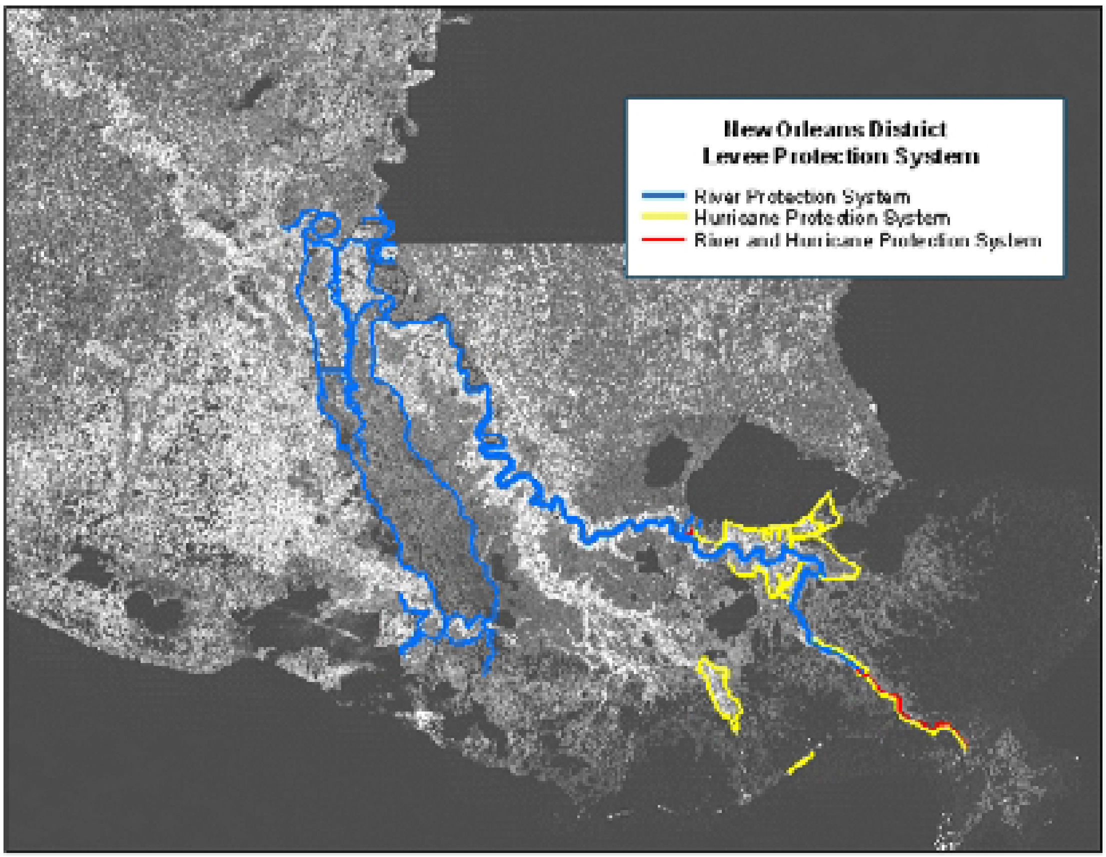


Figure 1 *– Overview of the levee system within the New Orleans District. Mississippi River and Tributaries protection system (MR&T) appears in blue. Hurricane protection system levees appear in yellow. Levees which were designed for both river and hurricane protection appear in red.*

It was obvious that duplicating levee geometry to record different attributions would only proliferate into a GIS data management nightmare. A new data model for the levee protection system was needed – one which could support storage of different attributes of the levee system without requiring that spatial features be broken into segments that represent the lowest common denominator of the attributions of interest. The levees data set would also need to be more flexible and include information about the surveyed height of the levee crowns and authorized design grade of levee sections. Finally, with dozens of construction projects either in progress, or planned, the new levees data model would need to support history of levee reaches and be able to record modifications to features as levee sections are either repaired or rebuilt with new configurations.

Modeling Levee Features:

With previous levee data sets that segregated levee features at breaks between earthen sections and floodwall sections, and data sets that distinguished levee features at breaks between construction projects, the GIS design team realized that the crucial question that would have to be answered was "what is a levee?" Was a levee feature a segment of the linear protection system which was built using a particular construction method? Was a levee feature a section of the protection system that shared a single authorized height and engineering design? Did levee segments have unique identities by which they were known to engineering teams working on the CEMVN design and repair efforts?

The rather obvious answer to the question about levee identities was yes – levees do have identities – there are named levee reaches that have traditionally been surveyed as individual units. The New Orleans District GIS had not been able to take advantage of these named survey reaches previously because our levee data sets were either intended to map the simple location of the levees, or had been designed to map levee attributes such as earthen construction versus floodwall construction. Levee reaches do have identities, and they are well established for the Mississippi River and Tributaries (MR&T) river protection system, which is periodically resurveyed at the level of the levee district, and less well established for the hurricane protection system, which includes some well-defined reaches but also includes several ambiguous reaches where historical survey jobs have used different starting points, surveyed different lengths of levee, or have run in different directions. The key to the definition of levee features was the survey data sets.

CEMVN levee field surveys produce two types of data files: a traverse file that records distance between consecutive points along the survey path, starting from a known established benchmark, and a survey file that includes the horizontal and vertical location of points measured along the centerline profile of the levee. The distance measurements from the traverse file are the source of the stationing, or address, along the levee reach. Locations of prominent features, such as floodgates or pipeline crossings, are traditionally reported in terms of a stationed distance along a levee reach.

The New Orleans District GIS had always been missing the capability to station its levee features. However, stationing is, in fact, an old concept in GIS, with roots in the original dynamic segmentation capabilities of work station Arc/Info and implementation in the routes and measures capabilities of ArcGIS. ESRI linear feature classes support the M, or measure dimension. These measures can either be physical distances, or measurements in another space such as travel time or travel cost. For the CEMVN Levees Data Model, a decision was made to use measures that represent actual distances, as based on the traverse stationing for levee reaches. Levee attribution, such as earthen levee versus floodwall construction, or location of construction projects along the levee system, can then be recorded as event table data whose location is referenced by specifying starting and ending stations along a levee reach. By using routes and route events, it would then be possible to store a single levee geometry and record a variety of levee classifications against that geometry.

Details of the CEMVN Levees Data Model:

In the CEMVN Levees Data Model, levees are linear features that include both Z and M values. The Z values are derived from the elevations of the surveyed profile centerline. The M values are assigned from the historic traverse stationing. After considerable debate, the team agreed that the new feature class would be named Topographic Centerlines, so as to semantically include levees, floodwalls, foreshore dikes, and other linear features of the river and hurricane protection systems.

The GIS design team realized that while levee features might be acquired from profile surveys of the protection system, a levee feature was not synonymous with a survey data set. The most recent survey of the hurricane protection system, a massive data collection effort undertaken in spring 2006, included notable gaps where surveyors had skipped segments that were under construction at the time. New survey data sets would be arriving piecemeal as repair and construction projects were completed. Surveys would stand alone as survey data sets, but topographic centerlines would be a combination of the best available survey information for each named levee reach. Because topographic centerlines would be compilation features, the GIS design team decided to model the lineage of source information at the level of individual points defining the topographic centerline. The topographic centerline linear feature includes X, Y, Z, and M information, as well as reach name, acquisition date information, and a reference to the survey traverse by which it is stationed. The topographic centerline point feature class includes the X, Y, Z, and M values of the vertices in the topographic centerline features. Additionally, the centerline point feature class includes a survey point code description and a reference to the survey data set from which it was derived, or a reference to a cartographic data set for cases where the point was acquired by cartographic digitization (figure 2).

Topographic centerlines are allowed to be proposed, as-built, or superseded. A proposed levee alignment can be entered from a cartographic data source and tagged with a proposed date, but no as-built date. This allows proposed levee alignments and projects along proposed levee alignments to be mapped alongside as-built levee reaches. Completed levee reaches can be tagged with a commenced date to indicate that the reach exists as a feature in the river or hurricane protection system. When a topographic centerline is replaced with new survey data, the previous as-built version is tagged with a superseded date to indicate that it is an historical version of that levee reach. Event information can then be copied from the old version of the centerline reach to the new version, and updated as needed to reflect any modifications to the geometry or stationing of the reach. Updating event table information records has proven to be simpler and more reliable than editing cartographic features and does not require a complicated check in and check out workflow.

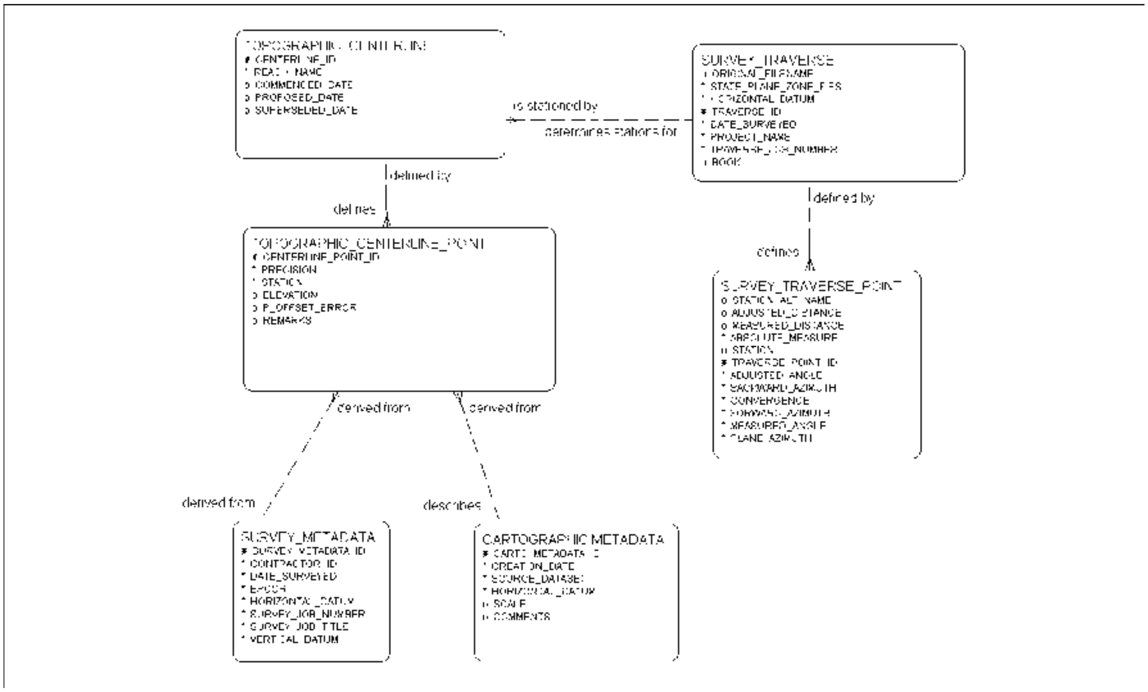


Figure 2 *– Entity-Relationship diagram for Topographic Centerlines and Topographic Centerline Points. Point features track lineage of the survey data set or cartographic digitization effort from which they were derived. A careful data user is able to assess which survey or surveys contributed positional information to the topographic centerline.*

Overview of Survey Traverse and Profile Data sets

A profile centerline is a series of surveyed points along a linear feature of interest. When surveyed in the context of a flood control system, the profile centerline represents the highest points along a levee or levee/floodwall configuration and can be used to measure the deficiency of a levee against its design elevation.

In addition to position and elevation, surveyed points from a levee centerline are also attributed with station values, which roughly correspond to the distance along the path of the centerline from a published benchmark location. The stationing is usually calculated from a separate survey called a baseline or traverse survey. A traverse survey is a series of angle and distance measurements starting at a published benchmark with an established elevation and proceeding to another published benchmark by establishing a series of control points. The primary purpose of the traverse survey is to provide a control network to which to tie the results of an elevation survey. The difference between the position of the starting published benchmark and the calculated position based on the traverse distance and angle measurements can be used to quantify the survey's systemic error.

The control network for a survey is referenced to a vertical datum. Current USACE-wide standards mandate that all surveys must be referenced to the NAVD88 vertical datum. Unfortunately, subsidence rates in Louisiana quickly add up to significant discrepancies between published benchmarks and the elevation results of field surveys. To account for highly volatile benchmark elevations, CEMVN has adopted two policies. First, in additional to a vertical datum, all surveys are referenced to a time period, called an epoch, for which the control network is valid. The current epoch is the 2004.65 epoch. Second, CEMVN has encouraged the use of Continuously Operating Reference Stations (CORS) [2] in survey control networks. CORS benchmarks electronically emit a data stream of elevations based on the Global Positioning System (GPS). Two such CORS benchmarks are located in southeast Louisiana at Hahnville and English Turn.

Although survey points can be collected with simple GPS receivers or leveling instruments, the most efficient method to collect survey data over wide distances is with Real-Time Kinematic (RTK) surveys. Rather than record one survey elevation at a time, RTK surveys collect continuous elevation readings. Once a reference station is established at a point of known elevation, an RTK system can use the GPS signals between the satellite, the base station, and the receiver to calculate an elevation difference when the phase of both signals align. The RTK receiver can be mounted on an ATV and driven along a levee to efficiently record elevations over long distances.

Generation of Levee Centerlines from Survey Traverses and Profiles

To load data from the various data sources, the CEMVN GIS team designed and implemented a custom data loading application. Python scripts were written to integrate with the Visualization Toolkit (VTK) [3] and the CEMVN-developed Geographic Extension for VTK. Surveys with historic stationing had to be compared with traverse features and matched to traverse stationing as closely as possible while still preserving path distance. The data loading program searches for a point in the traverse that is closest to the survey. Once the closest centerline point is identified, the stationing value from the traverse match point is assigned to that centerline point. Other points in the centerline are assigned stations based on the path distance before or after the matched closest point.

One common problem encountered during quality control was survey points that would appear out of order. Sometimes the problem was difficult to notice if the points were narrowly spaced. To mitigate the problem, CEMVN developed a validation script that measured the angular difference between every two consecutive pairs of points in the input centerline. An angular difference of 180 degrees indicates a path segment in the centerline that had reversed direction. Generally all values greater than 90 degrees were flagged for manual quality control.

The initial data for the topographic centerlines data set was acquired primarily from the RTK surveys from 2006 Southeast Louisiana Levee/Floodwall Assessment and the upcoming Mississippi River Hydrographic Survey and Mississippi River Navigation Book data sets. During the data loading process, surveys for areas under repair were not available and cartographic data from the IPET report on levee system performance during Hurricane Katrina was loaded for these gaps. Loading and quality checking of the MR&T and Southeast Louisiana HPS levees was completed in time for a GIS Day 2006 release of the new topographic centerline features. In addition to these major data sets, proposed alignments for the Morganza to the Gulf of Mexico Hurricane Protection Project [4], Donaldsonville to the Gulf of Mexico Hurricane Protection Project [5], and the West Shore Lake Pontchartrain Flood Control Project were loaded from cartographic data sources. Surveyed private levees from Plaquemines Parish were also acquired and loaded to supplement the coverage of the federal levee system. As of May 1, 2007, the entire hurricane protection system, the Mississippi River levees, and a subset of the local levees have been loaded into the CEMVN Levees Data Model (figure 3).

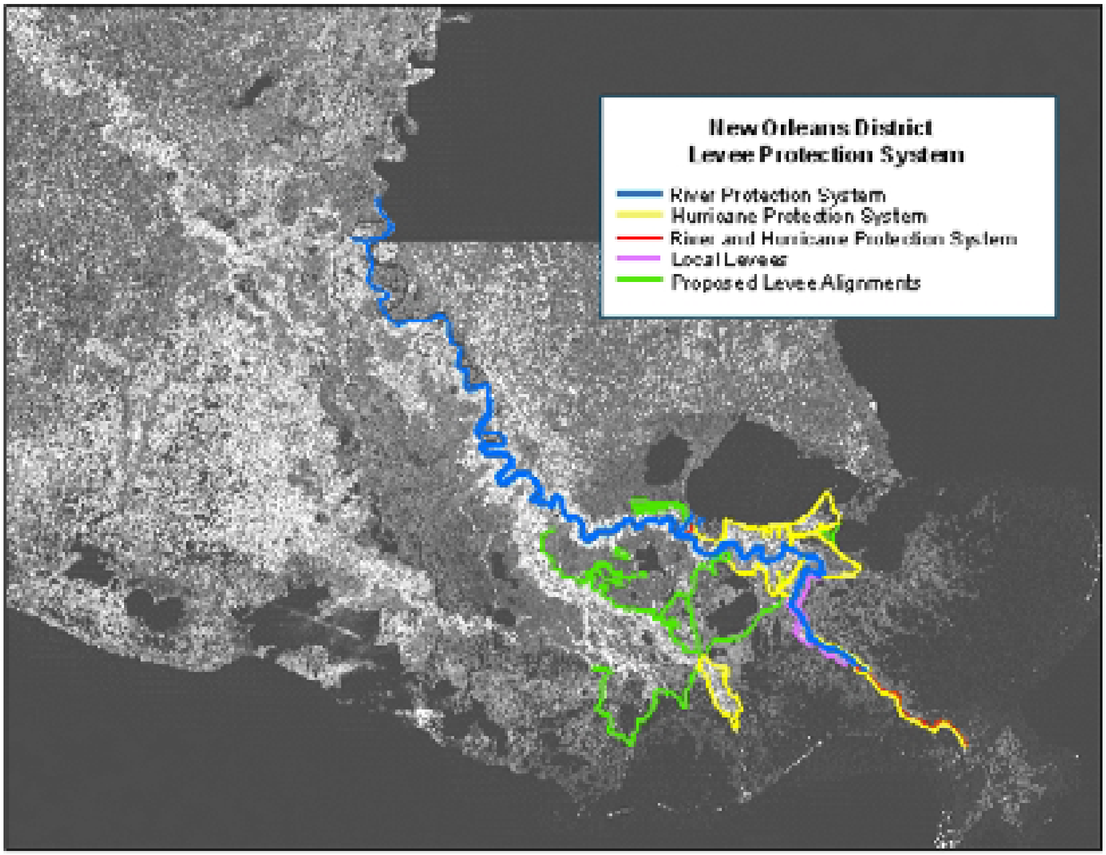


***Figure 3** – Overview map showing the portions of the New Orleans District protection system which have been uploaded into the CEMVN levees data model. River protection system appears in blue. Hurricane protection system is in yellow. Levees which meet both river and hurricane protection system requirements are in red. Local levees appear in purple, and proposed alignments are represented in green.*

In April 2006, a new project was launched to catalog available traverse and survey data for the Atchafalaya basin river protection system. All existing Atchafalaya surveys are referenced to the older NGVD29 vertical datum. Upcoming high resolution LIDAR flights of the Atchafalaya basin levees will be used to help develop NAVD88/2004.65 epoch elevation equivalents for the topographic centerlines, and levee features will be loaded with the most recent traverse stationing.

Balancing Historical Convention with Distance Preservation

The algorithm for assigning traverse stationing to topographic centerlines attempts to balance the error incurred by offsets or discrepancies between the traverse and the survey profile. Several special cases were encountered that required special attention. The first special case was a situation where a pump station floodwall is set back from the levee location. In some cases, the historical survey profile and traverse follow the floodwall alignment as it extends back to the pump station location (figure 4). In other cases, the historic survey profile and traverse cut directly across the mouth of the discharge canal, skipping the floodwall alignment (figure 5). Although it is possible to reference an approximate location for the pump station floodwall by using the stationing of the main levee reach, the stationing of the main reach cannot completely describe the location of the floodwall section, or provide real distance stationing for the floodwall alignment.

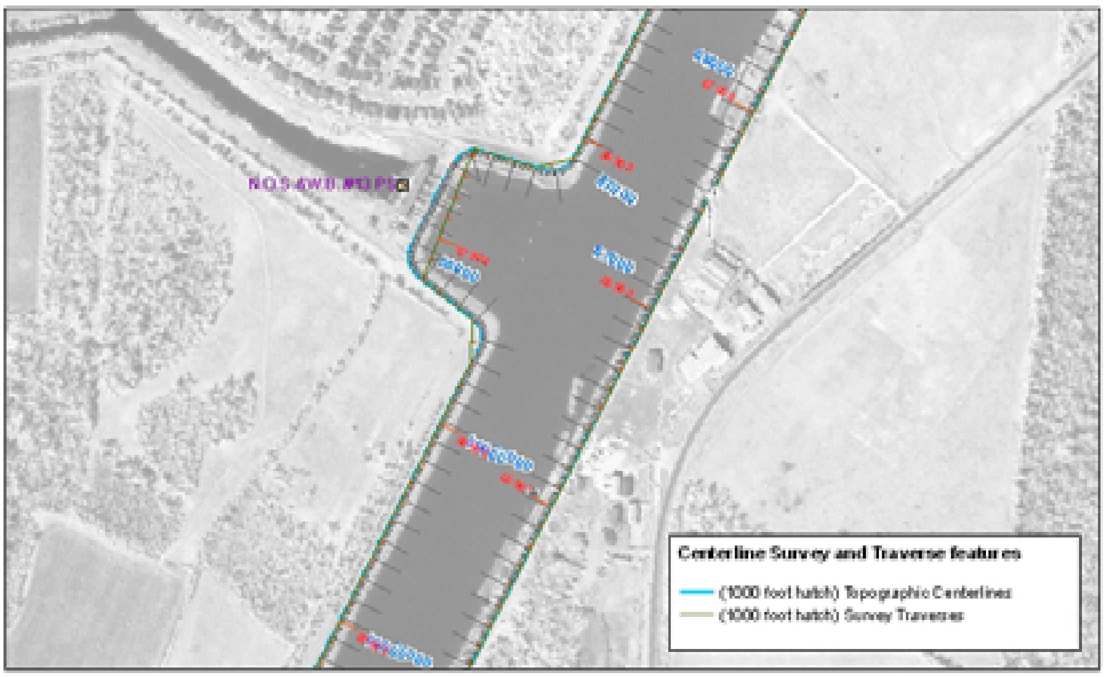


Figure 4 *– Example of survey (thick blue line with blue stationing numbers) and traverse (thin green line with red stationing numbers) from a section of the West Bank and Vicinity – Harvey to Algiers levee reach in the New Orleans West Bank hurricane protection system. In this example, the survey and traverse both follow the floodwall that extends back to the pump station structure. Traverse stationing was directly assigned to the survey centerline. Minor angular differences between the traverse and the centerline tend to cancel each other out over the length of the topographic centerline reach.*

If the topographic centerline was edited to include the pump station floodwall, the un-surveyed floodwall length would generate significant errors in the stationing for the remainder of the levee reach following the floodwall. The GIS team decided that the original traverse and survey profile should be maintained to preserve correspondence with the familiar stationing for the levee reach. A separate topographic centerline was generated for pump station floodwalls that were skipped by traverse stationing. In these cases, the stationing for the floodwall was defined to start at 0 and increase in the direction of the stationing for the main levee reach until the point where the floodwall rejoins the main centerline feature (figure 6).

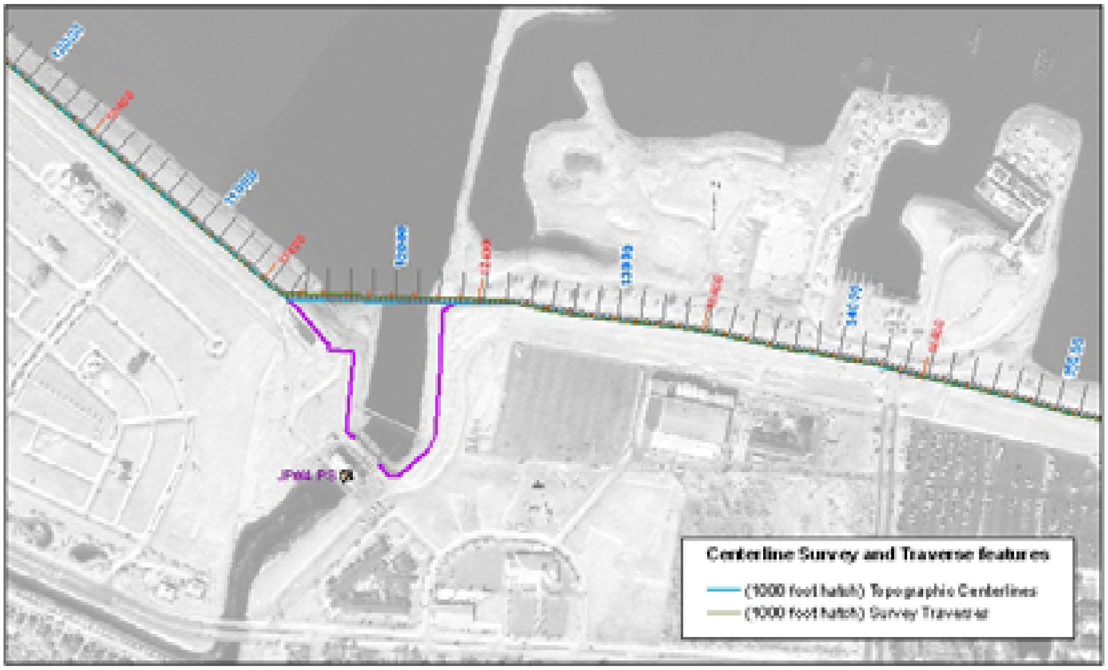


Figure 5 *– Example of survey (thick blue line with blue stationing numbers) and traverse (thin green line with red stationing numbers) from a section of the Lake Pontchartrain and Vicinity Jefferson Parish Lakefront levee reach in the New Orleans East Bank hurricane protection system. In this case, the survey centerline and traverse maintain a path along the lake edge, skipping the pump station floodwall (thick purple line). Assigning stationing from the lakefront reach to the pump station floodwall would have incurred hundreds of feet of discrepancy in the stationing for the lakefront levee.*

Another special case was the Jefferson-St Charles Return Levee. This levee reach was not only surveyed multiple times, with different starting points and different ending points, but was also surveyed in different directions at different times (figure 7). The oldest survey traverse for the topographic centerline ran south to north through an open area that would later become a runway within Louis Armstrong International Airport. No single survey traverse included the complete as-built length of the current alignment of levee and floodwall. A decision was made to generate a new stationing series for this levee reach, running south to north, and following the existing alignment of floodwalls that encircle the airport.

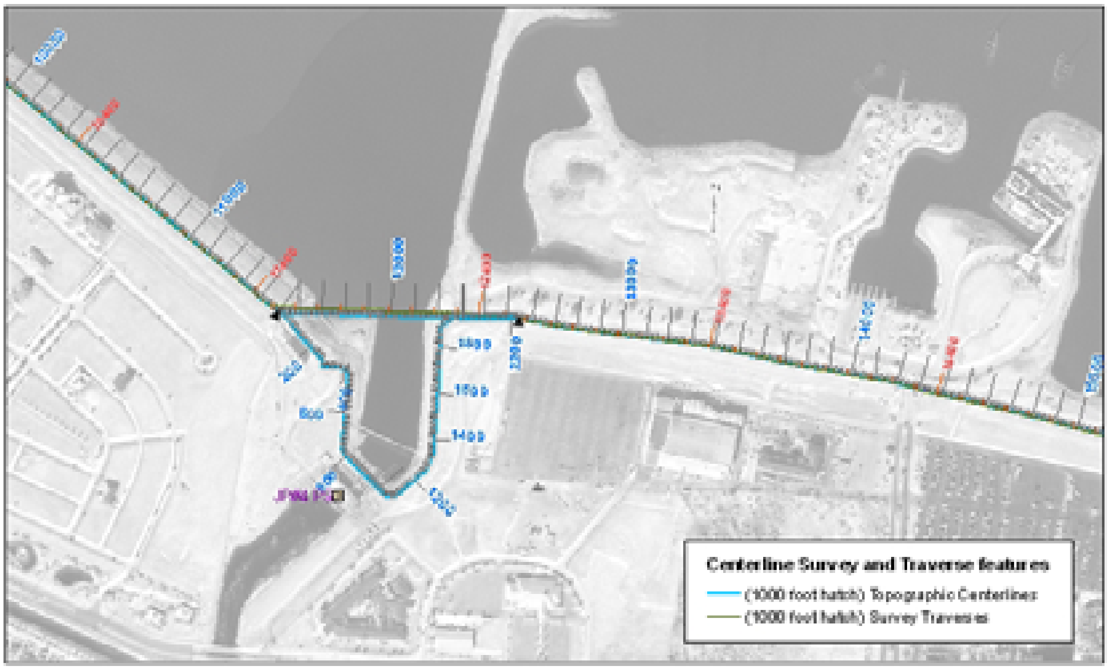


Figure 6 *– Pump Station Crossing along Jefferson Lakefront (same location as Figure 5). A separate reach has been created for the JP#4 pump station crossing. Its stationing starts at 0 and runs in the same direction as the Jefferson Lakefront levee stationing. Entire length of pump station crossing centerline is 2200 feet.*

Figure 7 *– Multiple traverse lines from past surveys of the St Charles – Jefferson Return Levee of the Lake Pontchartrain and Vicinity project of the New Orleans East Bank hurricane protection system. Traverses run in different directions, with different starting and ending points. An entirely new stationing was chosen for this levee reach, with measures starting at 0 and increasing northward toward Lake Pontchartrain.*

Topographic Centerline Classification Events

One of the most popular attributions of topographic centerlines is the IPET report classifications which distinguish jurisdictional authority, protection type, and construction description (figure 8). Jurisdictional authority is identified as either federal or local. Protection type is designated as river protection, hurricane protection, or river and hurricane protection. Because river protection and hurricane protection are not mutually exclusive categories, they are implemented as separate Yes/No flag attributes. Construction description is divided into levee, levee and floodwall, floodwall, foreshore dike, and structure gap. Because levee and floodwall are not mutually exclusive, these construction descriptions are also implemented as flag attributes. The structure gap description is used to identify breaks in the levee where there is a road, railroad, channel, or building structure. Gaps for roads, railroads, and bayous or drainage channels may either be gated or un-gated. A construction subtype attribute records the type of structure gap. If the construction material is floodwall, the construction subtype records whether the design of the wall is I-Wall, T-Wall, or L-Wall.

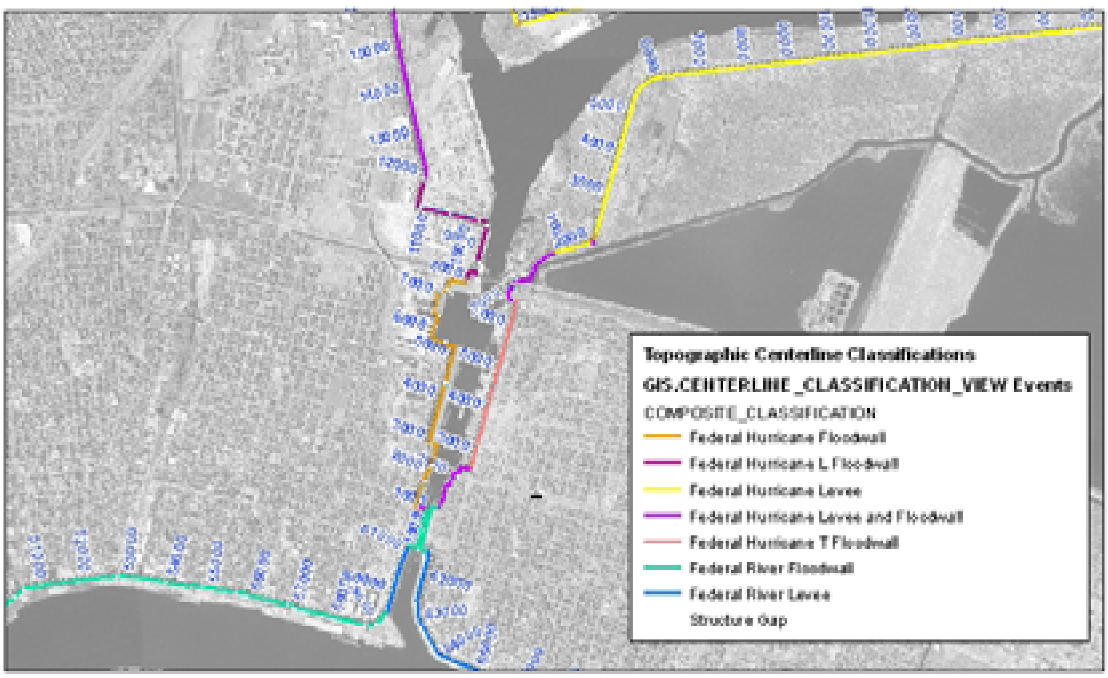
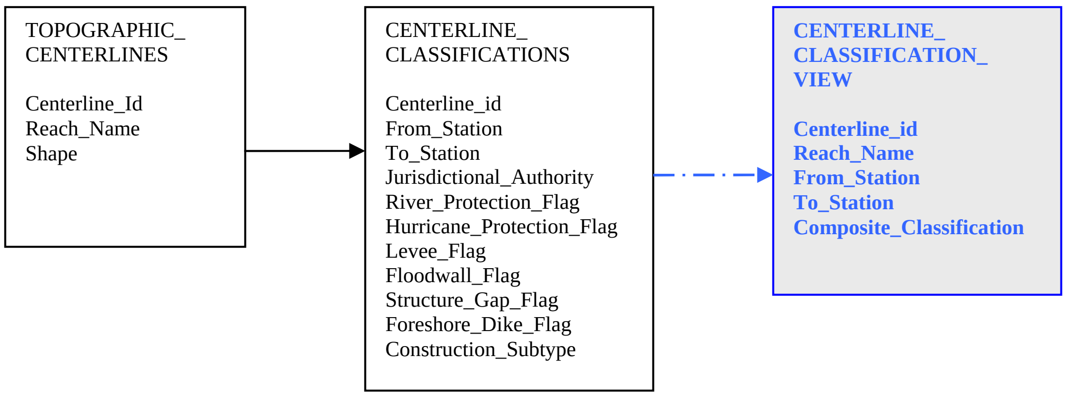


Figure 8 *– Example of standard map symbolization for topographic centerlines in the Inner Harbor Navigational Canal and Lock (IHNC) in New Orleans East. Composite classification is a combination of jurisdictional authority, protection type, and construction method. Note the river protection system in blue (levee) and green (floodwall) and the hurricane protection system in yellow (levee), orange (floodwall), and purple (levee and floodwall construction).*

An Oracle view decodes the information about jurisdictional authority, protection type, construction description, and construction subtype into a composite classification that is used in standard map attribution (figure 9). Categories in the composite classification include values like “Federal Hurricane Levee”, “Federal River Floodwall”, and “Local

Levee". These are the classification categories that have been used extensively in the past to symbolize the older digitized levees feature data sets. The new Centerline Classification events of the CEMVN Levees Data Model break down the old label categories into separate attributes. This allows the new classifications to be more detailed and flexible, however the old composite classifications can still be generated dynamically by logic in the database.




```
create or replace view centerline_classification_view as
   select
   cl_classification_id, tcntl_centerline_id, from_station, to_station,
     case jurisdictional_authority  when 'FEDERAL' then 'Federal_' when 'LOCAL' then 'Local_'
     end
     ||
     case river_protection_flag when 'Y' then
        case hurricane_protection_flag when 'Y' then 'River\Hurricane_' else 'River_'
        end
      else
        case hurricane_protection_flag when 'Y' then 'Hurricane_'
        end
     end
     ||
     case foreshore_dike_flag when 'Y' then 'Foreshore_Dike'
      else case structure_gap_flag when 'Y' then 'Structure_Gap'
         else case levee_flag when 'Y' then
           case floodwall_flag when 'Y' then 'Levee_and_Floodwall' else 'Levee'
             end
           else
             case floodwall_flag when 'Y' then
                case construction_subtype when 'T-WALL' then 'T_Floodwall' when 'L-WALL' then 'L_Floodwall'
                  else 'Floodwall'
                end
             end
          end
        end
     end as composite_classification,
        reach_name, jurisdictional_authority, river_protection_flag, hurricane_protection_flag,
     levee_flag, floodwall_flag, foreshore_dike_flag, structure_gap_flag, construction_subtype,
     section_name, 1 as offset_link_id
 from centerline_classifications, topographic_centerlines
 where tcntl_centerline_id = centerline_id;
```

Figure 9 *- Centerline classification information is accessed using the CENTERLINE_CLASSIFICATION_VIEW (an Oracle view that generates a single composite classification text string by combining jurisdictional authority, protection type, and construction type information). The attributes of interest can now be accessed separately or used as the traditional composite classification field.*

Information about jurisdictional authority and protection type applies to entire levee reaches and was easily acquired from existing sources. Information about construction description needed to be harvested at the highest possible level of detail. Some of the 2006 surveys included survey point codes that distinguished whether the survey point was crown of levee, top of floodwall, or top of structure. This information was aggregated from the topographic centerline points and assigned to centerline classification segments whenever available. When survey point codes were not available, the new topographic centerlines were compared to 6-inch resolution imagery data to find levee-floodwall breaks and floodgate locations. These original construction description assignments were later updated as floodwall design drawings, ground truthing expeditions, and new surveys have been submitted to the GIS team.

Once structure gap segments of levee reaches had been attributed as road, railroad, and channel floodgates, it became possible to replace a stand-alone floodgate point feature class in the database. Previously, levee centerlines and floodgate point locations had been digitized separately, at different scales, and, as a result, did not always align well on larger scale maps. A database view was created to calculate the median station of floodgate structure gaps and present them as single station values to be used as a point event theme (figure 10) . This Oracle view (figure 11) allows gated structure gap sections of levee to be symbolized with point features at the center of the gap. Floodgates will always fall precisely along the path of the topographic centerlines. A fourth type of floodgate, the industrial floodgate, was added to categorize gates in floodwalls where material is passed back and forth between docks and railroads, or between factories and railroads. Because floodgate locations are recorded as stationing along the topographic centerlines, it is possible to dynamically query the number and type of floodgates within other centerline events, such as the number of floodgates within a floodwall section or the number of floodgates within a project reach.

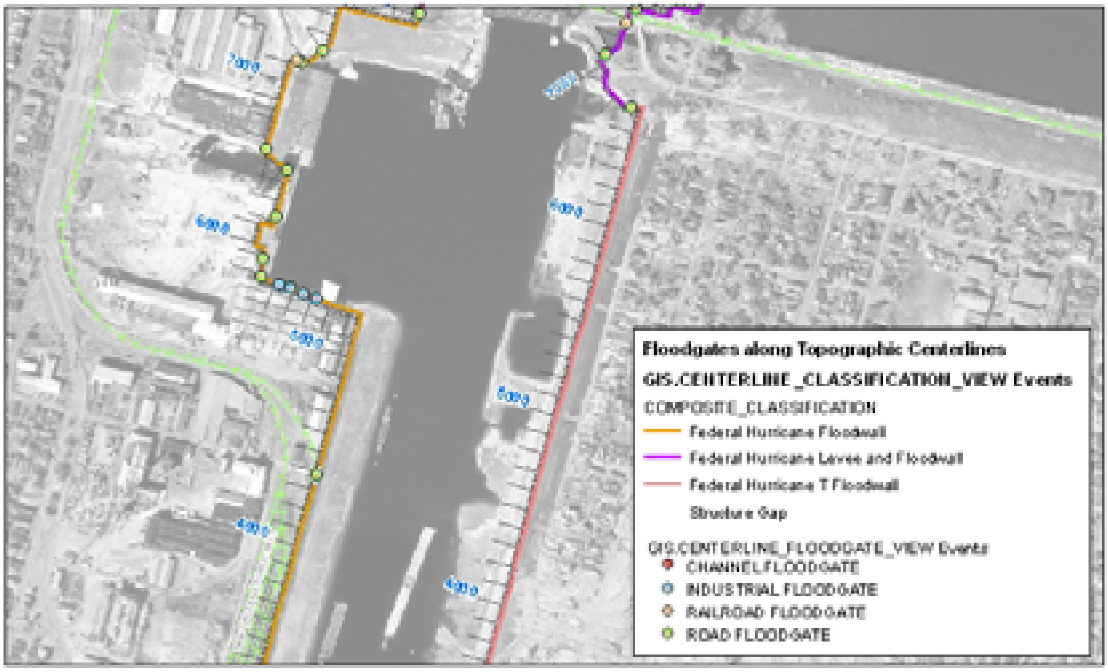
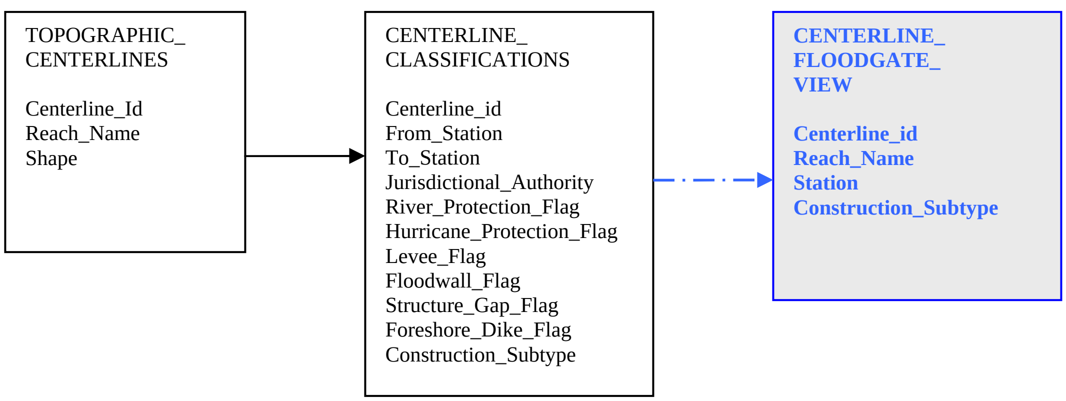


Figure 10 *– Example of floodgate view events along topographic centerlines from the Inner Harbor Navigation Canal and Lock (IHNC) in New Orleans East hurricane protection system. Road, railroad, and industrial floodgates are mapped as point events along the topographic centerlines.*




```
create or replace view centerline_floodgate_view as
 select tc.centerline_id, cc.cl_classification_id,
      cc.from_station + ((cc.to_station - cc.from_station) / 2) as station,
      cc.construction_subtype, cc.section_name, tc.reach_name
  from topographic_centerlines tc, centerline_classifications cc
  where tc.centerline_id = cc.tcntl_centerline_id and cc.structure_gap_flag = 'Y' and
      cc.construction_subtype in ('CHANNEL FLOODGATE', 'ROAD FLOODGATE',
                    'RAILROAD FLOODGATE', 'INDUSTRIAL FLOODGATE');
```

Figure 11 *– Floodgate locations are accessed using the CENTERLINE_FLOODGATE_VIEW (an Oracle view that generates a single event station for the median location within a gated structure gap section from CENTERLINE_CLASSIFICATIONS).*

Design Elevation Events

Design Elevations are elevations that are established as the height to which sections of a levee reach should be constructed. Within New Orleans District, there are several different design elevation series. The principal design elevation series is the Congressionally authorized design elevations that were mandated and funded under the Flood Control Act of 1965 [6] (figure 12). Since that Congressional authorization, there have been several hydraulic analysis efforts that have modeled hurricane frequencies and storm surge. Based on these models, engineers have calculated new design elevations to best protect Southeast Louisiana from storm flooding. The database design for Design Elevations includes a parent table for identifying information about the design elevation series and a child table Centerline Design Elevations which records the centerline identifier, starting station, ending station, and calculated design elevation for sections of levee reach. These two tables can store an unlimited number of design elevation recommendations.

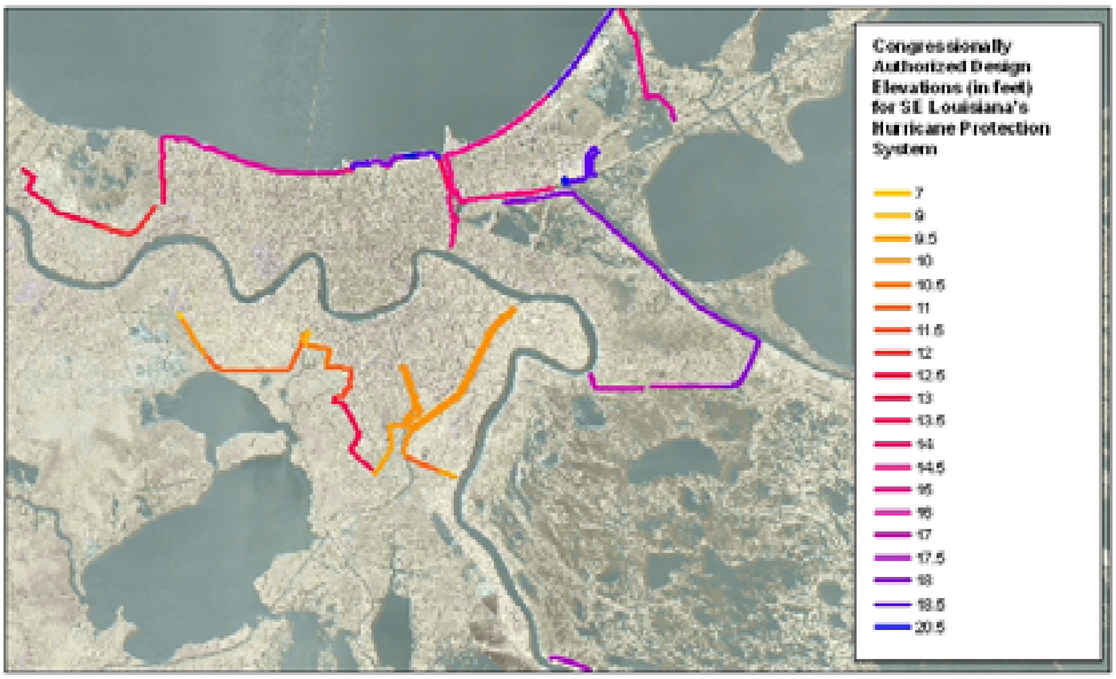


***Figure 12** – Overview map of Authorized Design Elevation for the hurricane protection system in Southeast Louisiana. Design elevations are stored as from station and to station references along the topographic centerline routes.*

A GIS user can find the results of the design elevation series they are interested in and display this elevation information as linear events along the topographic centerline routes. Design elevations can be compared to existing elevations, or other design elevation calculations, because all design elevations are recorded as stationing referenced to the same topographic centerline geometry. As hydraulic modeling for one hundred year storm probabilities is completed, the one percent exceedance design will be loaded into the same tables that store the 1965 Congressionally authorized design elevations.

Plan and Profile Map Generation

Using the CEMVN Levees Data Model, the New Orleans GIS team has been able to automate the map creation process for Plan and Profile maps. Plan and Profile maps offer a useful tool for engineers by showing a plan view of a levee reach in the top half of a map sheet above a profile view that contains a graph of elevation along the same reach (figure 13). Elevation values are plotted along the distance of the reach from its starting point in the map. The profile graph maintains the same horizontal scale as the plan map and employs an exaggerated vertical scale. Typically, a design elevation is plotted with the surveyed elevation, showing the potential height deficiency of the levee.

Prior to implementation of the topographic centerlines with route measures, Plan and Profile maps were only generated in CAD. Now, the GIS production team is able to specify a start-station, end station and scale for each map and run a Python script (that utilizes cx_Oracle [7] as the database client and matplotlib/pylab [8] as the charting engine) to generate a profile graph of elevations along the length of the topographic centerline that fall within the station range defined for the map sheet. Similarly, since the design elevations are also attributed with start and end stationing, the profile generation program can overlap design elevation events with the surveyed elevation of the topographic centerline feature.

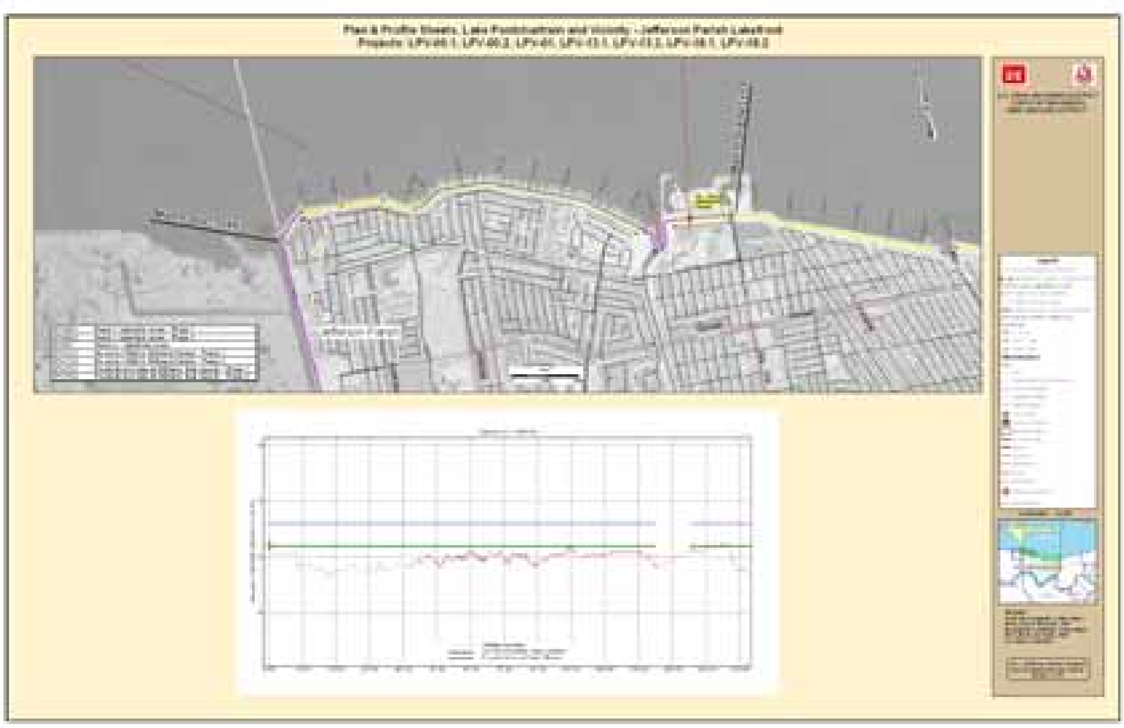


Figure 13 *– A Plan and Profile Map for the Jefferson Lakefront Levee of the Lake Pontchartrain and Vicinity hurricane protection system. Plan view of topographic centerline with station hatching appears on the top panel of the map sheet. Profile chart of surveyed elevation and authorized design elevation appears in the bottom panel.*

Construction Project Events

One of the highest priority requests from the Hurricane Protection Office (HPO) and Protection and Restoration Office (PRO) was a request to map construction projects along levee reaches. The GIS design for construction projects is an event table that stores a centerline identifier, starting station, ending station, and a foreign key reference to the project header record in a separate scheduling database. Construction projects can then be classified or queried by a number of different project attributes (figure 14). Construction projects can also be associated to pump stations and borrow site features in addition to sections along topographic centerlines.

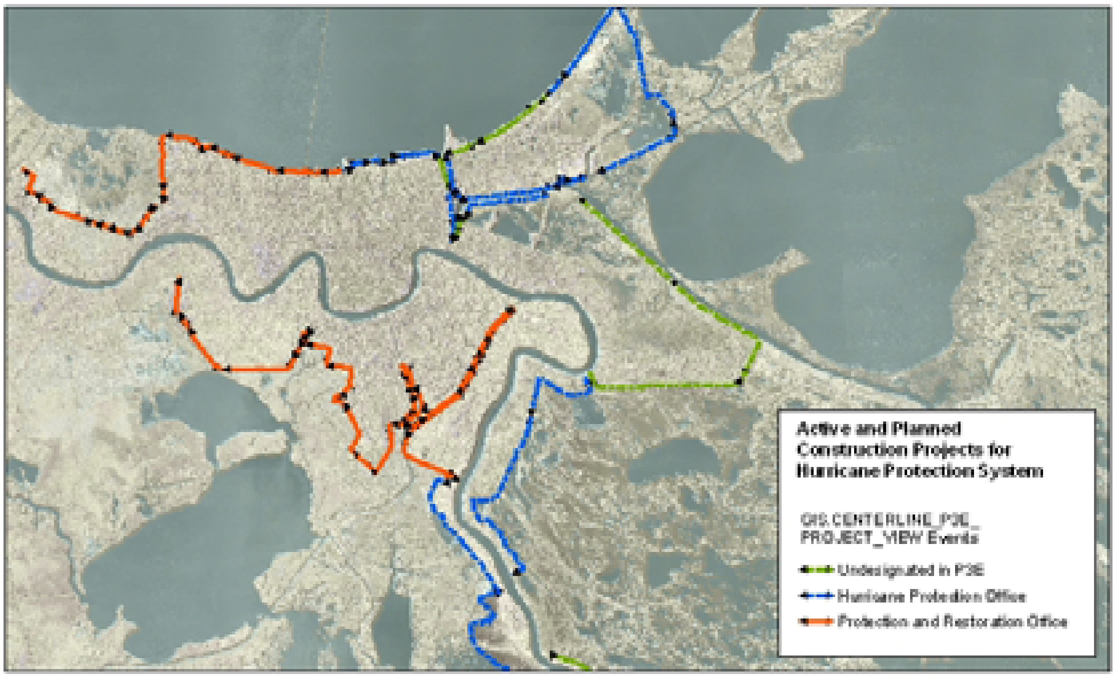


Figure 14 *– Overview map showing active and planned construction projects for the Hurricane Protection Office and Protection and Restoration Office. Projects include efforts to return the hurricane protection system levees and floodwalls to their authorized design grade as well as projects to build levees and floodwalls to one percent exceedance protection levels.*

Project managers working on the hurricane protection system make decisions, evaluate resources, and maintain schedules for the many steps required to raise a levee. The process involves many tasks, including obtaining right-of-way, performing soil testing, taking surveys, relocating utilities, and studying environmental and cultural impacts. The art of scheduling takes into account the fact that there are critical scheduling paths and the beginning of some steps depend on the completion of others. Ultimately a project manager needs to know, at any given time, the completion date when construction in his area will be complete.

A Primavera-based scheduling system called P3E and a variety of customized reports provide access to schedule information for the HPO and PRO projects. Project managers, however, also requested that project schedule information should be available at their fingertips from the GIS system. The GIS development team created an ArcGIS extension called Project Master to help project managers interact with construction projects in the GIS environment and produce project reports on the fly. The Project Master extension includes a base map of the District's available imagery, background layers, pump stations, borrow pits, and project reaches. The user can pick from a list of available project offices, project managers, and project names provided in listbox widgets on a custom toolbar. Selecting an entry applies a query definition to the project reaches and zooms to the minimum bounding rectangle of the features associated to the selected projects. For example, if a user selects a specific project from the toolbar, ArcMap will zoom to the extent of that single project and hide all other projects from the active view (figure 15).

***Figure 15** – An example of a Phase 1 construction project along the Jefferson Parish Lakefront levee of the Lake Pontchartrain and Vicinity hurricane protection system. Users of the Project Master extension can pick project choices from pull-down lists and interactively select project selection criteria.*

Employing a custom identify tool similar to the ArcGIS identify tool, a user can click on a project reach and view its project schedule information. Project Master includes a reporting component that generates an XML representation of records returned from dynamic queries. Nested information such as tasks within project schedules can be returned by inquiring against an associations table that records relationships between parent and child entities. The CEMVN associations table functions similarly to ESRI's relationship classes, but offers the added flexibility to manage spatial views and reference non-registered tables, such as materialized views of tables from the scheduling database. Using the XML generated by the query, Project Master applies XSLT to transform the XML into HTML and displays a rendered page in a pop-up window with an Internet Explorer ActiveX Component. The XML approach allowed the development team to separate content from presentation and complete the project on an accelerated timeline, while affording the team great flexibility in how to display information. Different XSLT stylesheets are prepared to present identical XML record sets in unique report layouts that cater to the presentation preferences of different user groups. Typical project reports include task tables, pictures of the project managers (figure 16), and even Gantt charts (generated by the JFreeChart library [9]) from an external web server (figure 17).

US Army Corps of Engineers
New Orleans District

Project Feature Report

Contract No.: LPV-02 1
Project Office: Protection and Restoration Office
Project Description: Reach 3 - Lakefront Levee (3rd Lift)-Phase 1

Section Length: 12000
Levee Length: 11996
Levee/Floodwall Length: 0
Floodwall Length: 0
Road Floodgates: 0
Railroad Floodgates: 0

Alfred Naomi
Project Manager
CEMVN-PM-E

Images:

Task Code	Task Name	Task Status	Target Start Date	Actual Start Date	Target Completion Date	Actual Completion Date	Detailed Task Status	Percent Complete
LPV02.1-A8010	LPV-02.1--P&S Effort	Complete	02/28/2006	02/28/2006	08/01/2006	08/01/2006	Finished Task	100
LPV02.1-A01	LPV-02.1--P&S Start	Complete	02/28/2006	02/28/2006	02/28/2006	02/28/2006	Finished Task	100
LPV02.1-A02	LPV-02.1--Soils Evaluation	Complete	02/28/2006	02/28/2006	03/13/2006	03/13/2006	Finished Task	100
LPV02.1-A05	LPV-02.1--30% Design	Complete	02/28/2006	02/28/2006	05/26/2006	05/26/2006	Finished Task	100

***Figure 16** – An example of the top of a project report generated by the Project Master extension. Information about the stationing of the project and the levee and floodwall lengths is queried from the GIS database. All project task and date information is accessed from snapshots of the P3E scheduling database.*

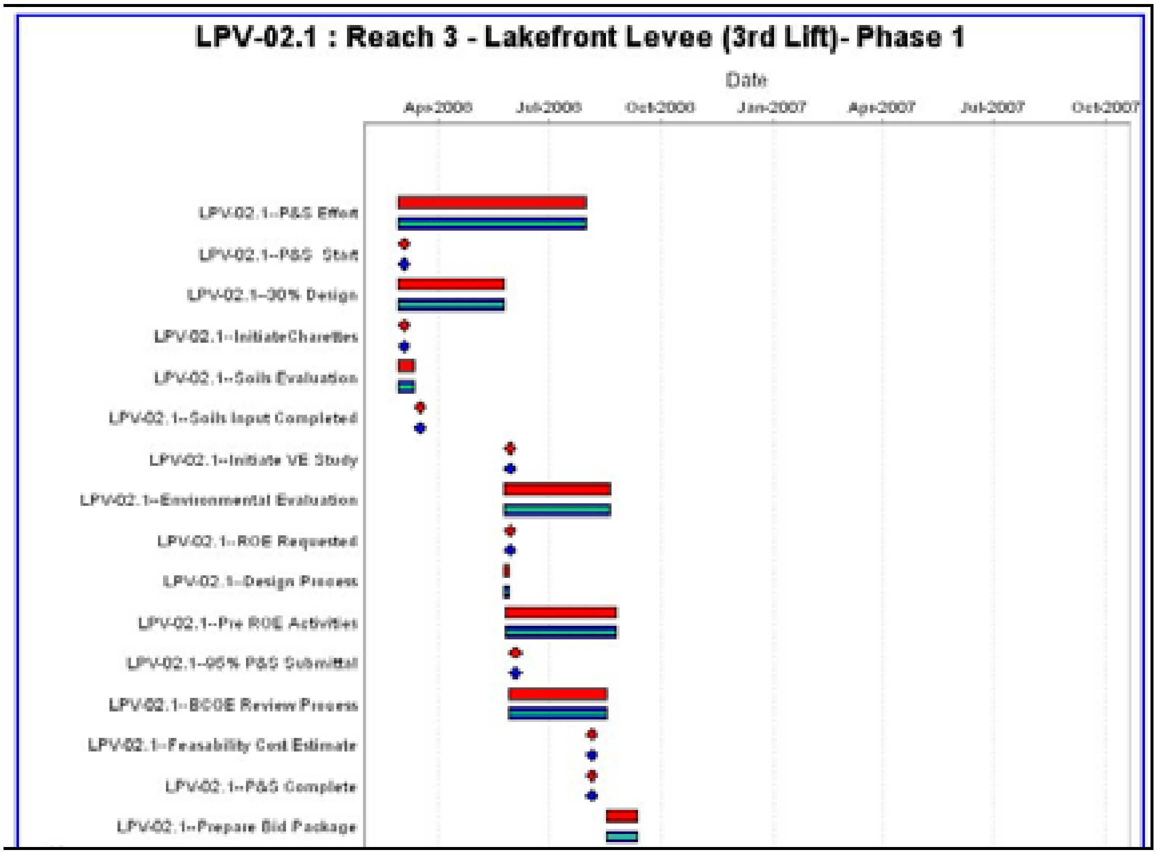


Figure 17 *– An example of a portion of the Gantt chart for the tasks in a project schedule. The Gantt chart is generated dynamically from project schedule information by a Java servlet that answers requests from the Project Master XML reporting engine.*

As part of future program enhancements, Project Master users will be able to query projects by expected milestone dates (such as projects that will have pile test work completed by a certain date, or projects that are expected to have construction completed by a certain date). At the center of this popular application is a levees database model that allows project locations to be mapped by specifying the beginning and ending station of the project work area along as-built and proposed topographic centerlines. Project information can be associated to any other information stored as stationing addresses against the topographic centerline data set. A plan and profile graph illustrating actual surveyed elevation compared to authorized design elevation can be generated with a single click against a centerline project feature and included in the Project Master XML reports (figure 18).

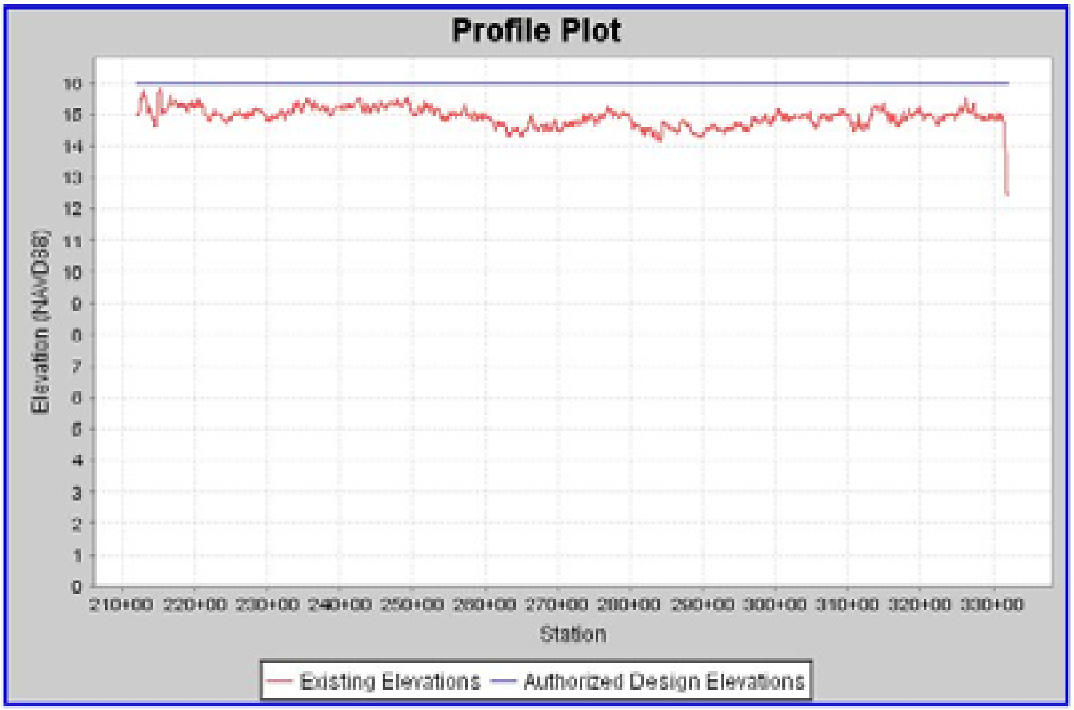


Figure 18 – An example of an elevation profile chart that has been generated for the Jefferson Lakefront levee project reach shown in figure 15. Existing elevation, represented with a red line, is queried from the elevation of the topographic centerline feature between the starting and ending station for the project. Authorized design elevation, represented with a blue line, is queried from the Design Elevations table for the stations that overlap the project extent.

The Road Forward for the CEMVN Levees Data Model

The U.S. Army Corps of Engineers was tasked in 2006 with the development of a National Levee Database [10]. The National Levees Database (NLD) project is being managed by the Remote Sensing/GIS Center of Expertise at the Cold Regions Research and Engineering Laboratory at Hanover, NH. Five USACE districts (Little Rock, Louisville, Sacramento, St Louis, and Portland) are participating in the pilot implementation of the NLD. New Orleans district, with its numerous repair and construction projects, and its requirement to model protection system design heights for hundred year storm events, could not wait on the design and implementation of the National Levees Database.

The NLD design was released at the beginning of 2007. The National Levees Database models separate linear feature classes for levee centerlines and floodwall centerlines, and includes aggregation tables that allow multiple levee and/or floodwall centerlines to be associated into Flood Control Segments, Flood Control Projects, and Protected Areas (figure 19). The NLD also includes a point feature class Levee Stationing Points which stores elevation and measured station of centerline points along a flood control segment.

In many ways, the New Orleans District GIS Team and the National Levees Database design team have been approaching the problem of levees data management in similar ways. New Orleans District, however, has found significant value in the assignment of stationing to levee reaches and the implementation of ESRI routes and measures. Having stationing as part of the topographic centerline linear feature, rather than recording stationing at regular point features that share topology with the linear levee segments, has added a flexibility for storing a wide range of levee information which has never been possible before. New Orleans District will keep its routes and measures and will be able to generate non-route levee and floodwall features, and stationing points, when needed, from the CEMVN Levees database, to create the spatial features required by the National Levees Database. The CEMVN GIS team will also begin a dialog with the National Levees Database team to share our experience with routes and measures and assess whether routes and measures can be adopted for levee data management at the national level.

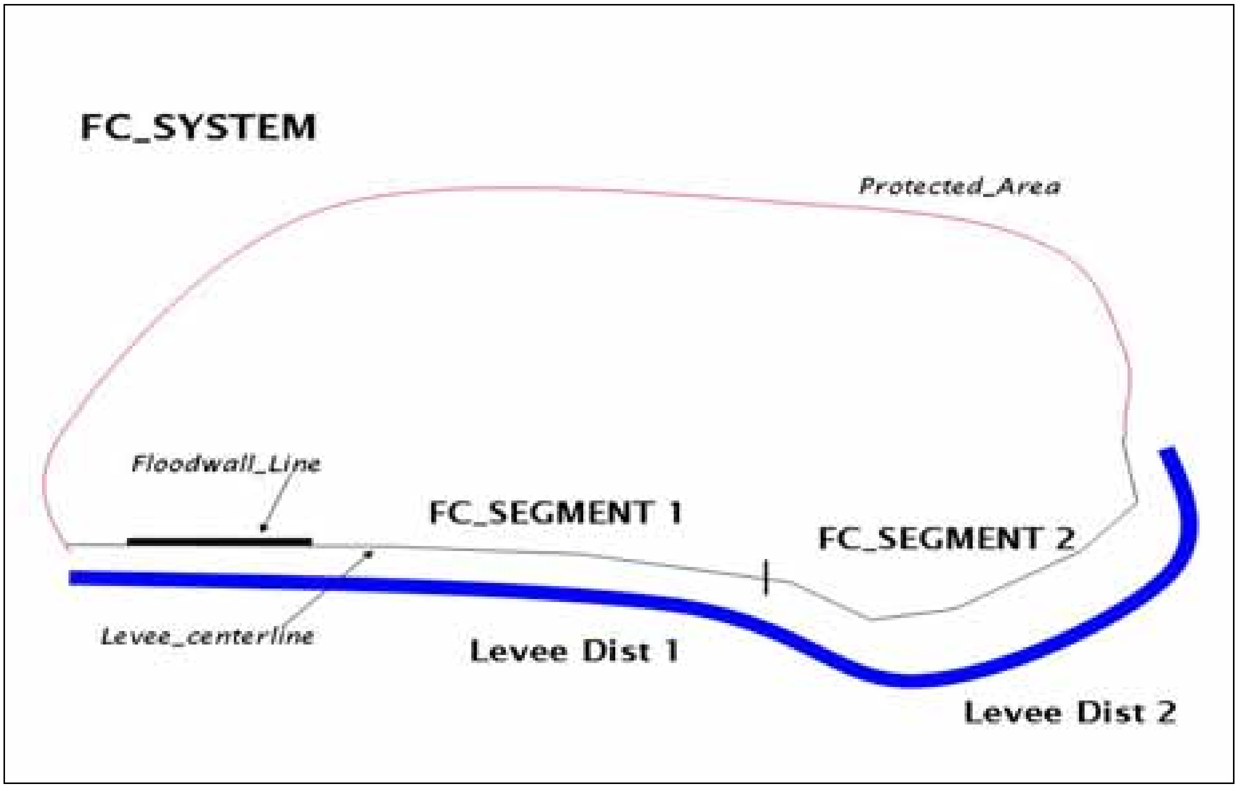


Figure 2. Relationships to FC_SYSTEM.

Figure 19 *– Representation of the hierarchy of levee features in the National Levees Database. This is a copy of Figure 2 from National Levee Database: Guidance, Standards, Specifications and ProductionPlan, USACE [10].*

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The GIS Design Team would like to thank Denis Beer, Enterprise GIS Task Manager for New Orleans District. Denis has offered unwavering support for team initiatives to improve GIS data management, and has kindly tolerated the various idiosyncrasies of the design and programming staff. Special thanks are also extended to Sam Falchook, who is the lead ArcObjects and Visual Basic programmer behind the success of the Project Master extension. Sam also repeatedly performs the thankless role of man behind the mouse at every meeting, demonstration, and training session. And, finally, special thanks are given to Shirley Rambeau and Mark Shields of CEMVN Design Services GIS production team. Shirley and Mark have contributed many long hours to produce the maps that have distributed our new levee features and their associated attributes to GIS consumers throughout New Orleans District. Without their brilliant cartography, few users would have benefited from the CEMVN Levees Data Model.

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