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**USGS Geophysical  
Documentation**

# USGS-FISC Borehole Geophysical Logging Equipment and Procedures

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## Introduction

This technical instruction is intended to provide technicians and managers with information about the available equipment, capabilities, limitations, and procedures for the borehole geophysical logging program at the office of USGS-FISC Fort Lauderdale, Florida. In the past, a lack of available knowledge on tool usage has resulted in equipment damage and misuse. This collection of tool-usage procedures is an attempt to create a single document where all aspects of the borehole geophysical logging program can be found. Continual updates to this instruction will be made in order for the most current information to be available. The borehole geophysical logging equipment available for use is contained in Appendix A. These tools are available via transport to a logging site in a USGS-FISC owned two-wheel drive logging van (Fig. 1). Geophysical logs that can be produced from these tools are contained in Appendix B. The log display format is a WellCAD montage that can be exported as an Adobe Acrobat PDF file (Fig. 2). Borehole requirements and limitations are contained in Appendix C. USGS-FISC is not a logging rental pool, but is intended to collect data for a regional perspective of the hydrology of Florida. The USGS-FISC borehole geophysical logging program is meant to provide complete service from planning through data gathering and data processing, to delivery of the final log montage and archival.

## Logging Procedures

### General

These procedures are meant to compliment the typical inadequate tool documentation in manuals provided by the manufacturers. In all cases, the first step is, read this document and the manufacturers tool manual. If there is any doubt about a procedure, ask someone. Mount Sopris personnel are only a phone call away and have always been most helpful (303-279-3211). More work is involved in sending a tool back for repair then in finding out a correct procedure. Also, when logging always keep an eye on the winch and tool depth. Answering questions, boredom, and general inattention can quickly lead to problems causing equipment damage, embarrassment, or both.

Equipment set-up begins with supplying power. There are two power inverters available, a van mounted (Fig. 3) Exel Tech Corp. XP 1100 (1100 WATTS, a second unit is available from the Data Section) and a back-up XP 600 (600 WATTS). A portable electric generator can also be used but fuel and venting requirements prohibit extended logging runs. Only the logging equipment should be connected. Other equipment such as portable electric pumps will cause an overload and melt the power inverter fuses. These should be run off an alternate source of power, such as a generator. Use of smaller inverters will not provide adequate power for the winch and associated equipment. Connect the inverter cables to the vehicle battery, attaching the negative cable first,

followed by the positive cable. Close the hood so that if it rains, water will not short the cables. The engine should be kept running, but it can be shut off for short periods up to a half hour if absolutely needed. Any time beyond that may not allow enough remaining power in the battery to start the vehicle. Shutting off the engine is not recommended though, as a power surge may occur when starting the engine. If the engine must be shut off, restart between logging runs so if a reset of the logging equipment is required, a logging run will not be wasted. If there is no power available from the inverter or the green operation light on the inverter front panel is not illuminated, use the spare inverter. If there is power with the spare inverter, check to see if the fuses have blown on the problem inverter. Fuse replacement requires that the front and back of the inverter be removed and the main circuit card pulled out to expose the fuse holders. Replace with the proper size fuses if necessary.

Begin the logging equipment set-up by placing the pulley tripod over the borehole, so that the cable will travel down the center of the borehole. Next pull the cable head and cable from the winch, and drape about a foot below the pulley, checking alignment with the center of the borehole. Do not attach a tool, as the winch has not been powered and the weight of the tool will cause the winch to unwind to the bottom of the well. Attach the power cable to the MGX II Portable Logger or one power cord each to the large 4MXC1000 winch (Fig. 4) and MGX II Console. Then if using the large winch connect the MGX II Console to the winch using the winch data cable. Finally connect the power cable to the computer and the computer to the MGX II Console or portable logger using the serial cable. Check the winch/portable logger to ensure the toggle switches on the control panel are in the run and hold positions. Turn on the computer first followed by the winch and the MGXII Console or portable logger. The last step is to attach the desired tool. Connect the tool by turning the tool and holding the cable head in a stationary position. Be careful to not twist the cable. Place the protective cover caps from the tool and cable head in a place where they will not be lost. Additional connections may be required depending on the tool being used.

Once the Windows desktop is open on the computer, run MSLConfig (icon found on desktop) and verify the settings (using Appendix A). Especially important are the following settings on the left side of the window, “Select Wireline”, “Wireline Length”, “Measuring System”, and “Winch type”. If any of the displayed settings are incorrect, select or enter the proper setting for the equipment being used. Tool files can be added or removed using the “Install/Change Tool Selection” button. Do not change any other settings without knowing fully what you are doing or in consultation with Mount Sopris personnel. Always run MSLConfig before starting MSLog or MSHeat.

Double click the MSLog icon starting the MSLog program. If you get a “No Hardware Detected” window, verify the tool connections and restart the program. After MSLog opens, select the tool attached to the cable head from the pull down menu. If you do not find it, exit the program and run MSLConfig to add the tool file, and restart MSLog. After all the associated windows for the selected tool have opened, power up the tool and set the tool depth by maximizing the depth window and clicking the “Zero Tool” button. Note, before you zero the tool, ensure the point where tool connects to the cable head is level with the point you want to use as a reference. The reference is usually ground level, but can be the top of a flush-mount well protector or top of casing. It is

best to determine your datum before leaving the office and always enter this information along with a drawing in the logging field notebook.

You should now be ready to begin logging. In most cases, it is best to log from the bottom of the hole upward, so that the tool will not hang up (stop) on an obstruction on the way down hole. Stopping of the tool during its downward motion can cause the cable to unspool on the winch and become tangled. Always pay attention to the proper spooling of the cable onto or off of the winch. If the cable does unspool, you must stop logging operations. If only a few turns have become unspooled, you may be able to realign them on the spool. If there are many, it is best to carefully pull the cable out behind the truck until all of the unspooled cable is off the winch. Then while keeping tension on the cable with one hand, use the other to retrieve the cable, and let it spool correctly onto the winch. Note that when using the portable logger you must manually align the cable as you run the tool up hole, otherwise the cable may become tangled on the winch.

After each logging run and upon completion of logging, wipe down all tools and equipment to prevent corrosion and deterioration. Make sure that the tool and cable-head connectors are clean and dry before replacing protector caps. Occasionally a small amount of silicone gel should be applied to the threads to both lubricate and protect the threaded connection. Cables and equipment must be properly stowed to prevent damage during transport. Sweep the van floor of any excess dirt. Double-check equipment tie-downs, stowage, and that all drawers are secure before departure from the well site.

### **Documentation**

A field notebook of all logging activities must be kept. It will provide an invaluable record of logger(s) present, time, and dates spent logging, geographical information, tool performance and calibration, and additional data that will aid in report preparation and GWSI input. Any field work done with the logging equipment must be entered in the notebook, including repairs and calibrations. When logging a new well record the following:

- Name of logger(s)
- Date and time of departure from office
- Time of arrival at the well site and local well name
- GPS reading of the latitude and longitude (NAD 83) of the well
- Elevation and datum by looking for local benchmarks or topographic map information
- Measuring point at well, for example, it could be ground surface, top of casing, or well protector.
- Total depth (TD) of well
- Any additional information or drawing that will add to the above
- For each log run enter the tool type, tool settings, time of start and stop, logging speed up and down, filename, problems encountered, remedies, calibrations, and tool specific requirements (for example, see heat pulse flow-meter below)
- Time that all logging is completed and tools restowed
- Time of arrival back at office

These are the recommended minimum entries and are situational dependant. It will always be more difficult, and give an unprofessional appearance, when trying to recreate them after the fact. When in doubt, record it in the logging field notebook.

### **Specific Tool Information**

#### **Natural Gamma-Ray with SP and SPR**

The natural gamma-ray tool (Fig 5.) is the easiest tool to use and requires no user calibration (it has been set at the factory, if calibration is in doubt contact Mount Sopris). It can be run in any borehole type, cased or uncased, plastic or steel. Gamma response in water-, mud-filled, and cased wells may be lower, and a correction factor may be applied (see tool manual). Warm the tool a few minutes before logging. Run a log on the way down to verify the actual final log, which will be run up the borehole. Recommended logging speed is 7 ft/min upward in shallow holes and 10 to 15 ft/min (30 ft/min maximum) in deeper wells. The gamma tool has a spontaneous potential (SP) and single point resistance (SPR) capability. Set up is described in the tool manual. Water may be added to the soil around the surface electrode to improve the electrical connection with the earth. After powering up the tool, only the green power light will be illuminated. The lower mA (current consumption) power light bar will not be illuminated. Calibration is set at the factory, but can be checked following the procedures described in the tool manual. The SP and SPR logs can only be run in open (uncased) water- or mud-filled boreholes.

#### **Three-Arm Caliper with Fluid Temperature and Resistivity**

The three-arm caliper tool (Fig 6) is simple to operate, but calibration checks should be made before beginning a logging project or when readings are more than 0.25 inches off known casing diameters. Most wells have, at least, a surface casing of known internal diameter that can be used to check tool performance. The calibration procedure in the tool manual is straight forward and easy to accomplish. The caliper log is only run upward in a hole, as the open arms would cause the probe to hang-up if an attempt was made to log downward. Usually fluid-resistivity and temperature log are measured on the first trip down hole. One important step to remember before removing the tool from the borehole or shutting down power to the tool is to close the caliper arms. Logging speed in shallow holes should be between 5 and 10 ft/min, but can be 15 to 20 ft/min in deeper wells. When entering casing, while logging upward with any tool, always slow down to prevent damage to the cable head and casing bottom or shoe.

The fluid temperature-resistivity tool instrumentation is permanently attached to the bottom end of the caliper tool (Fig 6b) and should always be run first before any other tools (except the OBI 40, digital optical televiewer), so that fluid conditions in the borehole are undisturbed. No calibration should be required as long as there have been no repairs or damage since the previous calibration, and the last tool settings from Mount Sopris are maintained. If calibration is required, it is recommended to return the tool to Mount Sopris, as they are better set-up to make the calibrations. If desired, calibrations or performance checks of resistivity can be made by using known conductivity standards and converting them to resistivity using the inverse relationship. Temperature can be

checked with a thermometer and is most difficult to maintain for calibration. The calibration procedures in the tool manual are easily understood, but the equipment is bulky and the tests are best done in a clean workbench environment. Important steps to remember when using the tool are that (1) the tool must be allowed to warm up for at least two minutes before logging (MSLog program default setting will not allow) and (2) after completion of logging, clean the inside of the instrumentation array to prevent clogging of the opening and keep any build-up or coating from developing. Logging speed in shallow holes should be between 5 and 10 ft/min, but can be 15 to 20 ft/min in deeper wells. If the operator is not satisfied with the quality of the log, it would be best to wait a day until normal fluid conditions are reestablished in the well.

### Electromagnetic Induction

The electromagnetic induction tool (Fig. 7) measures the bulk electrical conductivity of the rock formation and formation fluids by magnetic induction. Within the south Florida area few changes are required to operate the tool. There are three ranges to select from for tool operation. The first, 0-100 milliSiemens per meter (mS/m) should be used in shallow limestone wells with low salinity. The second range, 0-1000 mS/m should be used in shallow coastal wells affected by saltwater and along with the first range requires only that the proper tool file is selected in MSLog. The third range, 0-10,000 mS/m requires a change to be made to switches within the tool body as well as MSLog, and is for wells with very saline fluids. To date the use of this high range has not been required, but the proper procedure is described in the tool manual. Remember to return the tool switches to the factory settings after logging is complete. Care should be taken with the tool, because most of the black housing is fiberglass and plastic, which can be easily bent or split open. Logging speed in shallow holes should be between 5 and 10 ft/min, but can be 15 to 30 ft/min in deeper wells.

Calibration is an important issue with this tool and requires two people to complete. An initial calibration should be sufficient when logging wells with a similar formation fluid salinity. If the tool range is changed or wells with widely varying formation fluid salinities are logged, then the tool should be calibrated for each range or well. The calibration instructions in the tool manual are easy to follow, but several important factors must be taken into consideration. The calibration is made using a coil that fits over the end of the tool (Fig. 7b) and must be held at least 9 feet above the ground in an area with no power lines or with no large metal objects within 30 feet. Before calibration, the tool should be allowed to acclimate to the borehole fluid with power on for at least 15 minutes. After acclimating, the tool should be removed quickly from the well and taken the required distance away from metal objects and the calibration completed as quickly as possible. Ensure that the person holding the tool aloft also has no metal (such as big belt buckles, keys, and coins) on their person.

### Full Waveform Sonic

The full waveform sonic tool (Fig. 8) is long and bulky, and should only be handled with two people to prevent damage when assembling and inserting into the well. This tool requires assembly before use and selection of the correct centralizers (Fig. 9) is most important. The tool must be correctly centralized within the borehole, so the sonic wave travel time paths are symmetrical relative to the borehole and not shortened by

contact with the borehole. Also, centralizers should not be placed over or between the transmitters and receivers, as they cause “road noise” (scraping on the borehole), which can interfere with the received sonic wave. A tight or loose fit with the borehole wall can also cause excessive road noise, so the caliper log should be reviewed for the proper size centralizer to use. The tool is usually logged upward after running down hole to ensure proper centralizer selection and to prevent the tool being caught on obstructions. Logging speed in shallow holes should be about 5 ft/min to minimize road noise, but can be sped up slightly in deeper wells. Keep an eye on the wave shape in the wave-view window in MSLog and lower the speed if noise interferes with the signal.

Transmitter and receiver settings should be considered in advance for the type of desired logs and expected lithology using the tool manual. When logging in karstic limestone of south Florida, two runs at 1 and 15 KHz using the following settings should be able to provide all required logs after processing. The settings are:

<b>Run 1</b>		<b>Run 2</b>	
Transmitter (Tx)		Transmitter (Tx)	
Frequency	15 KHz	Frequency	1 KHz
Stack Interval	10 ms	Stack Interval	25 ms
Number of stacks	4	Number of stacks	4
Receiver 1 (Rx1)		Receiver 1 (Rx1)	
Gain	4	Gain	4
Hold-off time	250 $\mu$ s	Hold-off time	150 $\mu$ s
Sample rate	8 $\mu$ s	Sample rate	8 $\mu$ s
Number of Samples	512	Number of Samples	512
Receiver 2 (Rx2)		Receiver 2 (Rx2)	
Gain	8	Gain	8
Hold-off time	250 $\mu$ s	Hold-off time	150 $\mu$ s
Sample rate	8 $\mu$ s	Sample rate	8 $\mu$ s
Number of Samples	512	Number of Samples	512
Receiver 3 (Rx3)		Receiver 3 (Rx3)	
Gain	16	Gain	16
Hold-off time	250 $\mu$ s	Hold-off time	150 $\mu$ s
Sample rate	8 $\mu$ s	Sample rate	8 $\mu$ s
Number of Samples	512	Number of Samples	512

#### ALT Digital Optical Borehole Imager, OBI-40, MK III

The digital optical borehole imager (Fig. 10) is the most costly tool to operate, in terms of drilling contractor expenses, because of the optically clear-water requirements needed to create a useful digital borehole image log. The more detailed the desired image, the slower the logging speed and the higher the required standards for water clarity within the borehole. As with the full waveform sonic tool, centralizer selection is most important (Fig. 9). Centralizers that fit to tight against the borehole wall can scrape material off the wall and cloud the water on the way down the borehole. If the centralizers are too loose the lighting is eccentered, which will cause the image to be too

light or dark or both on opposite sides of the final image. The best borehole diameter is 7.5-in., which allows the optimal use of the copper bow-spring centralizers. The copper bowstrings can be clamped to spread them further apart along the length of the tool, thereby reducing the useable borehole diameter to 6 in. But care must be taken that the compression ring of the centralizer (the one that is screwed tight) is always towards the top end of the tool. This ensures that the lower part of the centralizer is free to move downward so that the tool will not become stuck in the hole when winching upward. Another method is to wrap electrical tape around the centralizers to reduce their width. Whichever type of centralizer is used, care must be taken to ensure that it does not cover or interfere with the optical window, or is placed over the top part of the tool that houses the magnetometers, which will misalign the image. See the tool manual for proper placement.

Tool settings are dependant on the borehole size and final image requirements. The best image is obtained in a 7.5-in. diameter borehole (best for bow-spring centralizers) at 80 percent light and 720 point (Pt) turns. While this will produce the best detail of the borehole wall, the logging speed can not exceed 1.39 ft/min or errors will occur, because the 56k modem speed is the limiting factor in how fast data moves up the cable. The faster the logging speed the more data that must be sent up the wire. To achieve higher logging speeds, the point turns per revolution must be reduced. Another way to improve the image or increase the logging speed is to adjust the rate of the depth mode settings in the tool sampling settings window, which can be accessed by clicking the MSLog acquisition window settings button. By increasing the value of this setting, the depth sampling interval is increased and less data (pixels), are collected over the vertical axis of the borehole wall area. Less data collected means less data up the cable allowing a faster logging time during the trip up the hole, but again it does reduce the number of image pixels per area of borehole and hence the quality of the image. To improve quality and achieve a high-resolution image the value in the depth mode settings must be reduced, which will increase the amount of sampling. The smallest practical depth sampling rate using the MGX II console is 0.0075 feet (default is 0.009 feet), any lower setting (smallest setting is 0.003 feet or 1 millimeter) will cause errors in the communication window, even though the winch is barely turning. The only other setting that should be adjusted in the tool settings window is the percent light. Other settings should be left at the default setting and only adjusted after reviewing the tool manual. In practice, it appears the WellCAD image is always darker than the MSLog image, and if the lighting is too bright, it can wash out parts of the image in a borehole with an uneven borehole diameter. It may be necessary in some cases to do several runs at different light levels to determine the correct setting.

Calibration procedures are explained in the tool manual, but unless the procedure is fully understood it is best to return the tool to Mount Sopris for adjustment. The most common damage that occurs to the OBI-40 is scratches on the plastic optical window (Fig. 10 inset). Repairs can be made by unscrewing and removing the plastic optical window and bottom tip assembly and polishing the scratch from the optical window using a desk grinder fitted with a spiral sewn buffing wheel. Emery compound is used to remove most of the scratch and final polishing using Tripoli compound completes the repair. Care must be taken not to over-buff or come in contact with the gray plastic material at the edges of the optical window, which may become heated and then smeared



into the clear plastic. It is also good to rotate the optical head buffing to an even thickness around the total circumference of the window. If unsure of your ability to complete the repair, it is better to send the optical head to Mount Sopris for repairs, since replacement cost of the optical head is approximately \$1,100.

### Heat-Pulse Flowmeter

Before using the heat pulse flowmeter (HPFM) a fluid temperature-resistivity log should be run to determine the fluid conditions within the borehole under ambient conditions. The fluid temperature-resistivity log must be run on the same day as the flowmeter measurements, so this should be the first log run before disturbing the borehole fluid within the well with further logging. The HPFM is relatively easy to operate and requires no calibration. If the operator suspects that calibration may be required, consult with Mount Sopris, and if recommended, return the tool to them for calibration. Tool set up begins with selecting the correct diverter for the borehole (Fig. 11), which should be about 2 in. larger in diameter than the borehole diameter. This will allow the operator to position the tool so that the diverter is in the correct configuration. For down flow within the borehole, the tool should be positioned so the diverter is concave upward, and for up flow the diverter should be concave downward. This configuration will ensure proper flow through the opening of the thermistor heating grid (Fig. 11b, c). If the borehole is uneven or the diverter is too small, water will flow around the diverter and flow can not be accurately measured. A centralizer should be placed at the top of the tool to maintain vertical alignment within the borehole (Fig. 11a). Not used with other logging tools is the trigger assembly, which plugs into the MGX II console or portable logger. See the HPFM tool manual, if unsure of the installation procedure. Digital image or caliper logs or both should then be used to determine where the tool diverter can be best placed, so that borehole fluid will be diverted through the tool. Cavities and irregular areas of the borehole wall should be avoided, because here borehole fluid can flow around and not through the HPFM affecting the accuracy of flow readings.

The HPFM uses MSHeat to operate the tool and display the results. Prior to starting MSHeat always run MSConfig to ensure the proper settings. Follow the MSHeat installation and configuration manual to first power up the tool. Adjust the top of the tool to the surface reference point (top of casing or ground level), and then set the depth to the flow measuring point (rubber flow diverter) from the top of the tool by clicking on the “Depth” button, and entering the depth (usually 3.28 feet). Next, check that the program settings (under the “Edit” menu) are the current recommended settings and reset if required as follows: Pick Window Minimum at 0.5 seconds, Pick Window Maximum at 20 seconds, Threshold at 15% Full Scale, Plotting Window Width at 40 seconds, and Plot Amplitude at 1. Lower the tool to the first pre-picked depth and allow at least 10 minutes for the temperature to equilibrate and the flow to settle. Once the trace settles out, arm the trigger and fire. If a reliable waveform is generated, configure the diverter for either up or down flow. It may take some experimenting with the winch to accomplish this. If no waveform is generated, adjust the settings and re-fire (30 second warm-up until ready to fire) until flow is detected. Reading the waveform requires some practice and it may require accumulating considerable experience to develop the skill.

After adjusting the settings and no waveform is generated there may be two possibilities for this problem: (1) there is no flow or (2) the flow may be too high to read. Try the HPFM at lower depths (they can have lower flow rates) and different settings until a reliable waveform is generated and then re-log the upper depths. When satisfied that everything is working save the waveform by using “save as” under the “edit” button and record the file name also logging it in the field notebook. Then hit save again to ensure the file is saved. It is recommended that at least three readings be made at each depth and the depth, flow, and time values be entered into the field notebook in case the data does not save properly and to ensure repeatability of the data. It is also recommended to hit save twice and scroll back to see if the previous reading was saved and then scroll forward to the current waveform. There are problems with the MSHeat not always saving the data, which is why the data acquired should be recorded in the field notebook. Also note in the field notebook any problems or change in settings. When data collection is completed do a final save and export the data. Select “yes” when asked if you would like the data to be averaged and combined at common depths.

After completion of the ambient flows, a pump may be used to pump from or to the well in order to determine the flow rate under pumping conditions. Adjust the pump flow so that the HPFM is not overwhelmed and re-log the well. The flow rate and pump size will depend on the borehole diameter and aquifer transmissivity, thus some planning must be done before going to the field, so that the correct equipment is available. Remember to determine the pump’s flow rate several times during the pumping test with the use of a bucket or garbage can and stopwatch. When finished logging, it is important to thoroughly rinse off the entire HPFM tool and associated accessories, especially the cage and thermister area.

### Spinner Flow Meter

The spinner flowmeter is used to measure relatively high flow rates in a borehole. Set-up requires only that the right size propeller and cage are used (Fig. 12), no centralizer is required, but the user should inspect the cage and propeller screw for tightness, and ensure that the propeller turns freely. The spinner flowmeter creates two logs, one of logging speed up or down hole and a second log showing propeller turns in counts per second (CPS). So, the recommended strategy is to conduct several runs up and down at various speeds to identify zones of inflow and outflow, and to bracket the vertical velocity of the flow. Runs up and down should be made at logging speeds that start at 5 ft/min and increase by 5 ft/min increments, until a significant change in the log character occurs. Each well is different and some skill is required to analyze the logs and determine how many runs to make. One problem that may be encountered when running the tool is that the cage tends to become stuck in or caught on edges of cavities. It is therefore important to ensure that the tool and wireline is centered in the hole and to pay attention to the cable tension at the winch, so that the cable does not play out when the tool stops moving. Usually a quick jerk on the wireline will free the tool and allow it to continue.

### EM Flowmeter (with fluid temperature and resistivity)

This tool is a Century Geophysical EM flowmeter (Fig 13) built around the Quantum Engineering Corporation electromagnetic borehole flowmeter. The tool was further modified for use with the Mount Sopris winch and console. A Mount Sopris single conductor cable probe top was added to the tool and a modem was added to the MGX II console (SN 1186a) that allows the MSLog program to communicate with the probe. The EM flowmeter tool can only communicate with the USGS-FISC's MGX II control console and will not work with any other control consoles. If repair problems occur that Mount Sopris cannot resolve, Century Geophysical may have to repair the tool. The information provided by Century Geophysical on tool operation is limited and contains several inaccuracies, thus it should be used with caution.

The measuring point of the EM sensor (Fig 13b) is located six inches from the bottom of the tool which is half the length of the EM sensor (12-in). The Mount Sopris MSLog TOL file (tool length) has been modified by this office to reflect this measuring point relative to the probe top. Care must be taken when lowering the probe that an additional half foot must be added to the depth reading on the MGX II console and MSLog to determine the actual depth of the tool bottom. The petal diverter is also placed at this point to simplify the depth placement within the borehole. Fluid resistivity and temperature data is collected by a sensor located above the EM flowmeter. The measuring point was also modified in the MSLog TOL file to reflect this difference.

Logging procedures with the Century Geophysical EM flow meter, after the standard basic tool setup and period of temperature stabilization, begin with static measurements under ambient flow conditions on the down hole run with the sampling mode in the time position. The petal diverter is set at depths determined from a caliper or digital optical image log. Once the tool depth is set and the flow stabilizes push the record button and create a file that records the flow data over at least a two minute interval. Ensure that the file name contains the well identifier, date, and depth. Record your best guess of the average flow in the field book. Proceed to the next depth and repeat, ensuring that an adequate numbers of depths are sampled adequately log the borehole. Each individual depth file can then be exported into WellCAD and reviewed. An average flow is the determined by exporting the flow log as a text file, and then importing into Microsoft Excel where the average can then be easily determined.

When static measurements are completed, lower the tool to the borehole bottom and change the sampling mode to "depth up", and then log up the hole at a steady logging speed. The logging speed will depend on the flow conditions and total depth to log. An additional run should be made down hole if the dominant flow direction is up. The well can then be pumped if desired and the above procedure repeated to determine flow conditions during pumping. Upon completion of logging rinse, the tool sensor with clean fresh water and allow the tool to dry before placing it in its case.

Calibrations of the EM flowmeter are made by inserting the tool into a home-made calibration rig built using 6-in. PVC with a cap and valve glued on one end. After filling with water, flow rates through the bottom valve can be determined with a large graduated container and stop watch, making several flow rate measurements and then taking the average. Tool calibrations are made with flow and no flow settings in both high and low gain using MSLog in a fashion similar to other tool calibrations. The fluid resistivity and temperature sensor can also be calibrated using a method similar to the one

used for the fluid resistivity and temperature tool on the caliper. At the present time, no attempt has been made to calibrate the EM flowmeter. Therefore, the exact procedures have not been worked out and some thought and planning will be required to calibrate this tool

## Figures



Figure 1. Front and back view of USGS-FISC logging van.



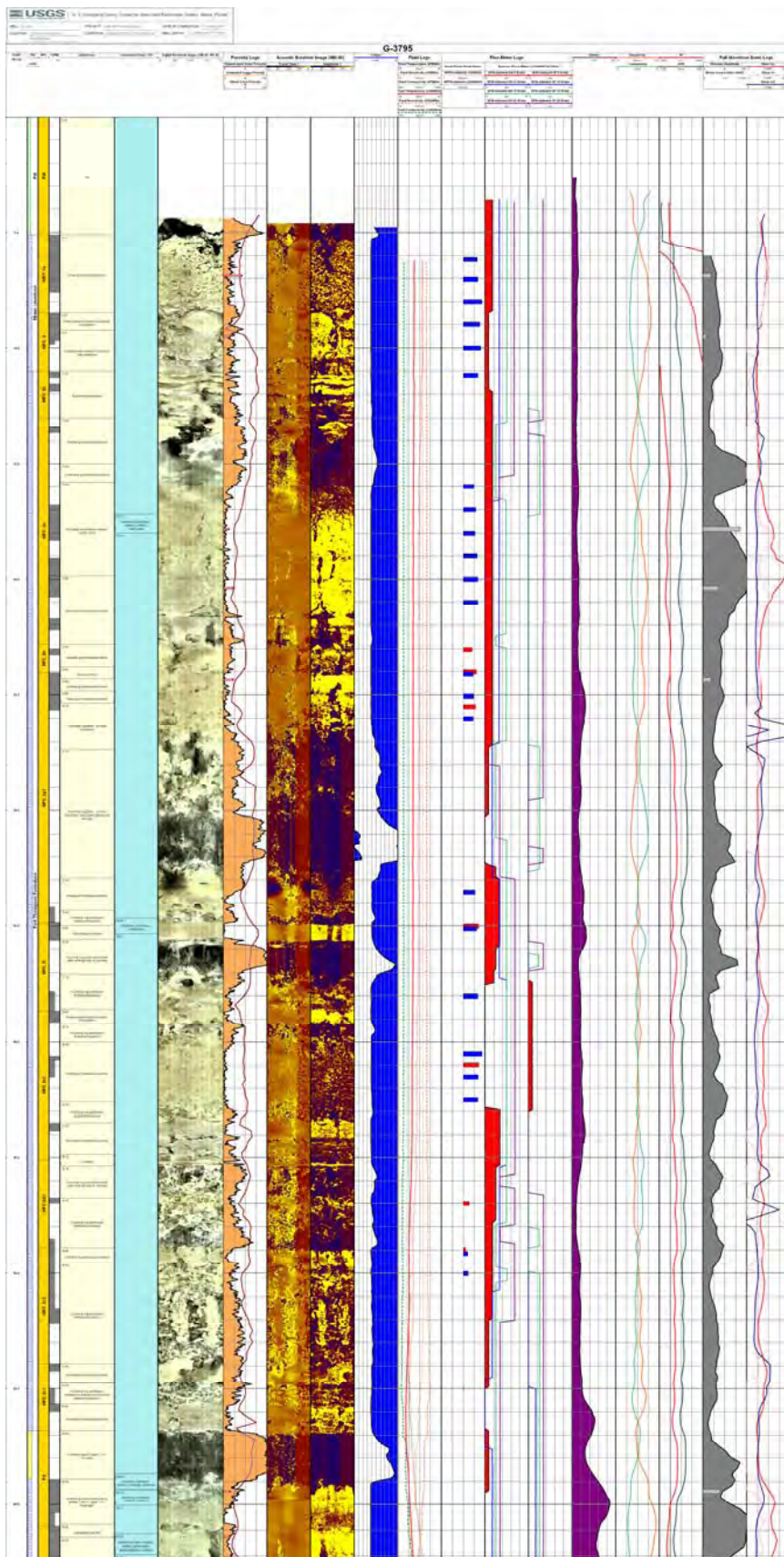


Figure 2. Log montage for corehole G-3795.



Figure 3. Wall mounted Excel Tech XP-1100 power inverter.





Figure 4. View of the large 4MCX1000 (3,280 feet of cable) winch.





Figure 5. Natural gamma and SP/SPR tool.



Figure 6. (a) Caliper and fluid temperature/resistivity tool with (b) detail of arms and fluid probe.



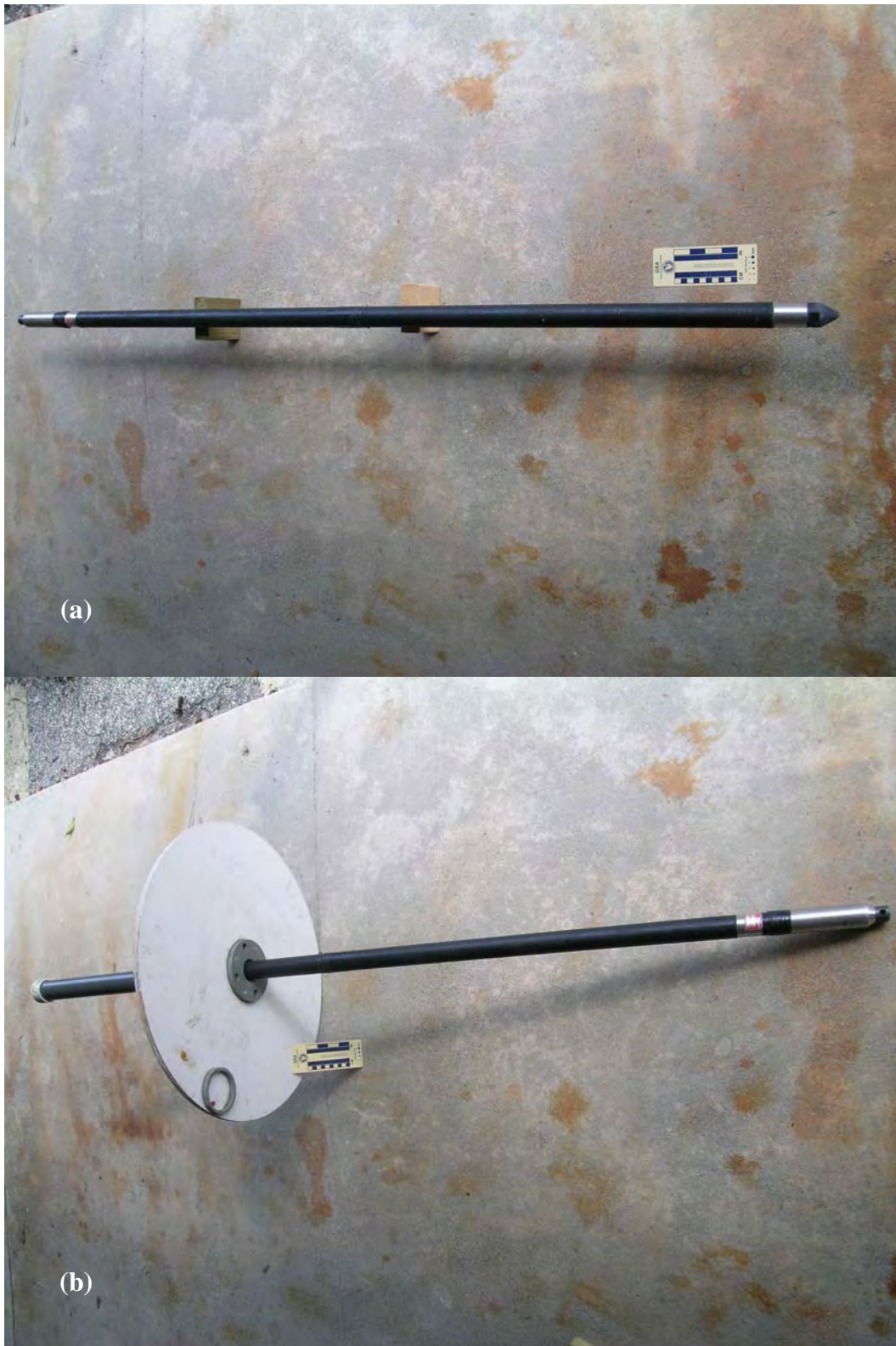


Figure 7. (a) EM induction tool and (b) calibration ring fitted over probe.

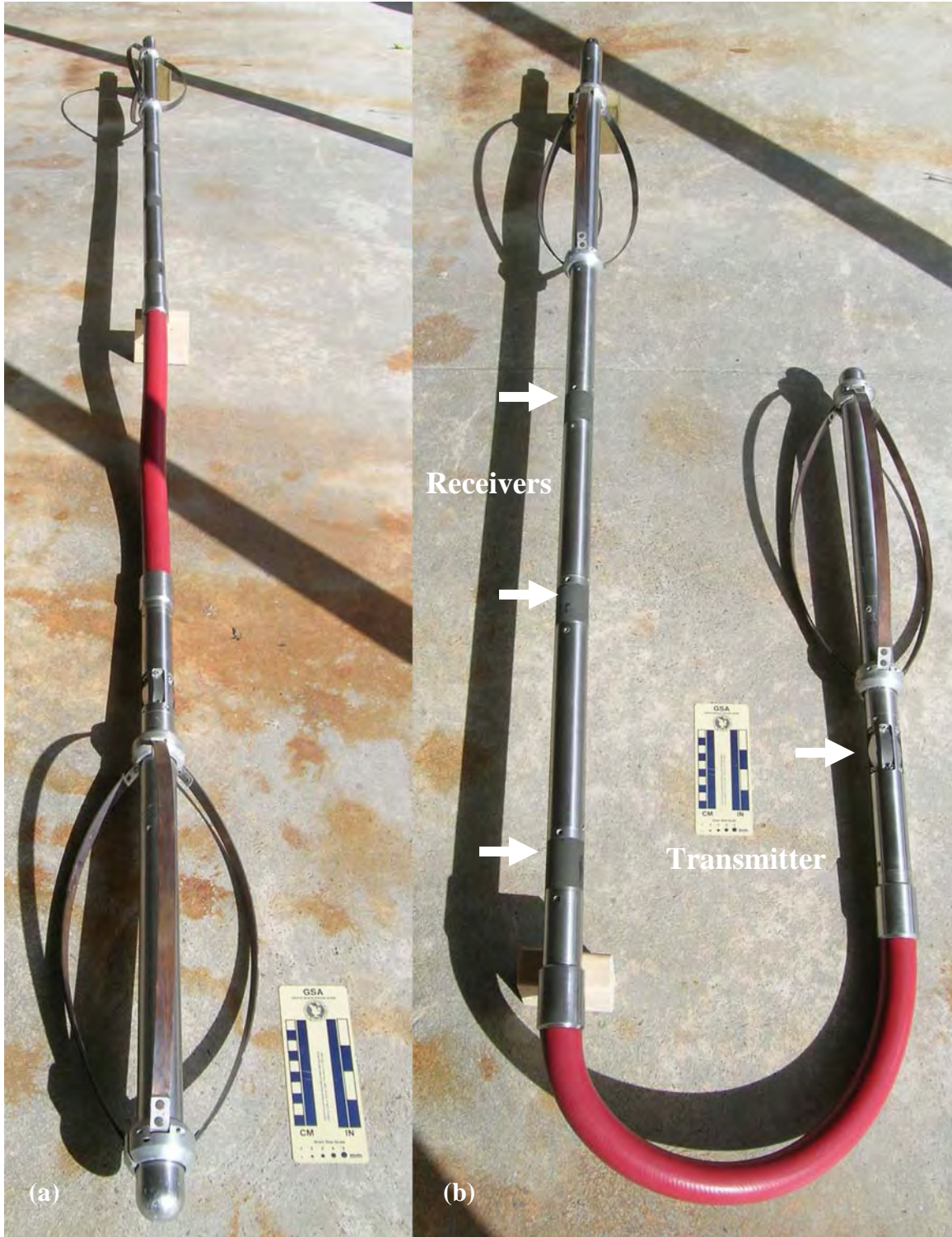


Figure 8. Views of full waveform sonic tool showing (a) full tool length and (b) detail of the transmitter and three receivers.



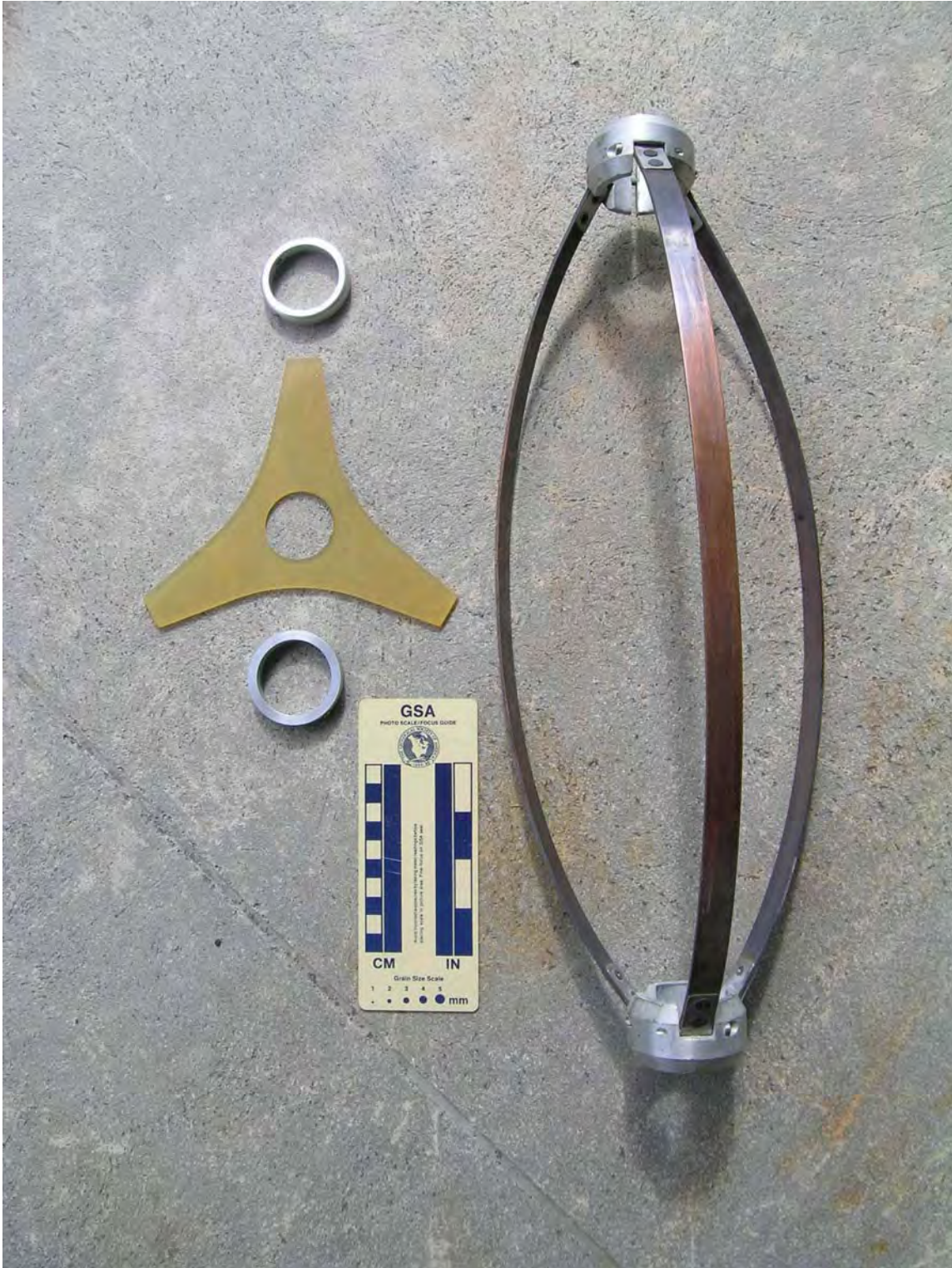


Figure 9. Available centralizer types, plastic rod-spring with locking collars (left) and copper bow-spring (right).





Figure 10. Student holding OBI-49 fitted with plastic rod-spring centralizers. Inset shows detail of optical head.



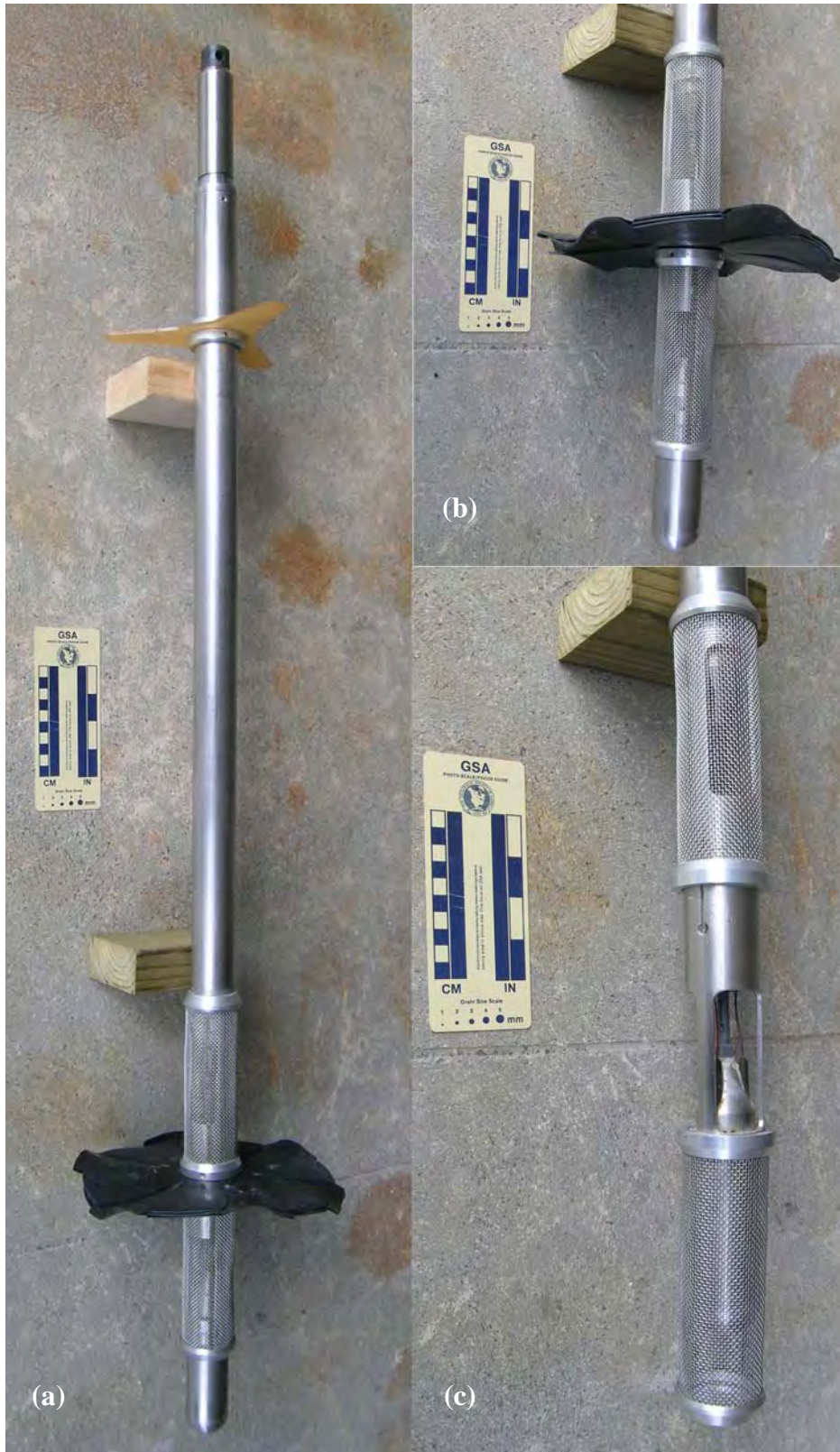


Figure 11. Heat pulse flowmeter showing (a) proper tool set-up, (b) detail of flow diverter and screens, and (c) detail of lower thermistor.

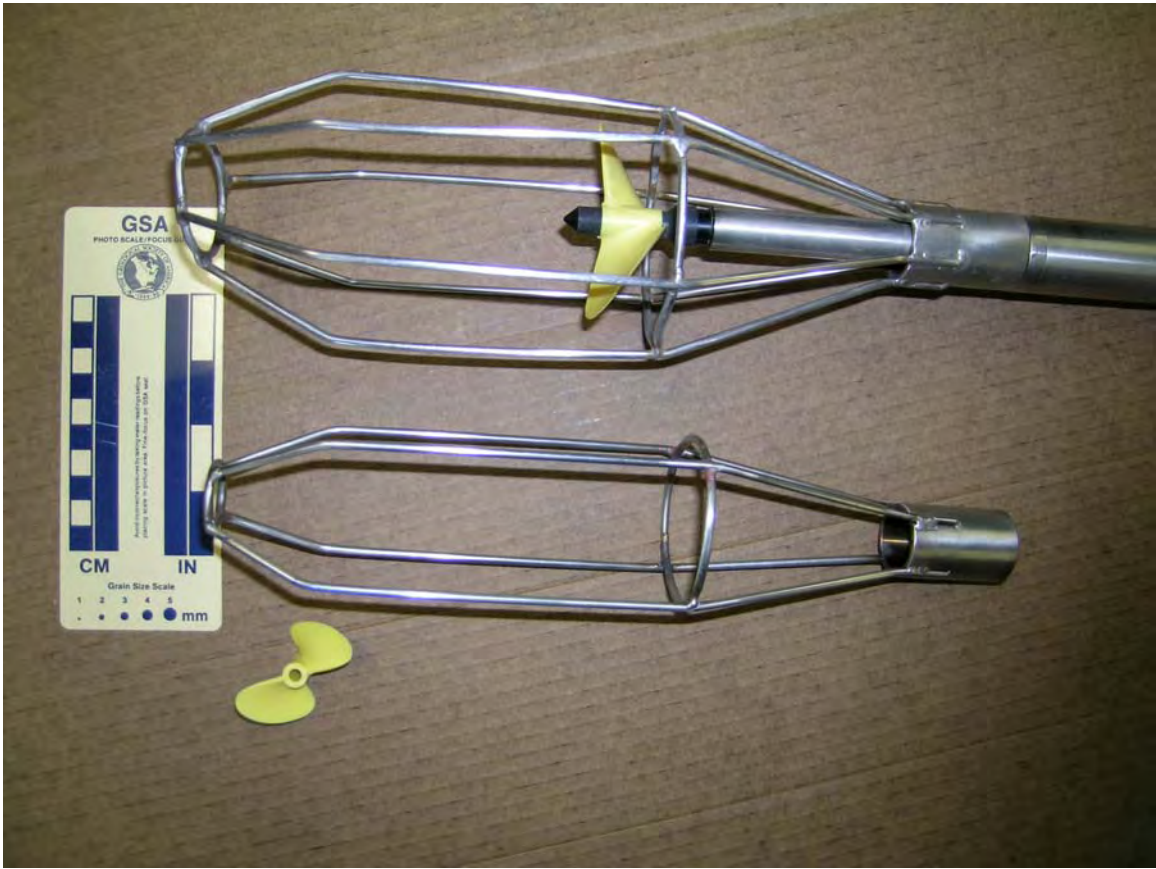


Figure 12. Lower section of the spinner flowmeter showing the two available cage and propeller sizes.

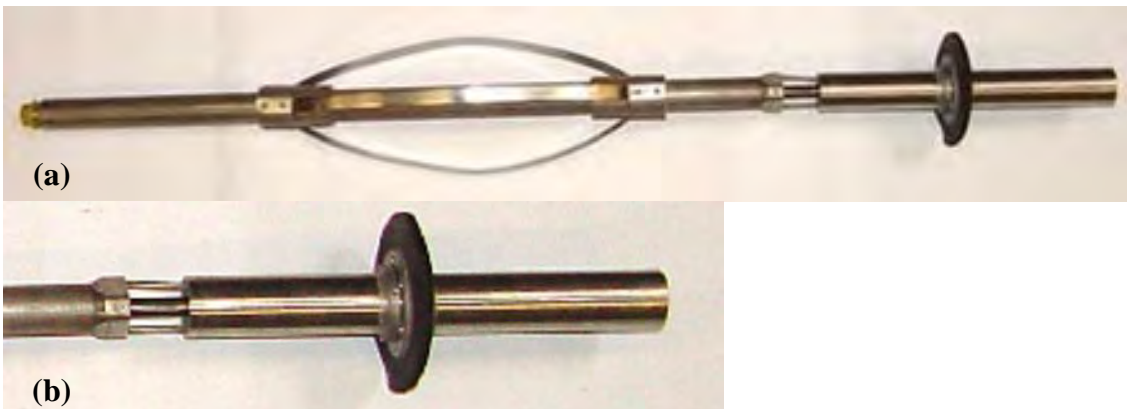


Figure 13. (a) EM flowmeter (USGS-FISC flowmeter does not have a centralizer) and (b) detail of flow diverter.



## Appendix A

### **Available Tools**

All tools and associated equipment are made or distributed by Mount Sopris Instrument Company, Inc., Golden, Colorado with the exception of the EM flowmeter, which is made by Century Geophysical Corp., Tulsa, Oklahoma. All are portable and can operate down to at least 3,280 feet.

Natural Gamma	HLP-2375/S	SN-2202
With spontaneous potential (SP) and single-point resistance (SPR) capability.		
Three-arm Caliper	2CAA-1000	SN-2702
w/ Fluid Temp. & Resist.	2SFB-1000	SN-2703
Electromagnetic Induction	2PIA-1000	SN-3114
Full Waveform Sonic	2SAA-1000/F	SN-3023
Transmitter		SN-3042F
Receiver One		SN-3047F
Receiver Two		SN-2863F
Receiver Three		SN-3088F
Digital Optical Borehole Imager	OBI-40, MK III	SN-3110
with vertical borehole deviation instrumentation.		
Heat-Pulse Flow Meter	HPF-2293	SN-2706
Diverter sizes: 5, 7, and 9 inches.		
Spinner Flow Meter	FLP-2492	SN-2372
Cage sizes: 2 and 4 inches.		
Electromagnetic (EM) Flow Meter	Century-9721	SN-1188
w/ Fluid Temp. & Resist.		

### **Available Winches**

Large Winch	4MXC1000	SN-2011
1000 m (3,280 ft) of 3.17 mm (0.125 in) single conductor cable		
MGXII Console	5MCA/5TMA	SN-1186
Portable Logger	5MGB-1000	SN-1083
170 m (558 ft) of 3.17 mm (0.125 in) single conductor cable		

### **Software/Hardware**

MSLog	Version 7.43 build 729	
MSHeat	Version 1.0 build 626	
MSLConfig	Version 2.3.9.25	
WellCAD	Version 4.0 build 729	SN-510133356
(Note: Dongle required)		
Image and Full Waveform Sonic modules activated.		
Log Cruncher	Version 1.0 build 307.27 Beta	SN-57C7118D7B06372C
Sonic Processing and Formation Evaluation modules activated.		
Dell Laptop	LATITUDE D-610	Windows XP

## Appendix B

### **Available Geophysical Logs**

#### Digital Borehole Image Log

Requires the borehole fluid to be clear with no suspended material. Can be aligned to magnetic north and exported in a BITMAP format.

#### Full Waveform Sonic Logs

Post processing produces compressional, shear, and Stoneley-wave velocity logs; Stoneley amplitude log can yield a sonic porosity log using the Raymer-Hunt or Wylie equations. Can also create a cement bond log and with additional processing, and logs of various engineering properties.

#### Flowmeter Logs

Measures vertical fluid flow within a borehole. Three types available based on flow velocity, (1) heat-pulse flowmeter (units are in gallons per minute, GPM, does not provide a continuous log) for flow less than 1.5 down to 0.03 GPM, (2) spinner flowmeter (units are CPS) for flow greater than 6.5 feet per minute (FPM), and (3) an EM flowmeter (units are GPM and FPM) which works in a wide range of flow velocities (0.01 to 10.6 GPM), but requires additional calibration and maintenance issues.

#### Borehole Deviation Log

Derived from OBI-40 three-axis orientation data.

#### Computed Vuggy Porosity Log

A computer generated log that requires a digital optical borehole image log and outside processing from a consultant.

#### Acoustic Borehole Image Log

Requires rental of the ABI-40 downhole tool. Additional logs available are Acoustic Caliper Logs, borehole volume computation and cross sections, and a virtual acoustic core.

#### Fluid Logs, temperature and resistivity

Additional logs are conductivity, specific conductance, and salinity (Riley and Skirrow, 1975).

#### Caliper Log

Mechanical, three-arm.

#### Natural Gamma

In units of counts per second (CPS).

#### Electromagnetic Induction, formation conductivity

A formation resistivity log is also produced using the inverse relationship.

#### Spontaneous Potential and Single Point Resistance

## Appendix C

### **Borehole Logging Requirements**

<b>Tool</b>	<b>Minimum Hole Diameter</b>	<b>Cased/Uncased</b>	<b>Fluid</b>	<b>Other</b>
Gamma	2-in	Both	No requirements	Casing corrections can be applied.
SP/SPR	2-in	Uncased	Fluid filled	None
Caliper	2-in with small arms and 2.25-in with large arms	Uncased	No requirements	Two arm lengths for maximum diameters of 17-inch or 30-inch.
Fluid/Resistivity	2-in	Both	No mud filled holes	Conductivities 0-1000 $\mu\text{S/cm}$ .
EM Induction	2-in	Both (PVC only)	No requirements	Three ranges: 0-100 mS/m 0-1000 mS/m 0-10,000 mS/m.
Full Waveform Sonic	2.5-in 10-in max. 7-in optimal	Both (uncased best for rock properties)	Fluid filled boreholes only	Centralizer noise effects quality.
Digital Optical Imager (OBI 40 MK III)	2.5-in 12-in max. 7.5 in optimal	Both (uncased for rock view)	<u>Clear</u> water only	Particulate settling time and air-lift for clear and stable hole.
Acoustic Borehole Imager ABI 40	2-in 24-in max. 7-in optimal	Both (uncased best)	Fluid filled (water/mud)	Must have space behind casing to image.
Heat-Pulse Flowmeter	3.5-in (2-in, no diverter)	Both (if slotted casing)	Fluid filled, little or no mud	0.03-1.0 GPM, can be read up to 1.5 GPM.
Spinner Flowmeter	2-in  Catches on obstructions in hole.	Both (if slotted casing)	Fluid filled, little or no mud	6-200 ft/min Output in CPS. Extensive calibration required to convert to GPM.
EM Flowmeter (Fluid resistivity and temperature)	3.75-in Diverters may have to be created or modified.	Both (if slotted casing)	Fluid filled, little or no mud	0.01-10.5 GPM Calibration and repair issues.

# Borehole Geophysical Logging Program: Incorporating New and Existing Techniques in Hydrologic Studies

## Overview

The borehole geophysical logging program at the U.S. Geological Survey (USGS)-Florida Integrated Science Center (FISC) provides subsurface information needed to resolve geologic, hydrologic, and environmental issues in Florida. The program includes the acquisition, processing, display, interpretation, and archiving of borehole geophysical logs. The borehole geophysical logging program is a critical component of many FISC investigations, including hydrogeologic framework studies, aquifer flow-zone characterization, and freshwater-saltwater interface delineation.

## New Borehole Geophysical Logging Capabilities in Florida

In addition to acquiring standard borehole-log information such as caliper, gamma, spontaneous potential, and electromagnetic induction data (table 1), FISC utilizes new technologies and procedures to generate advanced logs. Of particular importance are digital borehole imaging and electromagnetic flowmeter logging, both of which are now used to augment existing techniques.

Digital borehole optical viewers equipped with a high-resolution cameras can create detailed, 360-degree images of borehole walls and simultaneously collect borehole deviation data. The digital borehole images can be used to (1) accurately determine the depths for a well completion interval, (2) position a recovered core to its proper depth, (3) acquire a high-resolution borehole image that serves as a surrogate for intervals having no core recovery (Ward and others, 2003), and (4) characterize aquifer pore systems. Fracture and bedding plane orientations can also be determined, because borehole images can be oriented to magnetic north. In combination with a new digital log acquisition system, a digital borehole image can be acquired at relatively high logging speeds (about 3-15 feet per minute, depending on desired pixel density). Various log presentation software can be used to display these images, as well as standard logs on multilog-paper displays up to 36 inches wide. A digital copy of the display can be viewed on a computer using nonproprietary software readers.

To address difficulties in accurately quantifying relative transmissivity in aquifer flow zones, FISC is now using an electromagnetic flowmeter to accurately measure flow at intermediate velocities. Previously, heat pulse flowmeters and

spinner flowmeters were solely used to measure flow across all velocities. Heat pulse flowmeters, however, can only measure low-velocity flow and do not generate continuous logs. Spinner flowmeters adequately measure high velocity flow and generate continuous logs, but quantifying the amount of flow from spinner revolutions is time consuming and difficult. The electromagnetic flowmeter accurately measures medium flow velocities, generates a continuous log of flow velocity and direction, and can make stationary measurements like the heat pulse flowmeter. The logs generated by the electromagnetic flowmeter can help show the relative transmissivity of flow zones within a well. A fluid meter built into the tool also displays changes in temperature and fluid resistivity, which also aids in the identification of flow zones.

Although most borehole geophysical log acquisition is performed from a vehicle, equipment portability also allows easy transport to remote well sites, such as those in offshore marine or wetland environments. Wells up to 3,200 feet deep and greater than 2 inches in diameter can be accommodated, providing access to all major aquifers in Florida, including much of the Floridan aquifer system.

## FISC Hydrologic Investigations Employing Borehole Geophysical Logging Techniques

Geophysical logs run in exploratory or investigative boreholes can provide valuable hydrogeologic information, especially in areas with poor lithologic and (or) hydrologic control. Geophysical logs also can provide much needed information to help in determining the correct placement of well completion depths or intervals. The acquisition of borehole geophysical logs can become the determining factor in solving complex subsurface issues. The following studies highlight new and existing techniques used by FISC to resolve geologic, hydrologic, and environmental issues.

## Hydrogeologic Framework Studies

Partially recovered core samples typically can only be placed within a 5- to 10-foot range of core barrel depth. Placement of core material or recognition of void space within these poor recovery intervals is often difficult using examination of the core and standard borehole geophysical methods. With the aid of a digital optical borehole image log, a trained user can accurately

reconstruct core sample depths (Ward and others, 2003) and use image log data to aid in pore-type characterization (including large cavities) for both intervals with and without recovered core. Cunningham and others (2004a, b; 2006a, b) used digital images to identify lithology, pore type, and zones of concentrated ground-water flow to show the connection between stratigraphy and the development of porosity and permeability within the Biscayne aquifer. Further study led to the development of a multilayer, conceptual hydrogeologic framework for the Biscayne aquifer along the Everglades-Urban corridor (Lake Belt area) in northwestern Miami-Dade County (Cunningham and others, 2006a).

Digital optical borehole imagery was used in combination with core data to construct stratigraphic sections that show the areal extent of macroporous flow zones within the Miami-Dade Northwest Well Field (Renken and others, 2005; 2008). Tracer tests conducted during 2003-04 at the well field demonstrated the continuity of touching-vug flow zones and the potential for rapid, long-distance chemical and colloidal transport within the Biscayne aquifer (Shapiro and others, 2008; Harvey and others, 2008). Digital optical borehole imagery was used to determine the dimensions

of macropores, and was also used with core data to develop hydro-stratigraphic cross sections to help show the connectivity of macroporosity between wells. Previous studies may have underestimated the porosity, as well as the areal extent of macroporosity.

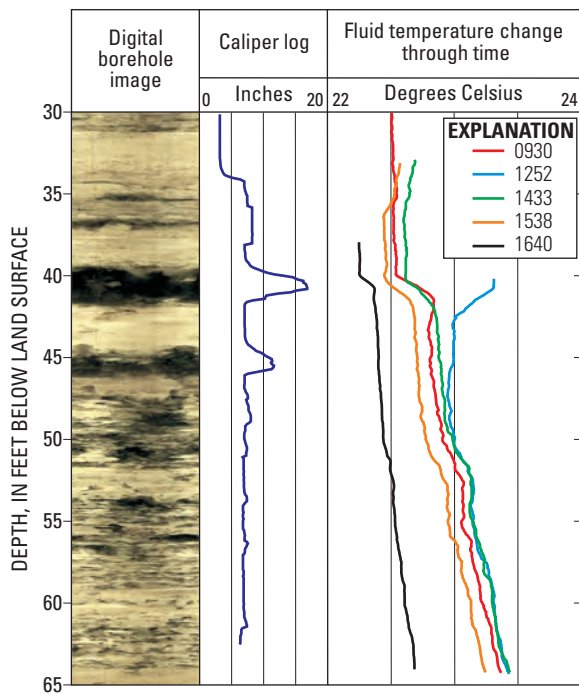
## Aquifer Flow-Zone Characterization

Borehole fluid temperature and conductivity logs collected during one of the Miami-Dade Northwest Well Field tracer tests have been used to illustrate well-to-well tracer movement within preferential flow zones (Cunningham and others, 2006b; Renken and others, 2008). Observation well borehole fluid temperature logs were used to show that a single flow zone constitutes the dominant horizon for well-to-well hydraulic interconnection and for the migration of most of the tracer mass (fig. 1). The observed monotonic increase in temperature with depth shortly after injection (1252 hours) suggests that conservative tracers traveling within the shallow flow zone approximately 41 feet below land surface arrived at the observation well prior to tracers traveling within touching-vug pore zones at greater depths (Renken and others, 2008).

**Table 1.** Available geophysical logs for use in FISC research.

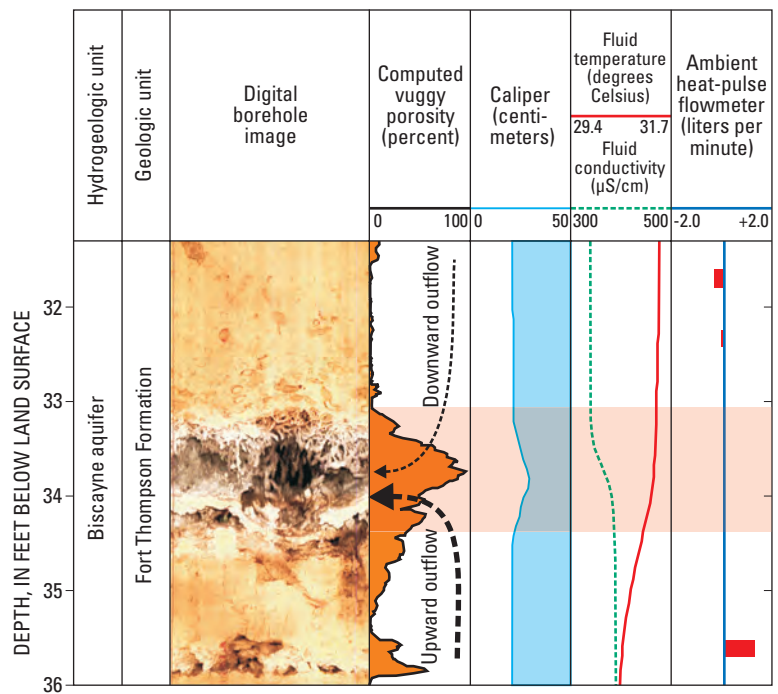
[cps, counts per second; EM, electromagnetic; FISC, Florida Integrated Science Center; ft/min, foot per minute; gal/min, gallon per minute; PVC, polyvinyl chloride]

Geophysical logging tool and log type	Tool use	Interpretive value of log
Borehole deviation	Measures deviation of borehole from vertical.	Used as input for calculation of true vertical depth.
Borehole fluid	Generates logs of water-quality properties that include the following: borehole fluid temperature, resistivity, conductivity, specific conductance, salinity, pressure, redox, dissolved oxygen concentration, and pH.	Identification of ground-water flow zones penetrated by the borehole and sources of incoming water.
Caliper	Measures borehole diameter, using mechanical, three-arm, or high-resolution acoustic caliper.	Determination of cavity size and geometry.
Digital, optical and acoustic borehole image	Televiwer creates digital, optical and acoustic images of borehole wall or casing.	Used to reference core to original depth, detect cavities, faults, and fractures, as well as characterize pore systems. Optical and acoustic log types can be aligned to magnetic north and exported in BITMAP format.
Electromagnetic induction	Measures formation conductivity in both cased and uncased wells. Produces a formation resistivity log using the inverse relations with conductivity.	Determination of depth to freshwater-saltwater interface in boreholes. Help identify zones of ground-water flow.
Flowmeter	Measures vertical fluid flow within a borehole. Measures flow under both ambient and pumping conditions. Tool choice is based on fluid flow velocity: (1) heat pulse flowmeter (units in gal/min) for flows less than 1.5-0.03 gal/min, (2) spinner flowmeter (units in cps) for flows greater than 6.5 ft/min, and (3) EM flowmeter (units in gal/min or ft/min) measures a wide range of flow velocities (0.01-10.6 gal/min).	Identification of ground-water flow zones penetrated by the borehole and determination of relative transmissivity of flow zones.
Full waveform sonic	Measures acoustic wave travel time through borehole fluid and the surrounding rocks. Post processing creates compressional, shear, and Stoneley-wave logs.	Compressional velocity logs are used to create a sonic porosity log with either the Raymer-Hunt or Wylie equations. Stoneley-wave amplitude log is used to estimate permeability. Additional processing yields cement bond logs, as well as logs showing various engineering properties, and synthetic seismic wiggle traces.
Natural-gamma	Measures gamma radiation of natural radioisotopes in surrounding formation (output is in cps).	Correlation of lithologic units between wells.
Spontaneous potential and single-point resistance	Measures the natural potential that originates from electrochemical differences between borehole and formation fluids at lithologic boundaries. Requires an open borehole.	Used to infer lithologic changes. Single-point resistance log can be used to detect sections of slotted casing in completed wells.



**Figure 1.** Temporal change in borehole temperature caused by the migration of a tracer within a touching-vug flow zone at a depth of 41 feet below land surface in an observation well (modified from Renken and others, 2008). Tracer injection occurred at 0930 hours. Fluid temperature log at 1252 hours was not completed because the top of the logging tool was lodged against the casing bottom.

High-resolution heat pulse, electromagnetic, and spinner flowmeters are routinely used by FISC scientists to measure vertical fluid flow within a borehole over a wide range of flow rates and under both ambient and pumping conditions. Borehole flowmeter measurements have been used to identify permeable flow zones in the Biscayne aquifer (Cunningham and others, 2004a; 2006a), and assess vertical hydraulic gradients. Flowmeter measurements combined with data from digital borehole images and fluid-temperature and conductivity logs can be used to accurately evaluate and characterize flow zones within the context of a high-resolution conceptual hydrogeologic framework (fig. 2). As an example, Cunningham and others (2004b) used ambient flowmeter and borehole fluid-temperature and conductivity logs to hypothesize sources of ground-water recharge. Data from flowmeter and borehole-fluid logs collected in seven wells along an 8-mile reach of the L-31 Canal in Miami-Dade County were used to identify sections that were consistent with aquifer recharge by surface water from Everglades National Park. Horizontal flowmeters were also placed within preferential flow zones of the Biscayne aquifer identified by digital borehole images during this study (Cunningham and others, 2004b) as part of a continuous ground-water monitoring program operated by the South Florida Water Management District. The real-time flow data (which are still being analyzed) from these horizontal flowmeters show variable ground-water flow directions and rates. These data, along



**Figure 2.** Comparison of borehole image, computed vuggy porosity, geophysical, and flowmeter logs for the G-3788 test corehole showing evidence of water outflow from the borehole into a preferential flow zone. Abbreviation μS/cm is microsiemens per centimeter.

with data from Cunningham and others (2004b), were later used to further hypothesize that nearby ground-water pumpage in excess of the permitted allotment was also influencing recharge.

## Freshwater-Saltwater Interface Delineation

Electromagnetic induction logs have been used to obtain detailed vertical profiles of the conductivity of the aquifer around each well, and used in combination with surface-geophysical methods and chloride concentration data, to map the position of the saltwater interface in southeastern Florida (Hittle, 1999). Detection and monitoring of the saltwater front through induction logging in cased wells over time is an ongoing effort by the USGS and State, county, and municipal cooperators. The induction logging tool measures the bulk electrical conductivity of rock and pore fluids to delineate lithology, porosity, and fluid salinity within open and polyvinyl chloride (PVC)-cased boreholes. Within these casings, this logging tool can measure changes in the dissolved-solids concentration of pore fluid over time. Data collected from USGS monitoring wells as part of the ongoing induction logging program indicate that interface movement is irregular within the vertical section of the well, and possibly related to differential lateral movement of brackish to saline water within zones of higher permeability (fig. 3).



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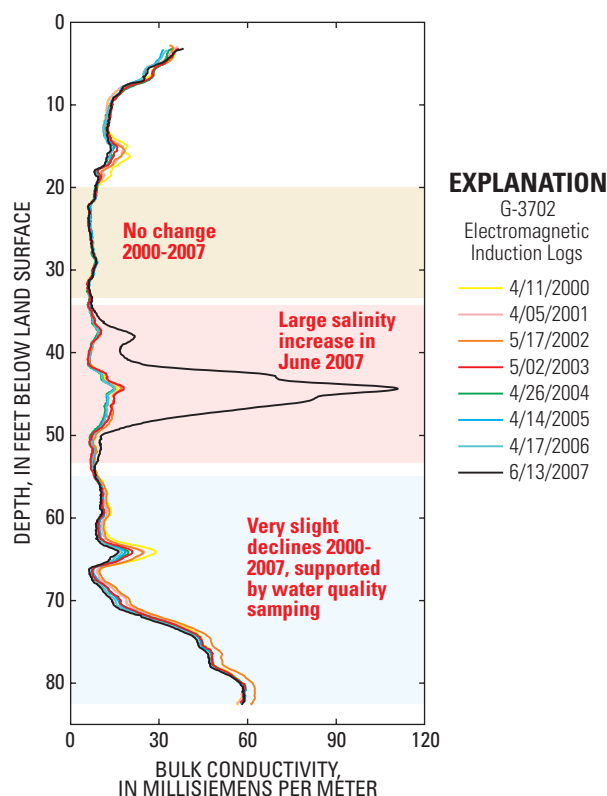
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**Figure 3.** Comparison of electromagnetic-induction logs collected in well G-3702 from April 2000 through May 2007 along Black Creek Canal in Miami-Dade County (Scott Prinos, U.S. Geological Survey, written commun., 2008). An increase in conductivity is evident between 40 and 50 feet.

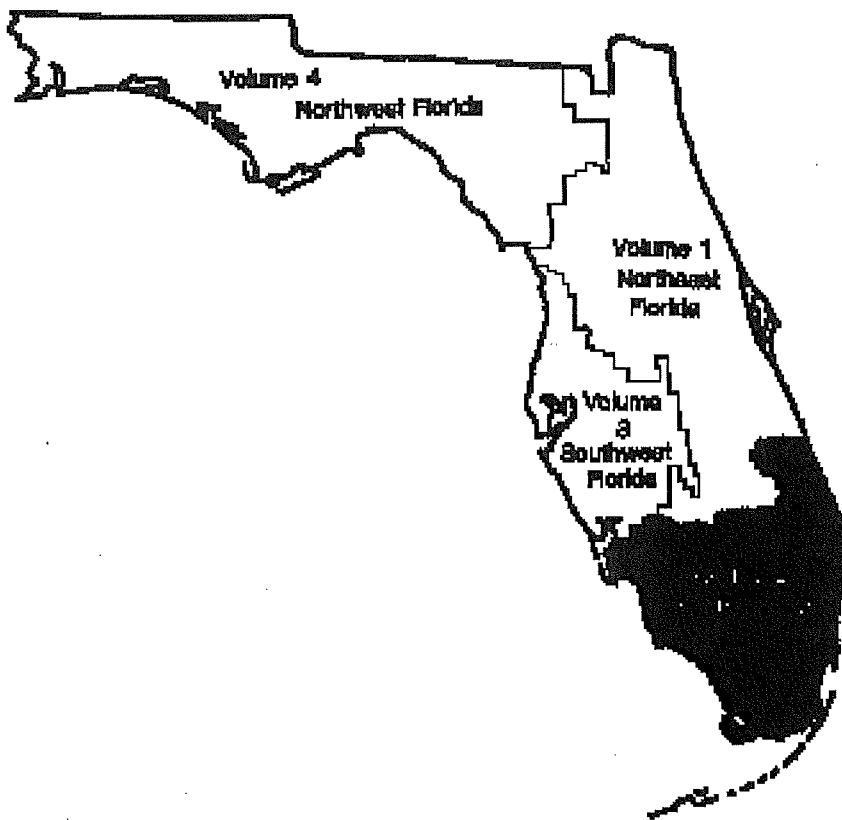
U.S. Department of the Interior  
U.S. Geological Survey

# Water Resources Data Florida Water Year 2001

## Volume 2B. South Florida Ground Water

By S. Prinos, K. Overton, M. Byrne

Water-Data Report FL-01-2B



Prepared in cooperation with the  
State of Florida and with other agencies





## VOLUME 2B: SOUTH FLORIDA

RECORDS OF BULK ELECTRICAL CONDUCTIVITY

Bulk conductivity is the combined electrical conductivity of all material (including pore water) within an approximately 8 to 40 inch doughnut shaped area surrounding an induction probe (McNeill and others, 1990). Bulk conductivity is affected by different physical and chemical properties of the material including the dissolved solids content of the pore water and lithology and porosity of the rock. PVC casings do not interfere with these measurements but for those wells where a steel or galvanized iron casing extends part way down the well, the probe can not sense the materials outside of the casing. Usually, as the probe moves down the well and out of the influence of a metallic casing, a spike is created in the data. As the probe passes through different layers of rock, the different physical properties will cause conductivity values to vary. Generally, a clean sand or sandstone will produce lower conductivity values than clay or mudstone. While the properties of the rocks or well construction will remain constant from year to year, those of the porewater may change due to saline intrusion. Conductivity values from freshwater-saturated rocks are typically less than 25 mS/m, whereas conductivity values from saltwater-saturated rocks are typically greater than 67 mS/m (Hittle, 1999). Therefore, induction logging can be used to assess increases or decreases in the conductivity of pore waters caused by movement of the saltwater interface.

Data Collection and Computation

Measurements are generally made during the period of lowest aquifer water levels in April of each year. However, some wells may have additional logs. During periods of decreased water-levels, saltwater intrusion into a freshwater aquifer is likely at a maximum. In wells where saltwater is detectable, the graphic representation of data from successive years will show any vertical movement of the saltwater-freshwater interface. Measuring this vertical movement of the interface is the primary use of the bulk conductivity logs published in this report. Upward movement of the interface between freshwater and saltwater in a monitoring well indicates that saltwater intrusion is increasing in that area. Downward movement of the interface indicates recession of the saltwater front near the monitoring well.

In the conductivity plots of some of the wells logged for this report, the interface position can be seen as the point where low values of conductivity increase suddenly to values generally above 67 mS/m (usually near the bottom of the well). However, the interface position is not as apparent in other wells and in some, there is no interface.

In wells selected for induction logging, a water sample may be collected and analyzed as a check on the level of salinity. Because the bulk conductivity is a function of fluid conductivity, lithology, and porosity, the relationship between these logs and the chloride samples may not be as obvious as the relationship between fluid conductivity and chloride concentrations generally are. If the rock is not very porous then the change in bulk conductivity caused by changes in the salinity of the pore water may be smaller than might be expected. None the less, the long-term changes in the bulk conductivity logs are sufficient to assess upward or downward movement of the interface. To aid in interpretation of the bulk conductivity logs whenever chloride samples are collected on the same day as that log, the chloride concentration is shown on the plot of bulk conductivity.

The instrument used to collect data for this report is calibrated prior to each field session. The calibration procedure results in a calibration factor that converts raw instrument readings into calibrated values of conductivity. When data were graphed for the 2000 annual water resources data report, offsets and amplitude differentials occurred in the calibrated values of bulk conductivity for each well between successive years. Investigation revealed that the discrepancies were a function of differing calibration factors between years. Most calibration factors differed because of temperature and humidity differences during calibration procedures. Calibration procedures, adapted during the 2000 water year, are designed to minimize the influence of variable temperature and humidity. Before calibrating, the induction probe was run into a well and allowed to equilibrate in the water column. The probe was then removed from the well and the instrument immediately calibrated.

Factors other than variable temperature and humidity also have caused offsets and amplitude differentials. Because of an error while calibrating the instrument for the 1998 water year, a high-end calibration parameter was used that differed from other years. The differing parameter caused a data offset at higher ends of the scale. A second factor that may have caused data offset and amplitude differentials occurred with data collected for the 2000 water year. Prior to logging for the 2000 water year, the instrument was updated with respect to firmware and software. After logging, it was found that the data had been truncated at the decimal point (see Accuracy of Bulk Conductivity).

## VOLUME 2B: SOUTH FLORIDA

Accuracy of Bulk Conductivity

There are two components that affect the quality of the induction logs published in this report: (1) vertical or depth accuracy and (2) accuracy and precision of measured bulk conductivity. As indicated in the preceding section, the vertical accuracy which affects the interface position is the most critical factor in this monitoring effort. Therefore, as long as the interface is clearly indicated in the logs of bulk conductivity, the accuracy with which its depth can be determined is the primary component of interest. A quality control program sets the velocity of the probe at 12 feet per minute while logging. Before logging begins, a spot on the probe, 3.32 feet above the sensing head, is aligned with the measuring point of the well. Wherever possible, the data that was recorded as the probe was moved up the well was used to produce the plots for this report. Depth values between successive water years were adjusted, if needed, to coincide at explicitly identifiable conductivity peaks recorded from an upper part of the well. Depth values are interpolated to the nearest tenth of a foot. The precision of depth determinations using this reporting method should be considered to be about  $\pm 0.1$  foot.

The accuracy and precision of measured bulk conductivity are a function of both the inherent accuracy of the induction probe and its calibration. The inherent precision of the probe is considered by the manufacturer to be  $\pm 5$  percent of the full scale. The induction probe was calibrated to a full scale of 1,000 mS/m. This translates into a precision of  $\pm 50$  mS/m at full scale. Analysis indicated that the offsets caused by the effects of temperature and humidity on calibration were well within this range.

Accuracy of data collected during the 2000 water year may have been affected by the firmware or software update in December, 1999. The data collected using this new software and firmware was considerably offset when compared to previous induction logs. In addition, the final values were truncated at the decimal point, whereas those collected prior to the update were recorded to the thousandths decimal place. These final values are the result of a multiplication of the raw data from the instrument and a calibration factor. It is unknown whether or not the raw values were truncated at the decimal point. If so, the resulting error could be on the order of 5 mS/m too low. Because the offsets data from the 2000 water year is often 5 mS/m lower than the data from other years, truncation of the raw data is probably the explanation.

Data Presentation

Records of conductivity are published individually on the page immediately following the well manuscript. Data for conductivity are identified by well number. Each record consists of a single graph representing conductivity, a lithologic log, and a brief explanation.