QUALITY ASSURANCE PROJECT PLAN

for the

Virginia River Input Monitoring Program

Prepared by

Douglas L. Moyer U.S. Geological Survey 1730 E. Parham Road Richmond, VA 23228

for Virginia Department of Environmental Quality Chesapeake Bay Office PO Box 1105 Richmond, VA 23218

Effective August 2016

Approvals:

Douglas Moyer, Project Manager, USGSDateDouglas Chambers, Acting Water-Quality Specialist, USGSDateCindy Johnson, Project Officer, VDEQDateCindy Johnson, Quality Assurance Officer, VDEQDatePeter Tango, Project Officer, US EPADate

Rich Batiuk, Quality Assurance Officer, US EPA

Date

QUALITY ASSURANCE PROJECT PLAN

for the

Virginia River Input Monitoring Program

Prepared by:

Douglas L. Moyer

U.S. Geological Survey

for

Virginia Department of Environmental Quality Chesapeake Bay Office Richmond, VA

updated August, 2016

TABLE OF CONTENTS

I. PROJECT DESCRIPTION 4

II. PROJECT ORGANIZATION AND RESPONSIBILITY 18

III. QA OBJECTIVES AND CRITERIA 21

IV. SAMPLING PROCEDURES 25

V. SAMPLE CUSTODY 26

VI. CALIBRATION PROCEDURES AND FREQUENCY 27

VII. ANALYTICAL PROCEDURES 28

VIII. DATA REDUCTION, VALIDATION, AND REPORTING 29

IX. INTERNAL QC CHECKS 30

X. PERFORMANCE AND SYSTEM AUDITS 31

XI. PREVENTATIVE MAINTENANCE 31

XII. ASSESSMENT OF DATA VARIABILITY, BIAS, ACCURACY, REPRESENTATIVENESS, AND COMPLETENESS 32

XIII. CORRECTIVE ACTION FOR OUT-OF-CONTROL SITUATIONS 32

XIV. QA REPORTING PROCEDURES 33

I. PROJECT DESCRIPTION

A. Background

Quantification of the loads of nutrient and suspended solids into the Chesapeake Bay, and evaluation of the trends in constituent loads are necessary in order to determine the effects that these constituents have on the ecosystems of the Chesapeake Bay. The Virginia River Input Monitoring Program (formerly known as the Virginia Fall Line Nutrient Input Program) was developed to quantify and assess the effectiveness of programs aimed at reducing the impact of nutrient and suspended solid inputs. Load estimates can further be used to calibrate and validate the computer-modeling efforts of the Chesapeake Bay Program.

The U.S. Geological Survey (USGS) began monitoring nutrients and suspended-solids in Virginia in 1984 in cooperation with the Virginia Department of Environmental Quality--Chesapeake Bay Office (VDEQ; at that time, the Virginia Water Control Board) to quantify loads entering Chesapeake Bay from its major tributaries in Virginia. The initial monitoring program consisted of collecting water-quality data on a twice-per-month scheduled basis at sites near the Fall Line on four tributaries to the Bay: the James, Rappahannock, Pamunkey, and Mattaponi Rivers. The Fall Line is geographically defined as the point where the Piedmont Physiographic Province meets the Coastal Plain, and in most instances this corresponds to the point farthest downstream that is unaffected by tides. Loads estimated for rivers at the Fall Line can therefore be used as single-point sources of loads to the Chesapeake Bay. The monitoring program was expanded over the years to include smaller basins that are tributary to the Potomac, Rappahannock, Pamunkey, and James Rivers.

Loads of nutrients and suspended solids are greatest during stormflow conditions because of higher discharge and often higher constituent concentrations. Therefore, the monitoring program was expanded in 1988 to include more frequent water-quality data collection during stormflow conditions at two major Virginia tributaries to the Chesapeake Bay, the James and Rappahannock Rivers. In July of 1989, the Pamunkey, Mattaponi and Appomattox Rivers were added to this storm-monitoring network. In 2005, the James River at the Blue Ridge Parkway was added to the storm-monitoring network (DEQ continues to collect the monthly scheduled sample at the Blue Ridge Parkway Site). Also in 2005, the USGS began monthly monitoring of water-quality conditions at the North and South Fork Shenandoah and Rapidan Rivers. In 2006, the James River (at Richmond) station was moved from the Huguenot Bridge to the Boulevard Bridge for safety reasons (note that the stream gage was left at the Huguenot Bridge site). In 2007, the USGS began monthly and storm monitoring at the North Anna and Chickahominy Rivers as well as monthly monitoring at the James (at Richmond at the Boulevard Bridge) River (this monthly monitoring was previously done by DEQ). In 2010, the USGS began monthly and storm monitoring at Smith Creek. In 2011 the Rivanna River and was added to the storm-monitoring network (DEQ continues to collect the monthly scheduled samples at this site). Also in 2011, the USGS began monthly and storm monitoring at the following stations: Accotink Creek, Muddy Creek, Difficult Run, South Fork Quantico Creek, and Dragon Swamp. In 2012 the Appomattox River (at Farmville), the Mattaponi (near Bowling Green), the Rappahannock River (at Remington), and the South Fork Shenandoah (at Lynnwood) were added to the storm-monitoring network (DEQ continues to collect the monthly scheduled samples at these sites). Also in 2012, the USGS began monthly and storm monitoring on Polecat Creek. A parallel program has been conducted on tributaries in Maryland by the USGS in cooperation with the Maryland Department of the Environment since 1982.

Weighted Regressions on Time, Discharge, and Season (WRTDS) (Hirsch and others, 2010) is used to estimate constituent concentration on days when no concentration data are available. The product of estimated concentrations and daily mean discharge provides daily load estimates, which are then summed to provide monthly and annual loads of selected nutrients and suspended solids. Through WRTDS, trends in nutrient and suspended-solids loads is quantified after integrating out the year-to-year variability in streamflow. These "flow-normalized" trends in loads represent the changes in loads resulting from changing sources, delays associated with storage or transport of historical inputs, and/or implemented management actions. A full description of the application of WRTDS for all Chesapeake Bay nontidal monitoring stations is provided in Chanat and others, 2015.

B. Objectives and Scope

The Chesapeake Bay River Input Monitoring Program is being used to define the magnitude, timing, and possible sources of nutrient inputs to the Chesapeake Bay from the nontidal areas of the larger tributaries in Virginia. This sampling program provides a data base of selected constituents (nutrients and suspended solids) for periods of varying flow and season, which are used to produce estimates of constituent loading to the Chesapeake Bay. The specific objectives of this program are to:

- (1) describe concentrations of selected nutrients and suspended solids in terms of flow and season,
- (2) compute monthly and annual loads of nutrients and suspended solids,
- (3) compare concentration data and load estimates between rivers,
- (4) compute trends in nutrient and suspended solid loads over time,
- (5) explain possible factors influencing concentration, loads, and trends of nutrients and suspended solids,
- (6) provide data for calibration of the Chesapeake Bay Watershed model and nutrient and sediment loading inputs to the Chesapeake Bay Water-Quality model.
- (7) assess quality-assurance results in order to describe the quality of the analyses provided by the participating laboratories, and
- (8) provide information needed to refine the network design for future monitoring programs for the Chesapeake Bay.

Station	Station ID	Start Date	Parameter List
James River at Cartersville	USGS 02035000, VDEQ 2-JMS157.28 (Discontinued sampling by DEQ 3/2001)	1988	RIM
Rappahannock River near Fredericksburg	USGS 01668000, VDEQ 3-RPP113.37 (Discontinued sampling by DEQ 3/2001)	1988	RIM
Appomattox River at Matoaca	USGS 02041650, VDEQ 2-APP016.38 (Discontinued sampling by DEQ 6/1999)	1989	RIM
Pamunkey River near Hanover	USGS 01673000, VDEQ 8-PMK082.34 (Discontinued sampling by DEQ 4/2003)	1989	RIM
Mattaponi River near Beulahville	USGS 01674500, VDEQ 8-MPN054.17 (Discontinued sampling by DEQ 4/2003)	1989	RIM
North Fork Shenandoah River near Strasburg	USGS 01634000, VDEQ 1BNFS010.34	2005	RIM Add-on
South Fork Shenandoah River at Front Royal	USGS 01631000, VDEQ 1BSSF003.56	2005	RIM Add-on
Rapidan River near Culpeper	USGS 01667500, VDEQ 3-RAP030.21	2005	RIM Add-on
James River at Blue Ridge Parkway*	USGS 02024752, VDEQ 2-JMS279.41	2005	RIM Add-on
James River near Richmond	USGS 02037618, VDEQ 2-JMS113.20	2007	RIM
North Anna River at Hart Corner near Doswell	USGS 01671020, VDEQ 8-NAR005.42	2007	RIM Add-on
Chickahominy River near Providence Forge	USGS 02042500, VDEQ 2-CHK035.26	2007	RIM Add-on
Smith Creek near New Market	USGS 01632900, VDEQ 1BSMT004.60	2010	RIM Add-on
Rivanna River at Palmyra*	USGS 02034000, VDEQ 2-RVN015.97	2011	RIM Add-on
Muddy Creek at Mount Clinton	USGS 01621050, VDEQ 1BMDD005.81	2011	RIM Add-on
Difficult Run near Great Falls	USGS 01646000, VDEQ 1ADIF000.86	2011	RIM Add-on
Accotink Creek near Annandale	USGS 01654000, VDEQ 1AACO014.57	2011	RIM Add-on
S.F. Quantico Creek near Ind. Hill	USGS 01658500	2011	RIM Add-on
Dragon Swamp at Mascot	USGS 01669520, VDEQ 7-DGN000.85	2011	RIM Add-on
South Fork Shenandoah River at Lynnwood	USGS 01628500, VDEQ 1BSSF100.10	2012	RIM Add-on
Rappahannock River at Remington	USGS 01664000, VDEQ 3-RPP147.10	2012	RIM Add-on
Mattaponi River near Bowling Green	USGS 01674000, VDEQ 8-MPN094.79	2012	RIM Add-on
Appomattox River at Farmville	USGS 02039500, VDEQ 2-APP110.93	2012	RIM Add-on
Polecat Creek at Route 301 near Penola	USGS 01674182	2012	RIM Add-on

The stations monitored, their station numbers, start of monitoring, and parameters include:

Stations with an * indicate the sites for which DEQ performs the monthly water-quality sampling

C. Data Usage

Data collected for the Virginia River Input Monitoring Program are used to help define the magnitude, timing, and sources of nutrient inputs to the Chesapeake Bay from the nontidal areas of the major tributaries in Virginia. Additionally, this information can help gauge the success of management practices aimed at reducing these inputs. These data provide a data base of selected nutrients and suspended solids collected during periods of varying flow and season, which are being used to estimate loads to the Chesapeake Bay of the selected constituents.

Concentration data and statistics from the concentration data will be used to describe the waterquality characteristics of each river, including concentration ranges and medians; the relations between concentration and discharge; and concentration and seasonality at each river. Load estimates will be compared to loads from other rivers in the Chesapeake Bay, in order to see the relative differences between the basins. Differences may be examined using land-use information, discharge records, and possibly point and nonpoint sources of constituents. Trend estimates will be used to determine the changes in constituent inputs over the period of study, and to assess the impact of management practices implemented during that time.

Historical data may be used as background information for comparison purposes. Quality assurance data are used on an ongoing basis to evaluate field and analytical methods for representativeness, variance, bias, and accuracy.

D. Study Design and Rationale

The contributing basins for this report together comprise about 22 percent of the total Chesapeake Bay drainage area. The James and Rappahannock River basins represent approximately 13 and 4 percent of the Chesapeake Bay drainage area; the Appomattox, part of the lower James River Basin, represents another 2.5 percent; and the Pamunkey and Mattaponi River basins represent about 2 and 1 percent of the total Chesapeake Bay drainage area. The remaining percentage of Virginia within the Chesapeake Bay watershed is comprised of the Potomac River basin and its tributaries including the Shenandoah River, which are monitored by the USGS Virginia, West Virginia, and Maryland Water Science Centers.

Table 1 presents the basin size, the percent land use in the Chesapeake Bay watershed, the percent land use in Virginia and the percent land use within each of the major basins monitored for this report. The locations of the river basins and the River Input monitoring stations are shown in Figure 1. A description of each river basin and each sampling station follows.

Table 1. Land use for the Chesapeake Bay, the Chesapeake Bay watershed in Virginia, and selected major river basins in Virginia

[mi², square miles;<, less than] (Neumiller and others, 1995; Chesapeake Bay Program, written commun.,1994)

Geographic	Drainage	Urban	Agricultural	Forested	Water	Total
Area	Area (mi ²)	(percent)	(Herbaceous)	(Woody)	(percent)	(Percent) ^{\underline{h}'}
			(percent)	$(percent)^{\underline{a}'}$	_	
Chesapeake	64,000	8	33	58	1	100
Bay						
Virginia	40,815	10	31	58	1	100
James River	10,206	8	25	65	1	99
Basin						
Rappahannock	2,848	6	40	54	<1	100
River Basin						
Appomattox	1,600	3	33	61	<1	98
River Basin						
Pamunkey	1,474	3	35	59	2	99
River Basin						
Mattaponi	911	2	27	69	<1	99
River Basin						

 \underline{a} Includes wetlands.

 $\frac{b}{D}$ Total percentage below 100 percent is possibly due to rounding and inaccuracies in area estimates.

Figure 1. Location of major river basins and the River Input Monitoring Stations.



Figure 1. Map of the 24 Chesapeake Bay Nontidal Nontidal Network stations in Virginia.

The area of the James River Basin is approximately 10,206 mi², or about one-fourth of the area of Virginia, and is the third largest source of freshwater to the Chesapeake Bay, after the Susquehanna and Potomac Rivers. The James River Basin extends from the eastern part of West Virginia

through four physiographic provinces (1) Valley and Ridge, (2) Blue Ridge, (3) Piedmont, and (4) Coastal Plain. The major cities in the James River Basin include Richmond, Lynchburg, Petersburg, Charlottesville, Williamsburg, Hopewell, and parts of Norfolk and Newport News.

The water-quality monitoring station at the James River near Cartersville, Va. (USGS station 02035000 and VDEQ station 2-JMS157.28 (Discontinued 3/2001)), represents the contributing area (6,257 mi²) to the Chesapeake Bay from Virginia near the Fall Line, or about 60 percent of the James River Basin drainage area. This station is about 40 mi upstream of the Fall Line, but was selected because of the well-documented long-term flow record, and because there are no major streams contributing to the flow between this station and the Fall Line at Richmond. Because of the size of the basin upstream of the sampling station, streamflow varies widely, depending on precipitation patterns which may result in either very localized or widespread stormflow events. The average discharge at this site, computed during a period of 114 years, is 7,024 ft³/s (U.S. Geological Survey, 2014). The location of this monitoring site is lat 37°40'16", long 78°05'09" (NAD83), which is at State Highway 45 at the Goochland/Cumberland County line, Va.

In 2004, one water-quality monitoring station was added in the James River Basin. This station is James River at Richmond (Huguenot Bridge, USGS station ID 02037500 and VDEQ 2-JMS117.35). In 2006, this station was moved downstream because of concerns over safety (note that the stream gage was left at the Huguenot Bridge site). This new station is James River at Boulevard Bridge at Richmond (USGS station 02037618 and VDEQ 2-JMS113.20). The drainage area for this watershed is 6,776 mi². The location of this monitoring site is lat 37°31'53", long 77°29'01" (NAD83) in Richmond, Va. In 2005, the water-quality monitoring station at the James River at the Blue Ridge Parkway, Va. (USGS station 02024752 and VDEQ station 2-JMS279.41) was added. The location of this monitoring site is lat 37°33'19", long 79°22'03" (NAD27) in Amherst County, Va. The drainage area associated with this station is 3,076 mi². In 2007, the water-quality monitoring station located at the Chickahominy River near Providence Forge (USGS station 02042500 and VDEQ 2-CHK035.26) was added. The drainage area for this watershed is 252 mi². The location of this monitoring site is lat 37°26'10", long 77°03'40" (NAD83) in New Kent County, Va. In 2011, the water-quality monitoring station at the Rivanna River at Palmyra (USGS station 02034000 and VDEQ 2-RVN015.97) was added. The drainage area for this watershed is 663 mi². The location of this monitoring site is lat 37°51'28", long 78°15'58" (NAD27), on State Route 15 in Fluvanna County.

The Rappahannock River Basin encompasses a land area of approximately 2,848 mi² which constitutes about 7 percent of the State of Virginia. The river flows from the eastern edge of the Blue Ridge physiographic province through the rolling hills of the Piedmont and Coastal Plain to the Chesapeake Bay, and is the second largest contributor of flow to the Chesapeake Bay from Virginia. The major cities or towns in the basin include Fredericksburg, Warrenton, Winchester, Culpeper, and Orange.

The Rappahannock River monitoring station (USGS station 01668000) is located upstream of Fredericksburg, Va. (This USGS station is at a cableway located 4.3 miles upstream of a VDEQ station (TF3.1 (Discontinued 3/2001)) at the Route-1 bridge; data from the VDEQ station is not used in this study). The area of the drainage basin upstream from the sampling station is approximately 1,596 mi², which is about 56 percent of the Rappahannock River basin. Upstream

from this station, most of the basin is in the uplands of the Piedmont Province, and because of the high relief, the river produces rapid or "flashy" streamflow peaks as a result of precipitation. The river therefore may carry large loads of suspended solids and other constituents relative to the size of the basin. The agricultural land use in the basin and expansion of the Washington, D.C., suburbs may increasingly affect the water quality of the river by causing elevated sediment concentrations in runoff, and an increase in concentrations of nutrients associated with the sediment, such as total phosphorus. The average discharge at this station is 1,679 ft³/s, computed during a period of 106 years (U.S. Geological Survey, 2014). The location of the current sampling station and gage in Spotsylvania County, Va., is: lat 38°18'30", long 77°31'46" (NAD83).

In 2005, one additional water-quality monitoring station was added in the Rappahannock River basin. This new station is the Rapidan River near Culpeper, Va (USGS station 01667500 and VDEQ station 3-RAP030.21). The drainage area for this watershed is 472 mi². The location of this monitoring site is lat 38°21'01", long 77°58'30" (NAD83), which is at State Highway 522. In 2012 another station, the Rappahannock River at Remington will be added within this basin (drainage area of 619 square miles, located at latitude 38°31'50", longitude 77°48'50" NAD27.

The Appomattox River Basin is within the James River basin, but because the Appomattox River enters the James River below the Fall Line, it is not included as a source to the James River monitoring station at Cartersville, and so is monitored separately. The basin area above the confluence with the James is 1,600 mi², approximately 16 percent of the James River basin and 4 percent of the area of Virginia. The Appomattox River basin begins in the Piedmont physiographic province, and flows through a small portion of the Coastal Plain before it flows into the James River near Hopewell. The Appomattox River basin is primarily rural, although the cities of Petersburg, Colonial Heights, and Hopewell are within the basin, downstream of the sampling station at Matoaca.

The drainage area of the Appomattox River basin above the sampling station at Matoaca (USGS station 02041650) is approximately 1,344 mi². The monitoring station is unique among the River Input Monitoring stations in that the flow is controlled by a dam at Lake Chesdin, 2.8 miles upstream of the sampling station. This tends to delay water-level rise from storms, so that the water level is very slow to rise and to fall in comparison to the other monitoring stations. Downstream of Lake Chesdin, the steep gradient due to the rapid elevation change, and a streambed of rocks and boulders result in expanses of rapids between the dam and the sampling station. The average discharge at this station is 1,281 ft³/s, computed during a period of 43 years (U.S. Geological Survey, 2014). The location of the site in Chesterfield County is lat 37°13'31", long 77°28'31" (NAD83). In 2012, another station will be added at the Appomattox River at Farmville (drainage area of 302 square miles, located at Latitude 37°18'25", Longitude 78°23'20" NAD27).

The total area of the York River Basin is approximately 2,650 mi², about 6.5 percent of Virginia's total land area, consisting of the Pamunkey River, the Mattaponi River, and the coastal area below the sampling stations. Agriculture is an important component of the economy of the York River basin, and the area is primarily rural. Although the Pamunkey and Mattaponi Rivers are often collectively presented as the York and have many similarities, each river has unique basin, flow and water-quality characteristics. The Pamunkey and Mattaponi River basins are monitored above their confluence to form the York, and are reported separately for this study.

The total area of the Pamunkey River Basin is 1,474 mi², or about 4 percent of Virginia. The Pamunkey River basin begins in the lower part of the Piedmont Province where the relief is relatively low and extends into the Coastal Plain. The basin contains expanses of forested wetlands

and marshes that are significant sources of wildlife productivity (Virginia Water Control Board, 1988). Ashland and Mechanicsville are the two major towns in the basin.

The Pamunkey River basin monitoring station (USGS station 01673000 and VDEQ station TF4.1 (VDEQ, Discontinued 3/2001)) is located near Hanover, Va. The area of the drainage basin above the sampling station is approximately 1,081 mi², which is about 40 percent of the York River basin. The low relief and relatively wide basin tend to produce stormflow peaks that are slow to peak and to recede. There is some regulation of the Pamunkey River from the dam at Lake Anna, approximately 100 mi upstream of the monitoring station, on the North Anna River. The average discharge at this station is 1,036 ft³/s, computed during a period of 41 years (U.S. Geological Survey, 2014). The location of the site in Hanover County, Va., is lat 37°46'04", long 77°19'56" (NAD83).

In 2007, one additional water-quality monitoring station was added in the Pamunkey River basin. This new station is the North Anna River at Hart Corner near Doswell, Va (USGS station 01671020 and VDEQ station 8-NAR005.42). The drainage area of this watershed is 462 mi². The location of this monitoring site is lat 37°51'00", long 77°25'41" (NAD83) in Hanover County, VA.

The Mattaponi River basin is 911 mi², or two percent of the area of Virginia, and also is located within both the Piedmont and Coastal Plain physiographic provinces. Like the Pamunkey River, it tends to have expanses of wetland areas (VWCB, 1991). The wetland areas tend to slow flow velocities, and the hydrographs during storms are slower to peak and recede than at the Pamunkey River.

The Mattaponi River monitoring station (USGS station 01674500 and VDEQ station TF4.3 (VDEQ, Discontinued 3/2001)) is located near Beulahville, Va. The area of the drainage basin above the sampling station is approximately 601 mi², which is about 23 percent of the entire York River basin, and two percent of the area of Virginia. Like the Pamunkey, the Mattaponi River basin has expanses of freshwater wetlands (VWCB, 1991). The average discharge at this station is 567 ft³/s, computed during a period of 71 years (U.S. Geological Survey, 2014). The location of the site in King and Queen County is lat 37°53' 16", long 77°09' 47" (NAD83). In 2012, monitoring stations were added to the Polecat Creek (drainage area of 49 square miles, located at the Route 301 bridge, near Penola, VA) and the Mattaponi River near Bowling Green (Drainage area of 256 square miles, located at latitude 38°03'42", longitude 77°23'10" NAD27.

In 2005, two additional water-quality monitoring stations were added in the Shenandoah River Basin. The first station is the North Fork Shenandoah River near Strasburg, Va. (USGS station 01634000 and VDEQ station 1BNFS010.34). The drainage area for this watershed is 768 mi². The location of this monitoring site is lat 38°58'36", long 78°20'10" (NAD83), which is at state Highway 55 in Warren County, Va. The second station is the South Fork Shenandoah River at Front Royal, Va. (USGS station 01631000 and VDEQ 1BSSF003.56). The drainage area for this basin is 1,642 mi². The location of this monitoring site is lat 38°54'50", long 78°12'39" (NAD83), which is at State Highway 619 in Warren County, Va. In 2010, a monitoring station was added at Smith Creek near New Market (USGS station 01632900 and VDEQ 1BSMT004.60). The drainage area of the watershed is 93.6 mi². The location of this monitoring site is lat 38°41'36", long 78°38'35" (NAD27), on State Route 620 in Shenandoah County. During 2011 new Shenandoah Valley monitoring stations were added at Muddy Creek (drainage area of 14.3 square miles, and located at Latitude 38°29'12", Longitude 78°57'38" NAD27), and the South Fork Shenandoah at Lynnwood (drainage area of 1079 square miles, located at Latitude 38°19'21", Longitude 78°45'18" NAD27).

Other monitoring stations that were added to the nontidal network include the following that were added in 2011 - Accotink Creek (drainage area of 23.9 square miles, located at Latitude 38°48'46", Longitude 77°13'43" NAD27), Difficult Run (drainage area of 58 square miles, located at Latitude 38°58'33", Longitude 77°14'46" NAD27), the South Fork Quantico Creek (drainage area of 7.6 square miles, located at Latitude 38°35'14", Longitude 77°25'44" NAD27), and Dragon Swamp (drainage area of 109 square miles, located at Latitude 37°38'01", Longitude 76°41'48" NAD27).

E. Description of Streamflow

Constituent concentrations within a river change as a function of streamflow, and streamflow data are necessary to compute constituent loads. A streamgage is currently operated at each of the network monitoring stations; these streamgages are operated as a joint network by USGS and VDEQ, following USGS protocols. Realtime streamflow data are available online at: http://waterdata.usgs.gov/va/nwis/rt/.

F. Monitoring Parameters and Frequency of Collection

Table 2 describes the field parameters that are collected for all samples. Table 3 and Table 4 show the constituents monitored for each of the RIM and RIM Add-on sites, as well as the the detection limits at each laboratory, and the reference to the method used.

RIM Samples are analyzed for the following constituents:

<u>Field Parameters</u> (water temperature, specific conductance, pH, dissolved oxygen, and turbidity)

<u>Nitrogen species</u> --particulate nitrogen, total dissolved nitrogen, dissolved ammonia nitrogen, dissolved nitrite plus nitrate, dissolved nitrate, total nitrogen. (Prior to February 1996, total Kjeldahl nitrogen - ammonia plus organic species - was also determined). The concentration of dissolved nitrite is the difference of dissolved nitrite plus nitrate concentration and dissolved nitrate concentration.

<u>Phosphorus species</u> --particulate phosphorous, total dissolved phosphorous, dissolved orthophosphorus, particulate inorganic phosphorus, total phosphorus.

<u>Other species</u> -- dissolved silica, particulate carbon, particulate inorganic carbon, dissolved organic carbon, chlorophyll a, total suspended solids, fixed suspended solids, suspended sediment and percent fines (RIM sites - Processed by the USGS sediment lab in Louisville, Kentucky. Add-on sites - processed by the Virginia Consolidated Laboratories).

RIM Add-On Samples are analyzed for the following constituents:

<u>Field Parameters</u> (water temperature, specific conductance, pH, dissolved oxygen, and turbidity)

Nitrogen species --total nitrogen, total ammonia, and total nitrate and nitrite.

<u>Phosphorus species</u> --dissolved orthophosphorus and total phosphorus.

<u>Other species</u> -- Suspended sediment - processed by the Virginia Consolidated Laboratories for total suspended solids, fixed suspended solids, suspended sediment and percent fines. Using current modeling approaches, 20 samples per year are needed to accurately estimate loads using the log-linear regression model selected for this study and utilizing the data previously collected for this project. All stations will have 20 water-quality samples collected each year. These 20 samples will be comprised of 12 routine samples and 8 stormflow samples. In addition to the once-per-month routine samples, up to 2 storm samples may be collected on either the rise, peak, or fall of a given storm hydrograph; with no more than 1 sample collected per day. This allows for the identification of the variability associated with each water-quality constituent over a wide range of stormflow events.

Appendix 1 shows an example of the record of field data planned, including quality assurance data. This form is also used by field personnel to document that the sample was collected. This record is kept for each of the stations.

G. Continuous Water-Quality Monitoring

In 2007, continuous water-quality monitors were added to the existing RIM project at the James River at Cartersville, Rappahannock River at Fredericksburg, and Pamunkey River near Hanover RIM stations. The Rappahannock River monitor was discontinued in 2009. In April 2010, a continuous water-quality monitor was deployed on Smith Creek. In 2012, a continuous water-quality monitor (YSI-6920) was deployed at Difficult Run; additionally, a continuous nitrate analyzer (SUNA) was at Difficult Run and Smith Creek. In 2015, a YSI-6920 was deployed at Accotink Creek; additionally, SUNA units were deployed at Accotink Creek and James River at Cartersville. YSI-6920 monitors are depolyed in situ and collect values every 15 minutes for pH, specific conductance, turbidity, and water temperature. SUNA units are deployed in situ and collect values every 15-minutes for nitrate-nitrite. These water-quality data are stored in the USGS NWIS database and also are available at http://nwis.waterdata.usgs.gov/va/nwis/rt. An USEPA Chesapeake Bay program approved Quality Assurance Project Plan is already in place for continuous water-quality monitoring ("Enhanced sediment collection for improving continuous sediment simulations - Quality Assurance/Quality Control Project Plan, December 2005"). A copy of the quality assurance/quality control plan is provided in Appendix 4.

Analyte	Parameter Code	Accuracy
Water Temperature	00010	+/- 0.15 degree Celsius
Specific Conductance	00095	+/- 0.5% of reading + 0.001 mS/cm
Dissolved Oxygen	00300	+/- 0.2 mg/L or 2% of reading, whichever is greater
рН	00400	+/- 0.2 unit
Turbidity	63680	+/- 2% of reading or 0.3 FNU, whichever is greater
Nitrate-Nitrite	99133	+/- 10% of reading or 0.028(V2) 0.056 (V1) mg/L, whichever is greate

Table 2. Field parameters that are collected with all USGS water-quality samples.

Analyte	NWIS Code (storet code)/ CEDS Code	VDCLS Analytical Method	Detection Limit ^{1/}	VDCLS Parameter Group	Container		
Dissolved Ammo- nia Nitrogen	00608/ 00608 ⁵	USGS I-2523-85	.006 ppm	CNTF2	250 mL plastic bottle (HDPE)		
Dissolved Nitrate+Nitrate	00631/ 631 ⁵	EPA 353.2	.004 ppm	-	Filter Immedi- atley and Pre- serve at 4 ^o C		
Dissolved Nitrite	00613/ 00613	EPA 353.2	.002 ppm	-			
Dissolved Orthophosphorus	00671/ 00671	EPA 365.1	-				
Dissolved Silica	00955/ 00955	USGS I-2700-85	.1 ppm				
Particulate Nitrogen	00601/ PNWLF	EPA 440.0	0.03 ppm	BAYR2	1 gallon Cubi- tainer		
Total Dissolved Nitrogen	00602/ TDNLF	Colorimetric, Chesa- peake Bay (D'Elia ^{2/})	.011 ppm		Preserve at 4°C		
Particulate Phosphorus	00667/ PPWLF	Colorimetric, Chesa- peake Bay (Aspila ^{3/})	.0013 ppm				
Particulate Inor- ganic Phosphorus	/ PIPLF	Colorimetric, Chesa- peake Bay (Aspila ^{3/})	.0008 ppm				
Total Dissolved Phosphorus	00666/ TDPLF	SM 4500-N part C)	.003 ppm	-			
Particulate Carbon	00694/ PCWLF	EPA 440.0	0.05 ppm				
Particulate Inor- ganic Carbon	Particulate Inor- 00688/ ganic Carbon 00688		0.02				
Total Suspended Solids	Cotal Suspended00530/Golids00530		3 mg/L				
Volatile Sus- pended Solids	00535/ 00535	Calculated	3 mg/L				
Fixed Suspended Solids	00540/ 00540	USGS I-3765-85	3 mg/L				
Dissolved Organic Carbon	00681	Standard Methods 5310 B (18th Ed.)	.36 ppm	DOCFF	4 oz. amber glass bottle (baked) Acid preserva- tion (HCl)		

Table 3. Virginia River Input Monitoring Program Analytes, Methods, and Detection Limits for RIM Sites.

Analyte	NWIS Code (storet code)/ CEDS Code	VDCLS Analytical Method	Detection Limit ^{1/}	VDCLS Parameter Group	Container
Chlorophyll A	70957/ 32211	EPA 446.0	.4 ppm	FCHLR	1 - 3 0.7um GF/F glass fiber filter (total vloume filtered = 300 mL)
Total Nitrogen	000600/ 000600	EPA Standard Method 4500-N Part C (20th ed)	0.02 ppm	BAYR2	See Above
Total Phosphorus	00665/ 00665	EPA 365.4	0.01 ppm	TPLL	125 mL plastic bottle (HDPE) Preserve with H_2SO_4 and store at $4^{\circ}C$
Suspended Sediment	80154/ SSC-Total	ASTM 3977-97 Method B		SSC	1 pint wide mouth glass bottle (USGS), or 500 mL clear plastic bottle (DCLS)
Suspended Sediment - Coarse > 62um	/ SSC-Coarse	ASTM 3977-97 Method C			
Suspended Sediment - Fine < 62um	70331/ SSC-Fine	ASTM 3977-97 Method C			

¹ Detection limits are determined on a yearly basis by VDCLS, using the procedure found in Appendix B of EPA CFR Part 136

^{2/}D'Elia, C.F., P.A. Steudler and N. Corwin. 1977. Determination of Total Nitrogen in Aqueous Samples Using Persulfate Digestion. Limnol. Oceanogr. 22:760-764.
^{3/}Aspila, Agemian and Chau, 1976. A semi-automated method for the determination of inorganic,

 $\frac{37}{2}$ Aspila, Agemian and Chau, 1976. A semi-automated method for the determination of inorganic, organic, and total phosphate in sediments. Analyst 101:187-197.

Table 4. Virginia River Input Monitoring Program Analytes, Methods, and Detection Limits for RIM Addon sites.

Analyte	NWIS Code (storet code)/ CEDS Code	VDCLS Analytical Method	Detection Limit ^{1/}	VDCLS Parameter Group	Container		
Total Ammonia Nitrogen	00608/ 00608 <u>5</u>	EPA 350.1	.006 ppm	BAYT3	Half gallon cubitainer.		
Total Nitrate+Nitrate	00631/ 631 ⁵	EPA 353.2	.004 ppm		Preserve at 4°C		
Dissolved Orthophosphorus	00671/ 00671	EPA 365.1	.002 ppm				
Total Nitrogen	000600/ 000600	EPA Standard Method 4500-N Part C (20th ed)	0.02 ppm				
Volatile Sus- pended Solids	00535/ 00535	Calculated	3 mg/L				
Fixed Suspended Solids	00540/ 00540	USGS I-3765-85	3 mg/L				
Total Suspended Solids	00530/ 00530	USGS I-3765-85	3 mg/L				
Total Phosphorus	00665/ 00665	EPA 365.4	0.01 ppm	TPLL	125 mL plastic bottle (HDPE) Preserve with H_2SO_4 and store at 4°C		
Suspended Sediment	80154/ SSC-Total	ASTM 3977-97 Method B		SSC-C2	500 mL clear plastic bottle (DCLS)		
Suspended Sediment - Coarse > 62um	/ SSC-Coarse	ASTM 3977-97 Method C					
Suspended Sediment - Fine < 62um	70331/ SSC-Fine	ASTM 3977-97 Method C					

¹ Detection limits are determined on a yearly basis by VDCLS, using the procedure found in Appendix B of EPA CFR Part 136f

 $\frac{5}{}$ The Add-on samples are whole water samples and the results are stored as total concentrations, rather than dissolved concentrations.

II. PROJECT ORGANIZATION AND RESPONSIBILITY

The organization of the project for the Virginia River Input Monitoring Program is outlined in the diagram below. The duties of the individuals are also described below.

Project Officer Cindy Johnson Chesapeake Bay Office/ VDEQ 804-698-4385 Fax 804-698-4032

Principal Investigators Douglas L. Moyer U.S. Geological Survey, WRD *804-261-2634 *Fax 804-261-2657

Field Sampling	Laboratory Analysis	<u>Data Management</u>	<u>Data Analysis</u>
USGS *Hydrologic	VDCLS Jay Armstrong	USGS	USGS
Technicians and	804-648-4480	*Hydrologist (2)	*Hydrologist (3)
Hydrologists as needed	(Nutrients) Chris Morton 804-648-4480 (Solids) Bailey Davis - Carbon and Chlorophyll A 804-648-4480	Hydrologic Technician	ffyurologist (3)
	USGS KY Sediment Lab	VDEQ Cindy Johnson	
	502-493-1944	804-698-4385	

*same phone and fax numbers as above

VDEQ, Virginia Department of Environmental Quality, Richmond, VA; USGS, U.S. Geological Survey; VDCLS, Virginia Division of Consolidated Laboratory Services, Richmond, VA; PROJECT OFFICER

Cindy Johnson Virginia Department of Environmental Quality Box 1105 Richmond, VA 23218

804-698-4385 Fax 804-698-4032

Responsible for overseeing the administrative aspects of the program including fiscal management, coordination among other administrators, and coordination with cooperating agencies and institutions. Approves technical design, conduct, and data analysis of the program.

PRINCIPAL INVESTIGATORS

Douglas L. Moyer - 804-261-2634 U.S. Geological Survey, WRD 1730 East Parham Road Richmond, VA 23228 Fax 804-261-2657

Responsible for the technical design, conduct, and data analysis of the program. Provides guidance to other key personnel and directs the efforts to organize, describe, and interpret the results of the monitoring. Has ultimate responsibility for quality assurance.

FIELD SAMPLING

Hydrologic Technician(s), U.S. Geological Survey, Richmond, VA Other Hydrologists and Hydrologic Technicians as needed

Coordinate all field activities of the program, including procuring all necessary equipment, collecting water samples according to the USGS sampling protocol, measuring field parameters, and coordinating all field quality assurance data collection.

<u>LABORATORY ANALYSIS</u> Virginia Division of Consolidated Laboratories (VDCLS), Richmond, VA

Jay Armstrong - Nutrients Chris Morton - Solids Bailey Davis - Carbon and Chlorophyll A

Complete laboratory analyses on a timely basis and return analytical results to VDEQ-CBO. Provide assistance with information concerning analytical techniques for constituents.

USGS Branch of Quality Systems Standard Reference Samples Project, Denver, CO

Mark Woodworth, Hydrologist

USGS Kentucky Sediment Laboratory

Aimee Downs, Geographer

Provides suspended sediment data for the primary RIM stations.

DATA MANAGEMENT

Hydrologist(s), U.S. Geological Survey, Richmond, VA Hydrologic Technician, U.S. Geological Survey, Richmond, VA

Cindy Johnson, Virginia Department of Environmental Quality, Richmond, VA

Responsible for maintaining the Virginia data base and transferring and checking all data from VDCLS to the USGS. Responsible for facilitating the transfer, collation, and retrieval of the data. Responsible for quarterly progress reports to VDEQ.

<u>DATA INTERPRETATION</u> Hydrologist(s), U.S. Geological Survey, Richmond, VA

Responsible for graphing, presentation and interpretation of the data; application of quality assurance data; and all formal report requirements for the program.

III. QA OBJECTIVES AND CRITERIA

Because data collected for the Virginia River Input Monitoring Program are used to (1) help define the magnitude and timing of nutrient inputs to the Chesapeake Bay at the Fall Line and (2) to provide a data base of selected constituents collected during periods of varying flow and season, several general quality assurance objectives are necessary in order for the program to be successful.

For Laboratory precision and accuracy, the Virginia Division of Consolidated Laboratories (DCLS) replicated approximately 10% of the samples and 5% of the samples analyzed are spiked samples. Detailed descriptions of the quality assurance practices for each of the analytical procedures conducted by DCLS, can be obtained upon request from DCLS - most analyses are described in the following SOPs:

Method 2506 Determination of Carbon and Nitrogen in Particulates of Estuarine/ Coastal Water Using Elemental Analysis. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2-510 The Determination of Chlorophylls A, B, & C in Marine and Freshwater Algae by Visible Spectrophotometry.Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2523 Determination of Ammonia Nitrogen by Automated Colorimetry. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2525 Total Dissolved Nitrogen and Method 2540 Total Dissolved Phosphorus Automated Colorimetric. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2526 Nitrate Plus Nitrite Nitrogen in Estuarine and Coastal Waters Low level, Automated. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2532 Carbon – Total Organic and Dissolved Organic Carbon. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2538 Phosphorus - Orthophosphate Low Level, Automated. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2539 Determination of Phosphorus in Sediments and Particulates of Estuarine/Coastal Waters. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2543 Molybdate Reactive Silica in Water and Wastewater. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

DCLS 2544 Total Suspended Solids. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2590 Determination of Inorganic Carbon in Particulates of Estuarine/ Coastal Waters Using Elemental Analysis. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

Method 2591 Determination of Inorganic Phosphorus in Sediments and Particulates of Estuarine/Coastal Waters. Commonwealth of Virginia. Department of General Services. Division of Consolidated Laboratory Services.

A. Comparability of Results

The data collected for this program must be comparable and reproducible. Therefore, sampling methods and sample analyses must be uniform and consistent among the agencies collecting and analyzing the data. This plan includes (1) a field component to assure that water quality samples are representative of river conditions and (2) a laboratory component to assess the variance, accuracy, and bias of analytical results.

The field component consists of documentation of field conditions, collection procedures, and equipment as follows:

(1) Water quality samples are collected using approved USGS guidelines to ensure the collection of samples that are representative of the river cross-section. These guidelines assure the collection of a representative, composite sample from the horizontal and vertical cross section of the river.

(2) Sampling criteria based on flow characteristics are documented for field personnel to ensure that water-quality samples are collected over a range in flow conditions. In addition, detailed recording of field procedures ensures consistency of procedures between field personnel.

(3) Proper use of sampling and monitoring equipment and sample collection techniques by field personnel is verified with in-house testing (field audits) of field procedures.

(4) Proper cleaning procedures of sampling equipment is documented through ongoing comparisons of field and equipment blanks, scheduled as in Appendix 1.

The laboratory component of this plan consists of the collection and analysis of duplicate and standard-reference samples as follows, and as scheduled in Appendix 1:

(1) Precision: Concurrent Replicate samples are used to document the variance of the analytical results. Replicate samples are prepared by collecting two concurrent samples. Both samples are then analyzed by VDCLS. The second subsample is disguised as an environmental sample by labeling it with a different time from the first subsample.

(2) Accuracy: Standard-reference samples document the ability of a laboratory to accurately analyze samples of known concentrations and to check for bias in analytical results. Standard-reference samples are prepared in the USGS laboratory and submitted to VDCLS and NWQL for analysis.

In addition to the field and laboratory components of the quality assurance plan, there is also inhouse checking of data that are received from the laboratory. All data are logged in as they arrive from VDCLS, then later are reviewed for transcription errors and corrected.

Calculations for all replicate data are also performed with the censored data equal to zero in order to define the range of variance for each constituent. Concentrations that appear to be outliers are reexamined, using the field notes to determine the presence of any unusual circumstances or hydrologic conditions. If there is no indication of anything out-of-the-ordinary, the laboratory is asked to review their records for accuracy. If necessary, data are corrected and changes are documented with the rationale and source of changes made.

B. Completeness of Sampling

A complete data set is needed to meet the objectives of the project. In particular, the suites of analyses must be comprehensive, and the sampling coverage must capture the variability of both base-flow and high-flow instantaneous loadings of the constituents. Completeness is documented by:

1. Periodic checks by the project water-quality data base manager which assess the completeness and accuracy of calculations for the analyses.

 Assessment of the number of samples collected versus the number of samples received. An ongoing list is kept to make sure that all analyses are received from VDCLS. Periodically, this list is sent to VDCLS and VDEQ, for their information and use.
Development of as complete and representative a data set as possible, covering all streamflow conditions.

4. Collection of field and quality-assurance data on a scheduled basis, with documentation of each sample as shown in Appendix 1.

C. Representativeness

The collection of water-quality samples representative of river conditions is essential. Samples therefore are collected using the USGS National Field Manual (U.S. Geological Survey, variously dated) for water-quality sampling, ensuring that water-quality conditions are represented as closely as possible.

Water-quality samples are collected monthly by VDEQ at the James River at Blue Ridge Parkway and Rivanna River stations, and by USGS (all other sites) during monthly and stormflow conditions. The USGS collects all water-quality samples using an equal-width increment (EWI) method, so that a sample representative of stream conditions is obtained. The EWI method, in which samples are collected at centroids of equal-width increments of the stream, is used most often in shallow or sandbed streams where the distribution of water discharge in the cross-section is not stable, or in streams where the distribution of discharge in the cross-section is unknown. The total number of stations sample across the stream-channel cross section depends on the total width of the channel. Channel cross sections greater than 100 feet will be sampled at 10 EWI stations. Channel cross sections less than 100 feet will be sampled at a minimum of 5 EWI stations. Samples are collected using a USGS-designed depth-integrating sampler (designation D-2, DH-95 or D-96) when average streamflow velocities exceed 1.5 ft/s, or a weighted sample bottle (WBH-96) at lower velocities when depth-integrating samplers are not effective. A depth- integrating sampler is designed to sample the vertical water column of the river proportionally to the velocity at each depth. These methods are documented by Edwards and Glysson (1988) and Ward and Harr (1990).

VDEQ collects all water-quality samples using width- and depth-integrating techniques. For further details on the VDEQ sampling protocol please refer to the "Virginia CBP Non-Tidal Network Water-Quality Monitoring Program Standard Operating Procedures Manual, July 01, 2016".

IV. SAMPLING PROCEDURES

Water-quality samples are collected according to established U.S. Geological Survey sampling protocol for nutrients and suspended solids. These methods are documented in the publications *Field methods for measurement of fluvial sediment*, by T.K. Edwards and D.G. Glysson, 1988; U.S. Geological Survey Open-File Report 86-531, in *Methods for collection and processing of surface-water and bed-material samples for physical and chemical analyses*, by J.R. Ward and Albert Harr, 1990, U.S. Geological Survey Open-File Report 90-140; and in *U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water*, by A.J. Horowitz and others, 1994, U.S. Geological Survey Open-File Report 94-539. More recently, all USGS field protocols have been summarized in a National Field Manual that is available online at: http://pubs.water.usgs.gov/twri9A

Samples are collected in a manner ensuring that they are representative of river conditions, which involves collecting horizontally and vertically integrated samples. Sampling equipment is made from non-contaminating materials, which includes epoxy-coated depth integrated samplers for collection of the nutrients and suspended solids samples. For the RIM stations, dissolved nutrient constituents (that is ammonia, nitrite, nitrate, orthophosphorus and silica) are filtered in the field using an in-line, 0.45 um Gelman capsule filter. Dissolved organic carbon is filtered in the field using an in-line, 0.45 um Gelman capsule filter and acidified with Hydrochloric acid to pH < 2. Total Phosphorus is not filtered but is acidified using Sulfuric Acid (1 mL 1:7). All other particulate constituents are collected as unfiltered samples. All RIM samples are analyzed for Chlorophyll a; the methods for field-processing Chlorophyll samples is provided in Appendix 4. All samples are stored on ice and delivered to VDCLS on the same day. For the RIM Add-on sites, whole water samples are delivered to the laboratory (field filtration is not performed). Total Phosphorus is the only sample that is acidified in the field using Sulfuric Acid (1 mL 1:7). All samples are preserved on ice and taken to VDCLS on the same day. NOTE: samples collected prior to January 15, 1994 and the RIM stations were filtered in the VDCLS laboratory; after this date, field filtering using the Gelman filter was instituted as part of the procedure at the RIM stations.)

Because of variations in flow conditions, width of each streambed, and differences in crosssectional morphology, sampling procedures between all rivers differ. Protocols were developed for each site, outlining where samples are to be taken in the cross section, what type and size of sampler to use, how samples are to be labeled, and the number of samples to collect, in order to ensure that all personnel responsible for sampling use the correct procedures.

Field parameters (pH, specific conductance, dissolved oxygen, turbidity, and water temperature) are collected at 5 stations across the cross section at each monitoring station. Monitoring stations that utilize 10 EWI sampling stations, field parameters will be collected at every other station. Monitoring stations that utilize 5 EWI sampling stations, field parameters will be collected at every station.

V. SAMPLE CUSTODY

Samples are collected in plastic "cubitainers", labeled using a VADEO tag, immediately put on ice and transported to the VDCLS laboratory. Hydrochloric acid and sulfuric acid are used to preserve the dissolved organic carbon and total phosphorus samples, respectively. At those times when it is impossible to take samples to the laboratory, samples are refrigerated at 4° C and taken to the laboratory as soon as possible. A Virginia Water Science Center field form is completed and kept on file in the Virginia Water Science Center as a record of the samples collected, to check for final completeness of the analyses, and to record field measurements, date and time of collection, and any unusual conditions. Associated field data are entered into and sample analyses are scheduled using the VADEO Comprehensive Environmental Data System (CEDS). Suspended-sediment samples for 5 monitoring stations (Rappahannock River at Fredericksburg, Mattaponi River near Beulahville, Pamunkey River at Hanover, James River at Cartersville, and Appomattox River at Matoaca) are analyzed by the USGS Sediment Lab in Louisville, Kentucky, samples for RIM stations are collected from the churn which is a composite of all of the cross-section EWI stations. This sediment sample is collected from the churn splitter using a 1-pint glass bottle, labeled and sent to the USGS sediment laboratory in Louisville, Kentucky. No preservation is necessary for suspendedsediment samples.

VI. CALIBRATION PROCEDURES AND FREQUENCY

Field parameters (pH, Specific Conductance, Water Temperature, Turbidity, and Dissolved Oxygen) are calibrated in the field using a YSI 6920 multi-parameter instrument before field data are collected. The YSI-6920 is calibrated at the beginning of each sampling day using traceable standards. Specific Conductance is calibrated using a 1,000 μ S/cm standard and checked using a 250 and 50 μ S/cm (RICCA standards). pH is calibrated using a 3-point calibration at 7, 10, and 4 pH levels (RICCA standards). Dissolved oxygen is calibrated to 100% saturation in saturated-air. Turbidity is calibrated to 1,000, 100, (using StabCal formazine standards) and 0 (using deionized water). Water temperature is checked quarterly using a water bath at 0, 15, 25, 30, and 40 degrees Celsius. Thermistors are recalibrated if the mean difference between the 5 checked temps. is greater than +/- 0.5 deg C. The USGS standard protocols that govern the use and calibration of continuous water-quality monitoring equipment can be found in Wagner and others, 2006; Chapter 6 of the USGS National Field Manual (http://water.usgs.gov/owq/FieldManual/index.html).

Calibration of laboratory equipment at VDCLS is documented in the publications entitled *Quality Assurance Plan for the Virginia Division of Consolidated Laboratory Services*, 1982, and *Quality Assurance Practices for the Chemical and Biological Analyses of Water and Fluvial Sediments*, by F.C. Friedman and D.E. Erdmann, Washington, U.S. Govt. Print. Off., 1982.

Calibration of the laboratory equipment at the USGS sediment lab in Louisville, KY is documented in the publication entitled *Quality-Assurance Plan for the Analysis of Fluvial Sediment by the Northeastern Region, Kentucky District Sediment Laboratory*, E.A. Shreve and A.C. Downs: Open-file report 05-1230, Louisville, Kentucky 2005.

VII. ANALYTICAL PROCEDURES

The majority of samples collected are analyzed by VDCLS. The only samples not analyzed by VDCLS are suspended-sediment samples collected at Rappahannock River at Fredericksburg, Mattaponi River near Beulahville, Pamunkey River at Hanover, James River at Cartersville, and Appomattox River at Matoaca. The sediment samples collected from these 5 stations are analyzed by the USGS Sediment Lab in Louisville, Kentucky.

Samples collected prior to January15, 1994 were filtered and analyzed by VDCLS under criteria established by Clesceri, Greenberg, and Trussell (1989) and the USEPA Environmental Monitoring and Support Laboratory (1983). Beginning January 15, 1994, samples have been filtered in the field using procedures established by Horowitz and others (1994) before being delivered to the laboratory for analysis.

Requirements set by the USEPA for regulatory laboratories state that nutrient samples be filtered within 24 hours and suspended-solids determinations be performed within 7 days. Samples collected on weekends are chilled to 4°C and held until they can be accepted by VDCLS the following week.

In some instances, the analytical method for certain constituents differs for the total constituent and the dissolved constituent. For each analytical method there is a range within which the actual concentration is expected, so that it is possible for the analytical result of the total concentration of a particular constituent to be less than that of the dissolved concentration for that constituent. Minimum reported concentrations may differ according to the detection limit, depending on the specific technique done by the laboratory. VDCLS has Standard Operating Procedures (SOP) for each laboratory analyte. The reference for each laboratory analyte SOP can be found in Section III (QA Objectives and Criteria).

The concentration of total nitrogen for this project is computed as the sum of particulate nitrogen and dissolved nitrogen for VDCLS samples and as the sum of dissolved nitrite-plus-nitrate nitrogen concentration and total ammonia-plus-organic (Kjeldahl) nitrogen concentration. Prior to February 1996, total nitrogen was computed as the sum of dissolved nitrite-plus-nitrate nitrogen concentration and total Kjeldahl nitrogen concentration for VDCLS samples. At six stations total phosphorus is both directly determined and computed as the sum of total dissolved phosphorus and particulate phosphorus. These stations are: Rappahannock River at Fredericksburg, Mattaponi River near Beulahville, Pamunkey River at Hanover, James River at Cartersville, James River at Richmond, and Appomattox River at Matoaca. At all other stations, total phosphorous is directly measured.

VIII. DATA REDUCTION, VALIDATION, AND REPORTING

Samples are collected, preserved and transported according to accepted SOP methods to DCLS Central Receiving by the USGS. Central Receiving (DCLS) personnel log in samples and distribute them to the appropriate laboratory for analysis. After analysis, the data results are transformed into the correct concentration units, keyed into the LIMS system (Laboratory Information Management System) by the chemist completing the analysis and reviewed by the appropriate laboratory personnel. Upon approval the results are shipped back to VADEQ via FDT transfer and entered into the CEDS2000 database. In the event data sheets are utilized to submit the samples to DCLS (e.g. due to a CEDS/WQM system failure) the results are printed out onto laboratory sheets and given to the VADEQ Laboratory Liaison. Results returned on paper are keyed into the CEDS2000 system by personnel in the Water Division and forwarded to the appropriate region or the Central office project manager.

Data go through a series of screens and reviews to identify invalid, qualified or QA supported data by both DEQ and USGS personnel. The qualified and QA supported data are then entered into the QWDATA water-quality data base.

The USGS Virginia Water Science Center field sheet that details field conditions and field parameter values is completed for each sampling trip and kept in the USGS Office along with a copy of the analytical services request forms. The field parameter values are entered into the Virginia Water Science Center QWDATA water-quality data base at the office.

Water-quality analyses performed are stored on the USGS Virginia Water Science Center QWDATA water-quality data base. Raw data are published in the USGS Annual Report for Virginia. The appropriate data originator is notified of errors so that the source data bases can be corrected and thus remain consistent with all others.

IX. INTERNAL QC CHECKS

A. Field

The quality assurance practices of field procedures include documentation of cross-section, depth-integrated variability; quality assurance of field personnel; documentation of field sampling status; and collection of field, equipment, and laboratory blanks. These practices are described in greater detail in Section III.

B. Laboratory

<u>VDCLS</u>--The quality assurance practices of VDCLS including quality control, quality assurance of analytical results, quality assurance of all materials used in the preservation and containment of water-quality samples, and the blind- reference sample quality assurance program, are documented in *Quality Assurance Plan for the Virginia Division of Consolidated Laboratory Services.* In each laboratory analyte SOP (see section III QA Objectives and Criteria), there is a quality control section that addresses a) assessing laboratory performance, and b) assessing analyte recovery and data quality. Most analytical procedures used are referenced in *Chemical Analysis for Water and Wastes:* USEPA-600/4-79-020, Environmental Protection Agency, 1983, and *Standard Methods for the Examination of Water and Wastewater* (21st ed).

<u>USGS Sediment Laboratory in Kentucky</u> -- The quality assurance practices of the USGS sediment lab are documented in the Open-File report entitled *Quality-Assurance Plan for the Analysis of Fluvial Sediment by the Northeastern Region, Kentucky District Sediment Laboratory*, OFR 05-1230, by E.A. Shreve and A.C. Downs, 2005. Included in this publication are: analytical methods development procedures; standard quantitative analysis techniques; instrumental techniques; laboratory quality control; quality assurance monitoring; documentation, summary, and evaluation of data; and material evaluation.

VDCLS participates in a nation-wide Standard-Reference Sample (SRS) quality-assurance program for nutrients and sediment. This program was designed to evaluate the performance of each participating laboratory as well as monitor long-term trends in the bias and accuracy of analytical methodologies. Samples are prepared at the NWQL, Denver, CO. Samples are prepared by the USGS Branch of Quality Assurance from which they are subsequently distributed to laboratories across the country. Results are published twice yearly and distributed to each participating laboratory and USGS Offices in each state. Furthermore, DCLS participates in both the Chesapeake Bay Program Coordinated Split Sample Program and the Chesapeake Bay Program.

X. PERFORMANCE AND SYSTEM AUDITS

Project reviews are conducted semi-annually by USGS staff, and periodically by the USGS Center Water-Quality Specialist. USGS technical reviews are conducted periodically at the request of the principal investigator.

A Water Science Center Water-Quality Review is held every three years by the USGS Regional Water-Quality Specialist, representatives of the USGS Office of Water Quality, and experienced scientists and technicians from across the Bureau. Field methods are observed for consistency with national USGS procedures, and the Center water-quality data base is examined for agreement between laboratory and field data.

The project officer and other staff from VDEQ are kept informed of the status of the project on a quarterly basis by the development of a quarterly report detailing the number of samples collected per site and any problems associated with sampling or analysis.

VDCLS and the USGS Kentucky Sediment Laboratory participate in the Standard-Reference Sample quality-assurance program that analyzes the laboratory's performance as described previously.

XI. PREVENTIVE MAINTENANCE

Preventive maintenance of field instruments is done on a routine basis to ensure that the instruments remain in good working order. All potentially fragile electrodes and cells are stored in such a manner as to prevent breakage. Additionally, they are kept clean and free from any build-up that may affect their performance; rejuvenation of electrodes is performed periodically. All field meters and calibration standards are removed from vehicles and brought indoors after use to avoid mechanical or electronic problems caused by extremes in temperature. Batteries are changed and/or units recharged regularly.

All field instruments are calibrated prior to use, as described in Section VI, Calibration Procedures and Frequency. If an instrument is not in good working order, spare instruments are readily available so that there is no interference with field operations. Instruments in need of repair are repaired in a timely manner.

XII. ASSESSMENT OF DATA VARIABILITY, BIAS, ACCURACY, REPRESENTATIVE- NESS, AND COMPLETENESS

Assessment of data variability and bias for the Virginia River Input Monitoring Program consists of collecting and analyzing duplicate and blank samples. The purpose of these quality assurance practices is to quantify the variability of results from VDCLS, the major laboratory that provides analyses for this study, and to check for bias at VDCLS.

Between 5 and 10 percent of the samples collected at each monitoring site are collected as duplicate samples. For each duplicate sampling, two unmarked duplicate samples labeled five minutes apart will be collected from concurrent replicate samples (that is, 2 separate churn splitters that were filled during a single pass across the bridge) and sent to VDCLS for the purpose of checking the variability associated with both the sample collection and the laboratory.

Field blanks analyzed by VDCLS are used to verify that clean sampling techniques are used by field personnel. Field blanks are collected by processing an analyte-free water through sampling equipment (sample bottle, churn splitter, tubing, filtration units, and sample bottles) at the field site.

Periodically, standard-reference samples are submitted to VDCLS and the USGS Kentucky Sediment Laboratory in order to check analytical results against a known standard. This allows for determination of the accuracy of each laboratory and the presence of any bias. Sources of reference samples may be either the Environmental Protection Agency or a commercial laboratory.

Completeness is assessed by comparing the number of base flow and stormflow samples completed with those scheduled. The reasons for any discrepancies are well documented.

XIII. CORRECTIVE ACTION FOR OUT-OF-CONTROL SITUATIONS

Out-of-control situations may occur in the field or in the laboratory as a result of equipment breakdown, despite careful planning and attention to procedures.

The primary methods for correcting out-of-control situations in the field are (1) repairing, recalibrating, or adjusting the malfunctioning instruments; or (2) substituting an alternative piece of equipment. Notes are made in the field log books and on the sampling field sheet when out-of-control situations occur. In most instances, no data are lost due to malfunctioning field equipment.

Potential out-of-control situations occurring in the laboratory may be identified by determining constituent concentrations that do not follow established concentration/discharge patterns or that seem out of range. The primary method of correcting out-of-control situations at VDCLS is to first re-examine the paperwork for clerical or translation errors, such as an incorrect date or station. The next step would be to examine the field paperwork to look for any written observations of problems at the site. Finally, if the source of the questionable value could not be discerned, the next step is to contact the laboratory to ask for confirmation of that concentration

and to ask for any bench observations that might influence the sample concentrations. Based on the result of any of these steps, any mismatched site information and data would be corrected if possible. No data are ever changed unless there is a logical, fact-based reason for doing so. Any changes and the rationale for the changes are clearly documented on the Field Sheet and initialed by the Project Chief or a senior project person.

XIV. QA REPORTING PROCEDURES

All samples collected will be analyzed at VDCLS in Richmond, VA. VDCLS performance will be evaluated through the use of duplicate and standard-reference samples. Results of the laboratory's performance will be evaluated annually.

Selected References

- Clesceri, L.S., Greenberg, A.E., and Trussell, R.R., eds., 2005, Standard methods for the examination and treatment of water and wastewater (21st ed.), Washington, D.C.
- Chanat, J.G., Moyer, D.L., Blomquist, J.D., Hyer, K.E., and Langland, M.J., 2015, Application of a Weighted Regression Model for Reporting Nutrient and Sediment Concentrations, Fluxes, and Trends in Concentration and Flux for the Chesapeake Bay Nontidal Water-Quality Monitoring Network, Results Through Water Year 2012: U.S. Geological Survey Scientific Investigations Report 2015–5133, 76 p., accessed January 14, 2015 at http://pubs.er.usgs.gov/publication/sir20155133/.
- Edwards, T.K., and Glysson, D.G., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86-531, 118 p.
- Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments, U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 703 p.
- Helsel, D.R., and Cohn, T.A., 1988, Estimation of descriptive statistics for multiply censored water quality data: Water Resources Research, v. 24, no. 12, p. 1997-2004.
- Hirsch, R.M., Moyer, D.L., and Archfield, S.A., 2010, Weighted Regressions on Time, Discharge, and Season (WRTDS), with an Application to Chesapeake Bay River Inputs: Journal of the American Water Resources Association, V. 46, no. 5, 5 p.
- Horowitz, A.J., C.R. Demas, K.K. Fitzgerald, T.L. Miller, and D.A. Rickert, 1994, U.S. Geological Survey protocol for the collection and processing of surface-water samples for the subsequent determination of inorganic constituents in filtered water: U.S. Geological Survey Open-File Report 94-539, 57 p.
- Langland, M.J., Blomquist, J.D., Sprague, L.A., and Edwards, R.E., 1999, Trends and status of flow, nutrients, and sediment for selected nontidal sites in the Chesapeake Bay Watershed, 1985-98: U.S. Geological Survey Open-File Report 99-451, 64 p.
- Pettyjohn, W.A., and Henning, R., 1979, Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio: The Ohio State University Department of Geology and Mineralogy Completion Report No. 522, 323 p.
- Shreve, E.A., and Downs, A.C., 2005, Quality-assurance plan for the analysis of fluvial sediment by northeastern region, Kentucky district sediment laboratory: U.S. Geological Survey Open-File Report 2005-1230.
- U.S. Geological Survey, 2014, Water-resources data for the United States, Water Year 2013: U.S. Geological Survey Water-Data Report WDR-US-2013.
- U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A10, available online at http://pubs.water.usgs.gov/twri9A.
- Wagner, R.J., Boulger, R.W., Jr., Oblinger, C.J., and Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1-D3, 51 p. + 8 attachments; accessed April 10, 2006 at http://pubs.water.usgs.gov/tm1d3.

- Ward, J.R., and Harr, Albert, 1990, Methods for collection and processing of surface-water and bedmaterial samples for physical and chemical analyses: U.S. Geological Survey Open-File Report 90-140, 71 p.
- White, K.E., and Sloto, R.A., 1990, Base-flow-frequency characteristics of selected Pennsylvania streams: U.S. Geological Survey Water Resources Investigation Report 90-4160, 67 p.

APPENDIX 1 -- EXAMPLE OF FIELD DATA RECORD

	F B L N K	S M L 0 1	S M L 0 2	S M L 0 3	C O N R E P	S M L 0 4	S M L 0 5	S M L 0 6	C O N R E P	S M L 0 7	S M P L 0 8	S M L 0 9	F B L N K	S M L 1 0	S M L 1	S M L 1 2	S M L 1 3	S M L 1 4	S M L 1 5	C O N R E P	S M L 1 6	S M L 1 7	S M L 1 8	S M L 1 9	C O N E P	S M L 2 0
Gage Height																										
Sample Date																										
Routine Sample																										
Storm Impacted																										
Gage Insp																										
Personnel																										

Water-Quality Sampling Schedule for Station 01634000 -- NF Shenandoah River, 7-1-2006 to 6-30-2007

FBLNK = Field Blank

CONREP = Concurrent Replicate
APPENDIX 2 -- VIRGINIA DISTRICT OFFICE RIVER INPUT MONITORING FIELD SHEET



U. S. GEOLOGICAL SURVEY SURFACE-WATER QUALITY NOTES

		NOR	6 RECORD NO		NWIS C	A REC #(DB 2)		
STATION NO .:	STATION NO .: SAMPLE DATE/ MEAN_SAMPLE TIME (CLOCK)							
STATION NAME: PURPOSE OF SITE VISIT (50280) TIME DATUM: EST EDT UTC_OTHER						TME DATUM: EST EDT UTC OTHER		
PROJECT NO. GC16LM009QE1000 PROJECT NAME: Fall Line Monitoring HYDRO EVENTHYDRO COND								
SAMPLING TEAM				TEAM LEAD SIGN	IATURE	DATE//		
Time: Label VA DCLS replicates 15 minutes past regular samples, KY sediment lab splits 5 minutes past regular samples, and blanks 5 minutes before regular samples. ANALY SIS SOURCE Sample Type: If a replicate or a lab split is collected, label both regular and replicate /lab split 7. G USGS Field & non-USGS Lab If a blank is collected, label the blank Sample Type 2 and the regular sample Sample Type 9. J USGS Lab & Field								
Sample Type	Time	Medium	Sample Type	Dupl. Type 99105	Analyzing Lat 00028	SAMPLES COLLECTED		
Regular		WS			85116	NUTRIENTS		
Replicate		wsq	7	30 (split)	85116	SUSP. SED CONC. S/F		
Lab Split		wsq	7	200 (lab-split)	80020	TPLL HTIT2		
Blank		OAQ	2		85116/80020	CHLOROPHYLL mL		
Reference		OAQ	б		85116/80020	DOC drops HCladded		
Other								
0			Fit	110 MEASUREMENTS				
GAGE HT (UUUKO)	·	_π	COND (UUUS) _	µS <i>i</i> cm	@ 29 *C	GAGE HEIGHT READINGS:		
.Dis Oxigen (00	300) <u>mg/L</u>		TEMP, AIR (0002	0) <u> </u>		@		
BARO METRIC PIRE	s. (0002)mm	Hg	TEMP, WATER (O	0010) <u> </u>		SOURCE:		
						DTHER:(REASON:		
TURBIDITY (6363)))FNU		pH (00400)	UNITS	-			
			SAk	IPLING INFORMATION				
Sampler Type (8	<mark>4164) 9</mark>	SamplerID	Sa	mple Compositor/Splitt	er. plastic te f u	ON CHURN CONE CHURN D		
Sampler Bottle/Ba	g Material: plastic te	FLON OTHER	Noz	zie Material: PLASTIC	TEFLON OTHER	Nozzle Size: 3/16" 1/4" 5/16"		
Stream Width :	ft mi Left Bank	Rig	ht Bank Me	an Depth:ft lo	e Cover%	Ave.lce Thicknessin.		
Sampling Points:								
Sampling Location	n: Wading Cableway	BOAT BRI	DGE UPSTREAM	DOWNSTREAM SIDE OF BR	NDGEft	mi above below gage		
Sampling Site: PO	DOL RIFFLE OPEN CHA	NNEL BRAIDED	BACKWATER Botton	NI: BEDROCK ROCK COM	BLE GRAVEL SAND) SILT CONCRETE OTHER		
Stream Color: BR	IOWN GREEN BLUE GRV	AY CLEAR OT	HER \$	Minearm Milixing: WELL-MC	XED STRATIFIED PO	DORLY-MIXED UNKNOWN OTHER		
Weather: sky- cli	EAR PARTLYCLOUDY CL	OUDY PRECIP	- Light Medium Hea	WY SNOW RAIN MIST	WIND-CALM LIGHT E	Reeze Gusty Windy est. Wind Speed		
TEMP- VERY COLD Sampling Method	о имямо нот Stage : s I (82398): EWI [10] EDI [TABLE, NORMA <mark>20] SINGLE VI</mark>	L STABLE, HIGH RISIN ERTICAL [30] MULT	ig Falling Peak Fvertical [40] othe <mark>f</mark>	<u> </u>			
			OF OVER 1			DATE.		
COMPLED BT:				н.		UNIC.		

STATION ID: _____

MULTIPARAMETER UNIT						
Meter Make/Modek		Meter SN:	Sonde Make/Model:	Sonde SN:	_	
Notes:						
		INDIVIE	UAL METERS			
		INDIVIE (IF MULTIPARA)	UAL METERS METER UNIT NOT USED)			
	рН М	INDIVIE (IF MULTIPARA) Meter Make/Model	UAL METERS METER UNIT NOT USED) Meter SN:			
	pH M DO M	INDIVIE (IF MULTIPARA) Meter Make/Model: Meter Make/Model:	DUAL METERS METER UNIT NOT USED) Meter SN: Meter SN:			
	pH M DO M SC M	INDIVIE (IF MULTIPARA) Meter Make/Model: Meter Make/Model: Meter Make/Model:	DUAL METERS METER UNIT NOT USED) Meter SN: Meter SN: Meter SN:			
	pH N DO N SC N Turbidity N	INDIVIE (IF MULTIPARA) Meter Make/Model: Meter Make/Model: Meter Make/Model: Meter Make/Model:	DUAL METERS METER UNIT NOT USED) Meter SN: Meter SN: Meter SN: Meter SN:			
	pH N DO N SC N Turbidity N	INDIVIE (IF MULTIPARA) Meter Make/Modek Meter Make/Modek Meter Make/Modek Meter Make/Modek Meter Make/Modek	DUAL METERS METER UNIT NOT USED) Meter SN: Meter SN:			

pH Calibration

pH BUFFER	BUFFER TEMP	THEO- RETICAL pHFROM TABLE	pH BEF ORE ADJ	pH AFTER ADJ	BUFFER LOT NO.	BUFFER EXPIRA- TION DATE	COMMENT S
pH 7							
pH 10							
pH 4							

Specific Conductance Calibration

STD VAL- UE	STD TEMP	SC BEF ORE ADJ	SC AFTER ADJ	STD LOT NO	STD EXPIRATION DATE	COMMENT S

Dissolved Oxygen Calibration

WATER TEMP °C	BAR OMETRIC PRES- SURE mm Hg	DO TABLE READ- ING mg/L	DO BEFORE ADJ. % mg/L		DO AFTER ADJ % mg/L		DO Charge

NOTES:

STD VAL- JE	STD TEMP	TURB. BEF ORE ADJ.	TURB AFTER ADJ	STD LOT NO	STD EXPIRATION DATE	COMMENT S

				CF	IOSS SECT	ON NOTES					
STATION	ft from left bank (00009) or ft from right bank (72103)	TIME	depth ft (81903)	00 mg/L (00300)	DO SAT % (00301)	pH units (00400)	Sc µS/cm (00099)	темр °C (00010)	TURBIDITY NTU 0	GAGEHT ft (00065)	SUB Q , (INST) cfs (00061)
Median											

LOT NUMBERS
PRESERVATIVES 4.5N H2SO4 (FOR NUTRIENTS&DOC)
BLANK WATER INDEGANIC (99200)
COMMENTS

STATION ID

FIELD NOTES

REFERENCE LIST FOR CODES USED ON THIS FORM

Sample Medium Codes

9 Surface water

R Quality-control sample (associated environmental sample -9 (SW)) Q Blanks

Sample Type Code Null-value Qualifiers

- 9 Regular e required equipment not functional or available
 - Replicate
- 7 2 1 Blank Spike

8010 Other

f sample discarded; improper filter used o insufficient amount of water

84164 SAMPLER TYPE

100	Van Dom Sampler
110	Sewage Sampler
125	Kemmerer Bottle
3039	US D-77 Tm
3040	US D-77 Tm Modified Teflon Bag Sampler
3044	US DH-81
3045	US DH-81 With Tetlon Cap And Nozzle
3046	Sampler, D-77 Tm, W/Reynolds Oven Collapsible Bag
3047	Sampler, Frame-Type, Plastic Bottle IW/Reynolds Oven Bag
3048	Sampler, Frame-Type, Teflon Bottle
3049	Sampler, Frame-Type, Plastic Bottle
3050	Sampler, Frame-Type, Plastic Bottle IVI/Teflon Collapsible Bag
3051	US DH-95 Tefion Bottle
3052	US DH-95 Plastic Bottle
3053	US D-95 Teflon Bottle
3054	US D-95 Plastic Bottle
3055	US D-96 Bag Sampler
3058	US DH-2 Bag Sampler
3060	Weighted-Bottle Sampler
3061	US WBH-96 Weighted-Bottle Sampler
3070	Grab Sample
3080	VOC Hand Sampler
4010	Thief Sampler
4115	Sampler, point, automatic
8000	None

Time Datum C	odes			
	Std	UTC	Daylight	UTC
	Time	Offset	Time	Offset
Time Zone	Code	(hours)	Code	(hours)
Eastern	EST	-5	EDT	-4
Atlantic	AST	-4	ADT	-3

ALKALINITY/ANC PARAMETER	82398 9	SAMPLING METHOD
CODES	10	Equal Width Increment (Ewi)
39086 Alkalinity, water, filtered, incremental titration, mg/L 00410 ANC, water, unfiltered, incremental titration, mg/L 29802 Alkalinity, water, filtered, Gran titration, mg/L 29813 ANC, water, unfiltered, Gran titration, mg/L	25 30 40 50 70 80 90 120	Equal Discharge Increment (Edi) Timed Samping Interval Single Vertical Multiple Verticals Point Sample Grab Sample (Dip) Discharge Integrated, Equal Transit Rate (Etr) Discharge Integrated, Centroid Velocity Integrated
	8010	Other Grab Sample At Water-Supply Tap
HYROLOGIC CONDITION A Not determined 4 Stable, low stage 5 Falling stage	50260	PURPOSE OF SITE VISIT
6 Stable high stage 7 Peak stage 8 Rising stage 9 Stable normalstage	1001 1002 1003 1004 1005 1006	Fixed mequency, surface-water Stom hydrograph, surface-water Extreme high flow, surface-water Extreme low flow, surface-water Diumal, surface-water Synoptic, surface-water
HYDR OLOGIC EVENT J Storm 9 Routine	1099	Other, surface-water THINK TWICE. WORK SAFE.



SAFETY FIRST - EVERY JOB - EVERY TIME

Appendix 3: Chlorophyll Collection and Processing for Fall Line Stations

- Standard collection procedures are followed, ensuring ample volume for sediment, nutrient, and chlorophyll samples. (approx. 5 liters sample needed)
- After drawing sediment sample, draw 500mL sample into amber bottle for chlorophyll filtration and set aside.
- Complete nutrient samples, raw and filtered.
- Assemble filter apparatus
 - Filter flask
 - Magnetic base and cup
 - \circ Hand vacuum pump
- Apply filter to base, attach cup, moisten filter with DI
- Gently agitate sample
- Measure 100mL sample in graduated cylinder and pour into cup
- Add 10 drops (1mL) Magnesium Carbonate solution to sample cup
- Apply vacuum and filter sample (vacuum not to exceed 15 cm/Hg, 6 in/Hg)
- When sample is filtered, remove cup. Using forceps remove filter and fold in half with particulate material inside
- Place inside foil sheet
- Repeat filtration three times, placing all filters in same foil sheet and ensuring they are separated within
- Wrap in larger foil sheet and place label on foil ensuring the number of filters and volume filtered through each is noted on the label
- Place in whirl-pac or Ziploc and put on ice until delivery
- Clean all equipment with liquinox and rinse well with tap and DI

APPENDIX 4 -- Quality Assurance Project Plan: Enhanced sediment collection for improving continuous sediment simulations, December 2005

QUALITY ASSURANCE PROJECT PLAN

Enhanced Sediment Collection for Improving Continuous Sediment Simulations

Prepared By:

Douglas L Moyer Kenneth E Hyer US Geological Survey Virginia Water Science Center 1730 E. Parham Road Richmond, VA 23228

December 2005

TABLE OF CONTENTS

Introduction and Project Description	Page 3
Objectives	4
Project Organization and Responsibility	4
Study Design	4
Continuous Water-Quality Monitoring Protocols	6
Discrete Water-quality Sampling Protocols	7
Data Analysis and Measures of Success	8
Schedule	9
References	10
List of Tables 1. Project Organization and Responsibility	4
2. Project Schedule, based on USGS Fiscal Years	9
List of Figures 1. Correlation of turbidity and suspended sediment on the James River	6

Introduction and Project Description

Elevated suspended sediment levels are causing an adverse impact on the living resources and associated aquatic habitat of streams, rivers, and estuaries. These elevated suspended sediment levels may impair the growth of aquatic vegetation through reduced light levels, bury filter feeding organisms, reduce the habitat available for macroinvertebrates, and contribute to decreased fish populations. These elevated sediment levels also may be playing an important role in the transport of particle- associated contaminants, such as phosphorus and bacteria (Christensen, 2001).

The Chesapeake Bay, the Nation's largest estuary, also has been degraded through waterquality problems, loss of habitat, and over-harvesting of living resources. Excess sediment is having an adverse effect on the living resources and associated habitat of the Chesapeake Bay and its watershed. Because of excess nutrient and sediment levels, the Chesapeake Bay was listed as an impaired water body in 2000 under the Clean Water Act. The Bay must meet regulatory water-quality standards by 2010, and the CBP needs information with which to evaluate current conditions and progress towards meeting sediment-reduction measures.

In most streams, the majority of suspended sediments are transported during stormflow periods (Wolman and Miller, 1960), the very time when the fewest data are generally collected. Although manual sampling of suspended sediment concentrations will produce an accurate series of point-in-time measurements, robust extrapolation to the many unmeasured periods (especially high-flow periods) has proven difficult because of the inherently complex nature of suspended sediment transport. Suspended sediment transport during storm events is extremely variable and it is difficult to relate a unique concentration to a given stream discharge. In one study, Christensen and others (2002) identified that only 50% of their eight study stations actually had significant correlations between suspended sediment and stream discharge. With the current limitations for predicting suspended sediment levels, innovative approaches for generating detailed records of suspended sediment concentrations are needed.

One promising new technology for improved suspended sediment determination involves the continuous monitoring of turbidity as a surrogate for suspended sediment Turbidity measurements are well correlated to suspended sediment concentrations. concentrations because turbidity represents an optical measure of water clarity and it is the presence of suspended sediments that directly influences this measurement of clarity. Using turbidity values as a surrogate for calculating suspended sediment concentrations is not new, but until recently, technological limitations have made this approach largely As early as 1977, Walling described this surrogate approach using unreasonable. turbidity and demonstrated a sharp reduction in suspended sediment prediction error using a turbidity-sediment relationship relative to a discharge-sediment approach. In the earlier-mentioned study by Christensen and others (2002) that demonstrated poor correlation between suspended sediment concentrations and discharge, 100% of their research stations demonstrated significant correlations between suspended sediment concentrations and turbidity measurements. The development of continuous turbidity records to calculate suspended sediment concentrations is now inherently more feasible because of technical improvements to in-situ water-quality sensors and improved Continuous turbidity measurement has now become a more telecommunications.

common field approach because it provides significantly more detailed and more accurate information on suspended sediment concentrations and loadings than was previously possible (Christensen and others, 2000; Christensen, 2001).

Objectives

This project will address the following objectives:

- (a) Evaluate the use of continuous turbidity sensors as a surrogate for predicting suspended sediment concentrations, and calculating suspended sediment loads;
- (b) Compare turbidity-derived suspended sediment loadings to loadings generated through classical approaches that rely on a relationship between flow and sediment (the ESTIMATOR model, for example).
- (c) Evaluate which approach provides the most detailed and accurate suspended sediment data that can be incorporated into the various water-quality models of the Chesapeake Bay Watershed;
- (d) Determine whether the turbidity-sediment surrogate approach is sufficiently robust over time that it results in reduced water-quality monitoring costs.

Project Organization and Responsibility

Personnel and Affiliation	Position	Responsibility	Contact
Doug Moyer, USGS	Hydrologist	Project Manager,	804-261-2634
		Data analysis,	dlmoyer@usgs.gov
		Sample Collection	
Ken Hyer, USGS	Hydrologist	Project Manager,	804-261-2636
		Data Analysis,	kenhyer@usgs.gov
		Sample collection	
Brian Hasty, USGS	Hydrologic	Monitor	Contact
	Technician	Maintenance	Project Managers
Amy Jensen, USGS	Hydrologic	Discrete Water-	Contact
-	Technician	Quality Sampling	Project Managers

Table 1. Project organization and responsibility

Study Design

Continuously monitoring turbidity probes will be installed at 3 of the River Input Monitoring (RIM) or Non-tidal Network Monitoring stations; these established stations are currently monitored by the USGS for the Chesapeake Bay Program, and comprise the 9 major non-tidal rivers that drain into the Chesapeake Bay. The most likely stations to be instrumented with continuous turbidity probes include the Potomac River, the Rappahannock River (USGS Station Number 01668000), and the James River (02035000); the specific site for continuous monitoring in the Potomac River Basin has yet to be identified. These three basins have been selected for this study because they are all major sediment-contributors to the Bay. Intensive manual sediment monitoring also will be performed during a broad range of flow conditions (including low-flow, intermediate-flow, and storm-flow conditions) to provide up to 45 paired measurements of suspended sediment concentrations and associated turbidity values. The intensive sediment sampling must be performed over the entire range of hydrologic conditions (including extremely high flows) because it is during storm-flow periods that the majority of sediments are transported. All sediment samples will be collected following the standard USGS protocols for suspended sediment sampling and representative sampling (USGS, 1998).

Locating the turbidity monitors at existing RIM stations provides several direct benefits to the study. As the team that manages the RIM project for all Virginia stations, we will integrate the current proposed study into the existing RIM program. By doing this, the proposed study will benefit from the historical body of data that has been collected at these stations, and the existing understanding of these systems. Additionally, by co-locating the turbidity probes with an established RIM station, we can use the existing telemetry equipment to provide nearly free real-time transfer and internet display of the turbidity data. Lastly, ongoing sediment and nutrient sampling at the RIM stations will defray many of the costs that would have been associated with sampling and maintaining equipment at any other location. For example, many of the costs associated with travel, sampling, laboratory costs, and salary required by the proposed study will be paid for as part of the RIM project.

The following approach will be used at each monitoring station to calculate suspended sediment concentrations and loads on the basis of measured turbidity values:

- Continuously recording turbidity meters will be installed at each stream gage. The turbidity meter must be installed in a location within the cross section that is representative. Upon installation, the meter will be connected to telemetry equipment that communicates the sensor data back to a central office location. Through this telemetry, the data can be observed and reviewed in "real time".
- During the first year of the study, manual samples will be collected over a large range of flow conditions and analyzed for suspended sediment concentrations.
- Site-specific regression equations will be developed to relate turbidity values and suspended sediment concentrations over this large range of flow conditions.
- The site-specific regression equations will be used to predict continuous suspended sediment concentrations from the continuous turbidity data. Using the unexplained variance from the regression equation we can quantify the uncertainty in the suspended sediment predictions.
- The continuous suspended sediment concentrations and the continuous discharge record will then be used to predict continuous sediment loadings from each river to the Chesapeake Bay. These predicted sediment loadings will be compared to sediment load estimates from other existing methods (e.g. ESTIMATOR).

Differences between the methodologies will be documented and evaluated. This approach is completely analogous to the standard methods for developing a continuous record of discharge in which stream stage (water level) is recorded over time, a rating curve is developed for the station, and the rating curve is then used to calculate discharge from the stream stage. A one-year pilot deployment of a turbidity probe on the James River during 2004 demonstrates a statistically significant correlation (p<0.01) between turbidity and suspended sediment concentrations (Figure 1).



Figure 1. Relation between turbidity and suspended sediment on the James River at Cartersville, VA, 2004.

Continuous water-quality monitoring protocols

All continuous water-quality monitoring operations in the USGS are to be performed according to the USGS standard methods for the operation of this equipment. These standard operating procedures have been thoroughly documented by Wagner and others (2000) in their Water-Resources Investigations Report entitled: Guidelines and Standard Procedures For continuous Water-quality Monitors: Site Selection, Field Operation, Calibration, Record Computation, and Reporting. Because these published USGS Standard Operating Procedures (SOP) will be followed during this study, only a summary of these procedures will be outlined below and an internet link to the full SOP Manual is provided in the references section.

The continuous water-quality monitor (likely a YSI Model 6920 multi-parameter monitor) will be deployed at three of the existing River Input Monitoring Stations and configured to measure water temperature, turbidity, specific conductance, and pH at 15-minute intervals (this interval is commonly referred to as producing continuous data). The instrument will be connected to data logging and telemetry equipment that will

transfer all data to the USGS office in Richmond, VA, where the data will be displayed on the internet for access by all interested individuals. Following the initial deployment, approximately monthly maintenance visits will be performed on the continuous waterquality monitor to clean the equipment and check the calibration of the sensors. In-field recalibration will be performed during these monthly maintenance visits as necessary (following the equipment tolerances as specified by the monitor manufacturer and those outlined by Wagner and others, 2000). Following the monthly maintenance visit, the maintenance data will be used to determine whether the monitoring equipment was subject to bio-fouling or calibration drift. If either of these conditions were observed to be outside the SOP tolerances, the continuous water-quality record may be shifted to correct these data. At the conclusion of each water year, the data will be reviewed for accuracy, all shifts will be checked, the quality of the data will be rated (as excellent, good, fair, or poor), a station analysis for the water year will be prepared, and the finalized data will be published in the Annual Virginia Water Science Center Data Report. By following the standard procedures outlined by Wagner and others (2000), these continuous data will be of known quality and will be able to be compared to any other continuous water-quality data that also were collected following these guidelines.

Discrete water-quality sampling protocols

Discrete water-quality samples will be collected from each of the three continuous monitoring stations, over a wide range of flow conditions, as part of the ongoing River Input Monitoring Project. These discrete water-quality samples will be collected following standard USGS protocols for the collection of water-quality samples (USGS, 1998). As these standard methods are well documented in published USGS manuals, only a summary is presented here. Samples will be collected over a wide range of flow conditions, with special effort paid to the collection of water-quality samples during storm-flow conditions. Samples that are collected following USGS protocols will be analyzed using USGS-approved methods for the analysis of those samples. Suspended sediment samples will be shipped to the USGS Eastern Region Sediment Laboratory for analysis following approved sediment-analysis techniques (Sholar and Shreve, 1998). Remaining water-quality analyses will be submitted to the Virginia Division of Consolidated Laboratory Services (DCLS). This laboratory has been reviewed and approved by the USGS for the analyses that are performed. As described in the USGS manuals for water-quality sampling and analysis, approximately 10 percent of the samples will be made up of quality-control samples, such as blanks and duplicate samples. Additional detailed information regarding the laboratory methods and analyses performed by DCLS are available in the form of a RIM Project-specific QAPP that is submitted to the Chesapeake Bay Program annually.

During the collection of all water-quality samples, a project-specific field form will be used to document the specific environmental conditions under which each sample was collected. In the field, this form will be the responsibility of the lead technician collecting samples. Upon returning to the Virginia Water Science Center, the field form will be delivered to the Virginia Water Science Center Data Manager for entry into the USGS water-quality database. Standard data-flow practices within the Virginia Water Science Center have been documented in the Virginia Water Science Center's Quality Assurance Plan for Water-quality Activities (USGS, 2003). This quality assurance plan documents the processing of all data collected within the office, including sample handling and tracking, data management, as well as data review and publication. Similar to the review of all continuous water-quality data at the end of a given water year, all discrete water-quality data will be reviewed at the end of the water year and published in the Annual Virginia Water Science Center Data Report after these data have been finalized and approved.

Data Analysis and Measures of Success:

Multiple-linear regression analyses will be used to develop statistically significant regressions between continuously measured turbidity and suspended sediment concentrations. Success will be measured through paired evaluations of the estimated sediment loadings to the Bay with (based on turbidity-sediment regressions) and without the enhanced data collection (ESTIMATOR approach). These data comparisons are expected to improve sediment loading estimates for the Bay. Additionally, this demonstration project should encourage the application of this technology at other existing RIM stations and other basins throughout the non-tidal portions of the Bay Watershed. Lastly, the project will provide refined estimates of suspended sediment loads and concentrations that can be used in existing and future sediment transport models.

Schedule

				(F M	F Y lor	06 nth	i s)									H (M	F Y lor	07 nth	s)									F (M	F Y lor	08 nth	s)				
	0	N	D	J	F	М	A	М	J	J	A	S	0	N	D	J	F	М	A	М	J	J	A	S	0	N	D	J	F	М	A	М	J	J	A	s
Project planning meetings with stakeholders; application for necessary permits																																				
Order and install instrumentation and equipment																																				
Write / submit QA/QC plans																																				
Collect turbidity data and storm samples.																																				
Develop initial turbidity-sediment regression equations																																				
Verify turbidity- sediment regression equations through continued data collection																																				
Compare sediment loads – turbidity vs. ESTIMATOR																																				
Annual CIMS data delivery																																				
USGS interpretive report describing results (by June 2008)																																				

Table 2. Project schedule, based on USGS Fiscal Years

References

Christensen, V.G., Jian, Xiaodong, and Ziegler, A.C., 2000, Regression analysis and real- time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995-99: U.S. Geological Survey Water- Resources Investigations Report 00-4126, 36 p.

Christensen, V.G., 2001, Characterization of surface-water quality based on real-time monitoring and regression analysis, Quivira National Wildlife Refuge, south-central Kansas, December 1998 through June 2001: U.S. Geological Survey Water-Resources Investigations Report 01-4248, 28 p.

Christensen, V.G., Rasmussen, P.P., and Ziegler, A.C., 2002, Comparison of estimated sediment loads using continuous turbidity measurements and regression analysis [abst.], in Proceedings of Turbidity and Other Sediment Surrogates Workshop, April 30-May 2, 2002, Reno, NV.

Moyer, D. L., 2005, Quality Assurance Project Plan for the Virginia River Input Monitoring Plan. Available upon request to: dlmoyer@usgs.gov, or kenhyer@usgs.gov

Sholar, C.J., and Shreve, E.A., 1998. Quality-assurance plan for the analysis of fluvial sediment by the northeastern region, Kentucky District Sediment Laboratory. U.S. Geological Survey Open-File Report 98-384, 27p.

USGS, 1998, National Field Manual for the Collection of Water-Quality Data: Techniques of Water-Resources Investigations, Book 9, variously paginated. Available on the internet: http://water.usgs.gov/owq/FieldManual/index.html

USGS, 2003, Quality-Assurance Plan for Water-Quality Activities in the Virginia District. This QA Plan is electronically available at: http://va.water.usgs.gov/LOCAL/QW_QAplan_2003.pdf

Wagner, R.J., Mattraw, H.C., Ritz, G.F., and Smith, B.A., 2000, Guidelines and Standard Procedures For continuous Water-quality Monitors: Site Selection, Field Operation, Calibration, Record Computation, and Reporting. U.S. Geological Survey Water- Resources Investigations Report 00-4252. Available online at: http://pubs.usgs.gov/wri/wri004252/

Walling, D.E., 1977. Assessing the accuracy of suspended sediment rating curves for a small basin, Water Resources Research, 13:531-538.

Wolman, M.G., and Miller, J.P., 1960, Magnitude and frequency of forces in the geomorphic processes: Journal of Geology, v. 68 p.54-74.

APPENDIX 5 – Procedures for Operation of the SUNA Continuous Nitrate-Nitrite Analyzer



SUNA Manual

For SUNA running firmware version 2.5 or later SAT-DN-00628, Rev. E, 2014-Dec-01

Satlantic LP 3481 North Marginal Road Halifax, Nova Scotia B3K 5X8 Canada

> +1 902 492 4780 info@satlantic.com www.satlantic.com

CONFIDENTIAL

This document contains information proprietary to Satlantic or to a third party to which Satlantic may have legal obligation to protect such information from unauthorized disclosure, use or duplication. Any disclosure, use or duplication of this document in whole or in part, or of any of the information contained herein, for any purpose other than the specific purpose for which it was disclosed is expressly prohibited except as Satlantic may otherwise agree to in writing.

© 2013, Satlantic LP, All rights reserved

Table of Contents

1. About This Manual	5
2. Start-up Guides	6
2.1 Start-up Guide for Terminal Interface	6
2.2 Start-up Guide for SDI-12 Interface	7
2.3 Start-up Guide for Analog Output	8
3. The SUNA Sensor	9
3.1 Introduction and Background	9
3.2 Specifications	9
3.2.1 Build Variants	9
3.2.2 Electrical Specification	13
3.2.3 Performance Specifications	14
3.3 Operating Principles	17
3.3.1 Absorbance Spectroscopy	17
3.3.2 Nitrate Concentration.	18
3.3.3 Interferences and Mitigation	18
4. Terminal Interface of the SUNA	20
4.1 Sensor Operating States	20
4.2 Command Line Interface	20
4.2.1 Status and Maintenance Commands	21
4.2.2 File Commands	22
4.2.3 Configuration Commands	23
4.2.4 Polled Mode Commands	38
4.2.5 SDI-12 Mode Commands	
4.2.6 Analog Output	42
5. Configuration Parameters in Context	46
5.1 Build Configuration	46
5.2 Input / Output Configuration	47
5.3 Data Acquisition Configuration	48
5.3.1 Continuous and Fixed-time Operating Mode	48
5.3.2 Periodic Operating Mode	49
5.3.3 Polled Operating Mode	49
5.3.4 SDI-12 Operating Mode	50
5.4 Data Processing Configuration	51
5.4.1 Basic Data Processing	51
5.4.2 Special Case: Bromide Tracing	51
5.4.3 Special Case: Highly Absorbing Water	51
6. Use Scenarios	53
6.1 Profiling	53
6.1.1 Objectives and Considerations	53

6.1.2 Example	53
6.2 Moored	54
6.2.1 Objectives and Considerations	54
6.2.2 Example	55
7. SUNA Frame Definitions	57
7.1 Frames with Synchronization Headers	57
7.2 APF Frame	58
7.3 MBARI Frame	60
8. SUNA Calibration File	61
8.1 File Name	61
8.2 File Format	61
8.3 File Interpretation	61
9. Firmware Upgrade	62
9.1 Firmware Upgrade Using SUNACom	62
9.2 Firmware Upgrade Using the Terminal Interface	62
10. Troubleshooting	63
10.1 Sensor Is Not Responsive	63
10.2 Sensor Output Is Unexpected	64
11. Accessories	65
11.1 Foul Guard	65
11.2 Wiper	65
11.3 Flow Cell	67
12. Maintenance	68
13. Safety And Hazards	69
13.1 Pressure Hazard	69
13.2 Electrical Hazard	69
13.3 Deployment and Recovery Safety	69
14. Warranty	70
14.1 Warranty Period	70
14.2 Restrictions	70
14.3 Provisions	70
14.4 Returns	70
14.5 Liability	70
15. Contact Information	71
16. Revision History	72
Index of Tables	
Table 1: Sensor dimensions, basic options	9
Table 2: Optional features	10
Table 3: SUNA dimensions depending on options	10
Table 4: Power requirements	13

Table 5: Electrical pin assignments and descriptions	.14
Table 6: General performance specifications	.15
Table 7: Accuracy specification for nitrate concentrations	.15
Table 8: Precision specification for nitrate concentrations	.16
Table 9: Limit of Detection and Limit of Quantification	.16
Table 10: File access commands	.22
Table 11: Build configuration parameters	.26
Table 12: Input / output configuration parameters	.29
Table 13: Data acquisition configuration parameters	.34
Table 14: Data processing configuration parameters	.37
Table 15: Combinations of data processing configuration parameters	.37
Table 16: SUNA build variants	.46
Table 17: Data acquisition configuration parameters by operating mode	.50
Table 18: Data processing configuration parameters in use case context	.52
Table 19: Configuration parameters illustrating a profiling deployment	.54
Table 20: Configuration parameters illustrating a moored deployment	.56
Table 21: Synchronization header frame definitions	.58
Table 22: APF data frame definition	.59
Table 23: MBARI data frame definition	.60
Index of Illustrations	
Illustration 1: Drawing of Standard SUNA with 10 mm path length	.11
Illustration 2: Drawing of Standard SUNA with 5 mm path length	.11
Illustration 3: Drawing of Standard SUNA with 10 mm path length and wiper	.12
Illustration 4: Drawing of Standard SUNA with 5 mm path length and wiper	.12
Illustration 5: SUNA SubConn MCBH8MNM bulkhead connector face view	.13
Illustration 6: Foul Guard	.64
Illustration 7: SUNA with integrated wiper	.65
Illustration 8: Space requirements for the integrated wiper	.65
Illustration 9: Flow Cell	.66

1. About This Manual

The SUNA is a versatile sensor that can operate in diverse environments. It is adaptable to a wide variety of deployment scenarios and supports multiple interfaces. This manual provides guidance on how to properly deploy the sensor and on how to interact with it.

Before operating the sensor, understand all warnings and cautions cited in section 13. Safety And Hazards.

Section 3. The SUNA Sensor gives performance specifications, sensor dimensions, and explains the measurement technology.

The SUNACom software provides a graphical user interface to facilitate working with the sensor. It supports sensor configuration, system testing, data management, and data re-processing. SUNACom has a separate user manual, which is available on the installation CD and from within the SUNACom application via context sensitive help.

SUNACom does not address the requirements for all deployment scenarios, particularly those related to integrated systems. For this reason, the complete firmware interface is specified in Section 4. Terminal Interface of the SUNA. Explanations on how to start when working in this environment are found in Section 2.1 Start-up Guide for Terminal Interface.

The decision on how to configure the sensor is driven by the type of deployment. Section 5. Configuration Parameters in Context provides an explanation of configuration parameters. Section 6. Use Scenarios discusses configuration choices for some types of deployments, and Section 7. SUNA Frame Definitions defines the output data.

Components supporting the deployment of the SUNA are specified in Section 11. Accessories.

Some deployments benefit from components that can be added to the SUNA.

The SUNA is a versatile sensor and research is ongoing to expand its performance and use. Support of new features can be coded into future SUNA firmware versions. Section 9. Firmware Upgrade provides instructions on how to install such a new firmware.

Explanation and remediation for some unexpected behavior of the SUNA are addressed in Section 10. Troubleshooting, and guidance on handling is provided in Section 12. Maintenance.

2. Start-up Guides

Refer to the **Quick Start** section of the SUNACom User manual available on your installation CD or bundled with the SUNACom software to test basic operation and configuration. The following start-up guides will guide you through the process of connecting to interfaces not available via SUNACom.

2.1 Start-up Guide for Terminal Interface

Terminal Emulator

The end user can interface with the SUNA by using terminal emulator software that can connect to a serial com port. Some computers have pre-installed terminal emulators (e.g., HyperTerm in some Microsoft Windows operating systems). Other terminal emulators are, e.g., Putty, Tera Term, Bray's Terminal. This guide assumes that the user is familiar with operating a terminal emulator.

Cable

In order to use the terminal interface, connect the sensor's serial cable to a com port of the computer, and power the sensor with 8–18 VDC (8–15 VDC for SUNA with an integrated wiper), capable of providing a current of at least 1 A.

Serial Interface

The SUNA communicates via serial port, using the RS-232 protocol at 8 bit, no parity, 1 stop bit and no flow control. The baud rate is factory set to 57600. If this baud rate does not work, try the other possible baud rates (9600, 19200, 38400, 115200) or use SUNACom to scan for the current baud rate.

Command Line

When power is applied to the SUNA, output and behavior depend on the current sensor configuration. In all instances the user can bring the sensor to the command line by repeatedly sending the \$-character to the sensor.

The sensor indicates that it is accepting commands by outputting the SUNA> prompt. All commands available at the command line are given in section 4.2 Command Line Interface.

An example command is *selftest*. It turns on all subsystems and briefly reports their status.

Using the get opermode command will report the current operation mode. Consult section 5.3 Data Acquisition Configuration to understand the different operating modes, and use the set opermode command if another operating mode is needed. Use the get cfg command for the current sensor configuration.

2.2 Start-up Guide for SDI-12 Interface

The SUNA has an optional SDI-12 interface.

Use SUNACom or the terminal interface to find out if the sensor is equipped with the SDI-12 Interface.

Within SUNACom verify the SDI-12 is listed as one of the options under the Operational Mode of the SUNA Settings display. See the SUNACom user manual for details.

At the terminal interface, use the get sdil2brd command. The response will be either Available or Missing.

Start SDI-12 Operation

SUNA sensors are not factory set to operate in SDI-12 mode. To operate the sensor as a SDI-12 device, it first has to be configured to do so.

In SUNACom select SDI-12 as the operating mode under the SUNA Settings display and Upload. See the SUNACom user manual for details.

At the terminal interface, use the set opermode SDI12 command.

Data Processing

Before deployment, the user should confirm that the data processing configuration is suitable for the expected deployment. See section 5.4 Data Processing Configuration for details.

Deployment

After the sensor has been configured to run in SDI-12 operation mode, and processing has been configured, the sensor can be rebooted or power cycled. At this point, the sensor will respond to SDI-12 commands. For supported SDI-12 commands, see section 4.2.5 SDI-12 Mode Commands.

End SDI-12 Deployment

In order to bring the sensor out of SDI-12 mode, either use SUNACom or the terminal interface.

In SUNACom select another operating mode under the SUNA Settings display and Upload. See the SUNACom user manual for details.

In the latter case, sending the \$ character brings the sensor to the command line, and allows the user to switch to another operating mode via the set opermode command.

2.3 Start-up Guide for Analog Output

The SUNA has an optional analog output system.

The end user can determine if the sensor is equipped for analog output either via the SUNACom software or the terminal interface (see section 2.1 Start-up Guide for Terminal Interfaceand section 4. Terminal Interface of the SUNA).

In SUNACom the DAC calibration function will be visible under the Advanced, Sensor menu item if this function is available.

At the terminal interface, use the get analgbrd command. The response will be either Available or Missing.

Interpreting Analog Output

When analog output is available, the sensor automatically generates output voltage and current.

The sensor generates an output voltage in the 0 to 4.096 V and an output current in the 4 to 20 mA range. The lower range of the respective output interval corresponds to the DAC Minimum and the upper range of the interval corresponds to the DAC Maximum configuration parameter.

Both the DAC minimum and DAC maximum values can be modified, either via SUNACom or via the terminal interface, to tune the output range to the expected nitrate concentration range.

While the output voltage and current generated by the sensor are highly accurate, losses may occur across cables that are used. For details on calibration and data interpretation, see section 4.2.6 Analog Output.

3. The SUNA Sensor

3.1 Introduction and Background

The SUNA (Submersible Ultraviolet Nitrate Analyzer) is a chemical-free nitrate sensor.

It is based on the ISUS (In Situ Ultraviolet Spectroscopy) technology developed at MBARI (cf. Kenneth S. Johnson, Luke J. Coletti, In situ ultraviolet spectrophotometry for high resolution and long-term monitoring of nitrate, bromide and bisulfide in the ocean, Deep-Sea Research I 49 (2002) 1291–1305).

3.2 Specifications

3.2.1 Build Variants

The SUNA housing is made from acetal, and is suitable for deployments of up to 500 m depth, or 100 m depth with the optional integrated wiper.

Dimension	Basic Variant
Material	Acetal / Titanium
Depth Rating	500 m 100 m (integrated wiper)
Diameter	63 mm
Length (without connector and anode)	567 mm
UV Deuterium Lamp	900 h lifetime
Path length	10 mm
Displacement	1749 cm ³
Weight	2.5 kg
Electrical connector	SubConn MCBH8MNM
Storage temperature	–20 to +50 C
Operating temperature	2 to +35 C

Table 1: Sensor dimensions, basic options.

Optional features and accessories change some sensor dimensions, as shown below.

Feature / Accessory	Comment
Reduced path length	5 mm
Calibration	Normal: NO3 only Optional: NO3 & seawater
Analog output	Optional
SDI-12 interface	Optional
Internal data logging	Optional 2 GB (or larger) solid state
Scheduling	Optional
USB connectivity	Optional
Active fouling control	Integrated wiper
Passive fouling control	Copper fouling guard
Sampling control	Flow through cell
Power supply	Battery pack

Table 2: Optional features

Table 3: SUNA dimensions depending on options.

Options	Length	Displacement	Weight
Standard SUNA, basic variant	567 mm	1749 cm ³	2.5 kg
Standard SUNA, 5 mm path length	562 mm	1745 cm ³	2.5 kg
Standard SUNA, integrated wiper	588 mm	2092 cm ³	3.1 kg
Standard SUNA, 5 mm path length, integrated wiper	583 mm	2084 cm ³	3.1 kg



Illustration 1: Drawing of Standard SUNA with 10 mm path length.



Illustration 2: Drawing of Standard SUNA with 5 mm path length.



Illustration 3: Drawing of Standard SUNA with 10 mm path length and wiper.



Illustration 4: Drawing of Standard SUNA with 5 mm path length and wiper.

3.2.2 Electrical Specification

The SUNA requires power in the 8–18 VDC range with a supply current of 1 A (8–15 VDC for SUNA with an integrated wiper). Power consumption depends on the operating state. During data acquisition, it is typically 7.5 W (\pm 20%). In standby, at the command prompt, the current draw is around 20 mA.

Polled and APF operating modes will time out after a configurable time of inactivity, bringing the SUNA processor into a low power state with a consumption below 3 mA. In fixed-time operation and between periodic operation event, power control is handed to a supervisor circuit, which reduces power consumption to less than 30 μ A.

State	Voltage	Current
Supervised Sleep	8–18 VDC	< 30 µA
Processor Sleep		< 3 mA
Standby	(8–15 VDC with integrated wiper)	~20 mA at 12 V
Sampling		~625 mA at 12 V (nominal)

Table 4: Power requirements

The SUNA connector is a SubConn MCBH8MNM. With a face view numbering as in the following illustration, the pin assignments are listed in the following tables.



Illustration 5: SUNA SubConn MCBH8MNM bulkhead connector face view.

Pin	Standard	Optional USB / Analog Out				
1	VIN	VIN				
2	GND	GND				
3	_	USB V+				
4	_	SDI-12				
5	TXD	TXD / D+				
6	RXD	RXD / D-				
7	_	VOUT				
8	_	IOUT				
Pin Assignment	Description					
VIN	External DC power supply, 8–18 VDC or 8–15 VDC					
GND	Power supply return, signal ground					
USB V+	USB 5V power	USB 5V power				
SDI-12	Serial data interface at 1200 bau	d				
TXD	RS-232 transmit (from SUNA)	RS-232 transmit (from SUNA)				
RXD	RS-232 receive (to SUNA)					
D+	USB D+					
D	USB D-					
VOUT	Analog volt output					
IOUT	Analog current output					

Table 5: Electrical pin assignments and descriptions.

3.2.3 Performance Specifications

The SUNA sensor is designed to measure the concentration of nitrate ions in water. The measurement result is in molar concentration, units of micro molar (μ M). For user convenience, this concentration is converted into units of milligram per liter (mg/l), and output in digital form as well. 1 μ M nitrogen corresponds to 0.014007 mg/l nitrate.

Measurement	Nitrate concentration [NO3]
Thermal compensation (optional)	0–35°C
Salinity compensation (optional)	0–40 psu
Optical path length	10 mm, optional 5 mm
Spectral range	190–370 nm

Table 6: General performance specifications

The performance of the sensor depends on a number of factors. One factor is the optical path length, normally at 10 mm, optionally at 5 mm. The optical path length influences the concentration measurement range covered by the sensor, and the accuracy of the results. Another factor is the type of calibration: a sensor specific calibrations are more accurate than a class-based calibration. The former uses extinction coefficients that are measured using the sensor itself; the latter uses averaged extinction coefficients, that were obtained from many sensors.

Concentration Range	10 mm Path Length	5 mm Path Length						
For regular seawater and freshwater calibrations								
up to 1000 µM	2 µM or 10%	4 µM or 10%						
up to 2000 µM	2 µM or 15%	4 µM or 15%						
up to 3000 µM	2 µM or 20%	4 µM or 15%						
up to 4000 µM	out-of-range	4 µM or 15%						
For c	class-based freshwater calibra	itions						
up to 1000 µM	2.5 µM or 20%	4.5 µM or 20%						
up to 2000 µM	2.5 µM or 25%	4.5 µM or 25%						
up to 3000 µM	2.5 µM or 30%	4.5 µM or 25%						
up to 4000 µM	out-of-range	4.5 µM or 25%						

Table 7: Accuracy specification for nitrate concentrations

The precision of the sensor depends on its data processing configuration (see section 5.4 Data Processing Configuration). In oceanographic or estuarine settings, data must be processed for seawater, in freshwater settings data processing is ideally selected to be for freshwater. In seawater settings, the sensor precision can be brought into the freshwater precision by post-processing in SUNACom with Temperature-Salinity-Correction applied.

	Table 8: Precision	specification	for nitrate	concentrations
--	--------------------	---------------	-------------	----------------

Processing configuration	Freshwater or Seawater with T-S-Correction	Seawater [0–40 psu]
Short-term precision [at 3o]	0.3 µM	2.4 µM
Drift [per hour of lamp time]	<0.3 µM	<1.0 µM

The limit of detection is defined as the nitrate concentration that has a value of 3 times the standard deviation of the blank nitrate concentration. As such, it is 3 times the standard deviation as measured for the sensor precision, which depends on the processing mode.

The limit of quantification specifies the limit at which two samples can be reasonably distinguished. Typically, it is 10 times the standard deviation of the blank nitrate concentration.

Processing configuration	Freshwater or Seawater with T-S-Correction	Seawater [0–40 psu]
Limit of detection [LOD]	0.3 µM	2.4 µM
Limit of quantification [LOQ]	1.0 µM	8.0 µM

Table 9: Limit of Detection and Limit of Quantification

Natural waters may contain a mixture of interfering species that are typically hard to delineate. The impact of interfering species on the measured nitrate concentration was determined under laboratory conditions. The specification covers two classes of interfering species: suspended particulate matter (Turbidity) and colored dissolved organic matter (CDOM). The impact is independent of the optical path length, from theoretical considerations as well as experimentally confirmed. However, the SUNA can only operate up to absorbances of approximately 1.5. This limit is typically reached at 625 NTU (Nephelometric Turbidity Units) for 10 mm path length, or at 1250 NTU for 5 mm path length. Naturally occurring CDOM concentrations stay within the operating range of the SUNA.

The following substances were uses as proxies for turbidity:

ARD Arizona Road Dust Kaolin Kaolin Powder TiO2 Titanium Dioxide

Turbidity Sample	NTU per mg/l	Absorbance at 225 nm (10 mm) per mg/l	NO3 shift µM in freshwater per mg/l	NO3 shift µM in seawater per mg/l
ARD	1.25	0.0016	<-0.002	0.01
Kaolin	1.5	0.0085	<0.001	0.02
TiO2	15.0	0.0090	<0.001	<0.001

The following samples, obtained from the International Humic Substances Society, were used as proxies for CDOM:

PLFA Pony Lake Fulvic Acid – Reference (1R109F) SRFA Suwannee River Fulvic Acid – Standard (1S101F) PPHA Pahokee Peat Humic Acid – Reference (1R103H-2)

CDOM Sample	QSD per mg/l	Absorbance at 225 nm (10 mm) per mg/l	NO3 shift µM in freshwater per mg/l	NO3 shift µM in seawater per mg/l
PLFA	N/A	0.017	0.4	0.6
SRFA	N/A	0.027	<0.1	<0.1
PPHA	42	0.003	<0.01	<0.1

An interfering species generates a spurious nitrate concentration when the spectral characteristics of the interfering species resembles that of nitrate. Typically, an RMSE value that is more than a few times the RMSE of a pure nitrate sample should be taken as an indication that interfering species are impacting the measurement. The RMSE value is the square root of the mean of the sum of the squared differences between the measured and the fitted absorbance; it provides a measure for the quality of the fit. Independent measurements of turbidity and CDOM, as well as an analysis of the absorption spectrum, can refine the impact analysis.

3.3 Operating Principles

3.3.1 Absorbance Spectroscopy

The SUNA measures the concentration of dissolved nitrate in water. The sensor illuminates the water sample with its deuterium UV light source, and measures the throughput using its photo-spectrometer. The difference between this measurement and a prior baseline reference measurement of pure water constitutes an absorption spectrum.

Absorbance characteristics of natural water components are provided in the sensor calibration file. The Beer-Lambert law for multiple absorbers establishes the relationship between the total measured absorbance and the concentrations of individual components. Based on this relationship, the sensor obtains a best estimate for the nitrate concentration using multi-variable linear regression.

The approach described above was initially developed at MBARI (cf. Kenneth S. Johnson, Luke J. Coletti, In situ ultraviolet spectrophotometry for high resolution and long-term monitoring of nitrate, bromide and bisulfide in the ocean, Deep-Sea Research I 49 (2002) 1291–1305) and the technology then transferred to Satlantic.

3.3.2 Nitrate Concentration

Nitrate processing uses the 217–240 nm wavelength interval, which contains approximately 35 spectrometer channels. For each channel, the absorbance is calculated, and decomposed into individual absorbers using the MBARI method.

The precision of the nitrate concentration depends on the number of absorbers into which the measured absorbance is decomposed. Thus, in freshwater deployments, the number of concentrations to be fitted should be set to 1.

High absorbance conditions introduce inaccuracies into the nitrate concentrations. Therefore, channels with an absorbance greater than 1.3 are excluded from processing. If less than about 10 channels remain, the sensor is unable to determine a nitrate concentration, and the measurement is no longer valid (out-of-bounds). Users can overturn the standard setting and increase the absorbance cutoff, obtaining reduced accuracy nitrate concentrations at higher absorbances. There is, however, a limit at around 2.5 absorbance units, when nitrate concentrations can no longer be determined.

3.3.3 Interferences and Mitigation

The quality of the nitrate measurements can be impacted in a number of ways. This impact has been quantified (see section 3.2.3 Performance Specifications) for some significant interfering influences. Here, interferences are explained, and mitigation options are explored.

Sample temperature: Seawater is known to have a temperature-dependent absorption. If this effect is not taken into account, a bias and/or imprecision are introduced to the reported nitrate concentration.

This effect can be mitigated by providing sample temperature and salinity to the nitrate calculation, either in real-time (supported in APF mode) or in SUNACom post-processing (collection of spectra and accompanying temperature and salinity data is required). Temperature-salinity correction follows the approach developed at MBARI (cf. Carole M. Sakamoto, Kenneth S. Johnson, Luke J. Coletti, Improved algorithm for the computation of nitrate concentrations in seawater using an in situ ultraviolet spectrophotometer, Limnol. Oceanogr.: Methods 7, 2009, 132–143).
Uncharacterized species in sample: A number of substances occurring in natural water absorb in the UV spectral range where nitrate absorbs. Usually, the spectral signature of those substances differs from that of nitrate. However, certain combinations of water constituents may cause a bias in the calculated nitrate concentrations.

If significant concentrations of interfering species are suspected, sporadic chemical analysis of water samples allows quantification and correction for the optical interference.

Sensor drift: Over time, lamp output and throughput of optical components exhibit drift. This drift translates into a drift in the measured nitrate concentrations.

A regular update of the reference (baseline) spectrum minimizes drift.

Lamp temperature: The lamp output depends on its temperature. Thus, the reference (baseline) spectrum is ideally collected under conditions that mimic deployment conditions.

If deployment temperatures are expected to vary by more than 10 °C, a temperature characterization and subsequent data correction may be attempted.

Optically dense constituents: The sensor performance is compromised in optically dense conditions, which transmit less light than necessary for the regression analysis. With increasing optical density, the quality of the measurement (signal-to-noise) decreases. Accuracy and precision of the nitrate concentrations decrease with decreasing data quality, until the data are essentially random (or are reported as out-of range, depending on sensor configuration).

The sensor can be configured to respond to optically dense conditions by repeating the measurement with an increased spectrometer exposure time, thereby extending the operating range of the sensor.

High optical densities are often caused by CDOM or turbidity in the water sample. It has been found that the CDOM concentration in natural waters does not cause optical extinction. On the other hand, highly turbid waters can cause such high absorption that the SUNA is not able to measure nitrate. The operation limit for the 10 mm path length variant is 625 NTU, and for the 5 mm variant it is 1250 NTU.

4. Terminal Interface of the SUNA

4.1 Sensor Operating States

At power-up, the SUNA's micro-controller starts the firmware. After initialization, it retrieves the current settings, and enters its operating mode.

Within each operating mode, the firmware is in one of three states:

standby,

data acquisition,

command interface,

where the transition between the states is controlled by the firmware or driven by user or controller input.

In standby, the sensor can be at different levels of power consumption. In periodic and APF mode, the sensor achieves the lowest level between data acquisition events, whereas in polled mode, the power level is a bit higher, and in SDI-12 mode, the power level is identical to the one when the sensor is at the command line.

The user can interrupt the SUNA's regular operation in order to enter the command line.

Data Acquisition to Command Interface

Sending a \$ character (possible multiple times) will bring the sensor to the command line. The command line reports via the SUNA> prompt that it is ready to receive commands.

Command Interface to Data Acquisition

The command line is terminated via the exit or the reboot command.

Data Acquisition to Standby

Only polled and APF modes have explicit commands (SLEEP and SLP, respectively) to send the SUNA to standby mode.

In periodic mode, the sensor alternates between standby and data acquisition.

Standby to Data Acquisition

Any input will cause the SUNA to come out of its standby state. Then, it waits for 15 seconds for the \$ input character to enter the command line, before returning to the standby state. When entering standby, the sensor requires approximately 15 seconds to completely discharge its internal circuitry. Any attempt to bring the sensor out of its standby state occurring within this 15 second period can lead to undefined behaviour.

4.2 Command Line Interface

Communication with the SUNA is conducted via RS-232 or USB connection. The sensor

checks for availability of a USB connection, and if present, uses a USB virtual com port for input and output. Otherwise, the sensor communicates via RS-232.

Commands can be broadly grouped into the following categories:

- 1. Status and Maintenance
- 2. File Management
- 3. Query and Modify Configuration
- 4. Polled Mode Commands
- 5. APF Mode Commands
- 6. SDI-12 Mode Commands

4.2.1 Status and Maintenance Commands

Selftest

The selftest checks operation of sensor components, performs measurements, and outputs the measurement results.

The last output line will be \$0k if all components performed according to expectations, or \$Error if one or more of the components failed the test. If a component did not perform as expected, the output line of that component is terminated by an exclamation mark (!), making it easier to locate the problem.

Get Clock and Set Clock

The get clock command outputs the time of the internal sensor clock. The time is factory set to UTC.

The set clock YYYY/MM/DD hh:mm:ss command sets the sensor clock to the specified value.

Used Lamp Time

The firmware keeps track of the total on-time of the lamp, and outputs the number of seconds via the get lamptime command.

Wiper Test

The firmware provides the special swipewiper command to run the wiper one time.

DAC Low and DAC High

These commands are only available for SUNAs that have an analog output system.

The DAC Low command will generate the lowest analog output that is possible, and the DAC High command will generate the highest analog output that is possible.

For details on how to make use of this feature, see section 4.2.6 Analog Output.

Upgrade

The firmware exits into the boot loader.

The boot loader allows installing of a new firmware onto the nitrate sensor. See section 9. Firmware Upgrade for details.

Reboot

This command causes the firmware to restart. It is equivalent to performing a power cycle.

Exit

The command line exits, and data acquisition as configured in the operation mode restarts. If the baud rate was changed in the current command line session, the sensor will reboot in order to re-initialize with the new baud rate.

4.2.2 File Commands

File commands give access to data log, message log, and calibration files. All file commands follow the syntax <Command> <FileType> [<FileName>]. Data and message log files are an optional feature. Use the selftest command to see if the sensor has an internal file system, and if so, the space that is available.

File types are CAL for calibration files, LOG for system log message files, and DATA for files containing logged measurement data.

Command	CAL	LOG	DATA	Comment
List	+	+	+	Output a list of all files of the specified type
Output	+	+	+	Output the content of the specified file. Recommended only for small ASCII files. The command cannot be interrupted.
Send	+	+	+	XMODEM transfer of file from sensor
Delete	+	+	+	Delete specified file from disk. Irreversible.
Receive	+			XMODEM transfer of file to sensor

Table 10: File access con	mands
---------------------------	-------

The sensor can have many calibration files. The user can query the name of the

currently active file via the get activecalfile command. The active file cannot be deleted from the sensor. When a calibration file is received by the sensor, it is made active. The user can change the active file by the set activecalfile calfile-name command.

4.2.3 Configuration Commands

Configuration commands allow the user to query and modify configuration parameters. The commands follow the syntax

get --<short name> set --<short name> <value> setrange --<short name> <value>,<value>

Below is a list of all configuration parameters with a brief explanation. Each subsection finishes with a table containing the parameters, the range of accepted values, and the short name for accessing the parameter using the above commands.

The setrange command only applies to the two pairs of wavelength values.

Build Configuration

All build parameters are for information only, and cannot be modified.

Sensor Type

The Sensor Type is SUNA.

Sensor Version

The Sensor Version is V2.

Serial Number

The Serial Number is factory set.

Sensor Brand

The Sensor Brand is **Satlantic**.

Super Capacitors

The super capacitors are either Available or Missing.

During start-up, the capacitors are charged to provide brief internal power in the event of a sudden power loss. Internal backup power allows the sensor to shut down into a safe state.

The disadvantage of super capacitors is an increased total power consumption.

PCB Supervisor

The PCB supervisor circuit is either Available or Missing.

Sensors are optionally equipped with the PCB supervisor, which allows the sensor to enter power saving mode.

USB Communication

The USB communication is either Available or Missing.

Sensors are optionally equipped with USB communication. Sensors can always communicate via RS-232. If USB is available and plugged in, communication switches to USB.

Relay Module

The relay module is **Missing**.

This feature is only available in the Deep SUNA.

SDI-12 Interface

The SDI-12 interface is either **Available** or **Missing**.

Sensors are optionally equipped with the SDI-12 interface.

Analog Output

The analog output system is either **Available** or **Missing**. Sensors are optionally equipped with analog output system.

Internal Data Logging

Internal data logging is either **Available** or **Missing**. Sensors are optionally equipped with memory for internal data logging.

APF Interface and Temperature-Salinity Correction

The APF interface and temperature-salinity correction is **Missing**. This feature is only available in the Deep SUNA.

Scheduling

The scheduling capability is either **Available** or **Missing**. Sensors are optionally capable to run on a configured schedule.

Optical Path Length

The optical path length is **5mm** or **10mm**.

Integrated Wiper

The integrated wiper is **Available** or **Missing**.

When a wiper has been integrated into the sensor, control of the wiper operation is enabled.

External Power Port

The external power port is **Missing**.

An external power port may be supported in future SUNA versions.

Addresses of Temperature Sensors

The addresses of the three SUNA internal temperature sensors are factory configured, and provided for troubleshooting.

Spectrometer Serial Number

The spectrometer serial number is factory configured.

Lamp Serial Number

The lamp serial number is factory configured.

Lamp Use Power

The power used by the sensor when the lamp is turned on in units of milliwatt [mW]. It is measured during sensor assembly, and serves as a reference point for the firmware to ascertain that the lamp is operating properly. It also allows to estimate the sensor's power consumption.

Custom ID

The Custom Identification string allows operators to assign their own identification to a SUNA. The string can be up to 15 ASCII characters long.

Parameter	Possible Values	Short Name
Sensor Type	SUNA	senstype
Sensor Version	V2	sensvers
Serial Number	1–9999	serialno
Sensor Brand	Satlantic	thebrand
Super Capacitors	Available, Missing	suprcaps
PCB Supervisor	Available, Missing	pwrsvisr
USB Communication	Available, Missing	usbswtch
Relay Module	Missing	relaybrd
SDI-12 Interface	Available, Missing	sdi12brd
Analog Output	Available, Missing	analgbrd
Internal Data Logging	Available, Missing	intdatlg
APF Interface	Missing	apfiface
Scheduling	Available, Missing	schdling
Optical Path Length	5mm, 10mm	pathlgth
Integrated Wiper	Available, Missing	intwiper
External Power Port	Missing	extpport
Address of lamp temperature sensor		owiretlp
Address of spectrometer temperature sensor		owiretsp
Address of housing temperature sensor		owireths
Spectrometer Serial Number		zspec_sn
Lamp Serial Number		fiberlsn
Lamp Use Power [mW]		lmpusepw
Custom ID	String, up to 15 characters	customid

Input and Output Configuration

Baud Rate

The baud rate is one of 9600, 19200, 38400, **57600**, or 115200.

A changed baud rate takes effect after the next power-up or reboot.

Message Level

The message level is one of Error, Warn, Info, Debug, Trace.

Messages are sent to the output stream and are also saved in a message log file.

Message File Size

The message file size is in the 0 to 65 MB range, and initially set to 2 MB.

Setting the file size to zero turns off logging of messages to file.

Data File Size

The data file size is in the 1 to 65 MB range, and initially set to 2 MB.

This value applies only if the data file type is set to Continuous. Daily and per-acquisition files will contain as much data as is generated during the day or the particular acquisition.

Output Frame Type / Logging Frame Type

The frame type is one of None, APF, MBARI, **Full_ASCII**, Full_Binary, Reduced_Binary, Concentration.

If set to **None**, no frame data will be written to serial output / data log file, respectively.

For reprocessing of data, Full_ASCII or Full_Binary frames are necessary. Reduced binary and APF frames allow reprocessing for seawater deployments. APF frames only allow reprocessing of data that were collected with the integration time adjustment turned off.

Output Dark Frame / Logging Dark Frame

Dark frames output and logging is either **Output** or Suppress.

This configuration flag is provided in case when dark frames are not required or desired.

Log File Type

The data log file type is one of Acquisition, Continuous, or Daily.

Data log files names have a single letter (A, C, or D) followed by a 7-digit number, followed by a 3-letter extension (csv for ASCII, bin for binary data).

Acquisition based data files are started new whenever power is cycled. (But see the following setting: Acquisition File Duration.)

Continuous data log files are appended to until the Data File Size is reached. Then, the file number is incremented, and data are added to the next file.

Daily data log files contain all data that are collected within a 24 hour period. The 7-digit

number is made up of 4-digit for the year and 3-digits for the day-of-year (1 to 365 or 366 for leap years).

Acquisition File Duration

The Acquisition File Duration is set to 60 minutes. This setting is only used if the Log File Type is set to Acquisition.

The duration can be in the range from 0 to 1440 minutes (one full day). It specifies the time interval over which data from subsequent power-cycle events are logged to the same file.

A value of zero forces the creation of a new data log file with every power cycle, while a value of e.g., 120 collects the data from all acquisition events that occur within 120 minutes into a single file.

When using acquisition based data log files with a high frequency of acquisition events (e.g., multiple events per hour) over an extended deployment duration, the total number of files can reach tens of thousands of files. Such a number of files will slow down SUNA internal data logging.

If daily of continuous log files are not an option, the use of the acquisition file duration will ensure the number of files stays small.

DAC Minimum / Maximum Nitrate

The DAC minimum nitrate value is initially set to -5 μ M, the DAC maximum nitrate value is set to 100 μ M.

These values effect the output generated by the optional analog output system. See section 4.2.6 Analog Output for details.

Dat Wavelength Low / High

The data wavelength values are set to 217 and 250.

These wavelength define the channels that are included in the APF frame.

SDI-12 Address

The SDI-12 address is factory set to the numerical value 48 (ASCII character '0').

This address is used by an SDI-12 controller when interfacing with a SUNA in SDI-12 operating mode. See section Error: Reference source not found Error: Reference source not found for details.

Parameter	Possible Values	Default Value	Short Name
Baud Rate	9600, 19200, 38400, 57600, 115200	57600	baudrate
Message Level	Error, Warn, Info, Debug	Info	msglevel
Message File Size [MB]	0–65	2	msgfsize
Date File Size [MB]	1–65	5	datfsize
Output Frame Type	Full_ASCII, Full_Binary,	Full_ASCII	outfrtyp
Logging Frame Type	Reduced_Binary, Concentration, APF, MBARI, None	Full_ASCII	logfrtyp
Output Dark Frame	Output, Suppress	Output	outdrkfr
Logging Dark Frame	Output, Suppress	Output	logdrkfr
Log File Type	Acquisition, Continuous, Daily	Acquisition	logftype
Acquisition file duration [m]	0–1440	60	afiledur
DAC Minimum Nitrate		-5.0	dcmonno3
DAC Maximum Nitrate		100.0	dcmaxno3
Data wavelength low [nm]	210–350	217	wdat_low
Data wavelength high [nm]	210–350	250	wdat_hgh
	For the setrange command, use:		wdatboth
SDI 12 Address	48–57 (ascii characters 0–9)	48 (ascii 0)	sdi12add

Table 12: Input / output configuration parameters

Data Acquisition Configuration

Operation Mode

The operation mode is Continuous, Fixedtime, Periodic, Polled, APF, or SDI12.

In **Continuous** mode the sensor starts to acquire data as soon as initialization is complete and countdown has expired. Data acquisition proceeds, depending on the Operation Control setting, either in a sample based (1 dark sample, then Light Samples, Dark Samples, Light Samples, ...) or time based (1 dark sample, then Light Duration, Dark Duration, Light Duration) infinite cycle.

In **Fixedtime** mode, the sensor behaves as in Continuous mode, but terminates after a maximum of Fixed Time Duration seconds.

In **Periodic** mode, the sensor acquires data in regular periods, and collects data, depending on the Operation Control setting, either a fixed number of light samples (Periodic Samples) or for a fixed time (Periodic Duration).

IIn **Polled** mode, the sensor stays in low power sleep, to acquire data only after woken up by activity on the RS-232 line and then receiving a command ("Start" for indefinite or "Measure n" for a fixed number of measurements).

In SDI-12 mode, the sensor operates as a SDI-12 device.

Operation Control

The operation control is **Duration** or Samples based.

Operation control applies to Continuous, Fixed time, and Periodic mode. Either of these operating modes is further controlled by additional parameters, and Operation Control determines which parameters apply.

Countdown

The countdown is measured in units of seconds, and initially set to 15.

The countdown is used in Continuous and Fixedtime operation modes.

Fixed Time Duration

The fixed time duration is measured in units of seconds, and can take any positive number up to and including 1000000.

Periodic Interval

The periodic interval is restricted to a subset of values that divide the day into integer parts: 1m, 2m, 5m, 6m, 10m, 15m, 20m, 30m, **1h**, 2h, 3h, 4h, 6h, 8h, 12h, 24h.

Periodic Offset

The periodic offset is measured in seconds.

Whereas the periodic interval establishes a grid of acquisition times, the offset locates the grid relative to the start of the day (hour 0).

Note: There is a side effect when an external device needs to run prior to data acquisition.

Periodic Duration

The periodic duration is measured in seconds.

This parameter is used when **Operation Control** is set to **Duration**.

Periodic Samples

The periodic samples are measured in number of light frames.

This parameter is used when **Operation Control** is set to **Samples**.

Polled Timeout

The polled timeout is measured in seconds.

It determines for how long the firmware will wait for a command upon wake-up before returning to low power standby. A value of zero means there is no timeout.

APF Timeout

The APF timeout is only available in Deep SUNA sensors.

Skip Sleep At Startup

This setting is either On or Off.

If this setting is On, the sensor will not enter the low-power state in polled mode when first powered up. This flag allows for faster sensor response.

Lamp Stabilization Time

The lamp stabilization time is in units of 1/10 of a second.

After the lamp has ignited, a short time is required to stabilize the lamp output. Typically, lamps can be used 500 ms after being switched on. This parameter is provided to adjust the stabilization time.

Lamp Switch-Off Temperature

The lamp switch off temperature is set to 35 C. The lamp should not operate at temperatures above 35 C.

When the lamp exceeds the switch-off temperature, the sensor overrides the configured (continuous and fixedtime operation) or enforces (polled and periodic operation) a light-to-dark cycle. Upon reaching the switch-off temperature, initially five cycles of 5-light to 5-dark samples are acquired, and after those, the cycle ratio drops to 1-light to 10-dark samples. As soon as the lamp temperature has dropped below the switch-off temperature, the configured acquisition cycle resumes.

If the sensor is deployed in a warm environment, and data acquisition is only sporadic, please consult with Satlantic on ways to safely changing this configuration.

Spectrometer Integration Period

The spectrometer integration period is factory set.

The integration period should be as large as possible, to obtain a good signal; the integration period must not be so large as to cause saturation of the signal.

The spectrometer integration time should not be changed, because the SUNA is calibrated for the factory configured value.

Dark Averages and Light Averages

The spectrometer can perform internal averaging. Internal averaging reduces the noise of a measurement at the expense of a reduced sampling rate. However, the sampling rate is higher using internal averaging when compared to averaging the samples after separate collection.

Another advantage of internal averaging is the reduction in the amount of data generated.

Dark Samples and Light Samples

These parameters are used when **Operation Control** is set to **Samples**.

Dark and light samples are used in Continuous and Fixedtime mode, and control the lamp off/on cycle.

Dark Duration and Light Duration

These parameters are used when **Operation Control** is set to **Duration**.

Dark and light duration are used in Continuous and Fixedtime mode, and control the lamp off/on cycle.

External Device

The external device is **None** or Wiper.

If the external device is set to Wiper, power will be applied whenever a data collection begins. Thus, there will be a single wipe at the beginning of a continuous data acquisition, a single swipe at each collection event in periodic mode, or a single swipe for each collection command in polled or SDI-12 mode.

External Device Pre-run Time

The external device pre-run time can be set to a value between **0** and 200 seconds.

This is the time that the sensor waits to acquire data after applying power to the external device. The purpose of this configuration parameter is to let the external device complete its action without interfering with the sensor's measurements.

External Device On During Acquisition

The external device on during acquisition can be set to On or Off.

This configuration parameter allows the sensor to control if the external device is to

continue operating during the sensor's data acquisition.

External Device Minimum Interval

The external device minimum interval is a value between 0 and 1440 minutes (one day).

This configuration parameter limits the frequency of the operation of the external device. At each data acquisition event when the device might be run, the SUNA compares the current time against the most recent time the device was run. Only if more than the configured minimum interval has passed, the device will be operated.

Parameter	Possible Values	Default Value	Short Name
Operation Mode	Continuous, Fixedtime, Periodic, Polled, SDI12	Fixedtime	opermode
Operation Control	Duration, Samples	Samples	operctrl
Countdown [s]	0–3600	3	countdwn
Fixed Time Duration [s]	1–1000000	10	fixddura
Periodic Interval	1m, 2m, 5m, 6m, 10m, 15m, 20m, 30m, 1h, 2h, 3h, 4h, 6h, 8h, 12h, 24h	1h	perdival
Periodic Offset [s]	any value	0	perdoffs
Periodic Duration [s]	0–255	10	perddura
Periodic Samples	0–255	10	perdsmpl
Polled Timeout [s]	0–65535	10	polltout
APF Timeout [h]	0–100	10	apfatoff
Skip Sleep At Startup	On, Off	Off	skpsleep
Lamp Stabil. Time [ds]	0–255	5	stbltime
Lamp Switch-Off Temp.	*	35	lamptoff
Spectrometer Integration Period [ms]	5–60000	N/A	spintper
Dark Averages	1–200	1	drkavers
Light Averages	1–200	1	lgtavers
Dark Samples	1–65535	1	drksmpls
Light Samples	1–65535	10	lgtsmpls
Dark Duration [s]	1–65535	10	drkdurat
Light Duration [s]	1–65535	120	lgtdurat
External Device	None, Wiper	None	exdevtyp
Ex. Dev. Pre-run time [s]	0–120	0	exdevpre
Ex. Dev. During Acq.	On, Off	Off	exdevrun
Ex. Dev. Min. Interval	0–1440	60	exdvival

Table 13: Data acquisition configuration parameters

Data Processing Configuration

Processing Wavelength Interval

The processing (also called fitting) interval is normally from **217** to **240 nm**.

Changing the fitting interval should be done with caution; an unsuitable fitting interval generates invalid results.

Concentrations to Fit

The number of concentrations to be used for processing is 1, 2, or 3.

Freshwater calibrated sensors only use **1** concentration; saltwater calibrated sensors can be made to act like freshwater sensor by setting concentrations to fit to **1**. Normally, saltwater calibrated sensors use **3** concentrations.

Baseline Order

The baseline order is fixed to 1.

Historically, different baseline orders were available. However, there is currently no need to change the baseline order.

Dark Correction Method

The dark correction method is one of SpecAverage or SWAverage.

The purpose of dark correction is to subtract the temperature dependent dark baseline from the measurement. When using SpecAverage, a dark spectrum is measured by either closing the shutter (of present) or switching off the lamp. Using the SWAverage works if seawater or bromide cause extinction below 200 nm, and the measurement in that wavelength range is used as a proxy for the dark baseline.

Temperature Compensation

The temperature compensation flag is On or Off.

Real-time processing temperature compensation only works for saltwater calibrated sensors running in APF mode. The current temperature and salinity values must be provided via the CTD command. This setting will be ignored if the sensor is not able to perform this task.

Salinity Fitting

The salinity fitting flag is **On** or Off.

Salinity fitting can only be switched off in saltwater calibrated sensors running in APF mode. The current temperature and salinity values must be provided via the CTD command. This setting will be ignored if the sensor is not able to perform this task.

Bromide Tracing

The bromide tracing flag is On or Off.

Freshwater calibrated sensors, or saltwater calibrated sensors set to operate as freshwater sensors (Concentrations to Fit set to 1) can be used to detect bromide, at an expense of the sensor's nitrate accuracy.

Absorbance Cutoff

The absorbance cutoff is a value between 0.01 and 10.0. It is normally set to 1.3.

Whenever the absorbance of a channel exceeds the specified absorbance cutoff, that channel is excluded from processing. Setting the cutoff to the maximum value of 10.0 will guarantee that all channels will be included in processing.

Integration Time Adjustment

Integration time adjustment can be Off, **On**, or Persistent.

When set to On or Persistent, in low transmittance conditions, the sensor multiplies the normal integration time by the Integration Time Step. When the transmittance increases later on, the integration time reverts to the normal value.

When set to Persistent, the current Integration Time Factor is kept at power-down to be used at the next power-up event. Otherwise, the sensor starts with the normal integration time.

Integration Time Factor

The integration time factor is initially set to 1.

When integration time adjustment is On or Persistent, the integration time factor can be greater than 1. Currently, only a value of 1 or 20 is permitted.

Integration Time Step

The integration time step is set to 20. It should not be changed.

Integration Time Maximum Factor

The integration time maximum factor is set to 20. It should not be changed.

Parameter	Possible Values	Default Value	Short Name
Fit wavelength low [nm]	210–350	217	wfit_low
Fit wavelength high [nm]	210–350	240	wfit_hgh
	For the setrange command, use:		wdatboth
Concentrations to fit	1–3	1 or 3	fitconcs
Baseline Order	1	1	bl_order
Dark Correction Method	SpecAverage, SWAverage	SpecAverage	drkcormt
Temperature Compensation	On, Off	Off	tempcomp
Salinity Fitting	On, Off	On	salinfit
Bromide Tracing	On, Off	Off	brmtrace
Absorbance Cutoff	0.01–10.0	1.3	a_cutoff
Integration Time Adjustment	Off, On, Persistent	On	intpradj
Integration Time Factor	1–20	1	intprfac
Integration Time Step	1–20	20	intadstp
Integration Time Max	1–20	20	intadmax

Table 14: Data processing configuration parameters

The processing configuration parameters completely determine how the spectrum is processed. Some of the parameters are applicable only in some cases; non-applicable (N/A) parameters are ignored. TS correction processing, even if configured, will only proceed if temperature and salinity values have been provided via the APF CTD command. The following table gives the valid parameter combinations.

Table 15: Combinations of data processing configuration parameters

Processing Mode	Fit Con.	Br Trace	TS Cmp.	Sal. Fit.	Comment
Freshwater	1	Off	N/A	N/A	
Freshwater and bromide trace	1	On	N/A	N/A	
Fit 3 species	3	N/A	Off	N/A	Non-T-S correcting processing
T correction (fit S)	3	N/A	On	On	If T unavailable, uses Fit 3 species
TS correction	3	N/A	On	Off	If TS unavailable, uses Fit 3 species

4.2.4 Polled Mode Commands

Polled mode is useful when the sensor is externally controlled. The sensor waits in low power standby for activity on its input line, and after initialization confirms its readiness to respond to commands via the CMD? prompt. The polled mode timeout setting controls for how long the sensor stays at the polled mode prompt before returning to low power standby.

Polled mode commands are:

Start	begin continuous data acquisition, terminate by sending the \$ character
Measure N	take N light data frames (if N is zero, take a single dark data frame)
Timed N	take light data frames for a duration of N seconds
CTD	send CTD data for temperature-salinity correction (sensor must be able to perform temperature-salinity correction, and processing must be configured for it)
Status	print a sensor status message SATMSG,SUNA,S/N,LampTime,Humidity,Voltage,LampTemp,SpecTemp
\$	enter command line
Sleep	enter low power standby

4.2.5 SDI-12 Mode Commands

The SUNA supports all basic SDI-12 commands, as required by Version 1.3 of the SDI-12 Specification. The commands and the SUNA response are described below. In these descriptions, 'a' refers to the SUNA's SDI-12 address, <CRC> refers to the 3-character Cyclic Redundancy Check Sum, <CR> indicates a carriage return character, and <LF> indicates a line feed character. The SUNA's address defaults to 0 but is configurable by the user. For commands not supported or explicitly described below, the SUNA responds per the SDI-12 v1.3 specification. Details of the command protocol are beyond the scope of this document. Interested users should refer to the SDI-12 specification.

SDI-12 operation has been tested using the SDI-12 Verifier from NR Systems Inc (<u>http://www.sdi-12-verifier.com</u>).

In SDI-12 operation, internal data logging can be used to collect full spectral data. Data can then be retrieved after deployment for further analysis or data reprocessing. If a wiper is integrated, SDI-12 measurement commands will cause the wiper to sweep before each measurement, adding to the time it takes to perform a measurement.

Command: Acknowledge Active (a!)

Response: a<CR><LF>

Notes: confirms SUNA SDI-12 address

Command.	Send Identification (all)			
Response:				
Notes:				
a	SUNA address			
u 11	2 character SDI-12 version e.g. 13 for version 1.3			
	8 character Vendor identification in this case SATLANTC			
mmmmmm	6 character sensor model in this case SUNA			
\\\\	3 character sensor version, e.g. v2			
****	up to 13 character optional field, here used for firmware version. Format: F <major>.<minor>.<patch> If the SUNA determines that the firmware information will not fit in the allocated space, it will not output this field</patch></minor></major>			
An example r	esponse is 013SATLANTC SUNA v2 0002F2.1.2 <cr><lf></lf></cr>			
Command:	Change Address (aAb!)			
Response:	b <cr><lf></lf></cr>			
Notes:	SUNA responds with its new SDI-12 address: b			
Command:	Address Query (?!)			
Response:	a <cr><lf></lf></cr>			
Notes:	SUNA responds with its SDI-12 address: a			
Command:	Verify (V!)			
Response:	atttn <cr><lf></lf></cr>			
Notes:	SUNA always responds with a0000 <cr><lf> No SDI-12 diagnostic information is supported.</lf></cr>			
Command:	Measurement (aM!) Measurement and CRC (aMC!) Concurrent Measurements (aC!) Concurrent Measurements and CRC (aCC!)			
Response:	atttn <cr><lf> (measurement) atttnn<cr><lf> (concurrent measurement)</lf></cr></lf></cr>			
Notes:				
ttt	the time, in seconds, until the sensor will have a measurement ready. The SUNA normally responds within less than 30 seconds.			

n or nn the number of measurement values the SUNA will return in one or more subsequent send data commands. For the SUNA, this value is 4.

For example: 00104<CR><LF> (measurement) 001004<CR><LF> (concurrent measurement)

The SUNA reports 10 seconds are required to make the measurements. Generally it will complete sooner and issue a service request to the controller.

In subsequent data commands, the four values returned will be:

nitrate concentration [µM] nitrogen in nitrate concentration [mg/l] light spectrum average dark spectrum average

Commands: Additional Measurements (aM1!) Additional Measurements and CRC (aMC1!) Additional Concurrent Measurements (aC1!) Additional Concurrent Measurements and CRC (aCC1!)

Response: atttn<CR><LF> (measurement) atttnn<CR><LF> (concurrent measurement)

Notes:

- ttt the time, in seconds, until the sensor will have a measurement ready. The SUNA normally responds with 4 seconds
- n or nn the number of measurement values the SUNA will return in one or more subsequent send data commands. For the SUNA, this value is 7.
- For example: 00047<CR><LF> (measurement) 000407<CR><LF> (concurrent measurement)

In subsequent data commands, the seven values returned will be:

lamp temperature [C] spectrometer temperature [C] lamp time [s] relative humidity [%] internal voltage [V] regulated voltage [V] supply voltage [V]

Commands:	Additional Measurements (aM2!), Additional Measurements and CRC (aMC2!), Additional Concurrent Measurements (aC2!), Additional Concurrent Measurements and CRC (aCC2!),		
Response:	atttn <cr><lf> atttnn<cr><lf></lf></cr></lf></cr>	(measurement) (concurrent measurement)	
Notes:			
ttt	the time, in seconds, until the sensor will have a measurement ready. The SUNA normally responds with 4 seconds		
n or nn	the number of measurement values the SUNA will return in one or more subsequent send data commands. For the SUNA, this value is 7.		
For example:	00109 <cr><lf> 001013<cr><lf></lf></cr></lf></cr>	(measurement) (concurrent measurement)	

In subsequent data commands, the 9 (or 13 for concurrent measurements) values returned will be:

	nitrate concentration [µM] nitrogen in nitrate concentra light spectrum average dark spectrum average measurement date measurement time absorbance at 254 nm absorbance at 350 nm bromide trace lamp temperature [C] spectrometer temp. [C] relative humidity [%] rmse of nitrate processing		tion [mg/l] (concurrent measurement only) (concurrent measurement only) (concurrent measurement only) (concurrent measurement only)
Command:	Additional Measurements (aM3! - aM9!), Additional Measurements and CRC (aMC3! - aMC9!), Additional Concurrent Measurements (aC3! - aC9!), Additional Concurrent Measurements and CRC (aCC3! - aCC9!)		
Response:	atttn <cr><lf> atttnn<cr><lf></lf></cr></lf></cr>	(meas (concu	urement) Irrent measurement)
Notes:	The SUNA supports of ttt is always 000. n is always 0. nn is always 00.	only 2 a	dditional measurements.

Command: Send Data (aD0! - aD9!)

Response: a<values><CR><LF> or a<values><CRC><CR><LF>

Notes: Sends group of data to the controller after a measurement or verification command. The response will vary depending on the previous measurement command.

After the M! or C! command, the SUNA will respond with the 4 above listed values (nitrate concentration in two units, light and dark spectrum average).

For example: 0+1039.040+14.8434+22799+671<CR><LF>

After the MC! or CC! command, the SUNA will respond as per the M! or C! command, but with a CRC value attached.

For example: 0+1038.452+14.8350+22683+672NtW<CR><LF>

After the M1! command, the SUNA will respond to the aD0! command with the first 4 values that are listed above (two temperatures, lamp time and humidity).

For example: 0+33.188+23.500+3315+23.2<CR><LF>

The SUNA will then respond to the aD1! Command with the remaining 3 values (three voltages).

For example: 0+11.92+5.43+13.68<CR><LF>

After the MC1! command, the SUNA will respond as per the M1! command, but with a CRC value attached.

For example: 0+33.813+23.500+3356+23.2AsF<CR><LF>, followed by 0+11.92+5.43+13.62EyF<CR><LF>

The response to the aC1!, aCC1!, aM2!, aMC2!, aC2!, aCC2! commands follows an analogous pattern.

Command: Continuous Measurements (aR0! - aR9!), Continuous Measurements and Request CRC (aRC0! - aRC9!)

Response: a<values><CR><LF>

Notes: Continuous measurements are not supported by the SUNA in SDI-12 mode due to limited lamp life time. The SUNA will always report a0<CR><LF> or a0<CR><CR><LF>.

4.2.6 Analog Output

The SUNA can work with analog input data acquisition systems, such as a Sea-Bird CTD profiler, by using the optional analog output system. The analog interface allows

merging of nitrate data with other data recorded at the same time. A standard application is to integrate the voltage signal into a CTD profiler's auxiliary port, providing a profile of conductivity, temperature, and nitrate versus depth.

Generating Voltage and Current for a Nitrate Concentration

The SUNA generates analog voltage and current representations of the calculated nitrate values. The voltage is generated using a precision 12-bit digital-to-analog converter (DAC) and is in the range of 0.095 to 4.095 Volts. The current is generated using a precision 16-bit DAC and is in the range of 4 to 20 mA.

The SUNA has two configuration values, DAC Minimum Nitrate and DAC Maximum Nitrate, that correspond to the lower and upper bounds of the voltage and current output. If the nitrate concentration is below the DAC Minimum, the output voltage and current will be the minimum voltage or current. If the nitrate concentration is above the DAC Maximum, the output voltage and current will be the maximum voltage or current.

Otherwise, the voltage and current are calculated via

$$V = V_{min} + \frac{V_{max} - V_{min}}{DAC_{max} - DAC_{min}} \cdot (C_{nitrate} - DAC_{min})$$
 and

$$I = I_{min} + \frac{I_{max} - I_{min}}{DAC_{max} - DAC_{min}} \cdot (C_{nitrate} - DAC_{min}) ,$$

where

$C_{nitrate}$	is the nitrate concentrations
DAC _{min}	is the nitrate concentration at minimum voltage and current
DAC_{max}	is the nitrate concentration at maximum voltage and current
V	is the generated voltage
V_{min}	is 0.095 V, the minimum voltage
V _{max}	is 4.095 V, the maximum voltage
Ι	is the generated current
I min	is 4 mA, the minimum current
I _{max}	is 20 mA, the maximum current

The actual voltage or current may differ slightly from the theoretical values. See below on how to accurately calibrate the analog output system.

Calculating Nitrate Concentration from Voltage and Current

The inverse voltage and current equations are

$$C_{nitrate} = DAC_{min} + \frac{DAC_{max} - DAC_{min}}{V_{max} - V_{min}} \cdot (V - V_{min}) \text{ and}$$
$$C_{nitrate} = DAC_{min} + \frac{DAC_{max} - DAC_{min}}{I_{max} - I_{min}} \cdot (I - I_{min}) ,$$

using the same symbols as above.

These equation can be written more compact as

$$\begin{split} C_{nitrate} &= A_0 + A_1 \cdot V \text{ and } \\ C_{nitrate} &= B_0 + B_1 \cdot I \text{ ,} \end{split}$$

where

$$A_{1} = \frac{DAC_{max} - DAC_{min}}{V_{max} - V_{min}}$$
 is the voltage scale coefficient

$$A_{0} = DAC_{min} - A_{1} \cdot V_{min}$$
 is the voltage offset coefficient
$$B_{1} = \frac{DAC_{max} - DAC_{min}}{I_{max} - I_{min}}$$
 is the current scale coefficient

$$B_0 = DAC_{min} - B_1 \cdot I_{min}$$
 is the current offset coefficient

In-System Calibration

The above defined scale and offset coefficients are based on the nominal minimum and maximum voltage and current values. In a deployed system, voltage and current may differ, due to transmission losses. Ideally, the true low and high voltage or current values are used instead of the nominal values.

In order to perform an in-system calibration, a Y-cable is required, that connects the SUNA to both the data acquisition device and a computer. Please contact Satlantic for assistance in creating or purchasing such a cable. With this cable in place, the SUNA is tasked to generate the low DAC and then the high DAC output. The low and high voltage or current values are measured in the data acquisition device, and used to calculate the in-system scale and offset coefficients:

$$A_{1} = \frac{DAC_{max} - DAC_{min}}{V_{high} - V_{low}}$$
 is the in-system calibrated voltage scale coefficient

$$A_{0} = DAC_{min} - A_{1} \cdot V_{low}$$
 is the in-system calibrated voltage offset coefficient
$$B_{1} = \frac{DAC_{max} - DAC_{min}}{I_{high} - I_{low}}$$
 is the in-system calibrated current scale coefficient

 $B_0 = DAC_{min} - B_1 \cdot I_{low}$ is the in-system calibrated current offset coefficient

The SUNA can be tasked to generate the low and high analog output via SUNACom (see the SUNACom user manual) or using the DAC Low and DAC High commands in the terminal interface (see section 4.2.1 Status and Maintenance Commands).

5. Configuration Parameters in Context

While section 4.2.3 Configuration Commands gives a complete list configuration parameters, this section describes groups of configuration parameters that are related because they are used alongside each other.

Configuration parameters are discussed in four categories: Build, Input/Output, Data Acquisition, Data Processing.

5.1 Build Configuration

Build configuration parameters describe the hardware of the sensor, and determine which capabilities are available. Build parameters limit the values some other configuration parameters can take. Only some combinations of build parameters are supported.

Sensor Identification:

Sensor Type	SUNA
Sensor Version	V2
Sensor Serial Number	0000–9999

Option	Description
Super capacitors	Provides short-term power in case when power is lost
PCB supervisor	Provides low-power sleep state
Relay	Allows the SUNA to disconnect itself from its power supply
Analog output	Generates a voltage or current representation of the nitrate values
SDI-12	Allows the SUNA to operate as a SDI-12 client
USB	Allows interfacing via USB, higher data rates than via serial communication
Internal logging	Permits the SUNA to operate as its own data logger
Scheduling	Permits the SUNA to autonomously schedule its data acquisition
APF Mode & T-S Correction	Provides the interface protocol used in APEX floats, and supports on-board temperature-salinity correction of nitrate values

5.2 Input / Output Configuration

Input to the SUNA is via serial RS-232 or if available, via USB, or in SDI-12 mode, via the SDI-12 port.

Output of the sensor is sent via serial RS-232. If available and connected, output is sent via UBS. Data can also be logged internally to file, or converted to an analog voltage or current for output.

With the exception of SDI-12 mode, output generation is independent of the operation mode (see next section), and multiple output destinations can be served concurrently.

Baud Rate	The RS-232 data rate.
Message Level	Error, Warning, Info, Debug, Trace
Message File Size	0–65 [MB]

The sensor generates log messages. The selected message level determines the amount of logging: the least messages are generated for the Error message level, and the most are generated for the Trace message level. Messages are always sent to RS-232, and logged internally if the sensor is equipped with internal logging. Internal logging of messages can be switched off by setting the message file size to zero.

Full_ASCII, Full_Binary, Reduced_Binary,
Concentration, APF, MBARI, None
Full_ASCII, Full_Binary, Reduced_Binary,
Concentration, APF, MBARI, None
Suppress, Output
Suppress, Output
Acquisition, Continuous, Daily
1–99 [MB]

Digital output of data is in the form of fixed or variable length strings of bytes (see section 7. SUNA Frame Definitions). If output or internal logging of frames is not desired, the frame type is set to None. Omitting frame generation, output, and logging when not needed increases the data rate of the sensor.

Dark data frames may be useful for monitoring sensor performance, but are not needed for regular data acquisition. When acquisition time and/or transfer speed or volume are an issue, dark frame output and logging can be suppressed.

Internal data log files are generated with an automated naming schema. Files may be per Acquisition (a new file with each power-up), or Daily (all data collected at one day are placed into a single file), or Continuous (a new file is started when the current file reaches a configured size).

The data log file type should be chosen to match the planned data acquisition and the intended method of data utilization.

For moored deployments, either in periodic mode or scheduled by a controller, daily

data log files are a good choice: The number of files generated over a number of months is modest, while it is easy to select data for a range of dates. If per-acquisition data log files were used instead, many thousand files could be generated. While a SUNA can manage such a number of files, it may become slower. Generally, managing thousands of files can be cumbersome.

For profiles, which are typically collected in continuous operation, per acquisition data log files are a convenient choice: All data between power up and power down will be placed into the same file, facilitating subsequent data management. Using daily or continuous data log files when acquiring multiple profiles can split a profile into two files, requiring manual realignment.

Continuous data log files in conjunction with the maximum data log file size offer control over the number of files and the size of the files that will be generated.

When logging data on board the SUNA, care should be taken to ensure there is sufficient space on the file system. Ideally, data are off-loaded from the SUNA prior to deployment, and the file system cleared as much as possible. When the on board file system is full, subsequent data can no longer be logged and will be lost.

DAC Minimum	Nitrate concentration representing minimum analog output.
DAC Maximum	Nitrate concentration representing maximum analog output.
SDI-12 Address	The address used by the sensor in SDI-12 mode. It is a number from 48 to 57, corresponding to ASCII values '0' to '9'.

5.3 Data Acquisition Configuration

Data acquisition is primarily controlled via the operating mode. Each operating mode has secondary configuration parameters for fine tuning. Both data processing and output generation configuration are independent of the data acquisition scheme. The exception is SDI-12 mode, which has its own output interface.

In the following paragraphs, each operating mode is described, and the configuration parameters relevant to that operating mode are explained.

5.3.1 Continuous and Fixed-time Operating Mode

Continuous mode generates an uninterrupted stream of data. Data collection is autonomous.

When powered, the sensor starts collecting and outputting data. Data acquisition ends when power is removed or the \$ character is sent via serial input. In fixed time mode, data acquisition proceeds for the maximum time configured via fixed-time duration, after which the sensor enters low-power standby.

When collecting data in continuous mode, changes in the spectrometer temperature impact the measured concentrations. For best accuracy, regular dark measurements are required to compensate for the changing temperature. The user can choose a dark

to light data rate based either of a number of samples or on the duration, via the Operation Control configuration parameter. Then, the sensor will collect data in a D-L-...-L-D-...-D-L... schema. If operation control is SAMPLES based, the user controls the respective numbers via the Light Samples and Dark Samples configuration parameters. When operation control is DURATION based, the user controls the respective durations via the Light Duration and Dark Duration configuration parameters.

Configuration: Operation Control, Countdown, Light Samples, Dark Samples, Light Duration, Dark Duration.

5.3.2 Periodic Operating Mode

Periodic mode generates short bursts of data at pre-configured times. Data collection is autonomous.

When powered, the sensor enters low-power standby. Any activity on RS-232 or USB brings the sensor within three seconds to the command interface, indicated by SUNA>. After a duration of Countdown seconds (configuration parameter) without input, the sensor returns to low power standby.

At the pre-configured times, the sensor collects a fixed number of data points, or data points for a fixed duration. After data collection, the sensor returns to low-power standby.

The start times of the data collection events are separated by a fixed interval. Possible values for the interval are 1, 2, 5, 10, 12, 15, 30, minutes, or 1, 2, 3, 4, 6, 12, or 24 hours. The time grid starts relative to the start of the day. The time grid can be offset from the start of the day via the Periodic Offset configuration parameter.

The data collection event can be either sample or duration based. This is controlled via the Operation Control configuration parameter. For sample based data collection, the Periodic Duration configuration parameter determines the number of data samples that will be collected. For duration based data collection, the Periodic Duration configuration parameter determines the number of seconds over which data will be collected.

Configuration: Operation Control, Periodic Interval, Periodic Offset, Periodic Duration, Periodic Samples, Countdown

5.3.3 Polled Operating Mode

Polled mode generates data in response to a command. Data collection is driven by a controller via the serial interface.

When powered, the sensor enters a low power standby. Any activity on RS-232 or USB brings the sensor within three seconds to the polled command prompt, indicated by CMD?. After a duration of Polled Timeout (configuration parameter, in seconds) without command input, the sensor returns to low power standby.

Supported commands are described in section 4.2.4 Polled Mode Commands.

Configuration: Polled timeout, Skip Sleep

5.3.4 SDI-12 Operating Mode

SDI-12 mode generates data in response to a command. Data collection is SDI-12 controller driven. When powered, the sensor enters a standby state where it responds only to SDI-12 commands. The sensor interface conforms to the SDI-12 protocol. Sending a \$ character via the RS-232 port gives access to the command prompt. Supported commands are described in section 4.2.5 SDI-12 Mode Commands.

Configuration: SDI-12 Address

Name	Acceptable Values	Explaining Subsection
Operation mode	Continuous, Fixedtime, Periodic, Polled, SDI12	
Operation control	Samples, Duration	Continuous mode, Periodic mode
Fixed time duration	1–1000000	Continuous mode
Light samples	1–65535	Continuous mode
Dark samples	1–65535	Continuous mode
Light duration	1–65535	Continuous mode
Dark duration	1–65535	Continuous mode
Periodic interval	1m, 2m, 5m, 6m, 10m, 15m, 20m, 30m, 1h, 2h, 3h, 4h, 6h, 8h, 12h, 24h	Periodic mode
Periodic offset	0–86399	Periodic mode
Periodic samples	1–255	Periodic mode
Periodic duration	1–255	Periodic mode
Polled timeout	0–65535	Polled mode
APF timeout	1–100	APF mode
Skip Sleep at Start	On, Off	Polled mode, APF mode

Table 17: Data acquisition configuration parameters by operating mode.

5.4 Data Processing Configuration

Data processing is independent of input/output and data acquisition configuration.

5.4.1 Basic Data Processing

Data processing normally uses the 217 to 240 nm interval of the measured spectrum. The measured absorbance in that interval is decomposed into absorbances due to individual absorbers, and the absorbance due to an absorber is converted to a concentration value for that absorber.

The sensor can decompose the absorbance either solely into nitrate (freshwater use) or, if calibrated for this, into nitrate, seawater, and seawater temperature effects (oceanographic use). If a sensor has been calibrated for oceanographic use, but is to be used in a freshwater environment where the salinity will be below 1 PSU, the user should constrain data processing to use only nitrate decomposition by setting the Concentrations-to-Fit configuration parameter from 3 to 1. Reducing the number of concentrations to fit improves the precision of the processed data.

Under normal conditions, no other processing parameters need to be changed.

Configuration: Concentrations to Fit, Fit Wavelength Low, Fit Wavelength High

5.4.2 Special Case: Bromide Tracing

In freshwater, bromide can be used as a tracer. If the sensor's Bromide Trace configuration parameter is set to On, the sensor will analyze the measured spectrum for the presence of bromide, and output the result in its regular frame.

Configuration: Bromide Tracing

5.4.3 Special Case: Highly Absorbing Water

Highly absorbing waters pose a challenge to the sensor. In its normal configuration, the part of the spectrum with an absorbance of more than 1.3 is excluded from processing. Using parts of the spectrum of higher absorbance will reduce accuracy and precision of the measured concentrations. The user may increase the Absorbance Cutoff to a higher value, to extend the operational range of the sensor at the expense of reduced data quality.

If the absorbance reaches values between 2.0 and 2.5, data quality deteriorates further. If the Integration Time Adjustment configuration parameter is set to On or Persistent, the sensor will start making measurement using a spectrometer integration time that is 20 times as long as the normal integration time. This longer integration time increases the signal-to-noise ratio in faint light conditions, and allows the sensor to operate in optically dense conditions. When the optical density drops, the sensor will revert to the normal spectrometer integration time. Configuration: Absorbance Cutoff, Integration Time Adjustment, Integration Time Factor, Integration Time Step, Integration Time Maximum Factor.

Nama	Acceptable Values	Cubaccian fan Funlanstian
Name	Acceptable values	Subsection for Explanation
Lower limit of fit interval	217–350	Basic processing
Upper limit of fit interval	217–350	Basic processing
Concentrations to fit	1–3	Basic processing
Temperature correction	On, Off	Temperature-Salinity Correction
Salinity fitting	On, Off	Temperature-Salinity Correction
Bromide tracing	On, Off	Bromide Tracing
Absorbance cutoff	0.01–10.0	Highly Absorbing Water
Integration Time Adjustment	Off, On, Persistent	Highly Absorbing Water
Integration Time Factor	1–20	Highly Absorbing Water
Integration Time Step	1–20	Highly Absorbing Water
Integration Time Maximum	1–20	Highly Absorbing Water

Table 18: Data processing configuration parameters in use case context
6. Use Scenarios

6.1 Profiling

6.1.1 Objectives and Considerations

A profile is a continuous series of measurements taken over a depth range, where nitrate concentrations may be collected for either down and up cast or both. The descent and ascent rate together with the sensor's data rate determine the spatial resolution of the profile.

The data rate depends on a number of factors. The integration period of the spectrometer sets a lower limit on the data rate. Additional time is required for data processing and data output. Output, even at high baud rates, is always slower than internal logging of data.

6.1.2 Example

This example assumes that the sensor is not outputting any data, but only logging data internally. The ascend and/or descend rates of the profiler are assumed to be rather modest, thus internal averaging of spectra is used to obtain improved data quality.

It is further assumed that temperature and salinity data are collected alongside the sensor, for post-processing employing temperature-salinity correction. Therefore, full spectral data are logged.

	Setting Parameter	Value in Profiling Deployment
Input /	Message Level	Warn
	Message File Size	2
	Output Frame	None.
Output	Logging Frame	Full_ASCII
	Logging Dark Frame	Output
	Log File Type	Acquisition
	Operation Mode	Continuous
	Operation Control	Samples
Data	External Device	None
Acquisition	Countdown	15
	Dark Averages	1
	Light Averages	5
	Dark Samples	1
	Light Samples	60
	Temperature Compensation	Off
	Salinity Fitting	On
Process	Bromide Tracing	Off
	Concentrations to fit	3
	Dark Correction Method	SpecAverage
	Absorbance Cutoff	1.3
	Integration Time Adjustment	On
	Fit Wavelength Low / High	217, 240

Table 19: Configuration parameters illustrating a profiling deployment.

6.2 Moored

6.2.1 Objectives and Considerations

In moored applications, power management, especially if running from battery, has to be considered.

Moored applications typically have infrequent service intervals. As most environments cause bio-fouling of the sensor, either passive (fouling guard) or active (wiper) counter-

measures are necessary.

The sensor can run autonomously (periodic mode), respond to a controller (polled, APF, or SDI-12 mode), or be powered up and down by a controller (running in continuous mode).

Regardless of the operation control, moored applications often collect discrete samples. The user can choose to either collect a series of samples, and perform averaging as a second data processing step. Alternatively, the sensor can be configured to collect a single data sample that already is an average of multiple measurements.

Before the deployment, the sensor must receive a reference spectrum update, where the reference spectrum is collected under data acquisition conditions that resemble the deployment data collection conditions.

6.2.2 Example

This example assumes that the SUNA operates autonomously in periodic operating mode. Data are collected in analog form by a data acquisition device, and also logged internally for post-deployment analysis.

The SUNA is also equipped with a wiper, that is internally controlled. It takes the wiper some 15 seconds to complete a sweep through the sampling volume. The wiper speed is highest for an unobstructed sampling volume, and when operating at the upper input voltage range. The minimum required delay between subsequent wipes is 30 seconds.

	Setting Parameter	Value in Moored Deployment
Input /	Message Level	Info
	Message File Size	2
	Output Frame	None.
Output	Logging Frame	Full_ASCII or Full_Binary
	Logging Dark Frame	Output
	Log File Type	Acquisition
	Operation Mode	Periodic
	Operation Control	Samples
Data	External Device	Wiper
Acquisition	External Pre-Run Time	15
	Periodic Interval	15m
	Periodic Samples	10
	Dark Averages	1
	Light Averages	1
	Temperature Compensation	Off
	Salinity Fitting	On
Process	Bromide Tracing	Off
	Concentrations to fit	3
	Dark Correction Method	SpecAverage
	Absorbance Cutoff	1.3
	Integration Time Adjustment	On
	Fit Wavelength Low / High	217, 240

Table 20: Configuration parameters illustrating a moored deployment.

7. SUNA Frame Definitions

7.1 Frames with Synchronization Headers

The frames described in this section start with a ten character header which uniquely identifies the sensor and data type. The unique header allows to extract sensor specific frames from arbitrary collections of data.

There are two types of such frames: Variable length frames and fixed length frames. In variable length frames, the fields are in ASCII format and comma separated . In fixed length frames, each field has a fixed size, and is usually in binary format.

The variable length frame headers start with SAT, followed by three characters identifying the frame type. SATSLF and SATSDF for full ASCII light and dark frames, and SATSLC and SATSDC for concentration light and dark frames, respectively. The last four characters are the sensor serial number. Example for serial number 1234: SATSLC1234 for concentration light frame.

The fixed length frame headers start with SAT, followed by three characters identifying the frame type: SATSLB and SATSDB for full binary light and dark frames, and SATSLR and SATSDR for reduced binary and dark frames, respectively. The last four characters are the sensor serial number. Example for serial number 1234: SATSLR1234 for reduced binary light frame.

For each field in these frames, format and size are given. The formats are ASCII Integer (AI), ASCII Float (AF), ASCII String (AS), Binary Unsigned Integer (BU), Binary Float (BF), and Binary Double (BD). Binary fields have fixed sizes, ASCII fields may have fixed or variable sizes. BF and BD data formats conform to the IEEE 754 standard. Binary data are in big endian order.

Field	Concentration	Full ASCII	Full Binary	Reduced Binary
Header and Serial Number	SATSLCnnnn SATSDCnnnn	SATSLFnnnn SATSDFnnnn	SATSLBnnnn SATSDBnnnn	SATSLRnnnn SATSDRnnnn
Date, year and day-of-year	AI 7	AI 7	BS 4	BS 4
Time, hours of day	AF	AF	BD 8	BD 8
Nitrate concentration [µM]	AF	AF	BF 4	BF 4
Nitrogen in nitrate [mg/l]	AF	AF	BF 4	BF 4
Absorbance at 254 nm	AF	AF	BF 4	BF 4
Absorbance at 350 nm	AF	AF	BF 4	BF 4
Bromide trace [mg/l]	AF	AF	BF 4	BF 4
Spectrum average	-	AI	BU 2	BU 2
Dark value used for fit	-	AI	BU 2	BU 2
Integration time factor	-	AI	BU 1	BU 1
Spectrum channels	-	256 x Al	256 x BU 2	32 x BU 2
Internal temperature [°C]	-	AF	BF 4	-
Spectrometer temperature [°C]	-	AF	BF 4	BF 4
Lamp temperature [°C]	-	AF	BF 4	BF 4
Cumulative lamp on-time [s]	-	AI	BU 4	-
Relative Humidity [%]	-	AF	BF 4	BF 4
Main Voltage [V]	-	AF	BF 4	-
Lamp Voltage [V]	-	AF	BF 4	-
Internal Voltage [V]	-	AF	BF 4	-
Main Current [mA]	-	AF	BF 4	-
Fit Aux 1	-	AF	BF 4	-
Fit Aux 2	-	AF	BF 4	-
Fit Base 1	-	AF	BF 4	-
Fit Base 2	-	AF	BF 4	-
Fit RMSE	AF	AF	BF 4	BF 4
CTD Time [seconds since 1970]	-	AI	BU 4	BU 4
CTD Salinity [PSU]	-	AF	BF 4	BF 4
CTD Temperature [°C]	-	AF	BF 4	BF 4
CTD Pressure [dBar]	-	AF	BF 4	BF 4
Check Sum	-	AI	BU 1	BU 1
Terminator	CR LF	CR LF	-	-

Table 21: Synchronization header frame definitions

7.2 APF Frame

Fields in the APF frame are comma separated.

Frame Field	Example Value
Record 16-bit CRC	0xE0B6
Record Data Type	A
Timestamp (GMT)	7/22/2011 19:04
CTD Timestamp (1970 epoch seconds)	0
CTD Pressure (dBar)	-1
CTD Temperature [°C]	-1
CTD Salinity	-1
Sample Counter	246
Power Cycle Counter	3
Error Counter	1
Internal Temperature [°C]	27.34
Spectrometer Temperature [°C]	28.12
Internal Relative Humidity (%)	4.21
Supply Voltage (V)	11.78
Supply Current (A)	0.523
Reference Detector Mean	2345
Reference Detector Standard Deviation	6.54
Dark Spectrum Mean	567
Dark Spectrum Standard Deviation	7.23
Sensor Salinity	32.23
Sensor Nitrate	12.21
Absorbance Fit Residuals (RMS)	1.23E-04
Output Pixel Begin	33
Output Pixel End	63
Output Spectrum (Hex Packed, 4 characters for each output channel, Begin-End+1 channels	0701079D085B092009F90ADC0BDD0CFC0E370F 88110512A41470165D187A1AAA1
Seawater Dark (Mean of Channels 1 to 5)	591.2

Table 22: APF data frame definition

7.3 MBARI Frame

MBARI frames are generated for dark and for light spectrum measurements. Dark frames begin with a D, light frames begin with an S. All fields in the MBARI frame are comma separated.

Frame Field	Example Value
Frame Type for dark frame, or for light (spectrum) frame	D S
Timestamp (GMT)	7/22/2011 19:04:23.1234
Internal Temperature [°C]	27.34
Spectrum Average for dark frame, or Reference Detector Average for light frame	2345.23
Spectrum Standard Deviation for dark frame, or Reference Detector Std. Dev. for light frame	6.54
Output Spectrum (256 channels)	12345
Terminator	CR LF

Table 23.	MRARI	data	frame	definition
1 0010 20.		uala	name	uemmuon

8. SUNA Calibration File

8.1 File Name

SUNA calibration files use the following file naming convention: The file name has a base of eight letters and a three letter 'CAL' extension. The file name is not case sensitive. The first three letters are 'SNA', followed by the four digits of the sensor serial number, and the last letter is a version letter. Version letters run from A to Z.

8.2 File Format

SUNA calibration files are text files, consisting of a series of header lines followed by a series of coefficient lines. A line is terminated by either a line feed character (hexadecimal 0A) or by a carriage return character followed by a line feed character (hexadecimal 0D 0A).

A header line always begins with the 'H,' character sequence, followed by auxiliary information. A coefficient line always begins with the 'E,' character sequence, followed by a series of comma separated floating point numbers.

The last line may be succeeded by a series of CTRL-Z (hexadecimal 1A) padding characters. These are introduced by the XMODEM protocol that is used to transfer calibration files from and to the SUNA, and must be ignored.

8.3 File Interpretation

The first header line always contains the sensor type (SUNA) and the sensor four digit serial number, followed by some generic comments. Subsequent header lines contain information about the generation.

If there is a header line with the keyword T_S_CORRECTABLE, the coefficients can be used for temperature salinity correction.

The temperature of the calibration is given in the T_CAL header line. This temperature is needed when applying the temperature salinity correction.

The last header line always consists of a comma separated list of labels. These labels describe the content of the coefficient lines. The number of labels in this line must match the number of entries in the coefficient lines. The first label is always Wavelength, the second label is normally NO3, and the last label is always Reference. For sensors calibrated for sea water, there are a SWA and a TSWA label between the NO3 and the Reference label.

Calibration files are used by the SUNA for on-board processing and by SUNACom for data re-processing.

9. Firmware Upgrade

9.1 Firmware Upgrade Using SUNACom

The firmware upgrade can be initiated via the SUNACom. See section Upload Firmware of the SUNACom user manual for details.

9.2 Firmware Upgrade Using the Terminal Interface

The firmware upgrade is initiated via the upgrade command given at the command line. See section 4.2 Command Line Interface for details.

After the upgrade command, the SUNA's bootloader program executs. It reports to the command line using the SATBLDR> prompt.

Use the w command to initiate the firmware upload. Then, send the firmware file using the XMODEM protocol to the SUNA. Firmware files have the sfw file extension.

The bootloader rejects invalid or corrupt files. The user can check if the uploaded file is valid by issuing the v (verify) command.

After a valid firmware file has been uploaded, use the a command to let the bootloader execute the new firmware at power-up.

Then, power cycle the sensor. The new firmware will execute on the sensor.

10. Troubleshooting

10.1 Sensor Is Not Responsive

Check Power

Confirm that sufficient power reaches the sensor. Use a voltage meter to confirm that the power cable supplies 8–18 VDC (8–15 VDC for SUNA with an integrated wiper). See section 3.2 Specifications for the cable pin-out.

Reset Sensor

It is possible for the sensor to get stuck in an undefined state if its input power is sporadically out-of-range. In that case, the sensor should be powered down for 60 seconds, and then re-powered.

Check Power Consumption

Using a power supply with an accurate current indication will tell if the sensor is operating at all, and what operating state it may be in.

If the current is above 500 mA, the sensor is acquiring data. Inserting a piece of white paper into the sampling volume should show a bright spot, showing that the sensor lamp is operating.

If the current is above 5 mA, the sensor is in standby, and should respond to input over its serial input.

If the current is above 100 μ A, the sensor is in a low-power mode, and should respond to input over its serial input.

If the current is below 100 μ A, the sensor is not operating. Please contact Satlantic for further assistance.

Test Serial Cable

The sensor may appear to be non-responsive due to a faulty communication cable. The user can check the communication cable for continuity. See section 3.2 Specifications for the connector and cable pin-out.

Operating Mode

The sensor may be unresponsive to the received input because it is in an unexpected operating mode. For example, if the sensor is in SDI-12 mode, it will not respond to normal commands, or may not output data as in other operating modes.

If a connection via SUNACom does not succeed, a terminal emulator connection may be attempted.

Regardless if the operating mode, sending a \$ character to an operational sensor will

generate a response.

If there is no response, please contact Satlantic for further assistance.

10.2 Sensor Output Is Unexpected

Unexpected results can take many forms. A sensor that performed fine over a long period of time may suddenly report results that differ qualitatively or quantitatively from previous results.

Below are listed a few checks that may identify the problem.

Warning or Error Messages

In case of obvious problems, the sensor outputs error or warning log messages. If the sensor has internal logging capability, these are also logged to file. Monitoring the log messages or reviewing the content of the message log file may point to the origin of the problem.

Inaccurate Nitrate

Systematically inaccurate, but otherwise stable nitrate concentrations indicate the need to clean the sensor windows and to perform a reference update.

A reference update is best performed from within the SUNACom software. A reference update involves replacing the reference spectrum in the currently active calibration file by a new reference spectrum. Detailed instructions are provided in the SUNACom user manual.

If the concentrations inaccuracies persist, please contact Satlantic.

Imprecise or Noisy Nitrate, Low Spectral Intensity

If the nitrate concentration changes by more than 25 μ M within a few samples while measuring a stable water sample, the measured spectral intensity is usually too low.

The spectral intensity of the sensor drops when the optical path gets obstructed or if optical component degrade.

Obstructions may be due to a change in the water content, or due to accumulation of matter (bio film, settled particles) in the sampling volume. If the spectral intensity remains low after cleaning of the sample volume, and especially the windows, please contact Satlantic.

High Humidity

If the relative humidity inside the sensor exceeds 90%, the sensor may have developed a leak, and needs to be returned to Satlantic for service. High humidity is problematic because it leads to failure of sensor components. Furthermore, high humidity may lead to condensation on optical components, making measurements inaccurate.

11. Accessories

11.1 Foul Guard

The foul guard is an optional accessory used for moored applications without an active pumping system. The foul guard consists of a strip of perforated copper plate that is formed around the SUNA sample volume. The guard is secured to the SUNA by a plastic clamp. The copper inhibits biofouling while the perforations allow passive flushing of the sample volume. When using the foul guard, the SUNA should be mounted so that the optical chamber is mounted at 90 degrees to the vertical. This orientation helps to prevent air bubbles and sediment from becoming trapped in the sample volume.



Illustration 6: Foul Guard

11.2 Wiper

The Zebra-Tech Hydro-Wiper is available as an integrated accessory. The wiper gently brushes the sample chamber to remove biological growth and particulate deposits from the optical path, ensuring consistent sampling conditions and data quality. The wiper reduces the need for site visits to manually clean the instrument, maintaining data quality through long deployments in harsh environments.

The integrated Hydro-Wiper is controlled by the SUNA and works with all operating modes such as periodic and polled modes. The wiper performs a single sweep before each sampling event. This option simplifies cabling and integration requirements for the user. The integrated Hydro-Wiper is not available for the Deep SUNA.

The wiper sweep angle is 90° for new models, 150° for old builds. For proper operation, the wiper movement must not be obstructed. The drawing below gives the minimum space requirements.

The wiper drive shaft features a slip mechanism, so the wiper arm can be manually moved if necessary. This also protects the wiper from damage if the wiper arm is subject to force during operation.



Illustration 7: SUNA with integrated wiper.



Illustration 8: Space requirements for the integrated wiper.

11.3 Flow Cell

The flow cell is an optional accessory used for moored applications with a pumped circulation system. It is also useful for calibration updates. The flow cell consists of a plastic cell that seals against the instrument housing and directs pumped flow across the optical path of the SUNA. The flow cell is equipped with a copper tube on the inlet port and a plastic barbed fitting on the outlet port that would be connected to the pump by flexible tubing. The kit includes additional elbow fittings that may be installed on the inlet or outlet ports to suit the physical arrangement of the instrument for deployment. The flow cell is secured to the SUNA by a plastic clamp. O-rings ensure the flow cell seals tightly around the sample volume.



Illustration 9: Flow Cell

12. Maintenance

Before a deployment, and regularly during the deployment, the sensor windows have to be cleaned. At the same time, the reference spectrum should be updated.

A reference update is best performed from within the SUNACom software. A reference update involves replacing the reference spectrum in the currently active cal file by a new reference spectrum. Detailed instructions are provided in the SUNACom user manual.

After every deployment, the sensor must be cleaned with freshwater prior to storage. Corrosion resulting from failure to do so is not covered under warranty.

At regular intervals, check the sensor's internal humidity. If the humidity increases by more than a few percent per day, there is the possibility of a leak, and servicing is suggested.

At regular intervals, check the spectral intensity in pure water. While the optical intensity is expected to decrease over time, sudden changes in intensity may indicate problems with a sensor subsystem. Contact Satlantic if there is a sudden drop in intensity by more than 20%.

13. Safety And Hazards

13.1 Pressure Hazard

Warning! If you suspect that the sensor has flooded, use **extreme caution** around the sensor. If the sensor leaked at depth it might remain pressurized when recovered. If you suspect a flood, make sure to check the sensor for signs of pressurization. If the sensor is pressurized you may notice the gap between the end cap and pressure case look to be extended.

To relieve the sensor pressure, stand to the side of the sensor. Relieve the pressure by **very** slowly unscrewing the bulkhead connector. Be extremely careful, as if the sensor is pressurized the connector may be forced out of the housing with extreme force and at high velocity.

13.2 Electrical Hazard

Use care when connecting power supply cables to the sensor. A shorted power supply or battery can output maximum current, potentially harming the user or the equipment.

When transporting or shipping, install the dummy plug with locking sleeve on the sensor connector to prevent accidental shorting of the terminals.

Handle electrical terminations carefully, as they are not designed to withstand strain. Disconnect the cables from the bulkhead connector by pulling on the connector heads and not on the cables. Do not twist or wiggle the connector while pulling, as this will damage the connector pins.

Do not use petroleum-based lubricants on connectors. Connectors should be free of dirt and lightly lubricated before mating. We recommend applying a thin film of DC-111 silicone grease (made by Dow-Corning) on the male pins prior to connection.

While probing with a voltmeter, take care not to short the probes. Shorts can damage equipment, create safety hazards, and blow embedded fuses.

13.3 Deployment and Recovery Safety

Do not leave the sensor in direct sunlight. Extreme heat (35°C or greater) can cause damage.

When deploying a sensor in water, do not leave it unattended. Boat drift can entangle the cable and cause damage or sensor loss.

Never lift the sensor by pulling it from the cable. This can cause damage to the bulkhead connectors, cables, and splices.

Dummy connectors should be replaced as soon as the equipment is retrieved. This will help protect the bulkhead connector from dirt and damage.

14. Warranty

14.1 Warranty Period

All Satlantic equipment is covered under a one-year parts and labor warranty from date of purchase.

14.2 Restrictions

Warranty does not apply to products that are deemed by Satlantic to be damaged by misuse, abuse, accident, or modifications by the customer. The warranty is considered void if any optical or mechanical housing is opened. In addition, the warranty is void if the warranty seal is removed, broken or otherwise damaged.

14.3 Provisions

During the one year from date of purchase warranty period, Satlantic will replace or repair, as deemed necessary, components that are defective, except as noted above, without charge to the customer. This warranty does not include shipping charges to and from Satlantic.

14.4 Returns

To return products to Satlantic, whether under warranty or not, contact the Satlantic Customer Support Department and request a Returned Material Authorization (RMA) number and provide shipping details.

All claims under warranty must be made promptly after occurrence of circumstances giving rise thereto and must be received by Satlantic within the applicable warranty period. Such claims should state clearly the product serial number, date of purchase (and proof thereof) and a full description of the circumstances giving rise to the claim. All replacement parts and/or products covered under the warranty period become the property of Satlantic.

14.5 Liability

IF SATLANTIC EQUIPMENT SHOULD BE DEFECTIVE OR FAIL TO BE IN GOOD WORKING ORDER THE CUSTOMER'S SOLE REMEDY SHALL BE REPAIR OR REPLACEMENT AS STATED ABOVE. IN NO EVENT WILL SATLANTIC BE LIABLE FOR ANY DAMAGES, INCLUDING LOSS OF PROFITS, LOSS OF SAVINGS OR OTHER INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING FROM THE USE OR INABILITY TO USE THE EQUIPMENT OR COMPONENTS THEREOF.

15. Contact Information

If you have any problems, questions, suggestions, or comments about the sensor or manual, please contact us.

Call us direct at <u>+19024924780</u> between 8 AM and 5 PM, Atlantic Time (GMT - 0400) or send us an e-mail any time at <u>info@satlantic.com</u>. For specific requests such as price quotations, product support, or return materials authorization (RMA) for repair or recalibration, please select the applicable contact:

 Sales:
 http://satlantic.com/contact-sales
 or sales@satlantic.com

 Support
 http://satlantic.com/contact-support
 or support@satlantic.com

 Service:
 http://satlantic.com/rma

Written inquires and returns may be sent to:

Satlantic LP Richmond Terminal- Pier 9 3481 North Marginal Road Halifax NS B3K 5X8 CANADA

Satlantic is not open for business during Canadian statutory holidays:

New Year's Day	January 1
Good Friday	The Friday before Easter Sunday
Victoria Day	The first Monday before May 25
Canada Day	July 1
Civic Holiday	The first Monday in August
Labor Day	The first Monday in September
Thanksgiving Day	The second Monday in October
Remembrance Day	November 11
Christmas Day	December 25
Boxing Day	December 26

SUNA Manual
For SUNA running firmware version 2.5 or later
16. Revision History

16. Revision History

Revision A, 2013-11-01:	Initial release.
Revision B, 2014-05-02:	 3.2.3 Refer for T-S-Correction to SUNACom. 5.2 Expand data file type explanation. 7.1 Fix typo in frame table, nitrate units. 11.2. Remove external wiper; enlarge wiper images.
Revision C, 2014-05-15:	3.2.3 Add μ M nitrate to mg/l nitrogen conversion factor.
Revision D, 2014-09-16:	 3.2.1 Add storage and operating temperature range. 3.2.2 Add 1 A current requirement of power supply. 4.2.3 Add acquisition file type duration setting. 4.2.3 Add minimum interval for external device. 4.2.5 SDI-12 operation: wiper and internal logging. 5.4.1 Specify 1 PSU limit for freshwater processing.
Revision E, 2014-12-01:	4.2.1 Added special swipewiper command.4.2.3 Remove unused legacy configuration parameters.4.2.3 Add Custom Identification configuration parameter.