LAKE BELT STUDY AREA: HIGH-RESOLUTION SEISMIC REFLECTION SURVEY, MIAMI-DADE COUNTY FLORIDA

US Geological Survey
Open-File Report 02-325

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Executive Summary

The Northwest Dade County Freshwater Lake Plan Area (commonly referred to as the Lake Belt Area) is vital to the future planning and development of southeastern Florida. This area is located within one of the most environmentally sensitive parts of the state – the eastern borders of the Everglades National Park (ENP). The Lake Belt Area and Water Conservation Area BB (WCA BB) provide half of the limestone mining resources used in the state every year. Starting in the mid-1800s canals and levees were built in the area to drain and help develop economic and water resources including protection from floods and droughts. These construction projects have changed the natural water flow (hydropattern and hydroperiod) through the hydrologic system. Changes to the hydropattern and hydroperiod of the area have also had an adverse impact by disrupting the normal breeding patterns of species within the Everglades ecosystem.

The last several years there has been much attention focused on the restoration of the natural hydropattern of the greater Everglades ecosystem including the Lake Belt Area. Water management is key to balancing the needs of Everglades Restoration, flood protection, and economics of the adjacent communities. The South Florida Water Management District (SFWMD) and US Army Corps of Engineers (USACE) will implement the Comprehensive Everglades Restoration Plan (CERP), including several major components that are located within the Lake Belt Area. Successful implementation of CERP will require a thorough understanding of the geology and hydrogeology of the Everglades and specifically the Lake Belt Area.

South Florida has a long history of geologic investigation and this report incorporates much information from previous studies. There has been a wealth of studies of the Quaternary geology of south Florida, but until recently the pre-Quaternary geology has been less studied. This study relies heavily on several of these studies including USACE Serial No. 20 (1953), Nemeth and others (2000), Reese and Cunningham (1999) and Cunningham and others (2001).

The Lake Belt Area consists of approximately 230 km^2 (89 mi^2) located in north central Miami-Dade County, south of the Miami-Dade/Broward County line. Water Management structures for this area includes the East Coast Protective Level (ECPL) system and a series of drainage canals.

The objective of this study was to develop a better understanding of the geology underlying the Lake Belt Area by conducting a high-resolution, seismic reflection survey of area canals. High-resolution, seismic reflection profiling is a water-based towed geophysical technique that can be used to identify subbottom geologic features. More than 109 line-kilometers (68 line-miles) of data were collected from 8 major canals plus the canal adjacent to the ECPL. Quality of profile data varied between good to moderate and poor depending on numerous variations in canal structure and lithology. Acoustic reflections were recorded from depths that varied greatly from 3 to 79 m (10 to 260 ft), but generally usable data were recorded from to 30 m (100 ft) below sea level. Approximately 80 per cent (84 km; 52 mi) of the canals yielded usable data including C-9, C-6, L-33, L-30, Wellfield Recharge, L-31, and Black Creek. Three canals from which there was no usable data include Tamiami Trail, Bird Drive, and the Snapper Creek Canal extension. The usable data were integrated with information from reports, published and unpublished core sections, original core descriptions from the SFWMD files, and personal communication with other researchers familiar with the study area.

In all canals surveyed, the Holocene sediments and Pleistocene Miami Limestone were removed during canal construction. The bottom of most canals has an acoustically transparent layer of undifferentiated muck. The first solid reflection recorded is the original surface left from canal construction within the Pleistocene Fort Thompson Formation that is typically composed of marine limestone, minor gastropod-rich freshwater limestone, and sandy limestone. The Fort Thompson Formation as described from core descriptions (pers. comm., see Appendix B) is a vuggy, hard to weak limestone (hard is described as good induration or 'the foundation was hard, solution-riddled limestone' USACE Ser. 20; weak is inferred as less dense friable limestone or poor induration). The rock-fabric facies within the Fort Thompson Formation stratigraphic cycles is moderately variable, but is conformable around much of the Lake Belt study area. The thickness of this unit varies from ~1 to ~25 m (~3 to ~80 ft). Beneath the Fort Thompson Formation are irregular alternating layers of sand, silt and limestone of the Tamiami Formation.

An acoustically transparent layer of undifferentiated sediment overlies a coherent reflection, which is the dredge surface of the canal. This surface is within the Pleistocene Fort Thompson Formation. In the upper acoustically transparent section there are numerous vertical features that are characteristic of shallow solution pipes or vugs, which commonly penetrate through more than one horizon and may be conduits for vertical water flow through the formation. In the Tamiami Formation, there are numerous features seen in seismic profile that are inferred as solution pipes and collapse structures. In general, the reflections shown in the upper 15 m (50 ft) of section shown in seismic profiles are flat continuous reflections that are assigned to the Ft Thompson and Tamiami Formations. An exception is the C-6 Canal, where instead there is a seismic reflection within the upper 15 m (50 ft) of section that is irregular but fairly continuous. Evidence from core descriptions indicates this reflection is produced by a lithologic contact within the Fort Thompson Formation between a weak limestone (poor induration) above and a moderate to hard limestone (good to moderate induration) below. This is a distinctive reflection not clearly identified beneath other canals.

In general, it is inferred that the highly variable depositional lithology of the area does not impact water flow as much as post-depositional dissolution that provides pathways and conduits for water to flow between units both laterally and horizontally.

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Figure 14. Seismic profile overlain with a core description (CB-S-4). There is a very irregular reflective horizon present in this profile (green highlight). It is inferred that the contact between the limestones with poor induration above and moderate induration below produces this reflection. The red highights may represent contacts (reflections) between the sand, silt, and clay units. Acoustic multiples (artifact of acquisition) partially mask the Ft. Thompson and Tamiami formation contact. Dashed line indicates the possible contact between formations as identified from core descriptions. Core descriptions were provided by SFWMD (see Appendix B). See Figure 13 for relative placement on seismic section and Figure 8 for map location.

Figure 15. Seismic profile overlain with core description (CB-S-5). It is inferred that the contact (continuous irregular green highlight) between the limestones with poor induration above and moderate induration below produces this reflection. The red highights may represent contacts (reflections) between the sand, silt, and clay units. Acoustic multiples (artifact of acquisition) partially mask the Fort Thompson and Tamiami Formations contact. Dashed line indicates possible contact between formations as identified from core descriptions Core descriptions were provided by SFWMD (see Appendix B). See Figure 13 for relative placement on seismic section and Figure 8 for map location.

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Appendix A. Boomer Seismic Reflection Profiles, Shotpoint Navigation, and Trackline Maps

Boomer Seismic Reflection Profiles, Shotpoint Navigation, and Trackline Maps of Data Collected During USGS Field Activities 01asr01, 01asr02, 02asr01, and 02asr02; by Karynna Calderon, Shawn V. Dadisman, Jack L. Kindinger, Dana S. Wiese, and James G. Flocks

Appendix B. Lake Belt Study Area: High-Resolution Seismic Reflection Survey, Miami-Dade County Florida

This Appendix services as an archive for digital resources used in this report

- Open-File Report text (PDF)
- Open-File Report Figures (Adobe Illustrator and PDF)
- Brower Index (Netscape and Internet Explorer)
- Core Descriptions Sheets (PDF and GIF)

Introduction

The Northwest Miami-Dade County Freshwater Lake Plan Area (commonly referred to as the "Lake Belt Area„) is vital to the future planning and development of South Florida (Fig. 1). This 230-km^2 (89 mi^2) area is located within one of the most environmentally sensitive parts of the state. It also provides half of the limestone mining resources used in the state every year. The majority of lands located within the Lake Belt Area are wetlands that were once part of the historical Everglades watershed and were part of the Shark River Slough headwaters. Historically, Shark River Slough was a deep-water slough that collected flows from the eastern portion of the Everglades, including the western side of the Atlantic coastal ridge, and moved that water to the southwest (Fig. 1).

In 1850, the federal government passed the Swamp and Overflowed Lands Act. Which granted the State of Florida the right to drain and develop the Everglades. By the 1930s, public works projects had successfully created 645 km (400 mi) of canals in the Everglades. At the eastern edge of the Everglades, a levee (East Coast Protective Levee, ECPL) was constructed to stop water from flowing east (Fig. 2). As a drought protection measure, shallow impoundments (Water Conservation Areas, WCA) were created in the Everglades to the west of the study area (Fig. 2). These impoundments are interconnected with a network of canals that traverses the study area and have gates (control structures) that control the flow of water through the area. This system of canals and impoundments provides a mechanism that helps speed water flow through the Everglades. Water stored in these areas provided a dry season water supply for the lower coast of Florida.

After completion of the ECPL and the adjacent WCA, lands east of the levee were cut off from surface water sheet flow and ground-water levels were lowered to provide flood protection. In addition, northeast Shark River Slough has received significantly reduced flow and the flora and fauna of the greater Everglades ecosystem, as a whole, has been impacted.

One of the consequences of the drainage has been an increase in ground-water flows from the WCA and Everglades National Park (ENP) to the urban drainage networks, to ultimately discharge into the ocean. One of the fundamental prerequisites for restoring the Everglades ecosystem is restoring the hydrology of the area. Hydrologic restoration efforts to date have focused on restoring more natural hydropatterns by implementing rainfall-driven water deliveries, improving water conveyance throughout the system, increasing storage capacity, and controlling the amount of water that is lost from the WCAs and Everglades National Park. Preventing water loss from the ecosystem through seepage is an integral component of restoration.

During the last several years, the greater Everglades ecosystem has been the focus of much attention. It has been a difficult task of balancing the needs of the mining industry and other land uses in the Lake Belt Area with the needs of the Everglades ecosystem. Hydropattern restoration is central to the recovery of several threatened and endangered species in the Everglades because of declining populations due to the disruption of their normal breeding patterns that resulted from disrupted water flow through the ecosystem. The recovery of these species will require the restoration of hydropatterns in the WCAs and ENP.

Water management is key to balancing the needs of Everglades Restoration, flood protection, and economics of the adjacent communities. Figure 2 shows the water-management canals within the study area. One of the by-products of flood protection has been the urbanization of significant areas of former Everglades located just east of the WCAs (Fig. 1, 3). Palm Beach and Broward Counties have been extensively urbanized to the edge of the Everglades in some areas. The pattern in north-central Miami-Dade County is different because the mining industry in north-central Miami-Dade County purchased large tracts of land during the 1960s and 1970s and since the mid 1970s the Dade County Comprehensive Plan has designated this area for open land uses and prohibited urban development (Fig. 3).

Over the next 50 years, significant change will come to the Lake Belt Area through major public and private investments. Mining interests will excavate limestone (Fig. 3) in accordance with federal, state and local permits, creating the largest network of freshwater lakes in south Florida. Miami-Dade County will implement wellfield protection regulations to protect the public water supply. The South Florida Water Management District (SFWMD) will acquire and restore wetlands necessary to mitigate for wetland losses that occur due to mining activities. The SFWMD and US Army Corps of Engineers (USACE) will implement the Comprehensive Everglades Restoration Plan (CERP, Fig. 4), including several major components that may be located within the Lake Belt Area. These future investments together compose an enormous opportunity to accomplish a number of public benefits related to Everglades restoration, water supply protection, public recreation, and the supply of building materials critical to the Florida economy.

Successful implementation of CERP will require a thorough understanding of the geology and hydrogeology of the Everglades, and specifically the Lake Belt Area. The primary concern to the SFWMD is surface- and ground-water flow, hydrology, and geology of the upper 61 m (200 ft) represented predominantly in this area by the Miami Limestone, Fort Thompson Formation and Tamiami Formation.

Previous Studies

Florida has a long history of geologic investigation, for a thorough up-dated summary the reader is referred to Randazzo and Jones (1997). Herein is a much limited referencing to the most relevant geologic and hydrogeologic studies. There have been numerous studies of the Quaternary rocks of southern Florida and the Florida Keys (e.g. Ginsburg, 1956; Stanley, 1966; Hoffmeister and Multer, 1968; Enos and Perkins, 1977; Harrison and Coniglio, 1985; Lidz and others, 1991; Shinn and others, 1989; Ludwig and others, 1996). Pre-Quaternary geology of southern Florida has been less studied until recently (e.g. Johnson, 1986; Warzeski and others, 1996). These studies refer primarily to regional geologic framework, lithologic, and stratigraphic topics. The following are more specific studies to the Lake Belt Area.

USACE - 1953 Pump Test Study in Central and Southern Florida

The USACE - Jacksonville District conducted pumping studies in south Florida in the early 1950s to examine the 'underseepage quantities ' and geologic sections along the conservation areas and protective levee system in what is now called the Lake Belt Area of the eastern Everglades (USACE Serial No. 20). The report states that pumping tests demonstrate that there is good correlation between aquifer lithology and thickness, and underseepage quantities. High quantities of underseepage were found at locations where the foundation was hard, solution-riddled limestone. The geologic cross sections and descriptions were excellent and have been included in this report where appropriate.

Seepage Study of the East Everglades:

Nemeth and others (2000) developed a coupled ground- and surface-water model (MODBRANCH) to estimate ground-water flow. This discussion relies heavily on the Nemeth and others (2000) report and the reader is referred to that report for details. The relative importance of Nemeth and others (2000) is due to its location in the central portion of this report’s study area. Nemeth and others (2000) identified seepage characteristics were for L-31N, a canal and levee system that separates the East Everglades from urban areas (Fig. 2, 3). The seepage study site is 110 km^2 (43 mi^2) and is located in the central portion of the Lake Belt Area study near the Tamiami Trail and Krome Avenue in Miami-Dade County, Florida (Fig. 4).

This site has been extensively monitored for ground-water stage, surface water stage and flow, and rainfall due to a municipal wellfield located within 2 km (1.2 mi) of the Everglades and concerns over the impacts of this wellfield on seepage rates.

The hydrogeology and some aquifer characteristics of the Nemeth and others (2000) study area are well defined based on previous studies by Causaras (1987) and Fish and Stewart (1991).

There are two semiconfining layers of low-permeability limestone in the study area. The shallower semiconfining layer is about 0.6 m (2 ft) thick and is located at the top of the Fort Thompson Formation, just below the Miami Limestone. The deeper semiconfining layer averages about 1.5 m (5 ft) thick and has nearly the same slope as the upper surface of the Tamiami Formation (Causaras, 1987). Regional water-table maps indicate that ground-water flows from west to east beneath Levee 31N (Fish and Stewart, 1991).

Hydrogeology of the Surficial Aquifer System

The surficial aquifer system underlies central Miami-Dade County to a depth of about 55 m (180 ft) below sea level (Fig. 5). The unconfined Biscayne aquifer in the upper part of the surficial aquifer system consists of the Pamlico Sand, Miami Limestone, Anastasia Formation, Key Largo Limestone, and the Fort Thompson Formation all of Pleistocene age as well as contiguous, highly permeable beds of the Tamiami Formation of Pliocene and Miocene ages. Fish and Stewart (1991) use permeability as a means to define the basal contact of the Biscayne aquifer beneath Miami-Dade and Broward Counties. The contact is where the Fort Thompson Formation, Anastasia Formation, or Key Largo Limestone grade laterally into less-permeable facies. If there are contiguous, highly permeable limestone or calcareous sandstone beds of the Tamiami Formation, the lower boundary is the transition from these beds to subjacent sands or clayey sands. Where the contiguous beds of the Tamiami Formation do not have sufficiently high permeability, the Fort Thompson Formation, Anastasia Formation, or Key Largo Limestone is the base of the Biscayne aquifer. In general, the basal contact extends from about 13 to 27 m (44 to 84 ft) below sea level in the southwestern and northeastern corners of the Lake Belt study area (Fig. 5). Below the Biscayne aquifer are less permeable limestone, sand, and sandstone of the Tamiami Formation.

The hydraulic conductivity is estimated to be 29,000 ft/d (feet per day) in the Biscayne aquifer and 470 ft/d in the Tamiami Formation below the aquifer (Fish and Stewart, 1991).

The Biscayne aquifer is recharged by rainfall in upland areas. This recharge infiltrates directly to the aquifer or by surface water that seeps downward through wetland sediments to the aquifer. In 1953, Levees 31N, 30 (to the north) and 31W (south of the study area) were constructed to store excess water during the wet season and transfer the excess water to areas of need during the dry season (Fish and Stewart, 1991).

South Florida Stratigraphic Studies

Stratigraphic investigations of Miocene-Pliocene siliciclastics of southern Florida prior to the 1990s focused on lithostratigraphy (Peck and others, 1979; Wedderburn and others, 1982;

Peacock, 1983; Missimer, 1984; Knapp and others, 1986; Scott, 1988; Smith and Adams, 1988; Missimer 1992). More recently, stratigraphic framework studies of the Miocene-Pliocene of southern Florida include Evans and Hines (1991), Warzeski and others (1996), Missimer (1997), Cunningham and others (1998), Guertin and others (1999), Missimer (1999), and Guertin and others (2000). In a regional stratigraphic study of southern Florida Reese and Cunningham (1999), and Cunningham and others (2001) provide excellent reviews of literature and stratigraphic discussion.

Reese and Cunningham (1999) have described the lithostratigraphy, geology and hydrogeology of south Florida including the study area (Fig. 6). Following on the earlier report, Cunningham and others (2001) integrated lithologic and paleontologic data from 89 test coreholes and cuttings from 18 test wells to map the lithostratigraphic boundaries, and developed facies associations and sequence stratigraphy of southern Florida. In their report, they use established chronologies integrated with new biostratigraphic data to describe depositional sequences of the proposed Long Key Formation (Cunningham and others, 1997) within the Peace River Formation (Hawthorn Group) and Ochopee Limestone and Unnamed Sand Members of the Tamiami Formation. Cunningham and Aviantara (2001) used ground-penetrating radar, digital optical borehole images, and cores to characterize the Biscayne aquifer. Their findings indicated that conduit-flow pathways within the Fort Thompson Formation are produced by well-connected, solution-enlarged pore space. These solution-enlarged pore spaces vary as a result of depositional textures, diagenesis in a meteoric-water system, and vertical position within the stacked lithofacies that combine to form each upward-shallowing cycle. Each depositional facies has unique solution features that are characteristic of the unit and can facilitate accurate assessment of the depositional and diagenetic facies. This would indicate that even though the rock-fabric facies within the Fort Thompson Formation stratigraphic cycles is moderately variable it is characteristically conformable within much of the Lake Belt study area.

Study Area

The Lake Belt Area consists of an approximately 230 km^2 (89 mi^2) area located in north-central Miami-Dade County, south of the Miami-Dade/Broward County line, west of the Homestead Extension of the Florida Turnpike (HEFT), east of Krome Avenue, and north of Kendall Drive (Fig. 7). Water Management structures for this area includes the ECPL System and a series of drainage canals. The ECPL System includes L-33, L-30, and L-31N, and separates the Lake Belt Area and lands to the east from WCA-3B and the ENP expansion area (Fig. 2). The levees allow higher water levels to be maintained in the WCA and ENP. Providing the primary drainage of lands to the east of the levees is a series of major canals that include the C-9, C-6, C-

4, and others (Fig. 2). These levees and canals are operated by the SFWMD. Smaller, secondary canals (such as Black Creek Canal) operated by Miami-Dade County and the South Broward Drainage District drain into the primary canal system.

Objective

The SFWMD and the US Geological Survey (USGS) have agreed to cooperatively work on a project to complete a high-resolution, seismic reflection profile of the area around several CERP projects. High-resolution, seismic reflection profiling is a continuously recorded towed geophysical technique that can be used to identify subbottom geologic features beneath bodies of water. The SFWMD needs to develop a better understanding of the geology underlying a number of areas within the Lake Belt Area. Characterization of the stratigraphy to a depth of about 61 m (200 ft) below land surface is considered critical to the success of several SFWMD projects. Analysis of the seismic data may identify sites for further detailed geologic investigation. The USACE is a partner to the SFWMD on all CERP projects.

The Lake Belt Reservoir Pilot Project and the L31N Seepage Management Pilot Project are the primary focus of this study. If time allowed, some seismic profiling may be done in other areas. The USGS, St. Petersburg Team agreed to complete high-resolution, single-channel seismic reflection profiling on up to 90 km (56 mi) of canals within the project area (Fig. 8).

Methods

Seismic reflection data is used to image and map sedimentary and structural features of the seafloor and subsurface. These data are useful in mapping the extent of the subsurface structure, sediment thickness, and depths to various stratigraphic horizons, as well as in assessing other submarine and subsurface geologic characteristics and features. These data were collected as part of the CERP project done in cooperation with the South Florida Water Management District. Seismic reflection profiles are acquired by means of an acoustic source (usually generated electronically) and a hydrophone or hydrophone array. Both elements are typically towed in the water behind a survey vessel (Fig. 9). The sound source emits a short acoustic pulse, which propagates through the water and sediment columns. The acoustic energy is reflected at density boundaries (such as the seafloor or sediment layers beneath the seafloor) and detected at the hydrophone. This process is repeated at intervals ranging between 100 milliseconds (ms) and 1 second (s) depending on the source type. In this way, a two-dimensional image of the geologic structure beneath the ship track is constructed.

Boomer and Navigational Data Acquisition

To collect the seismic profiles for this study a TritonElics Delph High-Resolution Seismic Profile System (HRS) was used with proprietary hardware and software running in real time on a BSI Portable PC, Win98 OS. Digital data were stored on internal hard disk and transferred to compact disk (CD-ROM). The acoustic source was an electromechanical device, a GeoPulse Model 5420A Power Supply firing an Applied Acoustics AA300 Boomer Plate mounted on a catamaran sled (Fig. 9). Power settings were 100 to 280 joules depending upon data quality during acquisition. The Boomer is a broad-band acoustic source with a frequency range of 2.0 to 6.0 kHz. A NextGen-10 channel hydrophone streamer was used to detect the return acoustical pulse. This pulse was fed directly into the TritonElics Delph system for storage. Variations in data collection were necessary to improve data quality as physiography and lithology changed. Seismic data were saved and stored in SEG-Y format, a standard digital format that can be read and manipulated by most seismic-processing software packages. The seismic profiles presented in Appendix A (CD-ROM insert) are the processed profiles only (see explanation – Boomer Data Processing below). These data are stored in GIF-formatted image files. Navigation data were collected using a CSI DGPS receiver using WAAS correction, Hypack Lite Navigation software on an Amrel Laptop PC (Win95 OS). Differential GPS navigation was fed to the seismic acquisition system every second by a WAAS/Beacon DGPS receiver. The accuracy of this receiver is to within 5 m, however, the recorded data required some editing. These edited results were used to generate the trackline maps presented here. The shotpoint data has not been corrected to reflect the offset between the source and the GPS antenna. Position fixes for every 500 shots and for the start of line are also provided as an aide for easy registering of the data after projection.

Field Activities

Each field excursion was given a unique field activity number that included a two digit year identifier (02ASR01), a three digit activity, project, or program identifier (02ASR01), and a two digit 'Cruise Leg' number (02ASR01). Under each activity are individual geophysical line numbers including a two digit year identifier (02b02), acquisition tool (b for Boomer, 02b02), and two digit line number (02b02).

Field Activity 01ASR01, the seismic source employed consisted of a boomer transducer providing 100 joules per shot. The reflected energy was received by the NexGen hydrophone streamer and recorded by PC-based TritonElics Delph Seismic acquisition software. The streamer contains 10 hydrophones evenly spaced every 2 m. Only data received by elements 7 and 8 were summed for line 01b01 and for line 01b02 through shot number 2,819 (Fig. 8 for locations).

Afterward, only data received by elements 8 and 9 were summed. The streamer was positioned parallel to the boomer sled and laterally separated from it by approximately 3 m (Fig. 9). The sled was towed approximately 5 m behind the GPS antenna. The sample frequency of the data was 12 kHz and the total record length was 100 ms. The Boomer firing rate was every 0.5 sec, which resulted in a shot spacing of about 0.64m.

Field Activity 01ASR02, the seismic source employed consisted of a boomer transducer providing 280 joules per shot. Only data received by elements 8 and 9 where summed for line 01b01 through shot number 8,903 (Fig. 8 for locations). Afterward, data received by element 10 was also summed. The streamer was positioned parallel to the boomer sled and laterally separated from it by approximately 3 m. The sled was towed approximately 5 m behind the GPS antenna.

Field Activity 02ASR01, the seismic source employed consisted of a boomer transducer providing 280 joules per shot. Only data received by elements 8, 9, and 10 were summed for line 02b01 and for line 02b02 through shot number 1,748. Only data received by elements 5, 6, and 7 were summed for line 02b02 between shot numbers 1,750 and 2,828. For the rest of line 02b02 and for all other lines, only data received by elements 4, 5, and 6 were summed. The streamer was positioned parallel to the boomer sled and laterally separated from it by approximately 3 m. The sled was towed approximately 5 m behind the GPS antenna. The sample frequency of the data was 12 kHz for line 02b01 and 24 kHz for all other lines.

Field Activity 02ASR02, the seismic source employed consisted of a boomer transducer providing 280 joules per shot. Only data received by elements 3 and 4 were summed. This resulted in a higher signal to noise ratio for the data. The streamer was positioned parallel to the boomer sled and laterally separated from it by approximately 3.5 m. The sled was towed approximately 5.5 m behind the GPS antenna through shot number 8,230 of line 02b01, and approximately 7.5 m behind the antenna for the rest of the line. The sample frequency of the data was 24 KHz and the total record length was 100 ms.

Boomer Data Processing

The raw SEG-Y data was processed using Seismic Unix (SU) to produce the GIF formatted seismic profiles included in this report. A representative data processing sequence consisted of: 1) bandpass filter: 300-500-2500-3000 Hz, 2) automatic gain control, 3) postscript display at 15 ms/in and 215 shots/in., and 4) convert postscripts to GIF format. These data are included (inset) as Appendix A on CD-ROM.

Data Interpretation

The TritonElics Delph Geophysical system measures and displays two-way travel time (TWT) of the acoustical pulse in milliseconds (ms). Amplitude and velocity of the signal are affected by variations in lithology of the underlying strata. Laterally consistent amplitude changes (lithologic contacts or correlations of acoustic impedance in similar lithologies) are displayed as continuous reflections on the seismic profiles. Depth to reflection is determined from the TWT, adjusted to the subsurface velocity of the signal. Carbonates have a wide range of velocities such as those reported by refraction studies conducted in areas within Alachua County, Florida (Weiner, 1982) yielded velocities of 1707 to 4939 m/s (5599 to 16,200 ft/s) for the Hawthorn Group sediments. Weiner (1982) reported lower velocities for the sand and clay sediments and higher velocities for the carbonate sediments. Suggested compressional velocities for Hawthorn Group sediments for the Florida Platform range from 1500 to 1800 meters per second – m/s (4920 to 5904 feet per second – ft/s; Tihansky, pers. comm.; Sacks and others, 1991, Kindinger and others, 1997, 1999). Due to the vertical variability of the Lake Belt Area geology (with alternating layers of carbonates, sand and silt) within this report (Cunningham. pers. comm.), we will use a mid-range velocity TWT of 2000 m/s (6560 ft/s) that is an average velocity for the Key Largo Li (Anselmetti and others, 1997).

More than 110 line-km (68 line-mi) of data were collected from 8 major canals plus the canal adjacent to the ECPL (Fig. 8). Quality of profile data varied between good to moderate and poor depending on numerous variations in canal structure and lithology (Table 1). These data were integrated with information from reports, published and unpublished core sections, original core descriptions from the SFWMD files, and personal communication with other researchers familiar with the study area.

Time to Depth Conversions

Time to depth conversions is a two-step process. Step 1 involves the conversion of the canal water column from time to a datum (depth in m/ft below sea level). A standard datum is necessary for the comparison of seismic profiles to cores. This standardization was accomplished using a velocity of 1500 m/s (4920 ft/s) as a general speed of sound through sea water (due to the resolution of the boomer data [1 m, 3.3 ft], higher resolution frequencies fall below the resolution of the data). This provided a scale by which to measure water depth, then subtracting 1.52 m (5 ft) for a standardized datum to sea level. For example in Figure 10, the standardization shows that the bottom of the C-9 canal is 2.1 m (7 ft) below sea level. Beginning at the canal bottom a velocity of 2000 m/s (6560 ft/sec) is used (general velocity of sound through variable carbonate units, see discussion above).

Results

Since 1993, the USGS (in cooperation with Florida water management districts) has been developing and redesigning marine seismic acquisition and processing techniques to be used in restricted freshwater lake and canal environments (Kindinger and others, 1997, 1999, 2000). Acquiring continuous, high-resolution, single-channel seismic profiles from shallow freshwater lakes and canals has had varying degrees of success. In most cases, it has been very useful in combination with core descriptions, gamma logs and other data in describing the shallow geology (0 to 400 m, 0 to 1300 ft). Geologic characterization is in turn used to identify conduits that may provide a mechanism for surficial and aquifer waters to mix. The technique has also had limited success in identifying subsurface structural anomalies, such as fractures and subsidence features that may inhibit or provide differential ground-water flow.

Success of these techniques is dependent on the lithology beneath each lake or canal, and availability of described cores. The core descriptions used in this report were from cores that were collected adjacent to the canals, thus projected a short distance directly into the canals where the seismic data was collected. The effective resolution of these data is approximately one meter (3.28 ft) but varies due to acoustic velocity differences with changes in lithology and depth within the profile. Canal structure (such as width and depth) along with the presence of 'biogenic gas' (from organic-rich sediment) also effects the quality and penetration of the acoustic signal.

Acquisition results from this survey had varying degrees of success (Table 1). The canals with good to moderate quality profiles were C-9 (Fig. 10, 11, 12), C-6 (Fig. 13, 14, 15), ECPL canal (Fig. 16, 17, 18, 19, 20, 21, 22), and Black Creek Canal (Fig. 23). Data from the Wellfield Recharge Canal (Fig. 24) was moderate to poor with the rest of the canals being poor. Considering all seismic data approximately 80 per cent (84 km, 52 mi) of the canals provided usable data. The canals that did not have usable data include the canals along Tamiami Trail (C-4), Bird Drive, and the Florida Turnpike (Snapper Creek Canal extension) (Fig.8). Typically during acquisition there were several profiles collected within each canal sometimes due to obstructions such as control structures or low bridges for roads. Profiles from each canal have been combined to provide continuous interpretations of each canal and to facilitate discussion and figure production. Depth of interpretations was limited by the acoustic penetration. Depth of acoustic penetration varied greatly from 3 to 80 m (10 to 260 ft), but generally there was usable data to 30 m (100 ft). Hard carbonate contacts (identified from core descriptions, USACE Ser. 20 (1953) and Switanek (in press) are prevalent in the upper section of many profiles causing multiples and acoustic ringing that masked the underlying data signal. Good interpretations were commonly made to >0.02 sec TWT (50 ft at velocity of 6560ft/sec). Less confident picks were made to depths of 0.05 to 0.06 sec (150 to 200 ft at velocity of 6560ft/sec). Multiples and acoustic noise prohibited clear recognition of deeper geologic features in much of the data. In figures, profiles may have been reversed from the original direction of collection to provide a continuous image of the canal.

In all canals surveyed the Holocene sediment and Pleistocene Miami Limestone were removed during canal construction. The bottom of most canals has an acoustically transparent layer of 1 to 3m (3 to 10 ft) thick of undifferentiated organic-rich sediment. The first solid reflection (green in all figures) is the original surface left from canal construction within the Fort Thompson Formation (i.e. Fig. 11) that is typically composed of marine limestone, minor gastropod-rich freshwater limestone, or sandy limestone (Fig. 6). The Fort Thompson Formation is a vuggy, good to poor induration (hard to weak) limestone and with horizontally moderate variation. The rock-fabric facies within the Fort Thompson Formation stratigraphic cycles is moderately variable, but is conformable around much of the Lake Belt study area. Thickness of this unit varies from a ~1 to ~25 m (~3 to ~80 ft) (Fig. 5). Beneath the Fort Thompson Formation is irregular alternating layers of sand, silt and limestone of the Tamiami Formation (Fig. 11).

The seismic profiles shown in this report have identifiable reflective horizons that may or may not be recognized in corresponding core descriptions. This is controlled by several factors: (1) inexact velocity predictions for specific units (2000m/sec or 6560ft/sec TWT, was used

2001 Lake Belt Study Data Quality

Seismic Line No.	Canal	Kilometers	Data Quality
01ASR01_01	C-9	6.5	Ringing, moderate upper section
01ASR01_02	C-9	2.0	Ringing, moderate upper section
01ASR01_03	C-9	3.5	Ringing, moderate upper section
01ASR01_04	C-6 Miami Canal	9.0	Good to moderate
01ASR01_05	C-6 Miami Canal	4.0	Good to moderate
01ASR01_06	Tamiami	–	Moderate to poor
01ASR01_07	Tamiami	5.0	Moderate to poor
01ASR02_01	L-30, ECPL	10.5	Ringing
01ASR02_02	L-30, ECPL	9.25	Ringing
01ASR02_03	Well field Recharge Canal	4.75	Ringing poor
01ASR02_04	Well field Recharge Canal	5.75	Ringing poor
01ASR02_05	C-9 west	0.75	Ringing moderate to poor
01ASR02_06	L-33, ECPL	3.5	Ringing poor
01ASR02_07	L-33, ECPL	–	Test, poor
01ASR02_08	L-33, ECPL	–	Test, poor
01ASR02_09	L-31, ECPL	5.25	Good
01ASR02_10	Black Creek East	6.75	Moderate
01ASR02_11	Black Creek West/L-33	9.0	Good
02ASR01_01	Bird Drive	2.25	Poor
02ASR01_02	Tamiami	4.0	Poor
02ASR01_03	Tamiami	1.5	Poor
02ASR01_04	Snapper Creek	4.5	Poor
02ASR01_05	Tamiami	2.5	Poor
02ASR01_06	Bird Drive	1.25	Poor
02ASR02_01	L-31, ECPL	7.0	Moderate
25 segments	10 canals	108.5	

Table 1. Data quality of seismic profiles collected for the Lake Belt Study High Resolution Seismic Reflection Seismic Profiling Survey November 2001 to January 2002. Ten canals were surveyed in 25 segments for a total of 108.5 kilometers (not including two test lines making the total collected more than 110 km). Good to Moderate data in general was interpretable to total subsurface depths ranging from 100 to 150 ft (occasionally deeper). Poor and data with strong acoustic ringing were for the most part unusable. The survey started in canals (larger and deeper) with a high probably of success (to gain experience with local conditions) moving to potential problem canals (smaller and shallower), thus the appearance of early success and less success later.

across the section or profile), (2) vicinity of borehole location to seismic line, (3) seismic reflections on profiles are created by density changes not always represented by lithologic changes, or other variations that affect correlation, and (4) the extent of inferred fractures or subsidence features (collapse structures) are not detected in borehole surveys. Reflections indicated on the profiles by color highlights represent inferred features such as solution pipes, vuggy limestone, fractures or displacement structures (possibly collapse). These profile sections are best used to indicate trends and changes in the geology associated with porosity, and rock hardness that may affect water flow within the surficial aquifer.

Canal C-9

Canal C-9 is a west to east canal in the northern most portion of the study area (Fig. 2, 8). Figure 10 is a composite of four seismic profiles (Lines 01ASR01-01b01, -01b02, -01b03, and 01ASR02 01b05). There are several continuous reflections in the upper 15 m (50 ft) of the section that may represent the first contact of native rock below the ‘muck’ acoustically transparent organic-rich sediment (green) and a contact between a good and moderate induration limestone within the Fort Thompson Formation (Fig. 10, 11, 12). These interpretations are best used as inferred features (i.e. Inferred Collapse?) to indicate trends and changes in the geology associated with porosity, and rock hardness. Numerous features that may be shallow solution pipes or vugs (blue highlights) that infrequently penetrate through more than one horizon and may be conduits for vertical water flow through the formation. In Figures 11 and 12 Cores CB-xx-4, -5, and -3, respectively, are overlain on seismic profiles 01ASR01 01b01 at Shots 3500 to 5100 and 7300 to 9000, showing the upper limestone unit (Fort Thompson Formation) underlain by variable sand, silt and limestone lithology (Tamiami Formation). The top of the Tamiami Formation as identified from core descriptions is found between 16 to 29 m (55 to 95 ft) (Fig. 10). There are numerous features (red highlight) that may represent solution pipes and collapse structures found in the upper 30 m (100 ft) primarily in the limestone units. The seismic character at Line 01b01 Shot 6500 (Fig. 10) represents the most prevalent of what may be a collapse structure that penetrates to more than 45 m (150 ft). Throughout much of the canal the hard limestone (good induration) has reflected the acoustic signal causing multiples in much of the deeper section. The core data agree with the seismic data in that they reflect significant lateral variability in lithology of the study area (Fig. 11).

Figures 11 and 12 include closely spaced cores (CB-xx-4 and -5, -3, respectively) overlain on the seismic profile. These core descriptions clearly indicate the lateral and vertical variability of the geology within the study area. In the upper portion of the section continuous reflective horizons seem to generally correlate lithologic changes in the section. The contact between the Fort Thompson and Tamiami Formations identified in core descriptions is masked by multiples.

The upper section of the profile demonstrates a consistent seismic character showing what appear to be numerous inferred dissolution features that may be fractured or displaced material, solution pipes or vugs. These produce similar seismic characteristics in profile that are indistinguishable. These acoustic patterns are commonly seen in similar karst environments (Kindinger and others, 1999, 2000).

Canal C-6 (Miami Canal)

C-6 Canal, also known as the Miami Canal, is in the northwestern part of the study area and cuts across from northwest to southeast (Fig. 2, 8). Figure 13 is a composite of two seismic profiles (Lines 01ASR01-01b04 and -01b05). Unlike C-9, the seismic profiles do not show flat continuous reflections in the upper 15 m (50 ft) of the section, instead there is an irregular but fairly continuous reflection (dark blue highlight). Evidence from core descriptions indicates this reflection is produced by a lithologic contact within the Fort Thompson Formation between a weak limestone (poor induration) above and a moderate to hard limestone (good to moderate induration) below (Fig. 13, 14, 15). Above the contact there are numerous discontinuous reflections and features that may be shallow solution pipes or vugs (blue highlight). The dashed line may represent the top of the Tamiami Formation a sand facies below the limestone units of the Fort Thompson Formation (Fig 14). The contact between the two formations cannot be clearly distinguished in the seismic profile and is inferred. At Line 01ASR01 01b04 Shots 4900, 8200, and 13000 to 13500 are examples of possible collapse or dissolution features, all penetrate deeper than 38 m (125 ft) (Fig. 13, 15). In the deeper portions of the seismic section acoustic noise has masked any coherent signal.

The seismic character of the rock units beneath the C-6 Canal are very different from the C-9 Canal. The C-6 has the irregular reflection (dark blue line) representing a much different lithology, possibly allowing better penetration and return of the acoustic signal. More lateral reflective features are seen in this section that probably represent rock surfaces while in the C-9 the seismic character potentially represents dissolution features.

East Coast Protective Levee (ECPL) Canal

The ECPL Canal is a northerly trending canal along the western boundary of the study area and is comprised of three leveesL-31, L-30, and L-33 with each having an adjacent canal (Fig. 2, 8). Figure 16 is a composite of six seismic profiles (Lines 01ASR02-01b01, 01b02, 01b06, -01b09, -01b011 (partial); 02ASR02 01b01) and is shown in three panels (Fig. 16, 19, 22). To the south half of the canal, the geology represented in these profiles has many of the same seismic characteristics as profiles from C-9, but more features and deeper signal penetration (greater than 61 m - 200 ft). There are several continuous reflections in the upper 15 m (50 ft) of the section (e.g. green and purple highlights). Numerous features that may be shallow solution pipes or vugs (blue highlight) that penetrate through more than one horizon, these may be conduits for vertical flow through the formation. An example can be found in Line 01ASR02-01b09 Shot 3200 (profile from the southern portion of the study area) showing reflections that may be displacement features with possible collapse below. Other examples are in the next profile north (specifically 01ASR02 01b11 at Shots 4000 and 6500). Also cores DLBS-3 and -9 (Fig. 17, 18) show varying types of rock units including shelly-limestone and sandy units. In this case the dipping beds in Figure 18 are associated with alternating units.

In the southern portion of the EPCL Canal profiles the contact between the Fort Thompson and Tamiami Formation (as identified from core descriptions) is clearly discernible (Fig. 16, 17, 18, 19). This reflection produces weak multiples in some areas to the south. Going north passed Shot 7500 (Line 02ASR02 02b01) increasing hardness of the units above produce strong multiples that mask the Fort Thompson/Tamiami Formations contact (Fig. 16, 18). As seen in Figure 18, the lithology has changed with the presence of a wackstone unit not found in the core description approximately 3.0 km (1.8 mi) south (Fig. 17). Within the Tamiami Formation, core descriptions indicate several alternating rock units each having the potential to produce acoustic reflections. In this specific area with weak or no multiples there are many possible reflections that represent contacts between units or internal structures within the units.

Proceeding north in this canal the data quality decreases as the upper limestone unit increases in hardness. Seismic character of the upper most portion of the section (~7.6 m, ~25 ft) indicates many inferred solution pipes or vuggy features (blue highlights) penetrating the top of the limestone. Figures 20 and 21 show noisy seismic profiles with strong multiples and less discernible units below the upper hard limestone. Core descriptions from this area indicate that packstone and wackstone units of the Fort Thompson Formation overlie shell and sand layers of the Tamiami Formation (Fig. 20, 21). Hard lithologic units in the upper section have produced strong multiples in the profiles of Figure 19. Similar features and structures are seen in Figure 22 along with noisy chaotic signal returns. Throughout this report interpretations are best used to indicate trends and changes in the geology associated with porosity, and rock hardness.

Black Creek Canal

Black Creek Canal in the southern part of the study area (Fig. 8) and is connected with the ECPL canal. Figure 23 is a composite of two seismic profiles (Lines 01ASR02 01b011 (partial), 01ASR01 01b10). The subbottom of this canal has very similar seismic character and penetration as the ECPL canal (Fig. 16) and can be described in similar fashion with continuous reflections in the upper 15 m (50 ft) of the section. Numerous inferred features that may be shallow solution pipes or large vugs. Several examples of collapse may be seen at Shot 1500 – Line 01ASR02 01b11 and 5000 – Line 01ASR01 01b10. No core descriptions were available for correlation to these profiles.

Wellfield Recharge Canal

The Wellfield Recharge Canal is in the northern part of the study area (Fig. 8) and is connected with the ECPL canal through a water-control structure (Fig. 19). Figure 24 is a composite of two seismic profiles (Lines 01ASR02-01b003 and -01b4). Data collection in this canal was a challenge due to the presence of multiple construction boomers across the canal. There are areas of continuous and non-continuous reflections in this canal with inferred solution and possible collapse features. Signal penetration was limited along much of the canal, but near the mid-portion of Line 01ASR02 01b04 better penetration was acquired to below 61 m (200 ft). Core descriptions of DLBS-4 indicate that the upper limestone in this area has moderate to poor induration indicating a weak limestone (Fig. 24, 25). This weak limestone may allow a better signal to noise ratio providing a ‘window’ of better data.

Summary

More than 68 line-mi of data were collected from 8 major canals plus the canal adjacent to the ECPL. Quality of profile data varied between good to moderate and poor depending on numerous variations in canal structure and subsurface lithology. Depth of acoustic returns varied greatly from 10 to 260 ft, but generally there are usable data to 100 ft below sea level. Approximately 80 per cent (52 mi) of the canals provided usable data. The canals that did not have usable data include C-4 Canal, Bird Drive Canal, and the Snapper Creek Canal extension.

In all canals surveyed the Holocene sediment and Pleistocene Miami Limestone were removed during canal construction. The bottom of most canals has an acoustically transparent layer of undifferentiated muck. The first solid reflection recorded is the original surface left from canal construction within the Pleistocene Fort Thompson Formation. The Fort Thompson Formation is a vuggy, with poor to good induration, and has moderate stratigraphic variability that is conformable around much of the Lake Belt study area. Thickness of this unit varies from ~1 to ~25 m (~3 to ~80 ft). Beneath the Fort Thompson Formation is the Tamiami Formation with irregular alternating layers of sand, silt and limestone. The interpretations discussed in this report are best used as inferred features without direct verification to indicate trends and changes in the geology associated with porosity, and rock hardness.

In the upper 50 ft of most canals, the seismic profiles reveal several continuous reflections and numerous vertical features that are inferred to represent shallow solution pipes or vugs. The solution pipes or large vugs frequently penetrate through more than one horizon and may be conduits for vertical ground-water flow through the formation. The Tamiami Formation has numerous similar inferred features that may represent solution pipes and collapse structures. An exception to the general description of Fort Thompson and Tamiami Formations in these canals is the C-6 Canal with seismic profiles that do not show flat continuous reflections, instead there is an irregular, but fairly continuous reflection. This reflection is probably produced by a lithologic contact within the Fort Thompson between a weak limestone (poor induration) above and a moderate to hard limestone (good to moderate induration) below. This reflection is distinctive and not recognized beneath other canals.

In general, it is postulated that the highly variable depositional lithology of the area does impact ground-water flow due to the formation of the inferred post-depositional dissolution that could provide pathways and conduits for ground-water to flow between units, both laterally and horizontally. The post-depositional solution-enlarged pore spaces vary as a result of depositional textures, diagenesis in a meteoric-water system, and vertical position within the lithofacies of upward-shallowing cycles. It been demonstrated by Cunningham and Aviantara (2001) that each depositional facies has unique solution features that are characteristic of the rock units. This would indicate that even though the rock-fabric facies within the Fort Thompson Formation stratigraphic cycles is moderately variable it is characteristically conformable within much of the Lake Belt study area. Using high-resolution seismic data to identify trends of post-depositional dissolution features provides valuable information about the mechanics of differential ground-water flow.

Recommendations

The objective of this study is to improve the understanding of the geology and hydrogeology underlying the Lake Belt Area by conducting a high-resolution seismic reflection survey of area canals. Acquiring continuous high-resolution seismic profiles from shallow freshwater lakes and canals in Florida has had varying degrees of success. In most cases it has been very useful in combination with core descriptions, gamma logs, and other data in describing the shallow geology. In this study, the objective was successful because we now have better information about the extent and variability of subsurface units, but the quality of data acquired did not have adequate penetration to span the entire thickness of rocks and sediments that comprise the surficial aquifer. Perhaps, in future studies modifications of acquisition techniques, hydrophone spacing, or acoustic output (power) might provide better results in canals such as the C-4 Canal. Other modifications, such as configuring hydrophones and source to be laid on the canal bottom or to be towed near the bottom to minimize reflections from canal walls, and to develop a method to shield receivers from top and side reflections. Canals similar to the Bird Drive Canal are the most challenging of canals due to the shallow and narrow nature of the canal prohibits data collection.

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The use of trade, product, and firm names used in this report are for descriptive purposes only and in no way imply endorsement by the U. S. Government. The U.S. Geological Survey and South Florida Water Management District prepares this information "as is" for its own purposes and this information may not be suitable for other purposes. This report has not been reviewed for conformity with U. S. Geological Survey editorial standards.

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STATEMENT OF WORK

HIGH RESOLUTION SEISMIC REFLECTION PROFILING

Introduction

The South Florida Water Management District (the District) and the US Geological Survey (USGS) have agreed to cooperatively work on a project to complete a high resolution, marine seismic reflection profile of the area around several Comprehensive Everglades Restoration Program (CERP) projects. High resolution, marine seismic reflection profiling is a surface geophysical technique that can be used to identify sub-bottom geologic features beneath bodies of water. The District needs to develop an understanding of the geology underlying a number of areas, including the following:

- near the proposed Lake Belt Reservoir and Pilot Study,
- near the L31N Seepage Management Project and Pilot Study,
- near the C-43 Reservoir and ASR projects,
- near the Hillsboro reservoir, and
- the perimeter canals near the Lake Okeechobee ASR project.

The District is particularly interested in identifying:

- stratigraphic layers and consistencies,
- solution features and anomalies,
- unconformities,
- changes in stratigraphy that can affect the interaction between ground-water and surface water, and
- potential paths of preferential flow.

Characterization of the stratigraphy to a depth of about 200 feet below land surface is considered critical to the success of the projects. Analysis of the seismic data may identify sites for further detailed geologic investigation. The US Army Corps of Engineers (USACE) is a partner to the District on all CERP projects.

Scope of Services

Scope of Work

The Lake Belt Reservoir Pilot Project and the L31N Seepage Management Pilot Project are the primary focus of this agreement. If time permits, some seismic profiling may be done in other areas. The USGS will complete high-resolution single channel marine seismic reflection profiling on up to 90 km of canals within the project areas. It is possible that one day of the work may be done on small lakes in the vicinity of the Lake Belt Reservoir and L31N Seepage Management Projects. The seismic reflection profile project area is shown on the map in Appendix A. The District, USGS, and USACE will select specific sites based on project needs, physical accessibility, and canal water levels. Staff from the District and USGS have visited a number of Lake Belt Reservoir and L31N area sites. Data from this visit will be used in planning the seismic profiling.

The USGS will:

1. Provide all necessary equipment and supplies to run high resolution marine seismic reflection profiling for up to 90 km.

2. Provide an appropriate sized boat to carry all equipment and staff. Staff may include one District/USACE technical observer.

3. Provide all necessary staff to run high resolution marine seismic reflection profiling for the duration of the project.

4. Work with District and USACE staff to plan the seismic profiling.

5. Obtain permission for ingress and egress at each project site, when necessary. The District and the USACE will assist the USGS with this task, as appropriate.

6. Collect and log real-time GPS data concurrently with the collection of the marine seismic reflection profiling. Horizontal data will be reported in 1983 NAD datum and vertical data will be reported in both 1929 NGVD and 1988 NAVD datum.

7. Provide post processing of the data to remove multiples or provide filtering to remove selected bandwidths.

8. Store and maintain all original seismic data and provide access to this data for reproduction as needed by the District and the USACE.

9. Prepare an interim report to include the following:
   a. A copy of the seismic field data and
   b. Field notes and aerial photographs designating alignments including start and finish locations, start and finish times, and start and finish stages.

10. Provide a final report/data package in formats acceptable to both the District and the USACE. This may necessitate the use of two formats. (Formats will be established by the SFWMD, the Corps, and the USGS prior to beginning the profiling.) The final report will include a comprehensive interpretive report and the following:
    a. Six printed copies of all seismic data.
    b. Six hard copy plots of locations of tracklines with identifying labels for correlation to seismic data (i.e. latitude/longitude, start location, start time, canal stage at start of transect, state planar coordinates, finish location, finish time, canal stage at end of transect, and elevations.)
    c. Digital ASCII text navigation files in either of the following formats: latitude (dms), longitude (dms), time or UTM easting, UTM northing.
    d. Electronic (CD) copies (6) of digital seismic data files.
    e. Maps of each of the study areas.

The SFWMD will:

1. Provide equipment and staff to launch and pull the boat from the water when a boat ramp is not readily accessible.

2. Assist the USGS to obtain permission for ingress and egress at each project site.

Project Schedule

The USGS will begin the field portion of the work by November 30, 2001. The USGS will complete post processing of the data within 30 days after completion of the fieldwork, will deliver an interim report within 60 days after completion of the fieldwork, and will deliver the final report to the District and UASCE within 180 days after completion of the fieldwork. Based on the availability of funds, the District may only authorize a portion of the work. The District reserves the right to terminate the contract without any further restitution other than payment for services rendered.

Deliverables

Deliverable to the District shall include reports as detailed below. A report will be completed for each CERP project included in the seismic profiling. At this time, it is assumed that the Lake Belt Reservoir Pilot Project and the L31N Seepage Management Pilot Project are the two CERP projects included in the study.

1. Four copies of the interim reports (completed within 60 days of completion of field work) that includes the following:
    a. A copy of the seismic field data and
    b. Field notes and aerial photographs designating alignments including start and finish locations, start and finish times, and start and finish stages.

2. Comprehensive interpretive final reports/data packages in the agreed upon format(s) to include the following:
    a. Six printed copies of all seismic data.
    b. Six hard copy plots of locations of tracklines with identifying labels for correlation to seismic data (i.e. latitude/longitude, Shotpoint number or time.)
    c. Digital ASCII text navigation files in either of the following formats: latitude (dms), longitude (dms), Shotpoint, time or UTM easting, UTM northing, Shotpoint, time.
    d. Electronic (CD) copies (6) of digital seismic data files.
    e. Maps of each of the study areas.

Schedule

The USGS shall complete a high resolution seismic reflection profile that includes all tasks and deliverables according to the time schedule stated above. The schedule is the same for the Lake Belt Reservoir Pilot Project and the L31N Seepage Management Pilot Project.

Task and Deliverable	Duration	Start Date	Finish Date
Task 1 – Contract Initiation	2 weeks	10/1/01	10/15/01
Task 1.1 – Kick off meeting USGS to draft work plan, delivery formats	1 day 4 days	10/1/01 10/5/01	10/1/01 10/5/01
Task 1.2 – Delivery of meeting minutes, draft work plan SFWMD and Corps review work plan	1 day 5 days	10/8/01 10/12/01	10/08/01 10/12/01
Task 1.3 – Delivery of final work plan by USGS	2 days	10/13/01	10/15/01
Task 2 – Field Planning	3 weeks	10/16/01	11/5/01
Task 2.1 - Determine access permission(s) needed	5 days	10/16/01	10/22/01
Task 2.2 - USGS to obtain permission, as needed	7 days	10/23/01	10/31/01
Task 2.3 – Schedule SFWMD staff and equipment	3 days	10/31/01	11/05/01
Task 3 – Data Collection	10 days	11/26/01	12/17/01
Task 4 – Completion of Interim Report	60 days	12/18/01	2/18/02
Task 5 – Completion of Final Report	120 days	2/19/02	6/17/02
Task 5.1 USGS to provide complete interpretive report to SFWMD and USACE	100 days	2/19/02	5/27/02
Task 5.2 – SFWMD and USACE to provide feedback	15 days	5/27/02	6/10/02
Task 5.3 – USGS to provide final report and data	5 days	6/10/02	6/17/02