FINAL REPORT

MINIMIZING THE IMPACT ON WATER QUALITY OF PLACING GROUT UNDERWATER TO REPAIR BRIDGE SCOUR DAMAGE

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ABSTRACT

The Virginia Department of Transportation (VDOT) has routinely used what is commonly referred to as *tremie concrete* (concrete or grout placed underwater by way of pumping through a metal tremie pipe) to repair bridge substructure and scour damage. VDOT also recently began to place concrete underwater to repair scour by pumping it directly into grout bags. Many of VDOT's rehabilitation projects that involve underwater concrete placement require environmental permits that VDOT's Environmental Division is responsible for securing from various regulatory agencies. Because the effects of tremie concrete on water quality have been a concern for some of these agencies, namely the Virginia Department of Environmental Quality and the U.S. Army Corps of Engineers, the acquisition of these permits has become a problem. As a consequence, the agencies put a number of VDOT projects on hold until the problems with tremie concrete were better documented and/or until VDOT developed a better method of repairing bridge scour. The Department of Environmental Quality requested that all in-stream scour repairs, with few exceptions, be conducted "in the dry."

The purpose of this study was to determine a way to allow VDOT to remain in compliance with current state and federal water quality standards and regulations while rehabilitating structures with significant scour using concrete placed underwater. The study included the monitoring of 31 sites in the field and a laboratory component to compare the effects of various placement methods on various water quality parameters.

Results showed that the primary water quality parameter affected by the placement of grout underwater is pH. Such placement can cause pH values to exceed 11 under particular flow conditions. However, in-stream pH values can be kept below the state water quality level of 9.0 through the use of a combination of placement techniques and/or an anti-washout admixture. The techniques required are very site specific but depend primarily on stream flow volume and grout pumping rates.

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INTRODUCTION

In the past, the Virginia Department of Transportation (VDOT) has routinely used tremie concrete for bridge repair projects designed to repair substructure and scour damage. The term *tremie concrete* refers to the pipe used to transfer concrete underwater, in this case, to fill voids near piers and/or abutments. The tremie typically consists of a vertical steel pipe, the lower end of which is designed to remain immersed in the concrete or grout (a mixture of cementitious material and water, with or without aggregate, proportioned to produce a pourable consistency) (American Concrete Institute, 2000) that is being pumped into the void so that a minimum amount of material comes in contact with the surrounding water (Gerwick & Holland, 1986; Khayat, Gerwick & Hester, 1993; Malisch, 1986). VDOT has recently begun to place concrete underwater to repair scour by pumping it directly into grout bags. The bags, made of a strong and close-textured nylon fabric, are designed to prevent the washout of cement paste and fines from the concrete mixture as it is being placed and serve as flexible forms. This allows the grout to conform to the shape of the void but prevents it from running outside the area to be filled.

Many of VDOT's rehabilitation projects that involve underwater concrete placement require environmental permits that VDOT's Environmental Division is responsible for securing from various regulatory agencies. Because the effects of tremie concrete on water quality have been a concern for some of these environmental agencies, namely the Virginia Department of Environmental Quality (DEQ) and the U.S. Army Corps of Engineers (Corps), the acquisition of these permits has become a problem. The concerns of the regulatory agencies stem from several incidents of fish kills and associated high pH levels in streams where tremie concrete was being used. Although spikes in pH levels were recorded at several sites, it was not known if other water quality parameters were also affected by the placement of concrete and therefore contributed to water quality degradation. As a consequence, the agencies put a number of VDOT projects on hold until the problems with tremie concrete were better documented and/or until VDOT developed a better method of repairing bridge scour. DEQ requested that all in-stream scour repairs, with few exceptions, be conducted "in the dry." Performing this type of work in the dry requires installing cofferdams around the perimeter of the pour area followed by pumping out the water inside the dammed area. Once the area is dewatered, the concrete is placed. After the concrete sets, the cofferdams are removed.

Based on several cost estimates for scour rehabilitation for several VDOT structures, the cost of performing the work in the dry is just over double that of performing the same work in the wet (i.e., pumping grout underwater). The increased costs are due to the installation of the cofferdams (and in some cases, the construction of causeways into the stream or river to provide access for the equipment needed to install the cofferdams) and the construction of dewatering basins. It is also safe to assume that performing the work in the dry has the potential for negative environmental impacts as well because the in-stream construction and dewatering activities can result in increased turbidity, streambed disturbance, and altered flow characteristics. Installing cofferdams (and the associated construction of causeways) also requires significantly more time than does pumping grout underwater, potentially resulting in increased lane closure time. In many instances, particularly for smaller structures requiring rehabilitation, installing cofferdams is all but impossible because of the lack of overhead clearance.

Based primarily on the four problems related to repairing structure scour damage in the dry (i.e., increased costs, negative environmental impacts, increased construction time, and difficulty with installation), VDOT's Environmental Division and Structure & Bridge Division asked the Virginia Transportation Research Council (VTRC) to determine a way to allow VDOT to remain in compliance with current state and federal water quality standards and regulations while effectively and efficiently rehabilitating structures with significant scour using concrete placed underwater.

PURPOSE AND SCOPE

As stated previously, the purpose of this project was to determine a way to allow VDOT to remain in compliance with current state and federal water quality standards and regulations while rehabilitating structures with significant scour using concrete placed underwater.

The objectives were twofold: (1) to characterize and document the effects of tremie concrete and grout placed in grout bags on water quality at a number of scour project sites undergoing rehabilitation, and (2) to identify alternative techniques for placing concrete underwater to repair bridge scour if the effects of tremie concrete were found to result in violations of current state and federal water quality standards and regulations. The scope was limited to 31 sites in three VDOT districts.

METHODS

Four primary tasks were completed to achieve the study objectives:

1. A field monitoring effort was conducted for VDOT bridges and culverts undergoing scour rehabilitation.

2. A laboratory analysis was conducted to determine the effects of placement techniques on water quality.

3. The factors contributing to the degradation of the water quality were assessed based on the findings in Tasks 1 and 2.

4. A flowchart was developed to help VDOT select the best method of placing concrete as a countermeasure for scour based on site-specific conditions.

Field Monitoring

In-field monitoring was conducted at 31 sites in three VDOT districts during the course of the study (see Table 1): the 11 sites in the Fredericksburg District were repaired using tremie concrete, and the 19 sites in the Staunton District and the 1 site in the Salem District were repaired using grout bags. Approximately 900 yd^3 of concrete were placed at the sites. Five of the sites yielded no water quality data because all concrete work was done in the dry because of abnormally low water levels.

Table 1. Sites Monitored During Concrete Placement for Scour Rehabilitation

Route No.	Water Body	County	Placement Technique	Quantity of Concrete Placed (yd^3)
198	Ferry Creek	Gloucester	Tremie	56
198	Harper’s Creek	Gloucester	Tremie	48
14	Courthouse Creek	King & Queen	Tremie	8
14	Burnt Mill Creek	King & Queen	Tremie	8
17	Dragon Run	Middlesex	Tremie	16
612	Bookers Mill	Richmond	Tremie	6
604	Presley Creek	Northumberland	Tremie	8
604	Hull Creek	Northumberland	Tremie	32
201	Croxton Branch	Northumberland	Tremie	16
3	Beaverdam Swamp	Gloucester	Tremie	24
606	Beaverdam Creek	Gloucester	Tremie	34
731	Hays Creek	Rockbridge	Grout bags	10
652	South River	Augusta	Grout bags	19
707	Middle River	Augusta	Grout bags	8
835	Moffet Branch	Augusta	Grout bags	6
747	Freemason Run	Augusta	Grout bags	28
747	Freemason Run	Augusta	Grout bags	10
759	Moffet Creek	Augusta	Grout bags	16
658	South River	Augusta	Grout bags	16
606	Hays Creek	Rockbridge	Grout bags	45
732	Tributary to Goose Creek	Augusta	Grout bags	8
613	Mossy Creek	Augusta	Grout bags	7
42	North River	Rockingham	Grout bags	144
844	South River	Augusta	Grout bags	88
641	South Branch Potomac River	Highland	Grout bags	16
604	Snake Run	Alleghany	Grout bags	8
610	Mill Branch	Alleghany	Grout bags	14
616	Blue Spring Run	Alleghany	Grout bags	11
616	Blue Spring Run	Alleghany	Grout bags	18
603	Wheat Spring Branch	Clarke	Grout bags	16
813	Roanoke River	Roanoke	Grout bags	170

DEQ required that VTRC develop a water quality management plan document prior to the initiation of any construction work related to the project. The purpose of the plan was to outline specific sampling procedures to be carried out during the study; document parameters to be measured; and, most important, specify procedures to be followed in the case of a water quality violation or fish kill during the monitoring. In this document it was stated that the researchers would immediately notify DEQ if at any time during the concrete pour the water quality standards as specified in 9 VAC 25-260-50 in Section 62.1-44.15(3a) of the *Code of Virginia* (pH > 9.0 or dissolved oxygen < 4.0) were violated. It was also agreed that if the water quality standards were violated, all concrete pouring operations would be stopped immediately and the steps outlined in the Violation Notification Procedures Section of the document would be followed. The water quality management plan is presented in the Appendix.

Parameters Measured

Water Quality

Water quality parameters measured during the monitoring included pH, dissolved oxygen, conductivity, temperature, and alkalinity. These parameters were selected based on input from DEQ. In previous instances where concrete was placed and fish kills occurred, in-stream pH values were high, but it was not known if this was the only factor contributing to the stress aquatic biota were experiencing or if other factors such as dissolved oxygen levels were also affected by the chemical constituents of the concrete. Temperature was a concern because the curing of large quantities of concrete can generate significant heat.

Stream Properties

Physical characteristics were recorded for each stream where work was being performed. Specifically, stream depth, width, and flow velocity were recorded, as was the dominant streambank vegetation.

Benthic Surveys

DEQ also requested that benthic surveys be conducted for most of the streams located in the Staunton District to determine the impact of concrete placement on bottom-dwelling aquatic insects. The staff of the Natural Resources Section of VDOT's Environmental Division conducted these surveys. Detailed information on how the benthic surveys were conducted is available from the author.

Site Instrumentation and Setup

At each site, water quality was monitored at three evenly spaced stations along transects located 10, 20, and 30 m upstream of the pour area; at the pour location; and at 10, 20, 30, 40, 50, and 60 m downstream of the pour area. A Horiba U-10 water analyzer containing multiple probes was physically carried to each monitoring location to measure each water quality parameter. In addition to the manual measurements, a series of CSI-M11-L pH probes connected to a Fisher Scientific CR-10 data logger were placed in the center station of each of the downstream transects to measure pH. Figure 1 is a sketch of the typical site setup.

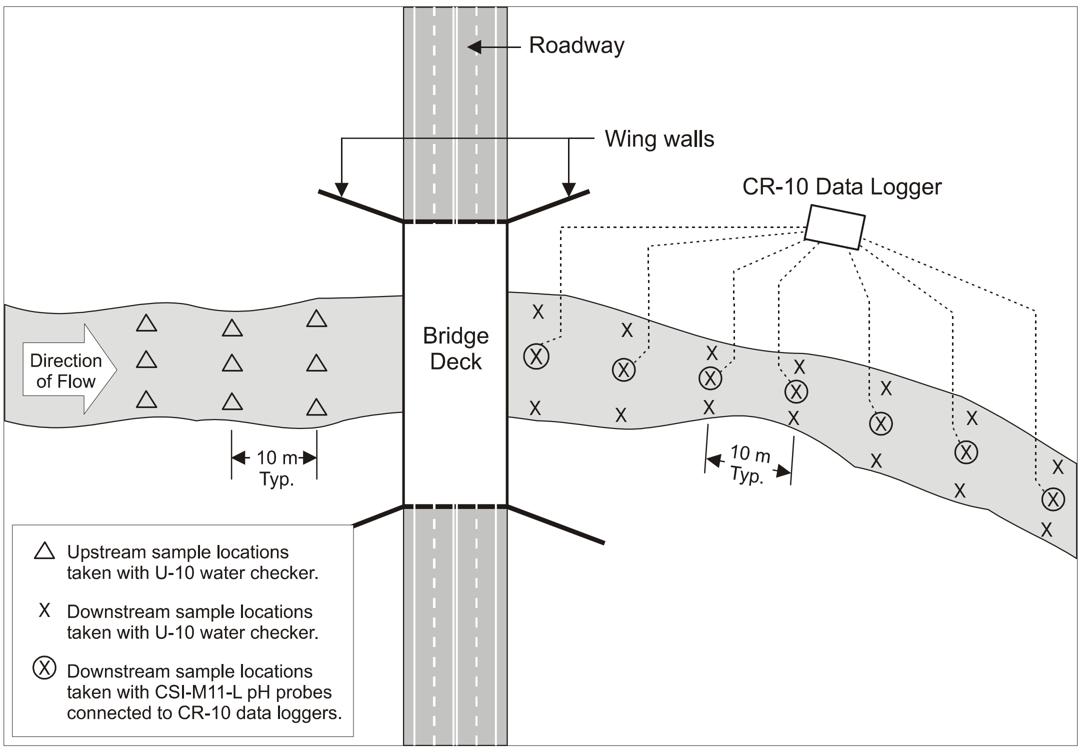

Figure 1. Instrument Setup for Monitoring Typical Structure Undergoing Scour Rehabilitation

Baseline Analysis

Baseline conditions of the five water quality parameters were measured for each site. In most cases, baseline readings were taken within 1 hour of the start of concrete placement to minimize any changes that could take place because of precipitation, temperature, and diurnal fluctuations caused by plant photosynthesis. Measurements of pH, dissolved oxygen, temperature, and conductivity were taken with the Horiba U-10 water analyzer at each monitoring station as shown in Figure 1. Single water samples were collected at the pour locations using 250-mL polyethylene bottles. The samples were analyzed for alkalinity at a commercial lab in Charlottesville, Virginia, after each pour was completed. Stream flow velocities and water depths were measured near the center of each transect using a Global

Water FP-201 stream velocity probe. All sampling equipment was calibrated in accordance with the manufacturer recommendations prior to establishing the baseline water quality for each site.

For streams requiring benthic surveys, samples were collected upstream of the bridge (between 0 and 30 m) and downstream of the bridge (between 0 and 60 m). Cross-sectional dipnetting techniques were used, and family, density, and diversity were recorded on a benthic/habitat data sheet. In addition, aquatic habitat information upstream of the bridge (between 0 and 30 m) and downstream of the bridge (between 0 and 60 m) was recorded, as were data such as water depth, riffle/pool/flat ratios, streambank vegetation, and streambank stability.

Monitoring During and After the Pour

Following the initiation of concrete pumping, water quality parameters were initially measured manually at three locations along each transect. It soon became apparent that the greatest water quality impacts were occurring immediately downstream of the pour location. Subsequently, for the Staunton and Salem districts, readings were taken at each of the three monitoring stations at the 10-m downstream transect every 15 minutes and hourly readings were taken for each monitoring station further downstream. For sites in the Fredericksburg District, water quality data were measured manually at least once every hour and pH was recorded every 15 minutes using the data logger system. Monitoring of water quality was continued following the completion of pumping at each site until the water quality parameters returned to baseline values.

Benthic and habitat surveys were conducted 3 to 5 days after the completion of the concrete placement.

Alteration of Placement Techniques

At the sites monitored during this project, grout was placed in the voids around or under the structures by one of two methods: pumping through a tremie pipe, or pumping into grout bags. The methods are described here.

Tremie Pipe

At all 11 sites monitored in the Fredericksburg District, grout was placed around or under the structure undergoing scour rehabilitation. This was accomplished by pumping the grout from a grout pump or pump truck located on top of the structure through a series of hoses and into a tremie pipe. The steel tremie pipe extended down beneath the surface of the water, through a geotextile fabric, under the structure, and into the void being filled (see Figure 2). The geotextile fabric served as a boundary to prevent the grout from coming out of the void while at the same time allowing the water being displaced by the grout to exit the void. Once the void was full, the grout was allowed to set and the tremie pipe was cut off below the surface of the water.

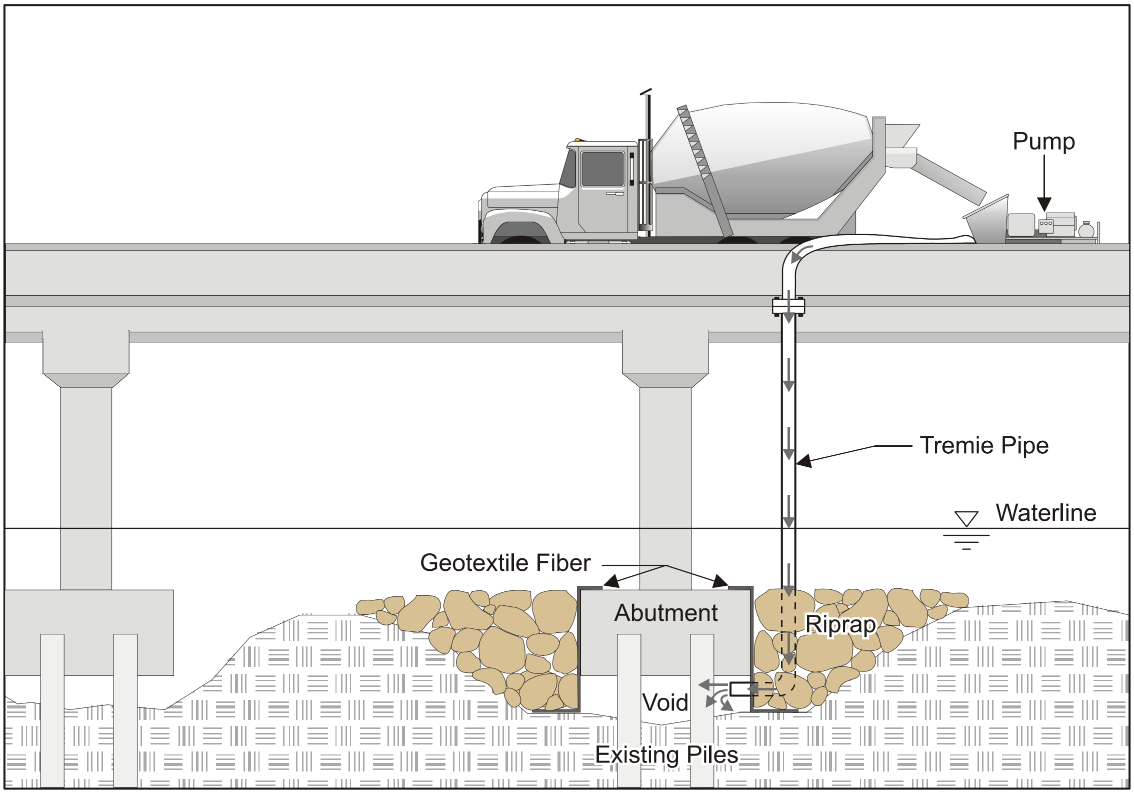

Figure 2. Typical Site Setup for Placing Concrete with Tremie Pipe

Grout Bags

All 19 sites in the Staunton District and the single site in the Salem District were repaired by pumping grout into grout bags. Most of the bags used for this project were purchased from Fabriform, but grout bags, which come in different sizes and weights, are available from a number of manufacturers. The sizes used for this project varied from site to site and even within a given site but typically ranged from 3 ft x 5 ft x 1 ft to 5 ft x 12 ft x 2 ft. The different sizes accommodated varying volumes of concrete to be placed depending on the dimensions of the scoured area being filled.

Turbidity Curtain

At several sites in the Fredericksburg District and nearly all sites in the Staunton District, turbidity curtains were installed just outside the pour area. Turbidity curtains are made of a thick plastic and suspended by way of a series of foam booms sewn in the top edge of the plastic. A metal chain weights down the bottom edge of the curtain. When placed in water, the curtain forms a barrier that although not impermeable, inhibits the flow of water from one side of it to the other (see Figure 3).

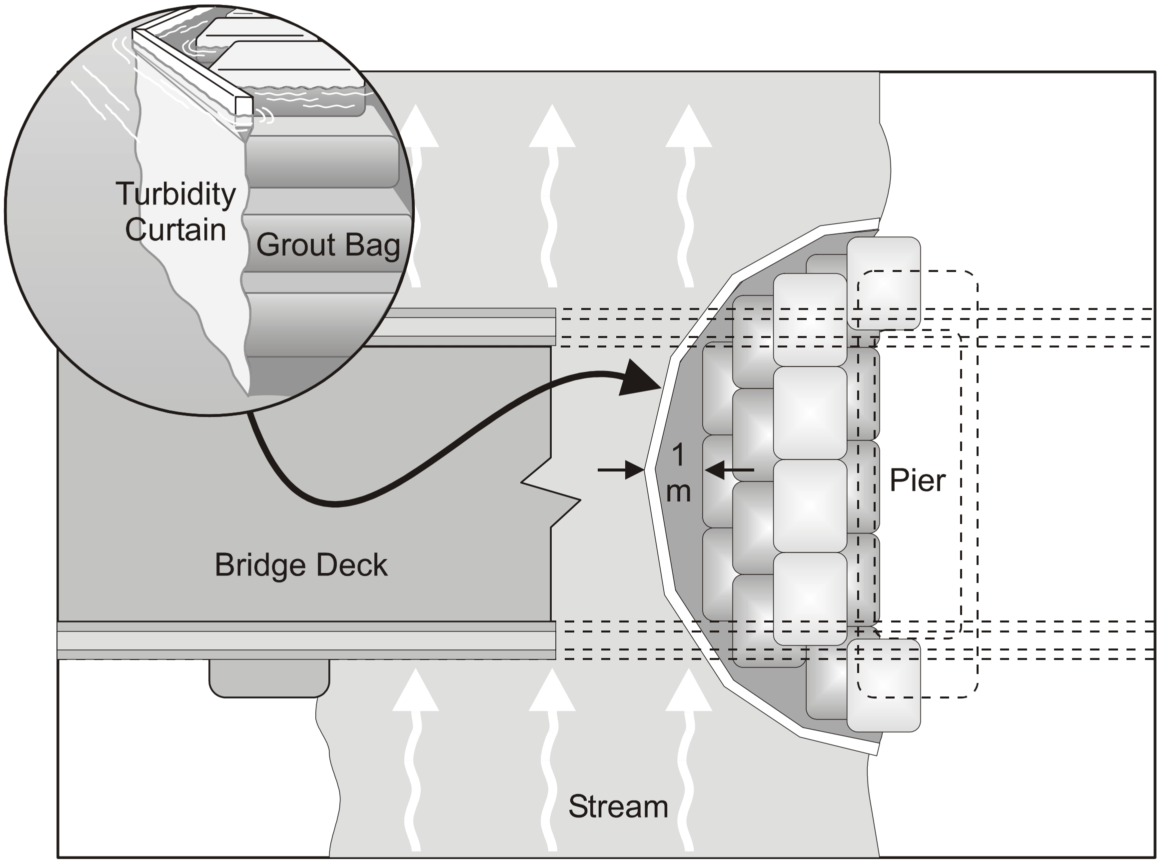

Figure 3. Typical Site Where Grout Bags Were Used in Conjunction with Turbidity Curtain

Anti-washout Admixture

An anti-washout admixture (AWA) designed to improve the performance (i.e., strength) of concrete placed underwater by decreasing the percentage of fines and cement paste that are washed out prior to setting was used on the Salem District site on the Roanoke River. The AWA used was Rheomac UW450m, and it was added at the manufacturer's recommended rate of 80 oz/yd^3 of concrete. Because there were concerns that the increase in the viscosity caused by its addition would negatively affect the ability to pump the grout, a water-reducing admixture, Rheomac 3030, was also added at a rate of 60 oz/yd^3. Normal pumping procedures were followed with the grout containing the AWA by pumping directly into grout bags.

Laboratory Analysis

To quantify further the water quality effects of the different placement techniques used in the field, several combinations of grout bag materials and admixtures were analyzed in a laboratory setting. All tests were run under controlled conditions in the concrete and geotechnical laboratories at VTRC.

Experimental Design

The laboratory analysis was designed to determine the *relative* differences between the placement techniques that were, or could easily be, implemented in the field. Because stream flow conditions, baseline water quality parameters, and quantities of concrete used in the field varied tremendously, these tests were not set up to replicate water flow conditions that might be experienced when concrete was actually placed underwater at a field site. As a consequence, the pH values obtained in the laboratory analysis would not be the same as those expected in the field. Instead, the laboratory values provided a statistically valid means by which to compare different placement scenarios that would be used in the field.

Cylinders constructed of polyvinyl chloride (PVC) pipe with an inside diameter of 38 mm and a length of 120 mm were covered on one end with filter fabric or one of two types of grout bag material. These were stretched tight over the end of the cylinders and held in place with plastic wire ties. Grout was mixed following a typical VDOT mix design and placed in the cylinders to a depth of 90 mm. The cylinders were then suspended in 1000-mL glass beakers containing 500 mL of tap water for 90 minutes (see Figure 4). A Fisher Scientific Accumet pH Meter 925 was used to measure the pH of each sample before and after insertion of the cylinders containing grout.

Figure 4. Laboratory Testing of Different Grout Bag Materials

Materials Analyzed

Two grout bag materials were tested in the laboratory tests: Fabriform PJ 400 and Fabriform Ballistic. The Fabriform PJ 400 grout bag was the same as that used at sites monitored in the field. The Fabriform Ballistic is a tighter weave fabric and was not used in the field. A standard geotextile fabric similar to that used when concrete was placed by way of a tremie pipe was also tested. All three materials were tested with the standard grout mix, and this same mix containing the anti-washout admixture Rheomac UW 450. The following combinations were analyzed:

- geotextile fabric and standard grout mix
- geotextile fabric and grout with AWA
- Fabriform PJ 400 grout bag and standard grout mix
- Fabriform PJ 400 grout bag and grout with AWA
- Fabriform Ballistic grout bag and standard grout mix
- Fabriform Ballistic grout bag and grout with AWA.

Controls (the three material types and cylinders containing no grout) were also run for each combination.

Sample Size Determination

As stated previously, the laboratory tests were designed to determine the differences between placement methods, not to predict absolute values for in-field water quality parameters. Initial sample sizes for the geotextile fabric tests and the Fabriform material with and without AWA were calculated based on the means and variances calculated from water quality data measured in the field. The number of samples required to determine if the pH values resulting from the different combinations was based on the assumption that the values were normally distributed. Satterthwaite's rule was used to determine the degrees of freedom in order to approximate a *t* distribution, thereby allowing for the computation of the number of samples needed to run a paired-samples *t* test to determine if the different treatments resulted in different pH values.

$$\text{Degrees of freedom} \cong [s_1^2/n_1 + s_2^2/n_2]^2 \,/\, [s_1^4/n_1^2(n_1 - 1) + s_2^4/n_2^2(n_2 - 1)]$$

where s_1^2 and s_2^2 are the sample variances and n_1 and n_2 are the sample sizes.

Assessment of Factors Contributing to Water Quality Degradation

Following the completion of the field monitoring and laboratory component of the study, an analysis of all the factors contributing to the degradation of the water quality at sites undergoing scour countermeasures was conducted by looking at the relationships between the site variables measured and the grout placement techniques both in the field and laboratory. Based on these findings, specific methods of reducing the chances of adverse impacts on water quality were identified.

Development of a Grout Placement Flowchart

Based on the assessment of factors affecting the water quality at the scour sites and methods to control them, a flowchart for grout placement was developed. The chart provides guidelines for materials and/or techniques to be used when grout is placed underwater for scour rehabilitation. The recommendations take into account general site conditions that are likely to influence the effects on the water quality.

RESULTS AND DISCUSSION

Field Survey

Numerous parameters were measured at close time intervals for extended periods of time at multiple locations for each site, resulting in the collection of a tremendous amount of data for the 31 sites undergoing scour rehabilitation. Consequently, only a subset of these data that represents the most important findings is reported here. Results of the benthic surveys are not included in this report but are available in a separate document from the author.

Tremie Concrete Placement

One of the first findings derived from the field monitoring was that of the four primary water quality parameters measured, only pH changed significantly during the concrete placement process. Temperature and dissolved oxygen had a diurnal fluctuation but changed only minimally during the placement process. The values never exceeded the ranges specified in VAR 680-21-01.5. Conductivity values did not appear to follow any specific pattern and varied as much or more from site to site as they did as a result of concrete placement.

No Turbidity Curtain Used

Summary data showing some of the maximum values for the five sites where tremie concrete was placed without using a turbidity curtain are shown in Table 2.

Table 2. Summary pH Data for Tremie Sites Without Turbidity Curtains

Property	Value
Maximum pH	10.9
Maximum increase in pH	4.1
Maximum pH @ 50 m downstream	10.9
Maximum time required for pH to return to baseline (h)	4.6
Number of sites pH exceeded 9.0 threshold	2 of 5

Significant increases in pH were recorded for most of these sites. The greatest changes were recorded within 10 m downstream of the pour area. The pH increases typically occurred within several minutes of the commencement of pumping, but this varied from site to site (see Figure 5). Two of the sites had pH values above the 9.0 state water quality standard. Approximately 20 dead minnows were observed floating within 30 m downstream of the pour area at the second site.

Once the pH of the water became elevated following the initiation of pumping, it declined only slightly at the downstream monitoring stations, indicating that dilution or dispersion of the high pH plume did not occur to any significant extent. With respect to time, the decline of the pH readings varied from 1.5 to 4.6 hours following the completion of the concrete placement. Those sites where the greatest quantity of concrete was placed did not have the highest total rise in pH, but the time it took the pH to return to baseline conditions was greater.

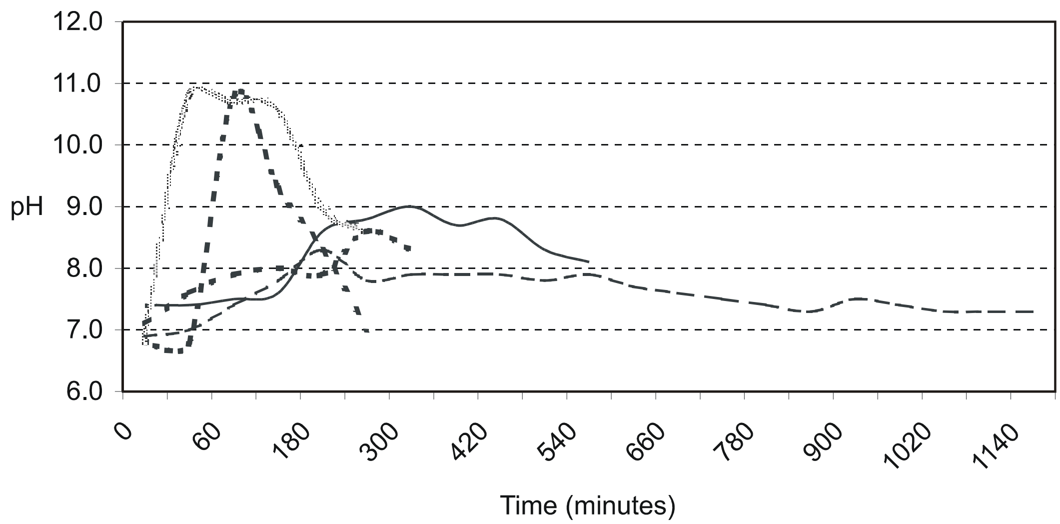

Figure 5. pH at 10-m Transect for Sites Where Tremie Concrete was Used Without Turbidity Curtain

Turbidity Curtain Used

Summary data for the six sites where tremie concrete was placed using a turbidity curtain are shown in Table 3.

Table 3. Summary pH Data for Tremie Sites With Turbidity Curtains

Property	Value
Maximum pH (outside curtain)	9.0
Maximum pH (inside curtain)	11.1
Maximum increase in pH (outside curtain)	1.8
Maximum pH @ 50 m downstream	9.0
Maximum time required for pH to return to baseline (h)	32
Number of sites pH exceeded 9.0 threshold (outside curtain)	0 of 6

Elevated, but not excessively high, pH values were recorded for most of the sites where tremie concrete was placed and separated from the remainder of the stream by a turbidity curtain. With few exceptions, the pH inside the curtained areas quickly rose above 10.0. This sudden jump in pH can be attributed to the lack of water coming into the curtained area, preventing the dilution of the higher pH concrete. This lack of dilution was evident in the bright gray color of the water contained in this area. pH values outside the curtain were significantly lower and never exceeded the 9.0 threshold for any of the six sites.

The elevated pH values both inside and outside the curtained area returned to baseline values more slowly than at the sites without the curtain. The pH values inside the curtain took longer to return to normal than those outside the curtain. Unless water was deliberately allowed inside through opening the upstream side, pH values inside the curtain remained elevated for at least 12 hours and in some cases more than 30 hours following completion of the pour. Because the curtains were not watertight, the high pH water inside slowly "bled off," contributing to the slightly elevated values (though still lower than sites where no curtain was used and below the 9.0 water quality threshold) outside the curtain for extended periods. As the higher pH water leaked out of the curtained area, it was replaced with water flowing in from upstream. Over a period of hours, the system reached equilibrium, with the pH being the same inside and outside the curtain. Figure 6 shows the pH outside the curtain area for the six sites monitored using this placement method.

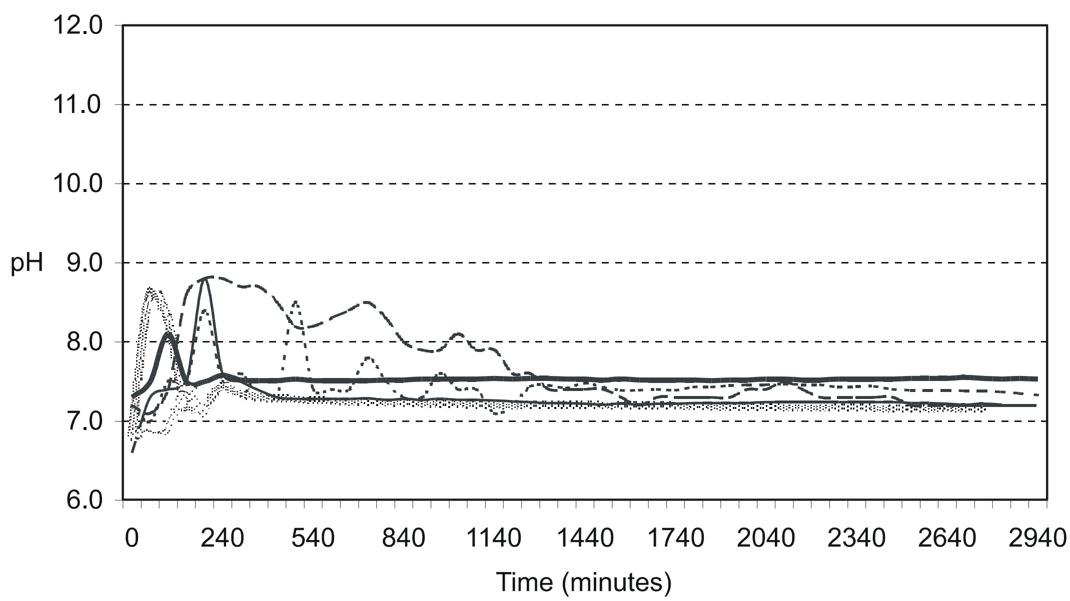

Figure 6. pH at 10-m Transect for Sites Where Tremie Concrete Was Used with Turbidity Curtain in Place

Grout Bag Placement

No Turbidity Curtain Used

At only two sites were grout bags placed in areas that were not contained by turbidity curtains. Both sites had very high pH levels, as can be seen in Figure 7. The dashed line in this

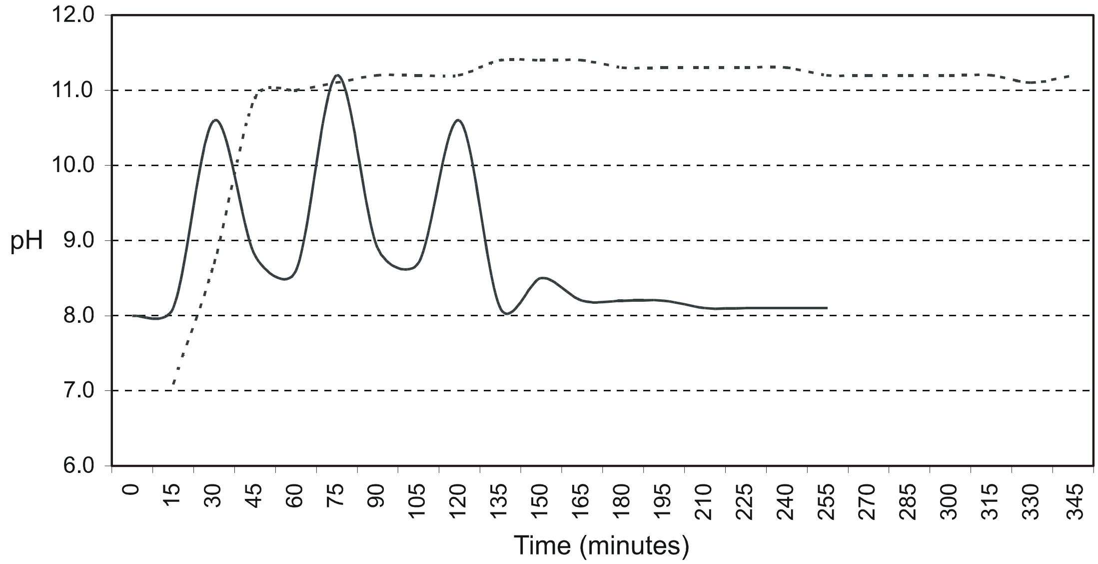

Figure 7. pH at 10-m Transect for Sites Where Grout Bags Were Used without Turbidity Curtain

figure represents the data obtained when grout bags were filled under a structure where stream flow had stopped because of dry weather conditions, leaving a large pool of standing water. As the grout bags were filled, the pH climbed quickly to just over 11 in the pool. These values did not decline for the 330 minutes shown graphically in Figure 7 or during the 23-hour period for which the site was monitored.

The solid line in Figure 7 represents a site that had low flow. Though efforts were made to prevent concrete from entering this flow by diverting the water around the area where grout bags were being placed, severe spikes in pH occurred during pumping. However, the levels quickly dissipated when pumping was complete for each of the three trucks, as shown in the three sharp declines in pH in Figure 7.

Turbidity Curtain Used

Data were collected at 12 sites where concrete was pumped into grout bags and the area was cordoned off by turbidity curtains. Table 4 is a summary of the maximum pH at these sites.

Table 4. Summary pH Data for Grout Bag Sites With Turbidity Curtains

Property	Value
Maximum pH (outside curtain)	9.8
Maximum pH (inside curtain)	11.5
Maximum increase in pH (outside curtain)	2.6
Maximum pH @ 50 m downstream	8.3
Maximum time required for pH to return to baseline (h)	9
Number of sites pH exceeded 9.0 threshold (outside curtain)	2 of 12

Ten of the sites with grout bags in conjunction with a turbidity curtain had in-stream pH levels below 9.0. As was the case when the turbidity curtains were used with the tremie concrete placement, pH values inside the curtain exceeded 10 most of the time during the concrete placement and returned to baseline values only after an extended period. Figure 8 shows the pH outside the curtain for each site at the 10-m transect.

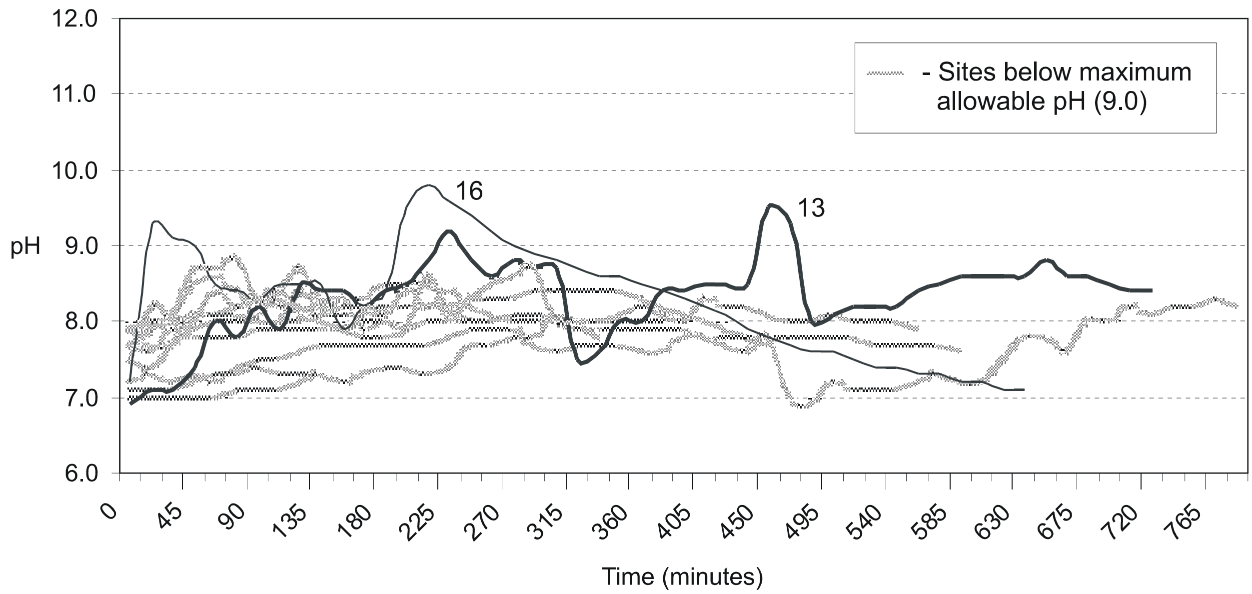

Figure 8. pH at 10-m Transect for Sites Where Grout Bags Were Used with Turbidity Curtain

Placement with Use of Anti-washout Admixture

Over a 7-day period, 170 yd^3 of grout containing an AWA was placed in grout bags at a single structure in the Roanoke River. Summary results for pH levels at this site are shown in Table 5. At no time during the pumping, even when pumping occurred in areas of slack water, did pH readings go above 8.9 (see Figure 9).

Table 5. Summary pH Data for Grout Bag Sites with Anti-Washout Admixture

Property	Value
Maximum pH	8.9
Maximum increase in pH	1.7
Maximum pH @ 50 m downstream	8.3
Maximum time required for pH to return to baseline (h)	2.5
Number of sites pH exceeded 9.0 threshold	0 of 1

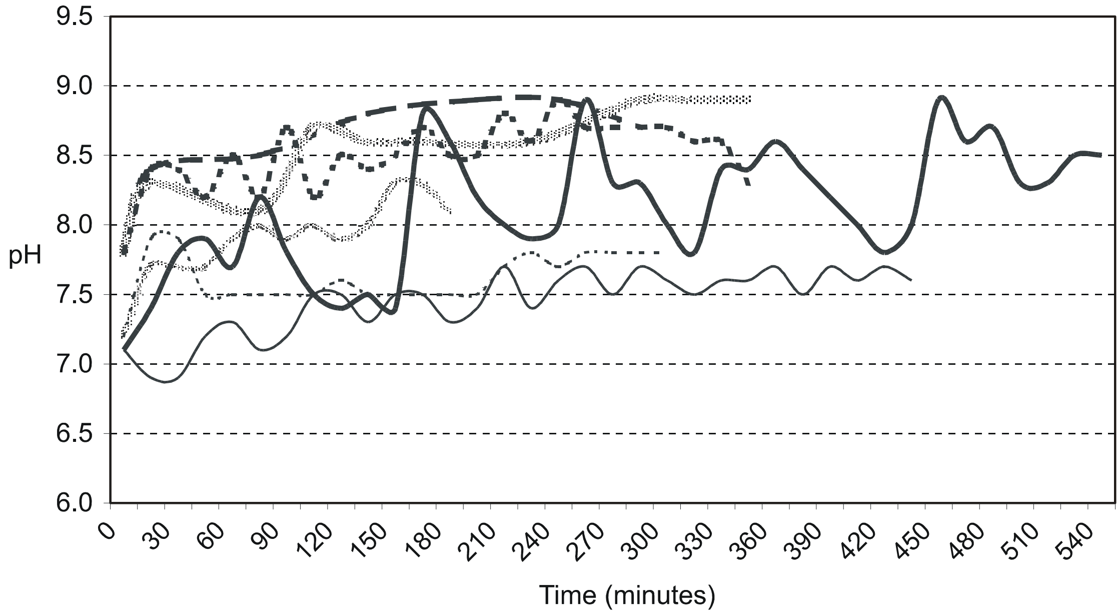

Figure 9. pH at 10-m Transect for 7 Days for Grout with AWA Placed in Grout Bags

Laboratory Analysis

The mean pH for each of the grout placement techniques tested in the laboratory is shown in Figure 10. The standard deviation associated with each of these was extremely small (the largest was 0.096). Of the 78 samples analyzed, those contained by filter fabric were associated with the highest pH values in the surrounding water. The grout samples with the AWA and contained by both types of grout bags were associated with the lowest pH values in the surrounding water. Again, the actual pH values are not indicative of what would be obtained in the field because of the small volume of water available for dilution. In most field situations, the water to grout ratio would be much greater, resulting in lower overall pH values.

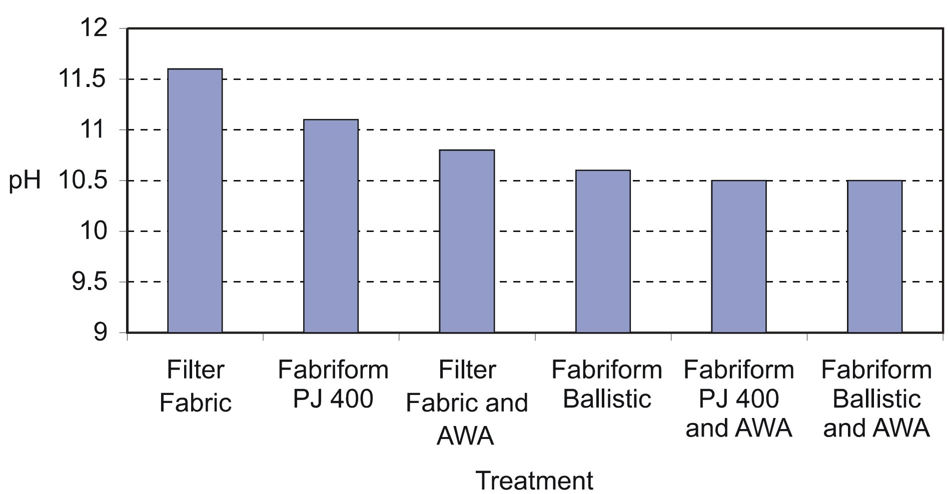

Figure 10. Mean pH Values for Each of Six Placement Techniques Measured in Laboratory

Assessment of Factors Contributing to Water Quality Degradation

Rises in pH represented, by far, the greatest changes in all of the water quality parameters measured. The rise in pH caused by the hydration of the cementitious materials in the grout results in the high concentrations of hydroxyl ions (OH^-) going into solution in the water surrounding the concrete. As a consequence, the factors contributing to or limiting the negative effects of grout on the stream water quality are related to the reduction of the relative amount of free hydroxyl ions in the water surrounding the pour area.

Stream Flow

Stream flow is a function of the velocity of the water moving through the pour area and the size of the stream (or volume of water for a given area in the stream). From data collected in the field, it appears that total stream flow is one of the most critical factors influencing the rise in pH when concrete is placed. The Mossy Creek site in the Staunton District is a Blue Ribbon Trout Stream. Because of this designation, there was great concern that rising pH levels would be detrimental to the fish known to be present at the site and immediately downstream. Because of the high volume of water moving through the site, pH values rose only 0.3 pH unit above baseline values. Even values inside the turbidity curtain at this site stayed well below 9.0 because of the strong current of water moving into and out of the curtained area. Most of the sites in the Fredericksburg District with pH values that remained below 9.0 had large volumes of water contributing to the dilution of the hydroxyl ion concentration. At the other extreme, one of the Freemason Run sites in Augusta County had no visible flow at the time of concrete placement, only pooled water immediately under the bridge structure. Within 30 minutes after pumping was started, pH values exceeding 11.0 were recorded. These values did not decline in 24 hours. This indicates that once the buffering capacity of the water is exceeded, the only way of bringing the pH back near baseline values is dilution by the introduction of additional water to the site.

Although stream flow volume is relatively easy to calculate for a stream, it is difficult to measure precisely the volume of water that will be immediately available for dilution at a given pumping location within the stream. Pumping typically occurs at several locations along one or more abutments or at a number of pier foundations for a structure. In many cases, each location has a different water depth and velocity. This results in different dilution factors for the same structure.

Grout Pumping Rate

The rate at which grout was placed also had a direct affect on the rise in the pH of the surrounding water. Similar to the stream flow variable, the rate at which grout was pumped underwater directly influenced the concentration of free hydroxyl ions in the surrounding water column. Most of the sites with pH values in excess of 9.0 (outside the turbidity curtain if one was used) were associated with pumping rates that exceeded 13 yd^3/hr. Some of these sites had as few as 6 yd^3 of grout placed for the entire job, but the *rate* at which the grout was placed exceeded 13 yd^3/hr.

When pumping rates are combined with stream flow volumes, the data become even more meaningful (see Figure 11). At rates above 10 to 12 yd^3/hr, it takes a large volume of water moving through the site to dilute adequately the free hydroxyl ions coming from the grout mix. Five of the six sites with in-stream pH values above the 9.0 standard had a water (stream flow volumes) to concrete (grout pumping volumes) ratio of 40:1 or less. The single site with a higher ratio had an unexpected release of high pH water from inside the turbidity curtain when one end of the curtain came untied.

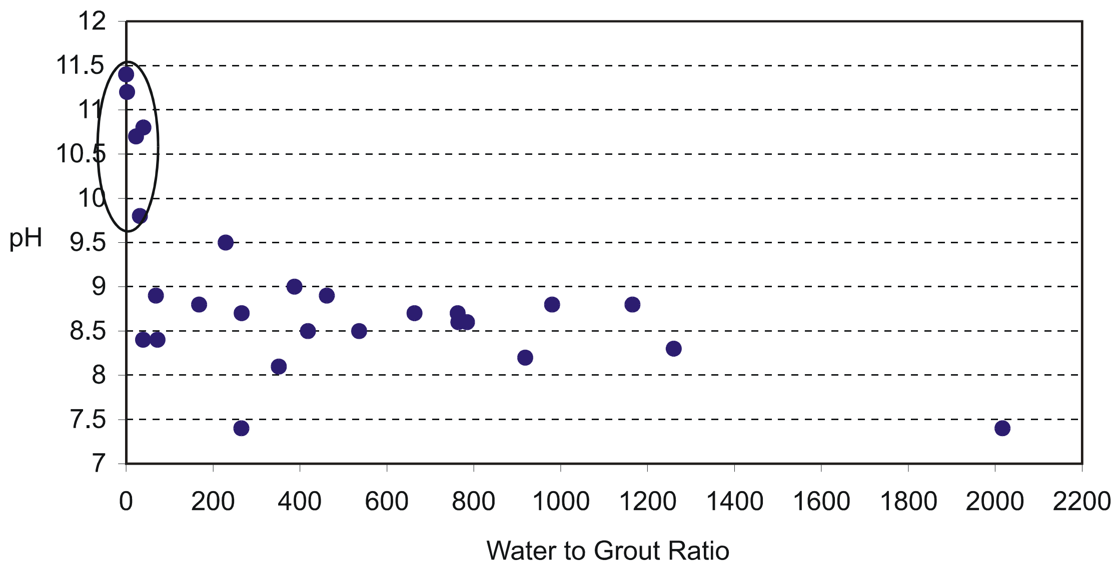

Figure 11. In-stream pH as Function of Water to Grout Ratio

Turbidity Curtains

Turbidity curtains helped keep in-stream pH values in check by simply containing the high pH water. Although containment resulted in relatively stable in-stream pH values because of the relatively small volumes of water inside the curtained area, pH values for this contained water were extremely high at most sites, resulting in a number of fish being killed. Once it became obvious that the turbidity curtain was trapping fish, efforts were made to install the curtain as close as possible to the bridge abutment and then move the curtain outward to its final location (no more than 1 m beyond the perimeter of the area where grout placement was to occur). This outward dragging motion helped prevent the inadvertent trapping of fish inside the curtained area, where the pour was to take place. Also, by keeping the curtain as close as possible to the outer edges of the grout bags, the volume of water within the curtained area was kept to a minimum.

The success or failure of the turbidity curtains to contain the high pH water depended upon how well the bottom of the curtain followed the bottom of the streambed and how well the ends were secured. On smooth, fine-grained bottoms, good contact was maintained. In cases where the bottom contained large rocks, riprap, or brush, adequate contact with the bottom was not possible, and therefore containment was not as good.

Grout Bags

Both field and laboratory data indicate that grout bags are beneficial in reducing the pH levels resulting from the placement of grout underwater. These same data, however, indicate that the use of the standard Fabriform PJ 400 grout bags alone is not sufficient to ensure that pH levels remain below 9.0 in all stream flow and/or pumping situations.

Research conducted by Construction Techniques, Inc. (1995), indicates that an estimated 0.5% of the total cement paste pumped into Fabriform PJ 400 grout bags will escape through the fabric. Based on this finding, and the average cement content for typical grouts, it was recommended that the rate of concrete placement (cubic yards/hour) not exceed the rate of water flow (cubic yards/minute) through the site to ensure that the rise in pH in the surrounding water did not exceed 1. This same ratio of 60 parts water to 1 part concrete is said to apply to grout placed in stagnant water (Construction Techniques, Inc., 1995; Lamberton, 1975). Although no specific tests were done to verify these findings, based on field data that were collected as a part of this study, it is safe to assume that with a 60:1 water to concrete ratio, the use of grout bags would keep in-stream pH values below 9.0 for streams with a baseline pH of 8.0 or less.

The data obtained from the laboratory component of this study show that the Fabriform Ballistic grout bag is significantly tighter than the Fabriform PJ 400 grout bag material, resulting in the escape of less cementitious material into the water column. Although the decreased porosity of the Fabriform Ballistic material would appear to be advantageous in most pumping conditions, this particular bag requires venting by way of a small vent pipe when being filled in the field (as a result of the weave being so tight). For most situations, the need to vent would prevent placing the tops of these bags underwater, as grout would then be allowed to escape from the vent pipe directly into the water.

Anti-Washout Admixtures

The AWA tested helped keep in-stream pH values in check by simply keeping the free hydroxyl ions from escaping the cement paste and entering the water column. The use of AWA alone resulted in a significant drop in pH in the surrounding water in comparison with the plain grout (see Figure 10). When the AWA was combined with either grout bag material tested, an even greater reduction in pH was obtained. From the different combinations tested, it appears that placing grout containing an AWA in a grout bag separated from the stream by a turbidity curtain would result in the lowest in-stream pH values.

Development of Grout Placement Flowchart

Based on the results of the field monitoring and the laboratory analysis, different grout placement methods are recommended, depending on the site-specific conditions. These are reflected in the form of the flowchart shown in Figure 12. To use the chart, one must know some of the basic characteristics of the site where the grout is to be placed. Most important, the stream flow volume in the immediate vicinity of the scour area must be calculated. This, along with an

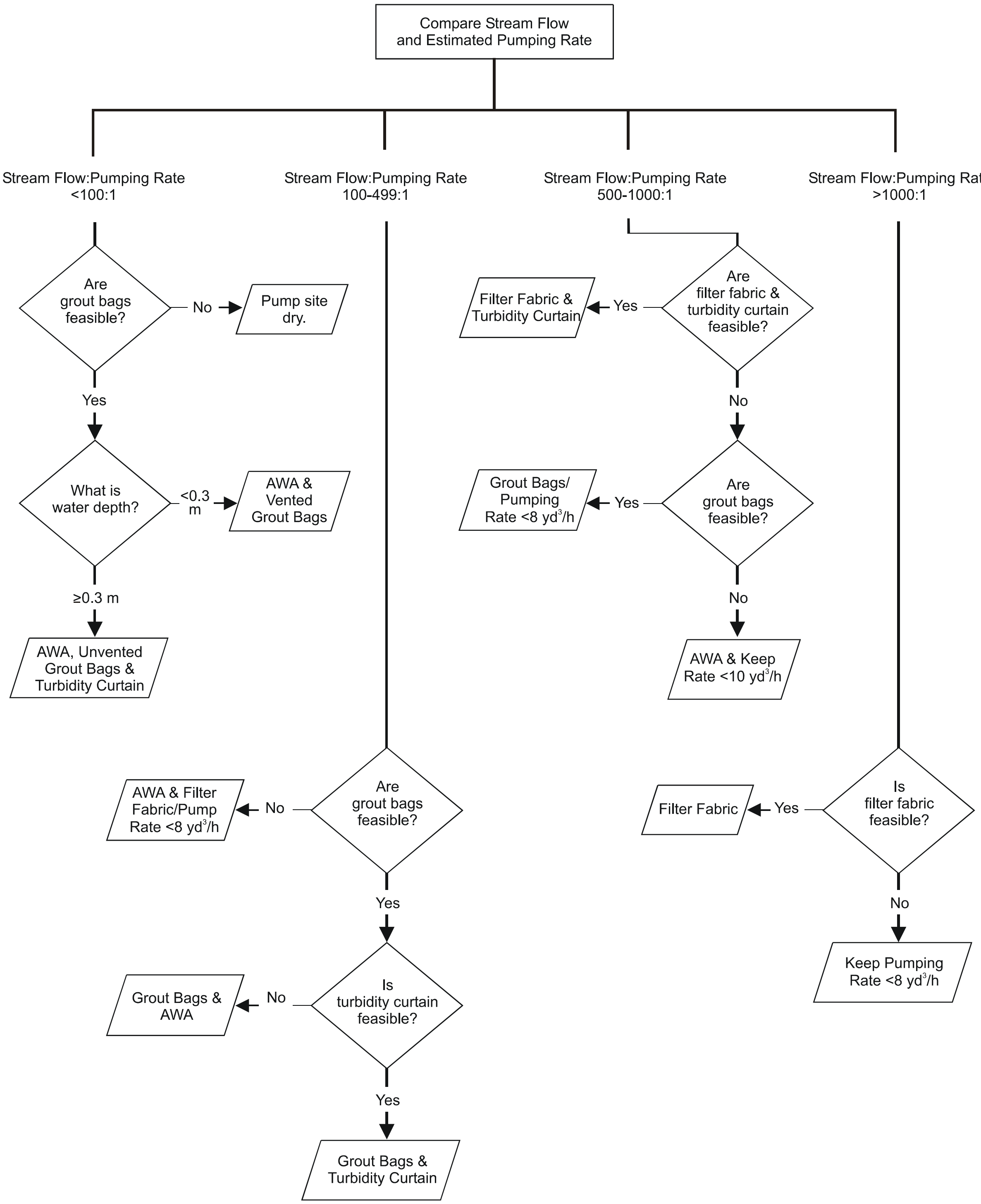

Figure 12. Grout Decision Flowchart to Aid in Selecting Methods of Placing Grout as Scour Countermeasure

estimated maximum grout-pumping rate, is the primary factor used for determining the placement technique to be used. Because different areas of the site will have different water velocities and different depths, the placement technique should be determined using the most conservative velocities and depths measured in pour area and immediately downstream (within 10 m of the placement area). It should also be noted that although the stream flow volume is directly related to the width of a stream, in the case of exceptionally wide bodies of water (>10 m), much of this water is not immediately available for dilution. It is possible that this water will not dilute the high concentrations of hydroxyl ions until the plume moves hundreds of meters downstream.

The placement methods shown in Figure 12 should prevent in-stream (i.e., not inclusive of water inside a turbidity curtain) pH levels from exceeding the state water quality standard of 9.0, assuming baseline pH values are below 8.0. The cutoff points or ranges for specific placement techniques were determined after a series of regression analyses were performed for the pH values measured in the field for each placement technique. Laboratory values were also used to determine the relative effectiveness of the containment materials and AWA combinations available. Because of the relatively few sites for each of the field techniques tested and the wide variety of conditions encountered, an additional "safety factor" was factored in when ranges for a given technique were specified. For example, the five sites where in-stream pH values rose above 9.0 had water to grout ratios of 40:1 or less. According to Figure 12, the recommended techniques for sites with water to grout ratios of 100:1 or less are either pouring in the dry or the most conservative technique of pumping a grout containing an AWA in a vented grout bag (if water depth permits this). It could be argued that this recommendation is overly conservative since three other field sites where the water to grout ratio was 39 or greater had pH values below 9.0. Likewise, for each of the other site types possibly encountered, more conservative techniques are recommended than would be suggested by the regression analysis calculated for the field data alone.

CONCLUSIONS

- *pH is the primary water quality parameter negatively affected by the placement of grout underwater for the rehabilitation of scour.* Other parameters such as dissolved oxygen, conductivity, and temperature do not appear to change significantly.

- *The placement of grout underwater can result in pH values well in excess of the DEQ-specified limit of 9.0 and in some cases approach 12.* The elevated pH levels will typically return to baseline values in 4 to 6 hours after grout placement is complete. The absolute rise in pH and the duration of the rise are dependent on a combination of stream flow volume and grout placement rates.

- *The rise in pH is not directly correlated with the volume of grout placed at a structure.*

- *When grout is placed underwater, in-stream pH values can be kept below the state water quality level of 9.0 by using a combination of placement techniques and/or an AWA.* The techniques required are very site specific but depend primarily on stream flow volume and grout pumping rates.

- *Significant savings can be realized by placing grout underwater at structures requiring scour countermeasures as compared with doing the repair in dry conditions.*

RECOMMENDATIONS

1. *The Natural Resource Section of VDOT's Environmental Division should develop a Memorandum of Agreement with DEQ's Water Resources Section to allow the use of grout placed underwater as a bridge and culvert scour countermeasure*. The agreement should specify that specific placement techniques will follow the recommendations outlined in Figure 12, the grout placement flowchart.

2. *The Natural Resource Section of VDOT's Environmental Division should ensure that all scour rehabilitation work done in any of VDOT's nine construction districts closely follow the placement techniques outlined in Figure 12.*

3. *District environmental staff should accurately characterize stream conditions (including depth and stream flow volume) and estimate the maximum grout-pumping rate prior to selecting any grout placement method for a specific structure*. Accurate widths (maximum of 10 m), depths, and stream flow velocities should be determined for each area of the structure that is to undergo rehabilitation.

ACKNOWLEDGMENTS

This project required the help, guidance, and field support of a great number of people within and outside VDOT. The author specifically thanks Carolyn Browder and Wendy Kedzierski in the DEQ for their willingness to allow VTRC to undertake the field component of this study; Ricky Woody, Leo Snead, and Pete Constanzer in VDOT's Environmental Division for supporting this research effort and conducting the benthic survey required by the DEQ; Brian Hawley in VDOT's Fredericksburg District and Brian Boyle in the Saluda Residency for allowing VTRC to monitor the sites in the Fredericksburg District; Michael Keeler in VDOT's Staunton District for field and logistical support; and Kevin Bradley in VDOT's Salem District for collecting field data and supporting the AWA field testing. The author also thanks VTRC's Lance Dougald for field and laboratory work; William Ordell and Michael Burton for laboratory assistance; Jim Gillespie for statistical guidance; Michael Perfater and Dan Roosevelt for reviewing the final report; and, as usual, Linda Evans for superb editorial efforts.

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APPENDIX

WATER QUALITY MANAGEMENT PLAN AND FIELD MANUAL FOR DETERMINING THE EFFECTS OF TREMIE CONCRETE ON WATER QUALITY

WATER QUALITY MANAGEMENT PLAN AND FIELD MANUAL FOR DETERMINING THE EFFECTS OF TREMIE CONCRETE ON WATER QUALITY

BACKGROUND

The effects of tremie concrete on water quality have been a concern for various environmental agencies including the Virginia Department of Environmental Quality (DEQ) and the U.S. Army Corps of Engineers (USACE). This concern stems from several incidents of fish kills and high pH levels in streams where tremie concrete, commonly used in the repair of scour around bridge piers and abutments, was poured.

The Virginia Transportation Research Council has agreed to conduct a research study aimed at quantifying the effects of typical tremie concrete pours on water quality and identifying alternative methods to ameliorate the effects of scour caused by increased flow volumes and velocities. This document serves as the Water Quality Management Plan and Field Manual requested by DEQ. It describes the design criteria, sampling techniques, and general procedures to be followed by field personnel involved with this project to ensure that no more than a minimum degradation of water quality occurs as a result of the study.

GENERAL PROCEDURES

As part of this study, we will determine the baseline conditions of the stream at each project site by analyzing certain water quality parameters and conducting benthic organism surveys. We will continue to monitor the water quality parameters during and after the placement of the concrete until those parameters return to original baseline values and stop all work immediately if water quality limits are violated. By the end of this study we hope to develop and document a method by which concrete/grout can be placed underwater without causing unacceptable degradation to the quality of the surrounding aquatic environment.

Sampling equipment will be calibrated and installed at the monitoring site prior to establishing the baseline water quality of each stream. The equipment we will be using in this study is listed in Table 1, and will be used to measure the parameters listed in Table 2. All parameters except alkalinity will be measured in real time (i.e., no lag in analysis). This will enable the field personnel to know immediately if water quality limits are being violated and therefore follow the Violation Notification Procedures outlined in the Field Manual. In addition to the monitoring done and analyzed in real time, a data logger will be used in conjunction with six stationary probes to measure and record pH at 10-m intervals downstream of the pour area (Figures 1 and 2). Data collected with this system will allow for a more complete analysis of how pH is affected by pour volumes, pour rates, and stream flow velocities. All water quality monitoring will conform to the requirements of ASTM's field monitoring methodology.

Table 1. Monitoring Equipment

Device	Manufacturer	Model No.
pH probes	Campbell Scientific	CSI M11-L
Data logger	Campbell Scientific	CR-10
Stream velocity probe	Global Water	FP 201
Water analyzer	Horiba	U-10

Table 2. Water Quality Parameters Measured

Parameter	Interval	Method
pH	3 min /15 min	Field
Dissolved oxygen	15 min	Field
Temperature	15 min	Field
Alkalinity	1 hr	Laboratory
Conductivity	15 min	Field

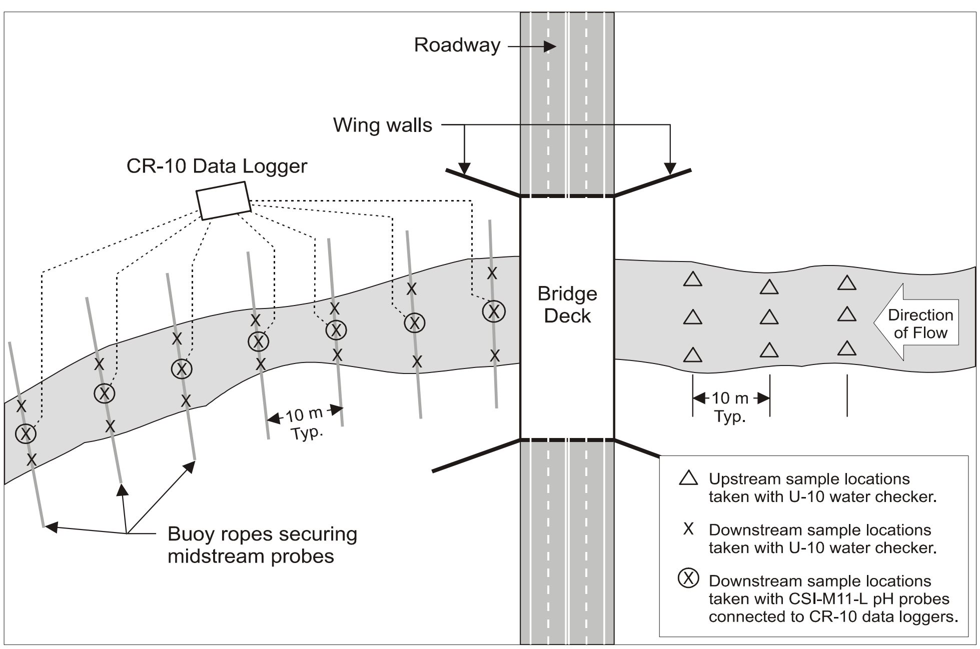

Figure 1. Plan View of Typical Site Setup

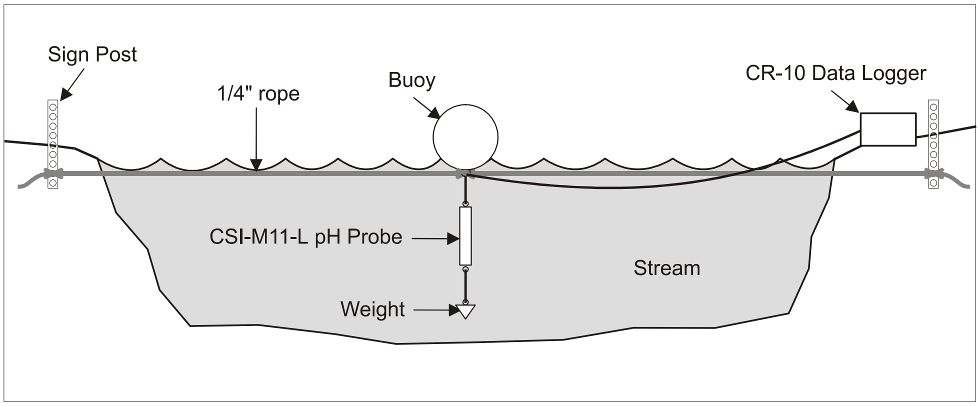

Figure 2. Detail of CSI-M11-7 pH Probe

FIELD MANUAL

SITE SETUP

1. Set up water quality monitoring stations at 10, 20, & 30 m upstream of the pour area; at the pour location; and at 10, 20, 30, 40, 50, & 60 m downstream of the pour area. See Figure 1 for a sketch of the typical site setup.

2. Horiba U-10 water analyzers shall be set up at every station. The CSI-M11-L pH probes connected to the CR-10 data logger shall be set up at the pour location and every downstream station.

3. Turbidity curtains may be used to help limit the spread of concrete fines downstream. This will ultimately result in a decreased chance of high pH water moving downstream. If curtains are deemed feasible for a particular site, the following steps must be followed:

    a. The curtain must initially be placed in the water immediately adjacent to the abutment or pier undergoing scour repair and then slowly pulled outward into the stream. This practice will minimize the chances of trapping fish between the curtain and the structure.
    b. At final placement, the curtain must be within 1 m of the perimeter of the outermost grout bags to minimize the volume of water contained inside the curtain area.
    c. The pH values for water inside the curtain will be recorded using the same methods and on the same interval as those downstream (see Monitoring Section).
    d. If pH values inside the curtain are found to exceed 9.0, pumping may resume but DEQ must be notified.

e. The curtain must remain in place until pH values for the water in the contained area are below 9.0.

ESTABLISHING BASELINE WATER QUALITY PARAMETERS

1. Take a single grab sample at the pour location for the alkalinity test, which will be analyzed in the lab after completion of the job.

2. Perform a benthic survey upstream of the bridge (between 0 & 30 m) and downstream of the bridge (between 0 & 60 m). Use cross-sectional dipnetting techniques, and record family, density, and diversity on the Benthic/Habitat Data Sheet.

3. Record aquatic habitat information upstream of the bridge (between 0 & 30 m) and downstream of the bridge (between 0 & 60 m). Record data such as water depth, riffle/pool/flat ratios, streambank vegetation, and streambank stability on the Benthic/Habitat Data Sheet.

4. Using the Horiba U-10 water analyzer, take one measurement of pH, dissolved oxygen, temperature, and conductivity at each of the monitoring stations as described in Site Setup and shown in Figure 1. Measure stream flow velocity at each of the monitoring stations. Enter all data values on the Water Quality Data Sheet.

MONITORING DURING AND AFTER THE CONCRETE POUR

1. After the pour has started, measure each water quality parameter at every monitoring station at the time intervals shown in Table 2. In summary, the intervals are as follows:

   Every 3 minutes – Monitor pH with the CR-10 data logger at the pour location and the downstream stations.

   Every 15 minutes – Monitor pH, dissolved oxygen, temperature, and conductivity with the Horiba U-10 water analyzer at every monitoring station. Enter these values on the Water Quality Data Sheet.

   Every 60 minutes – Take a single grab sample at the pour location for the alkalinity test.

   If water quality parameters are not returning to baseline values at the 60-m downstream monitoring station, add additional downstream monitoring stations at 10-m intervals until baseline values are reached. This will provide information on how far downstream the pours affect water quality.

If at any time during the concrete pour, the water quality standards as specified in VAR 680-21-01.5 (pH > 9.0 or dissolved oxygen < 4.0) or as appropriate for the water body for each study are violated, **stop all concrete pouring operations immediately!** and follow the steps outlined in the Violation Notification Procedures.

2. This monitoring shall continue after the concrete pour is completed until the water quality parameters return to baseline values.

3. Repeat benthic and habitat surveys (as previously described in baseline establishment) 3 to 5 days after the completion of the concrete curing process.

VIOLATION NOTIFICATION PROCEDURES

If at any time during the placement of the concrete the water quality standards as specified in VAR 680-21-01.5 (pH > 9.0 or dissolved oxygen < 4.0) or as appropriate for the water body for each study are violated, the following steps shall be carried out:

1. All concrete operations shall be ordered to cease immediately.

2. Monitoring at every station shall continue throughout the cessation period to record the degree and duration of the violation.

3. Any evidence of stress to aquatic organisms shall be recorded.

4. Ms. Carolyn Browder (804-698-4420) or Ms. Wendy Kedzierski (804-698-4503) of DEQ shall be notified immediately.

5. Adjustments to pumping rates and or placement techniques shall be made on-site to prevent exceeding the limits again.

6. Operations shall not be allowed to resume until the parameters being measured are within acceptable limits as appropriate for the water body.

REPORTING

A water quality monitoring report for each site will be submitted to DEQ and the USACE within 30 days of construction. Data will be summarized by site and statistically analyzed, and raw data (i.e., completed data sheets) will be made available in an appendix format.