FEASIBILITY OF USING FIELD TESTS FOR DETECTING SOURCES OF FECAL AND NITROGEN POLLUTION

HOOD CANAL WATERSHED POLLUTION IDENTIFICATION AND CORRECTION

Prepared for
Hood Canal Coordinating Council

Prepared by
Herrera Environmental Consultants, Inc.

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TABLES

1. INTRODUCTION

The Hood Canal Coordinating Council (HCCC) requested that Herrera Environmental Consultants (Herrera) evaluate the feasibility of using non-laboratory methods for pollution identification and correction (PIC) monitoring of the Hood Canal Watershed. The Hood Canal Regional PIC Monitoring Plan (HCCC 2014) consists of the following elements:

1. Marine water monitoring of fecal coliform (FC) bacteria, temperature, and salinity by the Washington State Department of Health (WSDOH) six times each year using a stratified random sampling approach

2. Ambient fresh water stream monitoring of FC and/or *E. coli* (EC) bacteria, temperature, pH, dissolved oxygen, and conductivity by multiple jurisdictions on a monthly basis at 36 stream/river locations using a stratified random sampling approach

3. Ambient lake monitoring of cyanobacteria and EC at swimming beaches, and dissolved oxygen, temperature, pH, EC, chlorophyll *a*, Secchi depth, total phosphorus, and total nitrogen at the center of 16 lakes by multiple jurisdictions on a monthly basis between May and October

4. Sanitary and shoreline surveys and assessments of FC bacteria sources by WSDOH. Sanitary surveys of commercial shellfish growing areas are conducted every 8 to 12 years. The PIC monitoring plan recommends conducting shoreline surveys for bacteria in prioritized areas, and lists regional potential PIC project areas. Shoreline surveys are targeted to clean up closed shellfish growing areas and to protect open growing areas on a rotating basis.

Local funding constraints have prevented local Hood Canal jurisdictions from implementing ongoing fresh water quality monitoring for even the most basic parameters: bacteria and temperature. The Hood Canal Regional PIC team is very sensitive to work plan element costs and came to the conclusion in the PIC monitoring plan that shoreline surveys area the most effective way to address fecal pollution discharges to the shoreline (HCCC 2014). Fresh water monitoring can be added as funding permits to develop data on upland discharges.

The HCPIC Regional PIC Program will utilize WSDOH marine water data to find and rank shoreline water quality problem areas. A shoreline survey element will be implemented first to effectively identify and correct fecal pollution discharges to the Hood Canal Action Area shoreline. The plan is to add fresh water monitoring as funding permits.

This report identifies potential methods and assesses the feasibility of using non-laboratory field tests for additional PIC monitoring to identify fecal bacteria and nitrogen sources in the Hood Canal Watershed, including marine and fresh waters, with an emphasis on detecting sources from onsite sewage systems (OSS). These field tests are intended to supplement and not replace ongoing PIC monitoring using laboratory analysis of water samples.

2. METHODS

Herrera gathered information from manufacturers, vendors, reports, and other literature that was readily available from online sources regarding available field meters and test kits for measuring:

1. Fecal bacteria (FC, EC and Enterococcus)

2. Fecal indicator parameters (optical brighteners, surfactants [MBAS], potassium, and ammonia nitrogen)

3. Nitrate, nitrite, ammonia, and total nitrogen

Field procedures were not evaluated for monitoring of non-priority water quality parameters such as nutrient indicators (e.g., photosynthetically active radiation [PAR], algae, cyanobacteria, and pH) or petroleum hydrocarbons.

Method attributes were compiled into tables that include the type of analysis, manufacturer, minimum detection limit, range, accuracy, ease of use, advantages, disadvantages, and costs. For comparison of method costs, example first and second year annual project costs (including equipment, materials, and labor) were estimated for 12 monthly tests at 36 locations using a labor rate of $100/hour.

3. RESULTS AND DISCUSSION

Tables 1 through 3 present compiled information of field test methods for fecal bacteria, fecal indicator parameters, and nitrogen parameters, respectively.

Recommendations for preferred field test methods and field sampling methods are presented in the following sections. It is recommended that specific manufacturers are contacted and further investigation of method effectiveness by experienced users be conducted prior to purchasing equipment to ensure that project objectives will be met using the specific field methods.

3.1. Fecal Bacteria

Table 1 presents field methods for EC and Enterococcus bacteria analyses. Two EC field methods and one Enterococcus field method were identified, and no FC field methods were identified by this evaluation. For EC analysis, the Coliscan Easygel test kit (total project cost of $30,072) is the more cost-effective method and requires less equipment cost than the Colilert-18 with Quanti-Tray/2000 method (two-year project cost of $38,128). In addition, the Coliscan Easygel test kit does not require incubation, which would reduce the total project cost to $28,072 without the purchase of an incubator. The Enerolert with Quanti-Tray/2000 field test method for Enterococcus has a two-year project cost of $39,580.

All field test kits are considered moderately difficult to perform. Some training on sterile techniques and interpretation of test results would be required, and would potentially compromise accuracy of the tests in comparison to laboratory testing. In addition, testing of a batch of 36 samples would occupy a considerate amount of counter space during the incubation period.

Currently, the Kitsap Public Health District uses an accredited commercial laboratory for FC and EC testing at per sample costs of $10.50 for EC analysis and $14.00 for FC analysis. These per sample costs are low compared to $20 to $35 by other commercial laboratories, possibly due in part to the large number of samples analyzed. For 12 monthly tests at 36 locations over a two year period, the total project costs are $9,072 for EC analysis and $12,096 for FC analysis, plus labor to deliver samples to the laboratory.

Field test kits for fecal bacteria are more expensive and less reliable than laboratory analysis. Therefore, it is recommended that the HCCC continue using only laboratory analysis of samples for EC and FC.

3.2. Fecal Bacteria Indicator Parameters

Table 2 presents field tests of the following fecal indicator parameter: optical brighteners, surfactants, and potassium. On occasion, these indicator parameters have been used successfully by others to detect contamination of surface waters by human wastewater (sewage) from OSS and municipal sanitary sewers. Three field test methods were identified for each of these fecal indicator parameters. Ammonia has also been used effectively as a fecal indicator parameter, as described in the following section and presented in Table 3.

Field tests of fecal bacteria indicators are routinely used for tracking sources of fecal pollution in surface waters from sanitary sewage sources as part of illicit discharge detection and elimination (IDDE) programs (see Brown et al. 2004, Britsch 2014, and Herrera 2012). The traditional approach is to test samples for surfactants, potassium, and ammonia. Possible sanitary sewage contamination is indicated if surfactants exceed 0.25 mg/L and the ratio of ammonia to potassium exceeds 1.0 (see flow chart in Figure 47 of Brown et al. 2004). Positive surfactants and a lower ammonia-potassium ratio indicate possible washwater contamination.

Optical brightener monitoring is also used to detect possible sanitary sewage contamination of surface waters/drainage and ground water. Optical brighteners are present in 97 percent of laundry detergents used in the United States (Hagedorn et al. 2005), and are relatively stable in the environment because they decompose slowly except through photo-decay (Burres 2011). Originally, optical brightener monitoring consisted of using cotton adsorbent pads to accumulate optical brighteners over time. The exposed pads are cleaned and illuminated with an ultraviolet light to detect optical brighteners, and may be scanned with a spectrofluorometer to quantify the optical brightener content in the laboratory.

The Kitsap Public Health District used the adsorbent pad/spectrofluorometer method in the Enetai Creek watershed in 2007 to detect OSS failures when the sampler was deployed near the OSS discharge, and the only strong positive detection was observed within 30 feet of a direct sewage discharge (L. Banigan, Kitsap Public Health District, personal communication). Herrera was not able or detect to optical brighteners or sewage discharges using this method at any of 12 stations in the Thornton Creek watershed (Herrera 2007a) or eight stations in the California Creek watershed (Herrera 2007b).

Optical brightener monitoring equipment and methodology has improved greatly in recent years by the development of fluorometers, which measure wavelengths specific to optical brighteners and are able to detect low concentrations of optical brighteners directly in water samples (see Hagedorn 2014a, 2014b and Burres 2011). Fluorometer methods provide immediate results by eliminating the need for extended deployment of adsorbent pads, and the specific wavelengths and low detection limits potentially extend the minimum distance needed to detect a sewage discharge.

One concern with optical brightener methods is the presence of contradictory results when comparing fluorometry and bacterial counts (Ecology 2011). Although various reports have documented a strong fluorescent signal and high numbers of fecal indicators, studies have also reported no correlation between fluorometry and counts of fecal bacteria (Hartel et al., 2007). The Kitsap Public Health District recently used a Turner Designs AquaFlor handheld fluorometer, expending many hours correlating fluorometer results to FC and EC concentrations, and eventually returning it for a full refund due to various calibration and operational challenges (L. Banigan, Kitsap Public Health District, personal communication). Users of this fluorometer preferred testing water samples at room temperature in the laboratory to reduce effects of condensation and other cuvette transparency obstructions on

Table 1. Fecal Bacteria Field Test Methods.											
Parameter	**Test Method**	**Manufacturer [a]**	**Minimum Detection Limit**	**Range (Target 100 – 10,000 / 100 mL)**	**Ease of Use**	**Advantages**	**Disadvantages**	**Materials Cost Per Sample**	**Equipment Cost**	**Labor Hours per Sample**	**Example Project Costs b**
E. coli	Coliscan Easygel test kit	Microbiology Laboratories	20 / 100 mL	Diluted 0 – 12,000 / 100 mL	Moderately difficult	Can incubate in incubator for 24 hours or at room temperature for 48 hours.	Test takes 24 to 48 hours. Without proper dilution, plates cannot be read properly. Media needs to be stored frozen.	$2.49 per sample (10 sample test kits)	Incubator - $2,000 (optional)	0.3	Year 1 = $16,036 Year 2 = $14,036
	Colilert® - 18 with Quanti-Tray®/2000	IDEXX	1 / 100 mL	Undiluted 0 – 2,419 / 100 mL	Moderately difficult	Detects coliform and E. coli simultaneously. Test takes 18 – 24 hours.	Cost of incubator/equipment. Need space to incubate samples, may be limited on space in incubator.	$7.07 per sample (20 sample test kit)	Quanti-Tray Sealer - $4,000 Incubator - $2,000 UV light - $265	0.3	Year 1 = $22,279 Year 2 = $16,014
Enterococcus	Enterolert® with Quanti-Tray®/2000	IDEXX	1 / 100 mL	Undiluted 0 – 2,419 / 100 mL	Moderately difficult	Test takes 24 hours. Lower false-positive rate than membrane filtration methods.	Cost of incubator/equipment. Need space to incubate samples, may be limited on space in incubator.	$8.75 per sample (20 sample test kit)	Quanti-Tray Sealer - $4,000 Incubator - $2,000 UV light - $265	0.3	Year 1 = $23,005 Year 2 = $16,740

[a] Manufacturer listed is an example of an available test method. There are many manufacturers and kits/instruments and we are not endorsing a specific manufacturer.
[b] Example first and second year annual project cost for equipment, materials, and labor ($100/hour) for 12 monthly tests at 36 locations.

Table 2. Fecal Indicator Parameter Field Test Methods.												
Parameter	**Test Method**	**Manufacturer [a]**	**Minimum Detection Limit**	**Range**	**Accuracy**	**Ease of Use**	**Advantages**	**Disadvantages**	**Materials Cost Per Sample**	**Equipment Cost**	**Labor Hours per Sample**	**Example Project costs [b]**
Optical brighteners	Absorbent pads	various	NA	NA	NA	Moderately difficult	Integrates exposure over time. No reagents.	Presence/absence only. Easily fouled, lost, or vandalized.	$3	UV lamp -$265 plastic mesh - $180 wire/line - $30	0.25	Year 1 = $12,571 Year 2 = $12,096
	AquaFluor® Handheld Fluorometer	Turner Designs, Ltd.	0.5 mg/L	0 – 30,000 mg/L	NA	Easy	No reagents.	Temperature sensitive.	--	Meter - $2,800 Cuvettes - $70	0.08	Year 1 = $6,326 Year 2 = $3,456
	Cyclops-7 submersible sensor	Turner Designs, Ltd.	0.6 ug/L	0 – 15,000 ug/L	NA	Easy	In-situ continuous monitoring. No reagents. Low detection limit.	Initial equipment cost.	--	Sensor with data logger - $5,689	0.03	Year 1 = $6,985 Year 2 = $1,296
Surfactants	Visual test kit	CHEMetrics, Inc.	0.125 mg/L 100 mg/L	0 – 3 mg/L 0 – 1,400 mg/L	NA	Easy	No calibration or maintenance.	Shelf life of reagents is 8 months. Not as accurate. Not in-situ.	$3.93 per sample (20 sample test kit)	NA	0.08	Year 1 = $5,154 Year 2 = $5,154
	Digital colorimeter kit	CHEMetrics, Inc.	0.25 mg/L	0 – 2.50 mg/L	NA	Easy	No calibration needed, just auto-zero.	Shelf life of reagents is 8 months.	$3.30 per sample (20 sample test kit)	$460 (includes 20 sample tests)	0.13	Year 1 = $7,436 Year 2 =$7,042
	SMART3 colorimeter	LaMotte	0.75 mg/L	0 – 8.00 mg/L	NA	Easy	One colorimeter for multiple tests.	Not in-situ.	$1.08 per sample (50 sample test kit)	Colorimeter - $925 c	0.13	Year 1 = $7,008 Year 2 = $6,083
Potassium	Ion Meter	Horiba	33 mg/L	0 – 3,900 mg/L	NA	Easy	Small sample volume required. No reagents.	Elevated detection limit.	--	Meter - $260	0.02	Year 1 = $1,124 Year 2 = $864
	SMART3 colorimeter	LaMotte	0.8 mg/L	0 – 10.0 mg/L	NA	Easy	One colorimeter for multiple tests.	Not in-situ.	$0.65 per sample (100 sample test kit)	Colorimeter - $925 c	0.1	Year 1 = $5,526 Year 2 = $4,601
	DR 2700 portable spectrophotometer	Hach	NA	0.1 – 7.0 mg/L	NA	Easy	Low detection limit.	Only one test parameter.	$1.72 per sample (100 sample test kit)	Spectrophotometer - $3,045	0.1	Year 1 = $8,108 Year 2 = $5,063

[a] Manufacturer listed is an example of an available test method. There are many manufacturers and kits/instruments and we are not endorsing a specific manufacturer.
[b] Example first and second year annual project cost for equipment, materials, and labor ($100 / hour) for 12 monthly tests at 36 locations.
[c] Colorimeter can be used with all SMART3 colorimeter tests (surfactants, potassium, and fluoride).
NA Not applicable or available.

Table 3. Nitrogen Parameter Field Test Methods.

Parameter	Test Method	Manufacturer [a]	Minimum Detection Limit	Range	Accuracy	Ease of Use	Advantages	Disadvantages	Materials Cost Per Sample	Equipment Cost	Labor Hours per Sample	Example Project costs [b]
Nitrate	Test Strips	Hach	1 mg/L	0 – 50 mg/L	NA	Easy	Disposable and inexpensive. No reagents.	Not as accurate readings.	$0.80 per sample (25 sample test kit)	--	0.03	Year 1 = $1,642 Year 2 = $1,642
	Visual test kit	Hanna	10 mg/L	0 – 50 mg/L	NA	Easy	Inexpensive.	Not as accurate readings. Not in-situ. Requires reagents.	$0.40 per sample (100 sample test kit)	--	0.13	Year 1 = $5,789 Year 2 =$5,789
	SMART3 colorimeter	LaMotte	0.10 mg/L	0 – 3.0 mg/L	NA	Easy	One colorimeter for multiple tests.	Not in-situ. Requires reagents.	$2.28 per sample (20 sample test kit)	Colorimeter - $925 [c]	0.1	Year 1 = $6,230 Year 2 = $5,305
	Sensor with portable meter	Hach	0.1 mg/L	0 – 14,000 mg/L	NA	Easy	Can use portable meter for other Sensor	Reagents required. Not in-situ sensor monitoring.	$0.50 per sample (100 sample pack)	Sensor - $781 Meter - $1,000 [d]	0.05	Year 1 = $4,157 Year 2 = $2,376
	Multiparameter Pro Plus – nitrate sensor	YSI	0.01 mg/L	0 – 200 mg/L	± 2 mg/L or 10% of reading	Easy	In-situ continuous monitoring. No reagents.	Fresh water only.	--	$1,581	0.03	Year 1 = $2,844 Year 2 = $1,263
	SUNA V2 UV sensor	Satlantic	0.007 mg/L	0 – 56 mg/L	± 0.028 mg/L or 10% of reading	Easy	In-situ continuous monitoring. No reagents.	High cost of equipment.	--	$25,000	0.03	Year 1 = $26,296 Year 2 = $1,296
	ProPS-CW UV process photometer	TriOS	NA	0 – 100 mg/L	NA	Easy	In-situ continuous monitoring. No reagents.	High cost of equipment.	--	$12,000	0.03	Year 1 = $13,296 Year 2 = $1,296
Nitrite	Test Strips	Hach	0.15 mg/L	0 – 3.0 mg/L	NA	Easy	Disposable and inexpensive. No reagents.	Not as accurate readings.	$0.80 per sample (25 sample test kit)	--	0.03	Year 1 = $1,642 Year 2 = $1,642
	Visual test kit	Hanna	0.2 mg/L	0 – 1.0 mg/L	NA	Easy	Inexpensive.	Not as accurate readings. Not in-situ. Requires reagents.	$0.40 per sample (100 sample test kit)	--	0.13	Year 1 = $5,789 Year 2 = $5,789
	SMART3 colorimeter	LaMotte	0.02 mg/L	0 – 0.80 mg/L	NA	Easy	One colorimeter for multiple tests.	Not in-situ. Requires reagents.	$2.28 per sample (20 sample test kit)	Colorimeter - $925 [c]	0.1	Year 1 = $6,230 Year 2 = $5,305
	Color disc test kit	Hach	NA	0 – 100 mg/L 0 – 2,000 mg/L	NA	Easy	Inexpensive and easy to use.	Not as accurate readings. Not in-situ.	$1.10 per sample (100 sample test kit)	--	0.12	Year 1 = $5,659 Year 2 = $5,659
	ProPS optical sensor	TriOS	NA	0 – 50 mg/L	NA	Easy	In-situ continuous monitoring.	High cost of equipment.	--	$12,000	0.03	Year 1 = $13,296 Year 2 = $1,296
Ammonia	Visual test kit	Hanna	0.5 mg/L	0 – 2.5 mg/L	NA	Easy	Inexpensive.	Not as accurate readings. Not in-situ. Requires reagents.	$1.50 per sample (25 sample test kit)	--	0.17	Year 1 = $7,992 Year 2 = $7,992
	Test strips	Hach	NA	0 – 6.0 mg/L	NA	Easy	Disposable and inexpensive. No reagents.	Not as accurate readings.	$0.80 per sample (25 sample test kit)	--	0.03	Year 1 = $1,642 Year 2 = $1,642
	SMART3 colorimeter	LaMotte	0.05 mg/L	0 – 1.00 mg/L	NA	Easy	One colorimeter for multiple tests.	Not in-situ. Requires reagents.	$0.83 per sample (50 sample test kit)	Colorimeter - $925 [c]	0.1	Year 1 = $5,604 Year 2 = $4,679
	Sensor with portable meter	Hach	0.07 mg/L	0 – 7,000 mg/L	NA	Easy	Low detection limit.	Reagents required. Not in-situ sensor monitoring.	$0.28 per sample (100 sample pack)	Sensor - $765 Meter - $1,000 [d]	0.05	Year 1 = $4,046 Year 2 = $2,281
	Multiparameter Pro Plus – ammonium and pH sensors	YSI	0.01 mg/L	0 – 200 mg/L	± 2 mg/L or 10% of reading	Easy	In-situ continuous monitoring. No reagents.	Fresh water only.	--	$1,581	0.03	Year 1 = $2,844 Year 2 = $1,263

[a] Manufacturer listed is an example of an available test method. There are many manufacturers and kits/instruments and we are not endorsing a specific manufacturer.
[b] Example first and second year annual project cost for equipment, materials, and labor ($100 / hour) for 12 monthly tests at 36 locations.
[c] Colorimeter can be used with all SMART3 colorimeter tests (nitrate, nitrite, and ammonia).
[d] Multimeter can be used with multiple sensors (nitrate and ammonia).
NA Not applicable or available.

sample measurements. Typically, fluorometer calibration is based on simple dilutions of a detergent (Tide 2X), results are compared among samples to identify unusually high values, and results are not expected to correlate to bacteria concentrations (Hagedorn 2014a, 2014b; Burres 2011).

Measurement of the relative optical brightener concentration in water samples is the recommended fecal indicator method because it is a direct measurement laundry detergents commonly present in human wastewater and can be detected at relatively low levels (in parts per billion or ug/L) in much less time than the traditional measurements of surfactants, ammonia, and potassium. For optical brighteners, two-year project costs in order from high to low are: absorbent pads ($24,667), AquaFluor handheld fluorometer ($9,779), and Cyclops-7 submersible sensor ($8,281). Use of absorbent pads can be labor-intensive and can foul easily or be vandalized while deployed. The handheld fluorometer requires the use of cuvettes and has a 1,000-times higher detection limit than the submersible sensor, which has more recently been developed.

The submersible sensor is recommended for measuring optical brighteners due to overall project cost, low detection limit, ease of use, and ability to log data over extended periods of time. The submersible sensor requires no additional equipment and can be installed to record continuous *in situ* readings overnight when storm event sampling is commonly needed and difficult to staff. However, additional research on sensor longevity, potential interferences, and application limitations should be conducted for this submersible sensor by contacting experienced users because it is new on the market and representative case studies using this specific instrument were not identified by this evaluation. For example, it may have a low detection limit for detecting sewage far from its source, but it does not have the accuracy and precision to adequately detect differences between sampling stations or in marine waters. In addition, long-term deployment of this instrument typically requires a vandal-proof housing that can be challenging to construct and is not included in the cost estimate.

3.3. Nitrogen Parameters

Table 3 presents nitrogen parameter field tests identified for nitrate, nitrite, and ammonia. No field test kits or meters were identified for total nitrogen. Nitrate and ammonia are preferred nitrogen parameters because they both are easily detected and present at relatively high concentrations in contaminated surface waters. Sanitary sewage in OSS contains high concentrations of nitrate+nitrite nitrogen (approximately 65 mg/L) and ammonia nitrogen (approximately 5 mg/L) (Ecology 2001). Ammonia nitrogen is readily converted to nitrate by nitrifying bacteria in the presence of oxygen. Surface waters without sewage contamination typically contain relatively low concentrations of nitrate (less than 1 mg/L), which are similar to concentrations of total nitrogen, and typically contain undetectable concentrations of ammonia (less than 0.01 mg/L). Thus, ammonia is better for detecting potential OSS contamination while nitrate is better for detecting total nitrogen sources.

The YSI multi-parameter Pro Plus meter with nitrate and ammonia sensors is the preferred field test method for nitrogen because it is the lowest cost (two-year project cost of $4,107 for each meter), provides a low detection limit (0.01 mg/L), and has the ability to analyze and log *in situ* data. Separate meters are required for nitrate and ammonia because it has a capacity of two sensors and a pH sensor is necessary for the ammonia meter to convert ammonium to ammonia. It is possible to use only one meter to measure nitrate and ammonium, which may be sufficient for sewage source identification. Significant limitations of the YSI Pro Plus meter are that it can only be used in fresh water and the sensors often need replacement every 6 months, which was not included in the two-year project cost.

The estimated two-year project cost of the YSI multi-parameter Pro Plus meter is approximately half the cost of laboratory analysis of nitrate and ammonia samples. For 12 monthly tests at 36 locations over a 2-year period, and assuming a laboratory cost of $10/sample, the 2-year project cost for laboratory analysis nitrate or ammonia s is $8,640, plus labor to deliver sample. Although laboratory analysis is more accurate and can be performed on marine water samples, the YSI Pro Plus meter has the ability to be installed for continuous measurement of nitrate or ammonia to obtain better estimates of average and peak concentrations over an extended period of time when sampling is not possible or would be costly. As noted above, long-term deployment of this instrument typically requires a vandal-proof housing that can be challenging to construct and is not included in the cost estimate. Another important advantage of nitrogen sensors over other methods is that the immediate results can be used to monitor additional locations to pinpoint nitrogen source locations without having to wait for laboratory results or complete test kit analyses.

Nitrate and ammonia sensor methods are relatively inaccurate and should not be used instead of ongoing laboratory analyses. The manufacturers reported accuracy is approximately ±2 mg/L for high levels or ±10 percent of the instrument reading for low levels, and depends on the amount of interfering substances in the tested waters. To maximize accuracy, the sensors require detailed calibration procedures on a daily basis, which requires training, and regular replacement (every 6 to 12 months). Although precision of sensor measurements is not reported by manufacturers, precision of replicate measurements are likely similar to the typical laboratory method precision of ±20 percent.

The sensors should be used to identify locations within a drainage basin during spatial investigation, or periods within a hydrograph during temporal investigation with remote deployment, that are substantially (at least 50 percent) higher from other measurements in the basin or hydrograph. The relative change in concentration is more important than the magnitude of the concentration for identifying suspected source locations or hot spots. Accurate nitrogen concentrations may then be determined at the identified hot spots using laboratory analysis of collected samples.

3.4. Field Sampling Methods

Samples can be collected either as grab samples or using an automated sampler. The cost of an automated sampler with bottles, power cables, and tubing is approximately $3,700. Estimated labor is 8 hours for initial set-up (4 hours for subsequent set-up) and 4 hours to retrieve sample bottles. At $100 per hour, each sample collected by automated sampler would be $800 to $1,200 for labor costs. Automatic samplers are not recommended for collection of fecal samples, and are more expensive than using *in situ* sensors for measurement of fecal indicator and nitrogen parameters.

The best time to sample for PIC monitoring to detect human wastewater is after the hydrograph drops and the soil is still saturated following a storm event. Therefore, it is recommended that field methods be used primarily during storm events to identify the potential presence of human wastewater from septic systems. As noted in the HCCC (2014) monitoring plan, monitoring during the wet season (October through April) is best to identify OSS failures caused by high seasonal groundwater and surface water drainage issues. In addition, targeting base flow in the dry season (May through September) is recommended for areas where stormwater masks sewage sources and where residences are only occupied in the summer.

Long-term deployment of sensors for optical brightener and nitrogen monitoring is an excellent method for determining how sources vary with time during storm events and base flow (in wet and dry seasons) to evaluate when sources are most prevalent for upstream or shoreline exploration of the identified sources. Sensors may be integrated with digital communication devices to receive data in real time or send signals when designated thresholds are exceeded. This allows identification of potential source events for deployment of sampling teams to collect samples for laboratory analyses. Remote communication also allows for timely detection of drift or other potential accuracy problems for sensor re-calibration, maintenance, or replacement.

Hand deployment of sensors for optical brightener and nitrogen monitoring is an excellent method for spatially tracking sources upstream and along shorelines during high priority events. Sensors installed in vandal-proof housings may be temporarily removed and used for hand deployment. Once calibrated, sensors are an efficient method for collecting data at many locations to pinpoint sources by providing immediate feedback on where unusually high concentrations are present and further investigation should proceed.

4. Conclusions and Recommendations

Potential field test methods were evaluated for additional PIC monitoring to identify fecal bacteria and nitrogen sources in the Hood Canal Watershed. Field tests for fecal bacteria are not recommended because they more expensive and less reliable than laboratory analysis.

The recommended field test method for fecal indicator bacteria is to measure optical brighteners using the Turner Designs Cyclops-7 submersible sensor due its relatively low project cost (two-year cost of $8,281), ease of use, and ability to log data over extended periods of time. However, additional research on sensor longevity, potential interferences, and application limitations should be conducted for this submersible sensor by contacting experienced users because it is new on the market and representative case studies using this specific instrument were not identified by this evaluation.

The YSI multi-parameter Pro Plus meter with nitrate and ammonia sensors is the preferred field test method for nitrogen because it is the lowest cost (2-year project cost of $4,107 for each meter), provides a low detection limit (0.01 mg/L), and has the ability to analyze and log *in situ* data. One limitation of the YSI Pro Plus meter is that it can only be used in fresh water. The nitrate sensor should be used for detecting nitrogen sources because nitrate concentrations are most similar to total nitrogen concentrations. The ammonia sensor should be used in conjunction with the optical brightener sensor to detect OSS sources specifically.

Automatic samplers are not recommended for additional PIC monitoring because they are not recommended for collection of fecal samples, and are more expensive than using *in situ* sensors for measurement of fecal indicator and nitrogen parameters.

The best time to sample for PIC monitoring to detect human wastewater is after the hydrograph drops and the soil is still saturated following a storm event. Therefore, it is recommended that field methods be used primarily during storm events to identify the potential presence of human wastewater from septic systems. In addition, targeting base flow in the dry season (May through September) is recommended for areas where stormwater masks sewage sources and where residences are only occupied in the summer.

Long-term deployment of optical brightener and nitrogen sensors is an excellent method for determining how sources vary with time during storm events and base flow (in wet and dry seasons) to evaluate when sources are most prevalent for upstream or shoreline exploration of the identified sources. If budget allows, it is recommended to integrate the sensors with digital communication devices to receive data in real time or send signals when designated thresholds are exceeded for deployment of sampling teams to collect samples for laboratory analyses.

Hand deployment of optical brightener and nitrogen sensors is an excellent method for spatially tracking sources upstream and along shorelines during high priority events. These sensors are an efficient method for collecting data at many locations to pinpoint sources by providing immediate feedback on where unusually high concentrations are present and further investigation should proceed.

Due to inaccuracies of the recommended field test methods and equipment, they should be used to supplement and not replace ongoing sampling and laboratory analyses. Further research, planning, and experimentation on how and where to best use these methods for tracking OSS sources of fecal bacteria and nitrogen contamination of surface waters should be conducted. A field monitoring plan should be developed that clearly defines the monitoring objectives and schedule, and specifies detailed procedures to cost-effectively meet the objectives within the budget constraints. A successful field monitoring program using the recommended methods requires a substantial investment of time and money, and will likely fail to meet expectations without an appropriate level of investment.

5. REFERENCES

Britsch, S. 2014. Snohomish County Quality Assurance Project Plan (QAPP) Snohomish River Tributaries, Stillaguamish River, North, Swamp and Little Bear Creeks. Fecal Coliform Bacteria Total Maximum Daily Load Monitoring and Source Identification. Accessed March 2014. Steve Britsch, Snohomish County Public Works, Surface Water Management Division, Everett, Washington. http://www.co.snohomish.wa.us/documents/Departments/Public_Works/SWM/WQ-SnoCoQAPP-SnoRivTribStillyNoSwampLtBear-FecalTMDL.pdf.

Brown et al. 2004. Illicit Discharge Detection and Elimination – A Guidance Manual for Program Development and Technical Assessments. Prepared by Edward Brown and Deb Caraco, Center for Watershed Protection, and Robert Pitt, University of Alabama. October 2004. http://www.ncsu.edu/ehs/environ/IDDE%20Guidance%20Manual.pdf.

Burres, E. 2011. Standard Operating Procedure (SOP) 3.4.1.4. Measuring Optic Brighteners in Ambient Water Samples Using a Fluorometer. Eric Burres, California Environmental Protection Agency, State Water Resources Control Board, Sacramento, California. Updated March 2011. http://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/3414.pdf.

CHEMetrics. 2014a. Visual test kit for detergents (anionic surfactants, MBAS) product page. CHEMetrics. Accessed March 2014. http://www.chemetrics.com/Detergents+%28anionic+surfactants%2C+MBAS%29.

CHEMetrics. 2014b. Detergents (anionic surfactants, MBAS) single analyte kit product page. CHEMetrics. Accessed March 2014. http://www.chemetrics.com/Detergents%20(anionic%20surfactants,%20MBAS)/Instrumental+Kits/I-2017.

Ecology. 2001. Washington State Septage Characterization Analysis. Washington State Department of Ecology, Solid Waste and Financial Assistance Program, Olympia, Washington. Publication No. 01-07-007. March 2001. https://fortress.wa.gov/ecy/publications/publications/0107007.pdf

Ecology. 2011. Review and Critique of Current Microbial Source Tracking (MST) Techniques. Washington State Department of Ecology, Olympia. Washingtonn. Publication No. 11-03-038. November 2011. https://fortress.wa.gov/ecy/publications/publications/1103038.pdf

Hach. 2014a. DR 2700 ™ Portable Spectrophotometer product page. Hach. Accessed March 2014. http://www.hach.com/dr-2700-portable-spectrophotometer-with-lithium-ion-battery/product?id=7640439008.

Hach. 2014b. Nitrate and Nitrite Test Strips product page. Hach. Accessed March 2014. http://www.hach.com/nitrate-and-nitrite-test-strips/product?id=7640211606&callback=qs.

Hach. 2014c. HQd Portable meter product page for nitrate and ammonia probes. Hach. Accessed March 2014. http://www.hach.com/hqd-portable-and-benchtop-meter-configurator/product-configurator?id=11590153550&callback=qs.

Hach. 2014d. Nitrogen, nitrate color disc test kit product page. Hach. Accessed March 2014. http://www.hach.com/nitrogen-nitrite-color-disc-test-kit-model-ni-6/product?id=7640220988&callback=qs.

Hach. 2014e. Ammonia (Nitrogen) Test Strips product page. Hach. Accessed March 2014. http://www.hach.com/ammonia-nitrogen-test-strips-0-6-0-mg-l/product?id=7640211610&callback=qs.

Hagedorn, C. 2014a. Fluorometric Detection of Optical Brighteners as an Indicator of Human Sources of Water Pollution, Part I. Description and Detection of Optical Brighteners. Charles Hagedorn, Professor, Virginia Tech, Blacksburg, Virginia. Accessed March 2014: http://filebox.vt.edu/users/chagedor/biol_4684/BST/OB%20Article-I.pdf.

Hagedorn, C. 2014b. Fluorometric Detection of Optical Brighteners as an Indicator of Human Sources of Water Pollution, Part II. Development as a Source Tracking Methodology in Open Waters. Charles Hagedorn, Professor, Virginia Tech, Blacksburg, Virginia. Accessed March 2014: http://filebox.vt.edu/users/chagedor/biol_4684/BST/OB%20Article-II.pdf.

Hagedorn, C., M. Saluta, A. Hassall, and J. Dickerson, 2005. Fluorometric Detection of Optical Brighteners as an Indicator of Human Sources of Water Pollution: Development as a Source Tracking Methodology. Environmental Detection News 2:1-13.

Hanna. 2014a. Fluoride Portable Meter product page. Hanna Instruments. Accessed March 2014. http://www.hannainst.com/usa/prods2.cfm?id=042003&ProdCode=HI%2098402.

Hanna. 2014b. Nitrate visual test kit product page. Hannah Instruments. Accessed March 2014. http://www.hannainst.com/usa/prods2.cfm?id=030004&ProdCode=HI%203874.

Hanna. 2014c. Nitrite visual test kit product page. Hannah Instruments. Accessed March 2014. http://www.hannainst.com/usa/prods2.cfm?id=029004&ProdCode=HI%203873.

Hanna. 2014d. Ammonia test kit product page. Hannah Instruments. Accessed March 2014. http://www.hannainst.com/usa/prods2.cfm?id=038013&ProdCode=HI%203824.

Hartel, P.G., Rodgers, K., Moody, G.L., Hemmings, S.N., Fisher, J.A. and J.L. McDonald. 2008. Combining Targeted Sampling and Fluorometry to Identify Human Fecal Contamination in a Freshwater Creek. Journal of Water and Health, Vol. 6, 105-116.

HCCC. 2014. Hood Canal Regional Pollution Identification and Correction Monitoring Plan. Hood Canal Coordinating Council, Poulsbo, Washington. January 9, 2014.

Herrera. 2007a. Monitoring Report: Thornton Creek and Matthews Beach Microbial Source Tracking Study. Prepared for Seattle Public Utilities, Seattle Washington by Herrera Environmental Consultants, Inc., Seattle Washington. March 12, 2007.

Herrera. 2007b. Monitoring Report: California Creek Optical Brightener. Prepared for Whatcom County Public Works, Stormwater Division, Bellingham, Washington by Herrera Environmental Consultants, Inc., Seattle, Washington. April 6, 2007.

Herrera. 2012. Illicit Discharge Detection and Elimination Field Screening Survey Results and Literature Review. Prepared for King County Department of Natural Resources and Parks and Washington Stormwater Center by Herrera Environmental Consultants, Inc., Seattle, Washington. November 2012.

Horiba. 2014. LAQUAtwin compact potassium ion meter product page. Horiba. Accessed 2014. http://www.horiba.com/us/en/application/material-property-characterization/water-analysis/water-quality-electrochemistry-instrumentation/compact/details/b-731-laquatwin-compact-potassium-ion-meter-17163/.

IDEXX. 2014. Water Testing Solutions for Colilert-18 and Enterolert with Quanti-Tray/2000. IDEXX. Accessed March 2014. http://www.idexx.com/view/xhtml/en_us/water/water-testing-solutions.jsf.

LaMotte. 2014a. SMART 3 Colorimeter product page. LaMotte. Accessed March 2014. http://www.lamotte.com/en/water-wastewater/instrumentation/1910.html.

LaMotte. 2014b. Fluoride Colorimeter product page. LaMotte. Accessed March 2014. http://www.lamotte.com/en/browse/3674-01.html.

Microbiology Laboratories. 2014. Coliscan Easygel information. Microbiology Laboratories. Accessed March 2014. http://www.micrologylabs.com/page/93/Coliscan-Easygel.

Satlantic. 2014. SUNA V2 UV nitrate sensor product page. Satlantic. Accessed March 2014. http://satlantic.com/suna.

TriOS. 2014. ProPS – UV process photometer product page. TriOS Optical Sensors. Accessed March 2014. http://trios.de/index.php?option=com_content&view=category&layout=trios&id=45&Itemid=74&lang=en.

Turner Designs. 2014a. AquaFlor® Handheld Fluorometer/Turbidimeter product page. Accessed March 2014. http://www.turnerdesigns.com/products/field-fluorometer/aquafluor-handheld-fluorometer-and-turbidimeter.

Turner Designs. 2014b. Cyclops-7™ Submersible Sensor product page. Turner Designs, Ltd. Accessed March 2014. http://www.turnerdesigns.com/products/submersible-fluorometer/cyclops-7-submersible-fluorescence-and-turbidity-sensors.

YSI. 2014. Multiparameter Meter product page on Grainger website. YSI. Accessed March 2014. http://www.grainger.com/product/4UYG5?gclid=CIbzxbnUnL0CFY0-MgodWHMAdQ&cm_mmc=PPC:GooglePLA-_-Lab%20Supplies-_-Water%20Testing%20Equipment%20and%20Meters-_-4UYG5&ci_src=17588969&ci_sku=4UYG5&ef_id=UfGh9gAAAIXEqJka:20140318175806:s.