Inventory and Assessment of the Present Status of Water Resources at Cape Hatteras and Cape Lookout National Seashores

JoAnn Burkholder, Elle Allen, Stacie Flood, and Carol Kinder

NCSU Center for Applied Aquatic Ecology

http://www.ncsu.edu/wq
The Outer Banks – 200-mile-long string of barrier islands with wide, open expanse of beaches - major tourist destination (3 million / year) and natural scenic wonder.

Serious conflicts over use of national parks, especially Cape Hatteras National Seashore
The NPS works to accommodate local interests insofar as possible while protecting these nationally renowned natural resources.

Photos:
Williams (2012; photo taken by E. Granado);
piping plover sticker - Repanshek (2011; photo taken by B. Mishak)
Photos of dead sea turtle run over by an ORV - taken by the NPS
Present status of surface water quality in these national parks?

Objectives

- **Inventory** the natural resources of both Seashores (parks), including synthesis of available information,

- Develop a set of indicators, quantitative insofar as possible, for natural resource conditions that can be tracked over time, and

- Create a **Report Card** for the present status of natural resources in each park.
## Scope - natural resources evaluated (emphasis, past 15 years)

<table>
<thead>
<tr>
<th>Resource</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Surrounding land use</td>
</tr>
<tr>
<td>Air quality</td>
<td><strong>Surface water quality</strong>, quantity (frw - sw)</td>
</tr>
<tr>
<td>Lightscape</td>
<td>Groundwater</td>
</tr>
<tr>
<td>Noisescape</td>
<td>Geology and soils</td>
</tr>
<tr>
<td>Aquatic biota</td>
<td>Terrestrial and wetland biota</td>
</tr>
<tr>
<td>Species of special concern</td>
<td></td>
</tr>
</tbody>
</table>

CAHA and the adjacent villages rely entirely upon septic systems to treat human sewage → high potential for contamination of park waters due to septic effluent leachate with high nutrients, fecal bacteria and other pathogens, etc.
Land use / land cover

Main map: NCSU CAAE (S. Flood);
Cape Hatteras National Seashore (CAHA)

Town of Nags Head just to the north - **year-round population, ~2835**

**+ Eight villages (listed from north to south**

- Rodanthe (yr-round, 260 people)
- Waves (135)
- Salvo (320)
- Avon (775)
- Buxton (1,400)
- Frisco (200)
- Hatteras (550)
- Ocracoke Village (950)

**~4,590 yr-round**

**+ 2.34 million visitors per year**

**CAHA - 1st U.S. national seashore; “some of the most historic and environmentally fragile real estate in the world.”** 4th most visited U.S. coastal park / yr; NPS is adding 29 new access points.

General area (303(d) List - 2014) - obvious association with population centers; and

Both parks are near 2 of NC’s top 5 mercury air emission point sources. **State-wide advisory on fish consumption due to mercury content (NC DPH).**
Cape Lookout National Seashore (CALO)

…something of an anachronism in this day of the almighty, and much sought, tourist dollar. The Seashore’s lack of paved roads, of air-conditioned rental units, of marinas bobbing with catamarans, fishing fleets and yachts, and of seafood-dispensing shacks....

how the National Park Service manages Cape Lookout perhaps comes closest to the agency’s prime directive to preserve the resources. That the Park Service is able to hew so closely to that mandate best at Cape Lookout …no doubt is due to this Seashore’s isolated nature.

- Repanshek (2011)

Map: modified from NPS (2001);
Cape Lookout National Seashore (CALO)

Accessible only by boat; primitive amenities only.

No immediately adjacent human population centers; Morehead City and Beaufort are separated from the park by 5 km or more of sound waters.

Carteret County - ~68,000 people, or 50.7 people / km² (131.3 people / mile²)
Past 15 yr: 606,200 visitors per year (mean or median)

Impaired waters on the mainland; none 303(d)-listed at CALO [but statewide advisory on fish consumption due to mercury]
diverse marine, estuarine, and palustrine forested and emergent wetlands (saltmarshes), tidal creeks, estuarine waters, and marine coastal waters

~few fresh surface water resources~
• Perennial freshwater ponds throughout in interdunal areas or more open, flat wetland areas (but data 20-30 yr old);

• Ephemeral ponds;

• Hydrology complicated by numerous ditches (1970s)

• No freshwater rivers.

Maps from Mallin et al. (2006)
CAHA freshwaters: ponds and wetlands (examples)

Unnamed pond on northern Ocracoke Island near the ferry landing

Jennette Sedge, the largest freshwater wetland on Hatteras Is.*

*Photo: M. Mallin, UNCW

*Photo: http://www.dwhike.com/North- Carolina-Hikes/North- Carolina-National- Parks/Buxton- Woods-Dare- County- NC/i-8S8sx9g/0/XL.jpg
Conflicts - CAHA

Two culverts drain Jennette Sedge - carry water north into Pamlico Sound (1 has maximum drainage volume of 2.5 mgd). Major rainfalls flood wetlands, nearby NPS-operated campground, and some roads and ramps.

The NPS controls a drainage gate on Cape Point; adjacent population centers expect the NPS to drain wet areas after rainstorms so that nearby roads, ramps, and campgrounds can re-open quickly.

Wells supply all CAHA potable water for visitors, park operations; few data from the past 15 yr. NPS concerns: substantial drawdowns, potential saltwater intrusion, contamination by septic effluent leachate.
Numerous freshwater ponds on Core Banks, especially in the north (Portsmouth Island); widely vary in size, pH, vegetation etc.;

Also freshwater ponds on Shackleford Banks, especially on west end; and

Series of abandoned drainage ditches that hold water.

Photo: M. Mallin, UNCW
NPS sampling approaches and WQ evaluation
NPS and partners

- **Estuarine waters** (5-yr intervals; evaluation modified from U.S. EPA 2012):
  
  Limited daily and seasonal data for DO, salinity, temperature, pH, turbidity (fixed stations; depth profiles, 0.5-to 1-m intervals).

  Monthly or seasonal data for nutrients (TDN, TDP), suspended microalgal chlorophyll a (discrete samples at 1 to 3 depths / site).

- **Benthic sediment quality** (10-yr intervals) -
  
  grain size, TOC, selected polycyclic aromatic hydrocarbons (PAHs), PCBs, pesticides, metals. Evaluations based on ERL (effects range low, 10th percentile) and ERM (effects range median, 50th percentile) (Long and Morgan 1990, O'Connor 2004).

- **Fish Tissue Surveys** (whole body) - little information so far.
**U.S. EPA (2012) recommendations** based largely on areas substantially influenced by nutrient pollution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Quality (5-yr sampling frequency)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolved oxygen (DO) (mg/L)</td>
<td>&gt; 5</td>
<td>2 - 5</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Chlorophyll a (chla) (µg/L)</td>
<td>&lt; 5</td>
<td>5 - 20</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Dissolved inorganic nitrogen (DIN), summer (mg/L)</td>
<td>&lt; 0.1</td>
<td>0.1 - 0.5</td>
<td>&gt; 0.5</td>
</tr>
<tr>
<td>Dissolved inorganic phosphorus (DIP), summer (mg/L)</td>
<td>&lt; 0.01</td>
<td>0.01 - 0.05</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>Water clarity (% surface light at 1 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naturally high turbidity (a = 1.0)</td>
<td>&lt; 2.30</td>
<td>2.30 - 2.99</td>
<td>&gt; 3.00</td>
</tr>
<tr>
<td>Normal turbidity (a = 1.4)</td>
<td>&lt; 1.61</td>
<td>1.61 - 2.30</td>
<td>&gt; 2.30</td>
</tr>
<tr>
<td>Naturally low turbidity (a = 1.7)</td>
<td>&lt; 0.92</td>
<td>0.92 - 1.61</td>
<td>&gt; 1.61</td>
</tr>
</tbody>
</table>

**Our suggested changes** - more protective for national parks

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Quality (at least every 2 yr)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolved oxygen (DO) (mg/L)</td>
<td>&gt; 5</td>
<td>3 - 5</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>Chlorophyll a (chla) (µg/L)</td>
<td>&lt; 3</td>
<td>3 - 15</td>
<td>&gt; 15</td>
</tr>
<tr>
<td>Dissolved inorganic nitrogen (DIN), summer (mg/L)</td>
<td>&lt; 0.08</td>
<td>0.08 - 0.2</td>
<td>&gt; 0.2</td>
</tr>
<tr>
<td>Dissolved inorganic phosphorus (DIP), summer (mg/L)</td>
<td>&lt; 0.01</td>
<td>0.01 - 0.02</td>
<td>&gt; 0.02</td>
</tr>
</tbody>
</table>

(a) To capture more stochastic events that strongly influence water quality (Burkholder et al. 2006 and references therein); (b) Diaz et al. (2001) and references therein; (c) Burkholder and Glibert (2013)
Overall by Site and Overall for Park: U.S. EPA's (2012) recommendations vs. our Revised Criteria (more protective of national parks)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Site Water Quality Index Rating</th>
<th>PARK Water Quality Index Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td>&lt; 1 Indicator Fair and NO indicator Poor [6 indicators]</td>
<td>&lt; 10% of sites Poor; or &lt; 50% of sites Fair or Poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 5% of sites Poor; or &lt; 20% of sites Fair</td>
</tr>
<tr>
<td>FAIR</td>
<td>1 indicator Poor, or &gt; 2 indicators Fair</td>
<td>10-20% of sites Poor, or &gt; 50% of sites Fair or Poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 20 of sites Fair and &lt; 20% of sites Poor</td>
</tr>
<tr>
<td>POOR</td>
<td>&gt; 2 of the 5 indicators Poor</td>
<td>&gt; 20% of sites Poor</td>
</tr>
<tr>
<td>MISSING</td>
<td>2 components of the indicator are missing and the available indicators do not suggest a Fair or Poor rating</td>
<td>-----</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rating</th>
<th>Sediment Contaminants Rating (SC) and % TOC</th>
<th>Site Sediment Quality Index</th>
<th>Park Sediment Quality Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td>No ERM concentrations are exceeded and &lt; 5 ERL concentrations are exceeded; and TOC is &lt; 2%</td>
<td>Site SC is Fair or TOC is Fair</td>
<td>Park SC is Poor or TOC is Poor</td>
</tr>
<tr>
<td></td>
<td>See condition; and &lt; 50% of the sites are in Poor condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAIR</td>
<td>SC is Fair or TOC is Fair</td>
<td>5-15% of the sites are in Poor condition, or &gt; 50% of the sites are in Fair or Poor condition</td>
<td></td>
</tr>
<tr>
<td>POOR</td>
<td>An ERM concentration is exceeded for ≥ 1 contaminant; and TOC is &gt; 5%</td>
<td>SC is Poor or TOC is Poor</td>
<td>&gt; 15% of sites are in Poor condition</td>
</tr>
</tbody>
</table>

Few sediment quality data yet available; ~98% Good
Cape Hatteras National Seashore
Available data at CAHA (past ~15 yr)

- **2000-2009**: WQ, sediment quality, and fish tissue surveys from CAHA estuarine waters and within a 32-km boundary around the park (Parman et al. 2012) - used annual averages, evaluated park waters as **Good** except
  - 25% of chla samples high (> 15 µg/L);
  - Sediments contaminated with arsenic relative to sediments outside the park [automobile pollution, surface runoff from population centers]. Note - no fish tissue data available from park waters.

- **2007 on**: NPS continuous monitoring data (1 station at Ocracoke Village), augmented monthly WQ sampling at the same station - hypoxic conditions on some dates in summer.
Available data at CAHA (cont’d.)

- **July 2010**: discrete sampling at 17 sites - WQ **Good** except:
  
  ★ Chla 14 - 19 µg/L (**Poor** - 2 dates), 6 µg/L (**Fair** - 1 date) [18% total]
  
  ★ Higher levels of TDN (0.5 to 0.6 mg/L) more common in northern soundside waters, reflecting higher human population;
  
  ★ Sediment quality **Good**.

- **2010, 2011 (monthly)**: discrete samples at the 1 continuous monitoring station: WQ **Fair**.
  
  ★ Chla **Fair** (5 - 20 µg/L) on 50% of dates.
  
  ★ Turbidity 8.4 NTU (monthly mean); maximum 440 NTU (not explained).
Available data at CAHA (cont'd.)

- **U.S. EPA STORET data**, QA/QC'd (georeferenced; each entry checked), including 29 stations *(2000 - 2014)*
  - 14 stations - NPS (sampled only on 1 [other] date)
  - 9 stations - NC Recreational WQ Program [of NC DEQ - Enterococcus]
  - 6 stations - U.S. EPA Estuarine Monitoring & Assessment Program (EMAP - sampled only on 1 date)

<table>
<thead>
<tr>
<th>Soundside:</th>
<th>Phosphate</th>
<th>Good - 30% (6); Fair – 60% (13); Poor - 1 (233 µg/L).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chla</td>
<td>Good - 42%; Fair - 58% <em>(revised criteria).</em></td>
</tr>
<tr>
<td></td>
<td>DO, turbidity, DIN</td>
<td>Good</td>
</tr>
<tr>
<td>Enterococcus</td>
<td>4% of samples exceeded state criterion (n = 40 of 1,431) - Good</td>
<td></td>
</tr>
</tbody>
</table>

Oceanside data for Enterococcus only - all but 1 sample (n = 3,608) **Good**.
Available data at CAHA (cont'd.)

- **Mallin and McIver (7 dates, April - Oct. 2007):** TN, NH$_4^+$N, NO$_3^-$N, TP, SRP, TOC, chla, BOD$_5$, fecal coliform bacteria, Enterococcus - captured **surface water and shallow groundwater:**

  Six large, brackish drainage ditches and creeks flowing westward from Nags Head through CAHA (D-1 through D-5; the first three open to Roanoke Sound), and the main drainage ditch along Old Oregon Inlet Rd (UR-D).

  Three ponds -
  - **urban pond (UR-P)** partly in CAHA - receives road runoff during storms, and is connected to the drainage ditches;
  - **pond WW-P** - estuarine, in CAHA, just west of Hwy 12; major use by wildlife.
  - **pond C-P ('control')** - estuarine, on the west side of Hwy 12, not connected to ditches.
Summary data for **biological water quality parameters**, South Bodie Island, CAHA and environs, April - October 2007 (n= 6 dates; medians and ranges). D = ditches; UR-P = urban pond; WW-P = wildlife pond; C-P = ‘control’ pond. From Mallin and McIver (2012).

<table>
<thead>
<tr>
<th>Site</th>
<th>TOC (mg/L)</th>
<th>BOD (mg/L)</th>
<th>Chla (µg/L)</th>
<th>Fecal Coliforms (CFU/100 mL)</th>
<th>Enterococcus (CFU/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-1</td>
<td>20 (8 - 25)</td>
<td>4.0 (1.5 - 6.0)</td>
<td>33 (6 - 47)</td>
<td>194 (29 - 700)</td>
<td>596 (220 - 2260)</td>
</tr>
<tr>
<td>D-2</td>
<td>24 (7 - 31)</td>
<td>4.9 (1.5 - 11.0)</td>
<td>30 (6 - 42)</td>
<td>213 (49 - 1180)</td>
<td>443 (113 - 2680)</td>
</tr>
<tr>
<td>D-3</td>
<td>24 (11 - 37)</td>
<td>5.0 (1.5 - 6.0)</td>
<td>41 (10 - 155)</td>
<td>216 (100 - 680)</td>
<td>348 (57 - 2480)</td>
</tr>
<tr>
<td>D-4</td>
<td>32 (13 - 38)</td>
<td>5.0 (2.0 - 8.0)</td>
<td>23 (10 - 86)</td>
<td>305 (79 - 1720)</td>
<td>272 (20 - 4000)</td>
</tr>
<tr>
<td>D-5</td>
<td>27 (17 - 57)</td>
<td>6.0 (5.0 - 9.0)</td>
<td>49 (6 - 275)</td>
<td>95 (3 - 940)</td>
<td>367 (18 - 2860)</td>
</tr>
<tr>
<td>UR-D</td>
<td>14 (6 - 16)</td>
<td>2.5 (2.0 - 8.0)</td>
<td>20 (7 - 52)</td>
<td>204 (117 - 364)</td>
<td>6267 (2000 - 25900)</td>
</tr>
<tr>
<td>UR-P</td>
<td>14 (13 - 16)</td>
<td>7.5 (1.5 - 12.0)</td>
<td>57 (32 - 175)</td>
<td>72 (25 - 315)</td>
<td>82 (2 - 440)</td>
</tr>
<tr>
<td>WW-P</td>
<td>18 (10 - 240)</td>
<td>3.0 (3.0 - 7.0)</td>
<td>35 (5 - 91)</td>
<td>289 (52 - 640)</td>
<td>715 (135 - 2620)</td>
</tr>
<tr>
<td>C-P</td>
<td>25 (16 - 36)</td>
<td>4.5 (1.5 - 7.0)</td>
<td>21 (9 - 62)</td>
<td>29 (1 - 540)</td>
<td>80 (1 - 1920)</td>
</tr>
</tbody>
</table>

**NC stds:**  
< 40  
< 14 or 200 (GM)  
< 104 (GM)

Mean BOD$_5$ 3.5 to 6.9 mg/L  [healthy waters < 3 mg/L - Mallin et al. 2006]  
Fecal coliforms, Enterococcus commonly in violation of NC standards at 6 of 9 stations.
Summary data for nutrient water quality parameters, South Bodie Island, CAHA and environs, April - October 2007 (n= 6 dates; medians and ranges). D = ditches; UR-P = urban pond; WW-P = wildlife pond; C-P = ‘control’ pond. From Mallin and McIver (2012).

<table>
<thead>
<tr>
<th>Site</th>
<th>Nitrate (µg/L)</th>
<th>Ammonium (µg/L)</th>
<th>TN (mg/L)</th>
<th>TP (µg/100 mL)</th>
<th>DIP (µg/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-1</td>
<td>20 (9 - 54)</td>
<td>120 (17 - 745)</td>
<td>1.59 (1.05 - 1.83)</td>
<td>363 (110 - 731)</td>
<td>163 (14 - 782)</td>
</tr>
<tr>
<td>D-2</td>
<td>30 (11 - 46)</td>
<td>71 (14 - 588)</td>
<td>1.38 (0.95 - 2.15)</td>
<td>183 (92 - 603)</td>
<td>71 (6 - 579)</td>
</tr>
<tr>
<td>D-3</td>
<td>30 (5 - 85)</td>
<td>46 (19 - 493)</td>
<td>1.46 (1.00 - 2.76)</td>
<td>224 (87 - 396)</td>
<td>84 (9 - 238)</td>
</tr>
<tr>
<td>D-4</td>
<td>13 (5 - 29)</td>
<td>70 (20 - 509)</td>
<td>1.71 (1.30 - 2.99)</td>
<td>140 (75 - 294)</td>
<td>37 (11 - 160)</td>
</tr>
<tr>
<td>D-5</td>
<td>14 (6 - 28)</td>
<td>124 (90 - 635)</td>
<td>2.21 (1.88 - 6.00)</td>
<td>232 (190 - 283)</td>
<td>54 (28 - 177)</td>
</tr>
<tr>
<td>UR-D</td>
<td>59 (29 - 141)</td>
<td>225 (137 - 354)</td>
<td>1.27 (0.64 - 1.61)</td>
<td>299 (92 - 387)</td>
<td>189 (20 - 279)</td>
</tr>
<tr>
<td>UR-P</td>
<td>30 (5 - 148)</td>
<td>43 (29 - 968)</td>
<td>1.99 (1.41 - 2.74)</td>
<td>248 (181 - 491)</td>
<td>81 (29 - 284)</td>
</tr>
<tr>
<td>WW-P</td>
<td>12 (5 - 41)</td>
<td>44 (26 - 158)</td>
<td>1.20 (0.88 - 1.58)</td>
<td>365 (35 - 161)</td>
<td>147 (65 - 326)</td>
</tr>
<tr>
<td>C-P</td>
<td>7 (1 - 38)</td>
<td>41 (24 - 45)</td>
<td>1.40 (1.40 - 2.92)</td>
<td>57 (35 - 161)</td>
<td>6 (4 - 46)</td>
</tr>
</tbody>
</table>

Mean chl a 28-83 µg/L; mean DIN > 200 µg/L (all stations); mean DIP > 50 µg/L at 8 of 9 stations, > 100 µg/L at 6 of 9 stations.
Significant positive relationship: \textbf{BOD}_5 \textit{vs. Chla}, South Bodie Island in and near CAHA (9 stations, \( n = 6 \) sampling dates). From Mallin and McIver (2012).
NH$_4^+$N and TP (means, n = 9 stations, biweekly in March - Nov. 2011), South Bodie Island surface waters in and near CAHA, compared to monthly municipal water use in Nags Head. Modified from Mallin and McIver (2012).
Ditch with cyanobacterial mats in Nags Head, contaminated by septic effluent leachate; this ditch emptied into Roanoke Sound. From Mallin et al. (2006).
Three interpretations

Septic system usage is widespread in the area; the villages adjacent to CAHA are all on septic systems and receive seasonal use by more than 2 million people.

Much more nutrient and fecal bacteria pollution in summer, coinciding with high algal growth.

The sandy soils, high water tables, and proximity to beach areas are conducive to potentially serious pollution impacts on surface waters, public safety.

*Supported by information from NC DEQ on shellfish bed closures due to excessive fecal bacteria.*
Cape Lookout National Seashore
Available data at CALO (past ~15 yr)

- **2000-2009:** WQ, sediment quality, and fish tissue survey from CALO estuarine waters and within a 32-km boundary around the park (Parman et al. 2012) - used annual averages, evaluated park waters as **Good** except:
  - Fish tissue data (near Core Banks) - **Fair** or **Poor** for arsenic, PAHs, and mercury. May reflect contamination from an aboveground storage tank, incinerator, and refueling pad on the island.

  (Note: Sediment quality data were questionable.)

- **2008 on:** NPS continuous monitoring data (1-2 stations), augmented monthly WQ sampling at the same 2 stations - **Good**; no hypoxia except occasionally in August at the Shackleford Banks site.
Available data at CALO (cont’d.)

• **July 2010:** 13 sites sampled; WQ **Good** - 
  - Chla  12 of 13 sites **Good** (< 5 µg/L), 1 site **Fair** (7 µg/L); 
  - DO  1 site indicating an algal bloom (9.23 mg/L).
  - Sediment quality **Good**.

• **2010, 2011, 2012 (monthly):** WQ at the 2 continuous monitoring stations 
  (discrete samples) - **Good** for all parameters.
Available data at CALO (cont'd.)

- **U.S. EPA STORET data, QA/QC'd** (georeferenced; each entry checked), including 29 stations within 8 km of the park (2000 - 2014)
  - 13 stations - NPS (sampled only on 1 [other] date)
  - 9 stations - NC Recreational WQ Program [of NC DEQ - Enterococcus]
  - 7 stations - U.S. EPA Estuarine Monitoring & Assessment Program (EMAP - sampled only on 1 date)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphate</td>
<td>Fair conditions (10-20 µg/L)</td>
</tr>
<tr>
<td>Chla</td>
<td>Good (&lt; 5 µg chla/L; turbidity also Good)</td>
</tr>
<tr>
<td>DO, DIN</td>
<td>Good (&gt; 5 mg/L, &lt; 100 µg/L, respectively)</td>
</tr>
<tr>
<td>Enterococcus</td>
<td>&lt; 0.5% of samples exceeded state criterion (3 of 836 samples) - Good</td>
</tr>
</tbody>
</table>

Oceanside data for Enterococcus only; 2% in exceedance (18 of 847) - **Good**
Limited Information on Groundwater at CALO

* Stable consumption over time;
* Very limited sampling - high nitrate, ammonium, and TP at some wells (Mallin et al. 2006)

Freshwater supply close to the land surface -

Thin soils likely inadequate to handle septic effluent leachate, wastes from horses (Mallin et al. 2006).

Photo: M. Mallin, UNCW
Final Evaluations
## Cape Hatteras National Seashore

<table>
<thead>
<tr>
<th>Surface WQ Indicators</th>
<th>NPS Management Target(s)</th>
<th>CAHA</th>
</tr>
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</table>
| **DO (mid-day)**      | U.S. EPA recs.: Good >5, Fair 2-5, Poor < 2
Revised: Fair 3-5, Poor < 3
State: > 4 | North of Hatteras Island, Soundside: U.S. EPA rec. or Revised - 100% Good (n = 27, 9 sites)
Hatteras Island and South, Soundside: U.S. EPA rec. or Revised - 100% Good (n = 45, 8 sites)
Oceanside - N.A. | **Good** |
| **DIP (µg/L)**        | U.S. EPA recs.: Good < 10, Fair 10-50, Poor > 50
Revised: Good < 10, Fair 10-20, Poor > 20 | North of Hatteras Island, Soundside (n = 12, 10 sites): U.S. EPA rec. - 25% Good (3), 75% Fair (9);
Revised - 25% Good (3), 67% Fair (8), 8% Poor (1).
Hatteras Island and South, Soundside (n = 21, 11 sites): U.S. EPA rec., Revised - 29% Good (6), 71% Fair (15).
Oceanside - N.A.
Overall (Soundside only) (n = 33, 21 sites): U.S. EPA rec. - 27% Good (9), 73% Fair (24);
Revised - 27% Good (9), 70% Fair (23), 3% Poor (1). | **Fair** |
| **DIN (µg/L)**        | U.S. EPA recs.: Good < 100, Fair 100-500, Poor > 500
Revised: Good < 80, Fair 80-200, Poor > 200 | North of Hatteras Island (n = 3, 3 sites):
U.S. EPA rec. or Revised - 100% Good (3)
Hatteras Island and South (n = 5, 3 sites):
U.S. EPA rec., Revised - 80% Good (4), 20% Fair (1).
Oceanside - N.A.
Overall Soundside (n = 8, 6 sites): too few data for evaluation. | **N.A.** |

Note: **Turbidity** data 98% **Good**.
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| **Chla** (µg/L)                  | U.S. EPA recs.: Good < 5, Fair 5-20, Poor > 20  
Revised: Good < 3, Fair 3-15, Poor > 15 | North of Hatteras Island (n = 22, 10 sites):  
U.S. EPA rec. - 86% Good (19), 14% Fair (3);  
Revised - 45% Good (10), 55% Fair (22)  
Hatteras Island and South (n = 33, 9 sites):  
U.S. EPA rec. - 94% Good (31), 6% Fair (2).  
Revised - 39% Good (13), 20 Fair (61%).  
Oceanside - N.A.  
Overall Soundside (n = 55, 19 sites):  
U.S. EPA rec. - 91% Good (50), 8% Fair (5).  
Revised - 42% Good (23), 58% Fair (32). | Good (EPA)  
Fair (Rev.) |
| **Enterococci** (CFU / 100 mL)   | NC Std. < 104 (GM)       | North of Hatteras Island, Soundside (n = 1,121; 7 sites):  
97% in compliance (19), 3% in violation (34), assuming GMs.  
Hatteras Island and South, Soundside (n = 310; 2 sites) - 98% in compliance (304), 2% in violation (6), assuming GMs.  
Oceanside (n = 1,984 N + 1,624 S) - 1 sample in violation (**100% in compliance).  
Overall Soundside (n = 1,431; 9 sites): 97% in compliance (1,391), 3% in violation (40). | Good |
# Overall Evaluation - Surface Water Quality at CAHA

<table>
<thead>
<tr>
<th>Evaluation* (Revised)</th>
<th>DO (mg/L)</th>
<th>Chlorophyll a (µg/L)</th>
<th>Water Clarity (Turbidity)</th>
<th>DIN (µg/L)</th>
<th>DIP (µg/L)</th>
<th>Entero (GM, CFU/100 mL)</th>
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<tr>
<td>Good &gt; 5</td>
<td>&lt; 3</td>
<td>Naturally high &lt; 2.30</td>
<td>&lt; 80</td>
<td>&lt; 10</td>
<td>≤ 10% in violation</td>
<td></td>
</tr>
<tr>
<td>Fair 3-5</td>
<td>3-10</td>
<td>Normal &lt; 1.61;</td>
<td>80 - 120</td>
<td>10 - 20</td>
<td>&gt; 10% to 30% in violation</td>
<td></td>
</tr>
<tr>
<td>Poor &lt; 3</td>
<td>&gt; 10</td>
<td>Naturally low &lt; 0.92</td>
<td>&lt; 2.30; &lt; 1.61; or &lt; 0.92</td>
<td>&gt; 120</td>
<td>&gt; 20</td>
<td>&gt; 30% in violation</td>
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**OVERALL SITE CRITERIA (6 parameters):**
- GOOD: ≤ 1 indicator is Fair, 0 indicators are Poor
- FAIR: 1 indicator is Poor or > 2 indicators are Fair.
- POOR: ≥ 2 indicators are Poor

**OVERALL SEASHORE CRITERIA (6 parameters):** (Revised - modified from U.S. EPA 2012)
- GOOD: ≤ 5% of sites are in Poor condition, ≤ 20% of sites are in Fair Condition
- FAIR: >20% of sites are in Fair Condition and < 20% of sites are in Poor Condition
- POOR: > 20% of sites are in Poor Condition

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Overall Evaluation - FAIR [DIP, Chla Fair - Revised criteria]

Overall Evaluation - GOOD [DIP Fair - U.S. EPA recomm.]
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<th>Surface WQ Indicators</th>
<th>CALO</th>
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<td><strong>DO</strong> (mid-day, mg/L)</td>
<td>Soundside: Pamlico S. - 21 Good; Core S.: 20 Good; Back S. - 22 Good (n = 63; 100% Good; sampled mid-day)</td>
<td>Good</td>
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<td><strong>Turbidity</strong> (1 m, ntu)</td>
<td>98% of samples Good</td>
<td>Good</td>
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<td><strong>DIP</strong> (µg/L)</td>
<td>Soundside: Pamlico S. - 4 Good (50%), 4 Fair (50%); Core S. - 3 Good (27%), 8 Fair (73%); Back S. - 5 Good (45%), 3 Fair (55%); Total (n = 27): 44% Good, 55% Fair.</td>
<td>Fair</td>
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<td><strong>DIN</strong> (µg/L)</td>
<td>Soundside: Pamlico S.- 4 Good (100%); Core S. - 4 Good (67%), 2 Fair (33%) Total (n = 10): 80% Good, 20% Fair - but sparse samples, inadequate for evaluation.</td>
<td>N.A.</td>
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<td><strong>Chla</strong> (µg/L)</td>
<td>Soundside: Pamlico S. - 10 Good (83%), 2 Fair (17%); Core S. - 20 Good (100%); Back Sound - 18 Good (100%)</td>
<td>Good</td>
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<tr>
<td><strong>Enterococci</strong> (CFU / 100 mL)</td>
<td>Soundside: Core S. - 184 of 188 samples in compliance (98%, 2 stations); Baek S. - 635 of 648 samples in compliance (98%, 4 stations) Oceanside: 829 of 847 samples in compliance (98%; 3 stations)</td>
<td>Good</td>
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<td>2.30-2.99; 1.61-2.30; or 0.92-1.61</td>
<td>&lt; 2.30; &lt; 1.61; or &lt; 0.92</td>
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**OVERALL SEASHORE CRITERIA (6 parameters):**

- GOOD: ≤ 5% of sites are in Poor condition, ≤ 20% of sites are in Fair Condition
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**Overall Evaluation – GOOD (both methods)**
Surface WQ at Cape Hatteras and Cape Lookout Seashores

Overall, surface WQ and groundwater supply were assessed as presently **Good** at CALO, whereas surface WQ is only **Fair** and groundwater supply is threatened at CAHA.

Surface WQ data collection sparse and sporadic; more frequent sampling needed at the 17 / 13 stations.

This approach can be used by the NPS in developing an easily understood evaluation based on consistent, quantitative assessment of surface water quality. It can be extended, as well, for use in evaluating other natural resources in these parks.

Photo:  https://s-media-cache-ak0.pinimg.com/originals/51/46/48/e0fb6078ed025718558fc7ed85.jpg
Thank you