Chesapeake Bay Program
A Watershed Partnership

www.chesapeakebay.net

Backgrounder

410 Severn Avenue, Suite 109 • Annapolis, Maryland 21403 • 410-267-5700 • toll free 800-YOUR-BAY

Oxygen is the lifeblood of the Chesapeake Bay. Without it, the fish, crabs and oysters that make the Chesapeake one of the most remarkable ecosystems in the world would not exist.

In summer, dissolved oxygen levels in the Bay's mainstem fall to levels that can harm all forms of aquatic life.

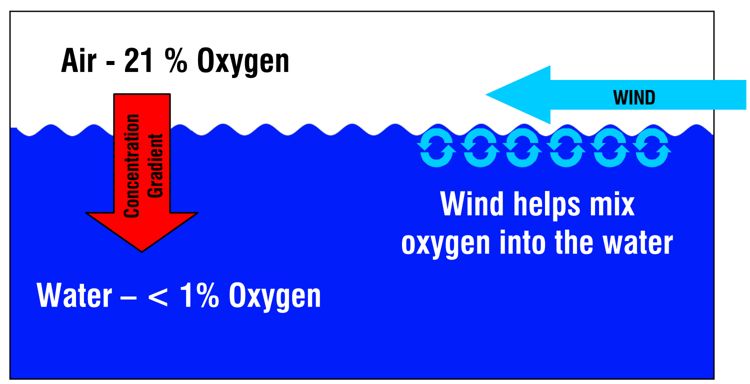
Each year vast amounts of nitrogen and phosphorus wash into the Bay and its rivers. This nutrient pollution – from sewage treatment plants, rural farms, suburban lawns, city streets and even the air – fuels algal growth in the Bay and its rivers. When combined with the Bay's shape and circulation patterns, it can cause large areas with little or no oxygen.

What Is Dissolved Oxygen and Why Is it Important to the Chesapeake Bay?

Dissolved oxygen (DO) refers to the amount of oxygen that is present in a given quantity of water. We measure it as a concentration using units of mg/l (i.e., the milligrams of oxygen dissolved in a liter of water). Keeping track of the Bay's oxygen levels is important because everything that swims or crawls in the Bay requires oxygen to live.

How does oxygen get into the Bay's waters?

In an estuary such as the Chesapeake Bay, there are several sources of DO. The most important is the atmosphere. At sea level, air contains about 21 percent oxygen, while the Bay's waters contain only a small fraction of a percent. This results in a large difference between the amount of oxygen that is concentrated in the air and in water. As a result, oxygen naturally dissolves into the water. This process is further enhanced by the wind, which mixes the surface of the water.



Two other important sources of oxygen in Bay waters are phytoplankton and submerged aquatic vegetation (SAV), or underwater grasses.

SAV includes a suite of terrestrial plant species that have evolved to live in or on water. Similarly, phytoplankton are a collection of tiny plants and bacteria that thrive in the sunlit upper layers of Bay waters. As everyone remembers from high school biology, plants take in sunlight and carbon dioxide to produce the substances they need to grow and thrive. A byproduct of this process is oxygen. In the Chesapeake Bay, phytoplankton and SAV release this oxygen directly into the surrounding water where it contributes to its overall DO concentration.

A final major source of DO in the Bay comes from water flowing into the estuary from streams, rivers and the Atlantic Ocean. Water flowing in from non-tidal streams and rivers is generally fast-moving and turbulent. This helps to mix in oxygen from the air. Ocean water generally has a higher oxygen content simply due to the fact that, given the ocean's tremendous volume, the factors that deplete oxygen are relatively small.

What determines dissolved oxygen levels?

The amount of oxygen that can dissolve in water is strongly limited by the temperature of the water and, to a much smaller degree, by other substances dissolved in the water such as salt. The colder the water, the more oxygen it can hold. Therefore, the waters of the Chesapeake Bay have a greater capacity to hold DO during the cold winter months than they do during the summer.

An instrument similar to the one pictured above is lowered through the water at 150 stations throughout Chesapeake Bay. The sensors on the instrument measure DO, temperature, salinity and several other water quality parameters.

Why is dissolved oxygen important?

All animal life in the Chesapeake Bay – from the worms that inhabit its muddy bottom, the fish and crabs found in its rivers, to the people that live on its land – need oxygen to survive. The oxygen we breathe allows us to extract the energy that our bodies need to function from the food we eat.

This process is essentially the same in all species, from worms and fish to crabs and people, with one major difference: Humans use lungs to extract oxygen from the air, while worms, fish and crabs use some form of gill to extract oxygen from the water. As water moves across these gills, DO is removed from the water and passed into the blood. As the oxygen concentration of the surrounding water increases, the gills operate more efficiently. Conversely, as oxygen concentration decreases, the harder it is for worms, fish, crabs and all other animals that inhabit the bay to extract the oxygen they need to survive.

Minimum Oxygen Requirements for Key Chesapeake Bay Species

Striped Bass	5 mg/l - 6 mg/l
American Shad	5 mg/l
Yellow Perch	5 mg/l
Hard Clam	5 mg/l
Blue Crab	3 mg/l
Bay Anchovy	3 mg/l
Spot	2 mg/l
Worms	1 mg/l

What's considered low levels of dissolved oxygen?

Bay scientists generally agree that DO concentrations of 5.0 mg/l or greater will allow the Bay's aquatic creatures to thrive. However, DO needs vary from species to species. The table to the left shows the oxygen levels needed for some of the Bay's most widely recognized species.

As concentrations fall below 5.0 mg/l, the situation becomes increasingly stressful to many of the Bay's inhabitants. Although some are more tolerant of low DO than others, DO can fall to the point where no animals can survive in some parts of the Bay. When the levels drop below 2.0 mg/l, that water is said to be "severely hypoxic," and when it drops below 0.2 mg/l the water is considered "anoxic."

Why are dissolved oxygen problems more acute in some areas?

Most areas of the Bay with low DO are the result of a complex interaction of several natural and manmade factors. These factors include the amount of nutrients in the water, the way phytoplankton grow, die and decompose, the amount of fresh water flowing into the Bay, the Bay's bathymetry and the peculiar way in which water flows in estuaries such as the Chesapeake.

Any one of these factors, taken alone, would not cause extensive areas of low DO. However, when they act in unison, they can leave relatively large areas of the Bay uninhabitable for a portion of the summer. In addition, most of these factors are affected by annual weather changes which in turn lead to large variations in low DO areas each year.

Where does all the dissolved oxygen go?

Bay scientists understand that temperature determines the amount of DO that water can hold, and that most of the Bay's DO problems occur in the summer when the Bay's waters are warmest. Yet, even at the warmest temperatures that we typically see in the Bay - around 91 degrees Fahrenheit – the water is still capable of having DO concentrations of about 6-7 mg/l. So although summer water temperature can impact DO levels, it is not solely responsible for hypoxic and anoxic conditions we've seen in the Bay over the past century.

> **Water Quality Terms**
>
> Dissolved oxygen levels are measured in terms of milligrams per liter (mg/l).
>
> **Healthy water** generally contains at least 5.0 mg/l of DO.
>
> **Hypoxia** occurs when water contains low levels of DO (2.0 mg/l - 5.0 mg/l).
>
> **Severe Hypoxia** occurs when water contains very low levels of DO (0.2 mg/l - 2.0 mg/l).
>
> **Anoxia** occurs when water contains very little or no oxygen (0 mg/l - 0.2 mg/l).

All organisms that live in the Bay take in oxygen during respiration, which is then converted to heat and carbon dioxide (CO2). Even phytoplankton, producers of oxygen during the day, begin to consume it when the sun goes down.

Some of the most important oxygen consumers are creatures that are invisible to the naked eye. These are the bacteria found floating throughout the water and living within the Bay's muddy bottom. These bacteria are responsible for decomposing the organic matter that washes into or is produced within the Bay.

This organic matter can consist of large things – such as dead fish and crabs – or very small things such as dead phytoplankton. But the root cause of a large portion of the Bay's DO problem comes from the bacterial decomposition of dead phytoplankton that sinks to the bottom.

In the Chesapeake Bay, phytoplankton produce roughly 400g of carbon per square meter of Bay water every year. When multiplied by the Bay's surface area (about 11.5 billion square meters), Bay scientists estimate that phytoplankton produce about 4.6 billion kilograms of carbon each year – or about the same weight as 14 Empire State Buildings. For a more Bay-specific comparison, in 2002, about 23.6 million kg of blue crabs and 300 thousand kg of oysters were harvested from the Bay.

What happens to the 4.6 billion kilograms of phytoplankton carbon? A portion of it is eaten by oysters, menhaden and other filter feeders which use it as their primary food source. Unfortunately, not all of it is consumed and this "leftover" phytoplankton sinks to the bottom of the Bay where it is decomposed by bacteria. As the bacteria decompose the phytoplankton, they consume DO until there is little or no DO remaining in the water.

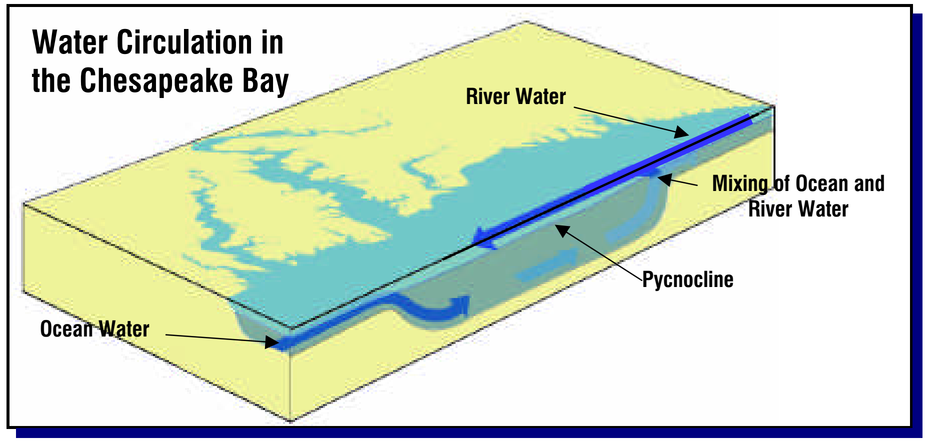
Why is there so much extra or "leftover" phytoplankton?

Extra phytoplankton is a direct result of nutrient pollution. It seems counterintuitive at first, as "nutrient" implies something good while "pollution" has a definite negative connotation.

The largest sources of nutrient pollution to the Bay are agriculture, sewage treatment plants, runoff from lawns, gardens and recreational areas, and air deposition. While all plants and animals need nutrients – specifically nitrogen and phosphorus – to grow and thrive, excessive amounts (which can be generated during lawn and golf course fertilization) can cause the Bay ecosystem to fall out of balance. At first glance, a large amount of phytoplankton doesn't sound like such a bad thing since it serves as the base of the Bay's food chain. However, so much nutrient pollution now enters the Bay that the system is overwhelmed. Filter feeders, such as oysters – whose numbers are already reduced due to over harvesting and disease – can't possibly consume all the phytoplankton. The unused phytoplankton end up falling to the bottom and decomposing, adding to the Bay's DO problem.

Why aren't oxygen-poor bottom waters replenished by oxygen-rich surface waters?

Estuaries such as the Chesapeake Bay are areas where freshwater from the land meets and mixes with saltwater from the sea. Ocean water is generally salty and cooler, while river water is fresh and warmer. Because of these differences, river water actually weighs less than ocean water and, without a strong mixing force such as wind, will actually float on top of the ocean water.

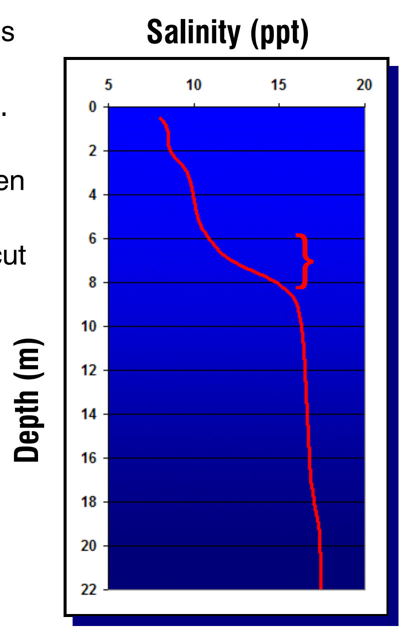


The mixing of fresh and salt water is one of the keys to the ecological productivity of the Chesapeake Bay. Fresh water flowing into the Bay from its rivers tends to flow toward the Atlantic Ocean on the Bay's surface, while saltwater flows up the Bay along its bottom. Where the two layers of water meet is called the pycnocline.

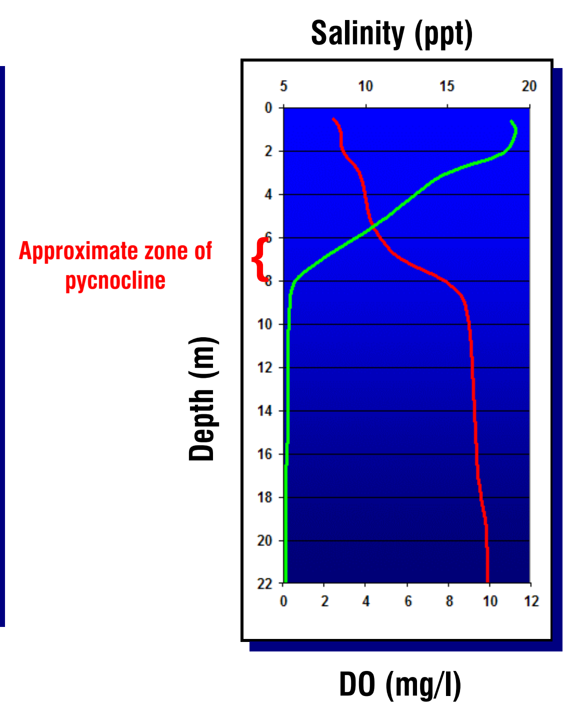
If you took a boat into the middle of the Bay and dove off the boat and swam to the bottom, you would find that the salinity would increase as you moved toward the bottom. Salinity would increase gradually for the first few meters, then increase dramatically for another few meters before returning to a more gradual increase the rest of the way to the bottom.

The zone of rapid salinity increase marks the boundary between fresher river water flowing towards the sea and saltier ocean water flowing in towards the land. This boundary – called the pycnocline – prevents surface waters from mixing with deeper waters below.

When bacteria decompose the excess phytoplankton settled on the bottom, they consume a great deal of oxygen. When a pycnocline develops – especially in the summer months when bacteria are most active – the oxygen-deprived bottom waters are cut off from the oxygen-rich surface waters, causing large areas of low DO in the Bay.



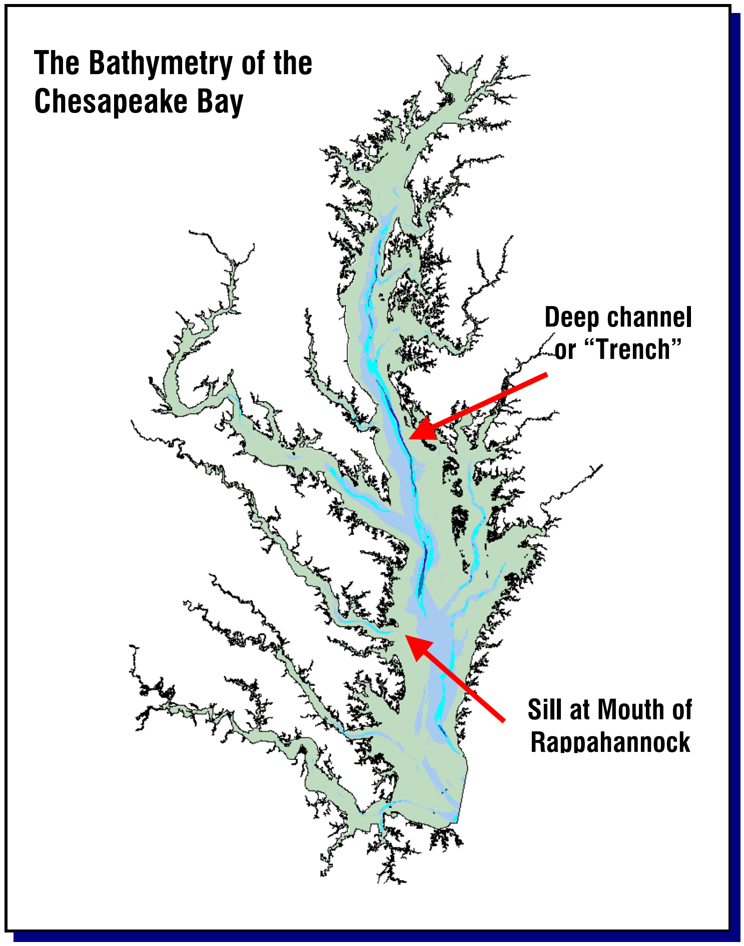
Rapid salinity changes occur at the pycnocline. In summer months, the pycnocline can prohibit oxygen-rich top waters from recharging oxygen-deprived bottom waters.



As depth increases, dissolved oxygen concentrations decrease, with the most rapid change as you approach the pycnocline. Once below the pycnocline, DO concentration remains consistently low all the way to the bottom.

How does the shape of the Bay contribute to DO problems?

The Chesapeake Bay is the flooded ancient Susquehanna River valley that filled with water at the end of the last ice age thousands of years ago. The bottom and sides of river valleys are not uniform and flat but are characterized by high and low areas that make up the topography of the terrain. When the river valley flooded, these high and low areas became the shallow and deep areas of the Bay. The different depths encountered as one moves around the Bay are collectively referred to as the Bay's bathymetry.



While nutrient pollution flowing into the Bay and its rivers is the driving force behind low dissolved oxygen problems ailing the Chesapeake Bay in summer months, the Bay’s complex bathymetry accentuates the problem in some parts of the Bay.

Most of the tidal tributaries and the Bay’s mainstem have deeper central channels that shoal rapidly as they get closer to the shore. These channels are generally at their deepest near the mouth of each river, and in some rivers – such as the Choptank, Patuxent and Rappahannock – the channel ends abruptly at a sill across the river’s mouth. In many cases, this sill prevents mixing of deeper bottom waters.

The pycnocline can interact with the Bay’s bathymetry to effectively isolate bottom waters from surface waters. The pycnocline can act as a lid over “bowl-shaped” areas of bathymetry. When this occurs, these waters cannot be replenished by vertical exchange from above or by horizontal exchange from the sides.

Some areas where this phenomenon occurs include the middle of the Bay’s mainstem extending from the Bay Bridge south to the mouth of the Potomac river; the lower Chester River; the lower Eastern Bay; the lower Potomac and the lower Rappahannock rivers. During the summer months, these areas regularly have hypoxic and anoxic conditions largely attributable to the interaction between bathymetry and pycnocline.

There are areas of the Bay that have relatively deep bathymetry and a pycnocline, yet do not suffer from significant DO problems. In these areas, such as the Bay's southern mainstem, the bathymetry does not restrict water from moving in under the pycnocline. In the case of the southern mainstem, waters below the pycnocline have a direct connection to oxygen-laden water flowing in from the ocean.

How will future oxygen problems be minimized?

By reducing nutrient and sediment loads, Chesapeake Bay water quality will improve, and in turn will provide the conditions needed for the Bay's living resources to thrive. Fewer nutrients flowing into the Bay will result in improved DO levels and abundant sunlight to fuel the growth of the underwater bay grasses that provide important shelter and nursery areas for a variety of Bay species. While reducing nutrient and sediment pollution cannot eliminate low dissolved oxygen occurrences, they will go a long way toward minimizing their size and frequency throughout the Chesapeake Bay.