Preparing Elements of a Quality Assurance Monitoring Plan to Conduct Water Quality Monitoring Near Dairies and CAFOs

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Preparing Elements of a Quality Assurance Monitoring Plan to Conduct Water Quality Monitoring Near Dairies and CAFOs

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Abstract

Recent revisions to RCW 90.64 stated that the Washington State Department of Ecology is to develop and maintain a standard protocol for water quality monitoring of waters in the vicinity of dairies and concentrated animal feeding operations (CAFOs). The protocol is to include sampling methods, procedures, and identification of water quality constituents. The cumulative impact to water quality in some watersheds is complex, and effectiveness of best management practices (BMPs) has not been described. This rigorous sampling protocol is intended to (1) identify pollutants, (2) partition pollution sources, and (3) quantify the magnitude of pollution problems. Results from monitoring activities will be used in an adaptive management strategy for improving farm plans and watershed planning.

Purpose

The purpose of this document is to provide guidance for designing and establishing monitoring projects that identify impacts to water quality originating from dairy operations and concentrated animal feeding operations (CAFOs). Impacts to water quality occur in a variety of ways and can be simple or very difficult to detect and then relate to sources. Information about the dairy or CAFO operation is important for determining how to design a monitoring project and then interpret the appropriateness and efficiency of best management practice (BMP) structures or activities. Objectives and goals for a monitoring project will guide the type of analyses and interpretations that can be made about pollutant-source relationships. Monitoring validates management decisions for improving water quality and provides feedback to make changes when necessary.

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Introduction

Livestock operations across Washington State vary in animal type and size from small backyard hobby farms to large range operations to intensive confined operations. Water quality effects from these operations are equally variable from no impacts to nonpoint sources, point sources, and surface water and groundwater impacts. Pollutant sources are primarily animal waste, runoff from feed and other stockpiled or spilled materials, and disturbance of riparian and aquatic areas. The combination of various waste and runoff pollutants is referred to as *livestock nutrients.*

In Washington, livestock operations that pose a risk to water quality are encouraged to use best management practices (BMPs) to control and prevent any discharges. When properly installed and managed, BMPs should prevent nutrients from reaching surface and groundwaters. The most recognized and used BMPs are those practice standards established by the Washington Office of the Natural Resources Conservation Service (NRCS) and used as the basis of various federal assistance programs.

Water Quality Regulations

All livestock operations, as well as all people and facilities in the state, are prohibited from discharging pollutants to surface or groundwater under the state Water Pollution Control Act, Chapter 90.48 RCW. This Act establishes a permit program that applies to certain livestock operations that confine animals in an area for much of the year.

This permit is administered by the Washington State Department of Ecology (Ecology) as a combined permit with the federal Concentrated Animal Feeding Operation (CAFO) permit. At the start of 2005, 101 dairies and 16 non-diary facilities were covered by the permit. The federal permit now includes a new requirement for all CAFOs to develop a nutrient management plan with a specific list of elements to include in the plan. Washington State will rely on the NRCS practice standards as the required technical standards that the plans will need to meet.

In addition, all licensed dairy cow operations (currently 556) in Washington are regulated through a state dairy program established in the Dairy Nutrient Management Act in 1998. Under this program, all dairies are regularly inspected for any existing or potential discharges to surface water or groundwater. The program also requires all dairies to develop and implement nutrient management plans. The plans must contain specific elements established by the Washington State Conservation Commission and must meet the NRCS standards. Since July 2003, the dairy program has been administered and inspections carried out by the Washington State Department of Agriculture (WSDA).

The dairy nutrient plans are similar to the CAFO permit plans. Dairy plans are approved and implementation plans certified by the local conservation district. Each dairy operator also certifies that they are managing according to the plan. Typical plan elements include over-winter storage of manure in lagoons; herd size management; land application of manure at agronomic rates; stormwater and erosion management in animal holding areas (such as gutters, downspouts, or curbing); and protecting riparian vegetative buffers on stream corridors by methods such as

fencing, leaving buffers next to field application areas, replanting, and restricted or remote stock watering.

CAFOs or dairies that have site or management water quality problems are referred to the local Conservation district or the operations consultant for technical assistance. Referrals may be made by Ecology or WSDA.

Most non-dairy livestock operations are not covered directly by either the CAFO permit or the dairy program. Operations that identify water quality issues may seek voluntary assistance through the conservation district or NRCS programs. Water quality problems are usually identified through complaints or special water quality studies. The farms will generally work with their local district to develop a farm plan, or at minimum, a nutrient management plan to control any sources of pollutants. Farms may be referred to the districts for assistance by Ecology or WSDA staff.

Monitoring

Surface water quality monitoring is not currently a regular part of either the CAFO permit or the dairy nutrient management plan. Surface water sampling usually targets the presence of fecal coliform bacteria, but can be expanded to include other pollutants. Samples may also be collected to verify a previous source is no longer present.

Nutrient management plans include periodic soil sampling to measure the level of nitrates and, more recently, phosphorus. The information is used to modify field applications to prevent accumulation of these nutrients so that they do not leach into groundwater or easily run off into nearby streams during rain events.

Recent legislation under Substitute Senate Bill 5602 amended RCW 90.64 that requires Ecology to develop and maintain a standard protocol for water quality monitoring within the vicinity of dairies and CAFOs. This protocol includes sampling methods, procedures, and water quality constituents to be monitored.

Water quality monitoring is an essential part of a BMP implementation program to reduce nonpoint source (NPS) pollution. In their evaluation of the Rural Clean Water Program, Gale et al. (1992) stated that:

"Effective land treatment and water quality monitoring for NPS projects and clear, well documented reporting of the results of such monitoring, is required to:

a) document progress toward water quality goals;
b) determine needs for further treatment;
c) maintain the interest of project participants and staff;
d) develop and transfer technology;
e) reduce the number of inconclusive studies conducted;
f) sustain Congressional support;
g) assure credibility; and
h) address increasing information needs."

Many, if not all, of the requirements listed above apply to the dairy nutrient management program in Washington State as well as the state and federal CAFO program. In addition, historically some members of the public have questioned the ability of BMPs to reduce water quality impacts (Kauzloric, 1995). Very few farm-specific water quality monitoring studies have been conducted that demonstrate the effectiveness of BMPs in the Pacific Northwest. Additional local, site-specific information that verifies the effectiveness of BMPs would help to dispel these doubts. Clearly, the state dairy nutrient management and CAFO program will benefit from effective monitoring and evaluation.

Many agencies are interested in evaluating how BMPs improve water quality, including Ecology, county governments, conservation districts, tribes, and other federal, state, and local agencies. Current emphasis on accountability and effectiveness of programs makes this even more important. Ecology has developed this guidance to provide assistance and support to those efforts, and to foster consistency between the groups conducting such evaluations.

Types of Stream Degradation from Dairies and CAFOs

Stream degradation (or any other water type) is identified as changes in surface water chemistry or in the physical habitat that supports aquatic life and their critical stages (e.g., spawning, rearing, and incubation). Changes in the aquatic environment affect biota and life stages in very specific ways and are dependent on tolerances and requirements for survival. Chemical changes to surface water affect the media requirements for aquatic life. Physical habitat changes affect needs that satisfy successful predator-avoidance, reproduction, and formation of microhabitat that influences overlying water chemistry.

Dairy operations are characterized by a concentration of animals in a large or small area of land. The primary pollutant materializes in the aquatic environment as bacteriological contamination whose severity is usually measured by the presence of fecal coliform concentration. The dairy cattle may contribute excrement directly or indirectly to the affected water type (e.g., stream, river, lake, and wetland) and can alter some of the adjoining physical land structure at the interface between land and water. Often, the BMP used in eliminating direct contact between cattle and stream is an enclosure such as fencing. Bacteriological contamination can still occur when rainfall events mobilize organic material toward natural drainages.

Concentrated animal feeding operations (CAFOs) often place a larger number of animals per unit of land area. The primary concern with a high animal density, especially near streams or lakes, is the destruction of natural barriers that prohibit pollution from reaching a waterway. Besides bacteriological contamination, several in-channel characteristics of streams or lakes can be altered and present challenges for resident aquatic life. Increased introduction of fine soil and sustained transport of these materials diminishes the ability for completion of egg incubation life stages for fish species. As well, critical living space for other aquatic life such as periphyton and aquatic insects is altered. Physical changes like these reduce the capacity of a stream or lake to achieve its beneficial uses, frequently resulting in the appearance of "nuisance" species that present unsightly and malodorous results. Health threats can be an issue under some circumstances.

The presence of nuisance species (e.g., algae and noxious aquatic plants) also indicates a supply of nutrients that is readily available from a nearby source. Soils are de-stabilized around CAFOs and are transported to streams during rain events. De-stabilized soils and excrement are the source for nutrient imports. These waste-products of CAFO activity are especially detrimental to nearby streams when waste lagoons overflow or fail.

Another impact on receiving water originating from CAFOs is pharmaceutical discharges. Herd health is maintained through use of pharmaceuticals. Production of dairy products and meat is highly dependent on healthy animals. Illness in herds is often detected through product analysis at which time appropriate pharmaceutical application is selected.

There are similarities between some dairy operation and non-dairy CAFO impacts. The animal density and timing of activities determine the influence on changes to stream (or other water type) quality. The effect of dairy operations on surface water quality has frequently been the focus for evaluating status and subsequent improvements when BMPs are implemented. Other animal feeding operations (AFO) and CAFOs may result in severe vegetation and soil disturbance that physically affect nearby aquatic systems. Pollutant introduction into nearby streams is more likely and will occur at a more intense rate with removal of physical barriers and vegetation. Sediment transport rates and associated pollutants will be a primary concern for protection of existing aquatic communities. These changes in availability of critical habitat can be addressed by using physical and biological assessment protocols. Biological evaluations are a direct measure for pollution abatement programs and their effectiveness. Additional evaluation protocols and examples for their use can be found in Appendix A.

Surface water contamination can also affect groundwater quality. Increases in groundwater nitrate concentrations occur with infiltration of water on dairy and CAFO operations. Groundwater monitoring would assist in isolating the direction and source of contaminants and provide guidance on protecting drinking water sources.

Sampling Schedule

Based on the recommendations of Gale et al. (1992), the ideal evaluation project should last at least six years, with the possibility of one to four years additional work depending on the status of BMP implementation, weather conditions during the study, and other factors affecting the ability of the study to meet its objectives.

Monitoring should consist of two components: BMP implementation monitoring (verify the BMPs are installed and working properly), and water quality monitoring (evaluation for changes in water quality following BMP placement). These two monitoring activities establish a relationship between BMP effectiveness and water quality changes.

The water quality monitoring program sampling schedule is determined by considering the detection of water quality changes due to the BMP and not the background variation associated with natural processes or other elements. Changes due to the BMP are called a “signal” and are distinct from the portion of variation due to causes other than BMPs that are called “noise”.

Spatial variability is controlled in upstream/downstream evaluations of BMPs through careful positioning of sampling stations and accounting for other potential sources for change such as nearby tributaries and land drainage patterns. Temporal variability is partially explained by variations in daily and annual weather patterns. This accounts for much of the background noise. Understanding factors that influence noise suggests partitioning data sets by season so that natural events like rainfall can be examined for effect on water quality degradation. Transport mechanisms for pollutants are identifiable when the signal for change is strong during individual climatic events.

A sampling program can be simple or can be a "nested" monitoring design. The simple plan can be an upstream/downstream evaluation of water quality conditions during the rainy season. The more complex programs may have "core" sites located at strategic reaches with nested monitoring evaluation of BMPs. A simple approach to water quality monitoring is to describe a routine with regular sample collection intervals. Adjustments might be made to a schedule resulting from severe weather, monitoring logistics, or personnel considerations. For example, monitoring surveys could be scheduled twice per month, at least two weeks apart, for a total of 24 surveys per year. This characterizes water quality under a variety of weather conditions. This monitoring strategy is simple to implement and predictable in terms of sampling preparation and logistics. However, this strategy requires a large number of sampling points collected over a longer time period in order to adequately generate a data distribution that reflects the range of environmental conditions. BMP effectiveness can be differentiated from other factors with this type of monitoring design.

When data are available that identify the critical season and that have severe water quality impacts, monitoring should be focused on that time period. Multiple water quality impairments often occur simultaneously, and it is appropriate to measure parameters causing the most severe impacts in order to determine improvements over time. If a sub-set of parameters are used to track water quality changes, then some understanding of dynamics that occur between parameters is necessary so that beneficial changes to the aquatic environment are measured and not a false signal. The total number of visits to each station per year should be 20 or more times. For example, the Totten-Little Skookum National Monitoring Project described in Seiders (1995) consists of 20 weekly surveys during the wet season. This was beneficial for determining changes in bacteriological characteristics of water affected by nonpoint source runoff.

The number of years included in the project, or samples per year, may be reduced from what is recommended here, if consideration is given to the statistical design of the project, knowledge of data variability from previous studies, critical weather or flow conditions, an anticipated large reduction in pollutant loading, or other factors. If the anticipated data variability can be estimated, statistical tools are available to estimate the optimal sample size for a given power of detection. However, reducing the number of years in the project should be approached with caution, since fewer samples over a shorter timeframe generally means a lower chance of detecting a change in water quality due to BMP activities and confusing this signal with background influences originating from seasonal weather patterns and other global effects.

Pollutant loading in streams and other water types is strongly influenced by the presence of human activity and by climatic events. The transport mechanism of pollutant load to stream must have a means for conveyance and is often carried by surface runoff during and following

storm events. If sufficient information is available describing the response of pollutant loading from rainfall events, monitoring during a rainfall event would characterize the vulnerability of receiving streams to nonpoint source degradation. This approach can allow more focused sampling and the collection of added information about "worst-case" runoff event scenarios. However, rainfall-driven sampling is logistically difficult (environmental laboratories may be limited in their flexibility to accept samples on short notice), and can produce biased results if data are not statistically representative of the variety of conditions and cumulative impact to receiving water.

An important consideration in the scheduling of the monitoring surveys is that the pre-BMP monitoring must be comparable to post-BMP monitoring. Both data sets must be taken from the same sampling population and must be subject to the same preconditions. For example, it would be inappropriate to compare a data set collected at weekly intervals to a data set collected for the purpose of characterizing rainfall events. However, it may be appropriate to select data from the weekly sampling with the same antecedent conditions as the rainfall event sampling, and then compare those two data sets (if other requirements of the statistical test are also met).

A paired watershed study design is another survey available as an alternative to the strategy previously described. This is a powerful evaluation method, but technically complex and potentially more costly, so it is only mentioned here briefly. A detailed description of the paired watershed method is presented in EPA (1993).

Monitoring of BMP implementation is the second major component determining the effectiveness of BMPs. For each dairy or concentrated animal feeding operation (CAFO) located at a study site, the status of BMP and nutrient management plan development and implementation should be reviewed and documented on a regular basis, either quarterly, semi-annually, or annually. Selecting indicators for monitoring BMP implementation should begin immediately with companion data added over the duration of the study. These indicators provide important information for relating causes to measurable water quality conditions. The changes in indicators over time provide some explanation for effectiveness of management decisions or the impacts of new pollution sources near stream or other water types.

For sub-basin study areas (large spatial areas), in addition to the specific measures of BMP implementation, the land-use patterns should initially be documented and reviewed annually (or upon availability of new information approximately every five years) to identify significant changes in land use. If resources are available, land-use data can be derived from a Geographic Information System (GIS) or through ArcMap© overages that have been converted from a GIS coverage. A schedule and task table should be prepared in order to maintain timely completion of milestones (Table 1).

Table 1. Schedule for project tasks.

Date for Task	Monitoring Program Task
Day/month/year	Begin monitoring program
Day/month/year	Begin data entry and summary statistics generation
Day/month/year	Complete seasonal characterizations
Day/month/year	Develop base of geographic information (land use) and BMP implementation descriptions
Day/month/year	Complete “draft final” and review
Day/month/year	Complete final report

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Project Description

Goals and Decision Statement

The goals should be specific, narrowly defined, and have quantitative endpoints. For example, the goals of a project might be "to achieve (1) completion of a BMP implementation plan specified in Farm X's animal waste management plan in a specific period of time, and (2) optimal BMP implementation that results in significant improvements to water quality in Stream Y adjacent to a farm."

Achieving goals are dependent on sites selected for evaluating improvements to water quality conditions, the extent of completion of the nutrient management plan, adequate characterization of water quality conditions through monitoring that isolates effects and their source, ability to relate monitoring results with extent of BMP implementation, and appropriate selection of statistical tools that interpret environmental information.

Objectives

Clear objectives should be outlined to evaluate surface water quality improvements following BMP implementation near dairies and CAFOs. The goal of these monitoring projects is to relate improvements in surface water quality with the nearby implementation of BMPs as prescribed by Washington's dairy and CAFO-nutrient management program.

In general, objectives of a project should be described with the following guidance in mind:

- Site selection is imperative in isolating effects from pollution sources and in measuring improvements from farm management plan elements. Site selection should be above and below the suspected source of pollution or the BMP. Distance from the BMP should be minimized in order to isolate pollution effects. Characterizing impacts without the presence of BMPs is important for describing conditions outside of any nutrient management plan activity. This information serves as background or provides perspective on water quality conditions in the absence of any management activities. Large-scale evaluations may not be able to relate the influence of individual source impacts on water quality as multiple land uses spaced over broad spatial scales result in “cumulative” impacts. Sources of pollution and causal mechanisms are more difficult to attribute from a single source.

- Develop site selection and general monitoring plans through partnerships with local agencies. The agencies can provide background information for land use and locations where historical impacts have influenced water quality conditions. These partnerships will also make important nutrient management plan information available prior to establishing a final monitoring plan.

- Monitor water quality using upstream/downstream site selection in order to isolate pollution impacts from a specific dairy or CAFO activity. Tributaries that join the stream reach under evaluation will have an influence on the pollutant signal at monitoring sites. The influence of water entering the study reach from tributaries can diminish the strength of pollutant signal at the downstream location from BMPs or pollutant sources under evaluation. If the tributary stream is not outside of the upstream/downstream site couplet, then it should be sampled at its confluence with the study reach. Primary sources of pollutants can be determined by comparing all three sampling points: upstream, downstream, or tributary sources. Monitoring should follow a schedule in which frequency, timing, and duration will isolate temporal variability and characterize changes attributable to dairy and CAFO nutrient management practices. Ideally, monitoring should include several years of pre-BMP water quality characterizations and several years of monitoring following full BMP implementation. A lag time for monitoring following BMP implementation may be necessary to allow for efficient operation and some measurable recovery in receiving water characteristics.

- Document the development and implementation of a nutrient management plan, including tracking the installation, operation, and maintenance of specific BMPs during the project for each farm-based project site and for all dairies in a project sub-basin site. Also, document land uses in the sub-basin sites and track changes in land use over the course of the project.

- Evaluate water quality monitoring and BMP implementation data to determine (1) water quality improvements have occurred and (2) suggest modifications to implementation of BMPs in order to sustain water quality improvements (adaptive management). Use quantitative statistical tools whenever appropriate, as well as evaluation of compliance with state Water Quality Standards (Chapter 173-201A WAC).

Constraints

Sampling is periodically cancelled due to poor weather, physical inaccessibility to a monitoring location, or equipment failure. Missed samples based on any of these factors can influence interpretation of results; therefore, a careful evaluation of collected data should be completed before analysis and interpretation.

Quality Objectives

Measurement Quality Objectives

The U.S. Environmental Protection Agency (EPA) defines measurement quality objectives (MQOs) as "*acceptance criteria* for the quality attributes measured by project data quality indicators. [They are] quantitative measures of performance…" (EPA, 2002). In practice, these are often the precision, bias, and accuracy guidelines against which laboratory (and some field) quality control (QC) results are compared. Precision may be assessed by the analysis of laboratory duplicates or check standard replicates, and bias by comparing the mean of blank and check standard results to known values. The acceptable levels listed in Table 2 are applied to batch-level data and may be assessed by only a few QC samples. Failing to meet these criteria would trigger corrective action (see *Correction Action* section later in this report).

Table 2. Measurement quality objectives.

Analyte	Accuracy (deviation or % deviation from true value)	Precision (% relative standard deviation)	Bias (% deviation from true value)	Lower Reporting Limit
Field Constituents				
Conductivity	± 5 µs/cm at 100 µs/cm	NA	NA	NA
Oxygen	± 0.2 mg/L	NA	NA	NA
pH	± 0.10 std. units	NA	NA	NA
Temperature	± 0.2 ºC	NA	NA	NA
Lab Constituents				
Ammonia-N	20%	7%	5%	0.01 mg L^{-1}
Fecal Coliform	NA	28%	NA	1 colony 100 mL^{-1}
Nitrate+Nitrite-N	20%	7%	5%	0.01 mg L^{-1}
Soluble Reactive Phosphorus	20%	7%	5%	0.003 mg L^{-1}
Suspended Solids	20%	7%	5%	1 mg L^{-1}
Total Nitrogen	20%	7%	5%	0.025 mg L^{-1}
Total Phosphorus	20%	7%	5%	0.01 mg L^{-1}
Turbidity	20%	7%	5%	0.5 NTU

* Lower reporting limits provided in this table originate from Ecology's Manchester Environmental Laboratory

Data Quality Objectives

EPA defines data quality objectives (DQOs) as "qualitative and quantitative statements that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors…." (EPA, 2002). DQOs may be used to evaluate whether the data are adequate to address the project's objectives. Among our objectives, the ability to detect changes in water quality (trends) is the cornerstone of a long-term sampling design. A historical perspective, which only long-term records can provide, is necessary in order to make informed decisions regarding water quality assessments, or the effects of regulatory actions on water quality. The data quality objectives, below, were developed to address statistical requirements for trend analysis. They will also be adequate to address their objectives.

Sample Size

Any of the goals we describe for evaluating water quality impacts from dairies or CAFOs focus on detecting "differences". These differences can be based on: (1) a simple comparison of upstream and downstream locations (isolating a dairy or CAFO), (2) upstream/downstream sites that evaluate effectiveness of a BMP, or (3) determining a trend over time at points on a stream below dairies or CAFOs in the absence of changes to upstream land-use activities.

Upstream/Downstream Differences

The effect of a streamside dairy or CAFO can be severe, and without BMP mitigation can result in a larger difference in specific water quality conditions. However, if upstream impacts are severe, the change due to a single dairy or CAFO further downstream can be undetectable. There are two important pieces of information that can be used to evaluate an impact to water quality: (1) the minimum detectable difference at a site for a single parameter, and (2) the number of samples required to detect this difference.

The formula that describes the minimum detectable difference between an upstream and downstream site is as follows:

Equation 1

$$\partial \geq \sqrt{\frac{2s^2{}_p}{n}}(t_{\alpha,\nu} + t_{\beta(1),\nu})$$

∂ - minimum detectable difference
$s^2{}_p$ - population variance
n - number of observations
t - critical value for the t-distribution
α - probability of committing a type I error
β - probability of committing a type II error
ν - degrees of freedom

By re-arranging this formula, the number of samples needed to detect this difference is as follows:

Equation 2 $$n \geq \frac{2s^2{}_p}{\partial^2}(t_{\alpha,\nu} + t_{\beta(1),\nu})^2$$

(Zar, 1984)

The population variance (s^2) is calculated from numerous preliminary upstream/downstream sample pair differences collected throughout the duration of a critical period.

Trends over Time

The ability to detect trends is related to the variance of the data, which for many constituents increases with increasing concentration. An example for the concentration ranges for the constituents monitored are provided in Table 3. This is also consistent with the ability to detect trends in high-quality (low-concentration) aquatic environments where the ecological impacts of a given $\Delta\mu$ are greater and earlier mitigation is more cost-efficient. For most constituents, the desired trend magnitude ($\Delta\mu$) is set to 20% of the upper bound for each range. (For a long-term monitoring project, this might be set over a ten-year period, not the annual change.)
When sufficient quality control data are collected (e.g., over a year period) prior to this type of analysis, the actual error attained ($s_{error(att)}$) can be evaluated. The error goals ($s_{error(mp)}$) and the actual errors obtained for different constituents and concentration ranges are shown in Table 3. When $s_{error(att)} > s_{error(mp)}$ indicates that *a priori* error goals are not met, it does not necessarily indicate that trends cannot be identified at the specified $\Delta\mu$. (Nor does meeting the error goal guarantee that trends can be detected for any particular data set.). The critical parameter is the *total* observed variance.

Precision

An estimate for precision can be derived from replicate field samples or through check standard replicates analyzed by the laboratory. Precision can be estimated from batch samples collected throughout the life of a project or on an annual basis if this is a long-term project. This can be a large error term if field collecting and laboratory procedures are not followed correctly.

Table 3 exemplifies the number of sample pairs collected used to determine detectable changes for numerous analytes and at increasing concentration ranges. The measure for precision is described by $s_{error\ (att)}{}^c$ and the change that is detectable $\Delta\mu{}^a$ over a ten-year period and at each concentration range μ for the parameter. This analysis illustrates the level of effort expended in sampling for detection of trends from water quality contamination near dairies or CAFOs. These expectations for length of monitoring project and number of samples required to describe precision can be extrapolated to any monitoring program as long as the collection period adequately describes the type of data distribution for each variable. For further detail on this subject, refer to Hallock and Ehinger (2003) and Hallock (2003).

Table 3. Examples for calculating maximum permissible error ($s_{error(mp)}$) values to detect a trend given $\beta = 0.1$, $\alpha = 0.1$, $\phi = 0.17$, and $n=120$. Actual error ($s_{error\ (att)}$) from data collected monthly over a five-year period. Actual errors not meeting *a priori* objectives (*i.e.*, $s_{error\ (att)} > s_{error\ (mp)}$) are shown in bold.

Variable (units)	Desired $\Delta\mu$ [a]	Conc. Range (μ)	$s_{error\ (mp)}$ [b]	Empirical	
				$s_{error\ (att)}$ [c]	No. [d]
Electrical conductivity (µS/cm)	10	< 50	4.4	0.99	39
	20	>50-100	8.8	1.6	67
	30	>100-150	13.2	3.7	43
	60	>150	26.4	5.6	51
Fecal coliform bacteria (colonies /100 mL)	200	<1-1000	88	12	665
	400	>1000	176	**178**	5
NH_3-N (µg N/L)	4	<20	1.76	**2.5**	165
	20	>20-100	8.8	3.1	29
	40	>100	17.6	1.5	4
Nitrogen, total (µg N/L)	20	<100	8.8	8.2	40
	40	>100-200	17.6	10.3	42
	100	>200-500	44	15.0	50
	200	>500	88	70.1	67
NO_3NO_2-N (µg N/L)	20	<100	8.8	2.5	76
	40	>100-200	17.6	10.4	30
	100	>200-500	44	3.5	37
	200	>500	88	28.6	56
Oxygen, dissolved (mg O_2/L)	1.6	<8	0.70	0.11	4
	2.0	> 8-10	0.88	0.10	40
	2.4	> 10-12	1.06	0.10	107
	4.8	>12	2.11	0.12	51
pH	1.5	N/A	0.66	0.13	0.13
Phosphorus, soluble reactive (µg P/L^{-1})	10	<50	4.4	0.65	176
	20	>50-100	8.8	**11.4**	18
	40	>100	17.6	**20.7**	5
Phosphorus, total (µg P/L)	10	<50	4.4	4.7	140
	20	>50-100	8.8	5.9	37
	40	>100	17.6	15.0	21
Solids, suspended (mg/L)	2	<10	0.88	0.49	303
	4	>10-20	1.76	1.2	95
	10	>20-50	4.4	2.5	99
	20	>50	8.8	8.6	60
Temperature (ºC)	6	N/A	2.64	0.13	191
Turbidity (NTU)	2	<10	0.88	0.17	525
	4	>10-20	1.76	0.45	71
	10	>20-50	4.4	0.88	64
	20	>50	8.8	6.5	33

[a] $\Delta\mu$ has been set to 20% of the upper end of the concentration range or 40% for the upper-most range. ($\Delta\mu$ is the change over the entire sample period, *i.e.*, 10 years.)

[b] $s_{error(mp)} = \Delta\mu 0.44$ (Equation 4).

[c] Attainable error calculated as the root-mean-square (RMS) error from field splits. For sediment and fecal coliform bacteria, where there is no field processing of samples, lab splits were used. For temperature, pH, and conductivity, where field splits are impractical, sequential samples were used (for these constituents, some of the variability is due to instream processes and not sampling or analytical error). Because results below reporting limits are censored by the laboratory, $s_{error(att)}$ for the lowest concentration ranges, particularly for nutrients, these results may be biased low.

[d] Number of pairs in the RMS calculation.

Bias

A consistently biased data set will not affect nonparametric trend analysis or testing of differences between two population means. However, if a bias is corrected (or imparted) at some mid-point in the sampling period, then the statistical analysis will be compromised. Overlapping new and old procedures for several months prior to abandoning the old method will assess bias due to changes in analytical or sampling procedures. When a project is ongoing and long-term, assume that any batch-specific bias in the chemical analyses will be corrected so that long-term bias will not occur within a single method. Sampling bias should be minimized by strictly adhering to the protocols discussed and referenced for the project. Bias due to the time (of day) of sample collection is an important issue and is discussed in the *Sampling Design/Representativeness* section of this document.

Reporting Limits

A certain proportion of results below reporting limits is expected and will not impair the ability to analyze data. However, a large percentage of data below reporting limits for certain constituents at key stations will affect the ability to analyze results (Table 4).

Table 4. Example of results that are below reporting limits from a long-term monitoring project.

Analyte	Percent of samples below reporting limit for worst-case station	Worst-case station	Percent of all samples below reporting limit	Reporting Limit
Turbidity	42	Finch Creek at Hoodsport	2.6	0.5 NTU
Suspended Solids	58	Finch Creek at Hoodsport	6.5	1 mg L^{-1}
Total Phosphorus	45	Various	13.1	0.01 mg L^{-1}
Soluble Reactive Phosphorus	100	Various	42.4	0.01 to 0.003 mg L^{-1}
--WY 2002 only	100	Various	17.3	0.003 mg L^{-1}
Nitrate+Nitrite-N	71	Pend Oreille @ Metaline Falls	9.8	0.01 mg L^{-1}
Ammonia-N	100	Various	61.7	0.01 mg L^{-1}
Total Nitrogen	8.3	Various	0.5	0.025 mg L^{-1}
Fecal Coliform	79	Columbia River at Grand Coulee	9.0	1 colony 100 mL^{-1}

Statistical analyses of data sets with a large percentage of results below the reporting limit can be problematic. The empirical results in Table 3, for example, are biased low for the lowest concentration ranges because the calculated variance between any two results below the reporting level is always 0. Also, especially for constituents that are log-normally distributed, changing detection limits can impart an artificial trend in a data set with a large number of near-detection limit concentrations.

At times, a method with a lower reporting limit is selected for some stations and analyses. Logistical and financial constraints usually force acceptance of any limitations on data. Detecting trends for ammonia concentrations are difficult to accomplish at most stations based on results that often occur below reporting limits. However, they can be useful in characterizing water quality conditions, especially when examining threats to aquatic life when periodically occurring at acute concentrations.

Sampling Design

Prior to conducting an evaluation project, study sites should be identified that provide the best opportunity to meet the study objectives. The final project plan should include a description of the study sites, monitoring stations, and sampling schedule.

The specific number of monitoring stations at each study location will be determined by the type and number of impacts to water quality. Each site should have at least an upstream and downstream monitoring location. Any significant local tributary or discharge channel present should also be monitored.

Stations should be positioned as close as possible to the farms associated with the site (to eliminate the influence of non-target pollutant sources), but far enough away for the study site to be representative. For example, the upstream station should be close enough to the study site to be below other sources of pollutants, but far enough away to be unaffected by the study site. Similarly, the downstream station should be far enough downstream for any pollutant inputs from the study site to be fully mixed across the width and depth of the stream, but still avoiding if possible the influence of non-target sources.

Figure 1 illustrates the placement of stream monitoring sites in order to evaluate the effectiveness of BMP implementation at a dairy operation. A tributary was monitored near its point of confluence with the primary stream reach which was the focal point for management of animal wastes. This provided some indication for the presence and severity of pollution originating from the tributary. Remaining sites were placed below the dairy BMP site to track the extent of pollution problems through seasons and over years. This sampling design illustrates the complexity of bacteriological contamination problems and the variety of sources contributing this type of pollution in a small portion of a watershed.

In order to characterize conditions using a consistent method, each station is usually monitored at mid-stream below the water surface with sampling beginning from upstream and moving toward downstream sites. Some knowledge of the stream's travel time between sampling stations can be useful in the interpretation of results. Following is a list of potential variables for inclusion in water quality impact studies. These constituents were monitored at all stations in this study.

- electrical conductivity
- oxygen, dissolved
- pH
- temperature
- suspended solids, total
- turbidity
- fecal coliform bacteria
- phosphorus, soluble reactive
- phosphorus, total
- ammonia, total
- nitrate + nitrite, total
- nitrogen, total

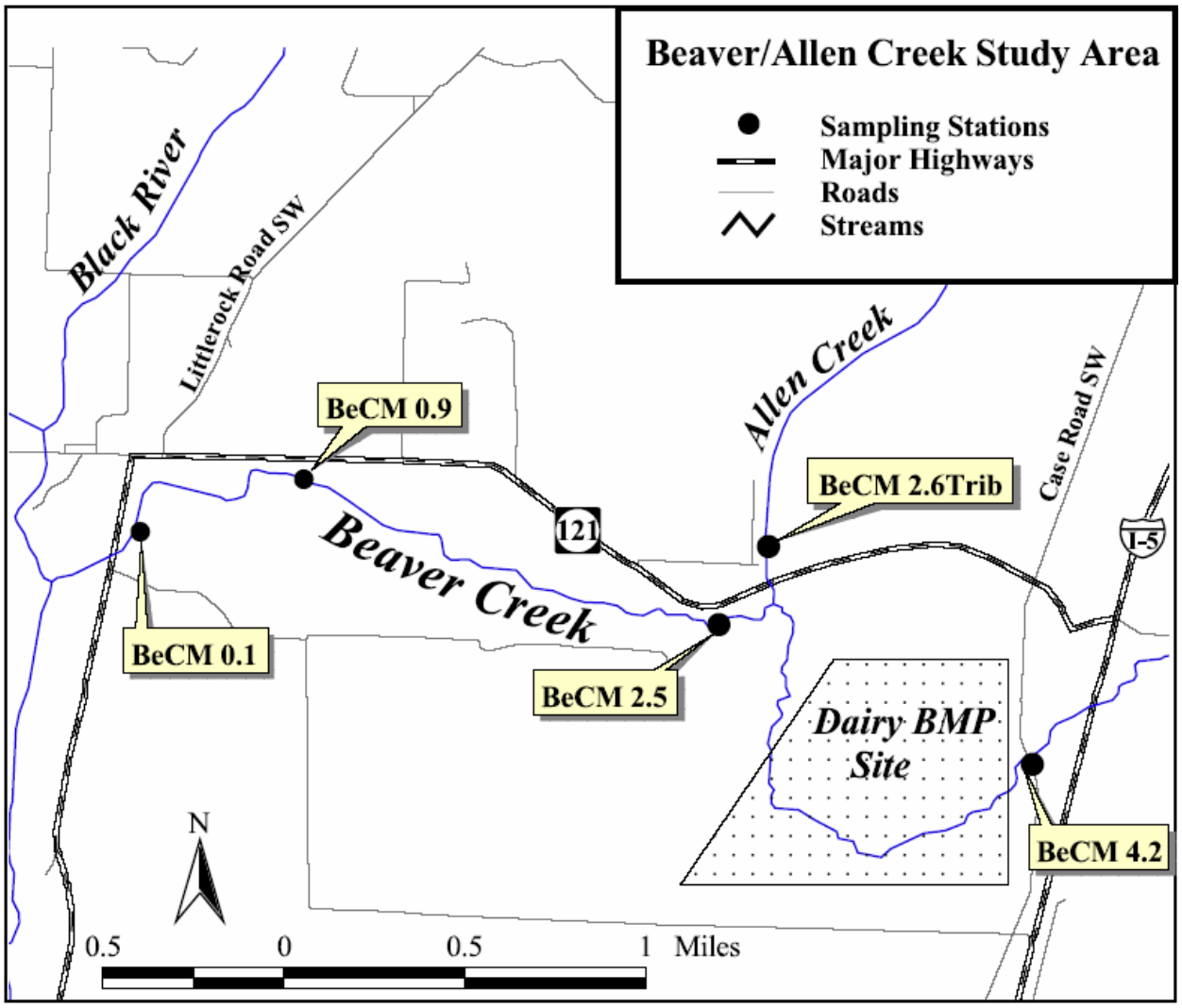

Figure 1. An example for sample site location when evaluating a dairy BMP and the extent of downstream pollution impact.

Representativeness

Monitoring parameters should be selected based on their association with dairy waste and CAFO pollution problems and the possible impact to adjacent streams, wetlands, or lakes. Table 5 shows the monitoring parameters commonly affected by dairy and CAFO activities in past surface water studies, and examples of BMP implementation measures. The parameters marked with an asterisk (*) are considered the most important for most projects, and the others are desirable or may be significant in a given situation. Parameters are also marked to indicate whether they are a problem in a particular season.

Table 5. Monitoring parameters used for evaluating BMPs.

Water Quality Parameters		BMP Implementation Parameters (measure effects from…)
Lab Parameter…and/or…	Field Parameter	
Fecal Coliform Bacteria (*, S, W)	Temperature (*, S)	Streambank fenced (length or %)
Turbidity (*,W)	Dissolved Oxygen (*, S)	Streambank re-vegetated (length or %)
Total Suspended Solids (W)	Flow (*, S, W)	Manure managed (tons/year)
Total Persulfate Nitrogen	pH (S)	Fields agronomically managed (acres)
Ammonia Nitrogen (S)	Conductivity	Rainfall or runoff diverted (acre-in/yr)
Nitrate/Nitrite	Precipitation (*, W)	Head-to-acreage ratio
Total Organic Carbon		Head under BMPs (# or % of total)

(*) = key parameter; (S) = usually summer problem; (W) = usually winter problem

Dissolved oxygen, temperature, pH, and conductivity are best measured in the field at each station during each survey using a portable measurement device appropriate to the range and accuracy required for the study. Flows should be measured at monitoring stations with a current meter using standard U.S. Geological Survey (USGS) methods if feasible, or by other appropriate methods.

At each station, all laboratory samples should be collected as grabs for analysis at an accredited laboratory. At all times with bacteria samples, and whenever possible with other parameters, samples should be collected directly into the bottle supplied by the laboratory. Samples must be stored on ice immediately after collection and shipped to the laboratory for analysis within holding times. Samples should only be analyzed at accredited laboratories, so that standard analytical methods will be used (APHA, 1998; EPA, 1983) and regulatory standards for quality will be met. Always try to use the same method, and if possible the same laboratory, for each parameter.

Storm events may be the primary source for conveyance of pollutants to streams that originate from dairies and CAFOs. Recent results from our region that monitored stormwater impacts to streams in agricultural settings reported increases in total suspended solids (TSS) and total

phosphorus (TP)(Brattebo and Brett, 2006). The TSS peak occurred prior to the peak in the hydrograph, whereas, TP peaked with the hydrograph. These results underscore the importance for adequate characterization of storm events and the timing for pollutant conveyance. Collecting data that reflects the dynamics of a storm event can be logistically difficult and requires a well-planned and dedicated effort. Knowing what mobilizes pollutants (e.g., nutrients, bacteria, and sediments) and when they move to streams provides important information for modifying management plans. Stormwater sampling is usually completed with automated sampling equipment. These samplers require time for programming, site-establishment, and maintenance (including activation and sample collection). The same procedures and equipment preparation (e.g., chemical cleaning and rinsing) apply to the automated sampling collection hoses and bottles as described for grab sample bottles.

For the monitoring of BMP implementation, specific activities should be tracked or quantitatively measured, such as the operation and maintenance of the nutrient management system. Land application of manure may be a critical component of BMP monitoring, and data collected can include the time, location, and amount of manure applied to fields. Associated hydrologic measures may be important, such as precipitation or field soil moisture. It may be desirable to have the farm operator keep a regular log of activities. The amount of fencing or re-vegetation, the head-to-acreage ratio, or other specific measures of BMPs can be included.

Comparability

All measurement and analytical procedures are documented so that the data generated by any group can be evaluated for comparability with samples collected and analyzed in a like manner. Some projects may be too costly or large to complete by a single group. Therefore, partnerships may be necessary to satisfy objectives for evaluating dairy nutrient impacts or those contributed from CAFOs. Evaluations may occur periodically, in which case results separated by a multiple-year time span will need to have careful documentation of data and methods quality. This information is closely evaluated for comparability in order to proceed with combining of results.

Field Procedures

Water samples should be collected about 30 cm below the water surface. A sample container should be dropped quickly through the surface layer to avoid any floating or micro-layer contaminants. Water for nutrient analyses should be collected in an acid-washed bottle if not collected in sample containers provided by an environmental laboratory. Water for fecal coliform bacteria evaluation is collected in an autoclaved bottle orienting the mouth of the bottle to the flow. If dissolved oxygen is determined using the Winkler (titrimetric) method, the sample should be collected in a 300 mL bottle with the mouth oriented away from the flow of water to avoid introduction of additional aeration. Temperature can be measured directly in the stream using a thermistor (periodically calibrated with a high Quality NIST thermometer) or other calibrated temperature devices.

Any sediment and bacteria samples are labeled and placed immediately on ice in storage coolers that accompany the sampling effort. If the Winkler titration method is used for characterizing dissolved oxygen concentrations, then it is fixed by adding $MnSO_4$ and sodium azide to the bottle. The bottle is stoppered, capped with a water seal, and stored in the dark. Dissolved oxygen samples are titrated (modified Winkler titration; APHA, 1998) upon return to a laboratory from between 12 to 96 hours after collection. Aliquots of the water sampled should be poured into cups for pH and conductivity measurements at a separate location from the source (Table 6).

Table 6. Parameters measured in the field.

Variable	Method	Resolution
Temperature	Thermistor	0.1ºC
pH	Glass electrode	0.1 unit
Dissolved oxygen	Titration	0.1 mg L^{-1}
Electrical conductivity	Electrode	1 µS/cm

Water collected in the acid-washed nutrient bottle is filtered in the field through a 0.45 µm membrane filter into a brown, opaque Nalgene® bottle for dissolved nutrient determinations at an environmental laboratory. All samples requiring laboratory analyses are placed in the containers provided by the lab and labeled with the date, sample site, sample identification number (may be provided by a laboratory for each sample), sampler's initials, and the chemical analyses requested. Preservatives, if required, are typically added to the bottle by an environmental laboratory prior to sampling. Samples are then packed in ice and delivered to the laboratory according to pre-arranged shipping procedures. Shipment of samples, preservatives, and sample holding times should conform to the laboratory providing analytical services.

Field measurements and comments are recorded on a form prepared prior to the sampling trip (Ward et al., 2001). Stream height measurements may also be recorded when water quality samples are collected.

Sampling equipment is rinsed thoroughly with de-ionized water after processing samples. The nutrient sampler is acid-rinsed. Examples for detailed pre- and post-sampling cleaning and meter operation and calibration procedures are described in Ward et al. (2001).

Information reported in Table 7 is from the Manchester Environmental Laboratory, Lab Users Manual (Ecology, 2005).

Table 7. An example for required container type, water volume required, method of preservation, and maximum permissible holding times for lab-analyzed samples by Ecology's Manchester Environmental Laboratory.

Determinand	Container Type	Sample Volume (mL)	Preservation	Holding Time
Turbidity	Poly	500	cool to <4ºC	48 hrs
Suspended Solids	Poly	1000	cool to <4ºC	7 days
Total Phosphorus	Poly	125	Adjust to pH<2 w/ H_2SO_4 and cool to <4ºC	28 days
Soluble Reactive Phosphorus	Brown poly	125	filter in field and cool to <4ºC	48 hrs
Nitrate+Nitrite-N	Poly	125	adjust to pH <2 w/ H_2SO_4 and cool to <4ºC	28 days
Ammonia-N	Poly	125	adjust to pH<2 w/ H_2SO_4 and cool to 4ºC	28 days
Total Nitrogen	Poly	125	adjust to pH<2 w/ H_2SO_4 and cool to <4ºC	28 days
Fecal coliform	Autoclaved glass or poly	250	cool to <4ºC	24 hrs

Laboratory Procedures

Accredited laboratories that perform chemical analyses follow Standard Operating Procedures and other guidance documents. Examples for analytical methods and lower reporting limits from Ecology's Manchester Environmental Laboratory are listed in Table 8. A similar table should be constructed using information provided by the accredited laboratory used for a project.

Table 8. Laboratory analytical methods and reporting limits.

Analyte	Sample Matrix	Number of Samples[a]	Method	Reference[b]	Lower Reporting Limit
Ammonia-N	Total	984	Automated phenate	SM4500NH3H	0.01 mg L^{-1}
Fecal Coliform	NA	984	Membrane filter	SM9222D	1 colonies 100 mL^{-1}
Nitrate+Nitrite-N	Total	984	Automated cadmium Reduction	SM4500NO3I	0.01 mg L^{-1}
Soluble Reactive Phosphorus	Dissolved	984	Automated ascorbic acid	SM4500PG	0.003 mg L^{-1}
Suspended Solids	Total	984	Gravimetric	EPA160.2	1 mg L^{-1}
Total Nitrogen	Total	984	Persulfate digestion, cadmium reduction	SM4500NB	0.025 mg L^{-1}
Total Phosphorus	Total	984	Persulfate digestion, ascorbic acid	SM4500PI	0.01 mg L^{-1}
Turbidity	Total	984	Nephelometric	SM2130	0.5 NTU

[a] Approximate annual total based on 12 samples per station, 82 stations per year. Does not include quality control samples.

[b] SM=Standard Methods (APHA, 1998); EPA=Environmental Protection Agency (EPA, 1983)

Quality Control

Laboratory

Each accredited environmental laboratory operates a standard Quality Control (QC) program. Several performance measures are reported for each batch of analyzed samples. The following are examples of QC performance measures reported from Ecology's Manchester Environmental Laboratory (MEL).

MEL operates a standard QC program, documented in (1) Ecology (2005), Standard Operating Procedures for individual analyses, and (2) their Quality Assurance Manual (Ecology, 2001). MEL's QC program includes the analysis of reference materials, check standards, duplicates, matrix spikes, and blanks.

Check Standards

Precision is addressed by the analysis of check standards (water with a known concentration of analyte) equal to about 10% of the total number of analyses. The mean value for a statistically significant number of check standard results may be used to judge whether there is any bias due to calibration. If the 95% confidence limit on the mean value does not include the true or reference value then bias due to calibration may be present.

Generally, calibration standards are set by an accredited laboratory as needed to bracket the concentration in a particular batch of samples. The check standards should equitably span the range of the expected results, ideally approximately 0.2 and 0.9 of the upper value for the range of calibration. The historical ranges for project data can be developed if a long-term record can be established. An example for development of these ranges is shown in Table 9 and was developed from a long-term water quality monitoring program in Washington State.

Table 9. An example for historical ranges and 90th percentiles for stream monitoring data based on monthly samples over a five-year period.

Analyte	Expected Range of Results	Approximate 90th percentile
Ammonia-N (mg/L)	<0.01 to 1.97	0.033
Fecal Coliform Bacteria (colonies/100mL)	<1 to 17,000	120
Nitrate+Nitrite-N (mg/L)	<0.01 to 17.1	0.995
Soluble Reactive Phosphorus (mg/L)	<0.003 to 2.14	0.045
Suspended Solids (mg/L)	<1 to 1970	41
Total Nitrogen (mg/L)	<0.025 to 16.5	1.2
Total phosphorus (mg/L)	<0.01 to 2.44	0.104
Turbidity (NTU)	<1 to 1,900	22

Analytical Duplicates

Laboratory sample splits are analyzed on one of each pair of field-split samples. Using the same sample that was split in the field allows partitioning sources of error between laboratory and field. The laboratory may split additional samples as well.

Matrix Spikes

Matrix interference leading to bias is assessed by analyzing river water that has been spiked with a known quantity of the analyte. The quantity of analyte added should not produce a final concentration that is excessively high when compared to the historic range of data (Table 9). Spike amounts should approximately double the concentration in the sample prior to spiking.

Blanks

The environmental laboratory should have internal QC protocols that include analysis of blank samples. Ecology's MEL QC program includes analyzing blank samples according to their internal protocols.

Field

Water is collected according to standard operating procedures that are updated as necessary and reviewed annually with field personnel involved in the project. Stations designated for QC sample collection are selected randomly before sampling activity begins. The number of QC sample stations is determined by identifying 10% from the total number of sites in the project. Of the QC stations identified, 20% of these will be designated for blank sample analysis, and the remaining 80% will be designated for replicate sample analysis.

Replicates

Short-term, temporal variability is assessed by collecting two samples sequentially, 15-20 minutes apart at QC stations. Results from the first sample are stored as the standard results. The second set of results is labeled as a QC sample, though the station is not identified to the laboratory. The difference between these results is used to calculate the expected variance that is due to short-term, instream factors, field collection and processing, and laboratory analyses. (The laboratory may also split this sample)

For constituents receiving field processing (Table 10, footnote), the duplicate sample is split into two sub-samples for field measurements and processing, and submission to the lab. One set is given the "duplicate" label, and the other is labeled "split" for data management purposes. These field-splits are used to calculate the variance that is due to field collection and processing, and laboratory analyses. The difference between split sample variance and the original sample variance is due to short-term, instream processes.

Table 10. Field quality control samples required annually (lab QC is specified in MEL guidance documents). QC samples are divided equally among the four sampling regions.

QC type	Field-processed constituents [a]	Constituents without field processing [b]
Field duplicate	80% of QC samples	80 5 of QC samples
Field split (of duplicate)	80% of QC samples	0
Field blank [c]	20% of QC samples	20% of QC samples

[a] Conductivity, total phosphorus, oxygen, turbidity, total ammonia, total nitrite plus nitrate, soluble reactive phosphorus, and total nitrogen.
[b] Suspended solids, fecal coliform bacteria, temperature, and pH. (Although pH measurements involve field processing, they are included in this category because samples cannot be split and measured consecutively without introducing error.)
[c] Blanks are not measured for oxygen, pH, fecal coliform bacteria, or temperature.

Blanks

Sample contamination is assessed by submitting field blanks at random intervals throughout the duration of the project. These are "transport blanks" for constituents where there is no field processing of the sample (total suspended solids), and "rinsate blanks" for other constituents. Fecal coliform bacteria blanks are not included because blank water is generally not considered sterile. Blanks results are expected to be below reporting limits.

Instrumentation

The pH and conductivity meters are calibrated daily according to the manufacturer's directions. The pH meter is checked immediately after calibration, at midday, and at the end of the day by recording the measurement of a low ionic strength pH 7 buffer. It is also checked whenever a measurement exceeds water quality standards criteria, above or below the acceptable range (WAC 173-201A). If the difference between the meter measurement and the expected pH exceeds 0.10 standard pH units, the instrument is recalibrated and the sample re-measured (see MQOs, Table 2). The conductivity and temperature meters are relatively stable; the conductivity calibration is generally checked only at the end of the day (100 µS calibration and check standards), and temperature calibration at the beginning of the sampling trip.

All meters are maintained in accordance with the user's manuals. Critical equipment and supplies should be listed on a check-sheet and are the responsibility of the field personnel.

Corrective Action

The laboratory continually monitors their results for QC sample determinations and takes appropriate action to correct problems. Samples may be re-analyzed after an analytical problem is corrected. This is also the case for field measurements with respect to check standard results. Due to sample holding time limitations, re-analysis is usually not possible if problems are discovered in field QC data. Corrective courses applying to subsequent data collection are possible, however.

If data are compromised due to poor precision, the source of the variability will determine the course of action that is required. Possible actions include (1) changing the standard operating procedures or instrumentation for field personnel, (2) informing the laboratory when lab error appears to be the source (and possibly changing analytical methods), and (3) re-evaluating the required precision when it appears that the required $s_{error(mp)}$ is unattainable.

A persistent, consistent bias in the data may warrant adjusting the values; otherwise the corrective action for bias will be to inform the laboratory, which will be expected to address the problem. Significant changes in methods, instrumentation, or protocols will be made only after it has been documented that these changes will not bias the data.

Data Management Procedures

Data should be managed in an electronic database like Access©. Constituents measured in the field are recorded manually on a standard form and can be entered by the sampler into a temporary Access table (or other format) upon return to the office. Validation of data entry should be made before ending a data entry session. A copy of the temporary table should be printed and the sampler review data entered, prior to declaring accuracy of the recorded information.

Laboratory data should be delivered in electronic form and then exported to the database. Key fields that will combine field results with laboratory results are station, date, and time of sampling. Characteristic (water quality parameter), method (of analysis), units, and sample fraction (if standardized per volume or mass) must match entries in a "parameters" table.

After field and laboratory data are combined, a two-tiered evaluation of results should be performed (see the *Data Review, Verification, and Validation* section in this report). Data determined to meet quality expectations should be uploaded to the EIM (Environmental Information Management) database maintained by Ecology. Data can be transferred to the EIM system through the "Import Module". The following web address guide's users through the data submittal process: https://fortress.wa.gov/ecy/eimimport/submit.htm

Reports

Statistical evaluations of results are the focal point for the scientific report. They interpret environmental information that will address objectives, including diagnosis for pollution type and source. Examples of statistical expressions commonly used for water quality evaluations include boxplots, linear regressions, and non-parametric comparisons of two populations of data. These methods can be used to evaluate the relationship between upstream and downstream differences in water quality changes over time and space. These comparisons are also used to evaluate effectiveness of BMP (best management practices) implementation on improvements to water quality conditions.

Selecting statistical evaluations guides the design of the monitoring routine. The selection of the statistical evaluation is guided by the specific objectives of a monitoring program. Statistical methods should be evaluated prior to a study and specified in the project plan as part of the project design, in order to ensure that sufficient data are collected over time and in locations that isolate pollution impacts. There are useful references that outline appropriate statistical applications for water quality studies and assist with development of a monitoring program.

In addition to statistical measures, evaluating improvements in water quality as measured by compliance with standards is useful. Water quality conditions exceeding (not meeting) standards will prompt the establishment of BMPs, and their effectiveness will then be evaluated. Comparison of water quality conditions to standards and among sampling years at downstream sites guides interpretation of BMP effectiveness. Documenting compliance with criteria at sites where BMPs have been implemented is an important component in restoration programs focused on specific beneficial uses (e.g., drinking water, recreational contact, and aquatic life).

Finally, data and analytical results should be reported that clearly describe how a project has met its objectives. Simple, vivid graphics usually are an effective way to show success. The goals of monitoring incorporate the need for determining (1) the status of water quality in and around dairy and CAFO operations, and (2) best management strategies for controlling pollution. Achieving these goals is possible through sound monitoring programs and an adaptive management strategy.

Data Review, Verification, and Validation

The environmental laboratory should verify data prior to issuance of a report to the project leader. This includes a continuous evaluation of laboratory performance through quality control results (e.g., using control charts).

A manual inspection and evaluation of each datum should be conducted at pre-determined intervals once received from the laboratory. Both field and laboratory data records should be verified against field forms and laboratory reports prior to final validation in the database. At least two personnel should be involved in the verification process to avoid errors from fatigue or oversight. Missing data are identified to ensure that values were not mistakenly overlooked during the data entry process. Printed copies of all stored environmental data should be made to ensure permanent records are available. The printed copy of results can be arranged in a "report" format so that information is useful for browsing.

These verification and validation steps are the responsibility of the data manager.

Missing Data

Missing data are rare. The majority of missing data are due to mechanical breakdown, inaccessible sample sites, and samples lost or misplaced during transport by commercial carriers. The effect of sample size, *n*, can alter interpretations derived from statistical evaluations of the data. Acceptable limits for missing data can be determined, in part, from data requirements of a statistical evaluation. Strict adherence to standard operating procedures and clear communication between field and laboratory personnel are the best measures to prevent lost or misplaced samples.

Loss of a small percentage of data from a long-term monitoring effort will have little impact on the resulting interpretations, but this is not true for sites where a limited amount of information is collected and, therefore, each data point has a larger influence on the description of water quality conditions.

Data Quality Assessment

Result-level data validation procedures are conducted on a routine basis and prescribed prior to beginning the environmental study. Batch-level quality assurance (QA) assessments are made by comparing calculated percent relative standard deviations (%RSD) (Equation 3) to those specified in the measurement quality objectives (Table 2).

$$\%RSD = 100\frac{s}{\bar{x}} = 100\frac{\sqrt{(r_1 - r_2)^2 / 2}}{(r_1 + r_2)/2} \qquad \text{Equation 3}$$

where

"s" is the standard deviation, $\bar{x}$ is the mean, and r_1 and r_2 are paired results, typically a known value (e.g., of a check standard) and the analytical result or measurement of the known value.

Duplicate measurements of environmental samples may also be used to estimate precision of the analytical method, but this can include error due to matrix effects. (RSD is also known as the coefficient of variation.)

The results of the analysis of blank samples and known standards will be used to determine overall bias of the results. If a consistent "method bias" is discovered, immediate notification should be made to all data users so that these changes, however small, do not result in poor interpretations from statistical evaluations. Bias due to time of day of collection should be addressed on a site- and variable-specific basis as described previously (see *Representativeness Section*).

Project-level QA assessments should be conducted as part of the interim reporting process. Sources of error (e.g., laboratory, field technique, instream spatial) are identified to the extent possible as outlined in the *Data Quality Objectives* section. For water quality parameters that fail data quality objectives, an evaluation of central tendency in variance of sample pairs may be compared by station, season, or sampler in order to identify stations, time periods, or part of the monitoring effort that is the focus for diminished precision.

The central tendency in variance of sample pairs is summarized by calculating the square root of the mean of the sample-pair variances (root mean square (RMS), Equation 4). This estimate provides an unbiased – and higher – estimate than other commonly used statistics (e.g., mean or median of the standard deviations). Because the variability of many parameters increases with increasing mean concentration, the RMS values of some variables should be evaluated according to concentration ranges. These results ($s_{error\ (att)}$) are then compared to performance standards listed in Table 3 ($s_{error\ (mp)}$).

$$RMS = (s^2_{avg})^{0.5} \qquad \text{Equation 4}$$

where

s^2_{avg} is the average of the variances of the paired results.

Characterizing Water Quality and Analyzing Trends

Specific data analysis techniques are selected based on the following factors:

- Disturbance history of the watershed,
- Specific objectives of an analysis (e.g., reporting water quality standards criteria violations, general characterization, and evaluation of management activities), or
- Spatial scope of the report (e.g., statewide, single station, and watershed).

Analyses typically use graphical displays for each type of evaluation. These graphical results are described in the document where interpretations and their significance are reported. Information generated from monitoring evaluations provides a reliable means for making management decisions that improve water quality.

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Appendix A

Resources for Designing and Implementing Monitoring Programs

The following are web addresses and report citations that can be used as examples for designing and conducting monitoring programs that evaluate the type of water quality impacts that result from dairies and concentrated animal feeding operations (CAFOs).

Current Web Addresses

Water Quality Monitoring

Quality Assurance Monitoring Plan
www.ecy.wa.gov/biblio/0303200.html

Stream Monitoring Protocols (Standard Operating Procedures)
www.ecy.wa.gov/biblio/0103036.html

Guidance for Evaluating Surface Water Quality Improvements Resulting from Dairy Waste Best Management Practices
www.ecy.wa.gov/biblio/96300.html

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*Contains additional citations useful for designing projects and analyzing data.

Appendix B

Title and Signature Page for the Quality Assurance Monitoring Plan

Preparing Elements of a Quality Assurance Monitoring Plan to Conduct Water Quality Monitoring Near Dairies and CAFOs

Month and Date

Approvals:

Name, Project Leader, Organization	Date
Name, Project Supervisor, Organization	Date
Name, Project Manager, Organization	Date
Name, Laboratory Director, Environmental Laboratory	Date
Name, Quality Assurance Officer, Organization	Date