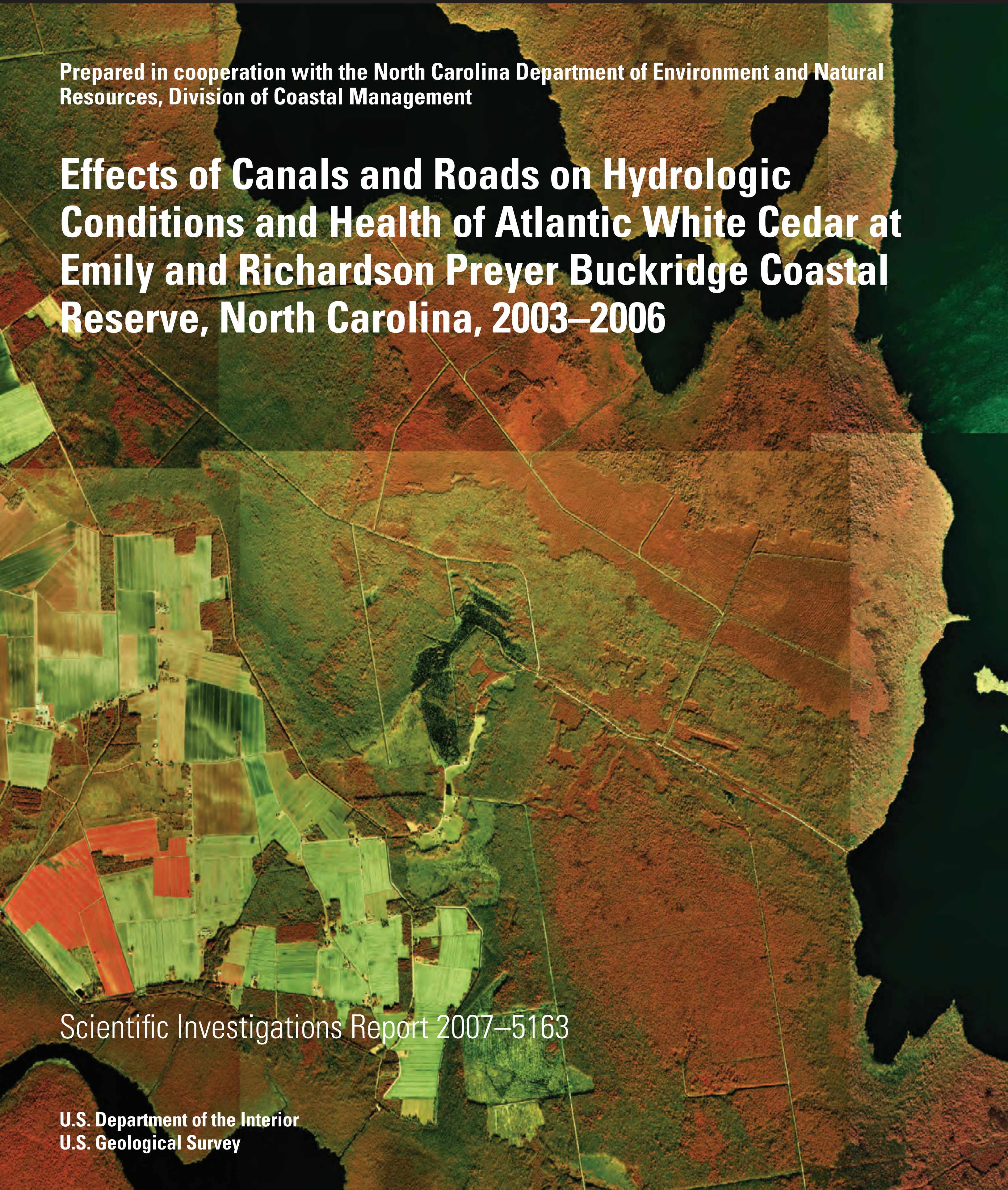
Prepared in cooperation with the North Carolina Department of Environment and Natural Resources, Division of Coastal Management

Effects of Canals and Roads on Hydrologic Conditions and Health of Atlantic White Cedar at Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–2006



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Cover. Aerial color infrared photograph of the Emily and Richardson Preyer Buckridge Coastal Reserve and surrounding areas, Tyrrell and Hyde Counties, North Carolina *(U.S. Geological Survey, 1988 Digital Orthophoto Swan Quarter Quadrangle color infrared aerial photo 3-meter pixel)*.

Effects of Canals and Roads on Hydrologic Conditions and Health of Atlantic White Cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–2006

By G.M. Ferrell, A.G. Strickland, and Timothy B. Spruill

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Contents

Abstract.....1
Introduction.....1
Coastal Wetlands and Atlantic White Cedar.....2
The Emily and Richardson Preyer Buckridge Coastal Reserve.....4
Purpose and Scope.....7
Methods of Investigation.....7
Site Reconnaissance.....9
Hydrologic Monitoring.....9
Precipitation.....13
Canal Monitoring.....13
Transects.....13
Root-Zone Water Quality.....16
Results and Discussion.....20
Precipitation.....20
Water Levels.....21
Canals.....24
Transects.....25
Water Quality.....30
Canals.....30
Transects.....41
Root Zone.....45
Effects of Canals and Roads on Hydrologic Conditions.....47
Acknowledgments.....48
References Cited.....48
Appendixes.....53

Figures

1. Location of the Emily and Richardson Preyer Buckridge Coastal Reserve in Tyrrell and Hyde Counties, North Carolina.....2
2. Locations of vertical water-quality profile sites, National Weather Service Cooperative Weather Station, and selected geographical features in the vicinity of the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina.....5
3. General topography and distribution of healthy and unhealthy areas of Atlantic white cedar in and around the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina.....6
4. Aerial photograph and generalized map showing the locations of gaging stations and wells at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina.....8
5. Locations of piezometers installed in the root zone of healthy and unhealthy stands of regenerating Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005.....17
6. Annual precipitation at the National Weather Service Cooperative Weather Station near Gum Neck, North Carolina, 1985–2005.....20

7. Summary of monthly precipitation at canal site 1 at the Emily and Richardson Preyer Buckridge Coastal Reserve and at the National Weather Service Cooperative Weather Station near Gum Neck, North Carolina, April 2004–February 2006, and monthly mean precipitation at the National Weather Service Cooperative Weather Station near Gum Neck, North Carolina, 1985–2005 21
8. (A) Daily precipitation at canal site 1 and (B) daily mean water levels at canal sites 1–3 at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006 22
9. (A) Daily precipitation at canal site 1 and daily mean water levels in the canals and selected wells along the transects in the area of (B) healthy and (C) unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006 23
10. Boxplots of daily mean water levels at canal sites 2 and 3 (A) before and (B) after the culvert in the Grapevine Landing Road canal was cleared on September 2, 2005, at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina 24
11. Periodic water-level measurements for selected dates in the canals and wells on the transects in the area of (A) healthy and (B) unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 2004–March 2006 26
12. (A) Daily precipitation at canal site 1, water levels at canal sites 1–3 and wells SC100 and SR100, and (B) specific conductance at canal sites 2 and 3 at 15-minute intervals at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, January 1–March 13, 2006 28
13. (A) Daily precipitation at canal site 1, water levels at canal sites 1–3 and well SC100 , and (B) specific conductance at canal sites 2 and 3 at 15-minute intervals at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, September 10–30, 2005 29
14. (A) Daily mean water temperature and (B) daily mean specific conductance at canal site 3 at the healthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006 31
15. (A) Daily mean water temperature and (B) daily mean specific conductance at canal site 2 at the unhealthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006 32
16. Water-temperature profiles at canal site 3 at the healthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) March–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006 33
17. Specific conductance profiles at canal site 3 at the healthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) March–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006 34
18. Water-temperature profiles at canal site 2 at the unhealthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) December 2003–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006 35
19. Specific conductance profiles at canal site 2 at the unhealthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) December 2003–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006 36

20. Specific conductance profiles at selected canals at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, September 2003 and September 2005 38
21. Sodium-to-chloride mass ratios in water samples from (A) canal sites 2 and 3 and (B) piezometers on the transects in the area of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005 44
22. Boxplots of physical and root-zone water-quality characteristics in stands of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005....46

Tables

1. U.S. Geological Survey monitoring network at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–06 10
2. Analytes in synoptic samples and dates of sampling at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005 14
3. Analytes measured in water samples collected at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005 15
4. Selected characteristics of water-level monitoring wells at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–06 16
5. Analytes in water samples from canal sites 3 and 2 at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005 40
6. Analytes in water samples from the mineral substrate well and piezometers on the healthy and unhealthy Atlantic white cedar transects at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005 42
7. Summary of selected site characteristics and water-quality measurements for root-zone samples in stands of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005 45

Appendix Tables

1. Precipitation recorded at the National Weather Service Cooperative Observation Weather Station (number 311949) near Gum Neck, North Carolina, 1985–2005....55
2. Daily precipitation totals at Juniper Road canal (site 1, U.S. Geological Survey site identification 354400076043101) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, March 2004–March 2006....56
3. Daily mean water levels at Juniper Road canal (site 1, U.S. Geological Survey site identification 354400076043101) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, March 2004–March 2006....59
4. Daily mean water levels at Juniper Road canal (site 2, U.S. Geological Survey site identification 354428076044301) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006....62
5. Daily mean water levels at spur road 3 canal (site 3, U.S. Geological Survey site identification 354442076044601) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006....65

6. Daily maximum, minimum, and mean values of top water temperature at Juniper Road canal (site 2, U.S. Geological Survey site identification 354428076044301) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006 68
7. Daily maximum, minimum, and mean values of top specific conductance at Juniper Road canal (site 2, U.S. Geological Survey site identification 354428076044301) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006....75
8. Daily maximum, minimum, and mean values of bottom water temperature at Juniper Road canal (site 2, U.S. Geological Survey site identification 354428076044301) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006 82
9. Daily maximum, minimum, and mean values of bottom specific conductance at Juniper Road canal (site 2, U.S. Geological Survey site identification 354428076044301) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006....89
10. Daily maximum, minimum, and mean values of top water temperature at spur road 3 canal (site 3, U.S. Geological Survey site identification 354442076044601) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006 96
11. Daily maximum, minimum, and mean values of top specific conductance at spur road 3 canal (site 3, U.S. Geological Survey site identification 354442076044601) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006....103
12. Daily maximum, minimum, and mean values of bottom water temperature at spur road 3 canal (site 3, U.S. Geological Survey site identification 354442076044601) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006....110
13. Daily maximum, minimum, and mean values of bottom specific conductance at spur road 3 canal (site 3, U.S. Geological Survey site identification 354442076044601) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006....117
14. Daily mean water levels in TY-089 Buckridge well SR100 (U.S. Geological Survey site identification 354428076044302) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006....124
15. Daily mean water levels in TY-090 Buckridge well SR45 (U.S. Geological Survey site identification 354428076044303) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006....127
16. Daily mean water levels in TY-091 Buckridge well SR15 (U.S. Geological Survey site identification 354428076044304) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–August 2005....130
17. Daily mean water levels in TY-092 Buckridge well SC12 (U.S. Geological Survey site identification 354428076044305) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006....132
18. Daily mean water levels in TY-093 Buckridge well SC100 (U.S. Geological Survey site identification 354428076044306) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–March 2006....135
19. Daily mean water levels in TY-094 Buckridge well HC100 (U.S. Geological Survey site identification 354442076044602) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006 138

20. Daily mean water levels in TY-095 Buckridge well HC19 (U.S. Geological Survey site identification 354442076044603) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006 141
21. Daily mean water levels in TY-096 Buckridge well HR16 (U.S. Geological Survey site identification 354442076044604) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–September 2005 144
22. Daily mean water levels in TY-097 Buckridge well HR50 (U.S. Geological Survey site identification 354442076044605) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006 146
23. Daily mean water levels in TY-098 Buckridge well HC100 (U.S. Geological Survey site identification 354442076044606) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, April 2004–March 2006 149
24. Daily mean water levels in TY-099 Buckridge well HC1000 (U.S. Geological Survey site identification 354437076043601) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 2004–March 2006....152
25. Water-quality profile measurements at Juniper Road canal (site 1, U.S. Geological Survey site identification 354400076043101) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February 2004–January 2006 155
26. Water-quality profile measurements at Juniper Road canal (site 2, U.S. Geological Survey site identification 354428076044301) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, September 2003–March 2006 158
27. Water-quality profile measurements at spur road 3 canal (site 3, U.S. Geological Survey site identification 354442076044601) at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, September 2003–March 2006 164
28. Water-quality profile measurements at selected canal sites at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, September 2003 and September 2005....171
29. Selected site characteristics and water-quality properties in water within the root zone of healthy and unhealthy stands of Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005....175

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above or below the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Effects of Canals and Roads on Hydrologic Conditions and Health of Atlantic White Cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–2006

By G.M. Ferrell, A.G. Strickland, and Timothy B. Spruill

Abstract

The effects of canals and roads on hydrologic conditions and on the health of Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve in North Carolina were evaluated by using data collected from the 1980s to 2006. Water levels were monitored along two transects established perpendicular to roads and canals in areas of healthy and unhealthy Atlantic white cedar as part of a study conducted from February 2003 through March 2006. Because of the low hydraulic gradient at the Reserve, the rate and direction of water movement are sensitive to disturbance. Canals increased drainage and contributed to lower water levels in some parts of the Reserve, whereas roads, depending on orientation, impeded drainage. Canals also appeared to facilitate movement of brackish water from the Alligator River into the interior of the Reserve during storms and wind tides. Data indicate that an influx of brackish water occurred in mid-September 2005 several days after the passage of Hurricane Ophelia. Although precipitation amounts and wind speeds associated with Hurricane Ophelia were not large, substantial changes in specific conductance occurred at the canal site on the unhealthy Atlantic white cedar transect. No corresponding increase in specific conductance was observed at the canal site on the healthy Atlantic white cedar transect.

The specific conductance of water samples from canals and piezometers was highly correlated with concentrations of chloride and sodium. Ion ratios of some of the water samples, particularly samples with high specific conductance, were similar to those of seawater. Thermal and chemical stratification of water in the canals occurred during summer and winter months, and turnover and mixing occurred in the spring and fall. Upwelling of ground water as a result of excavation for roads did not appear to have a significant effect on the water quality of samples from the canals or piezometers. The specific conductance of water samples from piezometers installed in the root zone of healthy stands of Atlantic white cedar generally was lower than in water samples from unhealthy stands. This pattern also was observed in samples from piezometers installed on the transects and in other areas of the Reserve. Roads appear to have isolated some areas of the Reserve from the high-conductivity water in nearby canals. The paths by which brackish water entered the Reserve cannot be determined from the data obtained during this investigation. It appears that water can enter the Reserve from various directions, depending on wind patterns and water levels in the Alligator River.

Introduction

The Emily and Richardson Preyer Buckridge Coastal Reserve, hereafter referred to as the Reserve, is a large freshwater wetland in eastern North Carolina (fig. 1) and is home to plant communities that are rare statewide and globally (Schafale, 1996a, b, 1999; Fuss, 2001). Plant communities in the Reserve include peatland Atlantic white cedar forest, pond pine woodland, nonriverine swamp forest, and tidal cypress-gum swamp (Schafale, 1996a,b). Notably, the Reserve contains the most extensive contiguous stand of Atlantic white cedar (AWC) in the eastern United States (Fuss, 2001). AWC is considered to be in decline throughout much of its natural range because of logging and loss of habitat. The AWC stand at the Reserve regenerated in the 1980s following intensive logging; however, in the late 1990s, dieback of regenerating AWC was observed in several areas of the Reserve, and regenerating AWC in other areas appeared to be unhealthy and was classified as either stressed or showing poor growth (Fuss, 2001). The decline continued, and by early 2003 AWC in many of the areas previously identified as unhealthy had died. Because the observed dieback and decline of AWC did not appear to be related to pests or pathogens (Woody Webster, North Carolina Division of Coastal Management, written commun., 2004), hydrologic conditions were considered

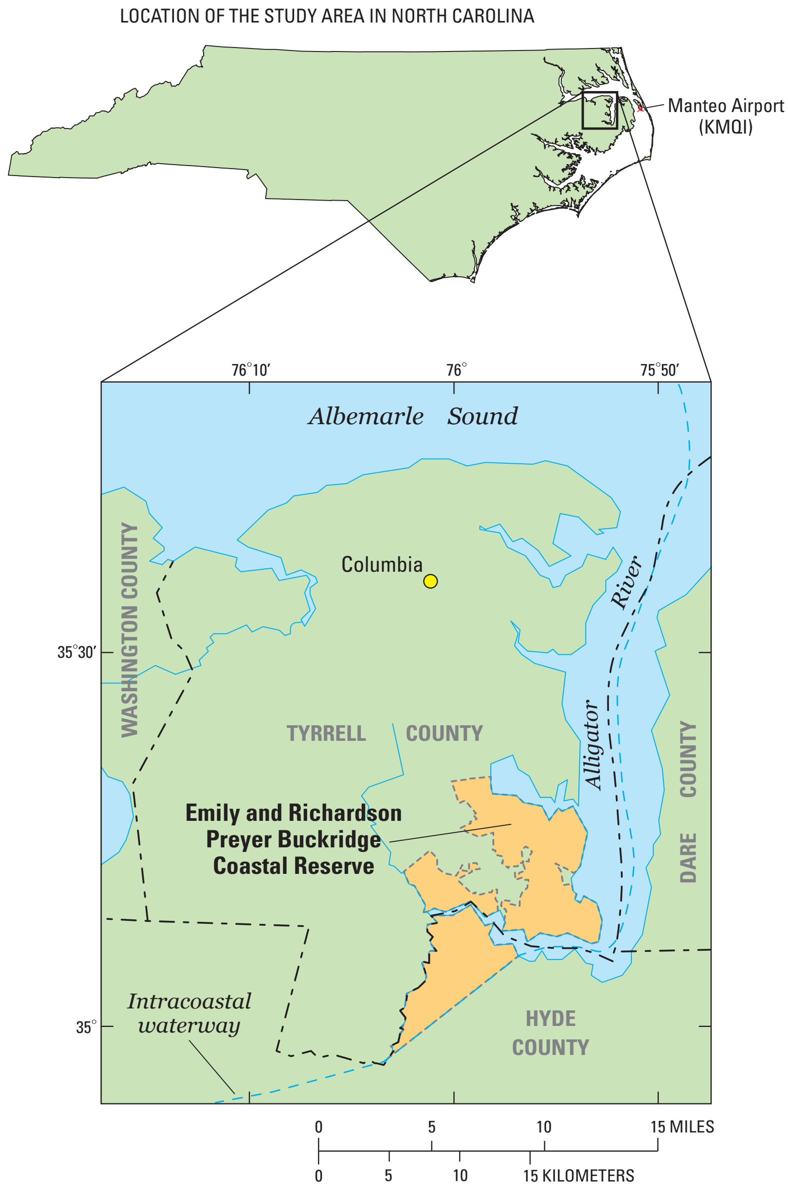


Figure 1. Location of the Emily and Richardson Preyer Buckridge Coastal Reserve in Tyrrell and Hyde Counties, North Carolina.

as a possible cause of the decline. In addition, the localized pattern of AWC dieback initially observed at the Reserve may indicate a response to hydrologic alterations associated with the presence of logging roads and canals rather than climatic conditions.

In an effort to identify the potential effects of hydrologic alterations associated with canals and roads on the health of regenerating AWC in the Reserve, the U.S. Geological Survey (USGS), in cooperation with the North Carolina Division of Coastal Management (NCDCM), initiated a hydrologic investigation that began in February 2003 and ended in March 2006. This investigation included an assessment of the effects of canals and roads on water levels, water chemistry, and water-level responses to precipitation, and an evaluation of the relation between hydrologic conditions and the health of AWC. Information provided by this investigation can be used by the NCDCM to assist in the development of a restoration plan designed to aid in returning the hydrology of the Reserve to conditions similar to those prior to construction of roads and canals, which should be conducive to the re-establishment and maintenance of AWC.

Coastal Wetlands and Atlantic White Cedar

Wetlands are environments that are transitional between terrestrial and aquatic settings and have characteristics of both (Cowardin and others, 1979). Wetlands are defined by the U.S. Fish and Wildlife Service as “lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. The single feature that most wetlands share is soil or substrate that is at least periodically saturated with or covered by water. The water creates severe physiological problems for all plants and animals except those that are adapted for life in water or in saturated soil" (Cowardin and others, 1979). Hydrologically, wetlands are defined as areas where the water table intersects land surface, or as areas where the water table is at or near the soil surface for a significant part of the growing season (Tiner, 1984; Sahagian and Melack, 1996).

Coastal wetlands are hydrologically complex systems (Winter, 1992) and are subject to alterations in hydrology and ecology from human and natural disturbances. Hydrologic alterations are varied and can include changes in water levels and hydroperiod as a result of flooding or drainage; changes in evapotranspiration rates as a result of vegetation loss or changes in type of vegetation; and changes in topography as a result of subsidence, compaction, or other disturbances. These physical alterations can contribute to chemical alterations in water quality associated with changes in the redox potential of the substrate, upwelling of ground water, and inflow of freshwater and seawater through drainage systems. Even small changes in topography or soil compaction can affect plant distributions (Ehrenfeld, 1995; Rodgers and others, 2003). Many of the plants in coastal wetlands are adapted to specific hydrologic regimes and are intolerant of alterations in water level and water chemistry (Kozlowski, 1984; Mitsch and Gosselink, 1993). As a consequence of logging and other human activities, changes have occurred in the vegetation of the Atlantic Coastal Plain since European settlement (Sharitz and Gibbons, 1982).

Canals and roads are common features of many coastal wetlands and can modify hydrologic conditions. Canals can decrease residence times, lower water levels, and alter water chemistry (Heath, 1975) to such an extent that AWC and other wetland plant communities are no longer supported (Laderman, 1989). Changes in hydroperiod and depth of inundation caused by stream channelization have altered the distribution of vegetation throughout the Coastal Plain of the southeastern United States (Shankman, 1996). Canals also can act as conduits for movement of seawater into the interior of wetlands during storms. Roads can act as barriers to surface and subsurface movement of water causing prolonged inundation in areas that lie on the upper side of roads and decreasing inflow to the lower side (Mylecraine and Zimmermann, 2000).

Natural disturbances, such as storm-driven influx of seawater and high winds, also affect hydrologic conditions and vegetation in coastal wetlands, especially in conjunction with hurricanes and tropical storms. Resulting increases in salinity can last for periods greater than a year in freshwater wetlands (Chabreck and Palmisano, 1973; Blood and others, 1991). Wind can damage woody vegetation and blow down large stands of timber. Natural variations in precipitation can cause flooding or drought. Lightning fires are important in the establishment and maintenance of coastal plain vegetation (Christensen and others, 1981). Variations in populations of browsing animals, including rabbits, deer, and beavers, can affect plant distributions as a result of herbivory (Crawley, 1983; Huntly, 1991). Beaver activity also can contribute to flooding and alterations in hydroperiod that affect vegetation patterns (Little and Somes, 1965; Zampella and Lathrop, 1997).

Human activities and natural disturbances have affected many of the coastal wetlands where AWC is endemic. Atlantic white cedar (*Chamaecyparis thyoides* [L.] Britton, Sterns, and Poggenburg), also referred to as southern white cedar or juniper, is an obligate wetland species that grows along the Atlantic and Gulf Coasts from southern Maine to northern Florida and westward to Mississippi in a narrow band that ranges from about 50 to 100 miles (mi) wide (Little and Garrett, 1990). AWC is valued as a timber tree because of its light weight, strength, and resistance to decay (Korstian and Brush, 1931).

Temporal patterns of inundation are considered to be major factors contributing to the distribution of wetland vegetation (Wharton and others, 1982; Mitsch and others, 1991). Although tolerance to flooding is a characteristic widely attributed to wetland plants, there is considerable variation in the degree of tolerance. Factors that can affect tolerance include quantitative aspects of flooding, such as depth, duration, and frequency, and qualitative characteristics of flooding, such as season, antecedent conditions, chemical characteristics of the flood waters, and the age of the plant. Townsend (2001) determined that episodic, extremely wet years played a greater role in the distribution of woody floodplain species than extremely dry years. Although AWC is considered tolerant of permanently flooded conditions, based on an assessment by Wharton and others (1982), it typically grows on the top of hummocks rather than in water-filled depressions adjacent to hummocks (Ehrenfeld, 1995). The genus *Chamaecyparis* is restricted to humid, low-nutrient settings within about 150 mi of a marine coast (Laderman, 1998). Other characteristics of this genus include shallow roots, moisture-conserving leaves, poor tolerance to salinity, and high production of windborne seeds (Laderman, 1998). Although AWC can grow in mineral soils in inland settings, its natural distribution is limited to organic soils. Establishment of AWC is associated with catastrophic events, such as flooding and fire (Korstian and Brush, 1931; Little and Garrett, 1990). Laderman (1998) describes AWC and other members of the genus as catastrophe-dependent, poor competitors that exist in harsh environments where competition from other plant species is low. Increases in nutrients associated with urbanization have been associated with a decline in AWC (Ehrenfeld and Schneider, 1991). Thus, changes that enable colonization of other woody plant species and catastrophic events are likely to contribute to the decline of AWC.

The extent of AWC in North America at the time of European settlement is estimated at 500,000 acres (Kuser and Zimmermann, 1995). By 1995, the extent of AWC was only about 115,000 acres, largely because of extensive logging and habitat loss through agricultural and urban development (Kuser and Zimmermann, 1995). The largest presettlement extent of AWC was in North Carolina, primarily in the Great Dismal Swamp and along the Alligator River; approximately half of this presettlement AWC was harvested from 1870 to 1890 (Ashe, 1894). By 1995, only about 10 percent of the presettlement acreage of AWC in North and South Carolina remained (Smith, 1995).

The decline of AWC has been linked to its failure to regenerate following logging and to hydrologic alterations, habitat loss, natural disturbances, and successional patterns related to competition with other plant species. Early logging techniques discouraged re-establishment of AWC (Kuser and Zimmermann, 1995). Agricultural drainage and the resulting subsidence also have contributed to loss of AWC habitat (Heath, 1975). Although generally considered resistant to disease and pathogens (Korstian, 1924; Korstian and Brush, 1931), the regeneration of AWC has been adversely affected by browsing white-tail deer (Little and Somes, 1965; Zampella and Lathrop, 1997). Flooding from beaver dams has been linked to loss of AWC (Kuser and Zimmermann, 1995); however, Little (1950) attributed beaver activity to maintenance of AWC stands. In assessing factors related to the distribution of AWC on the western shore of Maryland, Sheridan and others (1999) suggested that dieback patterns were related to hydrologic disturbances, such as increased salinity from high tides or lowered ground-water levels from ground-water withdrawals. Kuser and Zimmerman (1995) implicated saltwater influx resulting from stream channelization as a cause of the decline of AWC. However, Little and Garrett (1990) suggested that storm-borne influx of seawater was a mechanism for the establishment of monospecific AWC stands as the result of dieback of less salt-tolerant species. Information about the salt tolerance of AWC is largely anecdotal, and specific data are unavailable (A.D. Laderman, Marine Biological Laboratory, Woods Hole, MA, oral commun., 2006). AWC also is subject to wind damage (Korstian and Brush, 1931). Although fire can enhance germination, fire immediately following germination of AWC commonly results in establishment of hardwood species (Korstian, 1924).

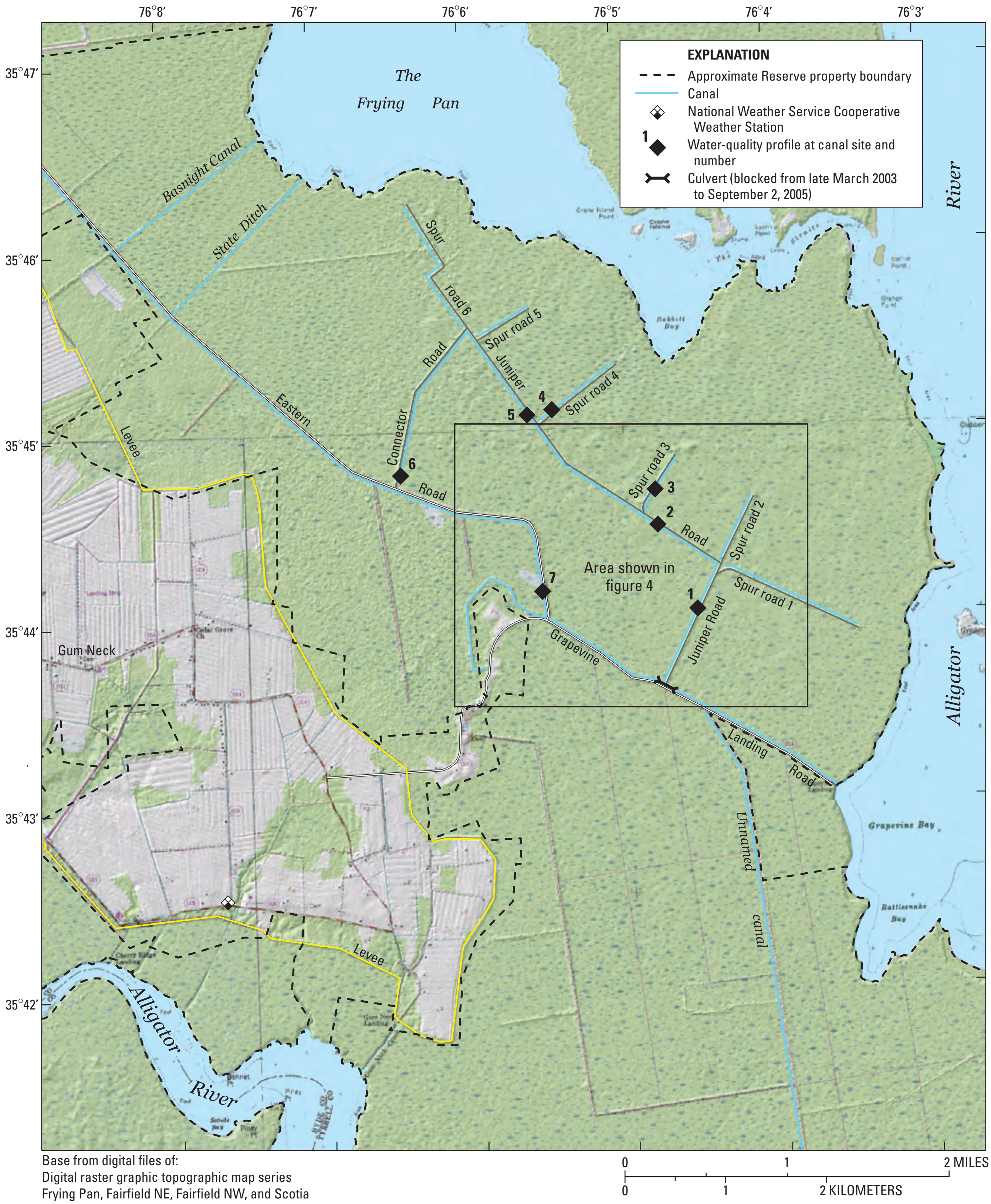
Although the transition of AWC to hardwood forests has been attributed to small-scale disturbance and successional patterns (Buell and Cain, 1943), studies by Motzkin and others (1993) based on analyses of pollen and stand-age structure of AWC on Cape Cod, Massachusetts, and Zampella and Lathrop (1997) based on remote-sensing data of AWC stands in the New Jersey Pinelands resulted in little evidence of this transition. Results of these studies were supported by a subsequent class-size analysis (Zampella and others, 1999). Thus, natural succession does not appear to be a major factor in the decline of AWC.

The Emily and Richardson Preyer Buckridge Coastal Reserve

The Emily and Richardson Preyer Buckridge Coastal Reserve is a 26,862-acre (42-square-mile (mi^2)) site on the Albemarle-Pamlico peninsula in Hyde and Tyrrell Counties, North Carolina, about 15 mi south-southeast of Columbia (fig. 1). The Reserve is bounded to the north by The Frying Pan embayment, to the east and south by the Alligator River and the Intracoastal Waterway, and to the west by the Alligator River, a levee, and drained farmland (fig. 2). The northern part of the Reserve contains the largest contiguous stand of AWC in the eastern United States (fig. 3). The Reserve is situated in a large depressional wetland complex overlain by peat soils (thicknesses greater than 19 feet (ft) were measured during this investigation) with isolated areas of mineral soils (Tant and others, 1988). The predominant soil types at the Reserve are the Pungo, Dorovan, and Belhaven mucks (Tant and others, 1988). A clay layer underlies the peat. Peat formed over a former seabed in response to blocked stream channels, high precipitation, low temperatures, low drainage gradients, high water tables, and fine-grained organic sediment accumulation (Daniel, 1981; Sharitz and Gibbons, 1982).

The climate of Tyrrell County during summer months is hot and humid; the mean July temperature is 78 degrees Fahrenheit (°F; Fuss, 2001). Winters are cool; the mean January temperature is 42 °F (Fuss, 2001). Annual precipitation amounts recorded during 1985–2005 at the National Weather Service (NWS) Cooperative (COOP) Weather Station near the community of Gum Neck (fig. 2) ranged from about 31.4 inches in 2001 to 86 inches in 2003, and the annual mean precipitation for the period was about 57.4 inches for the period (Appendix 1; Jacob and Arnette Parker, observers at the National Weather Service Cooperative Weather Station, no. 311949, written commun., 2005). Large amounts of rainfall typically occur in conjunction with tropical storms and hurricanes. Historically, the Reserve has been affected by hurricanes and tropical storms, which, depending on wind direction, can push brackish water from the Alligator River into the Reserve. Storm surge from hurricanes reportedly reached the interior of the Reserve several times during the1990s (Michael Clements, former site manager, Buckridge, Inc., oral commun., 2003; Joe Landino, former forest land manager, Westvaco, oral commun., 2005).

Four major canals are in the Reserve—Basnight Canal and State Ditch in the northwestern part, a canal along Grapevine Landing Road in the central and eastern part, and an unnamed canal that enters the Alligator River in the southern part of the Reserve (fig. 2). Numerous small canals and ditches, most of which were excavated to obtain fill materials for roads rather than to convey water, are present throughout the Reserve. These small canals and ditches can facilitate movement of tidally or wind-driven water from the Alligator River into the interior of the Reserve. Although the Reserve has no distinct elevational gradient to influence drainage, the land surface is highly irregular and consists of hummocks



Base from digital files of:
Digital raster graphic topographic map series
Frying Pan, Fairfield NE, Fairfield NW, and Scotia
Quadrangles, North Carolina. Map projection: North Carolina
State plane feet, NAD 1983, U.S. Geological Survey,
1:24,000 scale

Figure 2. Locations of vertical water-quality profile sites, National Weather Service Cooperative Weather Station, and selected geographical features in the vicinity of the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina.

Figure 3. General topography and distribution of healthy and unhealthy areas of Atlantic white cedar in and around the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina (modified from Fuss, 2001.

and depressions, with variations in elevation of several feet. A levee, which separates the Reserve from agricultural lands to the west (figs. 2, 3), was constructed in the 1960s (Fuss, 2001). The Reserve has no permanent infrastructure other than canals and roads. Although some of the 31 mi of unpaved roads have been maintained for access, no attempt has been made to maintain the approximately 49 mi of canals, which range in depth from 4 to 18 ft and have vegetation-stabilized banks.

Timber at the Reserve has been logged at several intervals since the 1700s (Fuss, 2001), and the hydrologic regime has been altered by the presence of canals and roads and by physical disturbances associated with logging. Prior to the late 1800s, logging activity was limited to areas suitable for access by oxen, which were used to transport logs (Lilly, 1981; McMullan, 1984). Many previously inaccessible areas were logged in the 1880s with steam-powered locomotives on narrow-gauge railroads (Ash and others, 1983). During this time, nearly all of the large, mature stands of AWC were harvested (Ashe, 1894). A road network was created to access the Reserve during the most recent AWC harvest (1970s and early 1980s), which was accomplished by using heavy equipment (Fuss, 2001). Roads were constructed from materials obtained by excavating peat and the underlying mineral soil. Logging operations affected the topography of the area and created numerous parallel depressions perpendicular to the roads as logs were dragged from the swamp to the road. These depressions are visible in aerial photographs (fig. 4; Fuss, 2001). Following logging operations of the 1970s and early 1980s, large areas of AWC regenerated at the Reserve (Michael Clements, former site manager, Buckridge, Inc., oral commun., 2003). Major disturbances, such as clearcutting, wind blowdown, or certain fire regimes, are necessary to induce regeneration of AWC. About 4,000 acres of regenerating AWC were reported at the Reserve in the mid-1990s (Michael Schafale, North Carolina Natural Heritage Program, oral commun., 2005).

Although most of the AWC at the Reserve is in an area along Juniper Road, several small stands of AWC are present in the southern part of the Reserve (fig. 3), and individual mature trees, inaccessible to logging operations, are scattered throughout the Reserve (Fuss, 2001). Juniper Road was constructed during logging operations in the late 1970s and early 1980s to harvest AWC. The logging roads perpendicular to Juniper Road are referred to locally as spur roads. For the purpose of this report, these roads are identified in the order of occurrence from northeast to northwest along Juniper Road from the intersection of Juniper Road and Grapevine Landing Road (fig. 2). For example, the first spur road is referred to as spur road 1; the next spur road is spur road 2, and so forth. The canal along Connector and Juniper Roads, referred to as the Juniper Road canal, drains into the canal along Grapevine Landing Road and flows into the Alligator River (fig. 2). The canals adjacent to the spur roads perpendicular to Juniper Road are not directly connected to the Juniper Road canal, although some water likely seeps through or under the roadbed.

To date, there has been little in-depth study at the Reserve to explain AWC dieback or to describe hydrologic conditions. Several biotic inventories were conducted at the Reserve (Schafale, 1996a, b, 1999) and are compiled in Fuss (2001). Comparison of Landsat Thematic Mapper satellite images indicates relatively small changes in vegetation at the Reserve from 1988 to 1994 (Fuss, 2001; Meyer and Fuss, 2001). General hydrologic observations of the canals at the Reserve were reported by Fuss (2001). Madden (2005) reported that a “salt wedge” moved into the Reserve through the canal along Grapevine Landing Road following Hurricane Ophelia (September 14–16, 2005). Specific conductance of water in the canals and peat along Juniper Road was elevated following the storm (Madden, 2005). Heath (1975) described general hydrologic conditions of the Albemarle-Pamlico peninsula, including the area occupied by the Reserve. Although few investigations have been conducted at the Reserve, effects of disturbance on hydrologic conditions in coastal plain settings as well as the natural history and hydrologic requirements of AWC have been studied in other locations and are presented in the previous section of this report.

Purpose and Scope

The purpose of this report is to present and interpret the hydrologic data collected at the Emily and Richardson Preyer Buckridge Coastal Reserve from February 2003 through March 2006 and to compare hydrologic conditions in areas of healthy and unhealthy AWC. The interpretations are based on information obtained during a reconnaissance of the study area and from a water-level monitoring network established during this investigation; in addition, water-quality data were obtained from various sites in areas of healthy and unhealthy AWC. Data from the monitoring network include continuous precipitation records for 1 site, continuous water-level records for 3 canals and 11 wells, continuous records of water temperature and specific conductance at 2 depths at 2 canal sites, and water-quality samples from canals, piezometers, and a well.

Methods of Investigation

Identification of alterations to pre-disturbance hydrologic conditions is a key component of wetland restoration. For coastal wetlands, however, this commonly is complicated by a lack of pre-disturbance data. Because information was unavailable in regard to hydrologic conditions prior to the construction of roads and canals at the Reserve, an attempt was made to identify hydrologic alterations by evaluating the hydrologic effects of canals and roads and by comparing hydrologic conditions in areas of healthy and unhealthy AWC. Canals and roads can alter hydrologic conditions in several ways. Canals can decrease water levels by increasing drainage (Winner and Simmons, 1977) and can facilitate

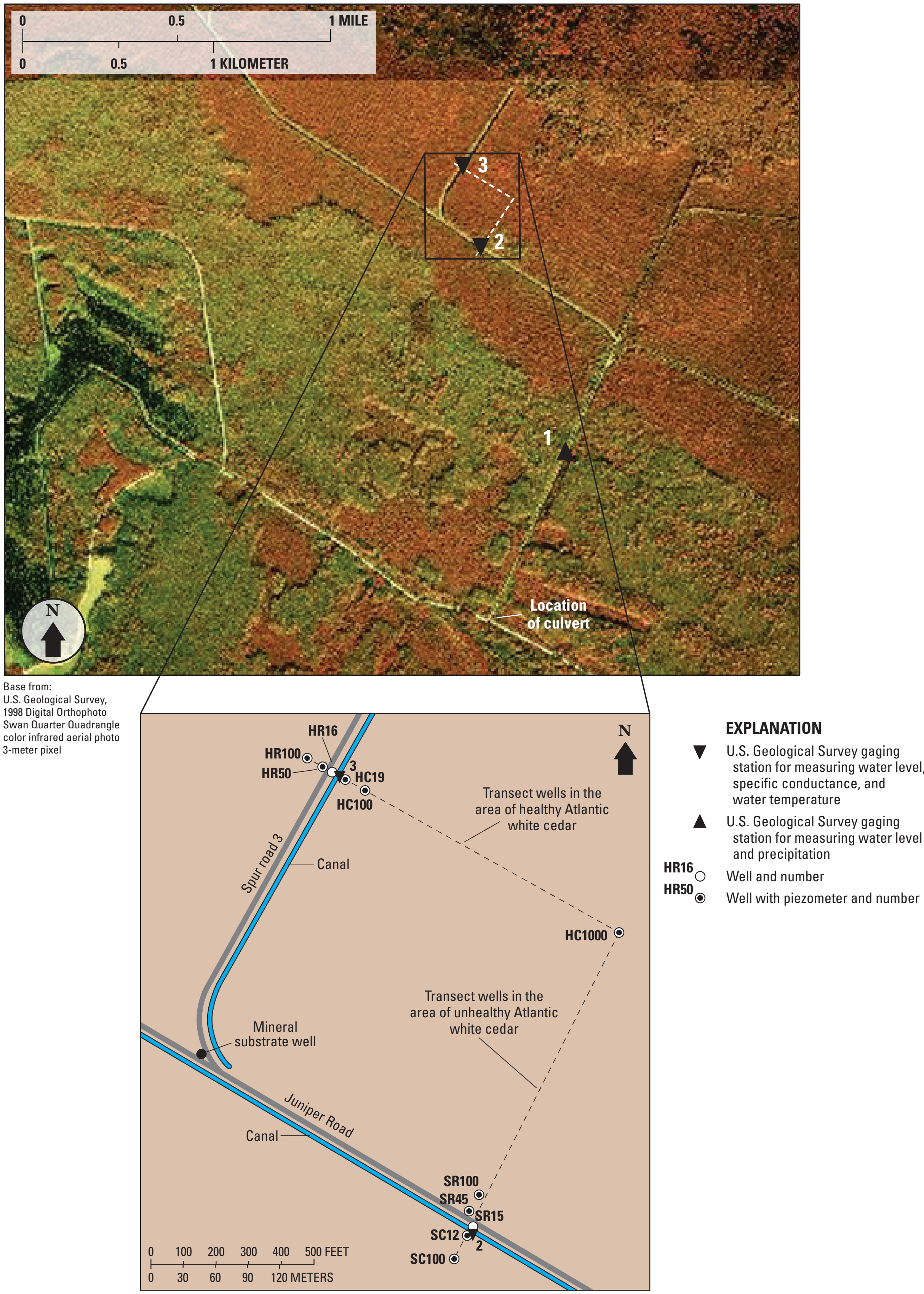


Figure 4. Aerial photograph and generalized map showing the locations of gaging stations and wells at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina.

the influx of water from other sources, such as the Alligator River with respect to the Reserve. Roads can act as barriers to surface and subsurface movement of water and, depending on orientation with respect to direction of flow and land-surface gradients, can cause impoundment of water on the upgradient side and decrease availability of water on the downgradient side. Excavation of soil during road construction can breach confining units and enable upward movement of underlying ground water into canals, thereby changing water levels and water chemistry (Laderman, 1989).

Approaches used to assess the potential hydrologic alterations associated with canals and roads and to relate such alterations to observed patterns in AWC health included (1) a reconnaissance of the site to determine general flow patterns, (2) establishment of a hydrologic monitoring network to evaluate water levels and water-quality conditions, and (3) a comparison of water-quality conditions in the root zone of healthy and unhealthy AWC.

Site Reconnaissance

To assess hydrologic conditions at the Reserve, an effort was made to determine the general patterns of water movement prior to establishing the monitoring network. Because of the inaccessibility of much of the Reserve, light-detecting and ranging (LIDAR) data from 2002 (North Carolina Division of Emergency Management, Floodplain Mapping Program, 2002; fig. 3) were used to determine general topographic characteristics of the study area. Although no major land-surface gradients are present at the Reserve, the LIDAR-based data indicated that land-surface elevations increase slightly in a northward direction from Juniper Road toward The Frying Pan embayment (fig. 3). Land-surface elevations generally decrease in a south to southwestward direction from the south side of Juniper Road toward Grapevine Landing Road (fig. 3). Elevations within the main stands of AWC along Juniper Road generally ranged from about zero to 2 ft above North American Vertical Datum of 1988 (NAVD 88) with several small areas, primarily on the southwest side of Juniper Road, that were below NAVD 88 (fig. 3). Land-surface elevations were similar in areas of regenerating AWC identified by Fuss (2001) as healthy and poor. However, elevations in the area southwest of Grapevine Landing Road, which was identified by Fuss (2001) as containing a stand of dead AWC, were lower (ranging from about zero to 0.5 ft below NAVD 88) than the elevations in areas where AWC had been designated by Fuss (2001) as either healthy or poor.

Locations of canals and roads initially were determined from records for the Reserve and from aerial photographs taken in 1993 (U.S. Geological Survey, 1993) and 1998 (U.S. Geological Survey, 1998). It was not possible to determine from the aerial photographs if the canals adjacent to the roads perpendicular to Juniper Road extended to The Frying Pan embayment. Because of the difficulty of overland access, the shoreline of The Frying Pan embayment was surveyed by boat to identify and locate mouths of canals and to determine if the canals in the northern part of the Reserve extended to the embayment. Outflows were visible at the mouths of Basnight Canal and State Ditch (fig. 2). The mouth of a shallow canal (about 1.5 ft deep) was found along Babbitt Bay. This canal is presumed to be a remnant of early logging activities or possibly an extension of the canal adjacent to spur road 4. Based on field observations, the canal along spur road 1 did not appear to extend to the Alligator River. Likewise, the canal adjacent to spur road 3 did not appear to extend to The Frying Pan embayment. Inspection of the canal along Juniper Road did not reveal evidence of culverts connecting it to the canals along the spur roads. Vertical profiles of specific conductance, water temperature, and pH were obtained at selected canal sites within the Reserve to assess general water-quality conditions and to aid in the selection of study sites (fig. 2).

To determine historical patterns in dieback and decline of AWC, aerial photographs, including high-resolution color photographs taken in 2005 by the U.S. Department of Agriculture (2005), were compared to locations of unhealthy and dead AWC mapped by Fuss (2001). Expansion of the unhealthy areas identified by Fuss (2001) was evident in the 2005 photographs, especially along the south side of Juniper Road where the LIDAR data indicated that land-surface elevations were below NAVD 88. Information provided by local residents also was used to assist in determining historical patterns in AWC dieback coupled with historical weather data. Various spectral bands of Landsat imagery (path 14, row 35) obtained from the USGS for 1991 and 1999 were analyzed and compared to known locations of healthy, unhealthy, and dead AWC to determine if AWC dieback at the Reserve could be detected. The resolution, however, was insufficient to evaluate dieback patterns.

Hydrologic Monitoring

A monitoring network was established to assess hydrologic conditions in areas of healthy and unhealthy AWC and in other parts of the Reserve. Gages, wells, and piezometers were installed to obtain precipitation, water-level, and water-quality data. The site locations, types of data collected, and time periods of data collection are given in table 1. The USGS station name and site identification number are unique to each canal site, well, and piezometer for which data were entered into the USGS National Water Information System (NWIS). In this report, the station names and numbers are used to identify monitoring sites included in the appendixes, and the abbreviated names given in table 1 are used in the text. Water-level and water-quality data recorded at 15-minute intervals are referred to as continuous data. Because of the complex interrelations between surface water and ground water in wetlands (Cowardin and others, 1979; Sahagian and Melack, 1996), no attempt was made to differentiate between surface water and ground water; for the purpose of this report, the term water

Table 1. U.S. Geological Survey monitoring network at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–06.

[NAD 83, North American Datum of 1983; RF, precipitation; WL, water level; T&S, water temperature and specific conductance; WQ, water-quality sampling; PP, physical properties of water; —, not measured or not applicable]

Station name	Abbreviated name (figs. 2, 4, 5)	USGS site identification	Latitude (NAD 83)	Longitude (NAD 83)	Data					Period of continuous record	Appendix
					Continuous			Periodic			
					RF	WL	T&S	WQ	PP		
Juniper Road canal (Site 1) at Buckridge Reserve, NC	Canal site 1	354400076043101	35°43'59.5"	76°04'31.3"	X	X	X	X	X	Mar. 2004–Mar. 2006	2, 3, 25, 28
Juniper Road canal (Site 2) at Buckridge Reserve, NC	Canal site 2	354428076044301	35°44'28"	76°04'43"	—	X	X	X	X	Feb. 2004–Mar. 2006	4, 6–9, 26, 28
Spur road 3 canal (Site 3) at Buckridge Reserve, NC	Canal site 3	354442076044601	35°44'42"	76°04'46"	—	X	X	X	X	Apr. 2004–Mar. 2006	5, 10–13, 27, 28
Spur road 4 canal (Site 4) at Buckridge Reserve, NC	Canal site 4	354505076052901	35°45'05"	76°05'29"	—	—	—	—	X	—	28
Juniper Road canal (Site 5) at Buckridge Reserve, NC	Canal site 5	354503076053301	35°45'03"	76°05'33"	—	—	—	—	X	—	28
Connector Road canal (Site 6) at Buckridge Reserve, NC	Canal site 6	354446076062901	35°44'46"	76°06'29"	—	—	—	—	X	—	28
Eastern Road canal (Site 7) at Buckridge Reserve, NC	Canal site 7	354411076053101	35°44'11"	76°05'31"	—	—	—	—	X	—	28
TY-089 Buckridge Well SR100	Well SR100	354428076044302	35°44'29.2"	76°04'42.7"	—	—	X	—	—	Feb. 2004–Mar. 2006	14
TY-090 Buckridge Well SR45	Well SR45	354428076044303	35°44'28.6"	76°04'43.4"	—	—	X	—	—	Feb. 2004–Mar. 2006	15
TY-091 Buckridge Well SR15	Well SR15	354428076044304	35°44'28.3"	76°04'43.3"	—	—	X	—	—	Feb. 2004–Aug. 2005	16
TY-092 Buckridge Well SC12	Well SC12	354428076044305	35°44'28.0"	76°04'43.5"	—	—	X	—	—	Feb. 2004–Mar. 2006	17
TY-093 Buckridge Well SC100	Well SC100	354428076044306	35°44'27.0"	76°04'44.3"	—	—	X	—	—	Feb. 2004–Mar. 2006	18
TY-094 Buckridge Well HC100	Well HC100	354442076044602	35°44'41.6"	76°04'44.6"	—	—	X	—	—	Apr. 2004–Mar. 2006	19
TY-095 Buckridge Well HC19	Well HC19	354442076044603	35°44'42.2"	76°04'45.6"	—	—	X	—	—	Apr. 2004–Mar. 2006	20
TY-096 Buckridge Well HR16	Well HR16	354442076044604	35°44'42.4"	76°04'46.0"	—	—	X	—	—	Apr. 2004–Sept. 2005	21
TY-097 Buckridge Well HR50	Well HR50	354442076044605	35°44'42.6"	76°04'46.3"	—	—	X	—	—	Apr. 2004–Mar. 2006	22
TY-098 Buckridge Well HR100	Well HR100	354442076044606	35°44'43.0"	76°04'46.9"	—	—	X	—	—	Apr. 2004–Mar. 2006	23
TY-099 Buckridge Well HC1000	Well HC1000	354437076043601	35°44'36.6"	76°04'36.3"	—	—	X	—	—	May 2004–Mar. 2006	24
TY-103 Buckridge Mineral Substrate Well	Mineral substrate well	354433076045201	35°44'33.4"	76°04'51.7"	—	—	—	X	X	—	—
TY-105 Buckridge WQ Piezometer P-SR100	Piezometer P-SR100	354428076044362	35°44'29"	76°04'43"	—	—	—	X	X	—	—
TY-106 Buckridge WQ Piezometer P-SR45	Piezometer P-SR45	354428076044363	35°44'28"	76°04'43"	—	—	—	X	X	—	—
TY-108 Buckridge WQ Piezometer P-SC12	Piezometer P-SC12	354428076044365	35°44'28"	76°04'43"	—	—	—	X	X	—	—
TY-109 Buckridge WQ Piezometer P-SC100	Piezometer P-SC100	354428076044366	35°44'27"	76°04'44"	—	—	—	X	X	—	29

Table 1. U.S. Geological Survey monitoring network at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–06. — Continued

[NAD 83, North American Datum of 1983; RF, precipitation; WL, water level; T&S, water temperature and specific conductance; WQ, water-quality sampling; PP, physical properties of water; —, not measured or not applicable]

Station name	Abbreviated name (figs. 2, 4, 5)	USGS site identification	Latitude (NAD 83)	Longitude (NAD 83)	Data: Continuous RF	Data: Continuous WL	Data: Continuous T&S	Data: Periodic WQ	Data: Periodic PP	Period of continuous record	Appendix
TY-110 Buckridge WQ Piezometer P-HC100	Piezometer P-HC100	354442076044662	35°44'42"	76°04'46"	—	—	—	X	X	—	29
TY-111 Buckridge WQ Piezometer P-HC19	Piezometer P-HC19	354442076044663	35°44'42"	76°04'46"	—	—	—	X	X	—	—
TY-113 Buckridge WQ Piezometer P-HR50	Piezometer P-HR50	354442076044665	35°44'42"	76°04'46"	—	—	—	X	X	—	—
TY-114 Buckridge WQ Piezometer P-HR100	Piezometer P-HR100	354442076044666	35°44'42"	76°04'46"	—	—	—	X	X	—	—
TY-115 Buckridge WQ Piezometer P-HC1000	Piezometer P-HC1000	354437076043661	35°44'37"	76°04'36"	—	—	—	X	X	—	—
TY-118 Buckridge Piezometer H1B	Piezometer H1B	354441076044401	35°44'40.8"	76°04'43.5"	—	—	—	—	X	—	29
TY-119 Buckridge Piezometer H1C	Piezometer H1C	354442076044301	35°44'41.5"	76°04'42.9"	—	—	—	—	X	—	29
TY-120 Buckridge Piezometer H1D	Piezometer H1D	354442076044101	35°44'42.0"	76°04'41.1"	—	—	—	—	X	—	29
TY-121 Buckridge Piezometer H1E	Piezometer H1E	354441076044501	35°44'41.1"	76°04'45.3"	—	—	—	—	X	—	29
TY-122 Buckridge Piezometer H1F	Piezometer H1F	354442076044401	35°44'41.7"	76°04'43.6"	—	—	—	—	X	—	29
TY-123 Buckridge Piezometer H1G	Piezometer H1G	354442076044402	35°44'42.3"	76°04'44.2"	—	—	—	—	X	—	29
TY-124 Buckridge Piezometer H1H	Piezometer H1H	354442076044501	35°44'41.6"	76°04'45.4"	—	—	—	—	X	—	29
TY-125 Buckridge Piezometer H1I	Piezometer H1I	354441076044201	35°44'40.5"	76°04'42.4"	—	—	—	—	X	—	29
TY-126 Buckridge Piezometer H2A	Piezometer H2A	354533076054901	35°45'32.7"	76°05'49.2"	—	—	—	—	X	—	29
TY-127 Buckridge Piezometer H2B	Piezometer H2B	354531076054901	35°45'31.4"	76°05'49.4"	—	—	—	—	X	—	29
TY-128 Buckridge Piezometer H2C	Piezometer H2C	354532076055001	35°45'31.7"	76°05'49.7"	—	—	—	—	X	—	29
TY-129 Buckridge Piezometer H2D	Piezometer H2D	354533076054801	35°45'32.8"	76°05'48.4"	—	—	—	—	X	—	29
TY-130 Buckridge Piezometer H2E	Piezometer H2E	354532076055002	35°45'31.9"	76°05'50.1"	—	—	—	—	X	—	29
TY-131 Buckridge Piezometer H3A	Piezometer H3A	354441076050301	35°44'40.6"	76°05'03.1"	—	—	—	—	X	—	29
TY-132 Buckridge Piezometer H3B	Piezometer H3B	354440076050201	35°44'40.2"	76°05'02.3"	—	—	—	—	X	—	29
TY-133 Buckridge Piezometer H3C	Piezometer H3C	354441076050201	35°44'40.6"	76°05'02.1"	—	—	—	—	X	—	29
TY-134 Buckridge Piezometer H3D	Piezometer H3D	354440076050202	35°44'39.7"	76°05'02.4"	—	—	—	—	X	—	29
TY-135 Buckridge Piezometer H3E	Piezometer H3E	354440076050203	35°44'39.9"	76°05'01.7"	—	—	—	—	X	—	29
TY-136 Buckridge Piezometer U1B	Piezometer U1B	354427076044401	35°44'26.9"	76°04'44.0"	—	—	—	—	X	—	29
TY-137 Buckridge Piezometer U1C	Piezometer U1C	354426076044401	35°44'25.9"	76°04'44.2"	—	—	—	—	X	—	29
TY-138 Buckridge Piezometer U1D	Piezometer U1D	354427076044501	35°44'27.4"	76°04'44.9"	—	—	—	—	X	—	29
TY-139 Buckridge Piezometer U1E	Piezometer U1E	354427076044301	35°44'26.9"	76°04'43.1"	—	—	—	—	X	—	29
TY-140 Buckridge Piezometer U1F	Piezometer U1F	354428076044501	35°44'28.3"	76°04'44.7"	—	—	—	—	X	—	29

Table 1. U.S. Geological Survey monitoring network at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–06. — Continued

[NAD 83, North American Datum of 1983; RF, precipitation; WL, water level; T&S, water temperature and specific conductance; WQ, water-quality sampling; PP, physical properties of water; —, not measured or not applicable]

Station name	Abbreviated name (figs. 2, 4, 5)	USGS site identification	Latitude (NAD 83)	Longitude (NAD 83)	Data					Period of continuous record	Appendix
					Continuous			Periodic			
					RF	WL	T&S	WQ	PP		
TY-141 Buckridge Piezometer U1G	Piezometer U1G	354427076044601	35°44'27.0"	76°04'45.6"	—	—	—	—	X	—	29
TY-142 Buckridge Piezometer U1H	Piezometer U1H	354427076044602	35°44'26.5"	76°04'45.8"	—	—	—	—	X	—	29
TY-143 Buckridge Piezometer U1I	Piezometer U1I	354428076044401	35°44'28.0"	76°04'44.2"	—	—	—	—	X	—	29
TY-144 Buckridge Piezometer U1J	Piezometer U1J	354428076044402	35°44'27.6"	76°04'43.8"	—	—	—	—	X	—	29
TY-145 Buckridge Piezometer U2A	Piezometer U2A	354505076053301	35°45'04.9"	76°05'32.9"	—	—	—	—	X	—	29
TY-146 Buckridge Piezometer U2B	Piezometer U2B	354506076053301	35°45'05.5"	76°05'32.7"	—	—	—	—	X	—	29
TY-147 Buckridge Piezometer U2C	Piezometer U2C	354505076053101	35°45'04.6"	76°05'31.3"	—	—	—	—	X	—	29
TY-148 Buckridge Piezometer U2D	Piezometer U2D	354504076053201	35°45'03.8"	76°05'32.1"	—	—	—	—	X	—	29
TY-149 Buckridge Piezometer U2E	Piezometer U2E	354505076053201	35°45'04.5"	76°05'32.1"	—	—	—	—	X	—	29
TY-150 Buckridge Piezometer U3A	Piezometer U3A	354353076032601	35°43'52.5"	76°03'26.2"	—	—	—	—	X	—	29
TY-151 Buckridge Piezometer U3B	Piezometer U3B	354353076032701	35°43'53.2"	76°03'27.0"	—	—	—	—	X	—	29
TY-152 Buckridge Piezometer U3C	Piezometer U3C	354354076032501	35°43'53.7"	76°03'24.9"	—	—	—	—	X	—	29
TY-153 Buckridge Piezometer U3D	Piezometer U3D	354354076032401	35°43'54.4"	76°03'24.1"	—	—	—	—	X	—	29
TY-154 Buckridge Piezometer U3E	Piezometer U3E	354354076032601	35°43'54.3"	76°03'26.2"	—	—	—	—	X	—	29

level is used to refer to both ground- and surface-water levels. Water levels generally are referenced to feet above NAVD 88.

Precipitation

Precipitation data were obtained from a tipping-bucket gage installed at canal site 1 (fig. 4). Precipitation data were recorded at 15-minute intervals. Historical precipitation data were obtained from a NWS COOP Weather Station near Gum Neck (fig. 2). The historical data were used to evaluate climatic conditions that could have contributed to the dieback of AWC and to provide a frame of reference for precipitation conditions during this study. Precipitation data collected at the NWS COOP Weather Station also were used to provide estimates of rainfall at the Reserve for periods when the precipitation gage at canal site 1 malfunctioned.

Canal Monitoring

To characterize water-level and water-quality conditions in the canals, gages were established at three sites (fig. 4). Site 1, which is in an area primarily vegetated by pine and deciduous trees, is on the lower Juniper Road canal about 0.6 mi northeast of the intersection of Grapevine Landing Road and Juniper Road. Site 1 was established to evaluate the water-level gradient in the Juniper Road canal. Site 2 is also on Juniper Road canal about 1.25 mi north of the intersection of Grapevine Landing Road and Juniper Road and is in a stand of unhealthy AWC. Site 3 is on the canal adjacent to spur road 3 north of Juniper Road in a stand of healthy AWC.

Water levels at canal site 1 were measured by using a float mounted in a stilling well. Water levels at canal sites 2 and 3 were measured by using a gas-purge system equipped with a built-in compressor and nonsubmersible pressure transducer. An orifice mounted in the canal was connected by an air line to the gas-purge system housed in an instrument shelter on the bank. Staff gages were installed at each canal site as reference gages. Recorded water levels were referenced to the readings at each staff gage. Elevations of the staff gages at each site were surveyed to a nearby North Carolina Geodetic Survey benchmark.

Sensors for the measurement of specific conductance and water temperature were installed at two depths near the center of the canal at sites 2 and 3. Although locations of the sensors at these water-quality sites are officially referred to as “TOP” and “BOTTOM” in the USGS NWIS database (J.C. Robbins, U.S. Geological Survey, written commun., 2006), in this report the location of the sensor nearest the bottom of the canal is identified as “lower” and the location of the sensor nearest the water surface is identified as “upper.” The total depth of the canal at site 2 on the unhealthy AWC transect was about 11 ft; a layer of debris about 5 ft thick was in the bottom of the canal. The sensors were installed at depths about 1 ft and 4 ft above this layer of debris. The total depth of the canal at site 3 on the healthy AWC transect was about 16 ft, and a layer of debris about 7 ft thick was on the bottom of the canal. The sensors at site 3 were installed about 2.6 ft and 7 ft above this layer of debris. The instrumentation was connected to a data logger at each canal site and was serviced at approximately 2-month intervals. A vertical profile of specific conductance, water temperature, pH, and dissolved-oxygen concentration was obtained periodically in the center of the canal at each site.

Water-quality samples were collected from canal sites 2 and 3 during February, May, and August 2005 (table 2) for the analytes listed in table 3. Vertical profiles of specific conductance, water temperature, pH, and dissolved-oxygen concentration were obtained at the canals prior to sampling to evaluate variations in water quality with depth. The specific conductance of water near the surface of the canal typically was less than near the bottom of the canal. Samples were collected with a peristaltic pump from two depths in the water column. The lower sample was collected in the zone of high specific conductance along the bottom of the canal, and the upper sample was collected near the upper sensor. The pump tubing was strapped to the side of a water-quality sonde and lowered to the desired sampling depth.

Transects

To evaluate the effects of canals and roads on water levels and to compare water levels in areas of healthy and unhealthy AWC, two transects were established at 90-degree angles to each other (fig. 4). One transect trends in a general southeastward to northwestward direction and is in a stand of healthy AWC north of Juniper Road on spur road 3. The other transect, which generally trends in a northeastward to southwestward direction, extends into a stand of unhealthy regenerating AWC south of Juniper Road. Each transect crosses a canal and the adjacent road. The point at which the unhealthy AWC transect crosses a canal coincides with the location of canal site 2, and the point at which the healthy AWC transect crosses a canal coincides with the location of canal site 3.

Five water-level monitoring wells completed in the peat were installed on each transect (table 4). The wells were instrumented with pressure transducers to measure water levels and were connected to a data logger. At each transect, a well was installed between the road and the canal. In addition, two wells were installed on the canal side of each transect, one at the edge of the canal and another about 100 ft from the centerline of the canal. On the road side of each transect, a well was installed adjacent to the road and a second well was installed approximately 100 ft from the centerline of the canal. Because the transects are perpendicular to each other, an additional well (HC1000) was installed at the point where the transects intersect. This well, located about 1,000 ft from each canal, was equipped with a pressure transducer and data logger. Water levels in the wells on the transects were recorded at 15-minute intervals. Water levels in these wells were measured periodically with an electric water-level tape to verify the accuracy of pressure-transducer readings.

Table 2. Analytes in synoptic samples and dates of sampling at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005.

[SC, specific conductance; ws, water surface; ls, land surface; —, not measured]

Abbreviated name (table 1; fig. 4)	Sampling date	Depth of sample, in feet below datum	Analyte												
			Dissolved-oxygen concentration	pH (field and laboratory)	SC (field and laboratory)	Water temperature	Acid neutralizing capacity	Major dissolved cations (calcium, magnesium, potassium, sodium)	Major dissolved anions (chloride, fluoride, silica, sulfate)	Dissolved nutrients (Kjeldahl nitrogen, ammonia, nitrite plus nitrate, orthophosphate, phosphorus)	Aluminum (dissolved)	Boron (dissolved)	Iron (dissolved)	Manganese (dissolved)	Mercury (dissolved)
Canal site 2	02/10/05	1.3 ws	—	x	x	x	x	x	x	x	—	x	x	x	x
	02/10/05	5.3 ws	—	x	x	x	x	x	x	x	—	x	x	x	x
	05/24/05	1.5 ws	x	x	x	x	x	x	x	x	x	x	x	x	x
	05/24/05	5.0 ws	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/02/05	1.5 ws	x	x	x	x	x	x	x	x	—	x	x	x	—
	08/02/05	5.0 ws	x	x	x	x	x	x	x	x	—	x	x	x	—
Canal site 3	02/11/05	1.3 ws	—	x	x	x	x	x	x	x	—	x	x	x	x
	05/25/05	2.5 ws	x	x	x	x	x	x	x	x	x	x	x	x	x
	05/25/05	8.5 ws	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/03/05	2.5 ws	x	x	x	x	x	x	x	x	—	x	x	x	—
	08/03/05	8.5 ws	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-SC100	02/10/05	3.0 ls	—	x	x	x	x	x	x	x	—	x	x	x	x
	05/24/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	5/24/2005[R]	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/04/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
	8/4/2005[R]	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-SC12	05/24/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/04/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-SR45	02/10/05	3.0 ls	—	x	x	x	x	x	x	x	—	x	x	x	x
	05/24/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/04/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-HC1000	02/10/05	3.0 ls	—	x	x	x	x	x	x	x	—	x	x	x	x
	05/24/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/04/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-HC100	05/25/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/03/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-HC19	05/25/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/03/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-SR100	05/24/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/04/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-HR50	02/11/05	3.0 ls	—	x	x	x	x	x	x	—	—	x	x	x	—
	05/25/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/03/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Piezometer P-HR100	05/25/05	3.0 ls	x	x	x	x	x	x	x	x	x	x	x	x	x
	08/03/05	3.0 ls	x	x	x	x	x	x	x	x	—	x	x	x	—
Mineral substrate well	02/09/05	17.3 ls	—	x	x	x	x	x	x	x	—	x	x	x	x
	05/23/05	10.3 ls	x	x	x	x	x	x	x	x	x	x	x	x	x

[R] Replicate sample.

Table 3. Analytes measured in water samples collected at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August, 2005.

[µg/L, microgram per liter; mg/L; milligram per liter; N, nitrogen; P, phosphorus; DKN, dissolved Kjeldahl nitrogen; na, not applicable; µS/cm, microsiemen per centimeter; °C, degrees Celsius]

Analyte	Reporting level	Units
Aluminum (dissolved)[a]	1.6	µg/L
Acid neutralizing capacity[b]	2	mg/L
Boron (dissolved)[c]	1	µg/L
Calcium (dissolved)[d]	.2	mg/L
Chloride (dissolved)[b]	.010	mg/L
Fluoride (dissolved)[b]	.1	mg/L
Iron (dissolved)[d]	6.4	µg/L
Magnesium (dissolved)[d]	.008	mg/L
Manganese (dissolved)[d]	.8	µg/L
Potassium (dissolved)[e]	.16	mg/L
Silica (dissolved)[b]	.1	mg/L
Sodium (dissolved)[d]	2.6	mg/L
Sulfate (dissolved)[b]	.18	mg/L
Fluoride (dissolved)[b]	.2	mg/L
Nitrogen, ammonia as N (dissolved)[d]	.01	mg/L
Nitrogen, nitrite plus nitrate as N (dissolved)[d]	.16	mg/L
Phosphorus, (dissolved)[f]	.004	mg/L
Phosphorus, orthophosphate as P (dissolved)[d]	.006	mg/L
Nitrogen ammonia plus organic as N (dissolved)[f] (DKN)	.1	mg/L
Mercury (dissolved)[g]	.01	µg/L
pH[b]	na	standard units
Specific conductance[b]	1	µS/cm
Dissolved oxygen	.1	mg/L
Temperature	.1	°C

[a] Faires (1993).
[b] Fishman and Friedman (1989).
[c] Struzeski and others (1996).
[d] Fishman (1993).
[e] American Public Health Association (1998).
[f] Patton and Truitt (1992).
[g] Garbarino and Damrau (2001).

Table 4. Selected characteristics of water-level monitoring wells at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, 2003–06.

[NAVD 88, North American Vertical Datum of 1988]

Abbreviated name (fig. 4)	Thickness of peat (feet)	Land-surface elevation (feet above NAVD 88)	Distance from centerline of canal (feet)[a]
Transect wells in the area of healthy Atlantic white cedar			
Well HR100	12	1.29	112
Well HR50	10	.75	50
Well HR16	11.8	2.23	16
Well HC19	10.6	1.50	19
Well HC100	10.7	1.02	120
Well HC1000	11.5	1.05	970
Transect wells in the area of unhealthy Atlantic white cedar			
Well HC1000	11.5	1.05	1,060
Well SR100	7.8	1.14	130
Well SR45	6.8	1.12	45
Well SR15	7.9	2.66	15
Well SC12	6.8	1.21	12
Well SC100	7	1.24	130

[a] Distance determined by using GIS.

Wells were named according to the transect on which they were installed and their relative position on the transect. Names for wells on the road side of the healthy AWC transect have the prefix HR, whereas wells on the canal side have the prefix HC. Similarly, names for the wells on the road side of the unhealthy AWC transect have the prefix SR, and wells on the canal side have the prefix SC. The number following the prefix denotes the approximate distance of the well from the centerline of the canal. For example, well HR50 was installed on the healthy AWC transect, on the road side of the transect, about 50 ft from the center of the canal.

Wells were installed by hand augering through the peat into the top of the mineral substrate. Wells were constructed with 5-ft lengths of 2-inch-diameter within 4-inch-diameter, 0.030-inch machine-slotted polyvinyl chloride (PVC) well screens pre-packed with sand. The base of the screen was placed on top of the mineral layer. The top of each well was extended to about 1.5 ft above land surface with 2-inch-diameter PVC casing. A section of 8-inch-diameter PVC pipe, which serves as a protective casing, was installed over each well and fitted with a locking cover. Elevations of measuring points for wells were surveyed to a nearby North Carolina Geodetic Survey benchmark. Water levels are referenced in feet above NAVD 88. A differential global positioning system (GPS) was used to determine the horizontal coordinates for wells in reference to North American Datum of 1983 (NAD 83).

Samples were collected from nine piezometers installed in the peat to a depth of about 4 ft below land surface near selected water-level monitoring wells (fig. 4; table 1). Piezometers were named with the prefix P and the name of the nearest well. Piezometers were constructed from 5-ft lengths of 1-inch-diameter PVC pipe, which were capped at one end. Four rows of 0.4-inch holes, placed about 2 inches apart, were drilled into a 3.5-ft section of the capped end of the pipe. The pipe was wrapped with at least two turns of fiberglass mesh screen, which was secured to the PVC pipe with nylon cable straps.

A well completed in the underlying mineral substrate was installed to characterize the quality of water below the peat layer. This well was located at the intersection of Juniper Road and spur road 3 (fig. 4). A trailer-mounted hollow-stem auger was used to drill through the peat and into the mineral layer to a depth of about 20 ft below land surface. The well was constructed with 2-inch-diameter PVC casing and a 5-ft length of 0.010-inch machine-slotted well screen. A section of 6-inch-diameter PVC pipe was placed over the well casing through the peat, which was about 8 ft thick, and pushed about 1 ft into the mineral substrate. The well screen was installed from about 15 to 20 ft below land surface. Clean sand was poured into the annular space around the screen. Above the screen, bentonite grout was poured into the annular space between the 6-inch-diameter pipe and 2-inch-diameter well casing. A section of 8-inch-diameter PVC pipe, which served as a protective casing, was installed over the well and fitted with a locking cover.

Water samples were collected from the piezometers on the transects and the mineral substrate well (table 2) and analyzed in the USGS National Water Quality Laboratory in Denver, Colorado, for the nutrients, ions, and metals listed in table 3. Samples were collected and processed on site in accordance with USGS protocols (U.S. Geological Survey, variously dated). Prior to sampling, a minimum of three casing volumes of water were removed from the piezometers and the mineral substrate well. A peristaltic pump was used to purge the piezometers, and a submersible pump was used to purge the mineral substrate well. Specific conductance, water temperature, pH, and dissolved-oxygen concentration were measured during purging. After the values of these physical and chemical properties stabilized, water samples were collected by using a peristaltic pump.

Root-Zone Water Quality

Water-quality conditions in the root zone of selected sites located in stands of predominantly healthy and unhealthy AWC at the Reserve were compared. Unhealthy AWC sites included a mixture of stressed, dying, and dead AWC. Three healthy and three unhealthy AWC sites were selected for evaluation (fig. 5). Accessibility was a major factor in site selection. During an inspection of AWC stands in the spring of 2005, some of the AWC in areas previously identified by Fuss (2001) as healthy were observed to be

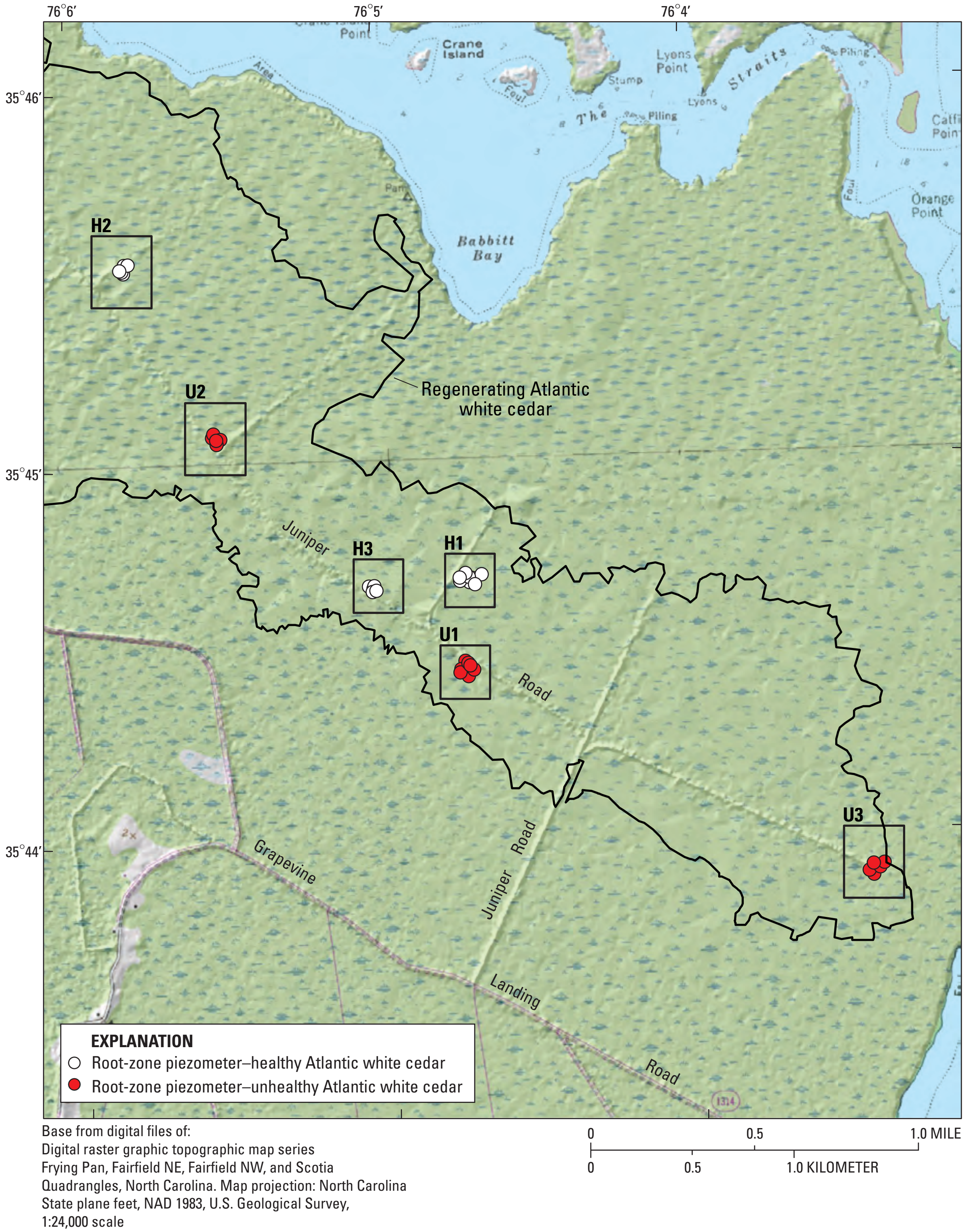
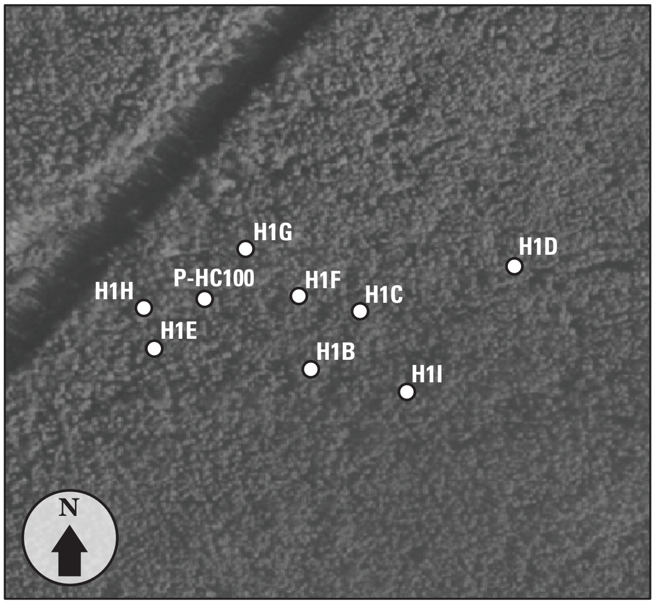


Figure 5. Locations of root-zone water-quality piezometers in stands of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005.

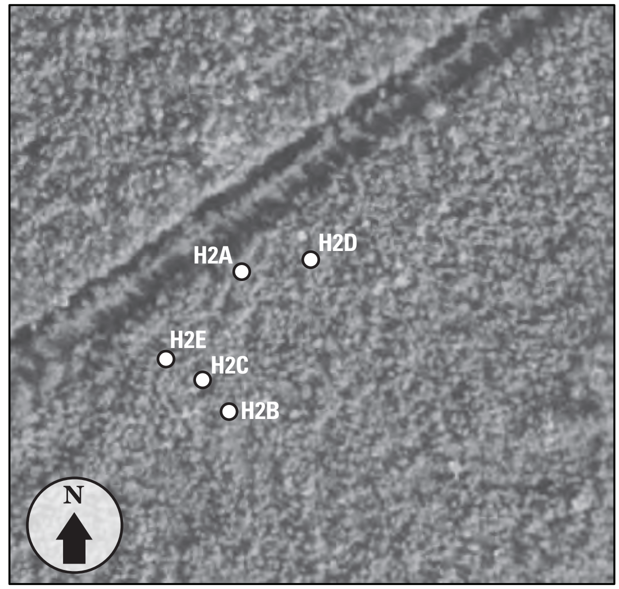
H1



Base from:
U.S. Geological Survey,
2003 Digital Orthophotography
Black and White,
2-foot Pixel Resolution, NAD 83

0 50 100 150 200 FEET
0 20 40 60 METERS

H2



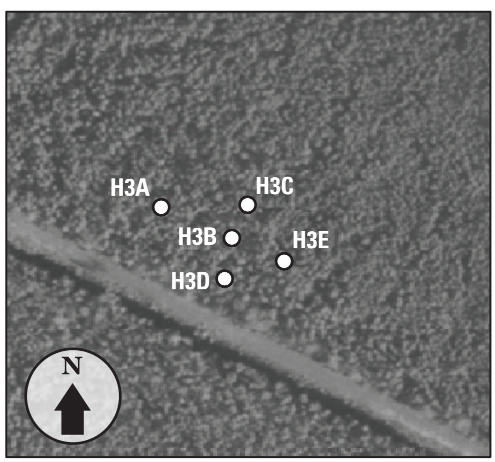
Base from:
U.S. Geological Survey,
2003 Digital Orthophotography
Black and White,
2-foot Pixel Resolution, NAD 83

0 50 100 150 200 FEET
0 20 40 60 METERS

EXPLANATION

○ Root-zone piezometer–healthy Atlantic white cedar

H3

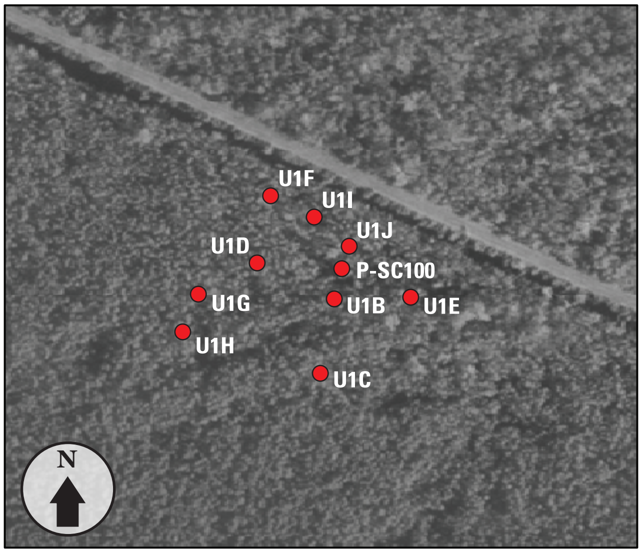


Base from:
U.S. Geological Survey,
2003 Digital Ortho-
photography Black and White,
2-foot Pixel Resolution, NAD 83

0 50 100 150 200 FEET
0 20 40 60 METERS

Figure 5 (Continued). Locations of root-zone water-quality piezometers in stands of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005.

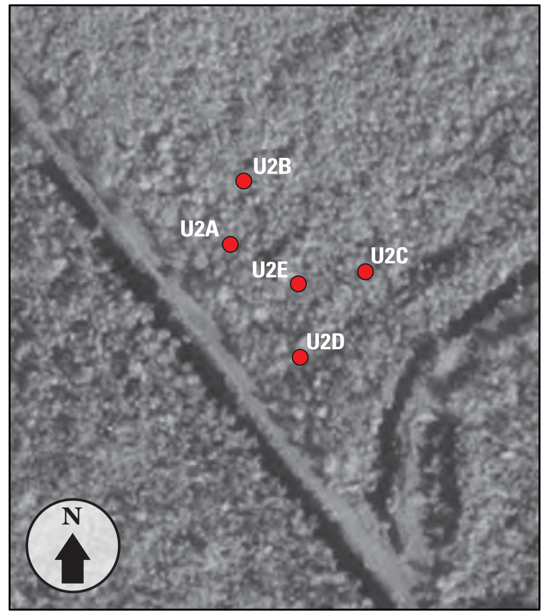
U1



Base from:
U.S. Geological Survey,
2003 Digital Orthophotography
Black and White,
2-foot Pixel Resolution, NAD 83

0 50 100 150 200 FEET
0 20 40 60 METERS

U2



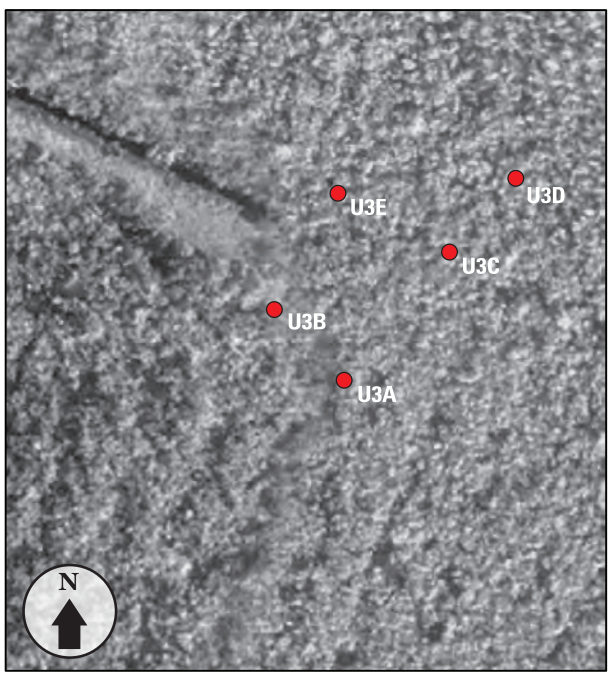
Base from:
U.S. Geological Survey,
2003 Digital Orthophotography
Black and White,
2-foot Pixel Resolution, NAD 83

0 50 100 150 200 FEET
0 20 40 60 METERS

EXPLANATION

● Root-zone piezometer–unhealthy Atlantic white cedar

U3



Base from:
U.S. Geological Survey,
2003 Digital Orthophotography
Black and White,
2-foot Pixel Resolution, NAD 83

0 50 100 150 200 FEET
0 20 40 60 METERS

Figure 5 (Continued). Locations of root-zone water-quality piezometers in stands of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005.

unhealthy, including site U3 where most of the AWC were dead.

A grid of 5 to 10 piezometers was installed to a depth of about 4 ft in the peat at each site. The first healthy AWC site (H1) was established in an area adjacent to the healthy AWC transect on the east side of the spur road 3 canal, and the first unhealthy AWC site (U1) was established in an area adjacent to the unhealthy AWC transect on the south side of the Juniper Road canal (fig. 5). The piezometers were constructed in the same manner as those installed on the transects. Two piezometers (P-HC100 and P-SC100; table 1) from the periodic sampling part of the study were used in the root-zone water-quality assessment. Piezometer P-HC100 was included in the grid at the H1 healthy AWC site, and piezometer P-SC100 was included in the grid at the U1 unhealthy AWC site for the root-zone water-quality assessment (fig. 5). Locations of piezometers were determined by GPS. Piezometers were spaced at least 20 ft apart, but the spacing generally was greater than 50 ft. Peat thickness near the piezometers was measured by probing to the mineral substrate with hand-auger extensions.

Piezometers were purged by using a peristaltic pump until at least three well casing volumes of water were removed. Specific conductance, water temperature, pH, and dissolved-oxygen concentration were measured during purging by using a multiparameter water-quality sonde. When these water-quality properties stabilized, values of specific conductance, water temperature, pH, and dissolved-oxygen concentration were recorded. Data from the sites were evaluated statistically by using a two-sample Mann-Whitney test (Conover, 1980) to determine if there were differences in water-quality properties within the root zone at healthy and unhealthy stands of AWC.

Results and Discussion

Information presented in the following sections includes precipitation data; water-level and water-quality data for the canal sites, wells, and piezometers on the transects; and water-level and water-quality data for the piezometers installed in the root zone of healthy and unhealthy stands of AWC. Daily precipitation amounts recorded at canal site 1 are provided in appendix 2. Daily mean water levels for canal sites 1, 2, and 3, and monthly mean, maximum, and minimum values are provided in appendixes 3–5. Daily maximum, minimum, and mean values of water temperature and specific conductance for canal sites 2 and 3 are listed in appendixes 6–13. Daily mean water levels and monthy mean, maximum, and minimum water levels for the wells on the transects are provided in appendixes 14–24. Water-quality profile data for canal sites 1, 2, and 3 are provided in appendixes 25–27, respectively. Water-quality profile data collected during September 2003 and September 2005 at canal sites 1–7 are listed in appendix 28. Data for piezometers installed in the root zones of healthy and unhealthy stands of AWC are listed in appendix 29.

Precipitation

Hydrologic conditions during this investigation were wetter than normal as indicated by precipitation records for 1985–2005 from the NWS COOP Weather Station near the community of Gum Neck (fig. 6; appendix 1). Annual precipitation amounts during this investigation (calendar years 2003–2005) exceeded the 21-year average of about

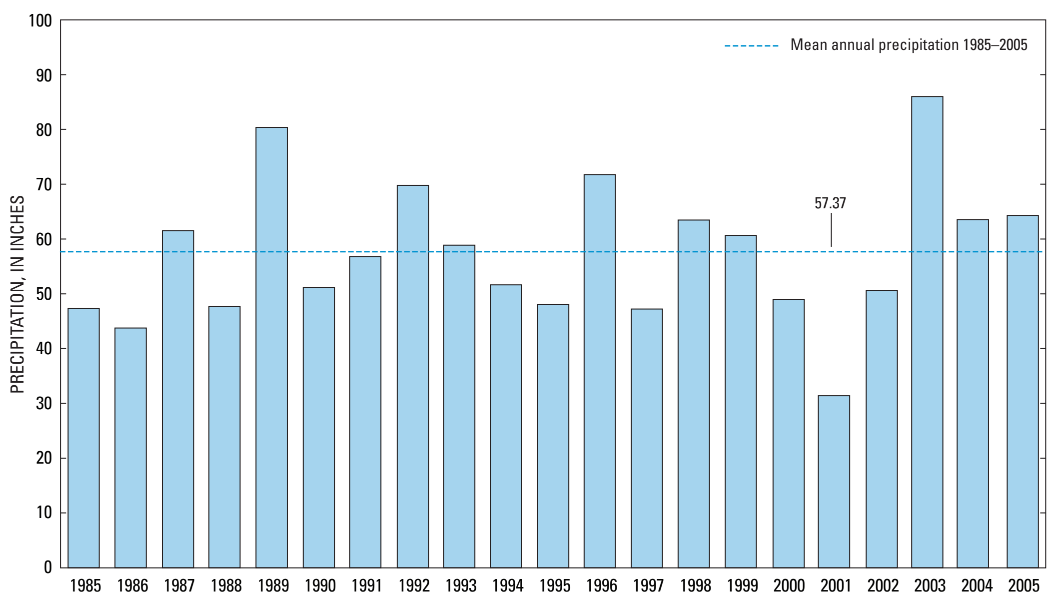


Figure 6. Annual precipitation at the National Weather Service Cooperative Weather Station near Gum Neck, North Carolina, 1985–2005 (modified from Jacob and Arnette Parker, Tyrrell County residents, written commun., 2005).

57.4 inches by about 50, 11, and 12 percent, respectively. The highest annual precipitation amount (86 inches) occurred in 2003, the first year of this investigation. Because precipitation during this investigation was higher than normal, based on the 1985–2005 records, it is likely that hydrologic conditions observed during this study are different from those at the Reserve at the onset of AWC dieback. A month-by-month comparison of precipitation amounts recorded at site 1 from April 2004 through February 2006 with amounts concurrently recorded at the NWS COOP Weather Station near Gum Neck showed monthly differences that ranged from 41.1 percent more rainfall (September 2005) to 34.2 percent less rainfall (December 2004) at site 1 than at the NWS COOP Weather Station (fig. 7). On average, monthly amounts were about 1.4 percent greater at site 1 than at the NWS COOP Weather Station. Between May 2004 and March 2006, the largest daily rainfall recorded at canal site 1, slightly more than 4.5 in., occurred on May 6, 2005 (figs. 8, 9; appendix 2).

Water Levels

Because wetlands occupy a position on the landscape where ground water and surface water intersect (Cowardin and others, 1979), it can be difficult to differentiate between these components of the hydrologic system, especially in flat-lying areas such as the Reserve where land and surface-water gradients are slight or poorly defined and natural stream channels are absent. In many parts of the Reserve, differences between the elevations of water ponded in depressions and water in adjacent hummocks are not measurable. Thus, it is difficult to differentiate ground water from surface water at this site. For the purposes of this report, the term water level is used to refer to the elevation of water relative to NAVD 88 and does not imply any differentiation between ground water and surface water.

Water levels in the canals and transect wells responded to precipitation and to seasonal changes in evapotranspiration.

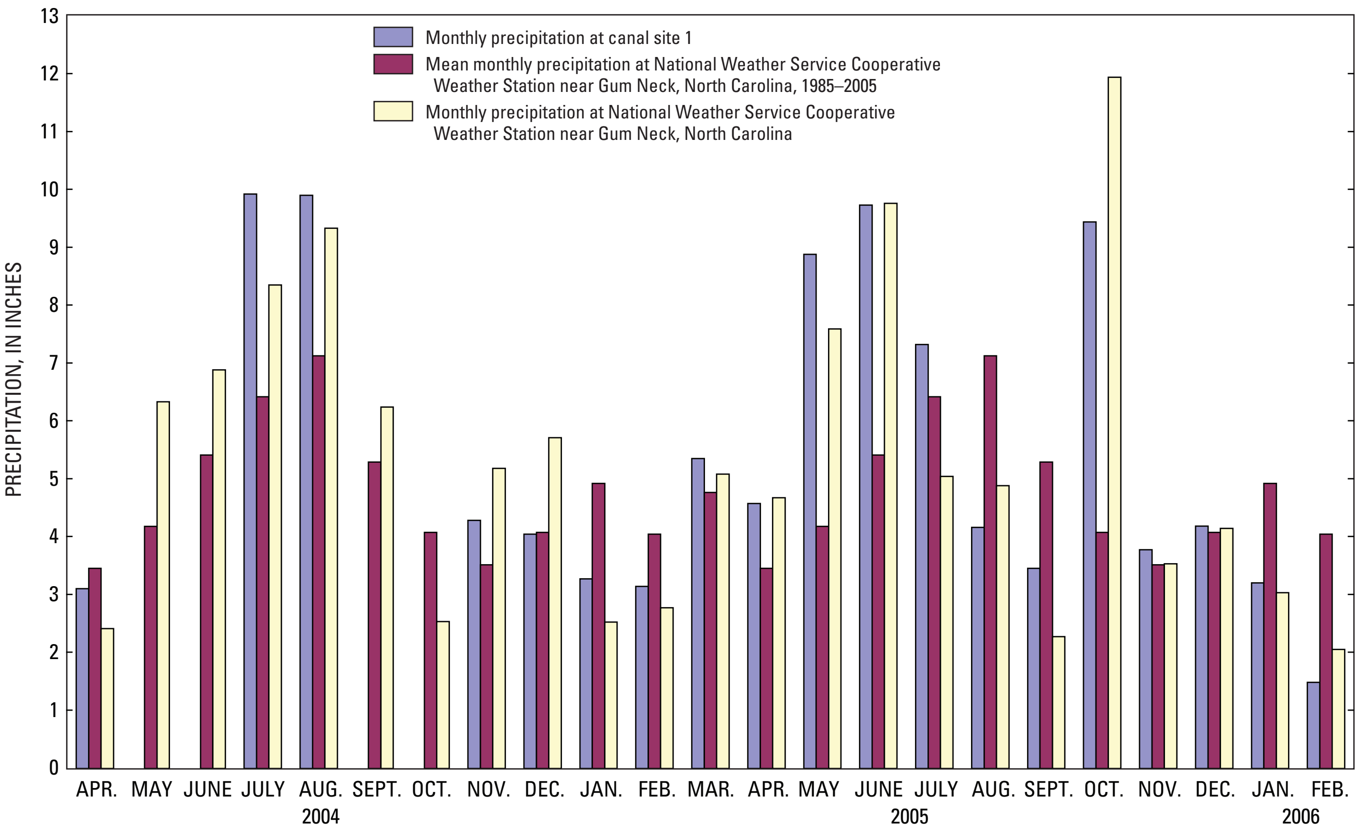


Figure 7. Summary of monthly precipitation at canal site 1 at the Emily and Richardson Preyer Buckridge Coastal Reserve and at the National Weather Service Cooperative Weather Station near Gum Neck, North Carolina, April 2004–February 2006, and monthly mean precipitation at the National Weather Service Cooperative Weather Station near Gum Neck, North Carolina, 1985–2005.

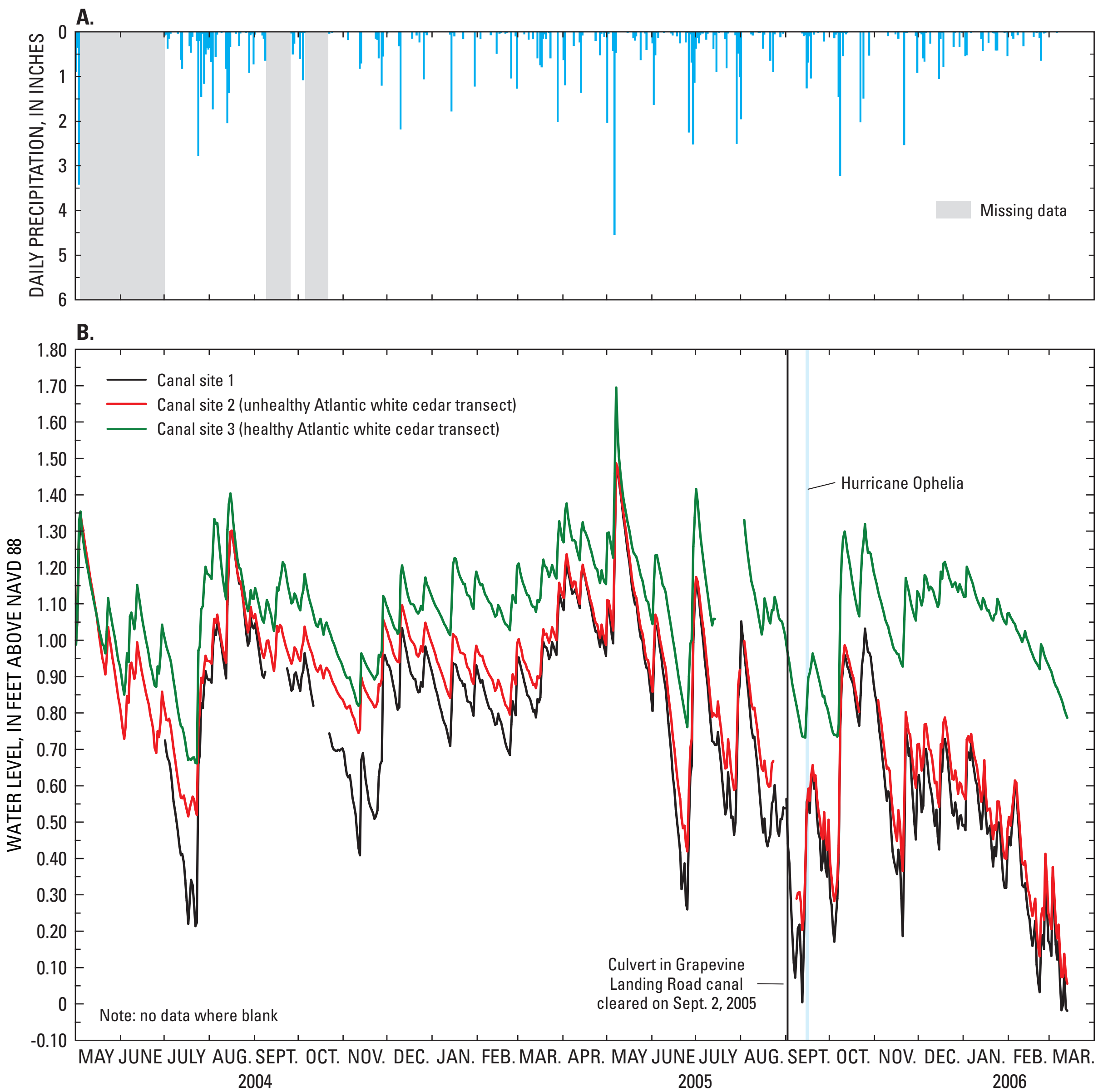


Figure 8. (A) Daily precipitation at canal site 1 and (B) daily mean water levels at canal sites 1–3 at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006.

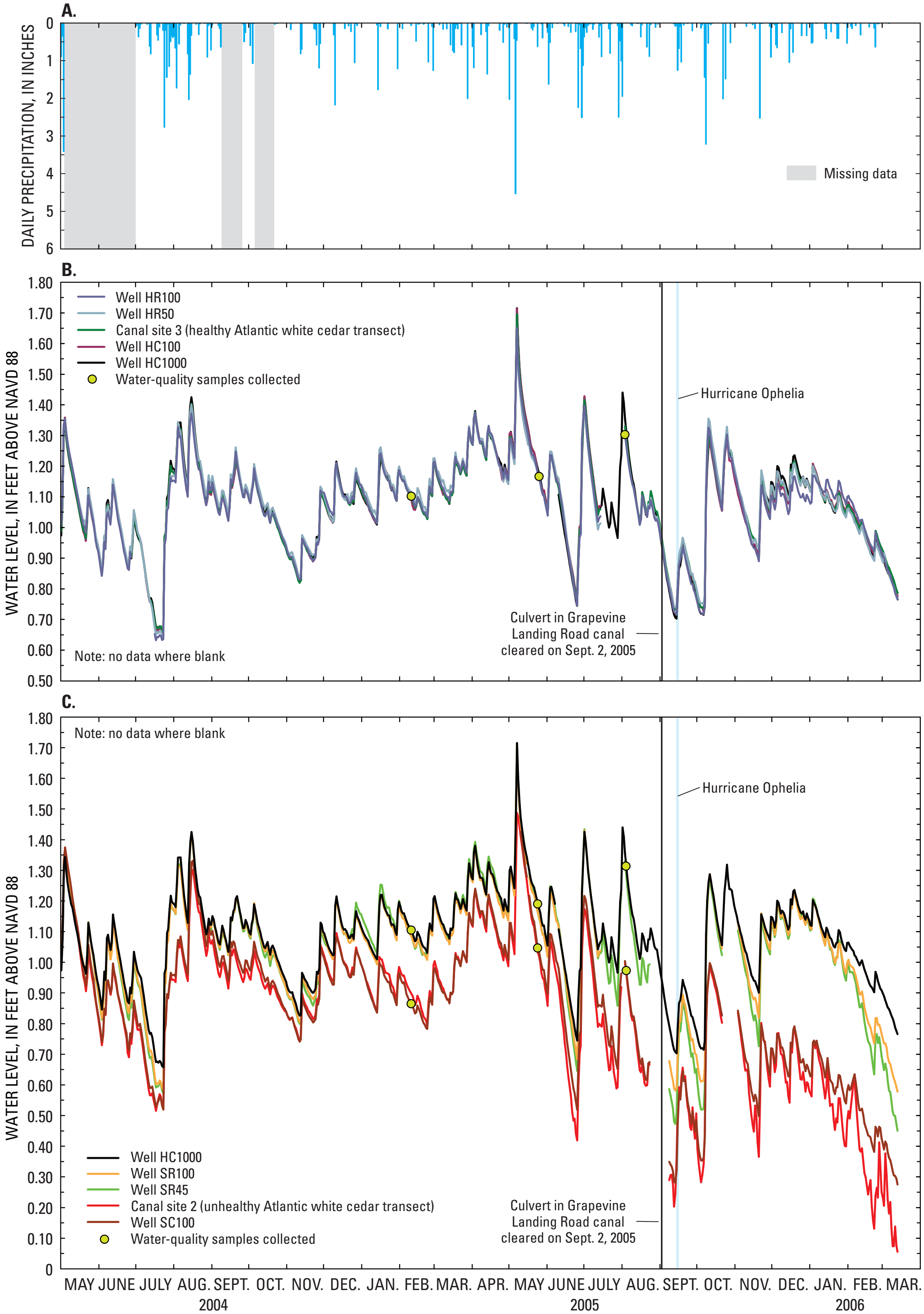


Figure 9. (A) Daily precipitation at canal site 1 and daily mean water levels in the canals and selected wells along the transects in the area of (B) healthy and (C) unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006.

Water-level gradients along the transects varied during the study, especially along the transect in the stand of unhealthy AWC. Culvert blockage and wind-driven increases in water levels in the Alligator River also affected water levels in parts of the Reserve at various times during the study. In addition to affecting water levels in the canals, wind tides, including those associated with the passage of Hurricane Ophelia in September 2005, affected water levels in the wells on the unhealthy AWC transect. The effects of Hurricane Ophelia on water levels at the Reserve are presented in a subsequent section of this report under the subheading "Transects." Because data collection began on different dates at different sites (table 1), discussion of water-level data primarily addresses the period when data were collected concurrently—May 1, 2004, through March 13, 2006.

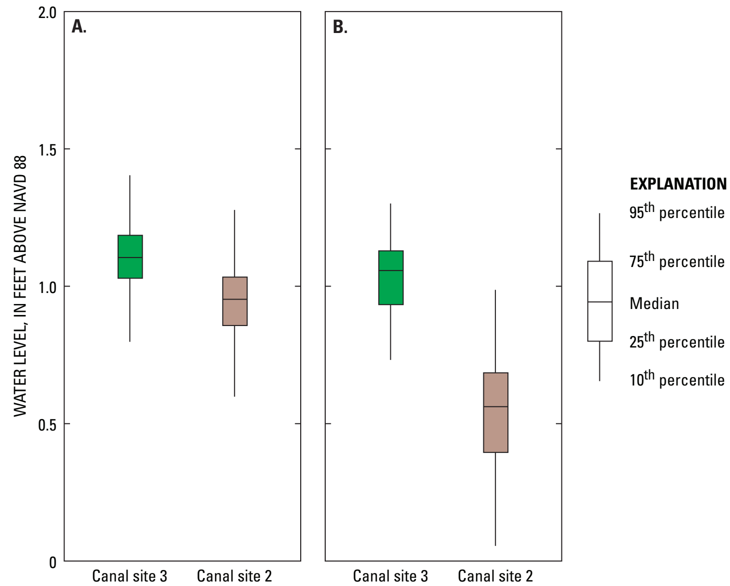


Figure 10. Boxplots of daily mean water levels at canal sites 2 and 3 (A) before and (B) after the culvert in the Grapevine Landing Road canal was cleared on September 2, 2005, at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina.

Canals

The relation between water levels in the Juniper Road canal at sites 1 and 2 and the canal along spur road 3 at site 3 changed in September 2005 (fig. 8). This change was exhibited by a decrease in the elevation and an increase in the fluctuation of water levels at the Juniper Road canal sites. In late-March 2003, shortly after canal sites 1 and 2 were instrumented and before canal site 3 on spur road 3 was instrumented, the culvert under Juniper Road at the intersection with Grapevine Landing Road (fig. 2) was blocked by apparent beaver activity. The canal along the west side of Juniper Road intersects the Grapevine Landing Road canal on the west side of the culvert. The blockage of the culvert under Juniper Road prevented eastward movement of water in the Grapevine Landing Road canal, which caused water to back up on the west side of Juniper Road. The culvert remained blocked until September 2, 2005.

While the culvert was blocked, water in the Juniper Road canal occasionally was observed flowing southward into the Grapevine Landing Road canal. Water in the Grapevine Landing Road canal was observed flowing to the northwest until reaching the Eastern Road canal. From the intersection of the Grapevine Landing Road canal and Eastern Road canal, water was observed flowing northward in the Eastern Road canal. The canal adjacent to Eastern Road connects to other canals (Basnight Canal and State Ditch) that extend to The Frying Pan embayment, which is connected to the Alligator River (fig. 2).

Water levels in the Juniper Road canal at site 2 and in the spur road 3 canal at site 3 initially were similar; however, in mid-May 2004, water levels at site 2 dropped below those at site 3 and remained lower through the rest of the study period (fig. 8). On May 20, 2004, water from low-lying areas was observed draining into the Juniper Road canal between sites 1 and 2. On the same day, water was observed flowing from the Juniper Road canal into the Grapevine Landing Road canal and subsequently northwestward in the Grapevine Landing Road canal toward the Eastern Road canal. This observed flow pattern allowed water to partially drain from the area south and west of Juniper Road and north of Grapevine Landing Road.

A contractor hired by the NCDCM cleared the blocked culvert on September 2, 2005, by driving a pine log, strapped to the bucket of a track-mounted excavator, through the culvert; this allowed water in the Grapevine Landing Road canal to flow eastward under Juniper Road and into the Alligator River. The effects of drainage were apparent in the water-level declines in the Juniper Road canal at sites 1 and 2. The median daily water level in the Juniper Road canal at site 2 decreased from 0.95 ft before the culvert was cleared to 0.56 ft after the culvert was cleared. In contrast, little change occurred in water levels in the spur road 3 canal at site 3 where the median daily water level was 1.10 ft before and 1.07 ft after the culvert was cleared (fig. 10). The lack of response of water levels at canal site 3 to the removal of debris blocking the culvert in the Grapevine Landing Road canal demonstrates the absence of a direct hydraulic connection between the spur road 3 canal and the Juniper Road canal.

Clearing the culvert also affected water-level fluctuations in the Juniper Road canal. Prior to clearing the blocked culvert, water-level fluctuations in the spur road 3 canal at site 3 were similar to those in the Juniper Road canal at sites 1 and 2 (fig. 8). Daily mean water levels at canal site 3 fluctuated from about 0.7 ft to about 1.7 ft above NAVD 88, a range of about 1 ft, between May 1, 2004, and March 13, 2006 (appendix 5). Daily mean water levels at canal sites 1 and 2 fluctuated from about zero to about 1.5 ft and from about 0.1 ft to about 1.5 ft above NAVD 88, respectively, during the same period (appendixes 3, 4). After the culvert was cleared, water-level fluctuations generally were much larger in the Juniper Road canal at sites 1 and 2 than in the spur road 3 canal at site 3. The increase in water-level fluctuations at site 2 following the clearing of the culvert also is apparent in the increased interquartile range shown in figure 10. The increase in water-level fluctuations at canal sites 1 and 2 following the clearing of the culvert appears to have occurred in response to rainfall and wind tides.

Transects

Water levels in the wells on the transects responded to rainfall and evapotranspiration. Water-level gradients on the transects also changed during the study as a result of rainfall, seasonal changes in evapotranspiration, effects of the culvert blockage and clearing, and wind patterns. Effects of evapotranspiration were most pronounced during the growing season, generally April through late November at the Reserve. Effects of wind tides associated with Hurricane Ophelia contributed to increased water levels at canal sites 1 and 2, which in turn affected water levels in the wells on the transect in the area of unhealthy AWC.

The highest water levels observed in the wells on the transects during the study period occurred in response to rainfall. The highest water levels in the wells on both transects occurred in response to 5.4 inches of rainfall recorded at site 1 between May 5 and 7, 2005 (appendix 2). Daily mean water levels as high as about 1.7 ft above NAVD 88 were recorded between May 7 and 9, 2005, at wells SR100, SR45, HC100, HC19, HR16, and HC1000 (fig. 9; appendixes 14, 15, 19, 20, 21, 24). The lowest water levels occurred during different periods for the two transects. Water levels as low as about 0.6 ft above NAVD 88 were recorded in the wells on the healthy AWC transect in July 2004 (appendixes 19–24). The lowest daily mean water levels in wells on the part of the unhealthy AWC transect north of Juniper Road, about 0.6 ft, were recorded in well SR100 during July 2004, September 2005, and March 2006 (appendix 14). In the other wells on the unhealthy AWC transect, however, the lowest water levels were measured after the culvert in Grapevine Landing Road canal was cleared. Daily mean water levels as low as 0.45 ft were recorded in March 2006 in well SR45 (appendix 15); well SR45 is on the north side of Juniper Road on the unhealthy AWC transect. South of the canal on Juniper Road, the minimum daily mean water levels for wells SC12 and SC100 were 0.05 ft and about 0.3 ft, respectively (appendixes 17, 18), in March 2006. Drainage of the area south of the Juniper Road canal following clearing of the culvert contributed to the low water levels in wells SC12 and SC100.

The depth of water, relative to land surface, varied along the transects. The peat soil was frequently saturated, and standing water was present in low-lying areas along both transects and throughout much of the Reserve during the study period. Local relief plays an important role in the depth of inundation. On the transect in the stand of healthy AWC, for example, land-surface elevations at wells HR50, HC1000, and HR100 are about 0.8, 1.1, and 1.3 ft above NAVD 88, respectively. From May 1, 2004, to March 13, 2006, water levels recorded at well HR100 were above land surface only about 7 percent of the time; whereas water levels recorded at well HC1000 were above land surface about 65 percent of the time, and water levels recorded at well HR50 were above land surface about 98 percent of the time during this period.

Water-level gradients on the transects, especially on the unhealthy AWC transect, varied throughout the study (fig. 11). The gradient on the healthy AWC transect was smaller than the gradient on the unhealthy AWC transect, with differences in water levels typically less than or equal to 0.1 ft. Although the water-level gradient on the unhealthy AWC transect typically sloped toward the canal, the slope changed in response to precipitation, to the clearing of the culvert at the intersection of the Grapevine Landing Road and Juniper Road canals, and to wind tides. Water levels generally were higher in the wells on the road side (wells SR45 and SR100) than in the wells on the canal side of the unhealthy AWC transect (wells SC12 and SC100; fig. 9). Water-level gradients on each transect are shown for selected dates in figure 11. Changes in water-level gradients on the transects also are apparent in the record of daily mean water levels (fig. 9). The water levels shown in figure 11 were measured during site visits, except those for March 13, 2006, which were recorded by instrumentation and included some of the lowest levels for the period of record.

On May 19, 2004, near the beginning of the concurrent data-collection period, the water level in the spur road 3 canal at site 3 on the healthy AWC transect was slightly higher than the water level in the Juniper Road canal at site 2 on the unhealthy AWC transect. At this time, the water-level gradient on each of the transects was small (fig. 11), and the difference between water levels in the wells and the respective canal was less than or equal to 0.05 ft. Differences between the water level at canal site 3 and the wells on the healthy AWC transect remained similar throughout the study, whereas the difference between the water level at canal site 2 and the wells on the unhealthy AWC transect generally increased during the study (figs. 9, 11).

On July 22, 2004, during a period of low water levels, the water level at canal site 3 on the healthy AWC transect was about 0.15 ft higher than the water level at canal site 2 on the unhealthy AWC transect (fig. 11). The water level in well SR45, located north of Juniper Road on the unhealthy AWC transect, was slightly higher than the level at canal site 2 but was about 0.1 ft lower than in well HC1000. The differences between water levels in the two wells indicate a slight gradient from well HC1000 toward well SR45.

On February 16, 2005, a time when evapotranspiration typically is low, the water level at canal site 3 on the healthy AWC transect was about 0.25 ft higher than the water level at canal site 2 on the unhealthy AWC transect. Although water levels in the wells on the unhealthy AWC transect north of Juniper Road (wells SR45, SR100, and HC1000) were similar, they were about 0.2 ft higher than the water levels at canal

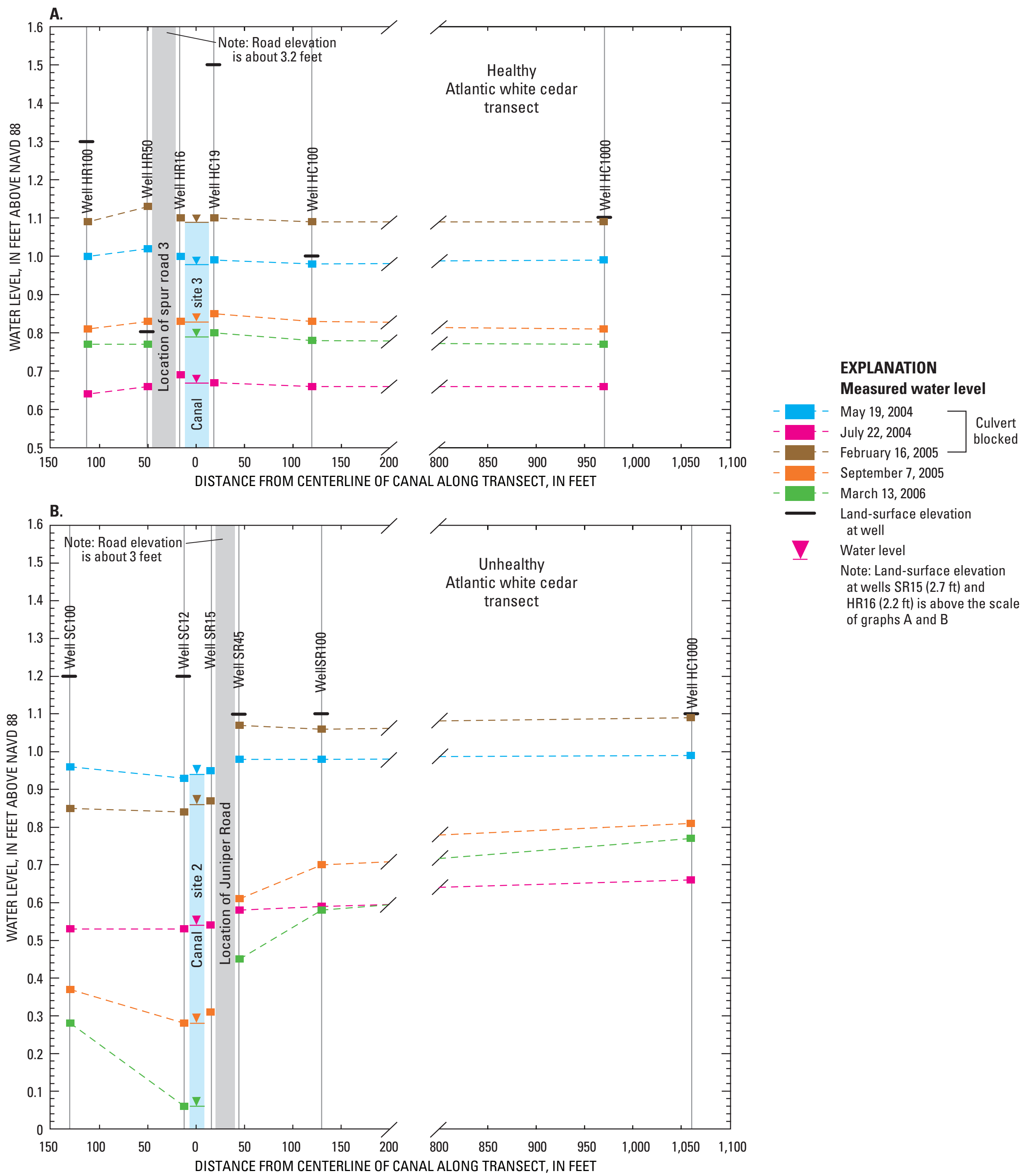


Figure 11. Periodic water-level measurements for selected dates in the canals and wells on the transects in the area of (A) healthy and (B) unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 2004–March 2006.

site 2 and in the wells south of Juniper Road (wells SR15, SC12, and SC100).

On September 7, 2005, shortly after the clearing of the blocked culvert, the water level at canal site 3 on the healthy AWC transect was 0.55 ft higher than the water level at canal site 2 on the unhealthy AWC transect. The water-level gradient on the unhealthy AWC transect was more pronounced on the road side of the transect than on the canal side, with a difference in water levels between canal site 2 and wells SC100 and SR45 of almost 0.1 ft and 0.35 ft, respectively. The water level in well SR45 was about 0.1 ft and 0.2 ft lower than the water levels in wells SR100 and HC1000, respectively, which indicates a gradient toward the canal throughout the length of the unhealthy AWC transect (fig. 11).

On March 13, 2006, the last day of the concurrent data-collection period, the water level at canal site 3 on the healthy AWC transect was about 0.75 ft higher than the water level at canal site 2 on the unhealthy AWC transect (fig. 11). On the unhealthy AWC transect north of Juniper Road, the water level in well SR45 was about 0.4 ft higher than the water level at canal site 2 and about 0.15 ft lower than the water level in well SR100 and about 0.3 ft lower than in well HC1000. South of Juniper Road, the water level in well SC100 was about 0.2 ft higher than the water level in canal site 2. This water-level gradient is similar to that shown for September 7, 2005, in figure 11 and indicates a gradient toward the canal on both sides of Juniper Road. In contrast, the water-level gradient on the canal side of the healthy AWC transect slopes away from the canal (fig. 11).

Whereas the canal along Juniper Road appears to facilitate drainage and contribute to lower water levels on the canal side of the unhealthy AWC transect, Juniper Road appears to impede drainage and contribute to higher water levels on the road side of the unhealthy AWC transect. Water levels in wells on the north side of Juniper Road (SR45 and SR100 on the unhealthy AWC transect and the wells on the healthy AWC transect) were higher than the water levels in the wells on the south side of Juniper Road (wells SC12 and SC100) (fig. 9). The elevation of Juniper Road between its intersection with spur road 2 and spur road 3 ranges from about 2 ft to more than 3 ft above NAVD 88 (fig. 3). Because its elevation is higher than the surrounding areas, Juniper Road acts as a barrier to southwestward surface flow of water north of the road. Juniper Road also appears to impede the lateral subsurface movement of water within the peat. The effect of spur road 3 on subsurface water movement along the healthy AWC transect was not as pronounced as the effect of Juniper Road on subsurface water movement along the unhealthy AWC transect. The orientation of these roads with respect to general land-surface gradients and to the direction of water flow prior to construction of the roads and canals could contribute to the different effects of Juniper Road and spur road 3 on water levels. Spur road 3 is roughly parallel to the southward land-surface gradient indicated by the LIDAR data for the Reserve, whereas Juniper Road, in the vicinity of the unhealthy AWC transect, is roughly perpendicular to the indicated gradient (fig. 3). The effect of Juniper Road on water-level gradients also was indicated by the declining trend in water levels recorded from January 1 to March 13, 2006, when precipitation was low (figs. 8, 12A). During this period, the difference between the water levels in well SC100 and at canal site 2 typically was less than 0.2 ft, whereas the difference between water levels in well SR100 and at canal site 2 typically exceeded 0.55 ft. Thus, it appears that Juniper Road acted as a barrier to flow and impeded southwestward movement of water following the clearing of the culvert at the intersection of Juniper and Grapevine Landing Roads.

The effects of wind tides on water levels at the Reserve were demonstrated by Hurricane Ophelia, a category 1 hurricane, that passed just off the North Carolina coast during September 14–16, 2005 (National Climatic Data Center, 2006). Continuous water-level and daily precipitation data for the period September 10–30, 2005, show the effects of Hurricane Ophelia and are presented in figure 13A. On September 12, water levels of about 0 and 0.2 ft were measured at Juniper Road canal sites 1 and 2 (fig. 13A). Soon afterwards, water levels began to rise in the Juniper Road canal at sites 1 and 2 with the approach of Hurricane Ophelia.

Slightly less than 2 inches of rainfall were recorded at site 1 as the hurricane brushed the coastline. Of that amount, 1.25 inches were measured on September 15, 2005. From early September 14 until late afternoon on September 15, the weather station at the Manteo Airport (KMQI; fig. 1) reported wind speeds increasing from about 12 miles per hour (mph) to 27 mph with gusts to about 38 mph. Wind directions mainly were from the east to east-northeast. Between late afternoon on September 15 and midday on September 16, reported wind speeds ranged from about 20 to 22 mph with gusts to 31 mph, and wind directions shifted from the east-northeast to the north. By late September 16, wind speeds deceased to less than 4 mph (The Weather Underground, Inc., 2006).

By late evening on September 14, 2005, water in the Juniper Road canal at site 1 rose to a level slightly higher than that at site 2 on the unhealthy AWC transect (fig. 13A). Water rose almost 0.2 ft to a level about 0.6 ft above NAVD 88 at both canal sites 1 and 2 by midday on September 15 and remained near this level for approximately 24 hours. By midday on September 16, water levels in the Juniper Road canal at site 1 dropped below those at site 2.

For about 32 hours between September 14 and 16, 2005, the water level in the canal along Juniper Road at site 1 generally was slightly higher than that at site 2, which indicates a water-level gradient from the Alligator River toward the interior of the Reserve. This gradient indicates that water from the Alligator River could have been pushed into the Juniper Road canal during the hurricane. Also, on early September 14, the water level at canal site 2 exceeded the water level in well SC100. The water level in well SC100, which is on the south side of Juniper Road on the unhealthy AWC transect, generally remained slightly lower than the water level at canal site 2 through mid-afternoon on September 16 (fig. 13A). During this period, there was a slight hydraulic gradient away from

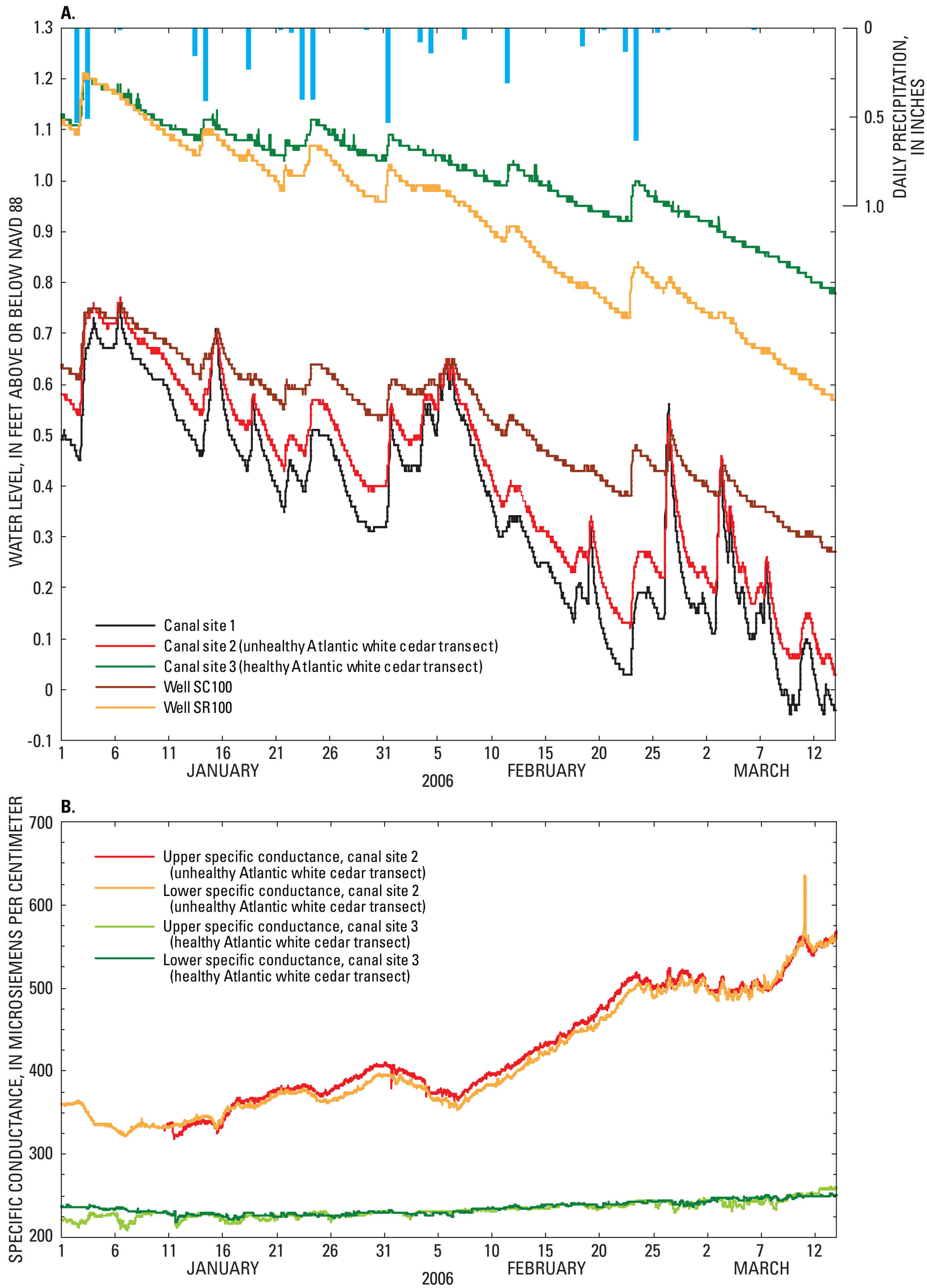


Figure 12. (A) Daily precipitation at canal site 1, water levels at canal sites 1–3 and wells SC100 and SR100, and (B) specific conductance at canal sites 2 and 3 at 15-minute intervals at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, January 1–March 13, 2006.

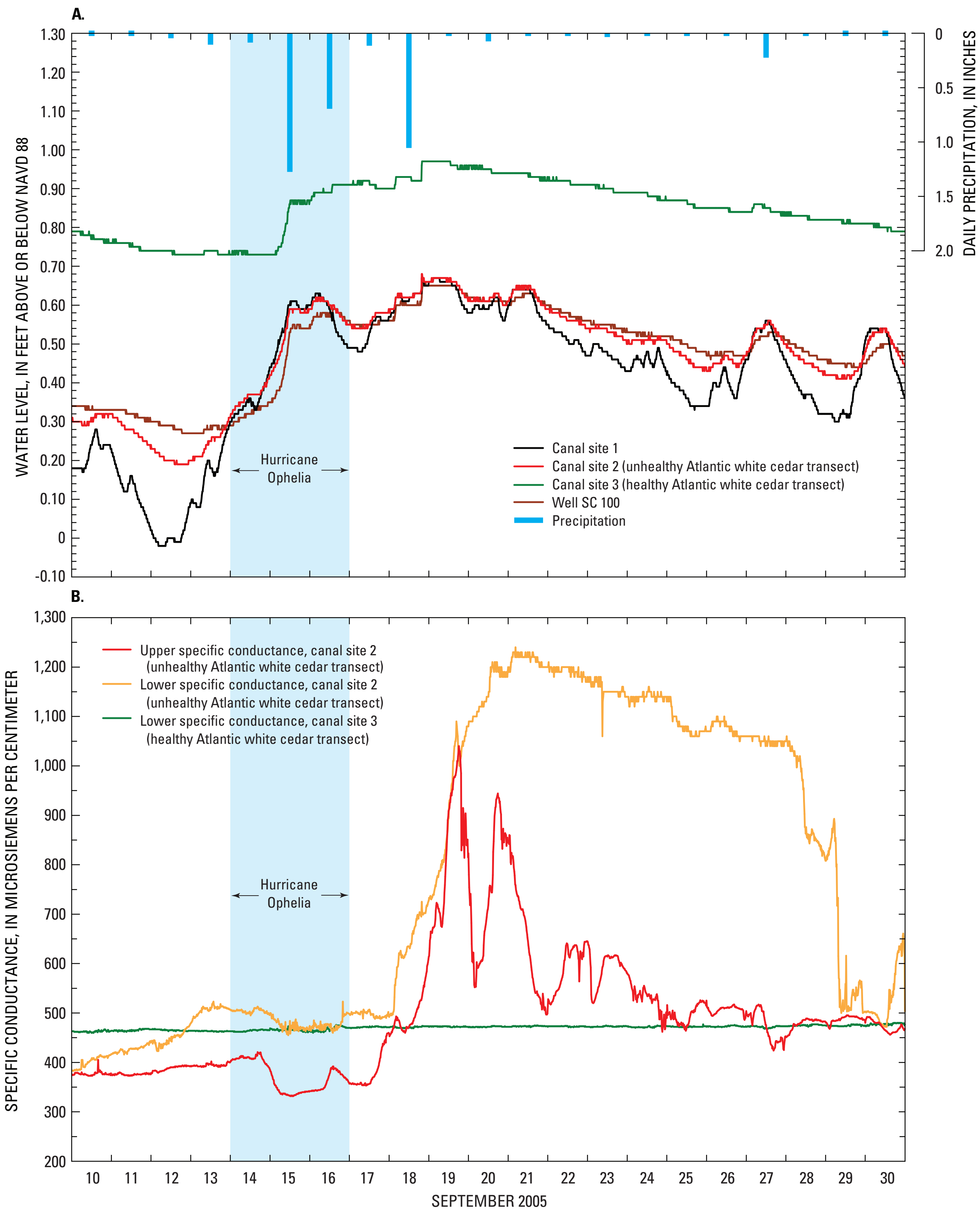


Figure 13. (A) Daily precipitation at canal site 1, water levels at canal sites 1–3 and well SC100 , and (B) specific conductance at canal sites 2 and 3 at 15-minute intervals at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, September 10–30, 2005.

the canal toward well SC100, which indicates the potential for water to move from the canal into the peat.

Similar hydraulic gradients between the Juniper Road canal and well SC100 also were observed on other days. For example, water levels in the Juniper Road canal at sites 1 and 2 exceeded those in well SC100 on September 27 and 29–30, 2005 (fig. 13A). The higher water levels in the Juniper Road canal appear to be associated with winds from a northerly to easterly direction pushing water from the Alligator River into the Grapevine Landing canal and, in turn, into the canal along Juniper Road.

The effects of wind tides are evident in the water-level record for Juniper Road canal sites 1 and 2 on February 20 and 26 and March 3–4, 7, and 11, 2006 (fig. 12A). Increases in water levels at these times were not associated with precipitation nor did a concomitant increase in water level occur at canal site 3 (fig. 12A). These events were associated with increased winds, especially winds from the north and east, based on data from the weather station at the Manteo Airport (KMQI) for these periods (The Weather Underground, Inc., 2006). Water levels in wells SC100 and SR100 also rose in conjunction with these events; however, the rise in water levels occurred several hours following the rise in water levels at canal sites 1 and 2 and was less apparent during the events on March 7 and 11, 2006, than during the other events. The decreased effects of wind tides observed in water levels in wells SC100 and SR100 during these dates could be a result of the lower magnitude of water-level rises in the Juniper Road canal or the lower water-level conditions.

Water Quality

Water-quality conditions, especially in the canals, varied during the study. Some of the variations appear to be related to seasonal factors and to differences in locations of sites. Other variations, particularly changes in specific conductance in the canals and ion ratios in samples from the piezometers, suggest that an episodic event (or events) occurred prior to the start of data collection and contributed to the observed patterns in water quality. Data for the canals, the piezometers on the transects, the mineral substrate well, and the piezometers installed in the root zone of stands of healthy and unhealthy AWC are presented in the following sections. Water-quality data for the canals include continuous records of water temperature and specific conductance and the analytical results for samples collected at canal sites 2 and 3 and water temperature, specific conductance, pH, and dissolved-oxygen concentration profiles in canals at various parts of the Reserve (fig. 2). Water-quality data for the transect piezometers and the well completed in the mineral substrate underlying the peat are presented in a subsequent section of this report describing the transects.

Canals

In addition to differences between sites, water-quality data for the canals showed temporal patterns related to season and weather-related events. The decline in water levels associated with the clearing of the blocked culvert at the intersection of Juniper and Grapevine Landing Roads also appears to have affected water quality in the Juniper Road canal at site 2. Water temperature and specific conductance generally were lower at canal site 3 than at canal site 2 (figs. 14, 15). Water temperatures varied seasonally and were highest during the summer and lowest during the winter at both sites (figs. 14A, 15A). Water quality in the canals also varied with depth. The highest values of specific conductance obtained from the continuous records of canal sites 2 and 3 were from the lower sensors (figs. 14B, 15B), which were installed about 1 ft and 2.6 ft, respectively, above the debris on the bottom of the canals. Specific conductance at the lower sensors at canal sites 2 and 3 was higher during late summer and early autumn than during other times of the year and was higher during 2004 than during 2005 (figs. 14B, 15B). Similar patterns were not evident in the specific-conductance readings from the upper sensors. Water temperature and specific conductance in the canals at sites 2 and 3 differed with depth as shown by the continuous-monitoring data (figs. 14, 15) and vertical profiles (figs. 16–19; appendixes 26, 27). Water-quality profile data for canal sites 2 and 3 do not necessarily correspond to the continuous-monitoring data because the sensors used to monitor water temperature and specific conductance were at fixed positions, whereas the depths at which measurements were made for the profiles were variable.

Seasonal patterns associated with the depth-related differences in water temperature and specific conductance appear to be caused primarily by thermal stratification. Continuous-monitoring data for canal sites 2 and 3 show the effects of stratification from spring through early autumn, with turnover and subsequent loss of stratification during winter months (figs. 14, 15). Brief periods of thermal stratification occurred during winter months in response to warm air temperatures, especially at canal site 3 (fig. 14A). Thermal stratification is caused by changes in the density of water that occur with changes in temperature. As air temperatures decrease during the autumn months, water near the surface cools and increases in density (Wetzel, 1975). This increase in density causes water at the surface of the canals to sink, thereby creating a vertical mixing cycle commonly referred to as turnover (Wetzel, 1975). Density gradients in the canals appear to be chemical, or meromictic, as well as thermal, based on the increase in specific conductance with depth (figs. 14–19).

Specific-conductance data for canal site 3 indicate increasing stratification from May 2004 until mid-October 2004 with an increase in specific conductance at the lower sensor and a decrease in specific conductance at the upper sensor, which correspond to thermal stratification (fig. 14). Turnover and mixing began in October 2004, and by early November, specific conductance and water temperature were similar

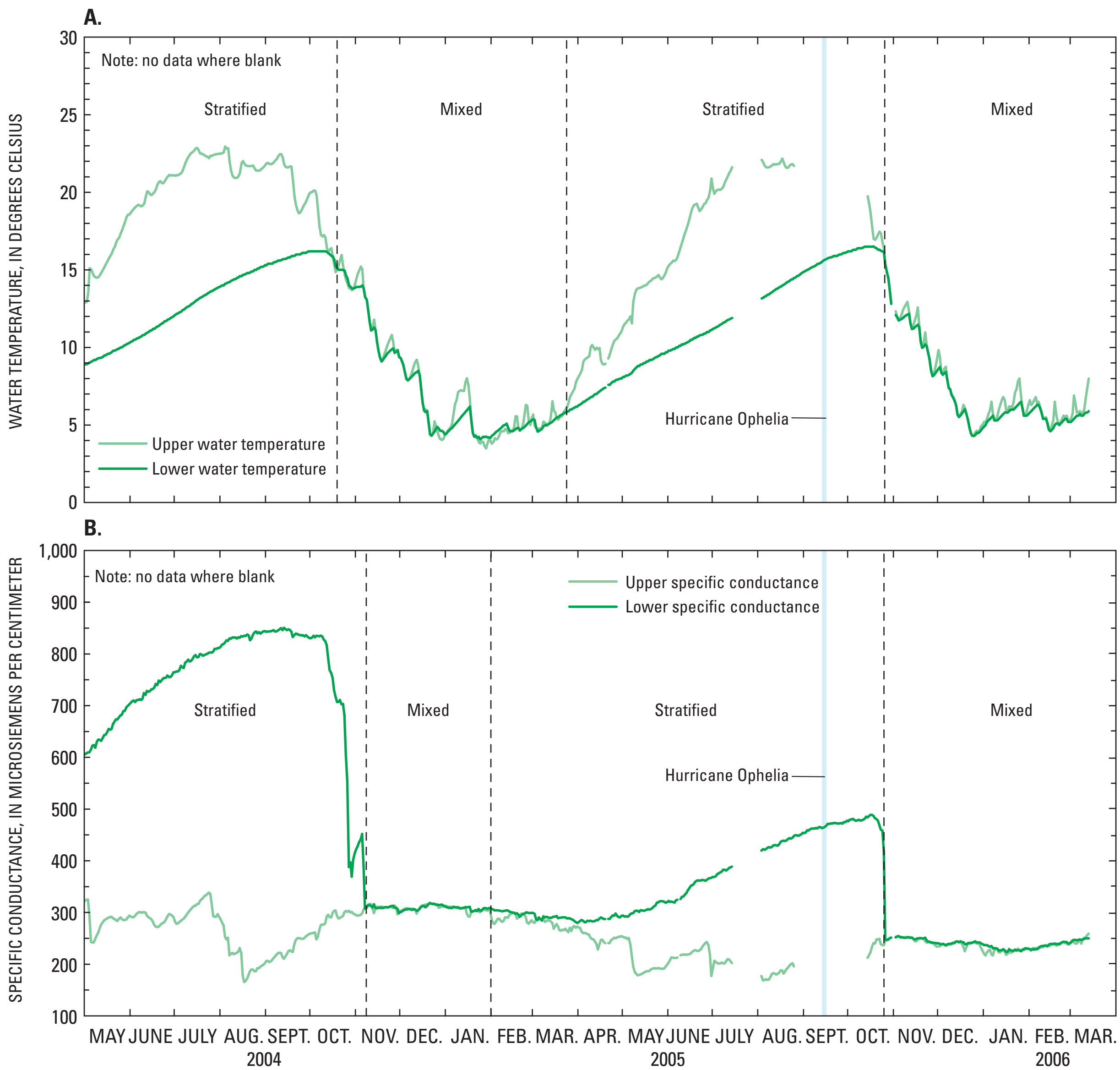


Figure 14. (A) Daily mean water temperature and (B) daily mean specific conductance at canal site 3 at the healthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006.

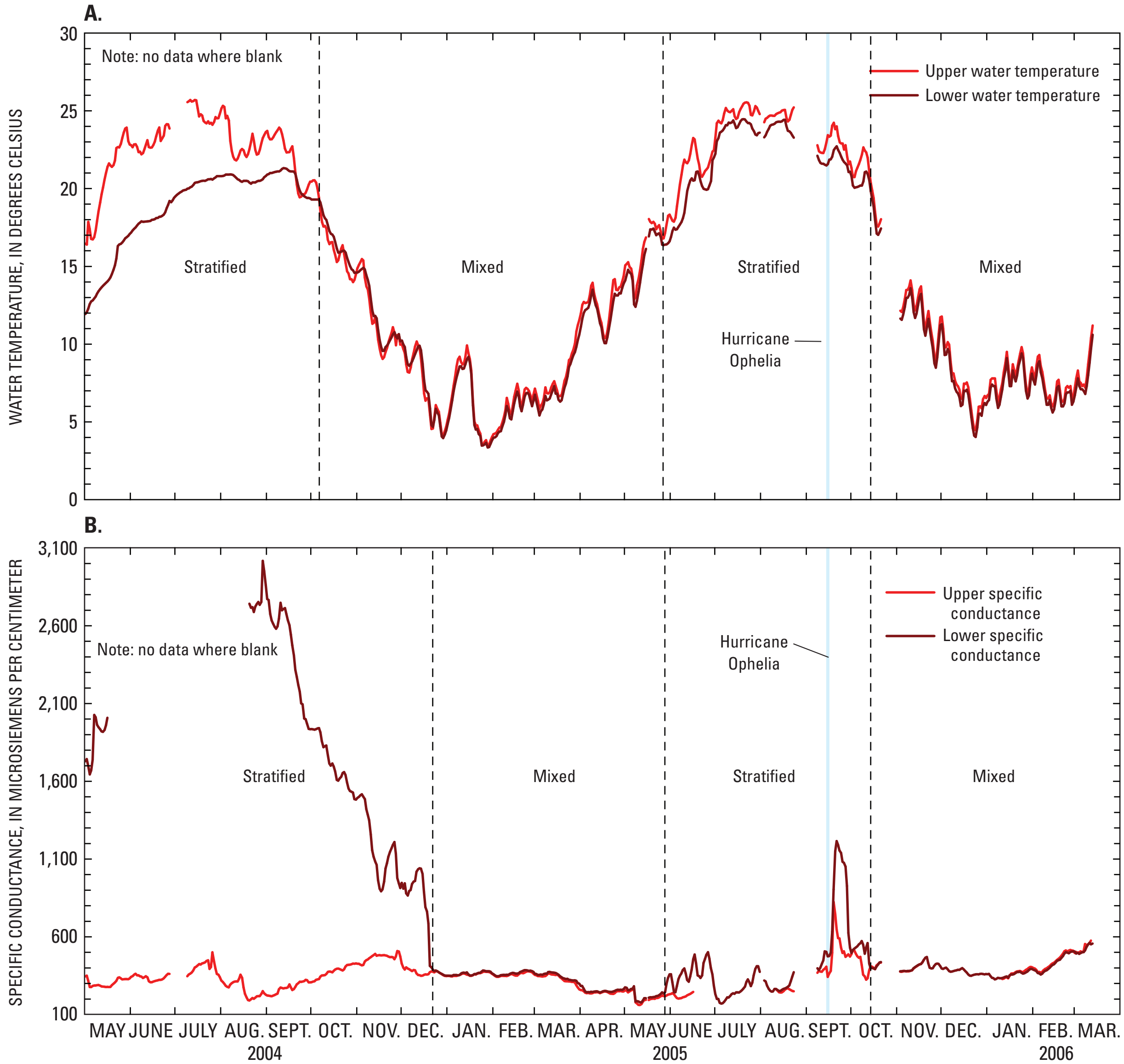


Figure 15. (A) Daily mean water temperature and (B) daily mean specific conductance at canal site 2 at the unhealthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, May 1, 2004–March 13, 2006.

at both sensors. Stratification resumed in March 2005 and increased until late October 2005 when mixing occurred and water temperatures and specific conductance again reached similar values. Little chemical stratification was evident at canal site 3 during the fall of 2005 as was indicated by the similar times at which overturn and mixing are indicated by records of temperature and specific conductance (fig. 14). Profiles show an overall decrease in specific conductance as well as a decrease in chemical stratification during the study period, and profiles measured in January and March 2006 show little chemical stratification in the water column (fig. 17). The decreasing trend in specific conductance also is apparent in most of the profiles obtained at other sites in the Reserve (fig. 20).

During 2004, the stratification patterns at canal site 2 were similar to those at canal site 3. However, specific-conductance data indicate that chemical stratification continued until December 2004 even though thermal mixing occurred in early October (fig. 15). Thermal stratification at canal site 2 was less during the summer of 2005 than during the summer of 2004, with an average of about 1 degree Celsius (°C) difference in mean daily water temperature between the upper and lower sensors from June to September 2005 compared to more than 2.5 °C during the summer of 2004. The effects of chemical stratification also were more pronounced at canal site 2 in 2004 than in 2005 and were not observed in the continuous monitoring data from October 2005 to March 2006 when data collection ended. The decrease in specific conductance at canal sites 2 and 3 during 2004–2005 probably contributed to a decrease in chemical stratification, which facilitated thermal mixing. Decreased depth of water following the clearing of the culvert at the intersection of Grapevine Landing and Juniper Roads (fig. 8) also appears to have decreased stratification at canal site 2. Following the clearing of the culvert and the passage of Hurricane Ophelia, specific-conductance readings at the upper sensor at canal site 2 remained similar to or less than those at the lower sensor until the end of the study. Temperature and specific-conductance profiles for canal site 2 also show decreasing stratification during the course of this study (figs. 18, 19). Differences in the orientation and depths of the canals affect exposure to sunlight and wind, which in turn could contribute to some of the observed differences in stratification. The greater water depth at canal site 3 probably contributed to the greater thermal stratification observed at this site in comparison to canal site 2 (figs. 14, 16).

Specific conductance at canal site 3 generally decreased throughout the period of record (fig. 14). Although the specific conductance at canal site 2 decreased from the high values recorded by the lower sensor during 2004, data from January through March 2006 indicate an increasing trend from around 325 and 340 microsiemens per centimeter at 25 °C (µS/cm) at the upper and lower sensors, respectively, to around 590 µS/cm at both sensors by March 13, 2006 (fig. 12B). The increasing trend in specific conductance could be the result of an influx of water from the Alligator River into the Juniper Road canal, which was facilitated by lower water levels that occurred during the latter months of this study. However, specific conductance at canal site 2 did not increase in conjunction with the water-level rises attributed to wind tides during February and March 2006, with the exception of the water-level increase that began on the afternoon of March 10 and peaked on the morning of March 11, 2006 (fig. 12). Specific conductance at the lower sensor at canal site 2 increased from 551 µS/cm near the end of the day on March 10 and peaked at 646 µS/cm early on the morning of March 11, 2006. A concurrent increase in specific conductance was not recorded by the upper sensor at canal site 2, which suggests movement of density-stratified brackish water up the Juniper Road Canal during this event. It is possible that a layer of brackish water was present at the bottom of the canal during other events but was below the level of the lower sensor. Alternatively, the gradual increase in specific conductance observed at canal site 2 during January–March 2006 could have been caused by drainage of high-conductance water trapped in the interior of the Reserve as a result of the culvert blockage. The gradual decline in water levels in the wells on both transects and the measurement of high specific conductance at canal sites in the interior of the Reserve (fig. 20) also indicate drainage of high-conductance water from the Reserve during this period.

Following the passage of Hurricane Ophelia in September 2005, a large increase in specific conductance occurred at canal site 2 (fig. 13B). Rainfall amounts associated with Hurricane Ophelia were not large (about 0.1 inch on September 14; 1.25 inches on September 15; and about 0.7 inch on September 16). During September 14–16, water levels in the canal along Juniper Road rose about 0.3 ft at both sites 1 and 2. The water level in the spur road 3 canal at site 3 rose about 0.2 ft during the same period. Specific conductance at the upper and lower sensors at canal site 2 decreased slightly during September 14–17, apparently as a result of dilution by rainfall (fig. 13). About 0.1 and 1 inch of precipitation also occurred on September 17 and 18, respectively, resulting in a rise in water levels from about 0.1 ft to 0.2 ft at the three canal sites (fig. 13A). Although the rise in water levels was small, a large increase in specific conductance followed (fig. 13B). At canal site 2, the increase in specific conductance began late in the day on September 17 at the upper sensor and early in the day on September 18 at the lower sensor. There was no corresponding increase in specific conductance at canal site 3. However, because the upper specific conductance sensor malfunctioned during this period, only data for the lower sensor were available for canal site 3. Specific conductance at canal site 2 continued to increase at the upper sensor until late in the day on September 19 when it reached a maximum of 1,040 µS/cm; thereafter, specific conductance decreased to about 550 µS/cm on the morning of September 20 (fig. 13B). A similar increase in specific conductance occurred again, reaching a maximum of about 950 µS/cm during the early evening of September 20. The pattern in specific conductance at the lower sensor differed from that at the upper sensor, increasing from about 500 µS/cm early in the morning

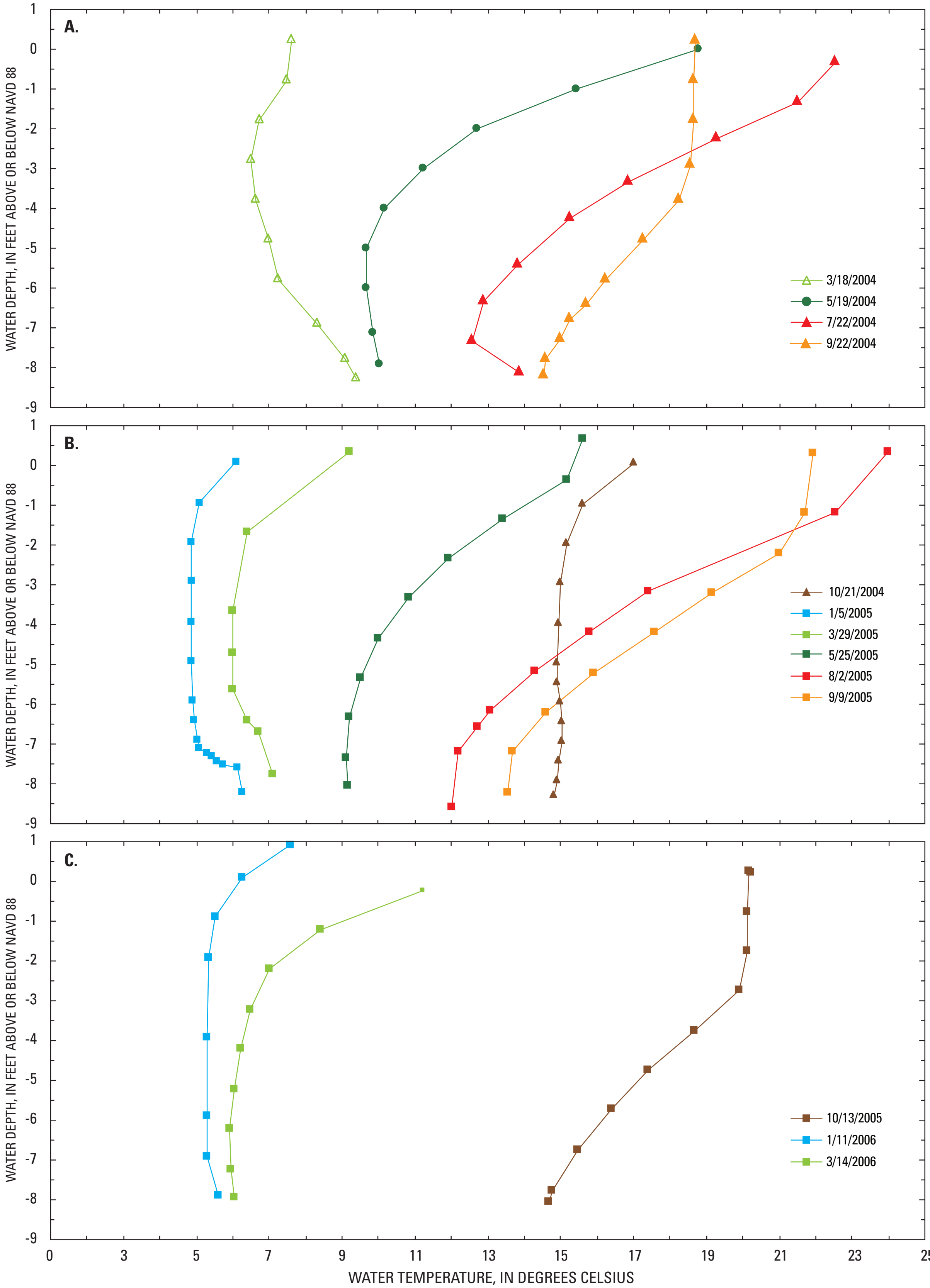


Figure 16. Water-temperature profiles at canal site 3 at the healthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) March–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006.

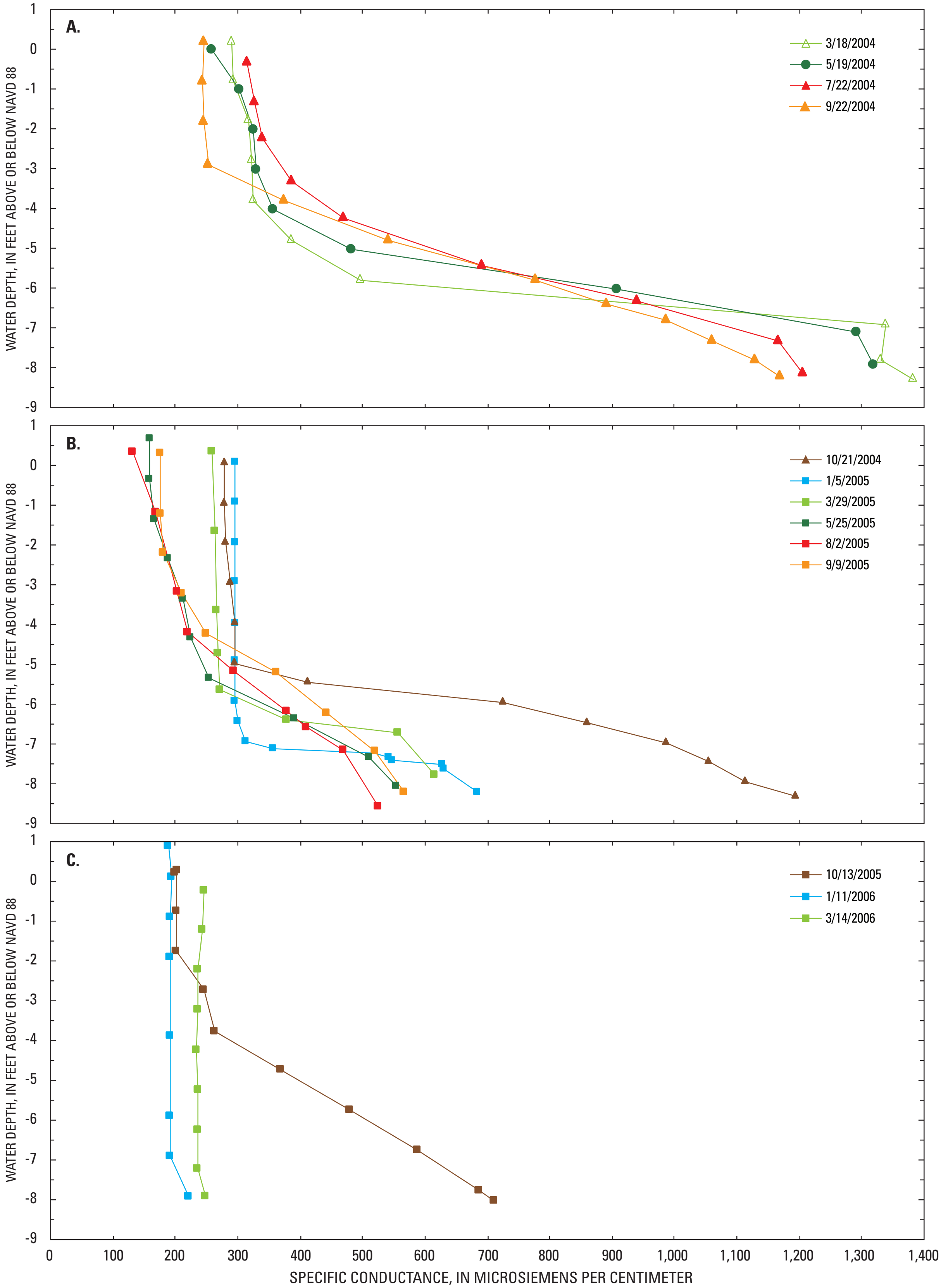


Figure 17. Specific conductance profiles at canal site 3 at the healthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) March–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006.

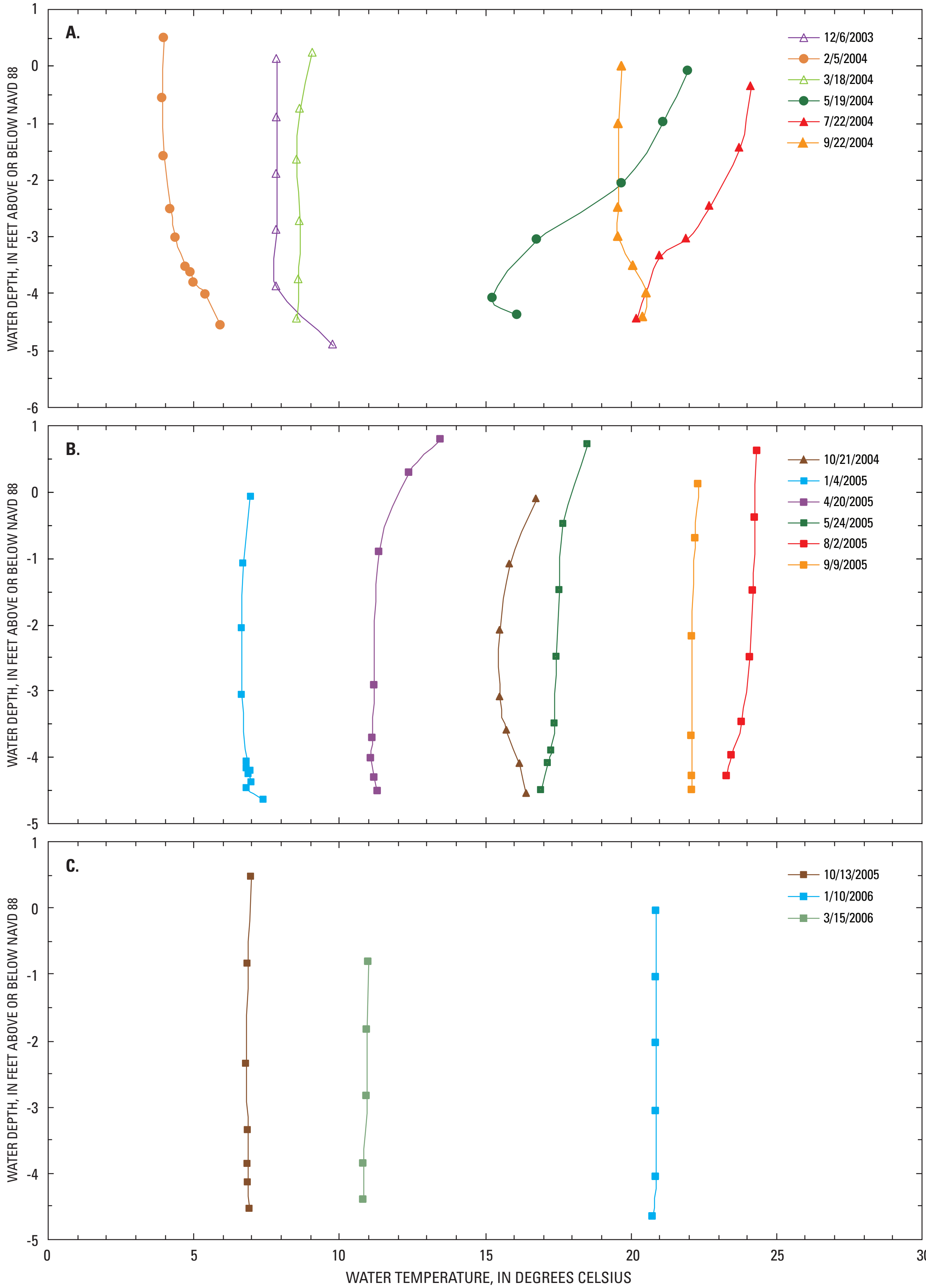


Figure 18. Water temperature profiles at canal site 2 at the unhealthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) December 2003–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006.

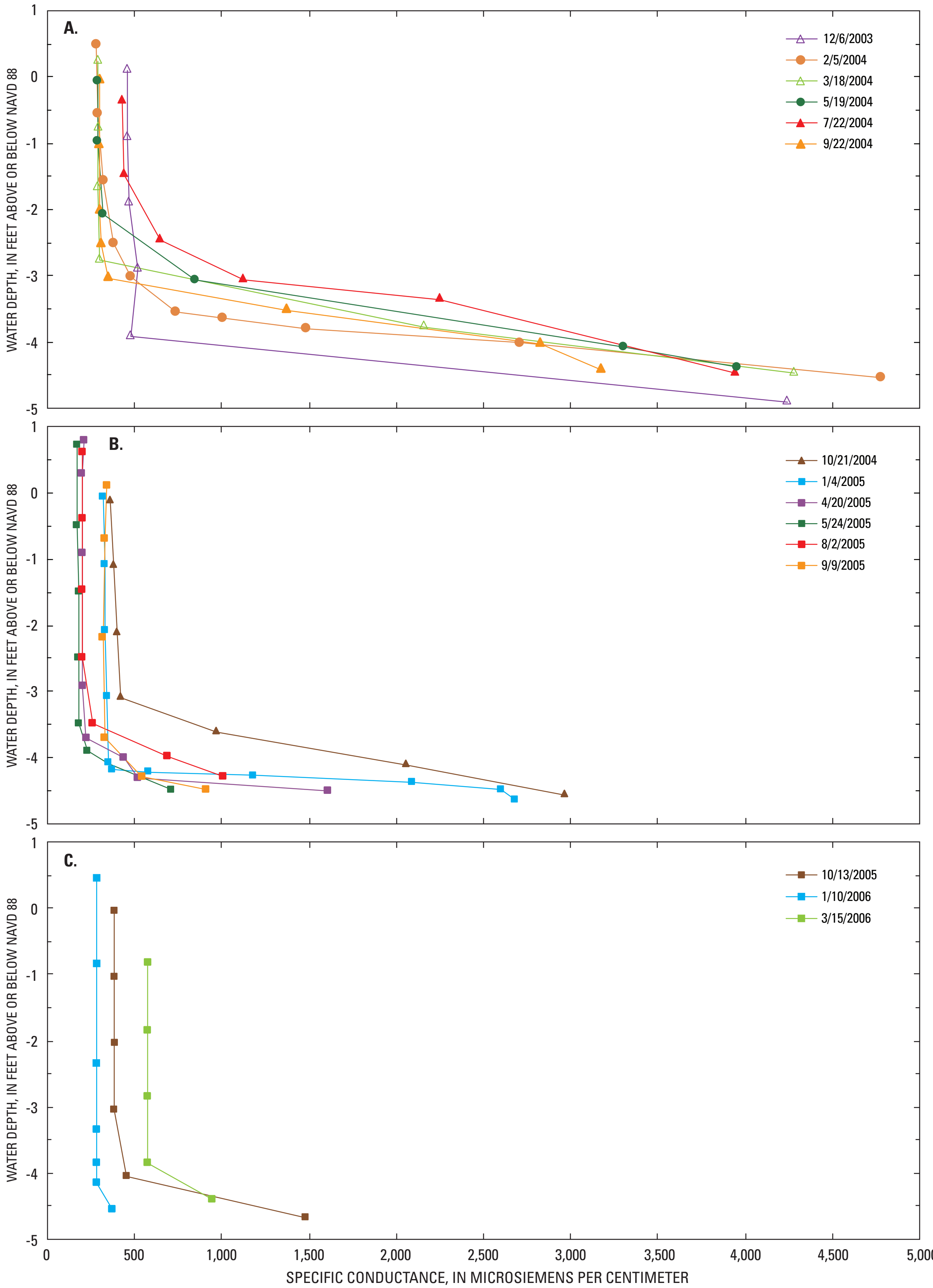


Figure 19. Specific conductance profiles at canal site 2 at the unhealthy Atlantic white cedar transect at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, (A) December 2003–September 2004, (B) October 2004–September 2005, and (C) October 2005–March 2006.

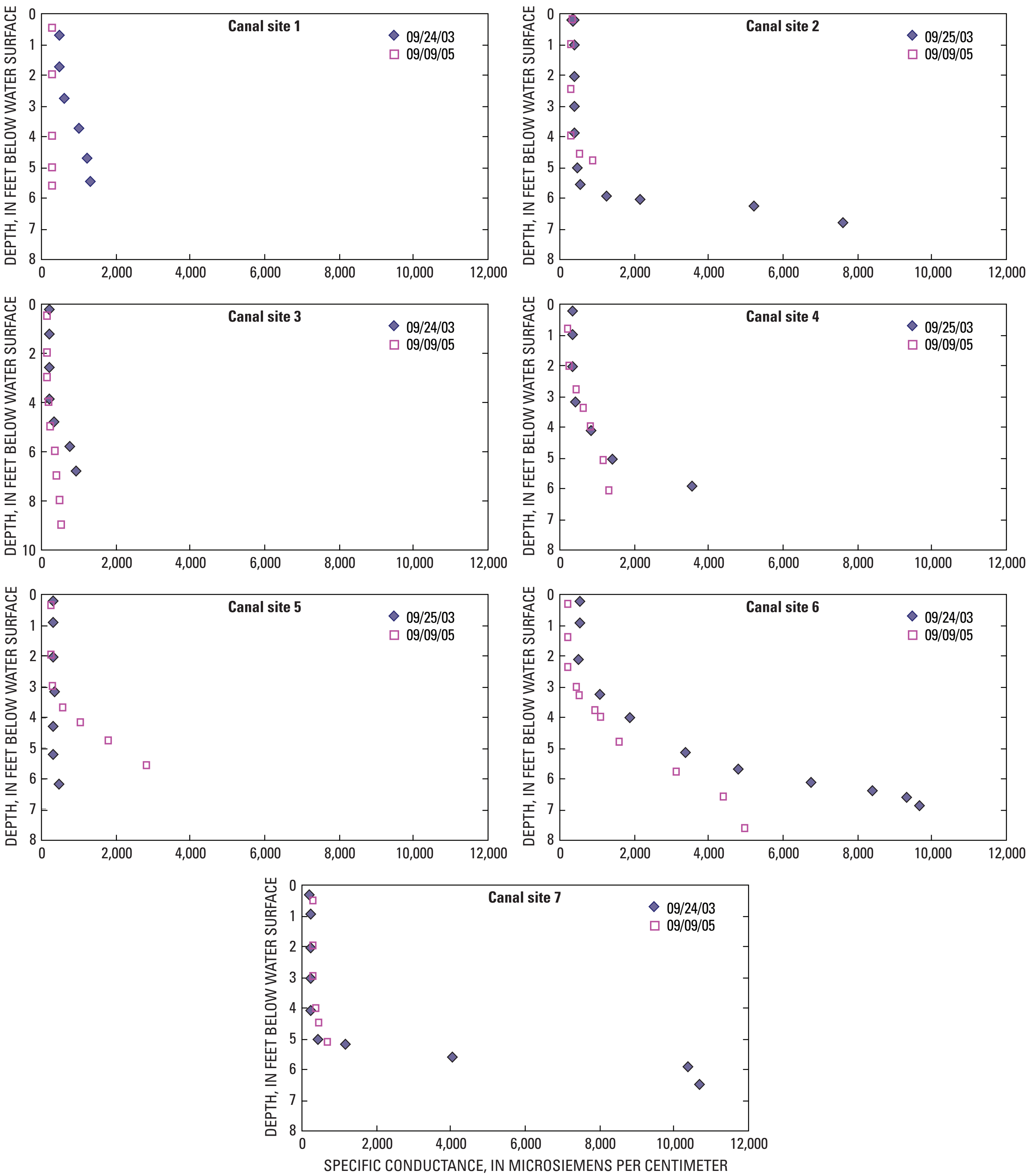


Figure 20. Specific conductance profiles at selected canals at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, September 2003 and September 2005 (canal site locations are shown in figure 2).

of September 18 to a maximum of about 1,240 µS/cm on September 21 (fig. 13B).

The increases in specific conductance during September 17–21, 2005, at canal site 2 are probably related to the effects of Hurricane Ophelia. Madden (2005) concluded that a "salt wedge" entered the canal along Grapevine Landing Road and moved up the canal along Juniper Road into the interior of the Reserve following Hurricane Ophelia. However, the initial increase in specific conductance at canal site 2 occurred at the upper sensor, which indicates an overland source or possibly an upstream source of brackish water rather than inland migration of a "salt wedge." However, because specific-conductance records were available at only one site (canal site 2) on the Juniper Road canal, the direction from which the high conductivity water entered the Reserve cannot be determined. Unlike the rapid increase in specific conductance following Hurricane Ophelia, the increase in specific conductance at canal site 2 from January through March 2006 was gradual and inversely correlated with water level (fig. 12). During this period, rapid changes in specific conductance generally were absent, even during times when water-level increases were attributed to wind tides. Specific-conductance data indicate that episodic events can have large effects on water-quality conditions.

Analytical results for the water samples from canal sites 3 and 2 are listed in table 5. Water in the canals was acidic, with values of pH ranging from 3.9 to 5.7. The specific conductance of samples from the canals was highly correlated with chloride ($r^2 = 0.95$) and sodium ($r^2 = 0.93$) concentrations. Chloride and sodium are the dominant anion and cation, respectively, in seawater (Drever, 1982). The mass ratio of sodium to chloride in seawater is about 0.556 (Holland, 1978), whereas the mass ratio reported as typical of freshwater is about 0.90 (Meybeck, 1979). Mass ratios of sodium to chloride in samples from the canal sites ranged from about 0.51 to almost 0.66 and were more similar to those of seawater than freshwater (fig. 21A). Sodium-to-chloride ratios less than 0.556 occur because of adsorption of sodium to peat, which results in relative enrichment of chloride ions (Emmerson and others, 2001). As a result, sodium-to-chloride ratios tend to decrease with increasing residence time and increasing distance along a flow path. Mass ratios of magnesium to calcium, which are about 3.14 and 0.25 in seawater and freshwater, respectively (Schlesinger, 1997), also indicate a seawater component in the canal samples. Boron concentrations (table 5), which typically are greater in seawater than in freshwater (Schlesinger, 1997), generally were greater in samples with high specific conductance than in samples with low specific conductance. Thus, the ionic composition of water samples from canal sites 2 and 3 indicates the presence of seawater, which is not unexpected given the proximity of the Reserve to the Alligator River.

Differences in redox conditions associated with depth also appear to affect water quality at canal sites 2 and 3. Concentrations of ammonia, a reduced form of nitrogen, were greater than those of nitrite plus nitrate, which are oxidized forms of nitrogen (table 5). Ammonia concentrations also were greater in water samples from the deep zones than in water samples from the upper zones at both sites. Although measured as ammonia, this nitrogen species is present as ammonium at the range of pH that was measured in the canals, and ranged in concentration from 0.028 to 0.22 milligrams per liter (mg/L) in samples from the upper zones and from 0.38 to 2.83 mg/L in samples from the lower zones of canal sites 2 and 3 (table 5). Only small differences in concentrations of total dissolved phosphorus and dissolved orthophosphate were observed between canal sites.

Iron and manganese concentrations were larger in the samples collected from the lower zones of the canals (table 5), which indicates that conditions were more reducing at depth. The solubility of iron and manganese increases under reducing conditions (Garrels and Christ, 1965). Sulfate concentrations at canal site 3 were about two times greater in samples from the upper zone than in samples from the lower zone (table 5). Sulfate concentrations in samples from canal site 2 did not show a consistent pattern with regard to differences between upper and lower zones. The pH was higher in the lower zones than in the upper zones at canal sites 2 and 3 (table 5; appendixes 26, 27) and at the other canal sites (appendixes 25, 28). The increase in pH at depth could be caused by a decrease in hydrogen ions resulting from reduction of nitrogen and(or) sulfate or possibly by upwelling of water from the mineral substrate underlying the peat. In general, analytical results for samples from the canals indicate the presence of seawater and the effects of reducing conditions. Concentrations of most constituents, especially those associated with seawater, were greater in samples from canal site 2 than in samples from canal site 3.

Water-quality data collected at canals in the Reserve showed effects of vertical stratification associated with thermal and chemical conditions. Specific conductance was highly correlated with chloride and sodium concentrations and appears to be a valid surrogate for salinity. Low concentrations of dissolved oxygen, especially at depth, and analytical data for nitrogen, iron, and manganese indicate that conditions were generally more reducing at depth than near the surface at canal sites 2 and 3. Specific conductance at canal site 2 increased during the days following Hurricane Ophelia. Similar increases in specific conductance did not occur in conjunction with rainfall events of similar magnitude at other times during this investigation or at canal site 3 following Hurricane Ophelia. Although the increase in specific conductance at canal site 2 following Hurricane Ophelia could have been caused by an influx of brackish water from the Alligator River, data are insufficient to make this determination.

Table 5. Analytes in water samples from canal sites 3 and 2 at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005.

[ft BWS, feet below water surface; mg/L, milligram per liter; °C, degrees Celsius; µS/cm, microsiemens per centimeter; <; less than; KN, Kjeldahl nitrogen; N, nitrogen; E, estimated value; P, phosphorus; µg/L; microgram per liter; —, not analyzed]

Abbreviated name (table 1) and sampling zone	Date	Sampling depth (ft BWS)	Dissolved oxygen (mg/L)	pH (units)	Specific conductance at 25 °C (µS/cm)	Temperature (°C)	Dissolved Ca (mg/L)	Dissolved Mg (mg/L)	Dissolved K (mg/L)
Canal site 3 (upper)	02/11/05	1.3	4.1	3.9	286	4.6	2.83	3.11	2.07
Canal site 3 (upper)	05/25/05	2.5	.1	4.0	166	13.3	1.80	2.14	1.71
Canal site 3 (lower)	05/25/05	8.5	< .1	4.7	519	9.1	4.71	8.77	3.94
Canal site 3 (upper)	08/03/05	2.5	< .1	3.9	166	22.3	1.89	2.07	1.9
Canal site 3 (lower)	08/03/05	8.5	.1	4.2	492	12	4.69	7.38	3.73
Canal site 2 (upper)	02/10/05	1.3	0.4	3.9	339	6.8	2.94	4.48	2.97
Canal site 2 (lower)	02/10/05	5.3	.2	5.7	1,410	6.2	9.31	23.2	7.3
Canal site 2 (upper)	05/24/05	1.5	.1	4.3	175	17.7	1.75	2.55	1.96
Canal site 2 (lower)	05/24/05	5.0	.2	4.4	192	17.3	2.82	4.42	2.21
Canal site 2 (upper)	08/02/05	1.5	.1	4.2	198	24.3	2.12	2.79	1.95
Canal site 2 (lower)	08/02/05	5.0	< .1	5.0	623	23.4	7.02	14.8	5.3

Abbreviated name (table 1) and sampling zone	Date	Dissolved Na (mg/L)	Dissolved Cl (mg/L)	Dissolved F (mg/L)	Dissolved Si (mg/L)	Dissolved SO_4 (mg/L)	Dissolved KN (mg/L as N)	Dissolved NH_3 (mg/L as N)	Dissolved NO_2+NO_3 (mg/L as N)
Canal site 3 (upper)	02/11/05	34.7	65.6	< 0.1	5.7	0.8	1.2	0.028	< 0.016
Canal site 3 (upper)	05/25/05	26.1	43.5	< .1	3.0	.3	1.4	.121	< .016
Canal site 3 (lower)	05/25/05	91.3	167	< .1	14.2	.7	3.2	1.8	< .016
Canal site 3 (upper)	08/03/05	25.3	41.9	< .1	4.1	.3	2.0	.27	.021
Canal site 3 (lower)	08/03/05	80.4	158	< .1	13.7	.8	3.6	2.32	< .016
Canal site 2 (upper)	02/10/05	48	87.8	< 0.1	3.2	1.5	1.3	0.151	< 0.016
Canal site 2 (lower)	02/10/05	199	379	< .1	9.7	2.4	3.0	2.13	< .016
Canal site 2 (upper)	05/24/05	30.6	47.4	< .1	1.4	.5	1.6	.13	< .016
Canal site 2 (lower)	05/24/05	47.8	73.1	< .1	2.7	.3	2.0	.38	< .016
Canal site 2 (upper)	08/02/05	32.8	55.8	< .1	3.0	1.3	1.7	.22	.022
Canal site 2 (lower)	08/02/05	130	237	.1E	9.1	1.1	4.7	2.83	.017

Abbreviated name (table 1) and sampling zone	Date	Dissolved PO_4 (mg/L as P)	Dissolved P (mg/L)	Dissolved Al (µg/L)	Dissolved B (µg/L)	Dissolved Fe (µg/L)	Dissolved Mn (µg/L)	Dissolved Hg (µg/L)	Na:Cl (mass ratio)
Canal site 3 (upper)	02/11/05	0.006	0.022	—	25	1,580	53.5	< 0.01	0.53
Canal site 3 (upper)	05/25/05	.03	.04	402	21	1,590	38.9	< .01	.60
Canal site 3 (lower)	05/25/05	.272	.33	540	51	4,730	76.0	< .01	.55
Canal site 3 (upper)	08/03/05	.088	.11	—	24	1,590	35.4	—	.60
Canal site 3 (lower)	08/03/05	.33	.36	—	39	4,200	74.3	—	.51
Canal site 2 (upper)	02/10/05	0.042	0.067	—	28	1,500	66.1	< 0.01	0.55
Canal site 2 (lower)	02/10/05	.214	.22	—	83	5,290	87.0	< .01	.53
Canal site 2 (upper)	05/24/05	.05	.08	261	24	1,440	38.9	< .01	.65
Canal site 2 (lower)	05/24/05	.093	.12	397	32	2,690	48.3	< .01	.65
Canal site 2 (upper)	08/02/05	.096	.13	—	30	1,760	38.9	—	.59
Canal site 2 (lower)	08/02/05	.37	.39	—	91	3,270	56.3	—	.55

Transects

Samples were collected from the piezometers installed in the peat on the transects in areas of healthy and unhealthy AWC and from the well in the mineral soil underlying the peat (fig. 4) and analyzed for the constituents listed in table 3. Analytical results for these samples are listed in table 6. Piezometers on the healthy AWC transect include piezometers P-HC1000, P-HC100, P-HC19, P-HR50, and P-HR100. Piezometers on the unhealthy AWC transect include P-SC100, P-SC12, P-SR45, and P-SR100. The chemical quality of water samples from the piezometers differed considerably from the chemical quality of water samples from the mineral substrate well. Water from the piezometers was acidic and had values of pH ranging from 3.4 to 4.7, whereas water from the well completed in the mineral substrate was circumneutral (pH = 6.8–6.9). The acid-neutralizing capacity of water from the mineral substrate well (350–360 mg/L as $CaCO_3$) was much greater than the acid-neutralizing capacity of water from the peat (table 6). Like the water samples from the canals, the specific conductance of the samples from the transect piezometers was strongly correlated with chloride ($r^2 = 0.99$) and sodium ($r^2 = 0.98$) concentrations. Mass ratios of sodium to chloride, calcium to magnesium, and boron to chloride also indicate that seawater was the major source of ions in the piezometer samples (fig. 21B). Sodium to chloride mass ratios of samples from the mineral substrate well, ranged from 1.48 to 1.49 in contrast to the ratios of samples from the peat, which ranged from about 0.52 to 0.68 (table 6). The differences between water samples from the peat and the underlying mineral substrate indicate that upwelling ground water was not a major source of the water in the shallow peat on the transects or in the canals at sites 2 and 3 (fig. 21; table 5).

Water-quality data indicate reducing conditions in both the mineral substrate and the peat. Nitrogen was primarily present in reduced forms, and concentrations of dissolved ammonia and dissolved Kjeldahl nitrogen (total ammonia plus organic nitrogen) exceeded concentrations of dissolved nitrite plus nitrate in piezometer samples. Nitrite plus nitrate concentrations were less than or near the reporting level of 0.016 mg/L, as nitrogen (table 6). Concentrations of dissolved manganese and iron also were high and indicate reducing conditions (Garrels and Christ, 1965). The highest manganese concentrations (57.0–62.9 micrograms per liter (µg/L)) were in samples from piezometer P-HR50, and the highest iron concentrations, 9,720 and 10,300 µg/L, were in the samples from the mineral substrate well (table 6). Iron concentrations in water samples from the peat ranged from 1,250 µg/L in a sample from piezometer P-HC1000 to 5,700 µg/L in a sample from piezometer P-HR50. In addition to having the highest concentrations of manganese and iron in water samples from the peat, samples from piezometer P-HR50 also had the highest pH. Unlike the other piezometers which were in dense stands of AWC, P-HR50 was in an open area about 30–40 ft from the stand of regenerating AWC.

Concentrations of ions in samples from the piezometers generally were more variable than concentrations of nutrients and metals. Sulfate concentrations in most of the samples were near the reporting level of 0.2 mg/L (table 6). The highest sulfate concentrations were in samples from piezometer P-SC100, which is in an area where many of the AWC are dead. Concentrations of sulfate, the second most common anion in seawater, are typically about two orders of magnitude lower in freshwater than in seawater (Livingstone, 1963). Under reducing conditions, sulfate is a terminal electron acceptor for microbial decomposition of organic matter. Introduction of seawater into freshwater wetlands has been linked to accelerated decomposition of peat (Portnoy and Giblin, 1997). Hydrogen sulfide is formed during sulfate reduction, and although tolerated by plant species in saltwater wetlands, it is toxic to many freshwater wetland plants (Lugo and others, 1988).

Concentrations of chloride, sodium, and specific conductance, which are considered to be indicators of seawater, varied considerably in the samples collected from the piezometers during February–August 2005. Concentrations of chloride, sodium, and specific conductance were greater in samples from piezometer P-SC100 than in samples from the other piezometers. Chloride concentrations in samples from piezometer P-SC100 increased from 221 mg/L in February 2005 to 286 mg/L in August 2005 (table 6). Samples from piezometer P-SC12, which is adjacent to the Juniper Road canal, had the next highest chloride concentrations (87.1 mg/L in May 2005 and 75.1 mg/L in August 2005). Chloride concentrations in samples from the upper zone of canal site 2 (47.4 mg/L in May 2005 and 55.8 mg/L in August 2005) were less than those in samples from piezometer P-SC12 (table 5). Although chloride concentrations and specific conductance were greater in samples from canal site 2 and the piezometers on the unhealthy AWC transect than the chloride concentrations and specific conductance in samples from canal site 3 and the piezometers on the healthy AWC transect, the observed dieback was not necessarily caused by elevated specific conductance or chloride concentrations, at least not at the values measured during this study.

Generally, sodium-to-chloride mass ratios in samples from the piezometers on the unhealthy AWC transect were more similar to those of seawater (0.556) than were the ratios in samples from the piezometers on the healthy AWC transect (fig. 21B; table 6). Sodium-to-chloride mass ratios varied considerably from February to August 2005. Three samples from piezometers on the healthy AWC transect (P-HR50, P-HC100, and P-HC1000), all of which were collected in February 2005, had sodium-to-chloride ratios that were less than 0.556 (fig. 21B). Sodium-to-chloride ratios in subsequent samples from these piezometers were higher, which suggests a decreasing influence of seawater. Interestingly, sodium-to-chloride ratios of samples from piezometers P-SC100 and P-SC12 south of Juniper Road decreased from May to August 2005, which suggests that the effects of seawater increased during this time. Because analytical data were collected over

Table 6. Analytes in water samples from the mineral substrate well and piezometers along the healthy and unhealthy Atlantic white cedar transects at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005.

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligram per liter; ANC, acid-neutralizing capacity; <, less than; —, not analyzed; E, estimated value; N, nitrogen; P, phosphorus; µg/L; microgram per liter]

Abbreviated name (table 1)	Date	pH (standard units)	Specific conductance (µS/cm)	Water temperature (°C)	Dissolved									
					Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	ANC (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Sulfate (mg/L)
Mineral substrate well	02/09/05	6.9	855	15.5	95.1	15.0	3.08	72.8	350	48.9	0.5	54.2	< 0.2
Mineral substrate well	05/23/05	6.8	943	15.0	95.7	16.2	3.20	78.0	360	52.7	0.5	53.6	< 0.2
Healthy Atlantic white cedar transect													
Piezometer P-HC1000	02/10/05	3.4	299	7.0	1.52	2.25	0.17	30.2	—	56.2	< 0.1	6.1	0.4
Piezometer P-HC1000	05/24/05	3.6	276	14.7	1.60	2.28	.19	29.9	—	49.8	< .1	5.6	< .2
Piezometer P-HC1000	08/03/05	3.6	234	22.5	1.50	1.79	.69	22.9	—	38.2	< .1	4.5	< .2
Piezometer P-HC100	02/10/05	3.5	337	7.3	2.25	3.43	2.24	38.5	—	74.7	< .1	5.9	.4
Piezometer P-HC100	05/25/05	3.8	245	14.6	1.50	2.25	1.90	29.2	—	48.5	< .1	3.5	.2
Piezometer P-HC100	08/03/05	3.8	242	22.0	1.60	2.18	2.30	27.3	—	45.8	< .1	3.9	.2
Piezometer P-HC19	05/25/05	4.0	266	15.1	1.77	2.48	1.96	34.2	—	56.6	< .1	4.0	.2
Piezometer P-HC19	08/03/05	3.9	187	23.2	1.31	1.58	1.70	22.1	—	34.0	< .1	3.0	.1E
Piezometer P-HR50	02/11/05	4.4	247	6.7	3.64	3.21	1.69	33.6	—	64.6	.1E	9.0	.3
Piezometer P-HR50	05/25/05	4.7	169	16.2	3.32	2.30	1.82	22.6	< 2	33.3	< .1	9.7	.5
Piezometer P-HR50	08/03/05	4.7	160	23.6	2.87	2.16	1.71	20.5	5	31.9	.1E	8.7	.2E
Piezometer P-HR100	05/25/05	3.9	294	15.8	2.21	2.96	2.31	39.1	—	64.1	< .1	4.8	< .2
Piezometer P-HR100	08/03/05	3.9	271	23.6	2.21	2.58	2.42	33.8	—	57.5	< .1	6.3	.3
Unhealthy Atlantic white cedar transect													
Piezometer P-SC100	02/10/05	4.1	758	8.0	3.85	10.8	5.76	119	—	221	< 0.1	3.8	2.7
Piezometer P-SC100	05/24/05	4.2	915	17.3	3.96	12.6	6.79	146	—	258	< .1	5.0	1.6
Piezometer P-SC100	08/04/05	4.1	1,020	23.6	4.53	13.7	6.75	149	—	286	< .1	6.4	1.2
Piezometer P-SC12	05/24/05	4.4	340	18.6	2.65	4.26	3.45	51.5	—	87.1	< .1	1.9	.4
Piezometer P-SC12	08/04/05	4.3	295	24.7	2.37	3.54	2.50	42.9	—	75.1	< .1	2.1	.3
Piezometer P-SR45	05/24/05	3.9	252	16.8	1.56	2.37	.84	29.4	—	52.4	< .1	3.0	.2
Piezometer P-SR45	08/04/05	3.7	194	24.3	1.19	1.61	.81	19.6	—	34.7	< .1	3.1	.2E
Piezometer P-SR100	05/24/05	3.8	261	16.6	1.50	2.20	.69	28.9	—	50.7	< .1	3.4	.1E
Piezometer P-SR100	08/04/05	3.6	301	23.6	1.73	2.64	.80	32.4	—	58.6	< .1	5.6	.3

Table 6. Analytes in water samples from the mineral substrate well and piezometers along the healthy and unhealthy Atlantic white cedar transects at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005. — Continued

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligram per liter; ANC, acid-neutralizing capacity; <, less than; —, not analyzed; E, estimated valueN, nitrogen; P, phosphorus; µg/L; microgram per liter]

Abbreviated name (table 1)	Date	Dissolved										
		Kjeldahl nitrogen (mg/L as N)	Ammonia (mg/L as N)	Nitrite plus nitrate (mg/L as N)	Orthophosphate (mg/L as P)	Phosphorus (mg/L)	Aluminum (µg/L)	Iron (µg/L)	Boron (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Sodium:chloride (mass ratio)
Mineral substrate well	02/09/05	1.1	0.44	0.29	< 0.006	0.19	—	10,300	76	41.6	< 0.01	1.49
Mineral substrate well	05/23/05	1.2	.35	< .016	< .006	.16	2	9,720	74	45.4	< .01	1.48
Healthy Atlantic white cedar transect												
PiezometerP-HC1000	02/10/05	1.2	0.029	< 0.016	0.015	0.032	—	1,250	40	37.8	< 0.01	0.54
Piezometer P-HC1000	05/24/05	1.7	.06	< .016	.051	.08	245	1,950	30	41.8	< .01	.60
Piezometer P-HC1000	08/03/05	1.9	.08	.018	.078	.11	—	1,770	24	34.1	—	.60
Piezometer P-HC100	02/10/05	1.2	.036	< .016	.013	.027	—	1,910	22	50.6	< .01	.52
Piezometer P-HC100	05/25/05	1.6	.087	< .016	.030	.06	278	1,760	22	33.5	< .01	.60
Piezometer P-HC100	08/03/05	2.4	.24	.017	.151	.25	—	1,660	28	32.6	—	.60
Piezometer P-HC19	05/25/05	1.8	.262	< .016	.035	.06	394	1,780	24	36.6	< .01	.60
Piezometer P-HC19	08/03/05	2.1	.29	.017	.069	.09	—	1,280	25	23.8	—	.65
Piezometer P-HR50	02/11/05	—	—	—	—	—	—	5,090	25	62.9	—	.52
Piezometer P-HR50	05/25/05	3.3	.884	.010E	.169	.24	1,390	5,700	21	57.0	.01	.68
Piezometer P-HR50	08/03/05	2.6	.62	.018	.169	.21	—	4,920	25	57.6	—	.64
Piezometer P-HR100	05/25/05	1.9	.134	< .016	.099	.15	371	2,230	39	51.3	< .01	.61
Piezometer P-HR100	08/03/05	2.0	.26	< .016	.194	.23	—	2,120	33	46.1	—	.59
Unhealthy Atlantic white cedar transect												
Piezometer P-SC100	02/10/05	2.1	0.98	< 0.016	0.136	0.166	—	1,310	103	48.3	< 0.01	0.54
Piezometer P-SC100	05/24/05	2.8	1.20	< .016	.184	.23	248	1,990	74	46.3	< .01	.57
Piezometer P-SC100	08/04/05	3.8	1.64	.02	.305	.32	—	1,990	82	46.7	—	.52
Piezometer P-SC12	05/24/05	1.8	.115	< .016	.068	.11	257	2,060	34	53.5	< .01	.59
Piezometer P-SC12	08/04/05	2.1	.28	.018	.108	.15	—	1,730	36	41.3	—	.57
Piezometer P-SR45	05/24/05	1.6	.14	< .016	.040	.10	341	2,070	24	46.0	< .01	.56
Piezometer P-SR45	08/04/05	1.7	.10	.013E	.095	.13	—	1,880	20	31.9	—	.56
Piezometer P-SR100	05/24/05	1.6	.07	< .016	.090	.13	238	2,540	20	42.7	< .01	.57
Piezometer P-SR100	08/04/05	2.1	.16	.016	.248	.28	—	2,770	24	46.9	—	.55

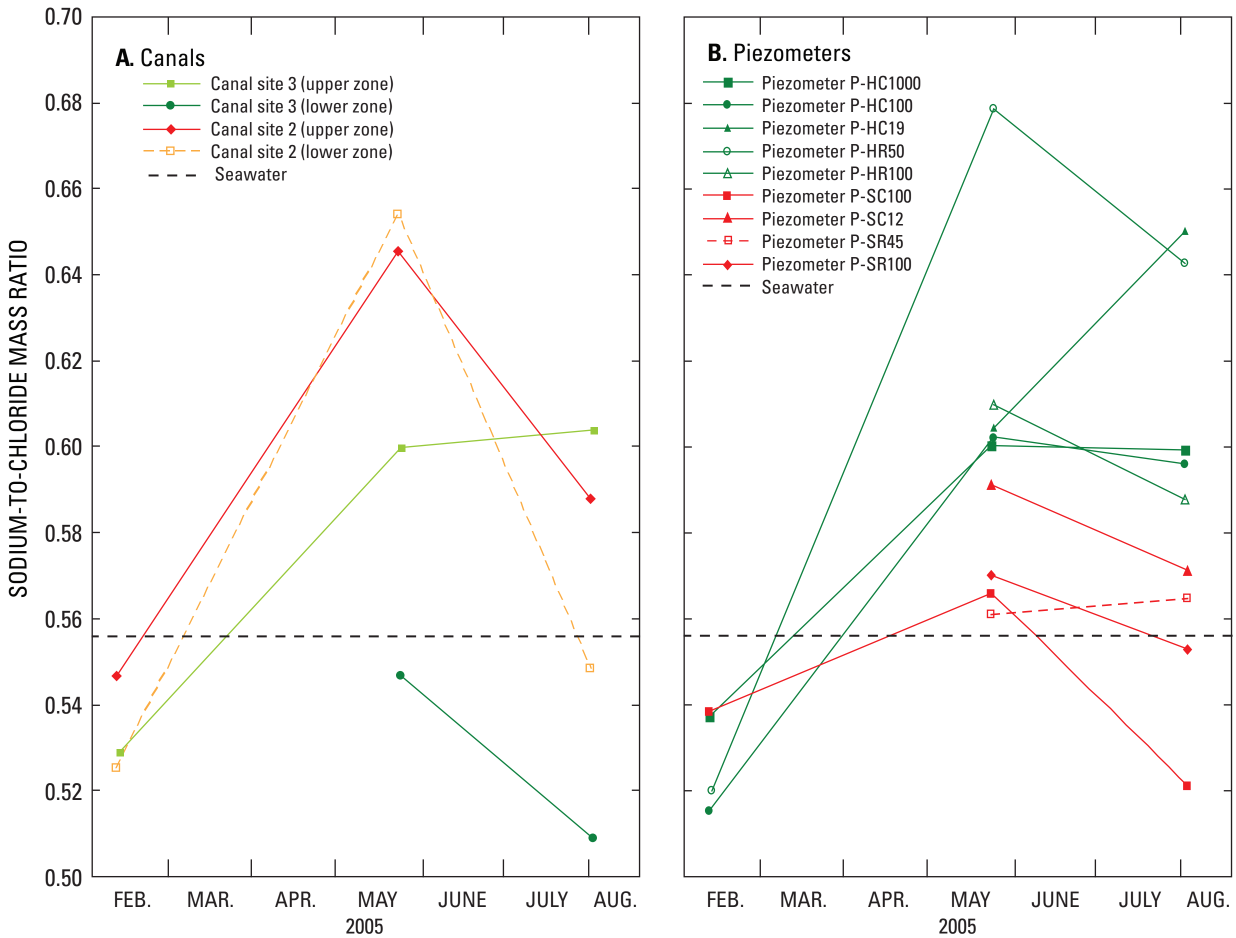


Figure 21. Sodium-to-chloride mass ratios in water samples from (A) canal sites 2 and 3 and (B) piezometers on the transects in the area of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, February–August 2005.

a short period (about 6 months) and were not collected at all of the piezometers during the initial sampling in February 2005, interpretation is limited. Although these data suggest an influx of seawater, the time at which this influx occurred and the direction from which the seawater entered the Reserve cannot be determined from data collected during this study. During storms, brackish water from the Alligator River could enter the Reserve from a variety of directions, either overland or through canals, depending on wind direction and intensity. The potential effects of roads are variable; roads can trap seawater in some areas or isolate other areas from the effects of seawater, depending on the orientation of the road and the direction by which brackish water enters the Reserve.

Root Zone

Differences in selected site characteristics and water-quality conditions in the root zones of sites in stands of predominantly healthy or unhealthy AWC were evaluated. Unhealthy AWC sites included a mixture of stressed, dying, and dead AWC. Three sites in stands of healthy and three sites in stands of unhealthy AWC were selected for evaluation (fig. 5), and 5 to 10 piezometers were installed and sampled at each site. During August–September 2005, 39 piezometers were sampled (table 1), and the sampling results are listed in appendix 29 and summarized in figure 22 and table 7. A two-sample Mann-Whitney test (Conover, 1980) was used to assess differences in the thickness of the peat, depth to water relative to land surface, water temperature, pH, specific conductance, and dissolved-oxygen concentration between healthy and unhealthy sites. Three piezometers (P-SC100, U1B, and U1J) at the U1 unhealthy AWC site (fig. 5) were sampled twice—first on August 10 or 11, and again on August 18, 2005. Differences between samples collected on the two dates were small, and values were averaged for statistical analysis. Averages of pH were calculated from hydrogen ion concentrations.

Specific conductance, pH, and temperature were lower ($p < 0.001$) in water samples from within the root zone of the healthy stands of AWC. Differences in peat thickness, depth to water, and dissolved-oxygen concentration between the two site types were not significant. However, depth to water below land surface was significantly greater ($p < 0.10$) at the healthy AWC sites than at the unhealthy AWC sites, indicating slightly greater inundation at the unhealthy AWC sites. Site accessibility and variation in antecedent conditions could have contributed to some of the observed differences in depth to water. Although the higher specific conductance at the unhealthy AWC sites suggests that water quality has affected the health of AWC, differences in water temperature and pH between healthy and unhealthy AWC stands are more likely a result of AWC dieback than a cause of dieback. Because of dieback, the canopy in the unhealthy AWC stands was more open, which enabled greater light penetration than in the healthy AWC stands. The increased penetration of sunlight is probably the cause of the higher water temperatures in the unhealthy AWC stands. Acidic root exudates and phenolic compounds leached from foliage of AWC likely contribute to the lower values of pH observed in the healthy stands of AWC (Peattie, 1948). With decline and dieback of AWC, the water in the root zone becomes less acidic because the source of the acidity is decreased. Although measurements of water temperature,

Table 7. Summary of selected site characteristics and water-quality measurements for root-zone samples in stands of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005.

[Values in **bold** type indicate statistically significant differences ($p < 0.001$) between stand type based on results of a two-sample Mann-Whitney test. ft, feet; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligram per liter; >, greater than]

	Water level (feet above or below (–) land surface)	Peat thickness (ft)	Water temperature (°C)	Specific conductance (µS/cm)	pH	Dissolved oxygen (mg/L)
			Healthy Atlantic white cedar stands			
median	0.26	10.7	**22.6**	**231**	**3.6**	0.2
minimum	.02	7.2	**22.1**	**183**	**3.5**	.1
maximum	.60	12.7	**24.0**	**323**	**3.8**	.4
n	19	19	**19**	**19**	**19**	19
			Unhealthy Atlantic white cedar stands			
median	0.14	10.7	**24.8**	**368**	**4.2**	0.2
minimum	– .01	7.4	**22.9**	**181**	**3.8**	.1
maximum	.33	> 19	**26.2**	**1,410**	**4.6**	.3
n	20	20	**20**	**20**	**20**	20

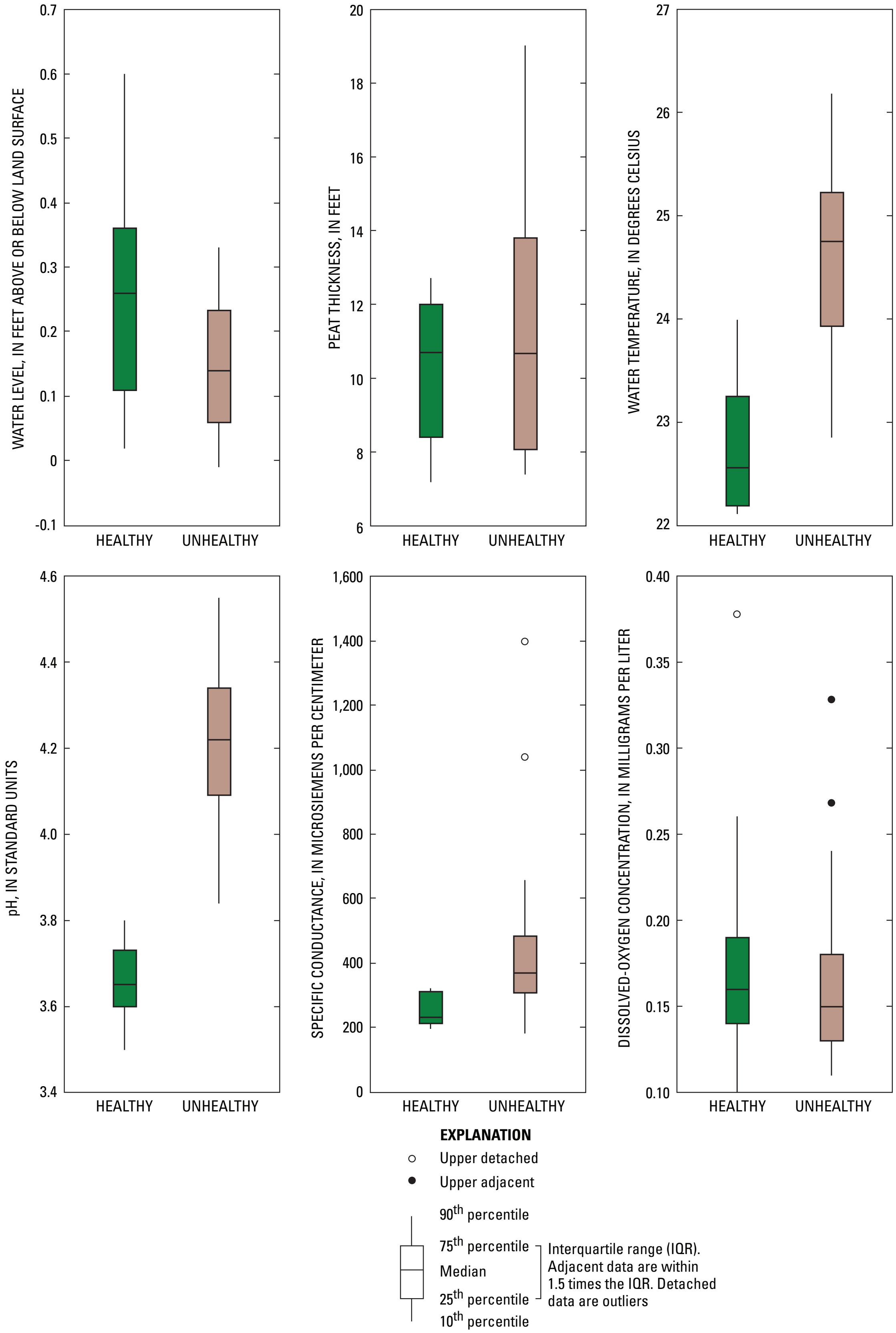


Figure 22. Boxplots of physical and root-zone water-quality characteristics in stands of healthy and unhealthy Atlantic white cedar at the Emily and Richardson Preyer Buckridge Coastal Reserve, North Carolina, August–September 2005.

pH, and dissolved-oxygen concentration were fairly uniform among the individual sites, specific conductance varied greatly over short distances (appendix 29). This variability in specific conductance was especially pronounced at the U1 site (fig. 5), where specific conductance ranged from 297 to 1,410 μS/cm at locations less than 100 ft apart. The cause of this variability was not determined.

Effects of Canals and Roads on Hydrologic Conditions

Coastal wetland systems, such as the Reserve, are hydrologically complex and are subject to climatic variability and episodic disturbances that occur at irregular intervals ranging from annual to greater than decadal. Human activities, including construction of canals and roads and harvesting of timber, further increase the hydrologic complexity of these systems. As indicated by the precipitation records for 1985–2005, annual precipitation during most of this investigation exceeded the 21-year average of about 57.4 inches per year. The highest annual precipitation during this 21-year period (86 inches) occurred in 2003, the first year of this investigation. In contrast, the annual precipitation in 2001 (31.39 inches) was the lowest for this 21-year period and was about 45 percent less than the annual average. This high variability in precipitation indicates a high variability in hydrologic conditions during recent years, and the conditions encountered during this investigation are not necessarily representative of those that occurred during the onset of the decline of AWC at the Reserve.

Water levels at the Reserve are sensitive to alterations because of the limited hydraulic gradient. This sensitivity was demonstrated by changes in water levels associated with the blockage and clearing of a culvert under Juniper Road during this investigation. The blockage of the culvert restricted the eastward flow of water in the Grapevine Landing Road canal and caused water to back up in the Grapevine Landing Road and Juniper Road canals. After the culvert was cleared on September 2, 2005, water levels in the Juniper Road canal declined. A similar decline in water levels occurred in the wells on the unhealthy AWC transect and was more pronounced in the wells on the south side of Juniper Road than in the wells on the north side of Juniper Road. Following the clearing of the culvert, water levels in the spur road 3 canal (canal site 3) and in the wells on the healthy AWC transect did not decline appreciably in comparison to water levels in the Juniper Road canal (canal sites 1 and 2). The slow decline of water levels in the wells on the north side of Juniper Road compared to the decline of water levels in the wells on the south side of Juniper Road following the clearing of the culvert indicates that Juniper Road restricts the subsurface movement of water. Although similar patterns in water-level fluctuations were evident in the canals and wells on both transects, water levels generally were higher north of Juniper Road and on the healthy AWC transect than south of Juniper Road. Effects of wind tides became increasingly evident during the last 2 months of the study, and increases in water levels occurred at canal sites 1 and 2 and in wells on the unhealthy AWC transect in association with these events. Increases in water levels associated with wind tides were more pronounced in the wells south of Juniper Road than in the wells north of Juniper Road, which also indicate that Juniper Road restricts subsurface water movement.

The area along the healthy AWC transect best exemplifies water levels under an unaltered hydrologic regime. Water levels on this transect varied in response to precipitation and evapotranspiration. The healthy AWC transect is farther from the Alligator River than the unhealthy AWC transect and crosses a canal that has limited hydraulic connection to the Juniper Road canal. In contrast to the unhealthy AWC transect, the water-level gradient on the healthy AWC transect did not slope toward the canal, and the spur road 3 canal appears to have little effect on water levels in this area.

The sensitivity of hydrologic conditions at the Reserve to storm-driven events was illustrated when Hurricane Ophelia brushed the North Carolina coastline on September 14–16, 2005. During this time, water levels in the Juniper Road canal at site 1 generally were slightly higher than those farther inland at site 2, which indicates that water from the Alligator River may have entered the Grapevine Landing Road canal and moved up the Juniper Road canal during the hurricane. Water levels in well SC100, which is on the south side of Juniper Road, also remained slightly lower than water levels in the Juniper Road canal at site 2 during September 14–16. During most of this period, a slight hydraulic gradient was evident from the canal toward well SC100, which indicates that water moved from the canal into the peat during this event.

Water-quality conditions were variable, both temporally and spatially. Specific conductance was highly correlated with sodium and chloride concentrations in samples from the canals and piezometers. Sodium-to-chloride ratios in samples from piezometers and canals on the transects were more similar to seawater than to freshwater, especially the samples with high specific conductance. Specific conductance in the canals was higher in 2004 than in 2005, as indicated by continuous monitoring data and vertical profiles. Stratification of water at canal sites 2 and 3 occurred during the summer months with periods of turnover as water temperatures cooled during early autumn. Turnover and mixing appear to have facilitated the flushing of dense, high-conductance water from the canals during this investigation. Specific conductance at canal site 2, however, gradually increased from January 2006 until March 2006 when the study ended. This increase in specific conductance occurred in conjunction with a gradual decline in water levels and could, in part, be the result of drainage of high conductance waters from the interior of the Reserve following the clearing of the blocked culvert as well as the result of low precipitation during this period. An influx of brackish water from the Alligator River, which was facilitated by declining water levels in the Juniper Road canal, could have contributed to the increase in specific conductance at canal site 2 during this period.

The effects of seawater, as indicated by specific conductance, chloride concentrations, and sodium-to-chloride ratios generally were more evident in water samples from sites on the unhealthy AWC transect than from sites on the healthy AWC transect. The largest effects of seawater were observed in samples from piezometer P-SC100 and the lower zone of canal site 2, both of which were on the unhealthy AWC transect. Results from the root-zone assessment also indicated a positive correlation between the specific conductance of root-zone water and the poor health of AWC. Variations in sodium-to-chloride ratios of water samples from the piezometers on the transects may be related to movement of water within the peat. Sodium-to-chloride ratios of samples from piezometers on the healthy and unhealthy AWC transects indicated the effects of seawater. Although salinity in the Alligator River typically is low, the river can serve as a conduit for inland movement of seawater during storms. Interpretation of the analytical data from the canals and piezometers is limited by the small number of samples and the brief period over which the samples were collected. Consequently, patterns observed from February to August 2005 may not be indicative of long-term conditions.

The canals and roads at the Reserve affect hydrologic conditions, which in turn appear to affect the health of AWC. Under some conditions, particularly in conjunction with storms, water from the Alligator River can enter the Reserve through canals. Although quantitative data are not available regarding the salinity tolerance of AWC, dieback following exposure to seawater has been reported anecdotally. In addition to osmotic stress associated with high salinity, dieback of vegetation can be caused by exposure to hydrogen sulfide formed when sulfate from seawater enters freshwater wetlands. High values of specific conductance were associated with poor health of AWC at the Reserve as was indicated by the assessment of root-zone water quality. Because the specific conductance of water samples collected during this investigation was highly correlated with chloride and sodium concentrations, specific conductance was considered to be an indicator of salinity. The specific conductance of samples collected from piezometers and canals on the transects generally was greatest in areas where the health of AWC was poorest. Thus, it appears that salinity derived from seawater is an indicator of water-quality conditions associated with the decline of AWC at the Reserve. Based on data available or obtained during this study, the point (or points) of entry for seawater cannot be ascertained. Declining values of specific conductance observed at most of the canal sites during March 2004 through mid-September 2005 suggest that brackish water entered the Reserve prior to this study, probably in conjunction with a storm. Increases in specific conductance in the canals following Hurricane Ophelia also suggest that a storm-related source of brackish water affected the Reserve.

Roads appear to impede the movement of surface and subsurface water at the Reserve as indicated by the response of water levels to the blockage and clearing of the culvert linking the Juniper Road and Grapevine Landing Road canals. Effects of roads depend on the orientation of the road relative to the direction of water movement. Roads appear to decrease the effects of brackish water influx by preventing the movement of brackish water into some areas and to increase the effects of brackish water by restricting its movement out of other areas. Roads, thereby, can have either a protective or a detrimental effect on water quality with regard to salinity, depending on the direction from which brackish water enters the Reserve. Likewise, canals can facilitate the flushing of brackish water from the Reserve as well as facilitate the transport of brackish water into the interior of the Reserve. The variable effects of roads and canals on the movement of brackish water in the Reserve are important factors to consider in the restoration of this site.

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