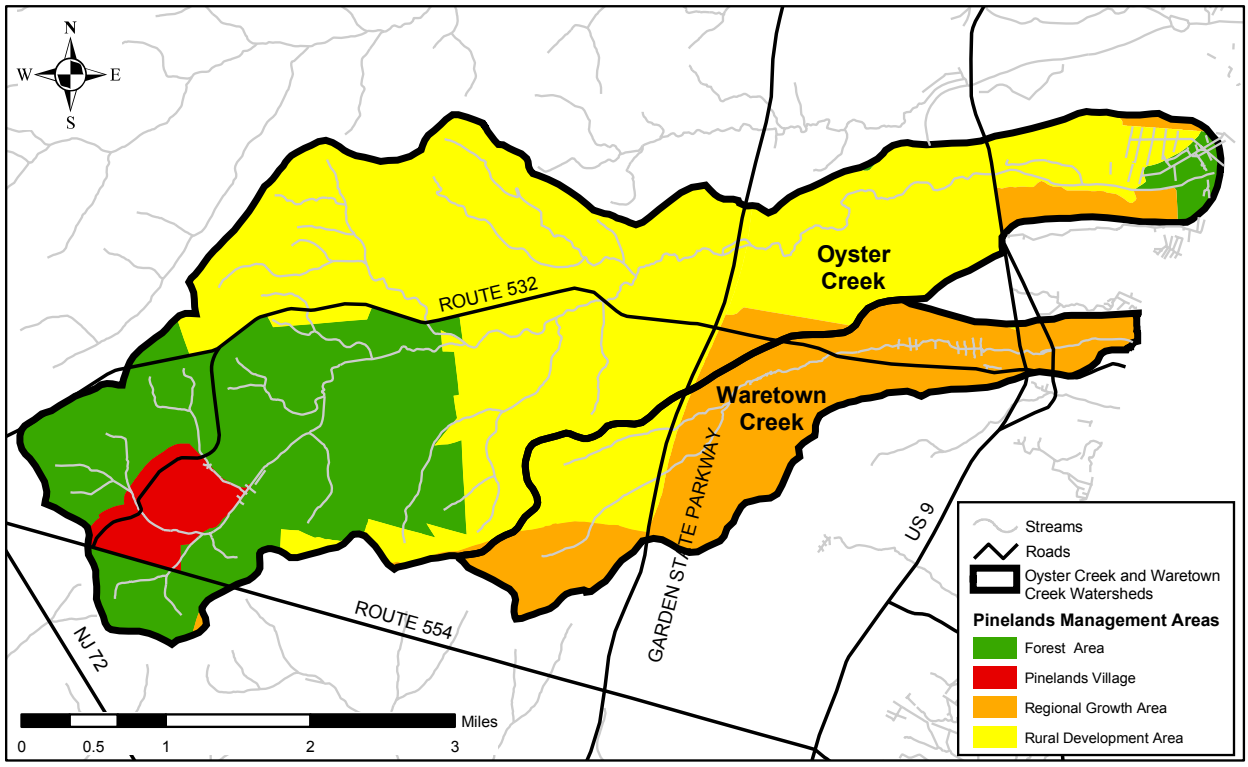
THE ESSENTIAL CHARACTER OF THE OYSTER CREEK WATERSHED

ROBERT A. ZAMPELLA, NICHOLAS A. PROCOPIO,
KIM J. LAIDIG AND JOHN F. BUNNELL



Pinelands Commission
P.O. Box 7
New Lisbon, NJ 08064

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Introduction

In the 1980 Comprehensive Management Plan (CMP, Pinelands Commission 1980), the Commission used several criteria to define the essential character of the Pinelands environment. Characterizing essential character was a first step in delineating Pinelands management areas within the Protection Area. The criteria used included undisturbed subwatersheds, wetlands, cranberry cultivation areas, areas of deep aquifer recharge, unique resources requiring high levels of protection, public lands managed for resource protection or recreation, and ecologically critical areas.

Undisturbed subwatersheds were drainages that had very little development in them, particularly development that degrades surface and groundwater quality and fragments the Pinelands ecosystem. Wetlands included cedar swamps, hardwood swamps, pitch pine lowland forests, bogs, inland marshes, and coastal marshes. Unique resources that require high levels of protection included the Pine Plains and a surrounding buffer zone and subwatersheds supporting characteristic Pinelands aquatic species. The presence of threatened and endangered species was generally the most important factor determining the designation of a subwatershed as an ecologically critical area.

The delineation of areas of essential character provided the basis for the designation of Pinelands Forest Areas. Designation of other management areas followed. Conflict areas were identified as a last step. Conflict areas were areas where lands considered suitable for appropriate patterns of development overlapped with areas displaying essential character. When a conflict area that was classified as a Rural Development Area exhibited essential character as an undisturbed watershed or had greater than seventy-five percent wetlands or critical areas, it was reclassified as a Forest Area. Additionally, areas of less than 1,000 acres that did not exhibit essential character but were entirely surrounded by areas of essential character became Forest Areas.

The 1980 CMP designated the majority of the 6,459-acre Pinelands Area portion of Oyster Creek as either Forest Area or Rural Development Area. Designation of the Rural Development Area, which was a conflict area, was due primarily to the presence of the Southern Ocean Landfill. Currently, 55% and 39% of the Pinelands Area portion of the watershed is designated Rural Development Area and Forest Area, respectively (Table 1, Figure 1). A small percentage of the Pinelands Area is classified as Pinelands Village (5.2%) and Regional Growth Area (< 1%).

The purpose of this report is to present information on the natural resources of Oyster Creek that may allow the Commission to reevaluate the existing land management designations. A brief description of the Waretown Creek watershed is also given. The primary question asked is: Does the Oyster Creek watershed display the essential character of the Pinelands? This question is answered by addressing the individual criteria used to define essential character.

Delineating Drainage Units

The 1980 CMP divided Oyster Creek into two subwatersheds of unequal size, including Oyster Creek above Wells Mills Pond and the rest of the drainage, which represented a majority of the watershed. For the reassessment of the Oyster Creek watershed, we created a detailed drainage-basin map that divided the area into many discrete drainage units. Using ten-foot contour lines depicted on digital USGS 1:24,000 scale quadrangles and on-screen digitizing, we delineated drainage areas for all permanent and intermittent streams shown on the maps. We cut drainage units at the confluence of two streams. This process resulted in the delineation of 49 drainage units in the Pinelands Area with an additional unit when the entire 8,314 acre (13 square miles) Pinelands National Reserve (PNR) portion of Oyster Creek was included (Figure 2). The size of the Pinelands Area drainage units ranged from 2.6–586 acres, with a 25^{th}, 50^{th} (median), and 75^{th} percentile of 63, 104, and 166 acres. The single drainage unit located east of the Garden State Parkway (unit 50) was 1855 acres. The size of the individual drainage units did not vary much with increasing stream order. The median area for units representing first, second, third, and fourth order stream basins was 104 acres, 98, acres, 160 acres, and 113 acres.

Table 1. Percent land use and Pinelands Management Areas for Oyster Creek above the Garden State Parkway (Pinelands Area: drainage units 1-49 in Figure 2) and at the mouth (Pinelands National Reserve: drainage units 1-50 in Figure 2).

Oyster Creek in Pinelands Area	Percent by Land-use Class							
Pinelands Management Area	Barren Land	Developed Land	Upland Agriculture	Upland Forest	Water	Wetland Agriculture	Wetlands	Total
Forest Area	1.5	2.1	0.0	79.3	1.1	0.5	15.6	39.2
Pinelands Village	0.9	17.9	3.2	67.0	0.8	3.1	7.0	5.2
Regional Growth Area	0.0	1.6	0.0	98.4	0.0	0.0	0.0	0.3
Rural Development Area	2.0	1.9	0.0	72.5	0.3	0.0	23.3	55.3
Total	1.7	2.8	0.2	75.0	0.6	0.3	19.4	100

Oyster Creek at mouth	Percent by Land-use Class							
Pinelands Management Area	Barren Land	Developed Land	Upland Agriculture	Upland Forest	Water	Wetland Agriculture	Wetlands	Total
Forest Area	1.4	2.0	0.0	75.8	1.6	0.4	18.8	31.9
Pinelands Village	0.9	17.9	3.2	67.0	0.8	3.1	7.0	4.0
Regional Growth Area	0.4	40.0	0.0	47.9	5.8	0.0	6.0	4.3
Rural Development Area	1.7	3.1	0.0	66.7	1.8	0.0	26.7	59.8
Total	1.5	4.9	0.1	68.8	1.9	0.3	22.5	100

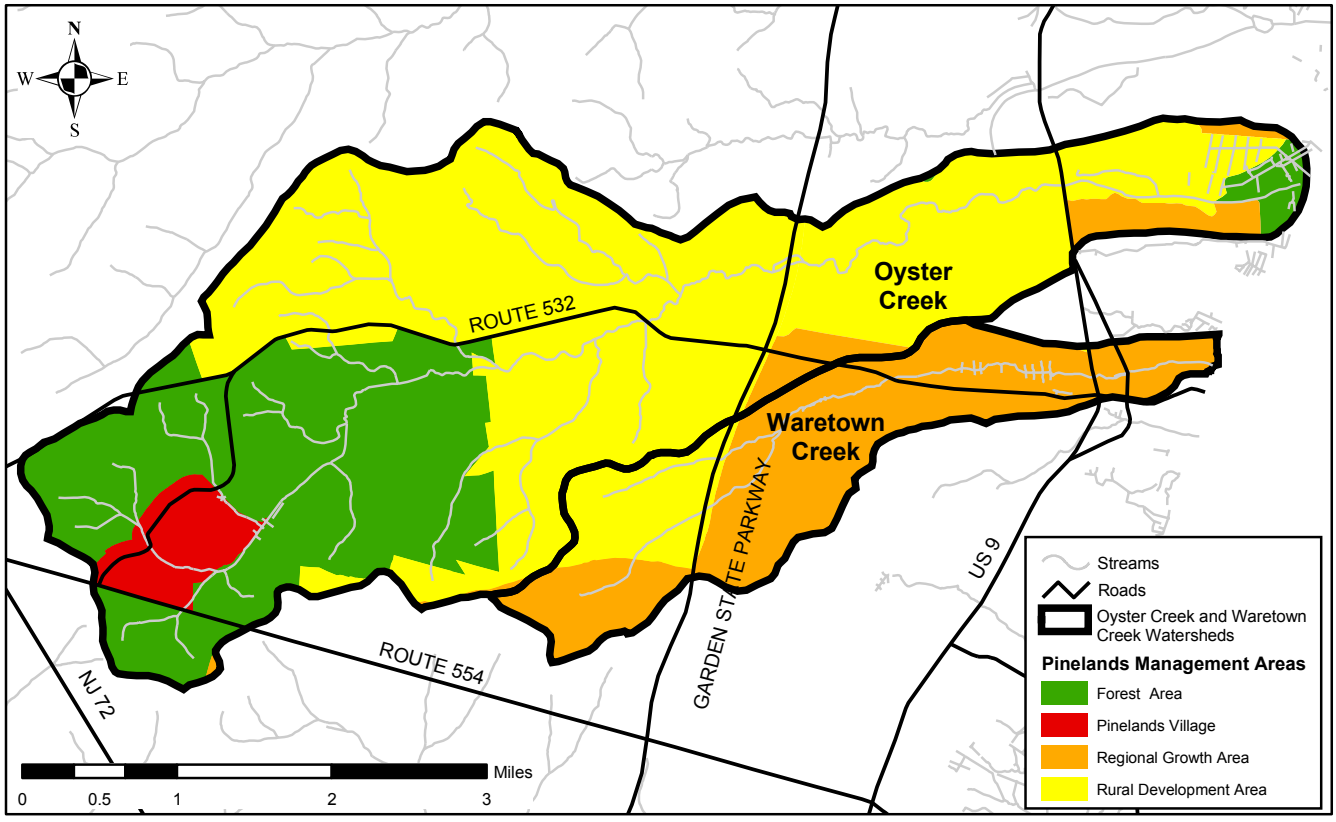

Figure 1. Pinelands Management Areas in the Oyster Creek and Waretown Creek watersheds.

Undisturbed Subwatersheds

The 1980 CMP classified subwatersheds as undisturbed if they satisfied all of the following criteria: 1) less than 5 percent in urban or developed land use-categories; 2) less than 10 percent of area in active agricultural land categories; 3) no point sources of pollution; and 4) no major solid waste disposal sites. Development that degrades surface and groundwater quality and fragments the Pinelands ecosystem was of particular interest. An assessment of land use and water-quality characteristics of the watershed is presented in this section, along with information on the Southern Ocean Landfill.

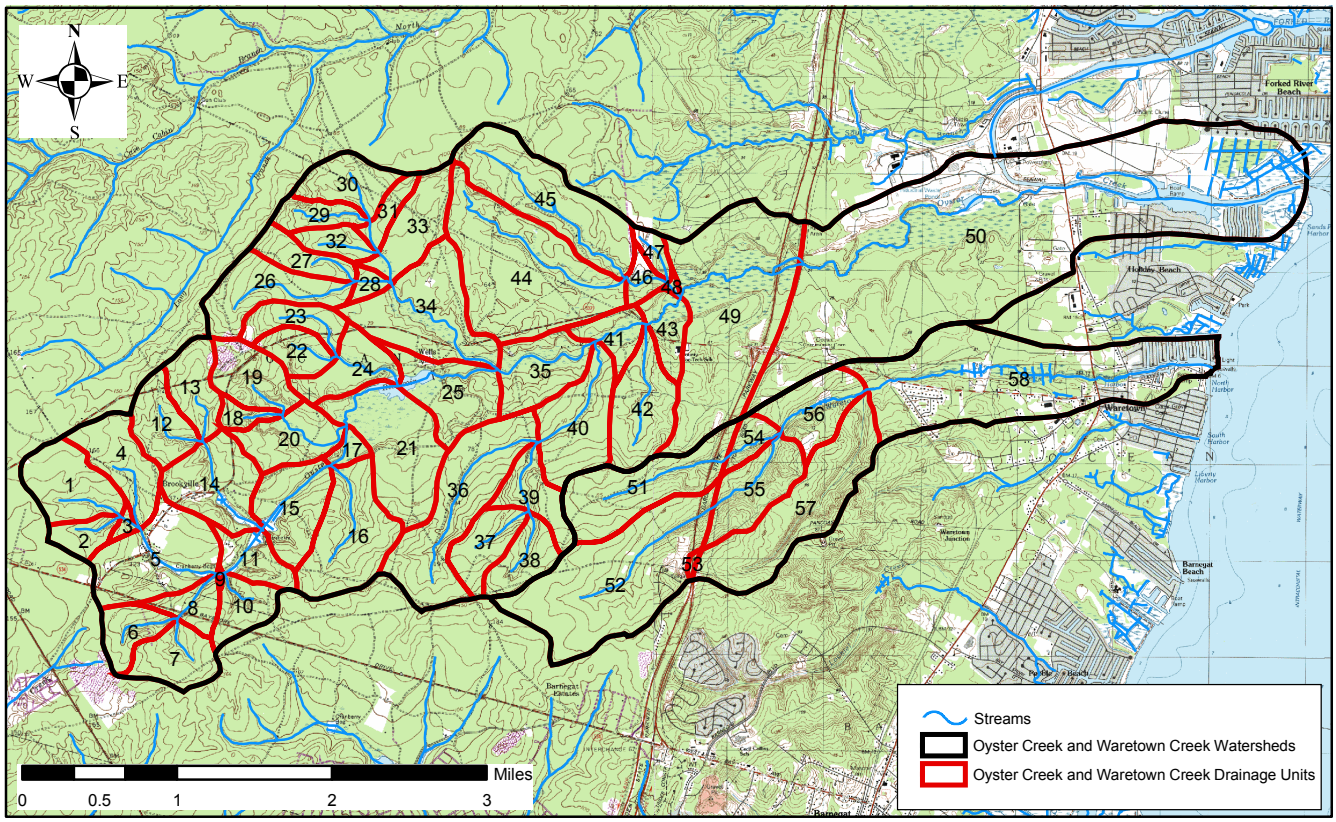

Figure 2. Individual drainage units of Oyster Creek and Waretown Creek.

Developed and Agricultural Lands

Using the digital NJDEP 1995/97 Land Use/Land Cover data, we prepared land-use profiles for each drainage unit by summing the area of major land-use/land-cover classes for the entire upstream drainage area. Land-use types included developed land (urban land), upland agriculture, including orchards (agriculture), wetland agriculture (agricultural wetlands), barren land (including most of Southern Ocean Landfill), upland forest (forest), wetlands, and water.

In 1995, nearly all drainage areas in the Oyster Creek were minimally disturbed, with the percentage of altered-land use (developed land and upland agriculture) within the 50 individual cumulative drainages ranging from 0% to 10.4% (Table 2, Figure 3). Forest land (upland forest, wetlands, and water) covered 95% of the Pinelands Area. Altered land, comprised of 2.8% developed land and 0.2% upland agriculture, covered only 3% of this area. A review of 2000 aerial photography indicates that there has been little increase in altered land within the Pinelands Area portion of the Oyster Creek watershed since 1995. At 5.1%, the percentage of altered land increased slightly when the entire PNR was included.

Median altered-land use (developed land and upland agriculture) percentages for first (headwaters), second, third, and fourth order streams in the watershed were 0%, 1.1%, 6.2%, and 3%, respectively. Only seven of the fifty cumulative drainage areas exceeded the five-percent developed-land criteria used to designate Forest Areas. Developed land in these drainages ranged from 5.6% to 8.8%. Most of the drainages were associated with

Table 2. Percent land-use of Oyster Creek drainage areas associated with individual drainage units. Refer to Figure 2 for drainage-unit locations (Pinelands Area: drainage units 1-49 and PNR: drainage units 1-50).

Drainage Unit Number	Stream Order	Barren Land	Developed Land	Upland Agriculture	Upland Forest	Water	Wetland Agriculture	Wetlands	Area (mi^2)
1	1	5.1	3.3	0.0	90.6	0.0	0.0	1.0	0.2
2	1	0.0	0.0	0.0	99.9	0.0	0.0	0.1	0.1
3	2	3.6	2.3	0.0	92.4	0.0	0.0	1.7	0.3
4	1	0.0	8.3	0.4	89.9	0.0	0.0	1.3	0.2
5	2	2.1	8.8	1.6	83.8	0.4	0.0	3.3	0.9
6	1	10.9	0.0	0.0	88.4	0.0	0.0	0.7	0.1
7	1	3.5	0.0	0.0	95.8	0.0	0.0	0.6	0.2
8	2	5.0	1.7	0.0	90.5	0.2	0.0	2.6	0.4
9	3	2.9	6.7	1.1	85.7	0.5	0.0	3.1	1.3
10	1	0.0	0.0	0.0	95.7	0.6	0.0	3.7	0.1
11	3	2.4	6.7	1.0	85.0	0.6	0.5	3.8	1.6
12	1	0.6	0.0	0.0	94.2	0.0	0.0	5.2	0.2
13	1	31.7	0.0	0.0	65.2	0.0	0.0	3.1	0.2
14	2	8.5	5.9	0.0	76.2	0.1	2.1	7.1	0.6
15	3	3.8	6.5	0.7	81.9	0.4	1.4	5.4	2.5
16	1	0.0	0.0	0.0	92.6	0.0	0.0	7.4	0.4
17	3	3.2	5.6	0.6	82.5	0.4	1.2	6.5	2.9
18	1	0.0	0.0	0.0	71.4	0.0	0.0	28.6	0.0
19	1	15.9	2.5	0.0	68.4	0.4	0.0	12.9	0.2
20	2	7.1	1.1	0.0	67.5	0.2	0.0	24.2	0.4
21	3	3.3	4.4	0.4	77.6	0.8	0.9	12.5	3.7
22	1	0.0	0.0	0.0	69.8	0.0	0.0	30.2	0.1
23	1	0.1	0.0	0.0	66.2	0.0	0.0	33.7	0.1
24	2	0.0	0.0	0.0	71.4	0.6	0.0	28.0	0.4
25	3	2.8	3.9	0.4	75.3	1.1	0.8	15.8	4.4
26	1	15.7	0.0	0.0	57.4	0.0	0.0	26.8	0.3
27	1	0.0	0.0	0.0	72.4	0.0	0.0	27.6	0.1
28	2	9.8	0.0	0.0	63.1	0.0	0.0	27.0	0.4
29	1	0.0	0.0	0.0	73.6	0.0	0.0	26.4	0.1
30	1	0.0	0.0	0.0	94.7	0.0	0.0	5.3	0.2
31	2	0.0	0.0	0.0	86.3	0.0	0.0	13.7	0.3
32	1	0.0	0.0	0.0	76.1	0.0	0.0	23.9	0.1
33	2	0.0	0.0	0.0	86.1	0.0	0.0	13.9	0.6
34	3	2.8	0.7	0.0	75.6	0.0	0.0	20.8	1.5
35	4	2.7	3.2	0.3	74.3	1.0	0.6	18.0	6.1
36	1	0.0	0.1	0.0	94.5	0.0	0.0	5.4	0.5
37	1	0.0	0.0	0.0	97.9	0.0	0.0	2.1	0.2
38	1	0.0	0.0	0.0	98.3	0.0	0.0	1.7	0.1
39	2	0.0	0.0	0.0	92.5	0.0	0.0	7.5	0.5
40	2	0.0	0.0	0.0	88.7	0.0	0.0	11.2	1.3
41	4	2.2	2.7	0.2	76.3	0.8	0.5	17.3	7.5
42	1	0.0	0.0	0.0	55.7	0.0	0.0	44.3	0.3
43	4	2.1	2.6	0.2	75.3	0.7	0.4	18.6	7.9
44	1	0.0	2.7	0.0	86.5	0.0	0.0	10.8	0.7
45	1	0.0	0.0	0.0	91.9	0.0	0.0	8.1	0.5
46	2	0.0	1.8	0.0	86.4	0.0	0.0	11.7	1.2
47	1	0.0	0.0	0.0	87.6	0.0	0.0	12.4	0.0
48	2	0.0	1.8	0.0	86.1	0.0	0.0	12.2	1.3
49	4	1.7	2.8	0.2	75.0	0.6	0.3	19.4	10.1
50	4	1.5	4.9	0.1	68.8	1.9	0.3	22.5	13.0

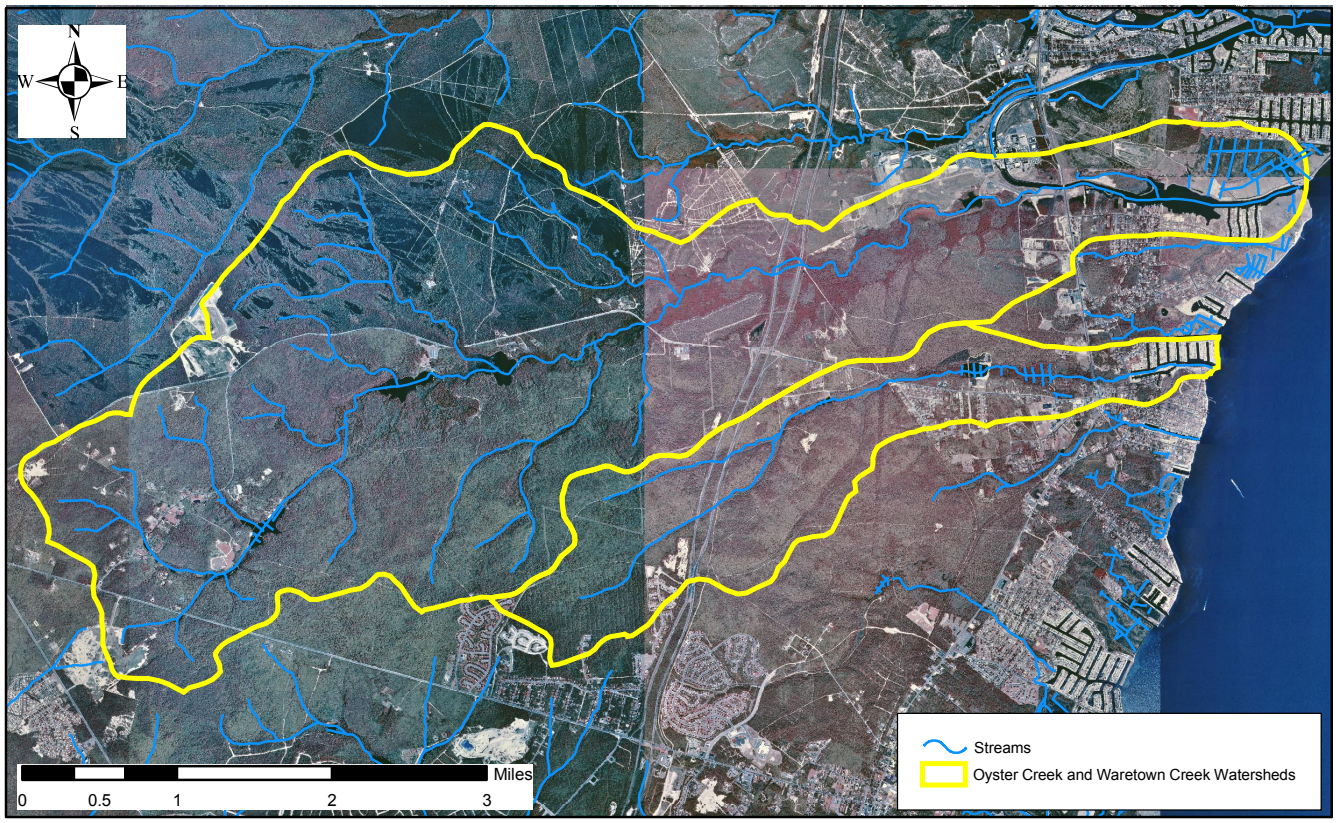

Figure 3. 1995 Aerial photograph of Oyster Creek and Waretown Creek Watersheds

Brookville, a Pinelands Village, with some developed land extending into the Forest Area. None of the drainages in the Rural Development Area exceeded the five-percent threshold. Upland agriculture was rare in the watershed, with cover ranging from 0% to less than two percent of any of the 50 cumulative drainage areas.

Surface-water Quality

Based on an assessment completed by a consultant to the Commission (BCM 1980), Part I of the 1980 CMP rated surface-water quality using 5-day biochemical oxygen demand (BOD_5), total nitrogen, suspended solids, total dissolved solids, and fecal coliform. The CMP described water quality in Oyster Creek as slightly disturbed based on high BOD_5 and fecal coliform levels. The use of BOD_5 by BCM was based on its traditional use as an indicator of organic loads. Fecal coliform was used as an indicator of fecal-waste contamination by warm-blooded animals or humans. BCM attributed the high levels of both variables in Oyster Creek to the possible effect of livestock or malfunctioning septic systems. Natural conditions were given as another possible cause of the high BOD_5.

The 1980 CMP characterization of Oyster Creek by BCM as slightly disturbed based on BOD_5 concentrations was inaccurate. First, the BOD_5 levels reported for Oyster Creek were not high. The BCM (1980) report indicates an average BOD_5 of 200 mg L^{-1} for raw sewage and 10 to 20 mg L^{-1} for secondary treated sewage, and notes that levels found in streams draining "virgin" territories in other areas range from 0.5 mg L^{-1} to 1.0 mg L^{-1}. Our analysis of BOD_5 data collected by the U. S. Geological Survey (USGS)[1] at Oyster Creek at Route 532 from 1973 through 1978 produced a median value of 0.6 mg L^{-1}, with values ranging from 0 mg L^{-1} to 1.2 mg L^{-1}.

[1] There is a discrepancy between BOD_5 values published in USGS annual data reports and electronic files stored on the national data base, which are based on the annual reports. Data from the data reports, which represent the original data source, were used in our analysis.

The 90th percentile value (used in the BCM analysis) was 1.2 mg L^{-1}. For comparison, the median BOD_5 value reported for McDonalds Branch by Hay and Campbell (1990) for the period 1975-1986 was 0.5 mg L^{-1}, with values ranging from 0 mg L^{-1} to 3.6 mg L^{-1}. McDonalds Branch is a national USGS benchmark site used to describe water quality in minimally disturbed watersheds. Secondly, available nutrient data for Oyster Creek do not support conclusions concerning sanitary waste pollution. Patrick (1979), who described Oyster Creek as a typical acid-water stream, also stated that it is probably affected by some sanitary wastes due to high fecal-coliform counts. However, Patrick also noted that BOD_5 was not very high and that because nitrate-nitrogen, ammonia, and phosphate levels were very low, it is difficult to explain the high fecal coliform bacteria count, and describes it as a possible error due to animal wastes. In the Pinelands, elevated pH and specific conductance values, and high concentrations of nitrates, ammonia and phosphates are associated with direct sewage discharges, whereas elevated pH, specific conductance, and nitrates may be associated with nonpoint sources such as septic systems and agricultural uses (Zampella 1994, Zampella et al. 2001). Water-quality data collected by both the USGS and the Pinelands Commission show that pH, specific conductance, and nutrients levels in Oyster Creek are typical of minimally disturbed streams, lending little credence to sanitary wastes as the source of "elevated" BOD_5 levels.

From February 1988 through February 1996, Pinelands Commission staff monitored water quality at Oyster Creek at Route 532. Samples were collected on 32 separate dates as part of the Commission's long-term environmental monitoring program. The Ocean County Health Department completed all laboratory analyses. The complete data set is presented in Table 3. Median pH and specific conductance values for the nine-year period was 4.5 and 40 μS cm^{-1}, respectively. The median nitrite plus nitrate as nitrogen value was 0.03 mg L^{-1}. Median total phosphorus and ammonia as nitrogen concentrations were < 0.05 mg L^{-1} and < 0.01 mg L^{-1}, respectively. All five water-quality variables are within the range of streams that are characteristic of minimally disturbed Pinelands reference sites (Zampella 1994, Zampella et al. 2001). The USGS sampled water-quality at the same site from 1965 to 1979. Median pH, specific conductance, nitrite, nitrate, ammonia, and phosphorus values for this period also reflect undisturbed or reference conditions (Table 4). Overall, water-quality in Oyster Creek can be ranked among the best of twenty streams that the Commission monitored in Ocean County (Zampella et al. 1994, Hunchak-Kariouk and Nicholson 2001).

Specific conductance and pH are especially valuable indicators of ecological integrity in Pinelands streams (Dow and Zampella 2000, Zampella et al. 2001, 2003). Non-native plants, fish, and frogs are generally found at sites with pH and specific conductance values exceeding those associated with minimally disturbed Pinelands reference sites. As part of a U.S. Geological Survey (USGS) investigation of acidity and water-quality characteristics of Oyster Creek, Fusillo (1980) measured pH and specific conductance on a single date (April 13, 1978) at ten stream stations throughout the upper portion of Oyster Creek (Figure 4). Specific conductance ranged from 39 μS cm^{-1} to 67 μS cm^{-1}, with a median of 56 μS cm^{-1} (Table 5). The pH at these sites ranged from 4.1 to 4.6, with a median of 4.4.

In 2003, Commission staff collected pH and specific conductance data at two sites along Oyster Creek, including the outflow of Wells Mills Pond and Oyster Creek at Route 532 (Table 6). Median pH at both sites was within the range associated with Pinelands reference streams (Zampella 1994, Zampella and Bunnell 1998, Zampella et al. 2001). These pH values are comparable to median 1988-1996 values previously reported for Oyster Creek at Route 532. Although the median specific conductance values (53 μS cm^{-1} and 56 μS cm^{-1}) are slightly higher compared with those reported for Pinelands reference sites and the longer-term median specific conductance value for the 1988-1996 monitoring period, they were within the range associated with native Pinelands aquatic communities. The median specific conductance values for Oyster Creek were also similar to those for the North Branch of the Forked River (57 μS cm^{-1}) and Factory Branch (55 μS cm^{-1}) during the same period. Both streams, which are near Oyster Creek, are also minimally altered by developed and agricultural land uses.

Table 3. Water-quality data for Oyster Creek at Route 532. Data were collected by the Pinelands Commission in cooperation with the Ocean County Health Department between February, 1988 and February, 1996. Calcium, magnesium, sulfate, nitrite + nitrate as nitrogen, ammonia as nitrogen and total phosphorus as phosphorus concentrations are expressed as mg L^{-1}. Specific conductance and pH are expressed as μS cm^{-1} and standard units, respectively.

Date	pH	Specific Conductance	Calcium	Magnesium	Sulfate	Nitrite + Nitrate	Ammonia	Total Phosphorus
02/16/88	4.3	--	0.84	0.89	7.6	0.12	<0.05	0.03
04/26/88	4.6	47	0.71	0.65	5.2	<0.01	<0.05	0.01
08/30/88	--	35	0.51	0.47	4.5	<0.01	0.14	<0.01
12/06/88	4.5	41	0.62	0.68	5.7	<0.01	--	0.01
02/14/89	4.6	34	1.25	0.71	6.0	0.05	--	<0.01
06/06/89	4.5	43	0.80	0.45	5.0	0.02	<0.05	<0.01
09/05/89	4.5	36	1.23	0.63	4.0	0.03	<0.05	0.01
12/12/89	4.5	--	0.59	0.66	8.0	0.10	<0.05	<0.01
02/27/90	4.6	38	0.50	0.50	4.0	0.03	<0.05	<0.01
05/08/90	4.6	41	0.90	0.70	10.0	0.02	0.10	0.34
09/18/90	4.5	34	0.54	0.58	8.0	0.04	0.12	<0.01
12/11/90	4.5	39	0.83	0.69	11.0	0.04	0.08	<0.01
02/19/91	4.4	52	--	--	7.0	0.09	<0.05	0.01
04/30/91	4.5	38	--	--	6.0	0.03	<0.05	0.08
09/17/91	4.6	34	--	--	6.0	0.02	0.07	<0.01
12/03/91	4.4	38	--	--	3.0	<0.01	<0.05	<0.01
03/17/92	4.5	38	<0.20	0.64	5.0	0.05	<0.05	<0.01
05/12/92	4.4	39	0.30	0.73	10.0	<0.01	0.08	<0.01
08/11/92	4.5	36	0.30	0.43	4.0	0.03	<0.05	0.01
09/22/92	4.6	36	0.90	<0.5	7.0	0.04	<0.05	<0.01
12/01/92	4.6	40	1.30	<0.5	7.0	0.04	<0.05	<0.01
02/23/93	4.4	44	0.8	<0.5	10.0	0.04	--	<0.01
05/11/93	4.5	44	1.5	0.51	7.0	0.14	0.12	0.01
07/20/93	4.5	43	0.9	0.44	7.0	0.06	0.11	<0.01
10/05/93	4.7	39	7.8	3.63	5.0	<0.01	0.06	<0.01
11/30/93	4.7	40	2.4	0.34	5.0	<0.01	--	<0.01
02/01/94	4.3	51	0.60	1.3	11.0	0.04	--	0.02
04/26/94	4.5	40	--	--	--	<0.01	--	0.02
05/23/95	4.7	42	--	--	4.0	<0.01	--	0.01
09/25/95	4.6	47	--	--	4.0	0.15	--	0.01
11/28/95	4.5	52	--	--	7.0	<0.01	--	0.02
02/20/96	4.5	50	--	--	6.0	0.02	--	<0.01
Median Value	4.5	40	0.8	0.63	6.0	0.03	<0.05	<0.01

Table 4. Water-quality data for Oyster Creek at Route 532. Data were collected by the United States Geological Survey between April, 1965 and November, 1979. USGS Station ID 01409095, Oyster Creek near Brookville, NJ.

Parameter	Median	N
Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius	40	58
pH, water, unfiltered, field, standard units	4.5	77
Total nitrogen, water, unfiltered, milligrams per liter	0.15	24
Ammonia, water, unfiltered, milligrams per liter as nitrogen	0.01	28
Nitrite, water, unfiltered, milligrams per liter as nitrogen	<0.01	26
Nitrite plus nitrate, water, unfiltered, milligrams per liter as nitrogen	0.01	23
Nitrate, water, filtered, milligrams per liter as nitrogen	0.01	2.0
Nitrate, water, unfiltered, milligrams per liter as nitrogen	0.01	27
Phosphorus, water, unfiltered, milligrams per liter	0.01	34
Calcium, water, filtered, milligrams per liter	1.0	42
Calcium, water, unfiltered, recoverable, milligrams per liter	4.3	2.0
Magnesium, water, filtered, milligrams per liter	0.5	42
Magnesium, water, unfiltered, recoverable, milligrams per liter	0.4	2.0
Chloride, water, filtered, milligrams per liter	5.6	44
Sulfate, water, filtered, milligrams per liter	4.5	48

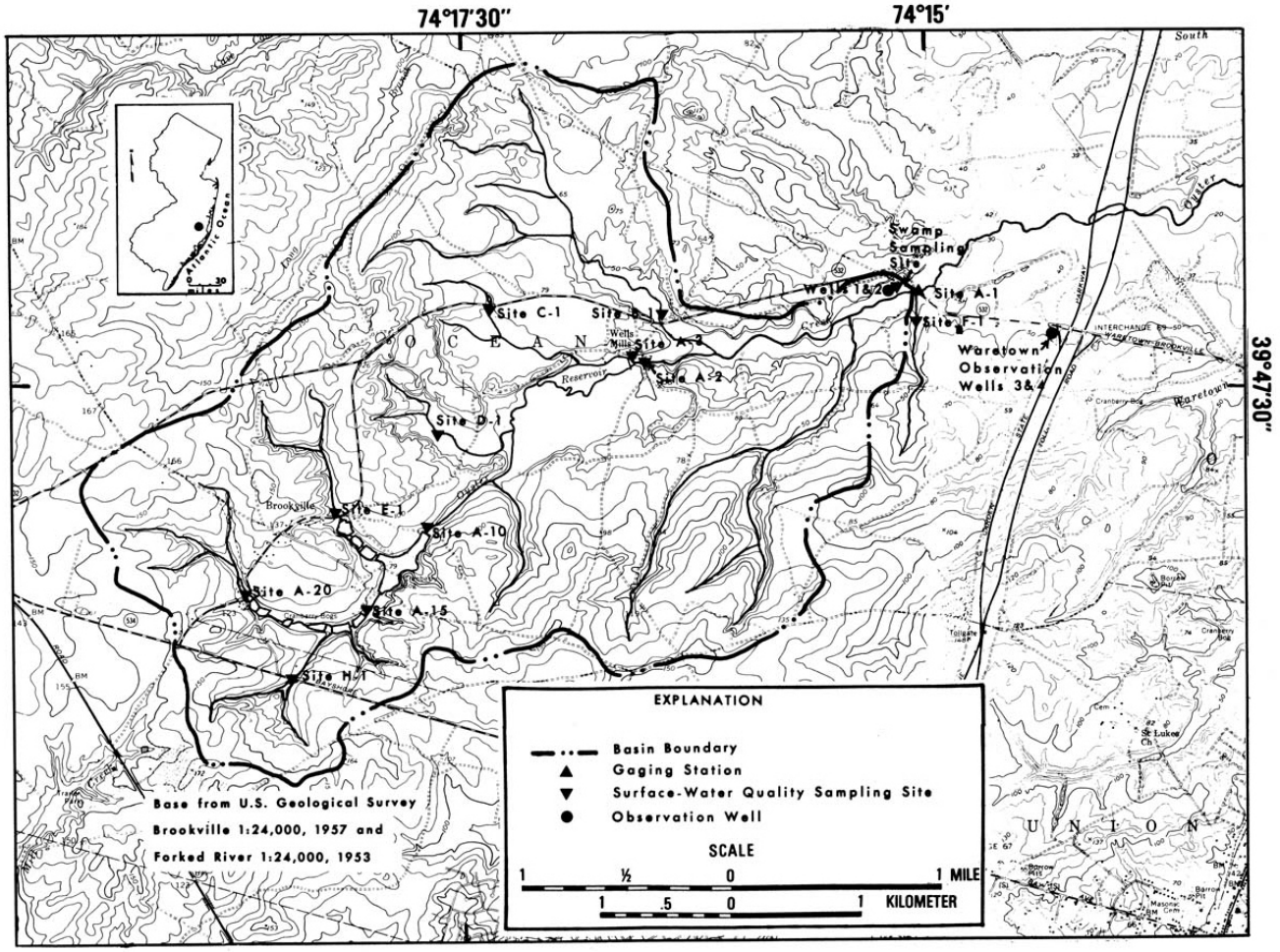

Figure 4. Specific conductance and pH monitoring sites in the Oyster Creek watershed (April 13, 1978, Fusillo 1980).

Table 5. Specific conductance and pH measured at ten Oyster Creek sites on April 13, 1978 (Fusillo 1980). See Figure 4 for the location of sampling sites.

Site	Specific Conductance (μS cm^{-1})	pH
A-1	45	4.4
A-2	46	4.4
A-10	59	4.4
A-15	60	4.4
A-20	53	4.6
B-1	39	4.4
C-1	67	4.1
D-1	65	4.2
E-1	53	4.3
H-1	60	4.2
Median	56	4.4
Minimum	39	4.1
Maximum	67	4.6

Table 6. Water-quality data collected at two Oyster Creek sites during 2003.

	Oyster Creek at Rt 532		Oyster Creek at Wells Mills impoundment	
Date	Specific Conductance (μS cm^{-1})	pH	Specific Conductance (μS cm^{-1})	pH
01/28/03	52	4.4	--	--
03/17/03	54	4.2	56	4.7
04/14/03	64	4.3	83	4.2
05/09/03	53	4.5	58	5.0
06/16/03	56	4.8	59	4.7
07/07/03	62	4.8	45	4.5
08/18/03	54	4.7	44	4.7
09/08/03	47	4.6	52	4.6
10/06/03	45	4.1	135	4.7
11/17/03	52	4.4	53	4.8
Median	53	4.4	56	4.7

Southern Ocean Landfill

Nearly all of the Southern Ocean Landfill was classified on the NJDEP land-use maps as barren land, with small areas within the boundary of the landfill designated as forest, water, or developed land. All land uses within the boundary of the Southern Ocean Landfill covered from 14.3% to 29.8% of drainage units 13, 19, and 26 (Figures 2 and 3). All three drainage units represented first order streams.

Using 1995 digital aerial photographs, we determined that the area within the outer boundaries of the Southern Ocean Landfill occupied 106 acres of land. Two-thirds of this area (71 acres) was located in the Oyster Creek watershed. Within the Oyster Creek watershed, 15% (11 acres) of the landfill was in the Forest Area and 85% (60 acres) was in the Rural Development Area. Ninety-four percent of the 71 acres was classified as barren land.

A remedial investigation of the Southern Ocean Landfill by Sadat Associates, Inc. (2002) on behalf of the Southern Ocean Landfill, Inc. found that the main direction of groundwater flow from the landfill is to the southeast (i.e., towards Oyster Creek). Localized groundwater flows were detected moving to the north and east (i.e., towards Long Branch, a tributary of the North Branch of the Forked River). A second plume of high ammonia was located off-site just south of the landfill and was assumed to be unrelated to the landfill. Groundwater samples collected over several years revealed ammonia concentrations ranging from as high as 280 mg L^{-1} at one monitoring well to levels below 0.10 mg L^{-1}. As of the date of the report, the contaminated plume appeared to be almost entirely contained within the boundaries of the landfill.

As part of the remedial investigation, surface-water quality was monitored at five sites in March 2001. Samples were collected at two sites along Long Branch and at three on-site detention ponds. Sadat Associates, Inc. reported that all water-quality parameters were present at levels below New Jersey Surface Water Quality Standards. Ammonia levels ranged from <0.10 mg L^{-1} to 1.3 mg L^{-1} at the three on-site detention ponds. Ammonia levels at the two Long Branch sites were 0.19 mg L^{-1} and 0.16 mg L^{-1}. Although Sadat Associates, Inc. concluded that the landfill does not affect the surface water quality of Long Branch, the ammonia concentrations are elevated in comparison to levels expected in undisturbed Pinelands watersheds. Surface water quality in the Oyster Creek was not addressed by the remedial investigation.

Wetlands

We used the digital NJDEP 1995/97 Land Use/Land Cover data to prepare wetland profiles using only the dominant cover type of a mixed wetland. For example, all cedar-swamp types, including PFO8, PFO8/1, and PFO8/4, were combined as PFO8. Wetlands comprise 20% of the Pinelands Area portion of the watershed and 22% of the entire watershed (Table 7). The percentage of wetlands in Oyster Creek is comparable to other nearby, minimally disturbed Barnegat Bay drainages within the Pinelands area, including the South Branch Forked River (29.2%), Chamberlain Branch (14.4%), North Branch Forked River (14.1%), Factory Branch (19.0%), Webbs Mill Branch (13.1%), Cedar Creek (18.6%), and Old Hurricane Brook above Horicon Lake (26.6%).

Pitch pine lowland was the dominant wetland type, followed by Atlantic white cedar swamp and hardwood swamp. The median percentage of wetlands was lowest in first-order (headwater) drainages and highest in fourth order drainages, and the number of wetland types increased with stream order (Table 7). Cedar swamps were generally associated with the fourth order drainages. A single polygon representing less than one-percent of the watershed was mapped as wetland agriculture (i.e., active cranberry bogs). This area appears as open water on the 1995 digital aerial photographs.

Table 7. Percentage of wetlands in the Pinelands Area and PNR portion of the Oyster Creek watershed.

		Percent of Watershed		Median Drainage-unit Percent Cover by Stream Order			
Cowardin Classification	Pinelands Description	Pinelands Area	Entire PNR	First	Second	Third	Fourth
PFO4	pitch pine lowland	5.8	5.6	2.0	2.4	1.1	5.8
PFO1	hardwood swamp	4.1	3.2	1.7	2.6	2.0	4.3
PFO8	cedar swamp	3.3	4.0	-	1.1	1.6	3.1
PSS1	broad-leaved deciduous scrub/shrub	2.3	2.1	-	-	1.8	2.4
PSS8	scrub/shrub cedar	2.0	2.8	-	-	0.4	1.2
PSS4	needle-leaved evergreen scrub/shrub	1.1	1.4	-	-	-	0.4
POW	open water	0.6	0.7	-	-	0.5	0.7
PEM1	emergent wetland	0.6	1.7	-	-	0.5	0.8
MODAg	wetland agriculture	0.3	0.3	-	-	0.8	0.4
PFO3	broad-leaved evergreen swamp	0.1	0.1	-	-	-	0.1
MOD	disturbed wetlands	0.007	0.3	-	-	-	0.007
R2OW	river	-	0.021	-	-	-	-
Wetlands	all wetlands	20.3	22.1	7.4	11.7	8.1	19.8

Unique Resources

Pine Plains Fireshed

The extreme northern portion of the Oyster Creek watershed falls within an area identified in the 1980 CMP as necessary to maintain the integrity of the Pine Plains. Windisch (1999) refers to such areas as firesheds, which he defines as "fire-prone landscapes with subcomponents having different long-term probabilities for fire due to local landscape influences on fire spread, frequency and intensity." He includes parts of the Oyster Creek watershed in the "plains-barrens" subregional fireshed, where intense, large, and frequent wildfires have historically occurred. In 1995, one of the most extensive wildfires in recent history burned the area north of Route 532 (Figure 3).

Aquatic Communities

An aquatic assessment prepared by Lloyd and others (1980) for the Commission summarized information on the aquatic ecology of the Forked River and Oyster Creek watersheds. Typical Pinelands aquatic plants were reported as recently collected in the vicinity of the Oyster Creek Nuclear Generating Station. Based on fish records, Lloyd and others described both stream systems as typical Pinelands streams. Fish collections from the Oyster Creek-Forked River area included ten native Pinelands fish species and two peripheral species. The peripheral species were pumpkinseeds and golden shiners. Although not noted by Lloyd and others, most of the Oyster Creek samples were collected in surveys conducted for the Oyster Creek Nuclear Generating Station located east of the Garden State Parkway. The only sampling that was definitely located west of the Parkway included only native Pinelands fish.

In 2003, Commission staff conducted biological surveys at Oyster Creek at Route 532 and Wells Mills Pond. American eels (*Anguilla rostrata*), banded sunfish (*Enneacanthus obesus*), creek chubsucker (*Erimyzon oblongus*), and chain pickerel (*Esox niger*) were present at the stream site. All are native Pinelands species. The same four species were found at Wells Mills Pond along with swamp darter (*Etheostoma fusiforme*), eastern mudminnow (*Umbra pygmaea*), yellow bullhead (*Ameiurus natalis*), and bluegill (*Lepomis machrocirus*). Except for the bluegill, all are native Pinelands species. The bluegill, which was introduced to New Jersey waters, is almost always associated with degraded water quality characterized by elevated pH (Zampella and Bunnell 1998, Zampella et al. 2001, 2003). Its presence is not consistent with the acid waters reported for the site. Only native frogs were heard during vocalization surveys conducted in 2003. Pine Barrens treefrogs (*Hyla andersonii*) were heard calling from an Oyster Creek tributary impoundment located above Brookville Road. Green frogs (*Rana clamitans*) were heard at this site and at Wells Mill Pond. A species-rich native Pinelands flora characterized Oyster Creek at Route 532 (Table 8). A total of fifty-four species was found at this site, including *Schizaea pusilla,* a species designated as threatened and endangered by the Commission. The species composition of the stream vegetation reflected the excellent water quality measured at this site.

Table 8. Stream vegetation observed at Oyster Creek at Route 532 in 2003.

Herbaceous species			Woody species
Agrostis sp.	*Eleocharis tuberculosa*	*Panicum virgatum*	*Acer rubrum*
Andropogon virginicus	*Eriocaulon aquaticum*	*Peltandra virginica*	*Aronia arbutifolia*
var. abbreviatus	*Euthamia tenuifolia*	*Pogonia ophioglossoides*	*Chamaecyparis thyoides*
Aster nemoralis	*Glyceria obtusa*	*Rhexia virginica*	*Chamaedaphne calyculata*
Aster novi-belgii	*Hypericum canadense*	*Rhynchospora alba*	*Clethra alnifolia*
Bartonia paniculata	*Juncus canadensis*	*Rhynchospora sp.*	*Eubotrys racemosa*
Carex exilis	*Juncus effusus*	*Sabatia difformis*	*Gaylussacia dumosa*
Carex livida	*Juncus militaris*	*Sarracenia purpurea*	*Ilex glabra*
Carex striata	*Juncus pelocarpus*	*Schizaea pusilla*	*Kalmia angustifolia*
Danthonia sericea var. epilis	*Lysimachia terrestris*	*Scirpus pungens*	*Magnolia virginiana*
Drosera filiformis	*Nymphaea odorata*	*Scirpus subterminalis*	*Myrica pensylvanica*
Drosera intermedia	*Orontium aquaticum*	*Sparganium americanum*	*Rhododendron viscosum*
Drosera rotundifolia	*Osmunda regalis*	*Triadenum virginicum*	*Vaccinium corymbosum*
Eleocharis robbinsii	*Panicum sp.*		*Vaccinium macrocarpon*

Threatened and Endangered Species

The Oyster Creek watershed has not been systematically surveyed for rare plant and animal species. However, there are numerous records of several species listed as threatened or endangered by the Commission. Records were obtained from several sources, including the Natural Heritage Program, the Endangered and Nongame Species Program (ENSP), the Pinelands Commission, and Zappalorti (1986). The majority of rare-plant records were provided by Ted Gordon. Only observations made after 1970 were included. To protect the confidentiality of the rare species records, rather than show point locations, each record was assigned to one of the fifty discrete Oyster Creek drainage units. Associating wetland species with a drainage area has an ecological basis. Although the same cannot be said for upland species such as pine snakes (*Pituophis melanoleucus*), the approach does provide a means of describing the general area where a species is found. Although assigning a species occurrence to a broad landscape feature may overestimate its actual distribution, this problem was minimized by limiting the record boundaries to relatively small drainage units. The complete species inventory, including associated dates and drainage units, is given in Table 9.

The available data include pine snake and Pine Barrens treefrog records. Both species occur in each of the two Oyster Creek drainage areas used in the original CMP to assign management areas. Seven plant species listed by the Commission as threatened or endangered are also reported as occurring in the watershed. These include Pine Barrens reedgrass (*Calamovilfa brevipilis*), Barratt's sedge (*Carex barrattii)*, New Jersey Rush (*Juncus caesariensis*), bog asphodel (*Narthecium americanum*), Knieskern's beaked-rush (*Rhynchospora knieskernii*), curly grass fern (*Schizaea pusilla*), and slender nut-rush (*Scleria minor*). Pine Barrens bellwort (*Uvularia pudica* var. *nitida*), a species classified as endangered by the state, is also found in the Oyster Creek watershed.

Public Lands

In 1980, there were no public lands managed for resource protection or recreation within Oyster Creek watershed. Today, the Ocean County Park at Wells Mills occupies nearly 1,000 acres in the watershed.

Areas of Deep Aquifer Recharge

Areas of deep aquifer recharge were described as areas where the depth to the unsaturated zone is 20 feet or greater and not underlain by either of the two extensive clay lenses in the east and southeast of the Pinelands. Maps presented in the original CMP show that both deep aquifer recharge areas and extensive clay lenses are found in the Oyster Creek watershed.

Waretown Creek

In 1980, the character of adjacent lands was an important consideration when delineating management areas. For example, areas of less than 1,000 acres that did not exhibit essential character but were entirely surrounded by areas of essential character became Forest Areas. Additionally, Forest Areas were used to buffer the Preservation Area. Within the Pinelands Area, the northern, western, and southwestern boundaries of the Oyster Creek watershed are surrounded by Forest Area. The Mill Creek and Waretown Creek watersheds are located along Oyster Creek's southern boundary. Portions of Waretown Creek represent an extension of the unaltered landscape that characterizes Oyster Creek.

The Pinelands Area portion of the Waretown Creek watershed covers 820 acres (Table 10). Forty-nine percent of this area is classified as Regional Growth Area. Fifty-one percent is designated Rural Development Area. We delineated Waretown Creek drainage units following the same method used in Oyster Creek. In 1995, altered land (developed land and upland agriculture) cover was less than 10% in the two first-order drainage units located in the Pinelands Area (units 51-52, Tables 10 and 11, Figure 2). Developed land covered 3.5% of unit 51, which is entirely Rural Development Area, and 7.5% of unit 52, which includes both Rural Development Area and Regional Growth Area. The 2000 photography shows a substantial increase in development within drainage unit 52.

Table 9. Threatened and endangered species reported to occur in the Oyster Creek watershed.

Drainage Unit	Scientific Name	Common Name	State Status	Pinelands Status	Last Date Observed	Source
4	*Pituophis melanoleucus*	northern pine snake	T	T&E	1990	ENSP
5	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1993	Commission
5	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1993	Commission
5	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	2003	Commission
8	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1993	Commission
19	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1994	T. Gordon
23	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1975	ENSP
23	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1993	Commission
24	*Rhynchospora knieskernii*	Knieskern's beaked-rush	E	T&E	2002	T. Gordon
25	*Juncus caesariensis*	New Jersey rush	E	T&E	2000*	T. Gordon
25	*Pituophis melanoleucus*	northern pine snake	T	T&E	1993	ENSP
25	*Pituophis melanoleucus*	northern pine snake	T	T&E	2000	ENSP
32	*Schizaea pusilla*	curly grass fern	S3	T&E	1995	Natural Heritage
33	*Calamovilfa brevipilis*	Pine Barrens reedgrass	-	T&E	2003	T. Gordon
33	*Schizaea pusilla*	curly grass fern	S3	T&E	2003	T. Gordon
33	*Scleria minor*	slender nut-rush	-	T&E	2000	T. Gordon
34	*Calamovilfa brevipilis*	Pine Barrens reedgrass	-	T&E	1999	T. Gordon
34	*Calamovilfa brevipilis*	Pine Barrens reedgrass	-	T&E	1995	T. Gordon
34	*Juncus caesariensis*	New Jersey rush	E	T&E	1999	T. Gordon
34	*Narthecium americanum*	bog asphodel	E	T&E	1995	Natural Heritage
34	*Narthecium americanum*	bog asphodel	E	T&E	1999	T. Gordon
34	*Narthecium americanum*	bog asphodel	E	T&E	1995	T. Gordon
34	*Narthecium americanum*	bog asphodel	E	T&E	1995	T. Gordon
34	*Pituophis melanoleucus*	northern pine snake	T	T&E	1999	T. Gordon
34	*Schizaea pusilla*	curly grass fern	S3	T&E	1999	T. Gordon
41	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1979	ENSP
41	*Juncus caesariensis*	New Jersey rush	E	T&E	1998*	T. Gordon
41	*Narthecium americanum*	bog asphodel	E	T&E	1995	Natural Heritage
41	*Narthecium americanum*	bog asphodel	E	T&E	1998*	T. Gordon
41	*Schizaea pusilla*	curly grass fern	S3	T&E	1995*	T. Gordon
43	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1993	Commission
43	*Juncus caesariensis*	New Jersey rush	E	T&E	1999*	T. Gordon
43	*Schizaea pusilla*	curly grass fern	S3	T&E	1971	Natural Heritage
43	*Schizaea pusilla*	curly grass fern	S3	T&E	2003	Commission
44	*Calamovilfa brevipilis*	Pine Barrens reedgrass	-	T&E	1985*	T. Gordon
45	*Juncus caesariensis*	New Jersey rush	E	T&E	1997	T. Gordon
45	*Schizaea pusilla*	curly grass fern	S3	T&E	1997	T. Gordon
46	*Calamovilfa brevipilis*	Pine Barrens reedgrass	-	T&E	2000*	T. Gordon
46	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1994	T. Gordon
46	*Schizaea pusilla*	curly grass fern	S3	T&E	2000*	T. Gordon
46	*Scleria minor*	slender nut-rush	-	T&E	2000*	T. Gordon
49	*Carex barrattii*	Barratt's sedge	-	T&E	1994	T. Gordon
49	*Carex barrattii*	Barratt's sedge	-	T&E	2002	T. Gordon
49	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1993	Commission
49	*Juncus caesariensis*	New Jersey rush	E	T&E	1993*	T. Gordon
49	*Narthecium americanum*	bog asphodel	E	T&E	2002*	T. Gordon
49	*Pituophis melanoleucus*	northern pine snake	T	T&E	1982	ENSP
49	*Rhychospora knieskernii*	Knieskern's beaked-rush	E	T&E	2002*	T. Gordon
49	*Schizaea pusilla*	curly grass fern	S3	T&E	2001*	T. Gordon
49	*Uvularia puberula var. nitida*	Pine Barren bellwort	E	T&E	1994	T. Gordon
50	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1986	Zappalorti (1986)
50	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1986	Zappalorti (1986)
50	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1986	Zappalorti (1986)
50	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1986	Zappalorti (1986)
50	*Hyla andersonii*	Pine Barrens treefrog	T	T&E	1986	Zappalorti (1986)
50	*Calamovilfa brevipilis*	Pine Barrens reedgrass	-	T&E	2000*	T. Gordon
50	*Juncus caesariensis*	New Jersey rush	E	T&E	2000*	T. Gordon
50	*Narthecium americanum*	bog asphodel	E	T&E	1995	Natural Heritage
50	*Narthecium americanum*	bog asphodel	E	T&E	2002	T. Gordon
50	*Pituophis melanoleucus*	northern pine snake	T	T&E	1986	Zappalorti (1986)
50	*Pituophis melanoleucus*	northern pine snake	T	T&E	1986	Zappalorti (1986)
50	*Pituophis melanoleucus*	northern pine snake	T	T&E	1999	ENSP
50	*Rhychospora knieskernii*	Knieskern's beaked-rush	E	T&E	2000*	T. Gordon
50	*Rhychospora knieskernii*	Knieskern's beaked-rush	E	T&E	2002*	T. Gordon
50	*Schizaea pusilla*	curly grass fern	S3	T&E	2003	Commission
50	*Schizaea pusilla*	curly grass fern	S3	T&E	2002*	T. Gordon

* Month and day were not reported. Reported as season and year.

Table 10. Percent land use and Pinelands Management Area for Waretown Creek in the Pinelands Area.

Management Area	Land Use	Acres	% Land Use	% Basin Area
Regional Growth Area	Barren Land	2.8	0.7	
	Developed Land	67.2	16.9	
	Upland Forest	328.1	82.4	
Subtotal		398.1		48.6
Rural Development Area	Barren Land	12.7	3.0	
	Developed Land	17.2	4.1	
	Upland Forest	364.3	86.4	
	Wetlands	27.3	6.5	
Subtotal		421.5		51.4
Grand Total		819.5		

Table 11. Percent land use of Waretown Creek drainages associated with individual drainage units. Refer to Figure 2 for drainage-unit locations. (Pinelands Area: drainage units 51-52 and PNR: drainage units 51-58).

Drainage Unit Number	Stream Order	Barren Land	Developed Land	Upland Agriculture	Upland Forest	Water	Wetland Agriculture	Wetlands	Basin Area (mi^2)
51	1	0.3	3.5	0.0	86.0	0.0	0.0	10.2	0.4
52	1	3.1	7.5	0.0	88.8	0.0	0.0	0.6	0.7
53	1	0.0	(Parkway) 59.6	0.0	40.4	0.0	0.0	0.0	0.0
54	1	0.2	4.1	0.0	82.7	0.0	0.0	13.0	0.4
55	1	2.4	8.5	0.0	85.7	0.0	0.0	3.5	1.0
56	2	1.9	7.5	0.2	82.8	0.2	0.0	7.4	1.6
57	1	0.0	1.9	0.0	88.3	0.0	0.0	9.8	0.5
58	2	1.0	14.9	0.1	72.1	1.7	0.0	10.1	3.2

In 2003, we sampled pH and conductance, stream vegetation, and fish at Waretown Creek at Route 9 in the Pinelands National Reserve portion of the watershed (Table 12). Anurans were surveyed at Waretown Lake and Recreation Area located between Route 9 and the Garden State Parkway. Median pH at the Route 9 site was 4.4. Although this value is typical of minimally altered drainages, the median specific conductance value of 97 μS cm^{-1} was high for a Pinelands stream. The elevated conductance was inconsistent with the land-use profile of the Pinelands Area portion of the drainage and may be associated with land-use impacts occurring downstream from the Garden State Parkway.

Table 12. Water-quality data collected at Waretown Creek at Route 9 in 2003.

Date	Specific Conductance (μS cm^{-1})	pH
01/28/03	108	4.3
03/17/03	105	4.3
04/14/03	105	4.2
05/09/03	57	4.3
06/16/03	96	4.5
07/07/03	77	4.3
08/18/03	99	4.8
09/08/03	90	4.7
10/06/03	96	4.4
11/17/03	98	4.7
Median	97	4.4

Thirty-two plants species were found along a section of Waretown Creek at Route 9. Twenty-nine species were characteristic of reference streams in the central Pinelands. The exceptions included two invasive species, common reed (*Phragmites australis*) and Japanese honeysuckle (*Lonicera japonica*), and wild black cherry (*Prunus serotina*). The presence of all three species probably reflects the physical disturbance associated with Route 9. Fish collected at Route 9 included the mud sunfish (*Acantharchus pomotis*), chain pickerel, and American eel. All three species are native Pinelands fish. Fowler's toad (*Bufo fowleri*) and the green frog, two native species, were heard at the impoundment. In 1986, Pine Barrens treefrogs were heard calling at three sites in Waretown Creek drainage unit no. 58 located east of the Garden State Parkway (Zappalorti 1986). ENSP records also list a 1994 occurrence of Pine Barrens treefrog in this same drainage unit.

Table 13. Stream vegetation observed at Waretown Creek at Route 9 in 2003.

Herbacecous species	**Woody species**
Bartonia paniculata	*Acer rubrum*
Dulichium arundinaceum	*Alnus serrulata*
Eriocaulon aquaticum	*Amelanchier canadensis*
Glyceria obtusa	*Chamaecyparis thyoides*
Juncus canadensis	*Clethra alnifolia*
Osmunda cinnamomea	*Ilex glabra*
Oxypolis rigidior	*Ilex opaca*
Panicum sp.	*Lonicera japonica*
Peltandra virginica	*Magnolia virginiana*
Phragmites australis	*Nyssa sylvatica*
Pogonia ophioglossoides	*Prunus serotina*
Scirpus subterminalis	*Rubus hispidus*
Sparganium americanum	*Salix sp.*
Triadenum virginicum	*Sassafras albidum*
	Smilax rotundifolia
	Toxicodendron vernix
	Vaccinium corymbosum
	Vaccinium macrocarpon

Conclusions

The Oyster Creek watershed is minimally altered and contiguous to other extensive landscapes in the Preservation Area and Forest Area. The stream system displays water quality that is characteristic of central Pinelands, acid-water reference sites and generally supports native aquatic and wetland communities. Numerous threatened and endangered plant and animal species records are reported for the watershed, which underscores the basins status as an ecologically critical area. Although the possibility that the Southern Ocean Landfill may pose a future threat to water quality cannot be discounted, there is no evidence that the stream system is currently degraded. Furthermore, the presence of the landfill does not diminish the ecological value of a majority of the upland ecosystem in the watershed, which is similar to adjacent lands designated as Preservation Area and Forest Area. Portions of Waretown Creek can also be characterized as minimally altered. This drainage represents an extension of the contiguous Oyster Creek watershed.

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Literature Cited

BCM. 1980. Technical Memos, Pinelands Commission Surface Water Quality. Pinelands Commission, New Lisbon, NJ.

Dow, C. L. and R. A. Zampella. 2000. Specific Conductance and pH as indicators of watershed disturbance in streams of the New Jersey Pinelands, USA. Environmental Management 26:437-445.

Hay, L. E. and J. P. Campbell. 1990. Water-quality trends in New Jersey streams. Water-Resources Investigations Report 90-4046. U. S. Geological Survey, Trenton, NJ.

Hunchak-Kariouk, K. and R. S. Nicholson. 2001. Watershed contributions of nutrients and other nonpoint source contaminants to Barnegat Bay-Little Egg Harbor Estuary. Journal of Coastal Research, Special Issue No. 32:28-81.

Fusillo, T. V., Schornick, J. C., Koester, H. E., Harriman, D. A. 1980. Investigation of acidity and other water-quality characteristics of Upper Oyster Creek, Ocean County, New Jersey. Water-Resources Investigations Report 80-10.

Loyd, T., R. W. Hastings, J. White-Reimer, J. R. Arsenault, C. Aresenault, and M. Merritt. 1980. Aquatic ecology of the New Jersey Pinelands. Prepared for the New Jersey Pinelands Commission, PO Box 7, New Lisbon, NJ>

Patrick, R., B. Matson, and L. Anderson. 1979. Streams and lakes in the Pine Barrens. pp. 169-193 in R. T. T. Forman (ed.), Pine Barrens: ecosystem and landscape. Academic Press, NY, NY.

Pinelands Commission. 1980. New Jersey Pinelands Comprehensive Management Plan. New Jersey Pinelands Commission, New Lisbon, New Jersey. USA.

Sadat Associates, Inc. 2002. Remedial Investigation Report for the Southern Ocean Landfill. Volumes I-IV. Sadat Associates, Inc., Trenton, NJ.

Windisch, A. G. 1999. Fire ecology of the New Jersey Pine Plains and vicinity. Ph.D. Dissertation, Rutgers, the State University, New Brunswick, NJ.

Zampella, R. A. 1994. Characterization of surface water quality along a watershed disturbance gradient. Water Resources Bulletin 30:605-611.

Zampella, R. A. and J. F. Bunnell. 1998. Use of reference-site fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8:645-658.

Zampella, R. A., Bunnell, J. F., Laidig, K. J., and Dow, C. L. 2001. The Mullica River Basin: A report to the Pinelands Commission on the status of the landscape and selected aquatic and wetland resources. Pinelands Commission, New Lisbon, New Jersey. USA.

Zampella, R. A., Bunnell, J. F., Laidig, K. J., and Procopio, N. A. 2003. The Rancocas Creek Basin: A report to the Pinelands Commission on the status of selected aquatic and wetland resources. Pinelands Commission, New Lisbon, New Jersey. USA.

Zampella, R. A., L. Craig, and M. Windisch. 1994. Water quality characteristics of Ocean County Pinelands streams. Pinelands Commission, New Lisbon, NJ.

Zappalorti, R. T. An habitat evaluation and herpetological survey of the site of the proposed resource recovery trash incinerator, Ocean County, New Jersey. HA File Number 86.18, Herpetological Associates, Inc.