Introduction

During the 1990s, in aquaculture facilities on the Eastern Shore of Virginia, significant numbers of developing shellfish have experienced alarming and dramatic mortality. In addition to the expected losses, a few complete batches of shellfish have died all at the same time. This mortality occurred primarily at the end of the larval stage, when the free-swimming larvae harden their shell and become bottom dwellers. The problem became more acute as time went on, with batches of eggs and small adults experiencing this unusual mortality.

Aquaculture is the process of raising aquatic life for commercial food in a controlled body of water. On the Eastern Shore, shellfish are grown in aquaculture facilities commercially by using the water from the local tidal creek or estuary. The water is pumped through indoor or on-land tanks to grow younger shellfish, (Figure 1) and place the older shellfish are placed directly in the water body to continue their growth. (Figure 2) The deaths occurred during the late spring and summer and appeared to be linked to periods of heavy rainfall. Poor water quality was presumed to be the problem, caused by periods of heavy runoff in the watershed. (Figure 3)

During the same period, some Eastern Shore farmers began growing valuable vegetable crops with the use of a plastic mulch. (Figure 4) Plasticulture increases the amount of runoff from the land by creating an impenetrable barrier over part of the ground. (Figure 5) Because wet conditions favor the development of certain diseases and deformities in vegetables, farmers encourage dry conditions for the growth of their crops, and direct the rainfall-generated runoff from their fields. Copper-based bactericides are applied by spraying the entire surface of the crop, so that when the rains come, the crop protectants are washed off the surface of the crop. This gives runoff little chance to penetrate into the soil due to the impermeability of the plastic and the rows in between. The runoff courses from the field, and eventually into the tidal creek. In some cases, fields engaged in plasticulture border the estuary, which decreases the amount of time for the runoff to enter the aquatic environment. In cases where aquaculture facilities are located on these creeks downstream of plasticulture fields, the water used in their facilities may be contaminated with the runoff from the fields. (Figure 6)
Figure 1. Raceways at an Eastern Shore aquaculture facility; water is pumped from the tidal creek or estuary through raceways and indoor facilities, and back to the waterway. Clams in raceways are approximately less than one inch in diameter. April 1997

Figure 2. Floating clam cages in a tidal creek on the Eastern Shore; they are used for growing clams larger than approximately one inch. April 1997
Figure 3. Agricultural runoff flowing from the field, down the side of a public road and directly into a tidal creek used for aquaculture. The total distance the runoff travels before entering the creek is approximately 100 meters. Summer 1996.
Figure 4. Field planted in tomato plasticulture on the Eastern Shore; long straight rows are entirely covered in black plastic. May 1997.

Figure 5. Field engaged in tomato plasticulture on the Eastern Shore after rain; water does not penetrate into the soil due to the plastic ground cover and compacted soil in between, so puddled runoff will eventually drain into nearby waterway. July 1997.
Figure 6. Aerial view of a watershed containing both plasticulture and aquaculture; the distance in the waterway between the fields and the aquaculture intake is less than a mile long and at least some of each field directly borders the estuary. Picture: Y. Bagwell.
It is well known that agriculture contributes to degraded water quality in some tidal creeks and estuaries. The practice of plasticulture increases the volume of runoff from agriculture and may therefore increase the concentration of potentially dangerous crop protectants in the local waterways (Scott, et al., 1990). Many of these crop protectants are toxic to aquatic life in low doses, particularly shellfish, which are sensitive species (O’Connor, 1996).

Copper is toxic to most forms of aquatic life in low concentrations. For *Mercenaria mercenaria* (*M. mercenaria*) larvae, the eight to ten day LC$_{50}$ is 16.4 ug/L added copper (as Cu), and for *Crassostrea virginica* (*C. virginica*) larvae, the twelve day LC$_{50}$ is 32.8 ug/L added copper (Calabrese, et al., 1977). These represent the two species most widely grown in shellfish aquaculture on the Eastern Shore of Virginia, the hard clam, and the bay oyster, respectively.

This research was therefore designed to investigate the impacts of agricultural runoff on water quality, particularly as it pertained to copper-based crop protectants and shellfish aquaculture on the Eastern Shore of Virginia. The specific objectives are listed below:

- Determine if agricultural practices involving copper-based crop protectants and plasticulture were affecting water quality in Eastern Shore waterways.
- Determine the fluctuations of these water quality effects over an annual cycle, and over several tidal cycles after a heavy rainfall event during the growing season.
- Determine the copper concentrations of runoff from various agricultural and non-agricultural areas.
- Determine the relationships between dissolved copper, total copper, and total suspended solids concentrations, as well as rainfall for Eastern Shore of Virginia water samples.
- Determine if sediment copper concentrations of tidal creeks and estuaries of the Eastern Shore are impacted by agricultural practices involving copper-based crop protectants and plasticulture.
- Determine the relationship between copper concentrations reported to be toxic to shellfish and concentrations measured in Eastern Shore of Virginia waterways.