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In-Situ Sediment Oxygen Demand Rates in Hammonton Creek, Hammonton, New Jersey, and Crosswicks Creek, near New Egypt, New Jersey, August–October 2009

Scientific Investigations Report 2013–5121

U.S. Department of the Interior
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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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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	
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
	Volume	
pint (pt)	0.4732	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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 in milligrams per liter (mg/L).

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In-Situ Sediment Oxygen Demand Rates in Hammonton Creek, Hammonton, New Jersey, and Crosswicks Creek, near New Egypt, New Jersey, August–October 2009

By Timothy P. Wilson

Abstract

Sediment oxygen demand rates were measured in Hammonton Creek, Hammonton, New Jersey, and Crosswicks Creek, near New Egypt, New Jersey, during August through October 2009. These rates were measured as part of an ongoing water-quality monitoring program being conducted in cooperation with the New Jersey Department of Environmental Protection. Oxygen depletion rates were measured using in-situ test chambers and a non-consumptive optical electrode sensing technique for measuring dissolved oxygen concentrations. Sediment oxygen demand rates were calculated on the basis of these field measured oxygen depletion rates and the temperature of the stream water at each site.

Hammonton Creek originates at an impoundment, then flows through pine forest and agricultural fields, and receives discharge from a sewage-treatment plant. The streambed is predominantly sand and fine gravel with isolated pockets of organic-rich detritus. Sediment oxygen demand rates were calculated at four sites on Hammonton Creek and were found to range from -0.3 to -5.1 grams per square meter per day ($g/m^2/d$), adjusted to 20 degrees Celsius. When deployed in pairs, the chambers produced similar values, indicating that the method was working as expected and yielding reproducible results. At one site where the chamber was deployed for more than 12 hours, dissolved oxygen was consumed linearly over the entire test period.

Crosswicks Creek originates in a marshy woodland area and then flows through woodlots and pastures. The streambed is predominantly silt and clay with some bedrock exposures. Oxygen depletion rates were measured at three sites within the main channel of the creek, and the calculated sediment oxygen demand rates ranged from -0.33 to -2.5 $g/m^2/d$, adjusted to 20 degrees Celsius. At one of these sites sediment oxygen demand was measured in both a center channel flowing area of a pond in the stream and in a stagnant non-flowing area along the shore of the pond where organic-rich bottom sediments had accumulated and lower dissolved oxygen concentration conditions existed in the water column. Dissolved oxygen concentrations in the center channel test chamber showed a constant slow decrease over the entire test period. Oxygen consumption in the test chamber at the near-shore location began rapidly and then slowed over time as oxygen became depleted in the chamber. Depending on the portion of the near-shore dissolved oxygen depletion curve used, calculated sediment oxygen demand rates ranged from as low as -0.03 $g/m^2/d$ to as high as -10 $g/m^2/d$. The wide range of sediment oxygen demand rates indicates that care must be taken when extrapolating sediment oxygen demand rates between stream sites that have different bottom sediment types and different flow regimes.

Introduction

As part of the Hammonton Creek Total Maximum Daily Load (TMDL) investigation and the Crosswicks Creek Nutrient Survey conducted by the U.S. Geological Survey (USGS), in cooperation with the New Jersey Department of Environmental Protection (NJDEP), sediment oxygen demand (SOD) rates were determined for possible use in a geochemical model of nutrient fate and transport. This study focused on four locations on Hammonton Creek and three locations on Crosswicks Creek. SOD is the rate (normalized to stream-bottom surface area) at which dissolved oxygen (DO) is consumed by processes occurring in the bottom sediment. Oxygen consumption is the result of inorganic reactions, biological respiration, and decomposition (abiotic and biotic) of organic matter. SOD is expected to be highly variable spatially and temporally in a stream, as a result of variation in stream conditions, such as bottom sediment type, inorganic composition, organic matter abundance, temperature, stream-water velocity, and turbulence. SOD is an essential primary variable used in numerical modeling of the geochemical evolution of stream water.

This report documents the rates of SOD measured at four locations on Hammonton Creek, Hammonton, N.J., and at three locations on Crosswicks Creek, near New Egypt, N.J., during August to October 2009, and describes the field techniques used to measure these SOD rates. Water temperature, initial DO concentration, and the decrease in DO concentrations with time were measured in the field. SOD rates and adjusted SOD rates for selected sites were calculated from these measurements and are given in tables. DO depletion curves and turbidity variation with time curves for the selected sites were plotted and are shown in illustrations.

Description of Study Area and Background

Hammonton Creek and Crosswicks Creek are small streams located in rural areas of central New Jersey. Hammonton Creek drains to the Atlantic Ocean, and Crosswicks Creek drains to the Delaware River.

Hammonton Creek

Hammonton Creek originates at Hammonton Lake, a small man-made impoundment located east of Hammonton, N.J. After leaving the lake, the stream flows easterly for approximately 7 miles (mi) until reaching the confluence with the Mullica River (fig. 1). The Hammonton Sewage-Treatment Plant discharges to the stream approximately 1,100 feet (ft) downstream from Hammonton Lake outfall. Six water-quality sampling sites (HC-1, HC-2, HC-3, HC-4, HC-6, and HC-7) were established along the first 4.8 mi of stream reach, beginning at the Hammonton Lake outfall (fig. 1). A seventh sampling site (HC-5) was located on a small unnamed tributary that drains a large blueberry field. Site HC-5 was sampled just upstream from the confluence of the unnamed tributary with Hammonton Creek.

All seven sampling sites were repeatedly sampled to measure water-quality characteristics during the TMDL study, beginning in the fall of 2008 and continuing through the summer of 2010. Samples of surface water were collected synoptically and analyzed for nutrients and other water-quality properties. During these sampling events, field measurements were made of water-quality characteristics, including temperature, specific conductance, dissolved oxygen, and pH. The SOD rates described in this report were measured at four of the six water-quality sampling sites (HC-1, HC-3, HC-4, and HC-5).

Crosswicks Creek

Crosswicks Creek originates as wetland drainage (fig. 2) and flows north for roughly 8.5 mi, then turns westerly and flows another 17 mi to its confluence with the Delaware River. A number of small tributaries and ponds are present along its course. The USGS established 13 sampling sites on Crosswicks Creek during the TMDL nutrient sampling program. Safe access to the stream for conducting the SOD tests could be made at only three of the sites (CW-1, CW-6, and CW-8). Site CW-1 is characterized as a woodland stream that drains a large swampy, forested woodland area. At sites CW-6 and CW-8, the stream flows through wooded lots, agricultural land, and horse pastures; the riparian right-of-way generally is heavily forested.

Methods

The SOD chamber, illustrated schematically in figure 3, consists of an aluminum bell-shaped pot that was inverted and pushed 1 to 2 inches (in.) into the bottom sediment of the stream (modified from Heckathorn and Gibs, 2010). Each chamber covers an area of 312 square inches (0.201 square meters) of the streambed. The inside volume of the chamber is 2,614 cubic inches (42.84 liters), including a correction for 1 in. of the bottom edge that is submerged in the sediment; no correction was made for the small volume occupied by the water-quality probes.

The chambers are equipped with a 3-in.-diameter port into which a YSI-6920 V2 water-quality sonde was inserted and sealed with a rubber sleeve and hose clamps. The measuring probes rest approximately 2 in. above the stream sediment.

Each SOD chamber is equipped with four vent holes that are opened when the chamber is emplaced to allow trapped air to escape. The chambers were rocked and tipped slightly during deployment to ensure that air bubbles did not remain in the top of the chamber and were placed approximately level on the streambed during the test. Once the chambers were seated on the bed, and before the test was started, the vents were plugged using rubber stoppers. At the sites where measurements were made, the SOD chambers were deployed for periods ranging from 3 to 12 hours.

The sondes were calibrated prior to each deployment using commercially prepared standards for turbidity and water-saturated air at the prevailing air temperature and barometric pressure for DO. DO concentrations were measured by a non-consumptive optical electrode; hence, DO should not be affected by suspended material in the water, and stirring within the chamber is not required to eliminate DO concentration gradients caused by the electrochemical determination of DO. The sondes were set to record the DO (in milligrams per liter and in percent saturation) and turbidity (in Nephelometric Turbidity Units (NTU)) at 3-minute intervals. During deployment, the real-time conditions in the chambers were monitored through a water-proof cable connecting the sonde to a hand-held meter and electronic data logger onshore. Except at Site HC-1 on Hammonton Creek where three chambers were deployed, the SOD chambers were deployed in pairs and left until DO levels dropped (optimally) approximately 1 milligram per liter (mg/L), which typically took a deployment time of 3 to 6 hours. The specific locations where the chambers were deployed in the stream were chosen so that bottom conditions were representative of the stream reach; chambers typically were located 3 to 4 ft apart.

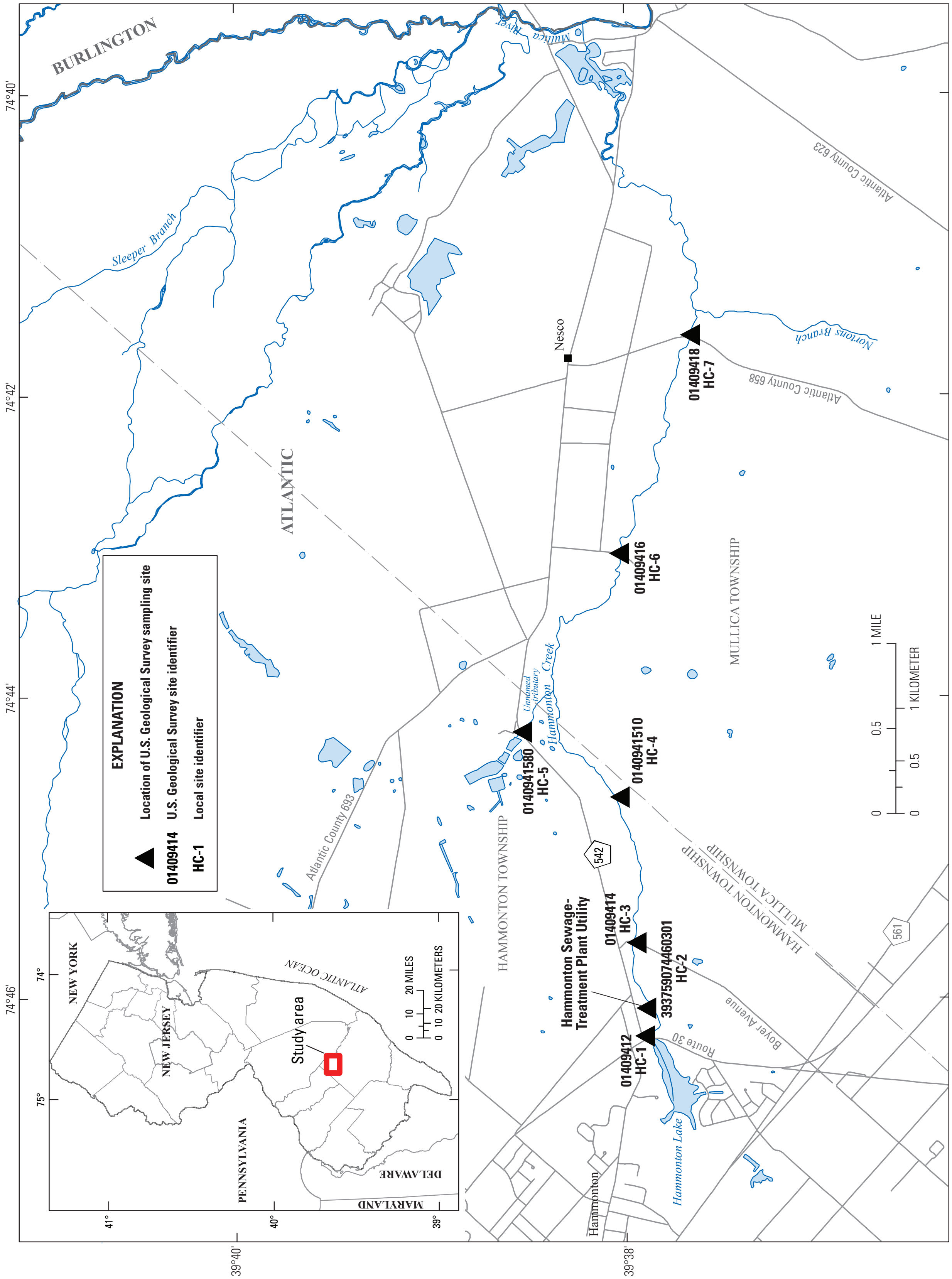

Figure 1. Location of study area and sampling sites on Hammonton Creek, Hammonton, New Jersey.

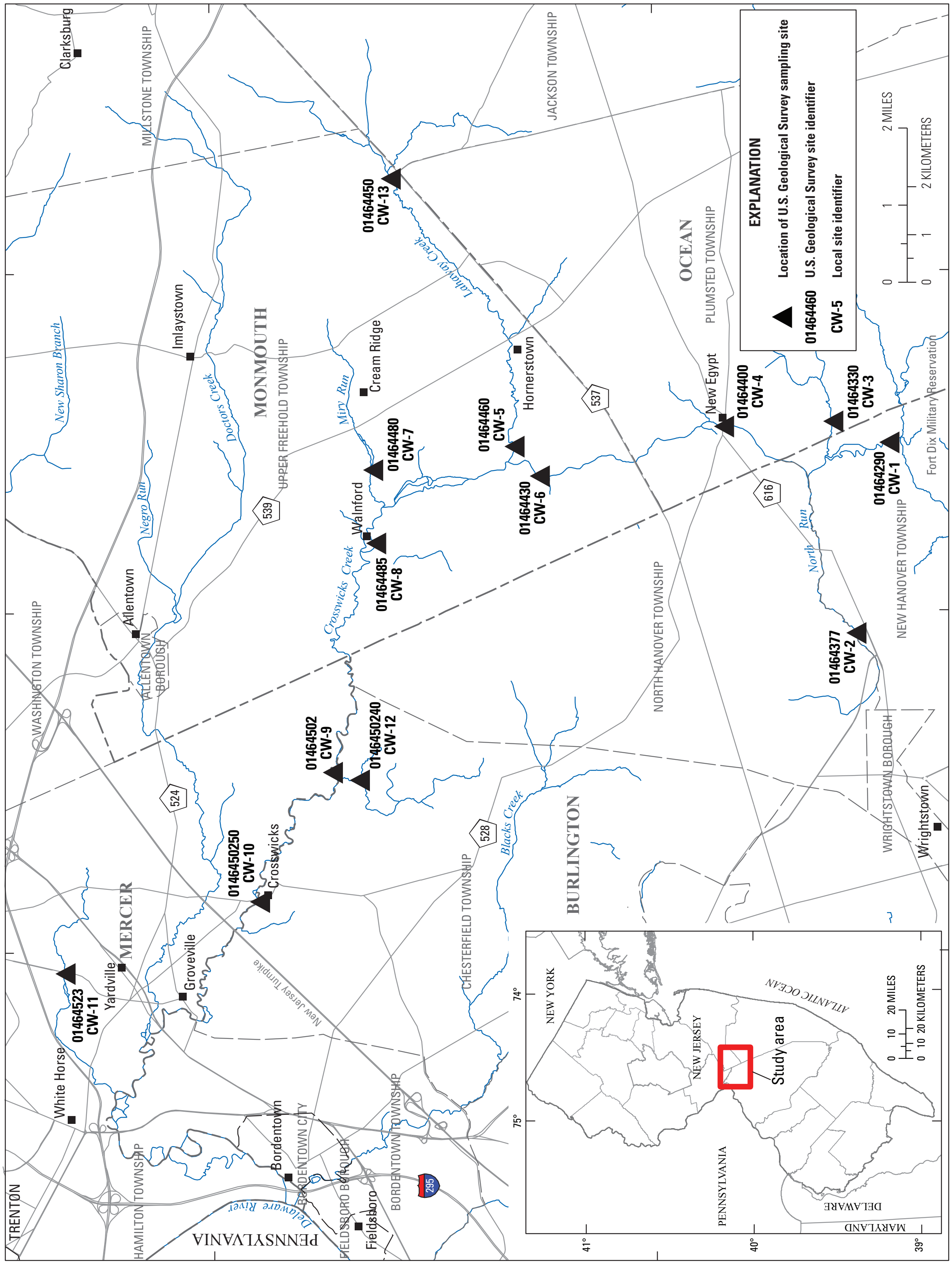

Figure 2. Location of study area and sampling sites on Crosswicks Creek, near New Egypt, New Jersey,

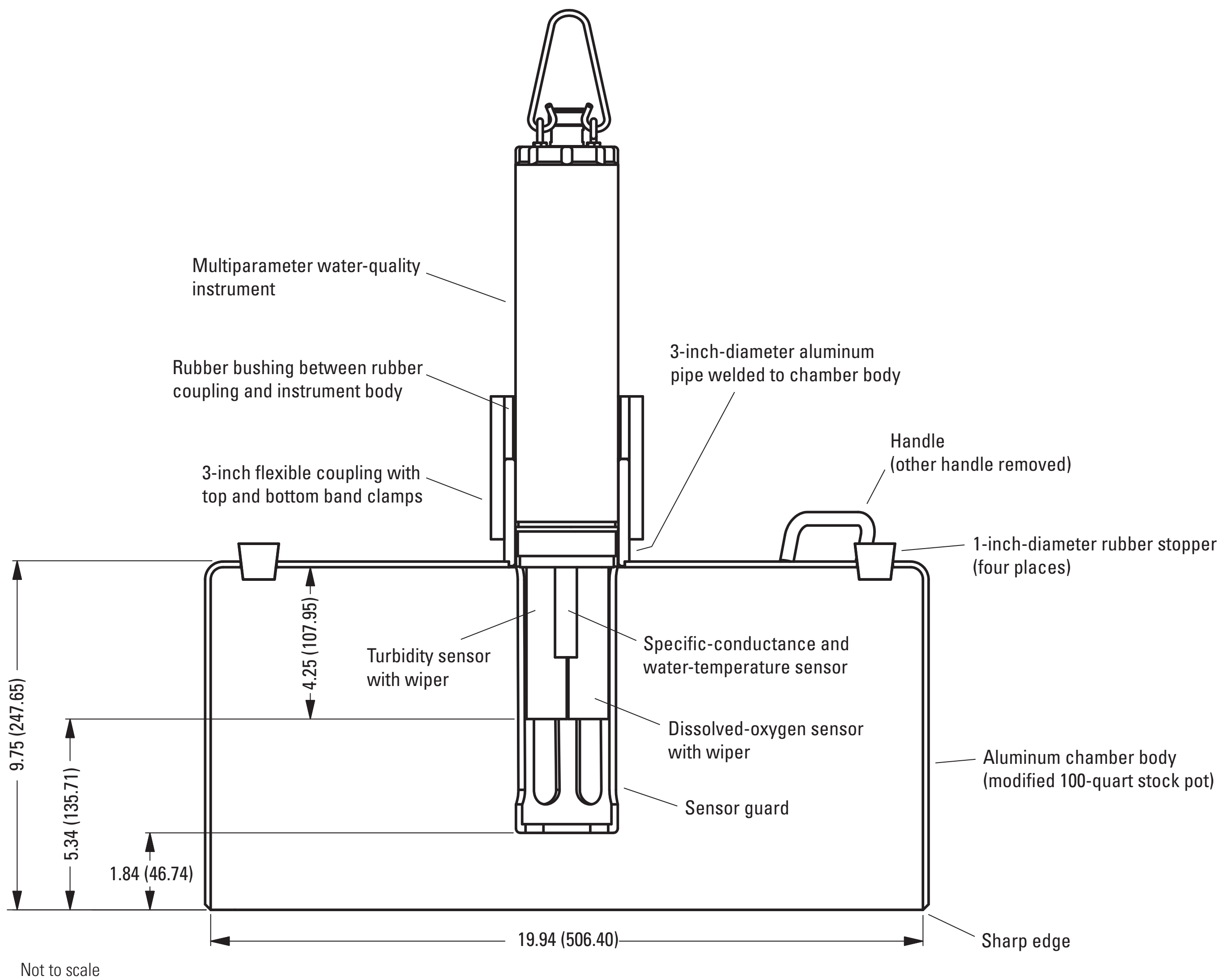

Figure 3. Sediment oxygen demand chamber as deployed in stream. [From Heckathorn and Gibs, 2010. Measurements are in inches; measurements in parentheses are in millimeters.]

Turbidity was measured inside the SOD chamber to determine the extent and length of time the stream bottom sediment was disrupted by the insertion of the chamber. Immediately after deployment, the turbidity in the chambers typically increased as the bottom sediment was disturbed. Turbidity then began to decline within the first 20 to 30 minutes, during which most of the fine materials settled out. After the fine materials had settled, the turbidity remained low and near the levels measured outside the chambers. However, the turbidity data were often noisy and showed occasional spikes; this is probably the result of either benthic organisms trapped in the chamber or materials striking the outside of the chamber.

DO concentrations in the chambers typically decreased after the first 30 to 60 minutes of deployment. This decrease indicated that the chamber was well seated and sealed from outside oxygenated stream water and that air was not likely to be trapped in the chamber. Field monitoring of DO levels allowed the progress of the test to be followed and provided confirmation that the chamber remained seated in the bottom sediment. On several occasions sediment around the edge of the chambers began to erode, causing the chamber to settle. In these instances, the chambers were reseated and the test repeated.

Calculation of Sediment Oxygen Demand Rates

The measured DO concentrations were plotted as a function of deployment time, resulting in a DO depletion curve. Although DO concentrations measured using these probes were, in principal, not affected by turbidity, the SOD rate was calculated after disregarding the DO concentrations measured during the first minute of chamber deployment when turbidity was usually elevated. The slope of the best-fit linear regression line (milligrams per liter per minute) of the oxygen depletion curve was calculated and used to determine the SOD rate using

$$SOD_T = 1.44\ (V / A) \times b, \qquad (1)$$

where

SOD_T is the sediment oxygen demand rate, in grams per square meter per day at water temperature, T;
V is the volume of the chamber, in liters;
A is the area of the streambed sediment covered by the chamber, in square meters;
b is the slope of the oxygen depletion curve, in milligrams per liter per minute; and
1.44 is a unit-conversion constant.

Reaction rates, both for biotic and abiotic reactions, can be sensitive to temperature. In order to standardize the in-situ measurements among locations and temperatures, the measured SOD rates were adjusted to 20 degrees Celsius using a standard Van't Hoff type equation (Heckathorn and Gibs, 2010):

$$SOD_{20} = SOD_T / 1.605^{(T-20)}, \qquad (2)$$

where

SOD_{20} is the sediment oxygen demand rate, in grams per square meter per day at 20 degrees Celsius, and
T is the water temperature, in degrees Celsius.

Sediment Oxygen Demand Rates

The rate of SOD in the streambed sediments was measured at several locations in the Hammonton and Crosswicks Creeks.

Hammonton Creek

SOD rates were measured in Hammonton Creek at Sites HC-1, HC-3, HC-4, and HC-5 (fig. 1) during the 2009 summer growing season. An attempt to measure SOD rates at Site HC-7 was unsuccessful because the chambers could not be properly seated in the coarse sand, gravel, and cobbles of the bottom sediment. The measured field characteristics and calculated SOD rates determined for each of these sites are listed in table 1.

The DO concentrations and turbidity in the chambers were plotted as a function of time for Hammonton Creek (figs. 4 to 11). The initial DO concentration and turbidity in the stream were measured. For example, at Site HC-1, the initial DO in the creek was measured as 8.73 mg/L (table 1), and the turbidity was low (1 to 3 NTU), which was typical for most of the other sites. Deployment disturbs the finer materials in the bottom sediment, causing an immediate increase in turbidity of 5 to 10 NTU or more depending upon local conditions. At Site HC-1, the first measurement of turbidity inside the test chamber was about 6 NTU. It then increased slightly and then declined to a background level of 2 NTU after approximately 120 minutes. The small increase in turbidity attests to that fact that only small amounts of fine materials are present in the bed sediment at this site. Occasionally, short-termed spikes in turbidity were measured; these spikes may be the result of the movement of bottom fauna trapped in the chamber, materials in the stream striking the chamber, or instrument noise. The turbidity in some of the chambers was found to rise slowly (in the case of Site HC-1, after approximately 660 minutes). The cause for the rise is not fully understood but may have been in response to instrument drift (caused by material adhering to the optical probe) or to changes in streamflow velocity (thereby causing the chamber to vibrate).

For each deployment, the dissolved oxygen values were plotted as a function of elapsed deployment time (in minutes) beginning from the time that the turbidity had returned to near

Table 1. Measured field characteristics and calculated sediment oxygen demand rates at selected stations on Hammonton Creek, Hammonton, New Jersey.

[mg/L, milligrams per liter; g/m^2/d, grams per square meter per day]

Local site identifier	U.S. Geological Survey site identifier	Chamber test number	Average stream-water temperature, in degrees Celsius	Initial dissolved oxygen concentration, in mg/L	Elapsed time of deployment, in minutes	Total decrease in dissolved oxygen, in mg/L	Calculated sediment oxygen demand rate, in g/m^2/d	
							At measured temperature	Adjusted to 20 degrees Celsius
HC-1	01409412	1	21.5	8.73	786	5.01	-5.6	-5.1
HC-3	01409414	1	24.3	6.42	258	1.29	-1.4	-1.1
HC-3	01409414	2	24.3	6.43	252	1.04	-1.6	-1.2
HC-4	0140941510	1	23.2	7.32	378	0.75	-0.58	-0.47
HC-4	0140941510	2	23.2	7.26	378	0.46	-0.37	-0.30
HC-5	0140941580	1	21.5	5.54	240	1.10	-1.5	-1.3
HC-5	0140941580	2	21.5	5.72	228	2.68	-3.8	-3.5

background levels and ending at the time the chamber was removed from the stream. The slope of the best-fit regression line for each dataset was calculated; the resulting SOD rates are listed in table 1 along with the SOD rates adjusted to 20 degrees Celsius using equation 2.

The measurements made in two or three chambers deployed at a single site typically produced similar SOD rates. This finding indicates that the equipment was working properly, that the chambers remained well seated in the streambed, and that the values are not an artifact of the technique used to measure DO concentrations. SOD rates measured in Hammonton Creek are within the range measured by Heckathorn and Gibs (2010) in the Saddle River (-0.8 to -1.5 grams per square meter per day (g/m^2/d)) and the Salem River (-0.6 to -7.1 g/m^{2}d) in New Jersey. However, few other measurements, if any, are known to have been made using this in-situ technique under similar stream conditions (sandy streambed and shallow, high-velocity water), so direct extrapolation of these SOD rates to other similar streams may not be possible. Each individual site produced different SOD rates that are likely related to physical conditions (type of substrate, presence of aquatic vegetation, or sunlight penetration), as described in detail below.

Site HC-1 on Hammonton Creek at Hammonton Lake Outfall

As described earlier, this test was conducted in a reach of the stream immediately downstream from Hammonton Lake Dam (fig. 1). This small dam is approximately 10 ft high with a spillway that runs under Route 30. The single chamber was seated in the stream at a location where the velocity had declined from that in the raceway and where a large deposit of soft, fine-grained, organic-rich sand was present. The stream banks were highly vegetated with trees, shrubs, piles of leaves, and grasses that restricted light penetration. The water was clear and flowed smoothly during the test.

The SOD test at this site was allowed to run for more than 12 hours and produced a linear SOD depletion curve over the entire deployment (fig. 4). The linear trend in the data is important because it indicates that similar results probably would have been obtained at other sites had the chambers been deployed for longer times.

Turbidity increased slightly immediately after the chamber was deployed; it declined over the next approximately 1.5 hours and remained extremely low thereafter (fig. 5). Spikes in turbidity occurred late in the test and may be the result of biota in the stream bottom, a physical object striking the outside of the SOD chamber, increased vibrations caused by traffic on the nearby road, or perhaps instrument noise. The DO concentration decrease in the SOD chamber was linear and resulted in a relatively high SOD rate (-5.64 g/m^2/d) (fig. 4 and table 1). This high value likely resulted from high biological demand in the organic carbon-rich bed sediment that accumulates at this site after being washed out of the lake. Analysis of the carbon content in the bottom sediment at this site (and the other sites) is needed to confirm this hypothesis.

Site HC-3 on Hammonton Creek at Boyer Avenue

The SOD chamber was installed approximately 50 ft downstream from the Boyer Avenue Bridge (fig. 1). The streambed material at this site was fine sand and gravel, which allowed the chambers to be well sealed. The heavy pine-oak woods at this site allowed little light to penetrate through to the stream. The banks of the stream near the bridge were covered with grass, but the stream had little aquatic vegetation in it. Water depth was approximately 3 ft, and the water was clear, flowing freely with little turbulence.

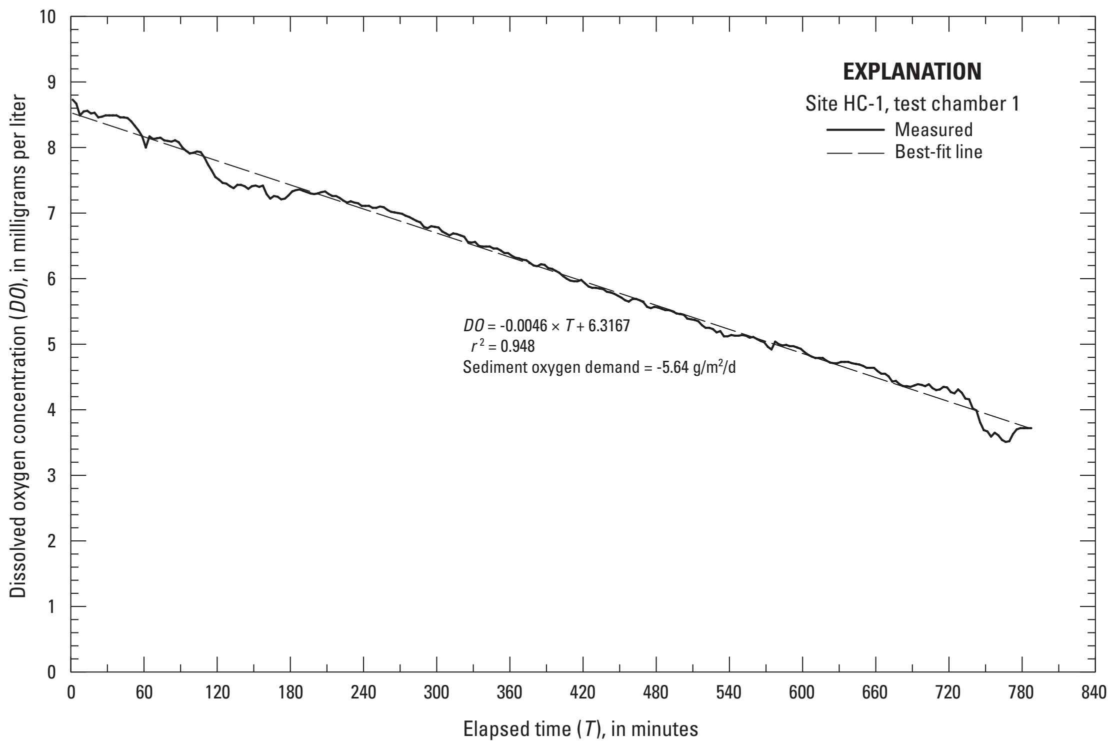

Figure 4. Dissolved oxygen depletion curve for chamber 1 at Site HC-1, Hammonton Creek, New Jersey, September 23–24, 2009. [g/m²/d, grams per square meter per day]

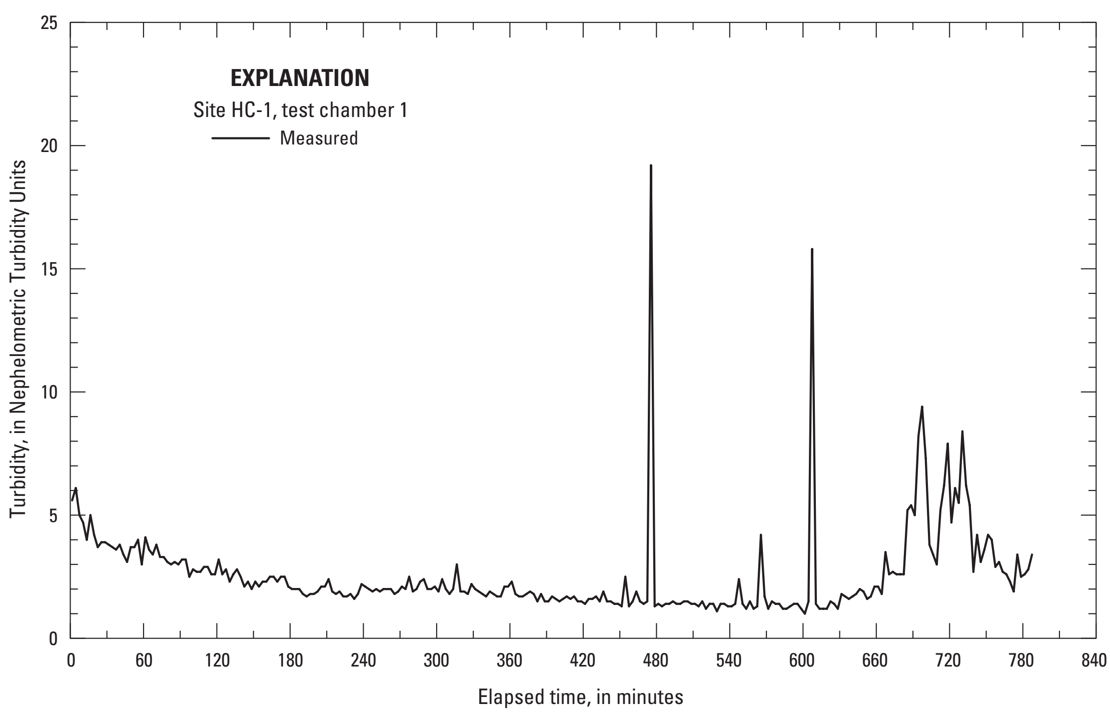

Figure 5. Turbidity in chamber 1 at Site HC-1, Hammonton Creek, New Jersey, September 23–24, 2009.

Initial DO concentrations in the creek were 6.42 and 6.43 mg/L (table 1). Calculated SOD rates were determined to be approximately equal in both test chambers (about -1.5 $g/m^2/d$) (fig. 6), which is approximately 3.5 times lower than that measured at Site HC-1 (table 1). Turbidity values in both chambers became elevated immediately after their deployment in the streambed, and it took about 50 minutes for turbidity to return to low, stable levels (fig. 7), though the turbidity in one chamber rose slightly after about 125 minutes. The streambed at this site does not contain excessive amounts of biodegradable carbon-rich material as might be expected for a reach that is downstream from the Hammonton Sewage-Treatment Plant outfall (HC-2).

Site HC-4 on Hammonton Creek

Site HC-4 is on Hammonton Creek at a wooden bridge behind the large blueberry processing plant and is located approximately 4,500 ft downstream from Site HC-3 on Boyer Avenue (fig. 1). Streamflow at Site HC-4 was swift, and the water was clear and shallow (about 2.5 ft), barely sufficient to cover the SOD test chambers. The bed materials were sand with small gravel, and the channel contained small patches of aquatic vegetation (water grasses). The streambanks were covered with tall vegetation and trees. In the reach immediately upstream from the bridge, the stream flows through a thick pine–oak forest that allows little sunlight to penetrate. Downstream from the bridge, the stream re-enters the forest, although the forest is less dense than upstream.

The initial DO concentrations in the creek at this site were 7.26 and 7.32 mg/L (table 1). The measured SOD rate was similar in both chambers, about -0.5 $g/m^2/d$ (fig. 8), which is roughly one-third the rates measured at Site HC-3 and about one-tenth the rate at Site HC-1 (table 1). The rates for Site HC-4 may be low because the total depletion of DO in both chambers was slightly less than 1 mg/L over the course of these tests. Turbidity in both chambers was elevated for about the first 20 minutes after the chambers were deployed, after which time turbidity slowly declined (fig. 9). The turbidity data at this site are noisy, which is probably the result of the chambers vibrating and shifting in the swift current.

Site HC-5 on Unnamed Tributary to Hammonton Creek at Amanda Lane

Site HC-5 is located on a small unnamed tributary that crosses under the road approximately 1,000 ft upstream from its confluence with Hammonton Creek (fig. 1). This tributary is a channel that drains a large blueberry field located to the north of the stream. At the sampling site, the flow in the tributary was slow, and the water depth was approximately 3.5 ft. Downstream from the tested location, the tributary flows through a swampy, forested wetland before joining Hammonton Creek. The channel material is sandy but contains observable deposits of organic-rich, fine-grained sediments. When wading through the tributary, one can smell rotting vegetation and hydrogen sulfide, indicating that local sub-oxic to anoxic conditions may exist. The channel is in complete sunlight as it passes through the blueberry field and at the sampling site, but it enters a shady wetland downstream from the sampling site. On one side, the stream bank is grass-covered and open, and receives morning sun, whereas on the other side of the stream, the bank is under a heavy forest canopy.

The initial DO concentrations in the stream at this site were 5.54 and 5.72 mg/L (table 1). The SOD rates measured at Site HC-5 differed by a factor of about 2 between the two test chambers (fig. 10); however, these rates were similar to those measured at Site HC-3 (table 1). Further testing at Site HC-5 for a longer period of deployment would be needed to verify these results. After deployment, the turbidity in both chambers at Site HC-5 declined exponentially for about 60 minutes (fig. 11). The final turbidity values for Site HC-5 were much higher (10–20 NTU) than the values for the other sites.

Crosswicks Creek

The streambed in Crosswicks Creek (fig. 2) is composed of fine-grained sand, silt, and clay. In many locations pockets of silty clay, which included large amounts of organic matter (muck), were observed. Under low-flow conditions the stream water appeared clear, but it rapidly became turbid with just minor increases in flow velocity. The measured field characteristics and calculated SOD rates for Crosswicks Creek are listed in table 2.

Site CW-1 on Crosswicks Creek at Cookstown-Hockamic Road

In this reach of the stream, the bed materials are predominantly fine-grained sand with some small gravel (20 percent) and only minor amounts of finer materials. The water was approximately 3 ft deep and was noticeably colored by organic matter that originated from the wetland located immediately upstream from the site. Although the stream appeared to have little suspended sediment, the turbidity (9–10 NTU units) at this site was greater than that found at other sites on Crosswicks Creek (fig. 2).

Only one chamber was successfully used at this site because the power in the sonde in the second chamber failed during the test. The initial stream DO concentration at this site was 6.75 mg/L (table 2). Dissolved oxygen levels in the operating chamber dropped steadily and deviated only slightly from a linear trend resulting in a calculated SOD rate of -1.99 $g/m^2/d$ (fig. 12). The turbidity in the test chamber was relatively constant (about 9.5 NTU) (fig. 13), showing a slow decline of only 1 NTU during the test. This high turbidity may be related to the organic coloring of the water.

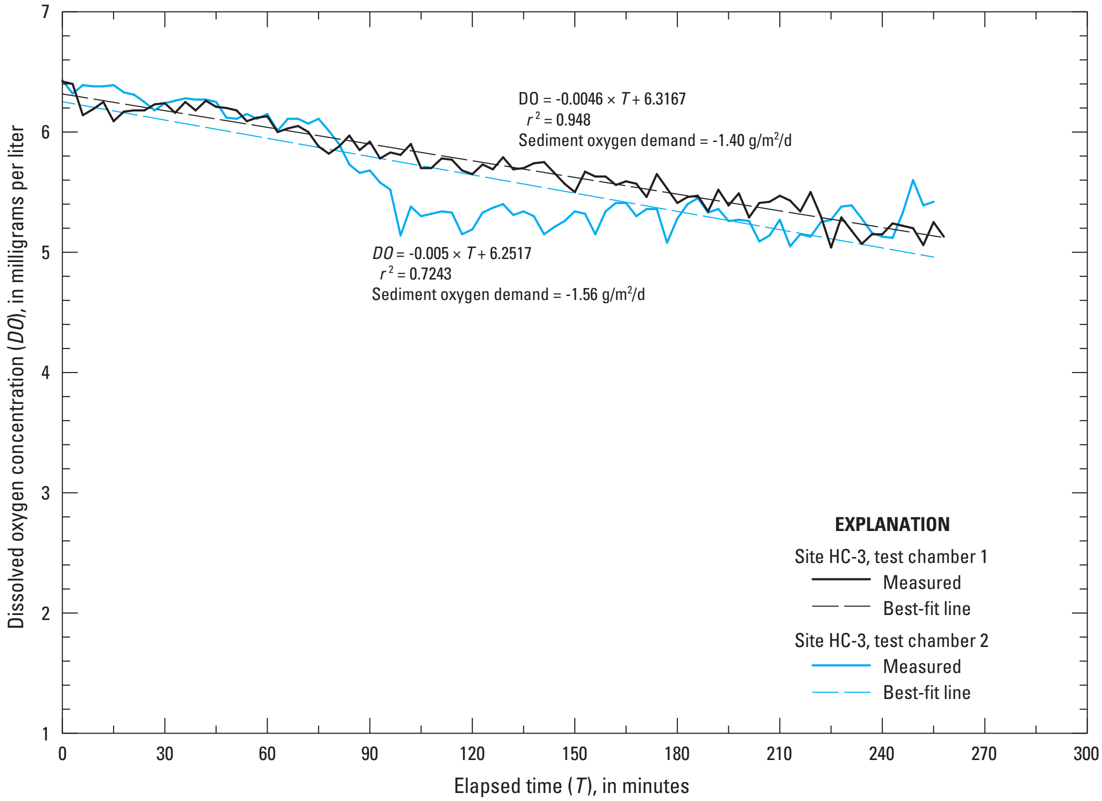

Figure 6. Dissolved oxygen depletion curves for chambers 1 and 2 at Site HC-3, Hammonton Creek, New Jersey, August 19, 2009. [g/m²/d, grams per square meter per day]

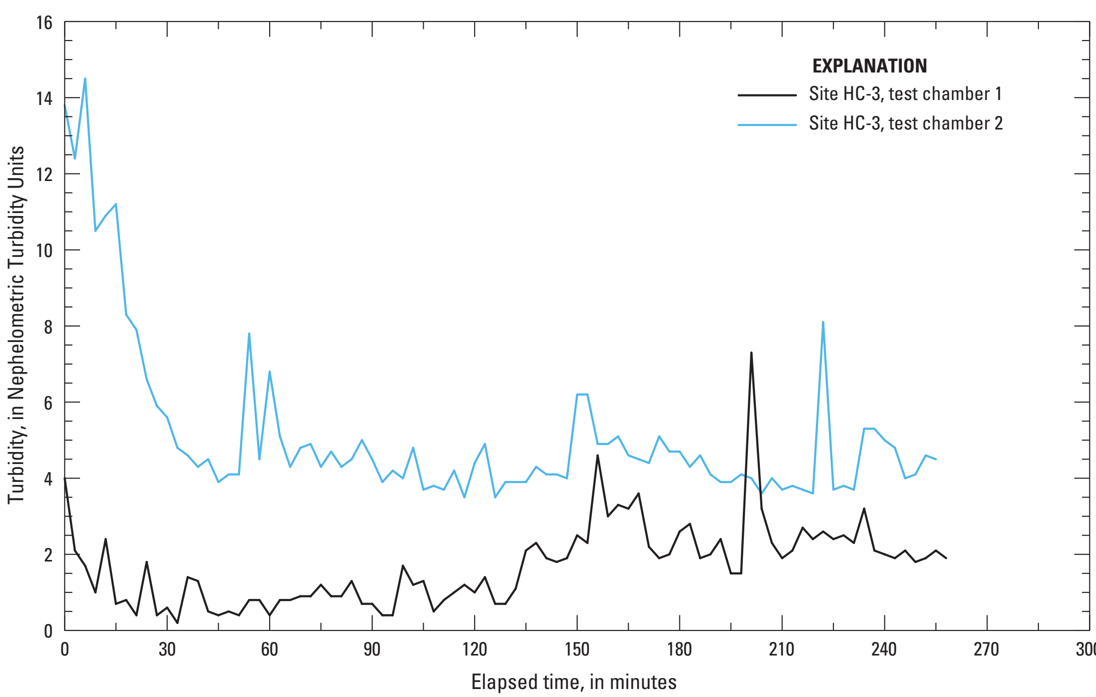

Figure 7. Turbidity in chambers 1 and 2 at Site HC-3, Hammonton Creek, New Jersey, August 19, 2009.

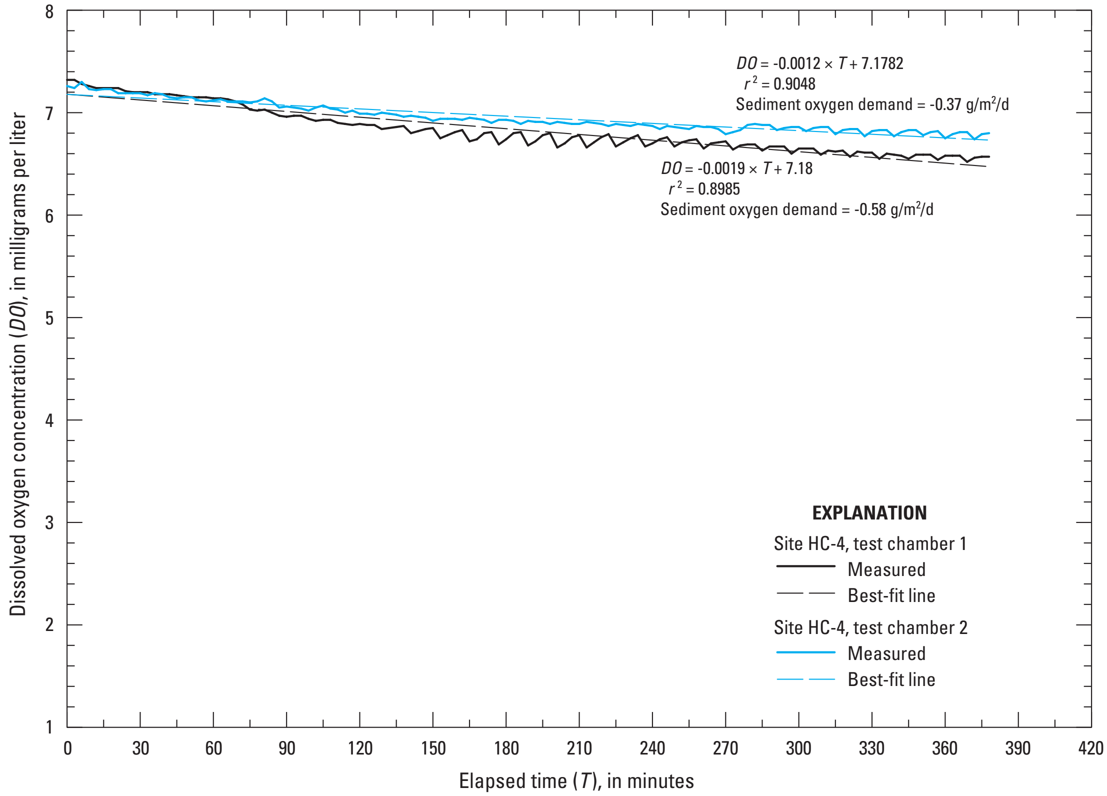

Figure 8. Dissolved oxygen depletion curves for chambers 1 and 2 at Site HC-4, Hammonton Creek, New Jersey, August 27, 2009. [$g/m^2/d$, grams per square meter per day]

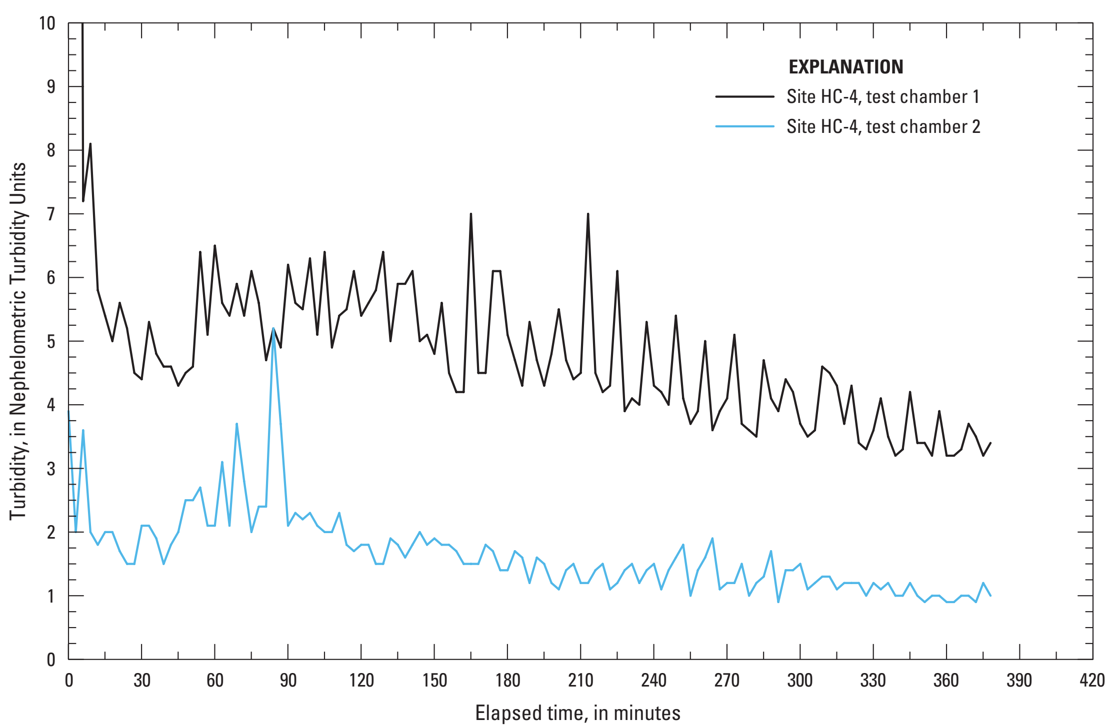

Figure 9. Turbidity in chambers 1 and 2 at Site HC-4, Hammonton Creek, New Jersey, August 27, 2009.

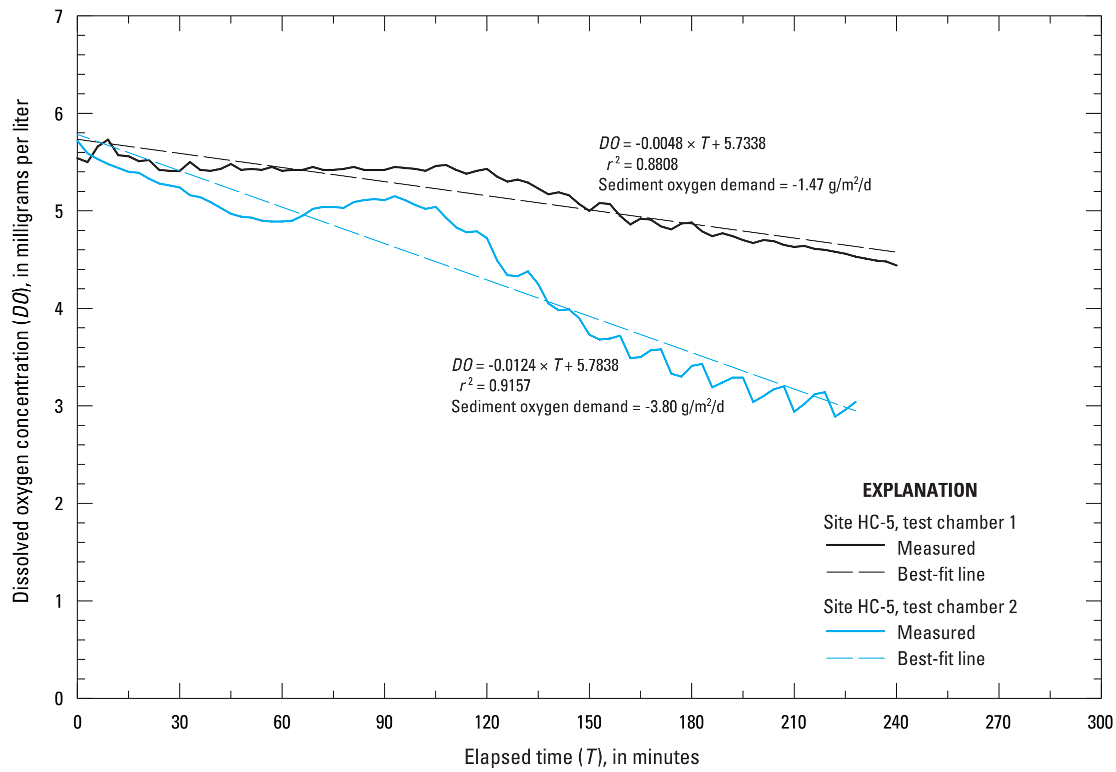

Figure 10. Dissolved oxygen depletion curves for chambers 1 and 2 at Site HC-5, unnamed tributary to Hammonton Creek, Hammonton, New Jersey, August 28, 2009. [g/m^2/d, grams per square meter per day]

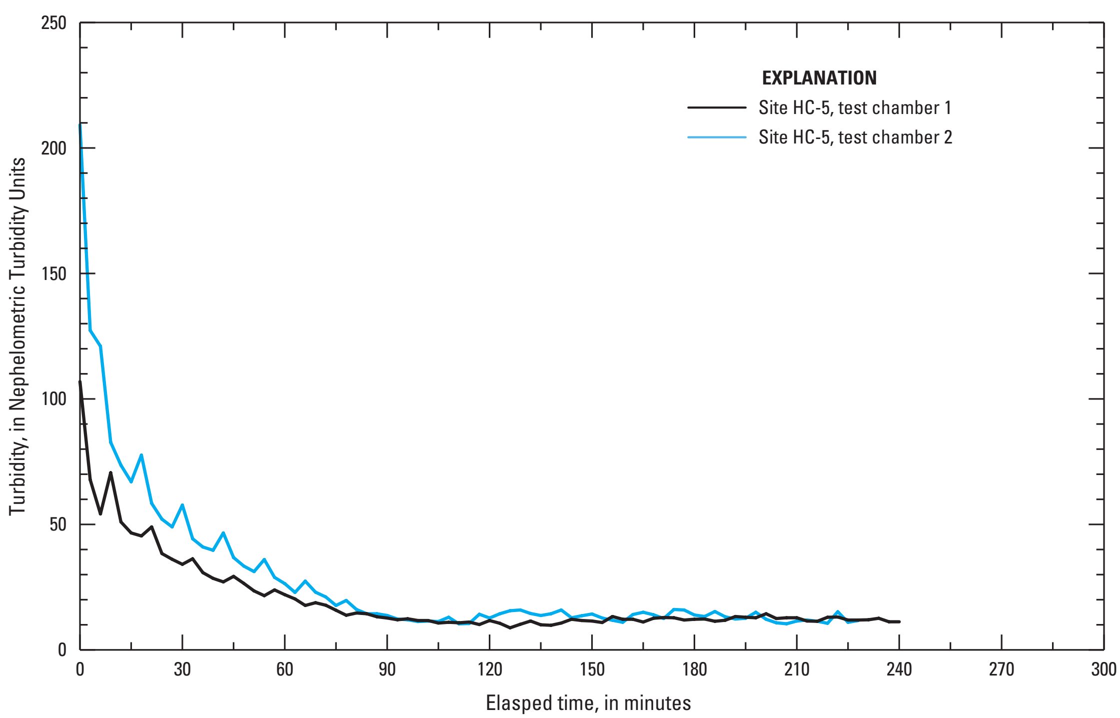

Figure 11. Turbidity in chambers 1 and 2 at Site HC-5, unnamed tributary to Hammonton Creek, New Jersey, August 28, 2009.

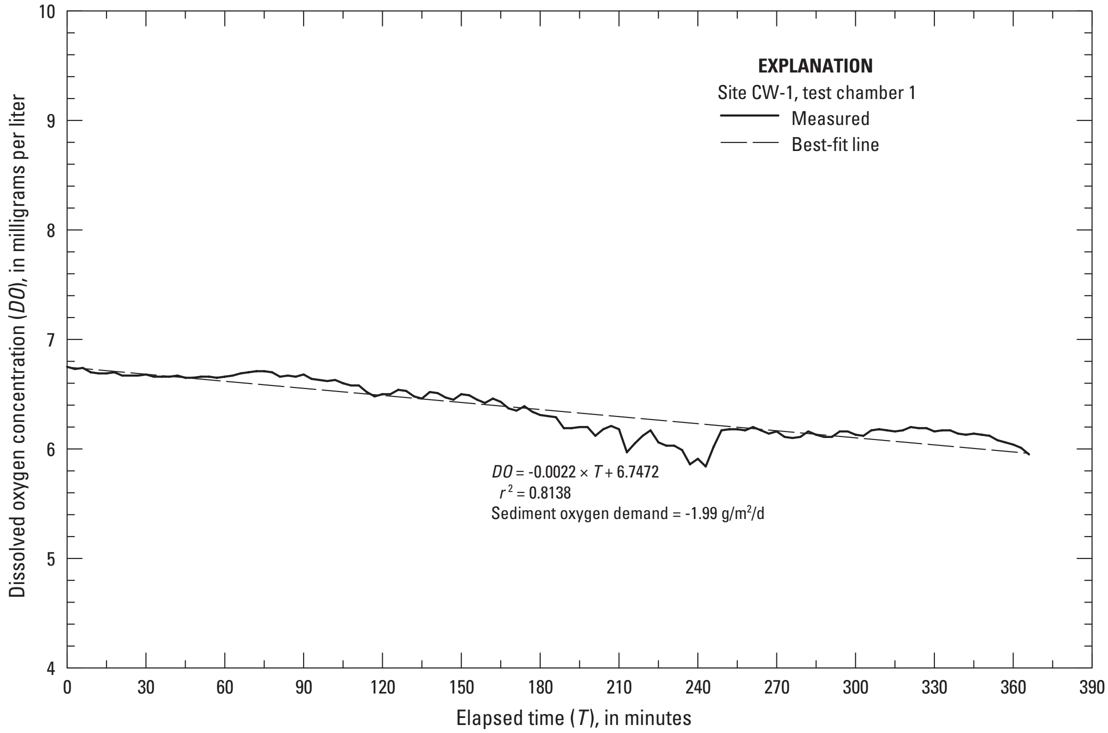

Figure 12. Dissolved oxygen depletion curve for chamber 1 at Site CW-1, Crosswicks Creek, New Jersey, October 7, 2009. [g/m²/d, grams per square meter per day]

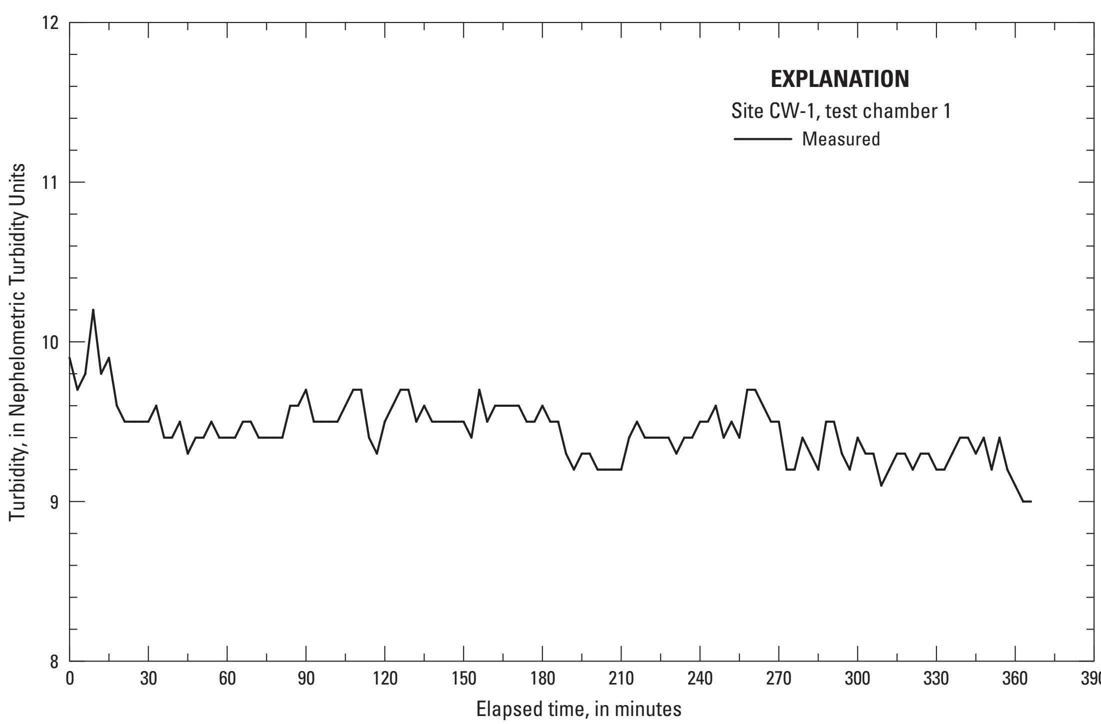

Figure 13. Turbidity in chamber 1 at Site CW-1, Crosswicks Creek, New Jersey, October 7, 2009.

Table 2. Measured field characteristics and calculated sediment oxygen demand rates at selected stations on Crosswicks Creek, near New Egypt, New Jersey.

[mg/L, milligrams per liter; g/m²/d, grams per square meter per day]

Local site identifier	U.S. Geological Survey site identifier	Chamber test number	Average stream water temperature, in degrees Celsius	Initial dissolved oxygen concentration, in mg/L	Elapsed time of deployment, in minutes	Total decrease in dissolved oxygen, in mg/L	Calculated sediment oxygen demand rate, in g/m²/d	
							At measured temperature	Adjusted to 20 degrees Celsius
CW-1	01464290	1	16.5	6.75	350	3.8	-1.99	-2.5
CW-6	01464430	1	19.3	8.13	366	0.66	-0.40	-0.42
CW-6	01464430	2	19.2	8.15	321	0.55	-0.37	-0.39
CW-6	01464430	3	19.2	8.25	324	0.40	-0.31	-0.33
CW-8	01464485	1	16.8	4.34	336	2.13	[1]-0.62	[2]-0.82
CW-8	01464485	2	17.5	8.52	324	0.90	-0.80	-0.94

[1]Rate dependent upon time range selected for use in calculation: -8.2 for 0 to 50 minutes; -0.025 for 50 to 325 minutes. (See figure 18.)

[2]Rate dependent upon time range selected for use in calculation: -10 for 0 to 50 minutes; -0.03 for 50 to 325 minutes. (See figure 18.)

Site CW- 6 on Crosswicks Creek at Arneystown-Hornerstown Road

Because the main channel at Site CW-6 was too deep to wade, the test chambers were deployed on the inside of a meander in approximately 2.5 ft of water (fig. 2). The streambed at this site consisted of sandy silt and clay. The streambed in the main channel, in contrast, appeared to be hard bedrock or packed clay. Although the test location was wooded, a substantial amount of sunlight penetration was observed. The stream channel did not contain aquatic vegetation.

The initial DO concentrations at Site CW-6 were measured in triplicate and ranged from 8.13 to 8.25 mg/L (table 2). Three chambers were used at this site because they were available and because it was an opportunity to get a better idea of the variability of the SOD results measured in close proximity to one another. The calculated SOD rates in the three chambers that were deployed at this site ranged from -0.31 to -0.40 g/m²/d (fig. 14). On the basis of the triplicate measurements, the mean SOD rate for this site was -0.36 g/m²/d with a standard deviation of 0.05 g/m²/d. This finding confirmed that the in-situ test chamber technique can provide reproducible results. Close inspection of the plots in figure 14 shows that the DO concentrations fluctuated rapidly during the test. However, these fluctuations were small and probably the result of vibrations of the sonde caused by flow in the stream channel. It was also noted that in two of the three chambers DO concentrations began to rise slowly, then fell between 175 and 275 minutes of elapsed deployment time. The cause for this behavior is unknown. Turbidity in the chambers (fig. 15) was high immediately after the chambers were set, but turbidity quickly returned to lower values within 20 minutes. Once settled, the turbidity declined slowly over the remainder of the test.

Site CW-8 on Crosswicks Creek at Walnford Pond

A small dam exists on Crosswicks Creek at Walnford forming a pond of approximately 0.5 acre in size. The stream was sluggish near the sides of the pond, but a smoothly flowing channel was evident through the center of the pond. The water depth in the center channel was roughly 6 ft during low flow. At the time of the test, the water was turbid throughout the pond and stream channel. The chambers were deployed at two sites in the pond, one along the shore of the pond where flow was not obvious and the second at the edge of the center channel where the water was observed to be flowing. At the near-shore site, the water depth was approximately 3 ft, and the bed was covered with a thick layer of dark, organic-rich, sticky muck that produced an odor of decaying vegetation and sulfide. At the center channel location, the color of the bed material was noticeably different, less dark, but the material appeared to be mainly silt-clay sized. The initial DO concentration at the center channel site (8.52 mg/L) was almost twice that found in the water along the shore (4.34 mg/L) (table 2). The pond surface received direct sunlight, although the stream banks were wooded and aquatic vegetation (reeds and lily pads) was growing along the shore.

Using the best-fit regression lines for the collected datasets resulted in similar calculated SOD rates at the two sites (-0.80 and -0.62 g/m²/d) (fig. 16). This finding was surprising considering the differences in the nature of the bed materials, the difference in initial DO values in the water, and the differently shaped DO depletion curves. At the center channel CW-8 site, the oxygen depletion curve is linear with an excellent fit ($r^2 = 0.98$) (fig. 16). At the near-shore CW-8 site, the linear trend line for the oxygen depletion curve is a poor fit ($r^2 = 0.25$) for the data. A logarithmic fit of the near-shore site dataset gave an improved fit ($r^2 = 0.68$) (fig. 16). Thus, a single

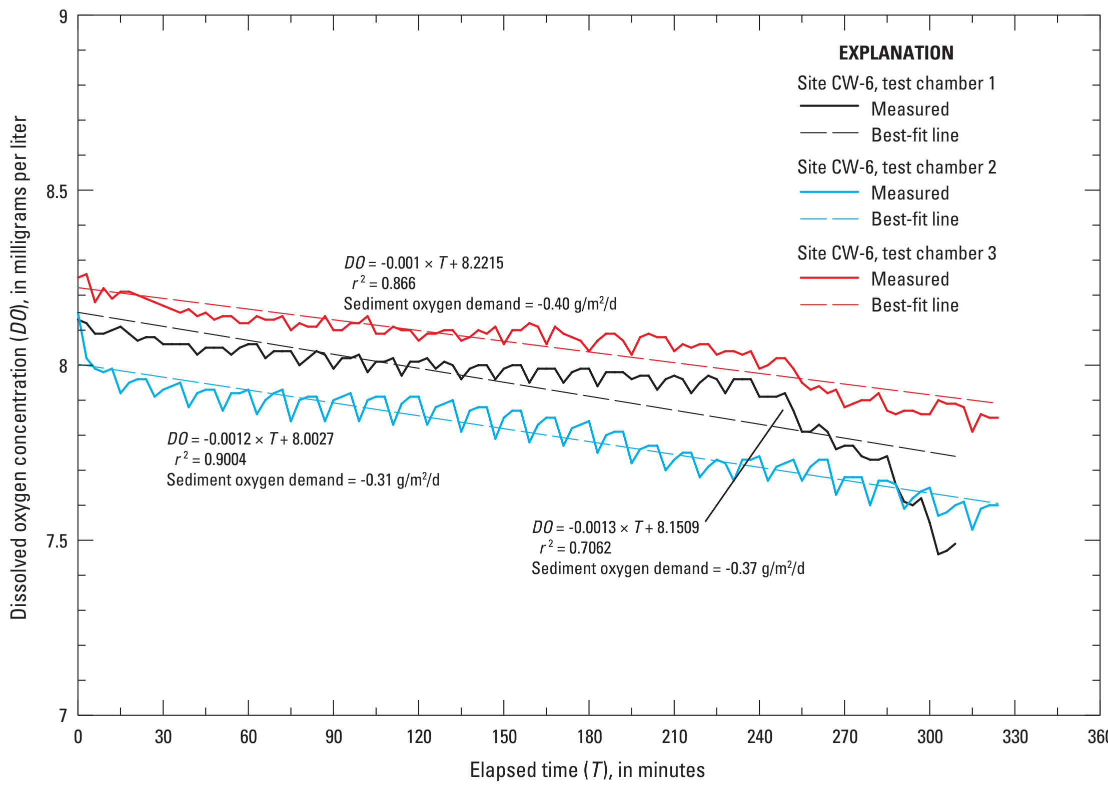

Figure 14. Dissolved oxygen depletion curves for chambers 1, 2, and 3 at Site CW-6, Crosswicks Creek, New Jersey, on August 16, 2009. [g/m²/d, grams per square meter per day]

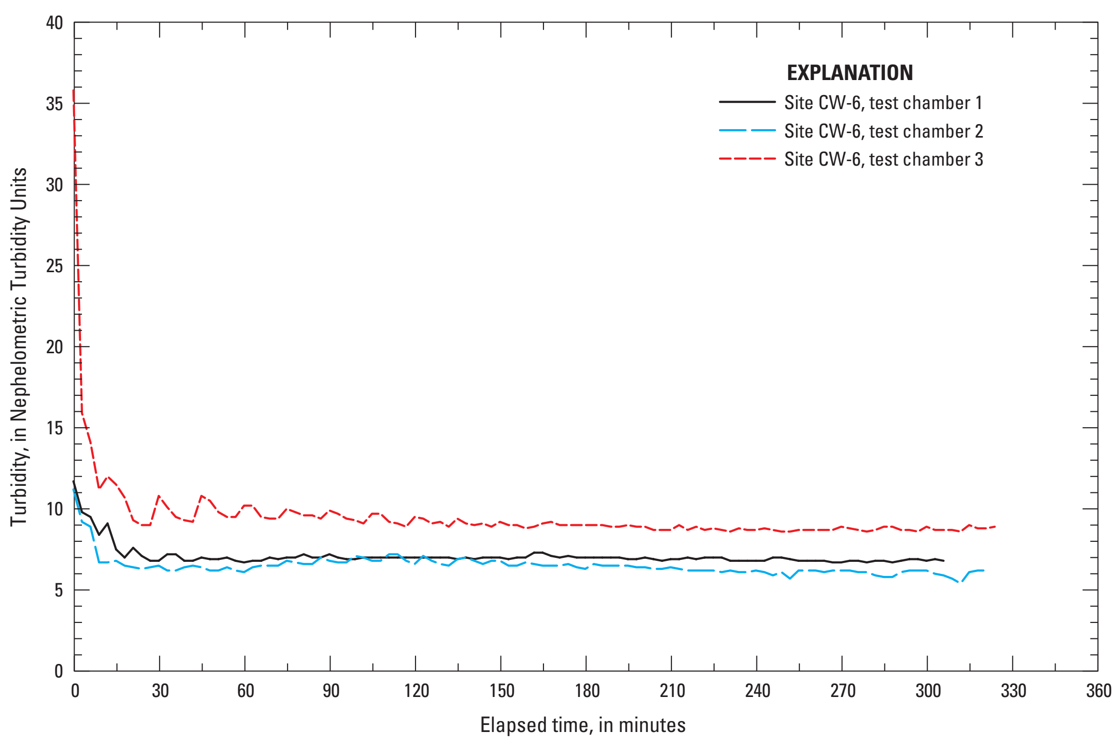

Figure 15. Turbidity in chambers 1, 2, and 3 at Site CW-6, Crosswicks Creek, New Jersey, August 16, 2009.

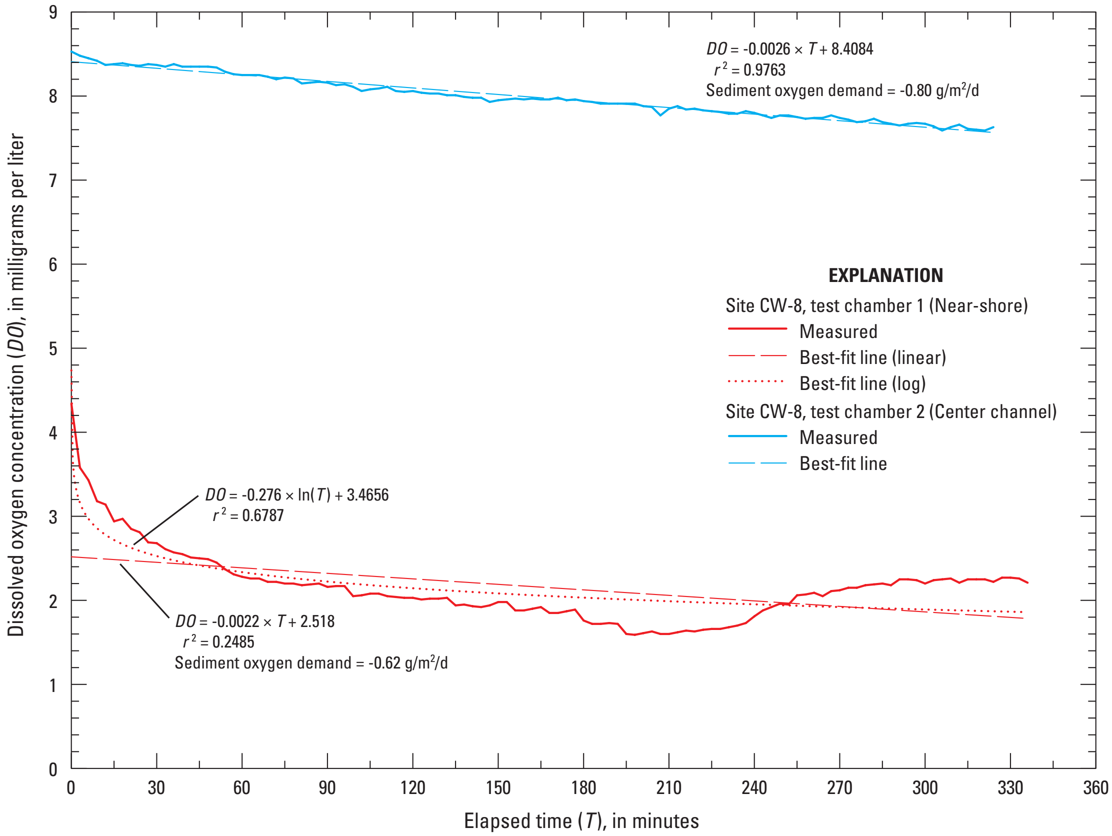

Figure 16. Dissolved oxygen depletion curves for chambers 1 and 2 at Site CW-8, Crosswicks Creek, New Jersey, August 18, 2009. [g/m²/d, grams per square meter per day]

linear rate of DO concentration decay is probably not appropriate at the CW-8 site.

The turbidity in the two chambers also decayed differently at the two sites (fig. 17). In the center channel location (test chamber 2), the turbidity quickly fell and remained low (about 8–9 NTU), whereas in the near-shore location (test chamber 1), the turbidity remained elevated (well over 50 NTU) for most of the test. These differences in turbidity relate to the difference in bed materials and perhaps stream velocities in the two locations.

Because of the differences in DO concentrations and turbidities, the DO dataset for the near-shore CW-8 site (test chamber 1) was split into two different time periods with two different oxygen depletion rates. SOD rates for each time period were recalculated (fig. 18 and table 2). Using data collected from 0 to 50 minutes after deployment, the SOD rate for test chamber 1 was recalculated to be -8.2 $g/m^2/d$, about 10 times faster than that measured at the central channel site (chamber 2) (fig. 18). Using data from the latter part of the curve (from 50 to 325 minutes of elapsed deployment time) the SOD rate was calculated to be only -0.025 $g/m^2/d$, about 30 times slower than that calculated for the center channel site (chamber 2). However, it should be noted that the linear fit to this latter subset of data was very poor ($r^2 = 0.001$). These data, along with the low absolute value of DO in the chamber, indicate that, in marshy areas of streams where pockets of organic-rich bottom materials are found, the range of SOD rates may be very large.

Protocols for Proper Use of In-Situ SOD Chambers

From this work, a number of protocols were developed for the proper use of the in-situ test chambers to measure oxygen depletion rates and to calculate SOD rates. Chambers should be deployed in pairs and left in place as long as possible or until at least a linear decay is observed. As a general rule, chambers should be left in place until a drop in DO concentration of at least 1 mg/L is recorded. The measurement of similar oxygen depletion rates from two (or more chambers) at the same site will confirm that the test chambers are well seated and producing reproducible data.

Sites should be chosen where stream bottom conditions allow a good seal to be obtained with the test chamber. Fine-grained bottom sediment having few cobbles or boulders is the preferred streambed material for testing. By monitoring the

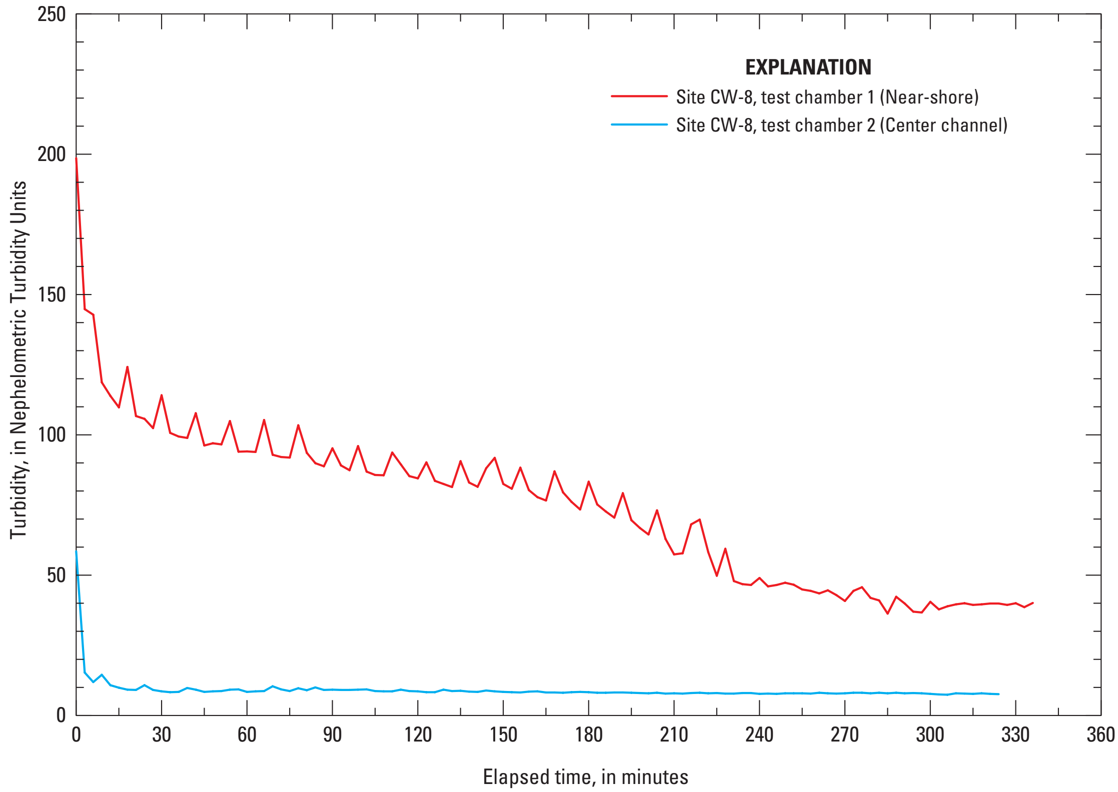

Figure 17. Turbidity in chambers 1 and 2 at Site CW-8, Crosswicks Creek, New Jersey, August 18, 2009.

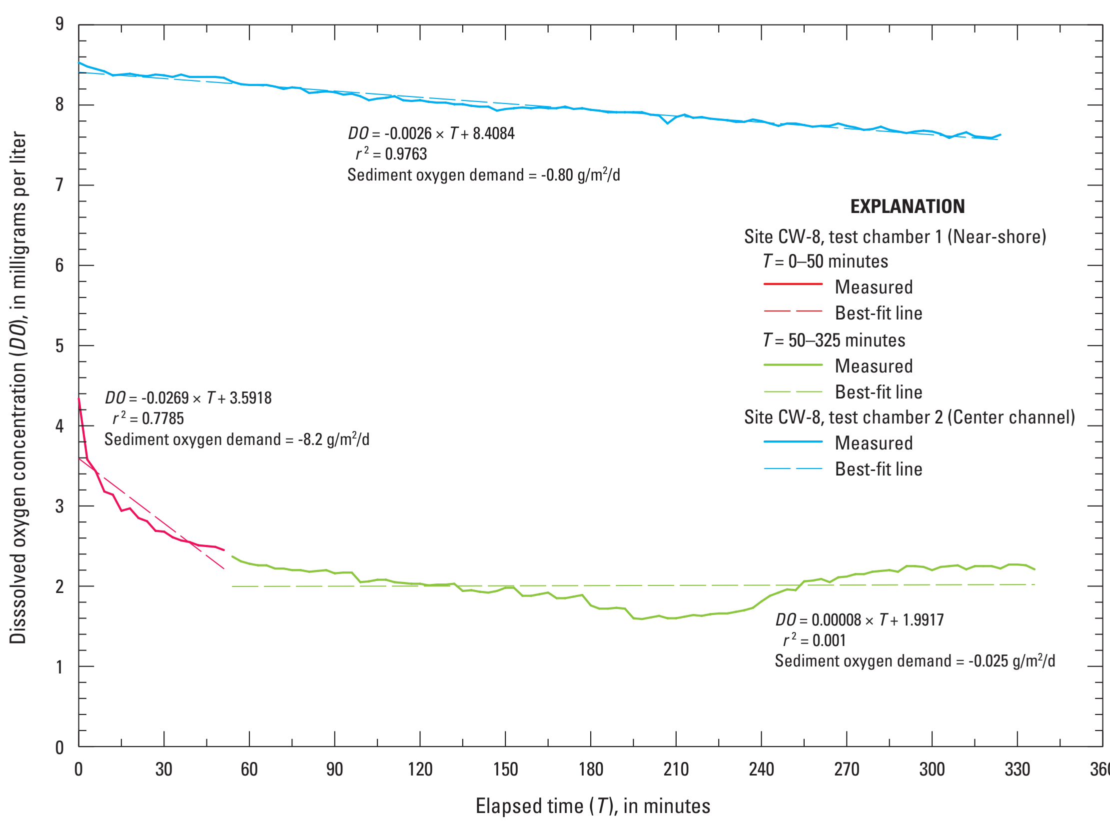

Figure 18. Recalculated dissolved oxygen depletion curves for chamber 1 (near shore) and chamber 2 (center channel) at Site CW-8, Crosswicks Creek, New Jersey, August 18, 2009. [g/m²/d, grams per square meter per day]

real-time DO concentrations in the chambers during the test period, it is possible to determine whether the chambers are sealed from exchange with more oxygenated stream water.

Water depth should be at least as deep as the chamber is tall, and test locations should be chosen where stream velocities are low. High stream velocities should be avoided because they favor streambed erosion in the vicinity of the test chamber, which may allow oxygenated stream water to exchange with the water inside the chamber and bias the data collection.

Care should be exercised when extrapolating calculated SOD rates from data collected from sites with different types of streambed materials and different flow regimes. SOD rates calculated from measurements made in ponds or marshy areas of streams or in near-shore areas along stream margins where water velocities are low and where organic-rich materials are deposited may be very different from those in areas where high stream velocities and inorganic bed materials are present.

Summary

Sediment oxygen demand (SOD) rates were measured in Hammonton Creek, Hammonton, New Jersey, and Crosswicks Creek, near New Egypt, New Jersey, during August through October 2009. These rates were measured as part of two ongoing Total Maximum Daily Load water-quality monitoring studies being conducted in cooperation with the New Jersey Department of Environmental Protection. Oxygen depletion rates were measured using in-situ test chambers and a nonconsumptive optical electrode sensing technique for measuring dissolved oxygen (DO) concentrations. SOD rates were calculated on the basis of the field measured oxygen depletion rates and stream-water temperatures at each site.

Hammonton Creek originates at an impoundment, then flows through pine forest and agricultural fields, and receives discharge from a sewage-treatment plant. The streambed is predominantly sand and fine gravel with isolated pockets of organic-rich detritus. Oxygen depletion rates were measured at four sites in the Hammonton Creek watershed, and the calculated SOD rates were found to range from -0.3 to -5.1 grams per square meter per day (g/m^2/d), adjusted to 20 degrees Celsius. When deployed in pairs, the chambers produced similar values, indicating that the in-situ test chamber method was working as expected and yielding reproducible results. At one site where the chamber was deployed for more than 12 hours, DO was consumed linearly over the entire test period.

Crosswicks Creek originates in a marshy woodland area and then flows through woodlots and pastures. The streambed is predominantly silt and clay with some bedrock exposures. Oxygen depletion rates were measured at three sites within the main channel of Crosswicks Creek, and the calculated SOD rates ranged from -0.33 to -2.5 g/m^2/d, adjusted to 20 degrees Celsius. At one of these sites, SOD rates were measured in both an oxygenated center channel flowing area of the stream and in a stagnant non-flowing area along the shore of the stream where organic-rich bottom sediments had accumulated and less oxygenated conditions existed in the water column. DO concentrations in the center channel test chamber showed a constant slow decrease over the entire test period. Oxygen consumption in the test chamber at the near-shore location began rapidly and then slowed over time as oxygen became depleted in the chamber. Depending on the portion of the near-shore DO depletion curve used, calculated SOD rates ranged from as low as -0.03 g/m^2/d to as high as -10 g/m^2/d. The wide range of SOD rates found indicates that care must be taken when extrapolating SOD rates from sites on the same stream that have different bottom sediment types and different flow regimes.

On the basis of this study, protocols for the proper use of the in-situ test chambers to measure and calculate SOD rates were developed. The protocols include (1) deploying the chambers in pairs at each site for a period of time sufficient to observe a drop in DO concentration of at least 1 milligram per liter, (2) choosing sites with fine-grained sediments with minimal gravel or cobbles for deployment, (3) choosing a site with a water depth at least as great as the test chamber is tall and with low stream velocity, and (4) exercising caution when extrapolating SOD rates from one location to another when the sites have different streambed materials and streamflow velocities.

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