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MARYLAND GEOLOGICAL SURVEY
Emery T. Cleaves, Director

ADMINISTRATIVE REPORT

COMPARISON OF BRACKISH-WATER INTERFACE IN 1988-90 AND 2005-06 IN THE AQUIA AND MONMOUTH AQUIFERS IN EAST-CENTRAL ANNE ARUNDEL COUNTY, MARYLAND, USING INDUCTION LOGGING AND CHLORIDE ANALYSIS

by

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Prepared in cooperation with the

Anne Arundel County Department of Health

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KEY RESULTS

Induction logs were run and chloride concentrations were measured in a set of test wells on the Broadneck, Annapolis Neck, and Mayo Peninsula to determine changes in the position of the brackish-water/freshwater interface in the Aquia and Monmouth aquifers, and to investigate whether brackish-water intrusion has occurred in the Magothy aquifer. The logging and water sampling follows an earlier investigation of brackish-water intrusion conducted by the Maryland Geological Survey between 1988 and 1990.

- Overall, the brackish-water/freshwater interface in the Aquia and Monmouth aquifers on Annapolis Neck and Mayo Peninsula, observed in a set of test wells, is stable. The extent of brackish-water intrusion in the Aquia and Monmouth aquifers is similar to that mapped in 1988-90.

- The induction logs indicate that there has been no intrusion of brackish water at sites where intrusion was previously undetected in the Aquia and Monmouth aquifers. Those sites include Annapolis Roads, Hillsmere, and South River Farms Park.

- There has been no intrusion of brackish water in the Magothy aquifer at Sherwood Forest (Annapolis Neck) and Moorings-on-the-Magothy (Broadneck) test sites

- At sites previously intruded with brackish water in the Aquia and Monmouth aquifers, there has been no appreciable change in the depth and thickness of the brackish-water/freshwater interface. Those sites include Londontown Park, Quiet Waters Park, Bay Ridge, Arundel-on-the-Bay, and Mayo Beach Park.

- The only movement of the brackish-water zone occurred deeper in the section at Arundel-on-the-Bay. At that site, the induction log showed a reduction in resistivity below about 170 feet below sea level in the Monmouth aquifer. The chloride concentration increased from 2,300 milligrams per liter in 1989 to 5,800 milligrams per liter measured in 2006. The increase in chloride concentration may be a delayed response to pumpage from the Aquia aquifer caused by intervening low permeability sediments, possibly cemented sandstone, that may impede the flow of brackish water.

INTRODUCTION

Background

Between 1988 and 1990 the Maryland Geological Survey and U.S. Geological Survey conducted an investigation to determine the extent and movement of brackish-water intrusion in east-central Anne Arundel County (Fleck and Andreasen, 1996). The purpose of the study was to provide the necessary scientific foundation for developing a management strategy to address the brackish-water intrusion problem in the Aquia aquifer on Annapolis Neck and Mayo Peninsula. The study included a refinement of the hydrogeologic framework and the development of digital models to simulate potential effects of increased pumpage on water levels and brackish-water intrusion. The primary area of concern was the Annapolis Neck and Mayo Peninsula where elevated chloride concentrations had been reported in domestic wells screened in the Aquia aquifer. The study also addressed the possibility of brackish-water intrusion in the Magothy aquifer on Annapolis Neck and Broadneck Peninsula. As part of the study, 25 monitoring wells were drilled, logged (resistivity and gamma radiation), constructed, and sampled for chloride and other major inorganic constituents. Eleven of the wells were screened in the Aquia aquifer, nine were screened in the Monmouth aquifer, and five were screened in the Magothy aquifer. Results of the resistivity logging and chloride analyses indicated that a wedge of brackish water from Chesapeake Bay and its tributaries was intruded approximately 200 to 500 feet (ft) inland in the Aquia and Monmouth aquifers on Annapolis Neck and Mayo Peninsula. The extent of the intrusion was further delineated with approximately 70 chloride analyses from domestic wells. No brackish-water intrusion was detected in the Magothy aquifer. A cross-sectional solute transport model (SUTRA) was constructed to assess the flow dynamics of the brackish-water/freshwater interface and to predict possible future movement of the interface resulting from pumpage. Results of the modeling suggested that the interface is in equilibrium with the fresh-water aquifer head. The model also simulated a 10- to 15-ft increase in the vertical position of the interface as a result of a 30-percent increase in domestic withdrawals over a 100-year period. It was determined that domestic wells screened in the freshwater portion of the aquifer just above the interface are at risk from contamination caused by up-coning. Based in part on the results of the study, the Anne Arundel County Department of Health requires new wells to be constructed in the deeper Magothy aquifer in the affected areas.

Purpose and Scope

The purpose of this study was to determine if the brackish-water/freshwater interface in the Aquia and Monmouth aquifers on Annapolis Neck and Mayo Peninsula had changed position since 1988-90, as tested in a series of test wells. In addition, the presence of brackish-water intrusion in the Magothy aquifer—not detected in the test wells in 1988-90—was investigated. Changes in the position of the brackish-water/freshwater interface were determined by comparing borehole geophysical logs (resistivity) and chemical analyses (chloride and specific conductance) run during this study to the earlier testing of test wells on Broadneck, Annapolis Neck, and the Mayo Peninsula.

Location of Study Area

The location of the study area is the east-central part of Anne Arundel County (fig. 1). This area encompasses Broadneck, Annapolis Neck, and the Mayo Peninsula. The three peninsulas are bordered by Chesapeake Bay, and the Magothy, Severn, South, and Rhodes Rivers, all of which are tidal within the study area. Eleven test sites, containing 25 wells, are located within the study area.

METHODS OF ANALYSIS

Induction Logging

Prior to construction of the test wells drilled between 1988 and 1990, a suite of borehole geophysical logs were run to determine the hydrogeologic framework (aquifer and confining beds), and to identify areas intruded by brackish water from Chesapeake Bay and its tributaries (Fleck and Andreasen, 1996). The geophysical logs included natural gamma radiation, spontaneous potential, single-point resistance, 6-ft lateral resistivity, and multi-point resistivity logs (16- and 64-inch electrode spacing). The brackish-water/freshwater interface was identified in the Aquia and Monmouth aquifers on resistivity logs at the Londontown Park, Quiet Waters Park, Bay Ridge, Arundel-on-the-Bay, and Mayo Beach Park test sites. The interface was characterized by a relatively abrupt reduction in resistivity corresponding to high conductance (salty) ground water. Comparing resistivity curves run in the same holes to the curves run in 1988-90 can provide a means of determining movement of the brackish-water/freshwater interface. However, the 6-ft lateral and multi-point resistivity tools are unable to penetrate the PVC well casing and screen of which the test wells are constructed. An alternate tool that is capable of determining formational fluid conductivity, and that can also penetrate PVC casing, is the electromagnetic induction probe. This tool generates a magnetic field, which in turn induces an electric current in the surrounding sediment. A secondary magnetic field, generated by the electric current in the sediment, is detected and measured by a receiver in the probe. Since the strength of the magnetic field is linearly proportional to the conductivity of the formation, the tool can be calibrated to read conductivity directly (McNeill and others, 1990). The U.S. Geological Survey ran induction logs in the deepest well at each test site on September 2, 2005 using a Century Geophysical Corporation Slim Hole Induction tool (Model No. 9512) and digital logging system. The probe was calibrated using a 690 mS/m (millisiemens per meter) conductivity calibration ring.

Chemical Analysis

Water samples for the analysis of chloride and specific conductance were collected from 21 test wells in the Magothy aquifer at Sherwood Forest, and in the Aquia and Monmouth aquifers at Quiet Waters Park, Londontown Park, Annapolis Roads, Hillsmere, Bay Ridge, South River Farms Park, Arundel-on-the-Bay, and Mayo Beach Park by means of a ½-horsepower Grundfos submersible pump between April 11 and May 1, 2006. Prior to sampling, a minimum of three well-casing volumes of water was pumped to remove stagnant water stored in the well casing. The water was discharged into an open bucket until periodic measurements of specific conductance, pH, and water temperature were stable. These parameters were considered stabilized after three consecutive readings varied by less than the following percentages: specific conductance, ±2 percent; pH, ±1 percent; and, temperature, ±1 percent. The water was then collected in bottles provided by the U.S. Geological Survey National Water Quality Laboratory (NWQL) in Denver, Colorado. The water was tested in the field for chloride using a

HACH test kit (mercuric chloride titration). Specific conductance and pH meters were calibrated to standardized solutions at the start of each sample day. Samples were passed through a 0.45-micron membrane filter using a peristaltic pump. The samples were labeled, packed in ice, and sent to the U.S. Geological Survey NWQL where they were analyzed for chloride, specific conductance, and pH.

Samples could not be collected at the Moorings-on-the-Magothy test site (wells AA Ce 133 and 134) because of excessive silt accumulated in the well casing. However, a specific conductance probe lowered to the bottom of both wells indicated fresh water. Specific conductance measured 108 and 115 microsiemens per centimeter at 25 degrees Celsius (µS/cm) in wells AA Ce 133 and 134, respectively. Both the Moorings-on-the-Magothy and Mago Vista Beach sites serve as "outpost" monitoring wells for the detection of brackish-water intrusion in the Magothy aquifer on Broadneck Peninsula. Because the Moorings-on-the-Magothy site is closer to the area where the Magothy aquifer subcrops beneath the Magothy River, brackish water would be detected at that site before the Mago Vista Beach site; therefore, because the specific conductance measurements indicated fresh water at Moorings-on-the-Magothy, it was not necessary to sample the Mago Vista Beach site.

COMPARISON OF THE EXTENT OF BRACKISH-WATER INTRUSION IN 1988-90 VERSUS 2005-06

Resistivity and Induction Logs

Resistivity curves from the original logging run in 1988-90, and from the induction logging run during this study (2005), were plotted for comparison (fig. 2). To help identify the hydrogeologic units (aquifers and confining beds), gamma-radiation logs were also plotted on figure 2. Since the gamma-radiation log is unaffected by formation water quality, it can delineate aquifer/confining bed boundaries within the brackish-water portion of the aquifer. The gamma logs and original resistivity logs were run in the open probe hole, and, therefore, are deeper than the induction logs, which were run in the finished (cased) wells.

The trends of the curves for the 1988-90 resistivity logs and the induction logs run during this study generally agree in both high-resistivity (freshwater sands) and low-resistivity (clays and brackish-water sands) zones. The 1988-90 resistivity logs tend to show more deflection in the higher resistivity zones; however, the resistivity tool may not have been fully calibrated. The depth and width of the brackish-water/freshwater interface at Londontown Park, Quiet Waters Park, Bay Ridge, Arundel-on-the-Bay, and Mayo Beach Park test sites, indicated by a transition to relatively low resistivity (approximately less than 5 ohm-meters), is similar on both sets of logs. The only significant deviation between the 1988-90 and 2005 resistivity curves occurs at the Arundel-on-the-Bay site, where resistivity has decreased in the Monmouth aquifer below approximately 170 ft below sea level.

Chloride Concentrations and Specific Conductance

Chloride concentrations and specific conductance (temperature adjusted to 25 degrees Celsius) in water sampled during this study were compared to measurements made during the 1989-90 sampling period (tab. 1). Figures 3 through 9 show graphs of laboratory-measured chloride concentrations and specific conductance during those two time periods. The changes in specific conductance are generally in agreement with the changes in chloride concentrations.

At the Sherwood Forest test site, the chloride concentration in the Magothy aquifer in well AA Ce 130 was unchanged at approximately 2 milligrams per liter (mg/L) (fig. 3).

At the Quiet Waters Park test site, chloride concentrations decreased slightly in the Monmouth aquifer in well AA De 200 (from 6,400 to 6,300 mg/L), and increased slightly in the Monmouth aquifer in AA De 201 (from 3,700 to 4,000 mg/L) (fig. 4). Well AA De 201 is screened approximately 5 ft deeper and is located approximately 130 ft farther from the shoreline than AA De 200. Chloride concentrations increased in the lower part of the Aquia aquifer in well AA De 196 (from 3,400 to 4,100 mg/L), and were virtually unchanged in the upper part of the Aquia aquifer in wells AA De 189 and 197 (fig. 4).

At the Londontown Park test site, the chloride concentrations were unchanged in the Monmouth aquifer in well AA De 193, and in the upper part of the Aquia aquifer in well AA De 195. Chloride concentrations more than doubled in the lower part of the Aquia aquifer in well AA De 194 (from 310 to 720 mg/L) (fig. 5).

At the Annapolis Roads test site, chloride concentrations were unchanged in the Monmouth aquifer (well AA Df 151), the upper part of the Aquia aquifer (well AA Df 153), and the lower part of the Aquia aquifer (well AA Df 152) (fig. 6).

At the South River Farms Park and Hillsmere test sites, chloride concentrations were unchanged in the Monmouth aquifer (wells AA Ee 83 and AA Df 154, respectively) (fig. 7). At the Bay Ridge test site, chloride concentrations increased in the Monmouth aquifer (well AA Df 155) from 6,500 mg/L in 1990 to 7,600 mg/L in 2006 (fig. 7).

At the Arundel-on-the-Bay test site, chloride concentrations increased in the Monmouth aquifer in well AA Ef 35 (from 2,300 to 5,800 mg/L) (fig. 8). The chloride concentration was unchanged in the lower part of the Aquia aquifer in well AA Ef 31, and decreased somewhat in the upper part of the Aquia aquifer in well AA Ef 30 (from 73 to 44 mg/L) (fig. 8).

At the Mayo Beach Park test site, chloride concentrations increased in the Monmouth aquifer in well AA Ef 32 (from 6,400 to 7,500 mg/L) (fig. 9). Chloride concentrations were relatively unchanged in the lower and upper parts of the Aquia aquifer (wells AA Ef 33 and AA Ef 34, respectively).

CONCLUSIONS

The induction logs and chloride concentrations indicate that there has been no intrusion of brackish water at sites where intrusion was previously undetected in the Aquia and Monmouth aquifers. Those sites include Annapolis Roads, Hillsmere, and South River Farms Park. There has also been no intrusion of brackish water in the Magothy aquifer at Sherwood Forest (Annapolis Neck) and Moorings-on-the-Magothy (Broadneck) test sites. At sites previously intruded with brackish water in the Aquia and Monmouth aquifers, there has been no appreciable change in the depth and thickness of the brackish-water/freshwater interface. Those sites include Londontown Park, Quiet Waters Park, Bay Ridge, Arundel-on-the-Bay, and Mayo Beach Park.

The only movement of the brackish-water zone—visible on the induction log—occurred deeper in the section at Arundel-on-the-Bay. At that site, the induction log showed a reduction in resistivity below about 170 ft below sea level in the Monmouth aquifer. This reduction was verified by a water sample from that zone which showed a chloride concentration of 5,800 mg/L compared to 2,300 mg/L measured in 1989. It was previously surmised that the earlier lower chloride concentration in the deeper part of the Monmouth aquifer was caused by an intervening layer of low permeability sediments, possibly cemented sandstone, that impeded the flow of brackish water (Fleck and Andreasen, 1996). This conclusion was based primarily on the presence of some hard, chalky calcareous material in drill cuttings around the depth of the resistivity increase in the Monmouth aquifer. It is possible, that with time, the brackish water could have traveled through this lower permeability material. The increase in chloride concentration is not likely caused by pumpage in the Monmouth aquifer because most wells in the area are screened in either the shallower Aquia aquifer or deeper Magothy aquifer.

Other increases in chloride concentrations occurred in the brackish-water zone of the Monmouth aquifer at Bay Ridge and Mayo Beach Park. Chloride concentrations increased from 6,500 mg/L in 1990 to 7,600 mg/L in 2006 at Bay Ridge, and from 6,400 mg/L in 1989 to 7,500 mg/L in 2006 at Mayo Beach Park.

To a lesser extent, chloride concentrations also increased near the brackish-water/freshwater interface at Londontown Park and Quiet Waters Park. Chloride concentrations increased from 310 mg/L in 1989 to 720 mg/L in 2006 at Londontown Park, and from 3,400 mg/L in 1990 to 4,100 mg/L in 2006 at Quiet Waters Park. However, the interface detected on the induction logs is in a similar position to the earlier log.

Part of the variations in chloride concentrations between the 1989-90 and 2006 sampling may be attributed to short-term cyclical fluctuations caused by tides or the influx of ground-water recharge. Water levels in the Aquia and Monmouth aquifers on Annapolis Neck and Mayo Peninsula show response to recharge (both short-term and seasonal), barometric and semi-diurnal tidal fluctuations (Fleck and Andreasen, 1996). There was no correlation, however, between water levels measured in the test wells and chloride concentrations during the 1988-90 and 2006 sampling periods.

In the early 1990's, the Anne Arundel County Department of Health implemented a management strategy to prevent further intrusion of brackish water in the Aquia and Monmouth aquifers on Annapolis Neck and Mayo Peninsula by limiting its use. The strategy required new wells be drilled to the Magothy aquifer, while allowing replacement of existing wells screened in the Aquia aquifer. The overall stability of the brackish-water/freshwater interface in the Aquia aquifer, observed in the set of test wells, suggests that the strategy has been successful.

REFERENCES

Fleck, W.B., and Andreasen, D.C., 1996, Geohydrologic framework, ground-water quality and flow, and brackish-water intrusion in east-central Anne Arundel County, Maryland, with a section on Potential for brackish-water intrusion in the Aquia aquifer in the Annapolis area by Barry S. Smith: Maryland Geological Survey Report of Investigations No. 62, 136 p.

McNeill, J.D., Bosnar, M., and Snelgrove, F.B., 1990, Resolution of an electromagnetic borehole conductivity logger for geotechnical and ground water applications: Geonics Limited, Technical Note TN-25, 28 p.

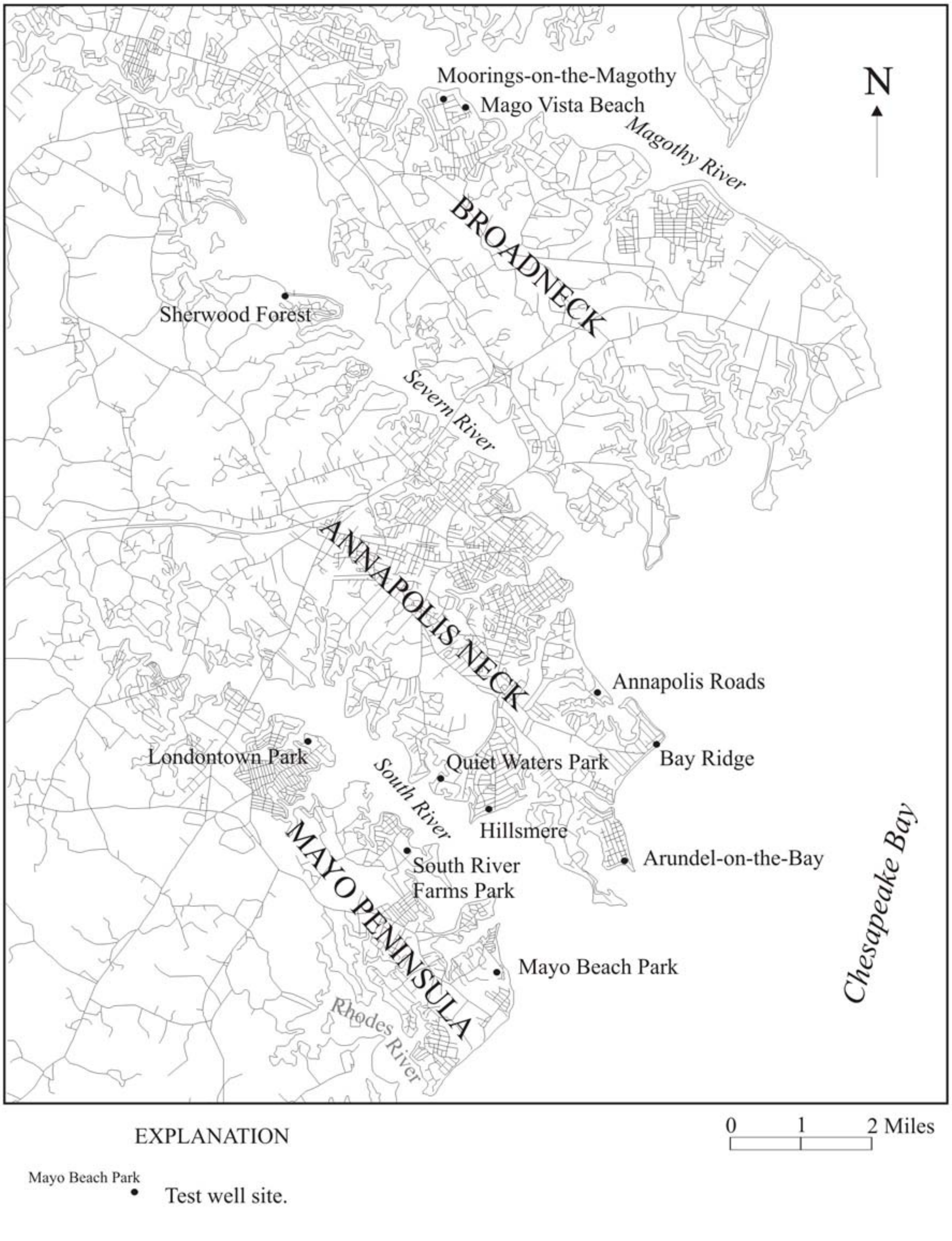


Figure 1. Location of study area and test well sites.

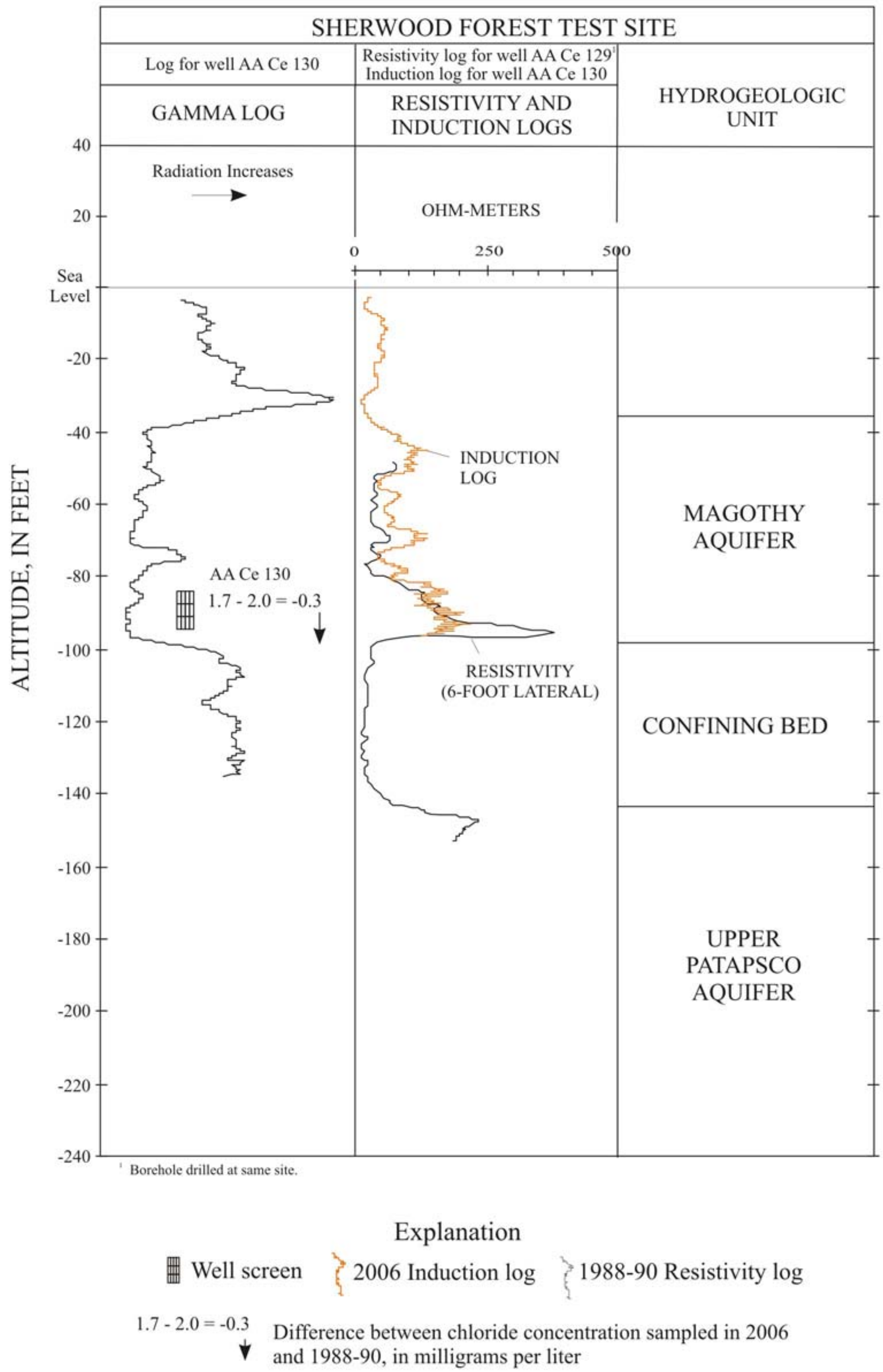
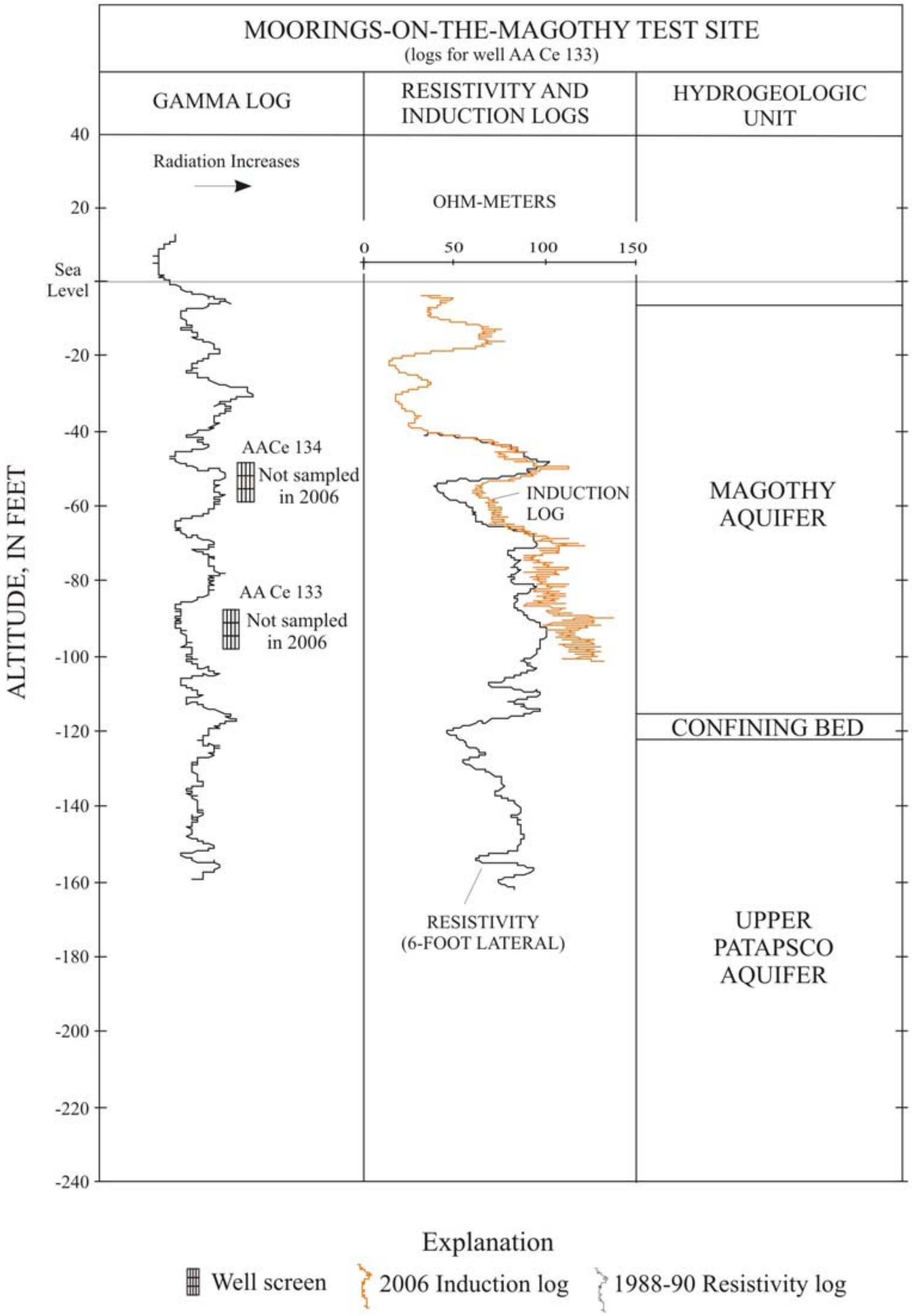


Figure 2. Comparison of resistivity and induction geophysical logs between 1988-90 and 2006.



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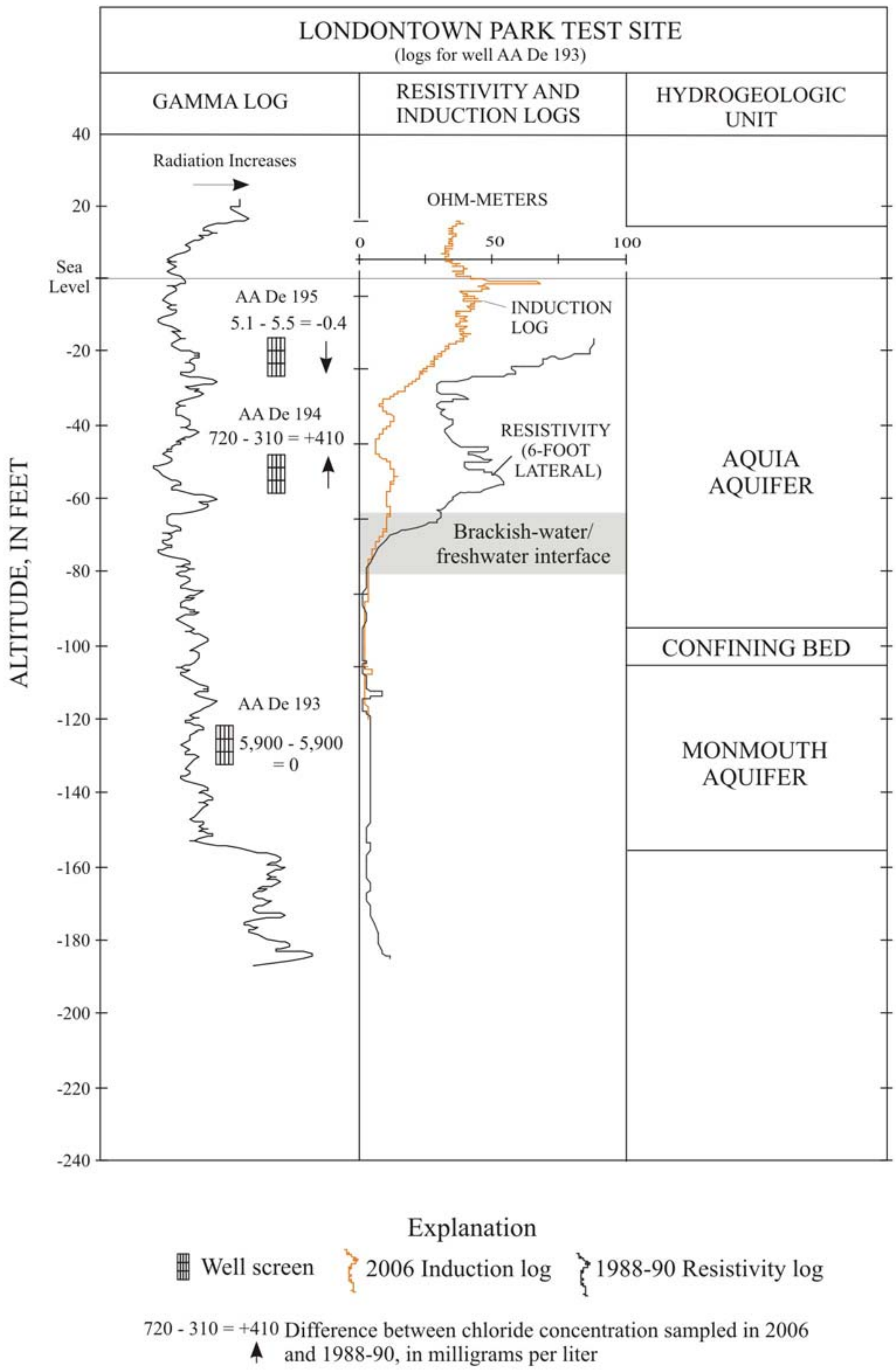

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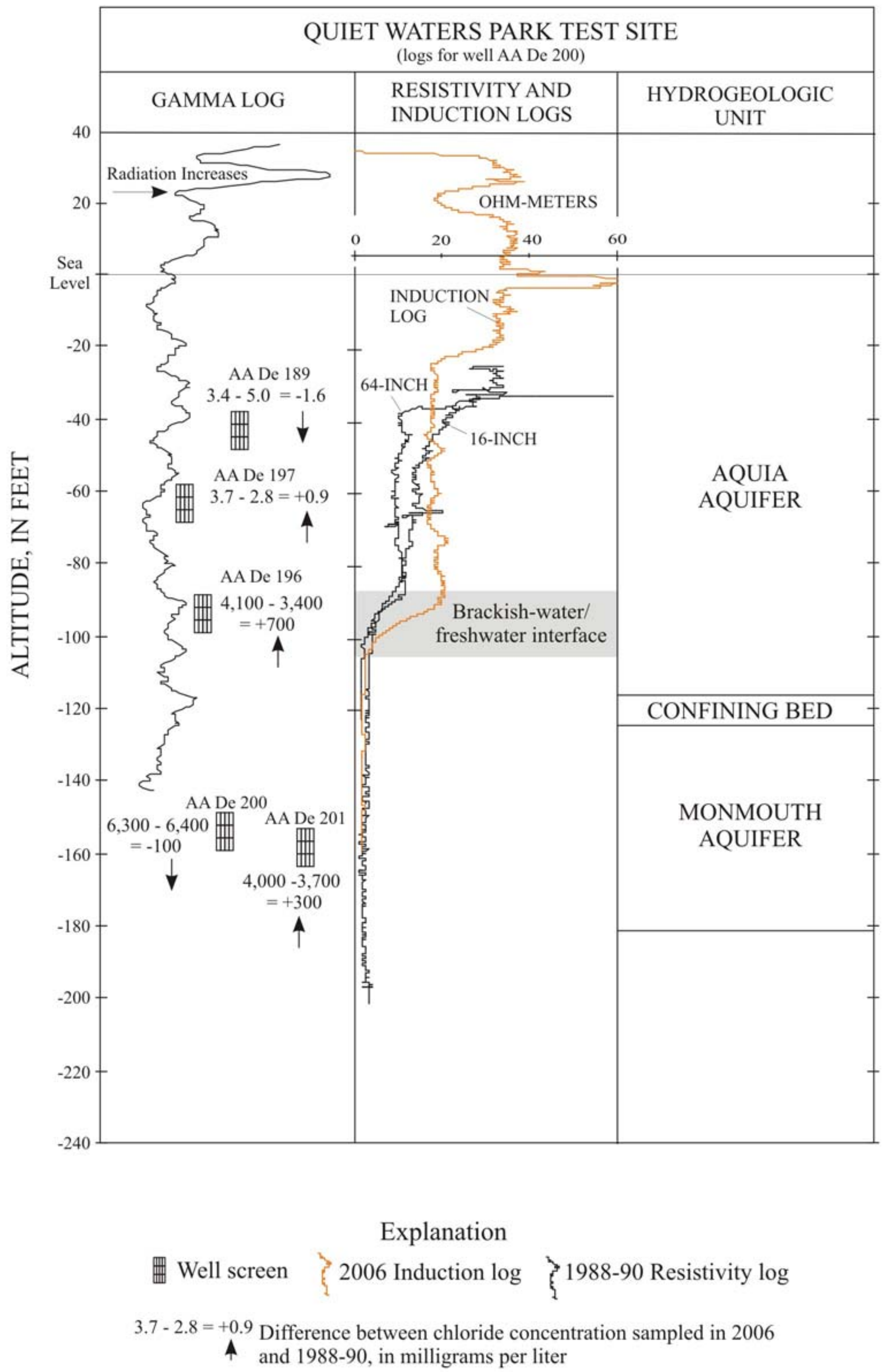

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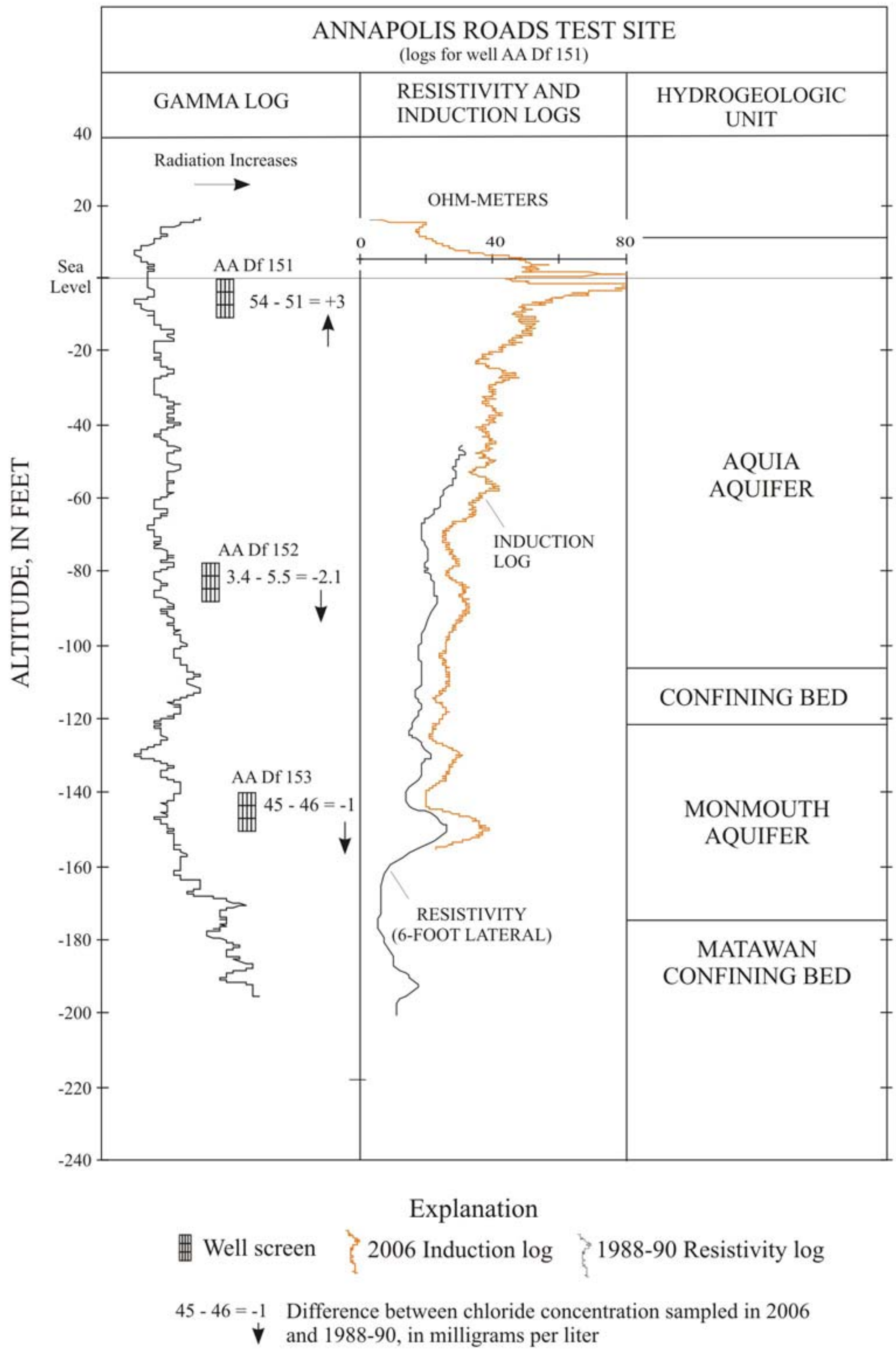

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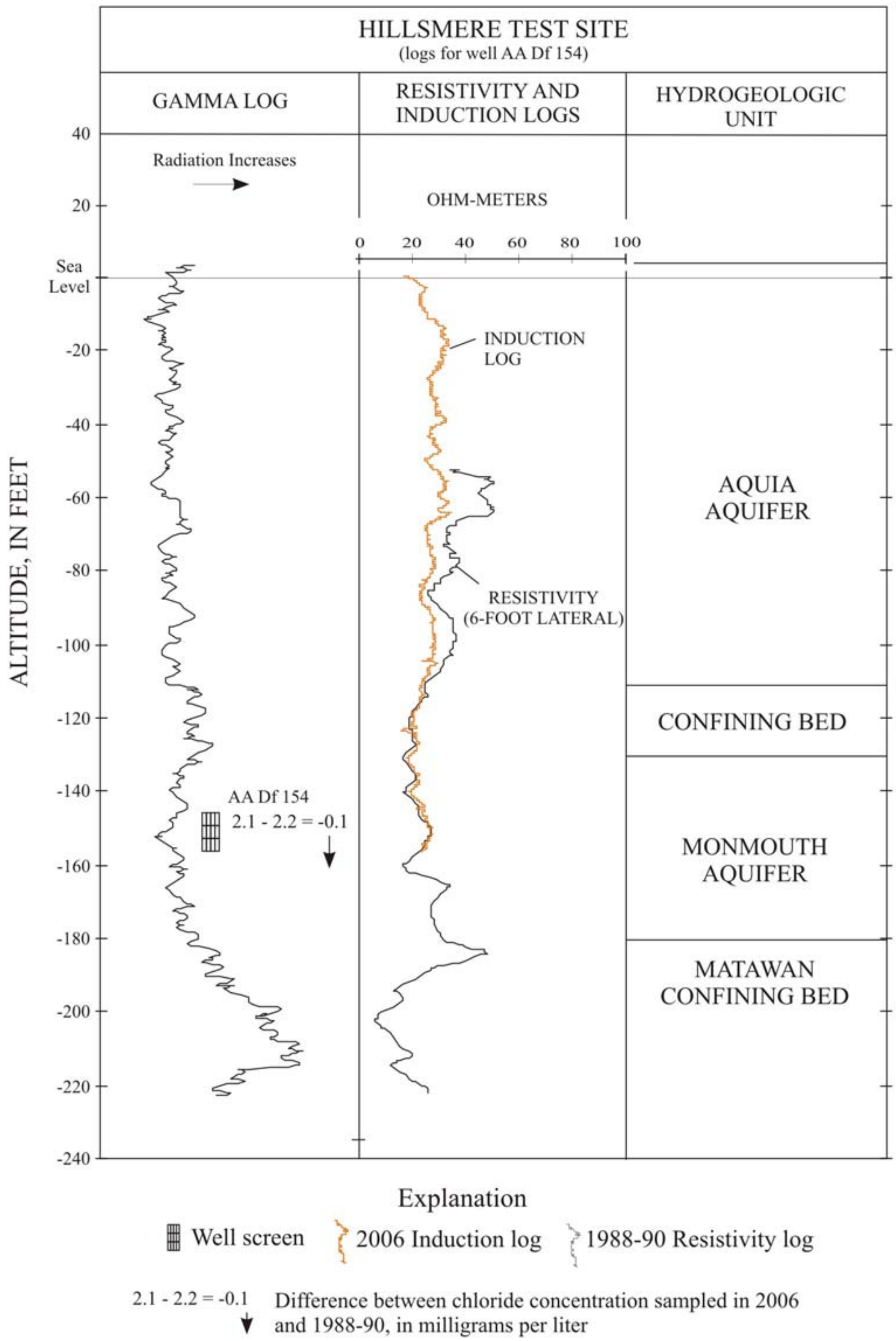

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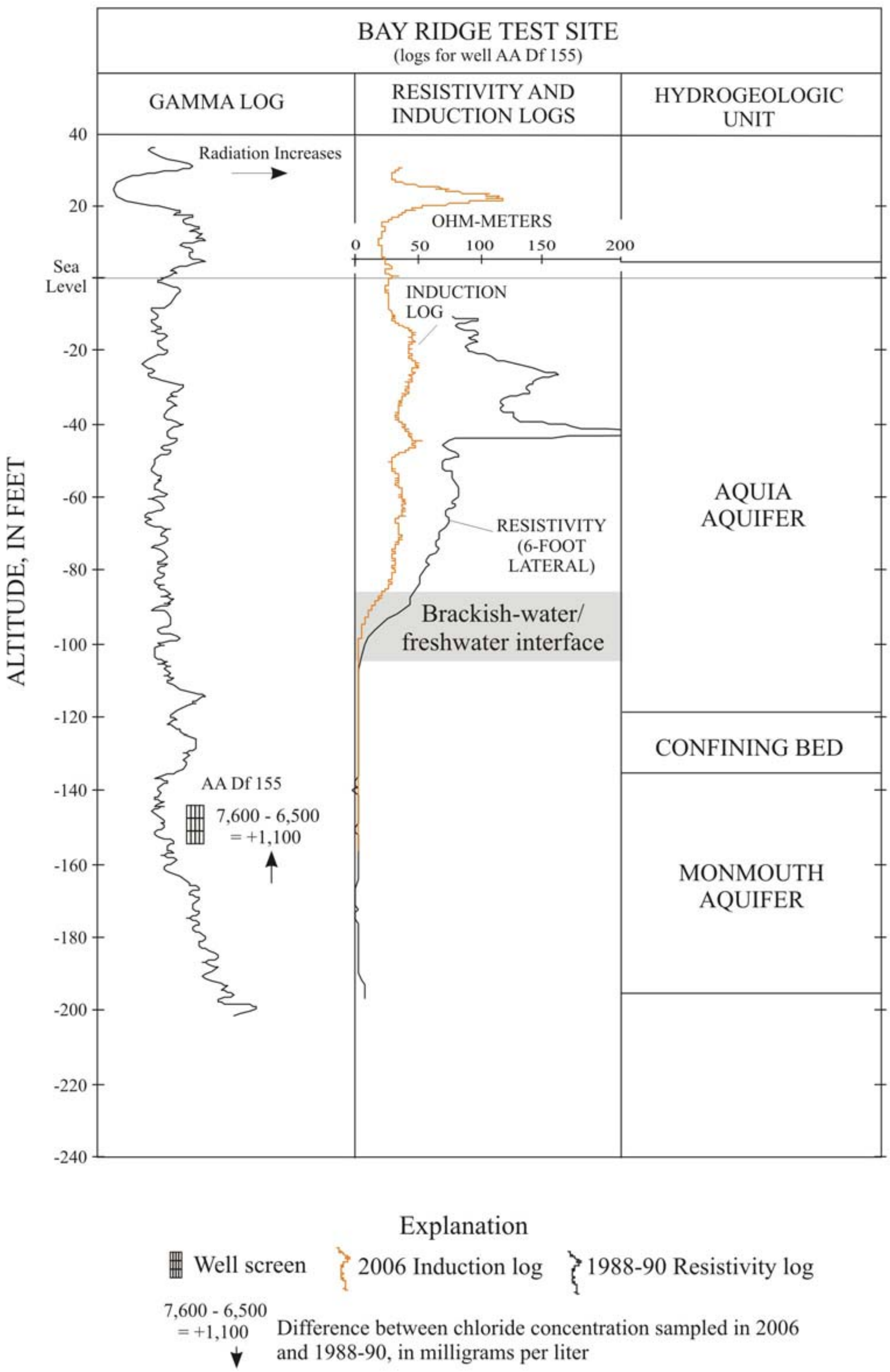

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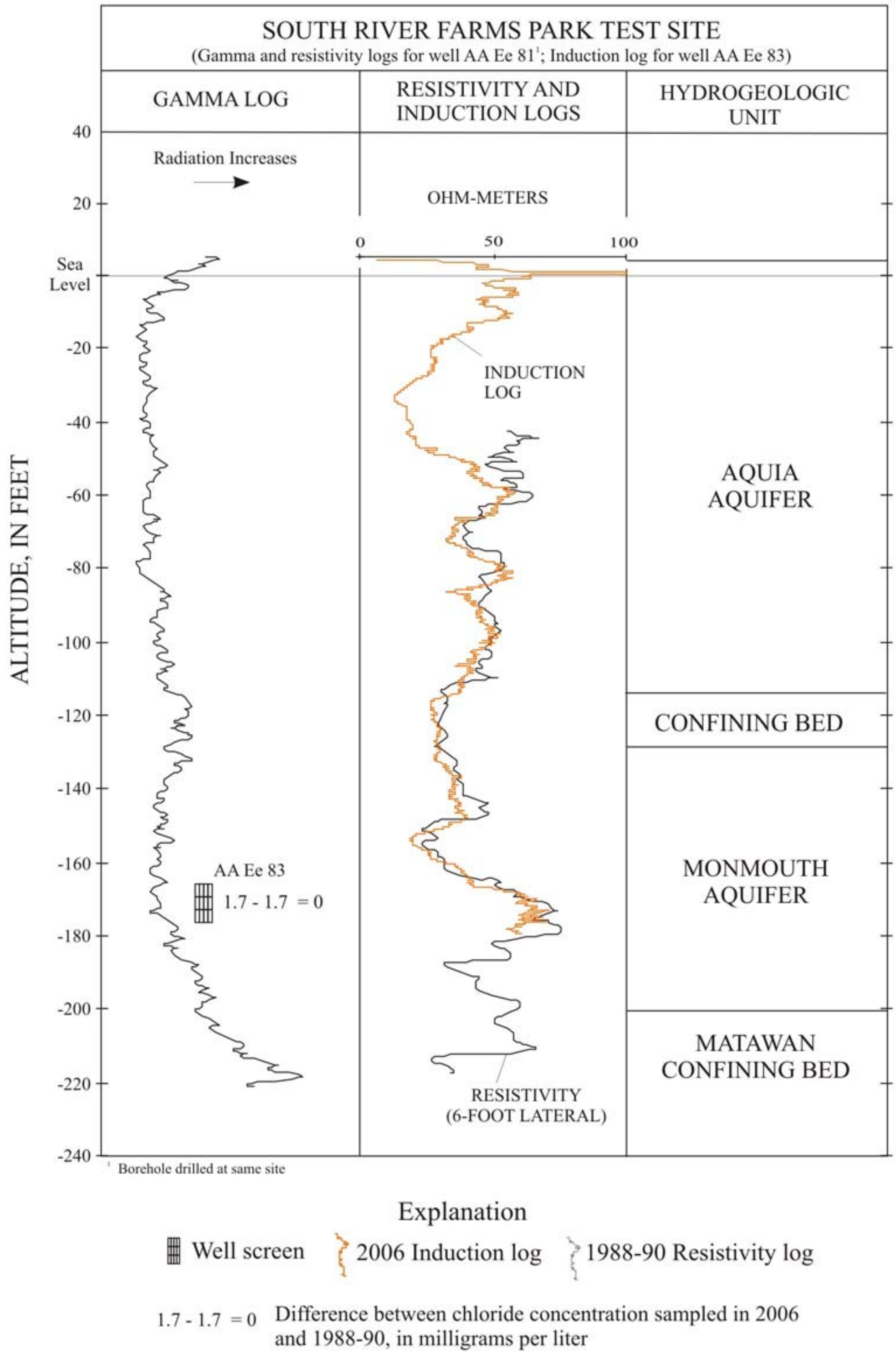

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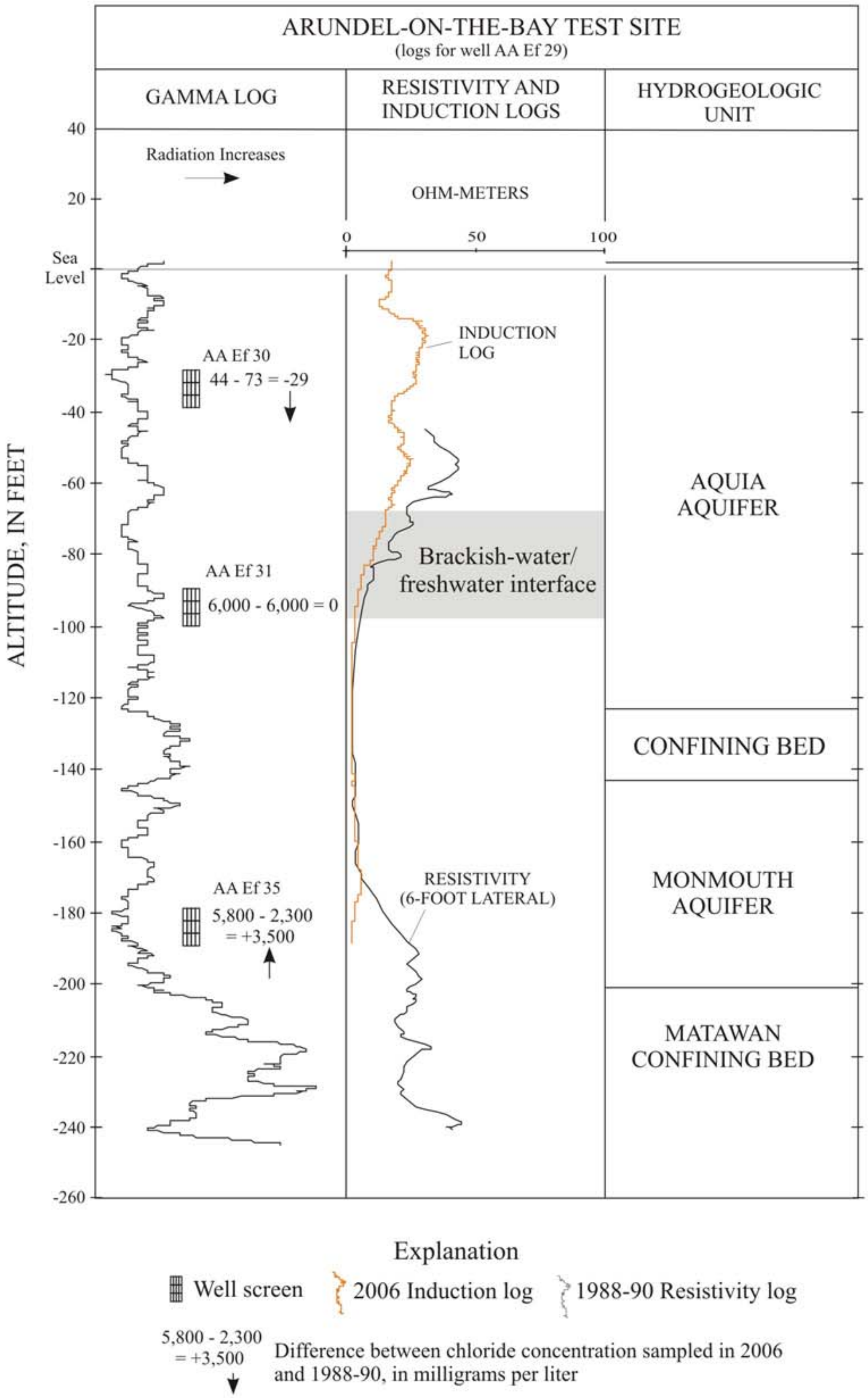

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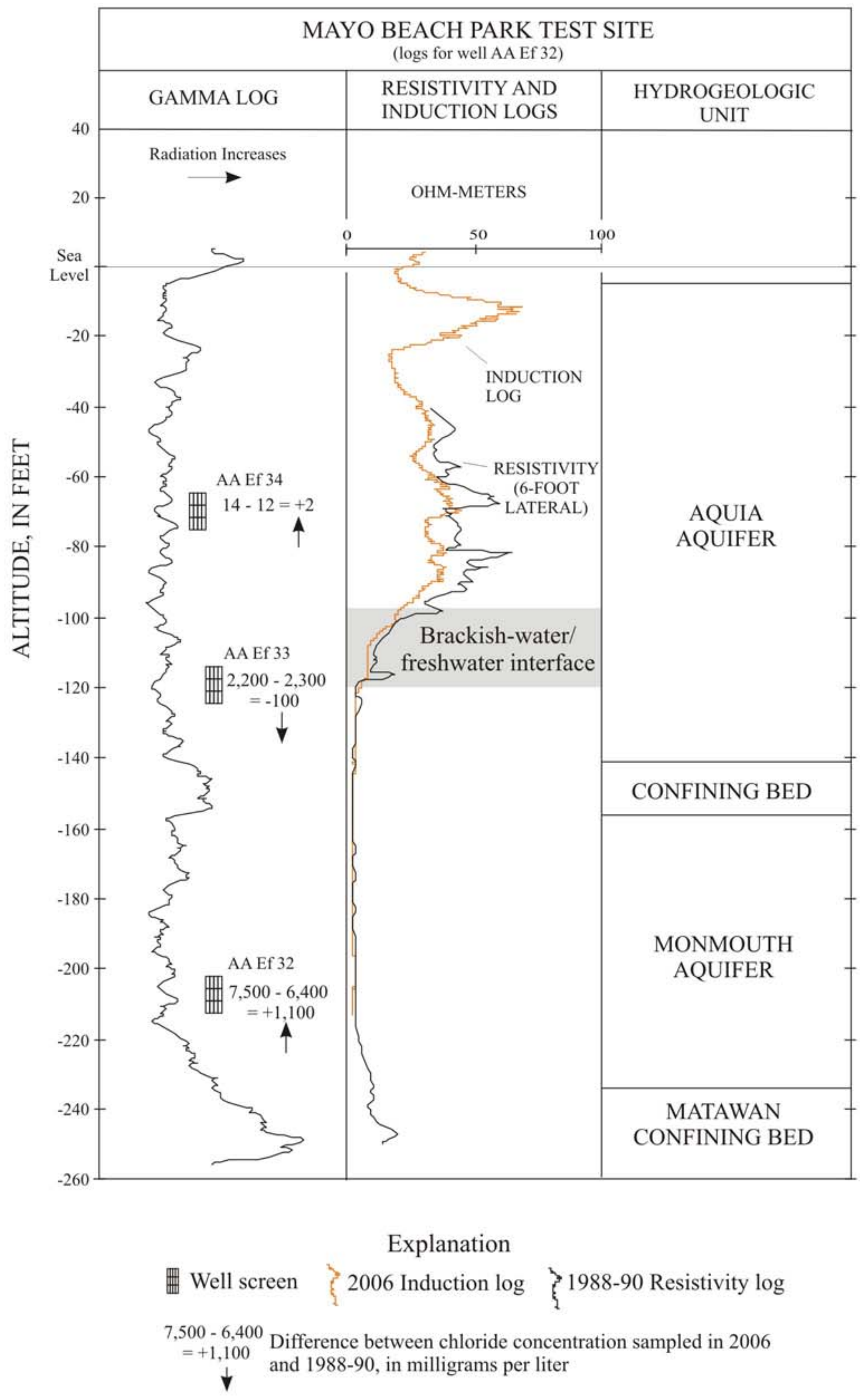

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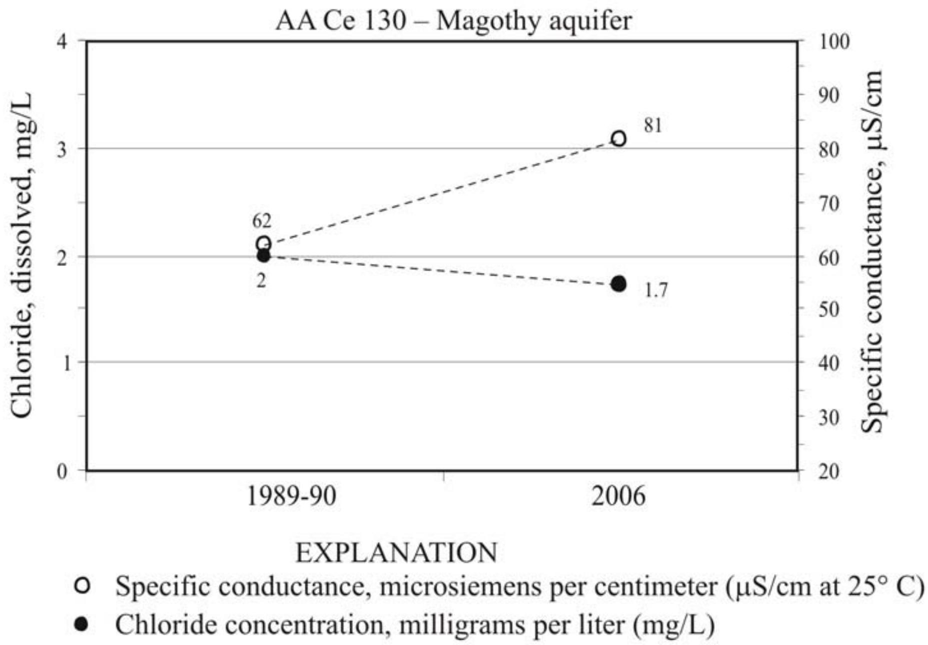


Figure 3. Change in dissolved chloride and specific conductance between 1989-90 and 2006 at Sherwood Forest test site.

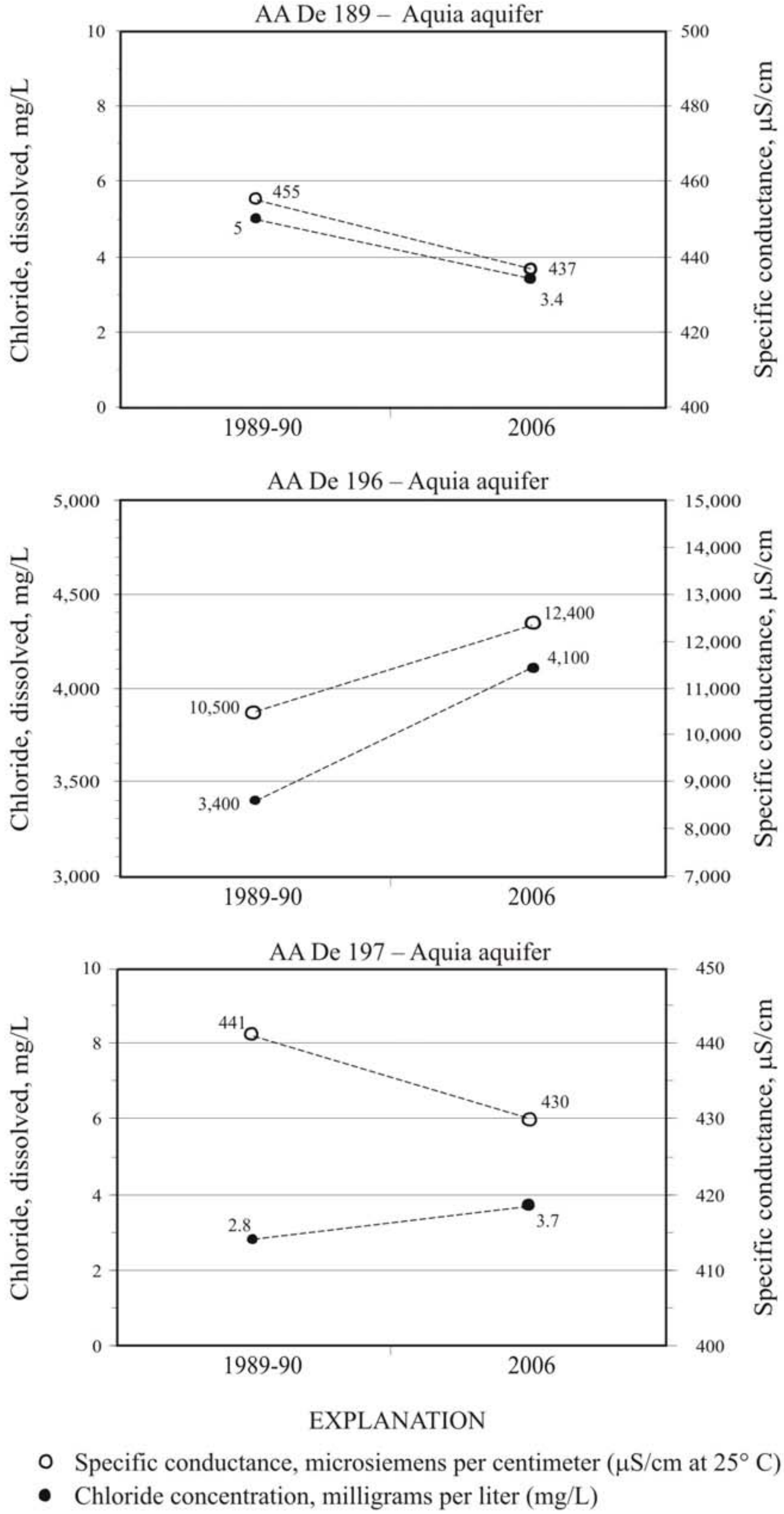
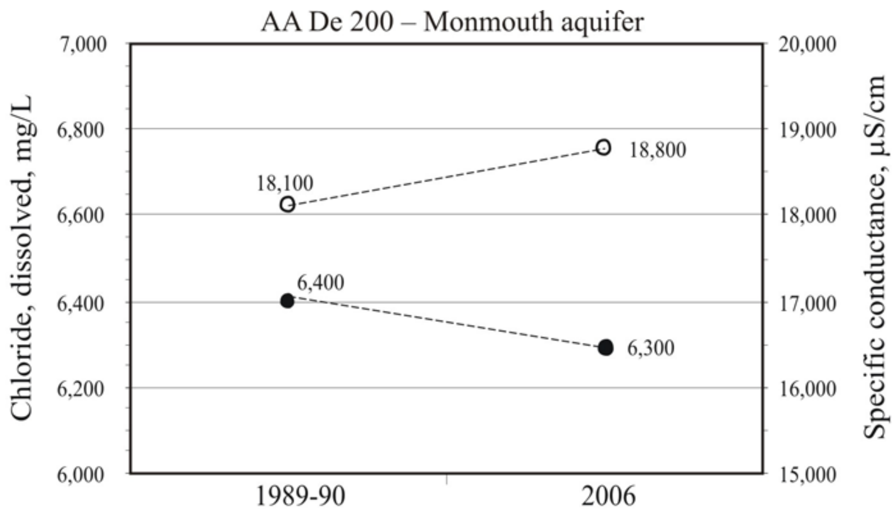
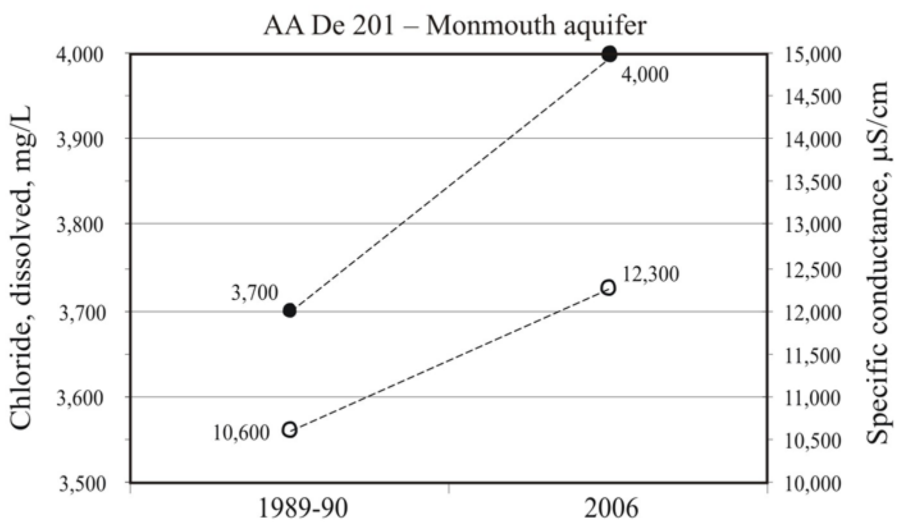


Figure 4. Change in dissolved chloride and specific conductance between 1989-90 and 2006 at Quiet Waters Park test site.





EXPLANATION

○ Specific conductance, microsiemens per centimeter (µS/cm at 25° C)
● Chloride concentration, milligrams per liter (mg/L)

Figure 4. Continued.

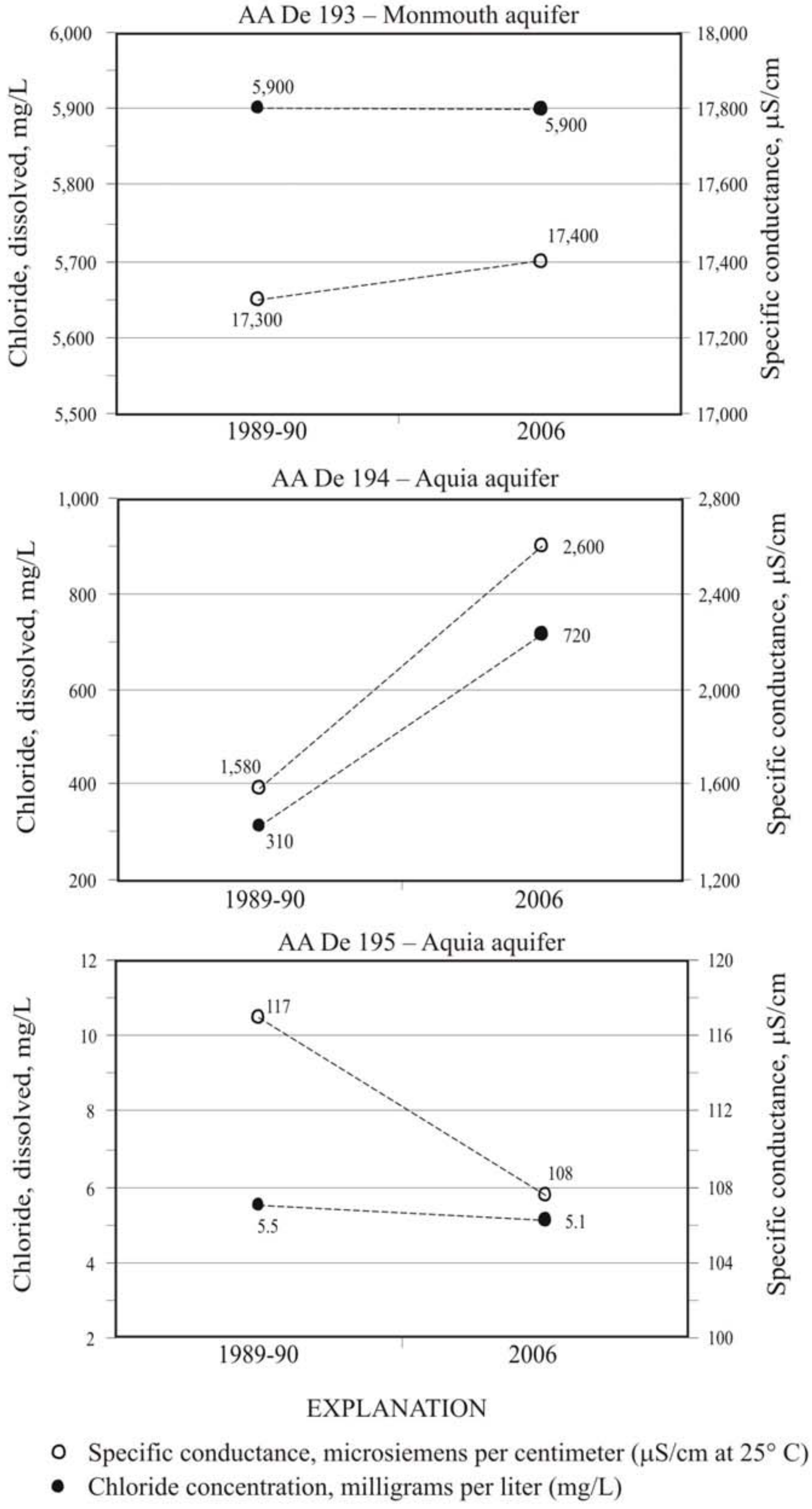


Figure 5. Change in dissolved chloride and specific conductance between 1989-90 and 2006 at Londontown Park test site.

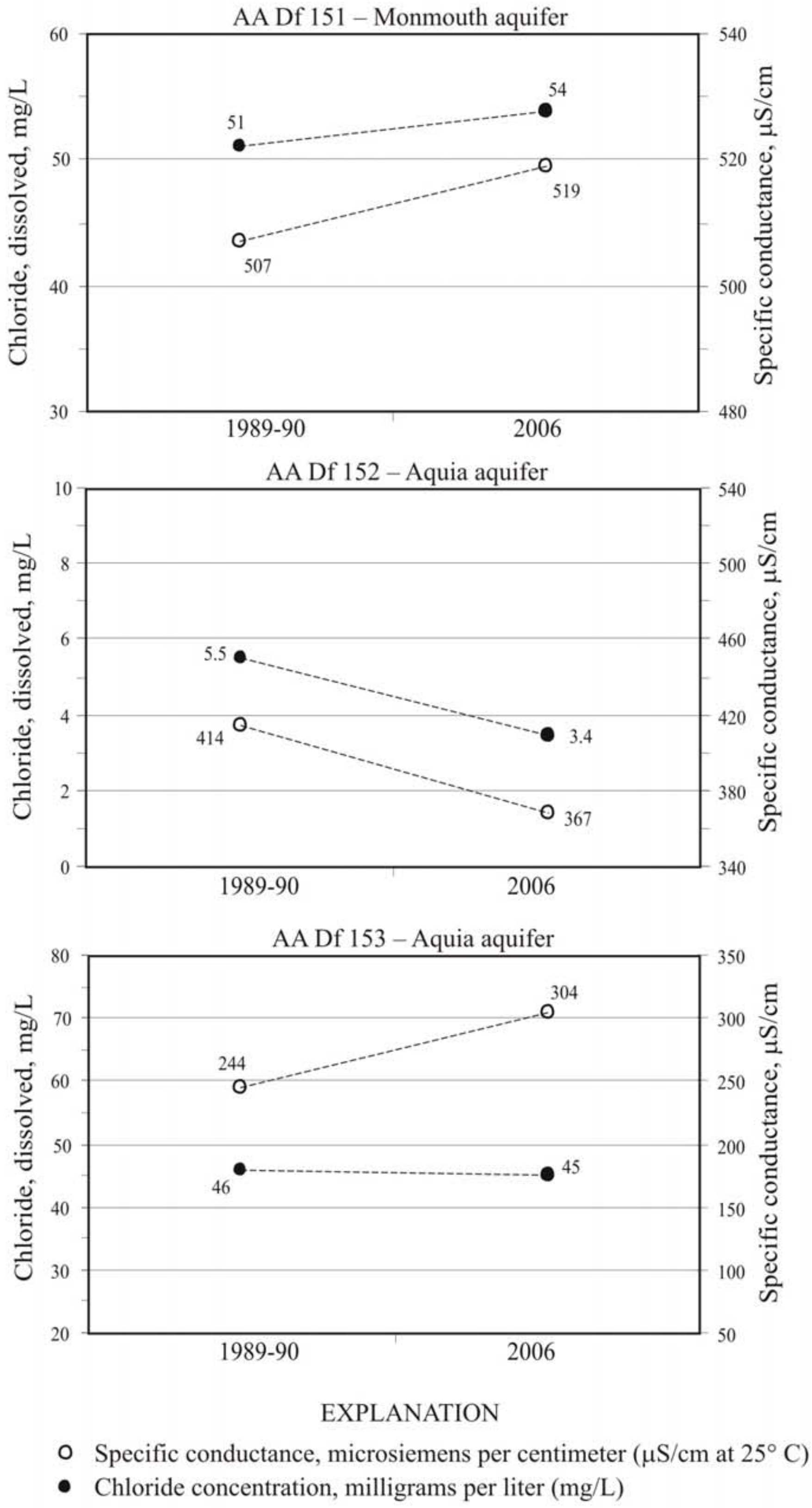


Figure 6. Change in dissolved chloride and specific conductance between 1989-90 and 2006 at Annapolis Roads test site.

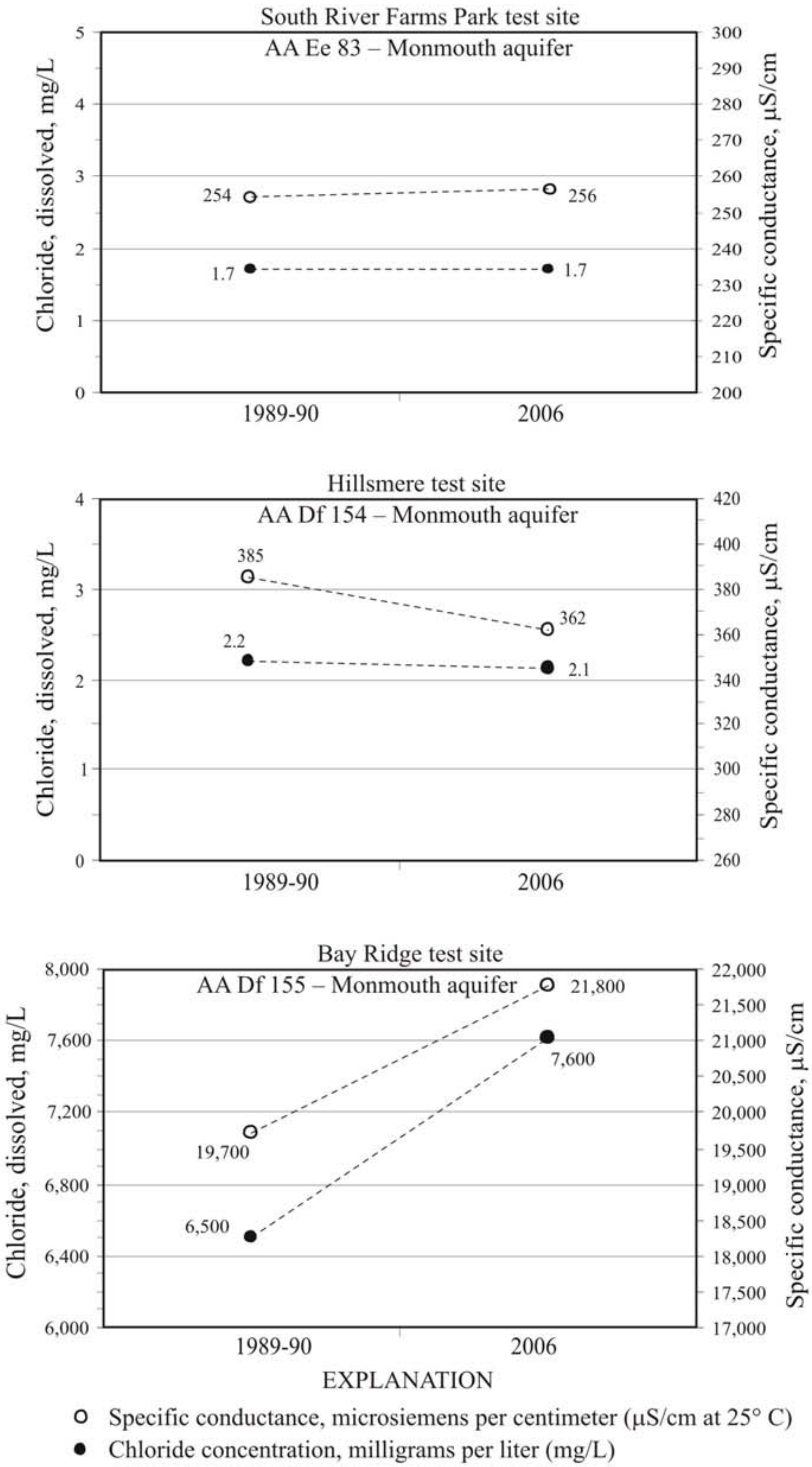


Figure 7. Change in dissolved chloride and specific conductance between 1989-90 and 2006 at South River Farms Park, Hillsmere, and Bay Ridge test sites.

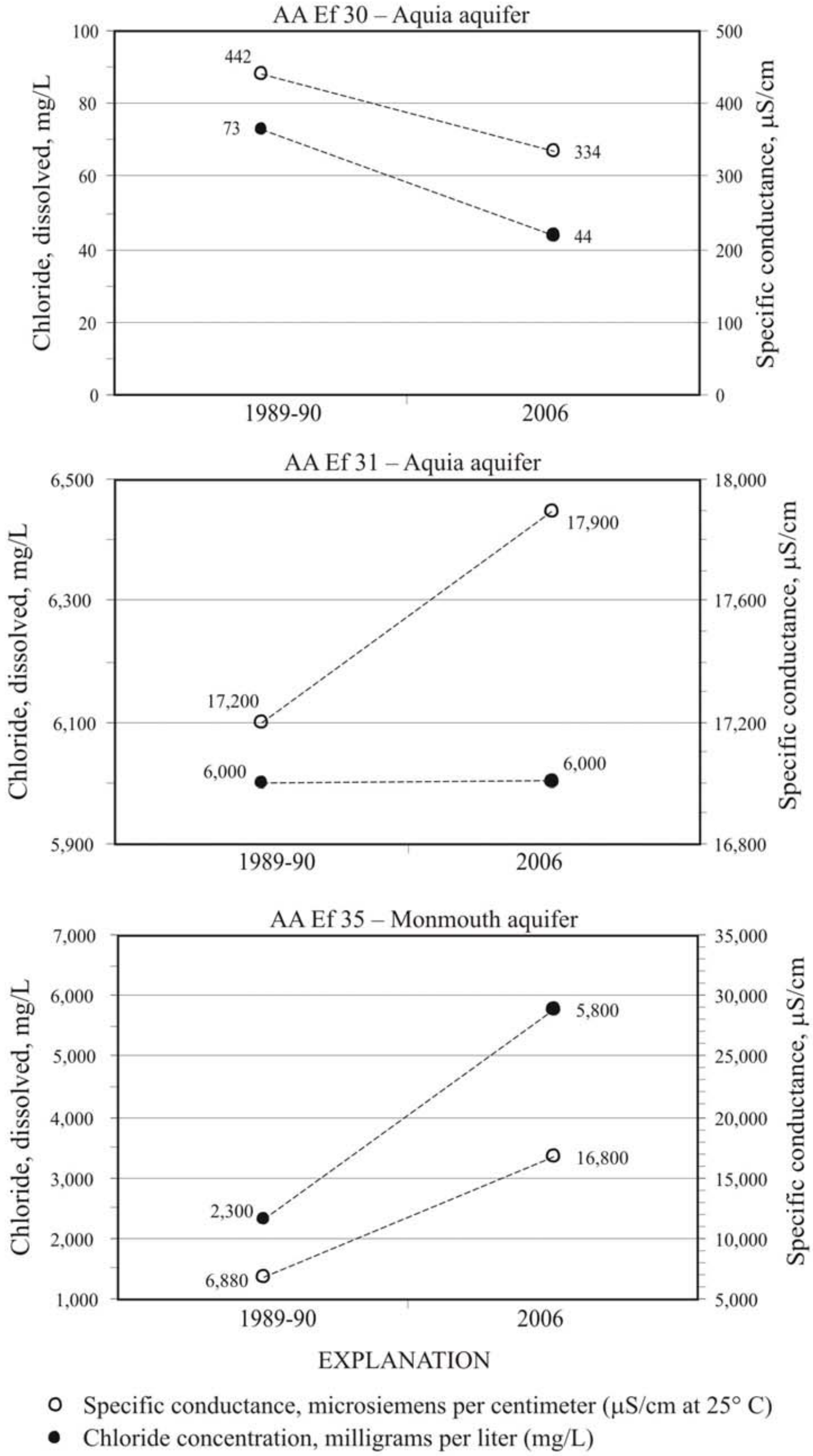


Figure 8. Change in dissolved chloride and specific conductance between 1989-90 and 2006 at Arundel-on-the-Bay test site.

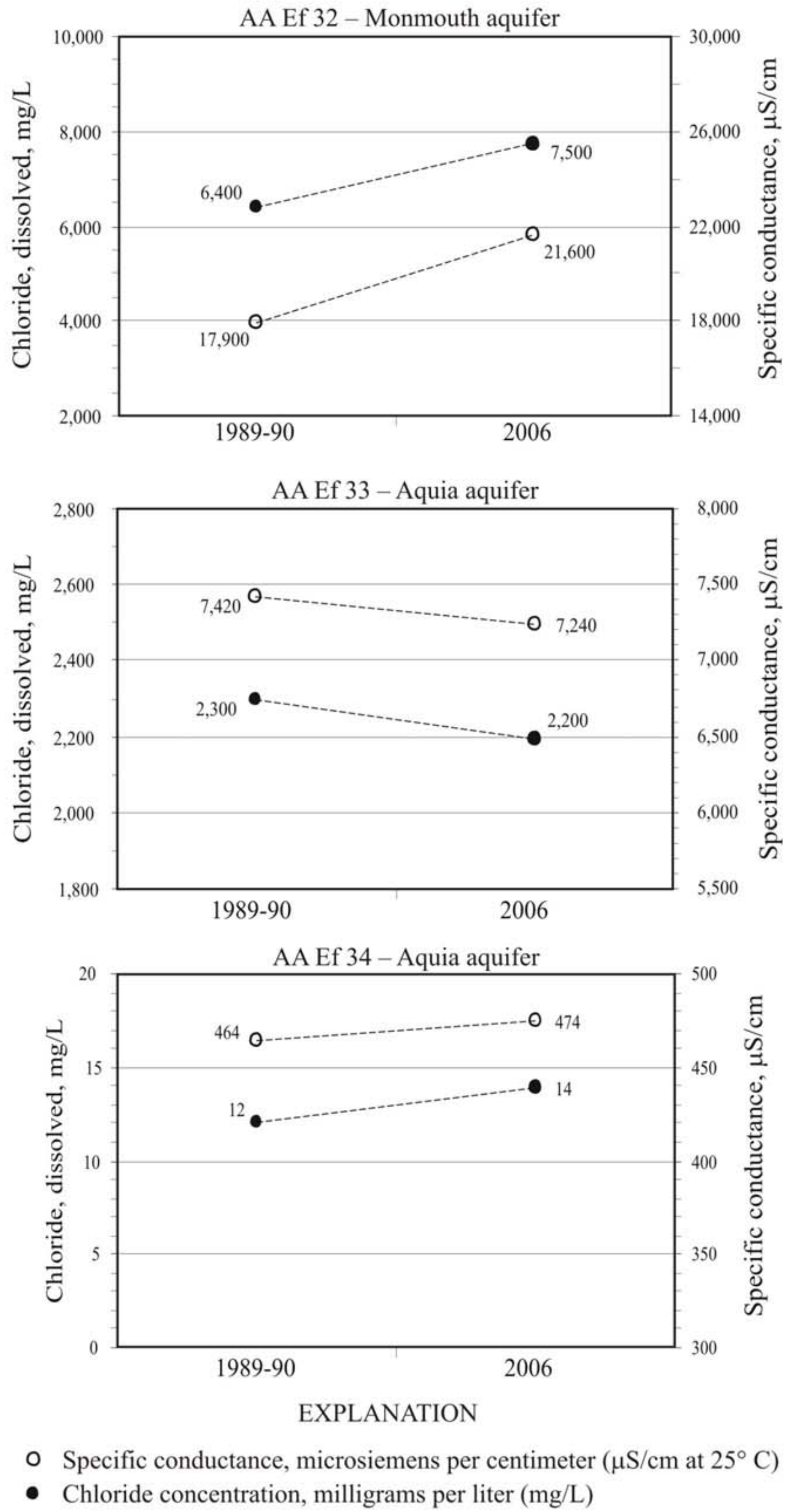


Figure 9. Change in dissolved chloride and specific conductance between 1989-90 and 2006 at Mayo Beach Park test site.

Table 1. Chloride concentrations and specific conductance in water from test wells

[mg/L -- milligrams per liter; na -- no analysis; µS/cm -- microsiemens per centimeter at 25 degrees Celsius]

Test well location	Well number	Well permit Number	Aquifer	Land surface altitude, feet	Well depth, feet	Screen position, feet below land surface	Chloride concentration (1989-90), mg/L (laboratory)	Chloride concentration (2006), mg/L (field)	Chloride concentration (2006), mg/L (laboratory)	Specific conductance (1989-90), µS/cm (lab)	Specific conductance (2006), µS/cm (field)	Specific conductance (2006), µS/cm (laboratory)
Mago Vista Beach	AA Ce 127	AA-88-1899	Magothy	7	75	60-70	3.5	na	na	169	na	na
	AA Ce 128	AA-88-1901	Magothy	7	175	160-170	0.9	na	na	169	na	na
Sherwood Forest	AA Ce 130	AA-88-3765	Magothy	5	103	88-98	2.0	4	1.7	62	58	81
Moorings-on-the-Magothy	AA Ce 133	AA-88-4893	Magothy	15	117	102-112	1.2	na	na	122	108[1]	na
	AA Ce 134	AA-88-4892	Magothy	15	77	62-72	1.3	na	na	196	115[1]	na
Quiet Waters Park	AA De 189	AA-88-4027	Aquia	42	95	80-90	5.0	3	3.4	455	420	437
	AA De 196	AA-88-4026	Aquia	41	145	130-140	3,400	4,700	4,100	10,500	12,500	12,400
	AA De 197	AA-88-4028	Aquia	42	115	100-110	2.8	2	3.7	441	415	430
	AA De 200	AA-88-4029	Monmouth	42	205	190-200	6,400	6,900	6,300	18,100	18,700	18,800
	AA De 201	AA-88-4127	Monmouth	41	230	195-205	3,700	4,700	4,000	10,600	12,400	12,300
Londontown Park	AA De 193	AA-88-1497	Monmouth	37	155	140-150	5,900	6,500	5,900	17,300	18,000	17,400
	AA De 194	AA-88-1496	Aquia	37	97	82-92	310	720	720	1,580	2,710	2,600
	AA De 195	AA-88-1495	Aquia	37	65	50-60	5.5	4.5	5.1	117	105	108
Annapolis Roads	AA Df 151	AA-88-1491	Monmouth	22	178	163-173	51	62	54	507	492	519
	AA Df 152	AA-88-1490	Aquia	22	118	103-113	5.5	3	3.4	414	341	367
	AA Df 153	AA-88-1489	Aquia	22	38	23-33	46	56	45	244	285	304
Hillsmere	AA Df 154	AA-88-1891	Monmouth	5	165	150-160	2.2	1	2.1	385	390	362
Bay Ridge	AA Df 155	AA-88-2046	Monmouth	39	199	184-194	6,500	8,500	7,600	19,700	21,500	21,800
South River Farms Park	AA Ee 83	AA-88-1416	Monmouth	11	191	176-186	1.7[2]	4	1.7	254[2]	274	256
Arundel-on-the-Bay	AA Ef 30	AA-88-1498	Aquia	5	50	35-45	73	52	44	442	318	334
	AA Ef 31	AA-88-1499	Aquia	5	135	120-130	6,000	6,600	6,000	17,200	17,900	17,900
	AA Ef 35	AA-88-1500	Monmouth	5	200	185-195	2,300	6,500	5,800	6,880	16,400	16,800
Mayo Beach Park	AA Ef 32	AA-88-1494	Monmouth	8	225	210-220	6,400	8,800	7,500	17,900	22,000	21,600
	AA Ef 33	AA-88-1493	Aquia	8	137	122-132	2,300	2,400	2,200	7,420	7,550	7,240
	AA Ef 34	AA-88-1492	Aquia	8	85	70-80	12	8	14	464	458	474

1 Down-hole specific conductance measurement

2 Analysis from well AA Ee 81 screened in same interval and abandoned in 1989