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Tools and Data Acquisition of Borehole Geophysical Logging for the Florida Power & Light Company Turkey Point Power Plant in Support of a Groundwater, Surface-Water, and Ecological Monitoring Plan, Miami-Dade County, Florida

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U.S. Department of the Interior
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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Abbreviations and Acronyms

ABI	Acoustic imaging tool
O_2	Dissolved oxygen
FPL	Florida Power & Light Company
KHz	Kilohertz
OBI	Optical borehole imaging tool
REDOX	Oxidation reduction potential
SN	Serial number
SP	Spontaneous potential
SPR	Single-point resistance tool
TPGW	Turkey Point Ground Water Monitoring Well Site
USGS	U.S. Geological Survey
WQ	Water quality

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Abstract

Borehole geophysical logs were obtained from selected exploratory coreholes in the vicinity of the Florida Power & Light Company Turkey Point Power Plant. The geophysical logging tools used and logging sequences performed during this project are summarized herein to include borehole logging methods, descriptions of the properties measured, types of data obtained, and calibration information.

Introduction

In 2010, the U.S. Geological Survey (USGS) acquired borehole geophysical logs in 14 exploratory coreholes in an area around the Florida Power & Light Company (FPL), Turkey Point Power Plant (fig. 1) as a data-collection element for implementation of a monitoring plan required of FPL as a condition for certification of two power unit uprates. The requirements were mandated by the Florida Department of Environmental Protection, South Florida Water Management District, and Miami-Dade County Department of Environmental Resource Management. The monitoring plan is intended to provide information to determine the vertical and horizontal extent of the hypersaline water within the cooling canal system at the Turkey Point Power Plant and on existing and projected surface-water, groundwater, and ecological conditions surrounding the Turkey Point Power Plant area.

The first corehole was logged on February 18, 2010, and the last on June 12, 2010. All geophysical logging equipment and tools used for this project were manufactured and/or sold by the Mount Sopris Instrument Company, Inc. of Denver, Colorado (Mount Sopris).The exception was an electromagnetic flowmeter, which was manufactured by Century Geophysical Corporation of Tulsa, Oklahoma, and then modified to work on a Mount Sopris 4-conductor winch. Over the course of the project some of the geophysical logging equipment required repair and/or replacement due to operational activities. Equipment repairs were performed by the manufacturer. Replacement equipment was either rented from Mount Sopris directly or borrowed from the USGS Office, Groundwater Branch of Geophysics, Storrs, Connecticut.

Geophysical logging was performed by the USGS at each site location (Wacker and Cunningham, 2008). Geophysical logs were used to identify the base of the Biscayne aquifer and zones of higher permeability within the Biscayne aquifer for the construction of three discreet monitoring wells (shallow, middle, and deep) at each of the 14 site locations. At each site, an exploratory corehole was advanced to a depth of about 20 feet into relatively poorly consolidated materials of the Tamiami Formation, which typically acts as a semi-confining unit below the base of the Biscayne aquifer. Airlift development was then performed on the nominal 6-inch diameter exploratory corehole until it was clear of any obstructions and stable to a depth below the base of the Biscayne aquifer. At two site locations (TPGW-11 and TPGW-14), the presence of large and unstable, loose, sand-filled zones in the exploratory corehole required two separate stages of airlift development and geophysical logging. The first geophysical logging stage at sites TPGW-11 and TPGW-14 was performed from the top of the corehole to the total depth reached during the first stage of airlift development. Following the first geophysical logging stage, the unstable section of the exploratory corehole was

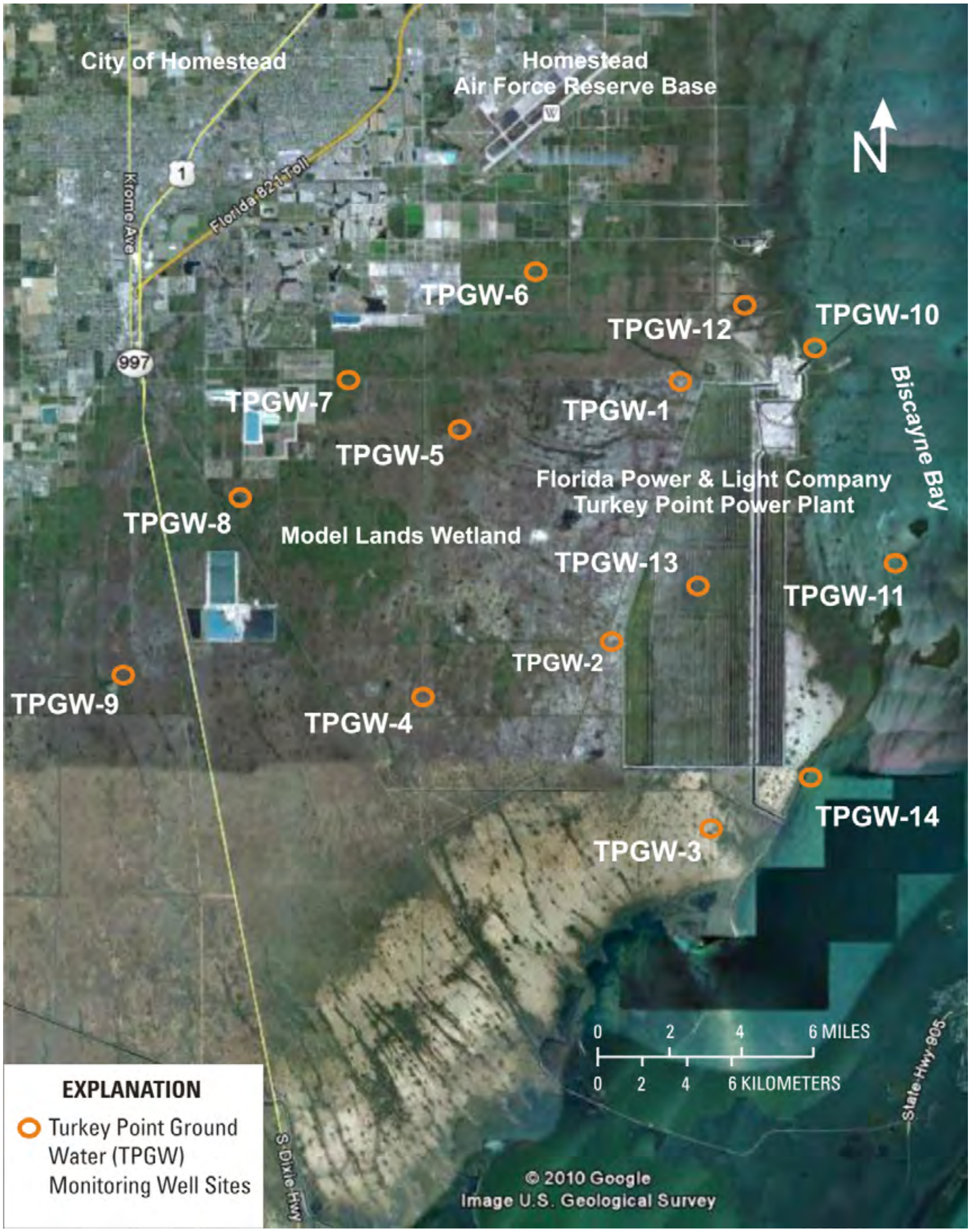

Figure 1. Groundwater monitoring well locations.

cased off using 6-inch diameter steel coring casing to a depth just below the sand-filled zone. Following installation of the 6-inch casing, the corehole was airlifted to a depth below the base of the Biscayne aquifer. The second geophysical logging stage was performed from the base of the 6-inch steel coring casing to the total depth of the airlifted corehole. Geophysical logs performed for this project are referenced to land surface for sites TPGW-2, 3, 4, 6, 7, 8, 9, and 12; and to the top of the surface casing for sites TPGW-1, 5, 10, 11, 13, and 14 which are located in wetlands or Biscayne Bay.

At each site, geophysical logging of the exploratory corehole was started about 24 hours after airlift development was completed to allow for the settling of suspended sediment in the corehole fluid column. The 24-hour wait period generally resulted in clear formation fluid in the corehole, which is required for a digital optical borehole imaging log. In some instances, geophysical logs (caliper, gamma, spontaneous potential, single point resistance, electromagnetic induction, and full waveform sonic) were run immediately after the airlift development because these logs are not affected by borehole water clarity.

Following acquisition of all logs in the field, the log data were then processed and displayed using Advance Logic Technology, WellCAD version 4.3 and saved in a format that allows the logs to be viewed in WellCAD Reader. WellCAD Reader allows the viewing of all logs simultaneously where they are assembled in vertical tracks to form a single log montage, the viewing of logs at different scales, and printing of a paper copy. The digital images on the log montage are best viewed at a scale of 1 to 12 or less, whereas all other logs are best viewed at a scale of 1 to 48 or greater. PDF files of each log montage at these two scales are presented in the Appendix. Planned monitoring well completion zones are shown on the final log montage with depths relative to land surface for wells located on dry land (TPGW-2, 3, 4, 6, 7, 8, 9, and 12) and relative to the top of the casing for wells located in wetlands (TPGW-1, TPGW-5, and TPGW-13) and offshore (TPGW-10, TPGW-11, and TPGW-14).

Borehole Image Logging

Two types of geophysical imaging tools were used at each site location for this project. At each site location, the OBI MK-IV, digital optical borehole imaging tool (OBI) (Serial Number (SN)-3981) was the first logging tool run in the exploratory corehole. The OBI log was run at 95 percent light, 720 turns or every half degree of circumference, and sampled vertically every 0.0027 foot of depth. The second logging tool was an ABI-40 digital acoustic imaging tool (ABI) (SN-4594). The ABI tool was run at 288 turns or every 1.25 degrees of circumference and sampled vertically every 0.0055 foot of depth. Both OBI and ABI tools acquired data while logging upward from the base of the corehole to the land surface or top of casing.

Borehole Fluid and Caliper Logging

A USGS Mount Sopris, Idronaut 303 (Mount Sopris 2IFA-1000, SN-4219) water quality (WQ) tool was typically the third logging tool run at each site. The WQ tool acquired data while logging both upward and downward in the corehole, and measures borehole fluid temperature, conductivity, pH, dissolved oxygen (O_2 percent), and oxidation reduction potential (REDOX). Three different Mount Sopris WQ tools were used due to tool malfunction, which occurred at various times during the project. Malfunctioning WQ tools were sent to the sensor manufacturer's plant in Italy for repairs and calibration. Rental WQ tools were acquired from Mount Sopris, and were utilized during the duration of repairs. At all sites, a calibrated and properly functioning WQ tool was run by the USGS. Additionally, the WQ tool calibration was checked with a separate and independently calibrated YSI conductivity meter during logging.

At sites with freshwater borehole fluids, a Mount Sopris, 2FSB-1000 fluid probe (SN-2703), which was attached to the bottom of a Mount Sopris, 2CAA-1000 three-arm caliper tool (SN-2702), was used to acquire borehole-fluid temperature and resistivity (reported in the Appendix as conductivity) data while logging downward from the top of the corehole. Fluid probe data were used for comparison with the WQ tool when available. Caliper logging with the caliper tool was then performed to determine the corehole diameter, and was run upward acquiring data from the base of the corehole to land surface.

Induction/Gamma/Spontaneous Potential/Single-Point Resistance Logging

Following caliper logging, a Mount Sopris, 2PIA-1000 electromagnetic induction tool (SN-3114) (logged up and down), HLP-2375/S natural gamma tool (SN-2202) (logged up), and combined spontaneous potential (SP) and single-point resistance (SPR) tool (logged down) were run. Rental and borrowed 2PIA-1000 electromagnetic induction tools were used on wells after May 14, 2010, due to a USGS tool malfunction. The USGS 2PIA-1000 electromagnetic induction tool was calibrated at the Fort Lauderdale office prior to project commencement and also recalibrated in the field when the values seemed inaccurate to the operator according to procedures in the Mount Sopris tool operations manual. Rental and borrowed tools were also calibrated at the USGS Fort Lauderdale office upon receipt and prior to use, and recalibrated as needed in the field. A final electromagnetic induction log was run on each deep monitoring well as they were completed.

The initial electromagnetic induction log for TPGW-9 corehole may be inaccurate as a tool malfunction was discovered after logging the well. Well construction had begun prior to the discovery of tool issue. The completed TPGW-9 deep monitor well was logged with the calibrated rental tool and is accurate. The natural gamma tool and SP/SPR tool do not require calibration.

Full Waveform Sonic

Following induction logging, a Mount Sopris, 2SAA-1000/F full waveform sonic tool (SN-3023) tool was run in each corehole. Two runs were made with the sonic tool, one with an acoustic signal transmitted at 15 KHz (used later for porosity calculations) and one transmitted at 1 KHz (used later for relative permeability estimations). The full wave form sonic logs were processed using Log Cruncher software. Log Cruncher is used to determine the mean primary compressional wave and Stoneley wave velocities. The compressional wave velocity was used as input into the Raymer-Hunt porosity equation for calculation of sonic porosity. Sonic porosity values calculated from compressional wave velocities are frequently higher than whole-core porosity measurements by laboratory air permeameter. Known values of laboratory measured porosity on rock cores were not available to calibrate a computed porosity curve. The amplitude of the Stoneley wave was also measured from the receiver closest to the transmitter (receiver 1). The Stoneley wave amplitude has a predictable qualitative relation to permeability, which can be used to estimate a qualitative permeability of the rock surrounding the corehole. Generally, low amplitudes can represent high permeability, and high amplitudes can represent low permeability. The computed value, therefore, can be cautiously used in a qualitative manner to estimate zones of high and low permeability.

Flow Logging

Flow logging of the exploratory corehole was performed under both ambient (static) conditions and under dynamic/pumping conditions at each site. Three different types of flowmeters were used during the course of the project due to variability in borehole-fluid conditions. Saline fluids are more conductive and may have an effect on the performance of the USGS electromagnetic flowmeter and, to a lesser degree, the USGS heat pulse flowmeter. The spinner flowmeter is not affected by the conductivity of the borehole fluid. Depth-to-water-level measurements were recorded in each borehole under both ambient and pumping conditions to determine the amount of drawdown while pumping. Each corehole was pumped using a 2-inch centrifugal trash pump with a 2-inch suction line placed within the open corehole. Flow rates were measured by timing the rate at which the discharge water filled a 20-gallon container and are shown on each log heading. Pumping rates during geophysical logging ranged from 68 to 156 gallons per minute. Rates varied depending on depth to water and length of discharge hose.

Following the above-mentioned borehole geophysical data acquisition, the logs were plotted in the field to determine appropriate depths to acquire stationary measurements of vertical borehole fluid flow using borehole flowmeters. A Mount Sopris, HPF-2293 heat pulse flowmeter (SN-2706), with 7-inch petal diverter was set at each of these predetermined depths and at least three repeatable measurements taken at each stationary depth under ambient borehole fluid-flow conditions.

Following logging with the heat pulse flowmeter, a Century Geophysical 9721 electromagnetic flowmeter (SN-1188) was logged both up and down the borehole to create a continuous log of vertical borehole flow under ambient conditions. The electromagnetic flowmeter also contains a sensor to measure borehole fluid temperature and resistivity, which were recorded. After the ambient borehole fluid flow was measured in the corehole, the electromagnetic flowmeter was run in the borehole under pumping conditions acquiring data while trolling both upwards and downwards to create a continuous flow log. Additionally, the electromagnetic flowmeter acquired stationary pumping flow measurements at the same depths as those acquired by the heat pulse flowmeter under ambient conditions.

In some coreholes, the borehole fluid was too saline to use the heat pulse or electromagnetic flowmeters because these two tools do not operate reliably in highly conductive saline fluids. If the borehole fluid was too saline, a Mount Sopris, FLP-2492 spinner flowmeter (SN-2372) was run up and down under both ambient and pumping conditions to determine flow within the borehole.

Reference Cited

Wacker, M.A., and Cunningham, K.J., 2008, Borehole geophysical logging program: incorporating new and existing techniques in hydrologic studies: U.S. Geological Survey Fact Sheet 2008-3098, 4 p.

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