QA/QC Demystified: The Case for Quality Checks

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Abstract

Assuring the quality of data generated in any discipline of environmental monitoring, or area of inquiry, calls for a myriad of actions intended to affect data quality. The effectiveness of these actions must be confirmed by quality checks, whose outcomes must be recorded and reported with the data. Writers of Quality Assurance Project Plans can find numerous examples of quality checks for chemical analyses and field measurements, but finding examples for biological and physical habitat assessments can be challenging, particularly in the realm of biota sample-collection and generation of evaluative results. Conceptually, a quality check is a quality check is a quality check, and there are several unifying categories that apply to all areas of inquiry, as well as span all aspects of data quality. Quality checks are an essential part of any measurement system, be it a system for collection and analysis of water samples, or for biota capture and taxonomic identification, of for estimation of percent riffle in a given length of stream. The common data elements related to quality checks can be arranged in a simple – and universal – data structure, fit for communication and information sharing across multiple environmental monitoring disciplines.

Key Words: Data quality, quality checks, QA/QC, data elements, unifying concepts

1. Introduction

Generic guidance for implementing QA/QC (Quality Assurance/Quality Control) in environmental monitoring, such as the guidance provided by state and federal agencies, is necessarily vague; it lacks specificity because it has to fit multiple situations. The US Environmental Protection Agency (USEPA) has created an excellent set of Quality System guidance documents (e.g., USEPA 2001,2002), including documents that explain the 24 elements of a Quality Assurance Project Plan (QAPP), but (a) they are focused on water chemistry, and (b) very few project personnel (e.g., field operators or data managers) are required to read them. The 24-element QAPP itself, when prepared for a project by a “QA/QC expert”, is often incomprehensible to the operators themselves.

One of the major issues is the language. Although QA/QC embodies a set of unifying concepts common to all area of inquiry, these concepts are not always defined and distilled in written documents, not even in project-specific Standard Operating Procedures which are very detailed step-by-step instructions.

This paper provides a translation, a separation, a categorization, and a suggestion.

2. Actions to affect and check the quality of monitoring data

US EPA guidance defines Calibration as "Comparison of a measurement standard, instrument, or item with a standard or instrument of higher accuracy to *detect* and *quantify* inaccuracies and to *report* or *eliminate* those inaccuracies by adjustments" (USEPA 2001)

Although this definition conveys the meaning of calibration, it does not communicate what has actually been done (or needs to be done) among the actions mentioned. It can be "translated" into more specific language if it is separated into its parts:

- **Accuracy check**: Comparison of the instrument's reading with a value believed to be the "true" value, without adjustments of the reading – i.e., [*detect and quantify* inaccuracies]; and
- **Calibration adjustment**: The action of adjusting the reading of an instrument to have it match a "true" value – i.e., [*eliminate* inaccuracies].

In other words, there are two separate kinds of actions - adjusting the reading of an instrument to the value of the standard (to **affect** accuracy) is not the same as measuring how much it had drifted since the previous adjustment (to **check** accuracy); both are essential for *assurance* of data quality. Similarly, training project's operators is not the same as checking their proficiency; both are needed for *assurance* of data quality.

The EPA definition also mentions a third action – to [*report*], with the assumption that inaccuracies have been recorded. Thus, we are looking at four types of actions: **Affect, Check, Record and Report,** or ACRR

Table 1 shows lists of actions to affect and check a variety of data quality aspects in different phases of monitoring activities. The grouping indicates a mix of specificity and commonality of actions among various areas of inquiry. Coupled with instructions to record and report the actions to affect, and the outcomes of actions to check, this is what QA/QC is about for project operators who perform the monitoring!

The organization of an operator's "to do list" in a matrix similar to Table 1 was offered to monitoring operators in California since 2002 (CWT 2006), with positive responses (many of them hung prints on their cubicle walls). In 2008, the Aquatic Sensors Workgroup (ASW) adopted it to develop the ASW QA (ACRR) Matrix for sensors, with separate pages for the five basic water quality characteristics that are measured *in situ* with probes. The types and frequencies of actions in the ASW QA Matrix were boiled down to the minimum required for generation of data of known and documented quality; these recommendations reflect the consensus of leading authorities on sensors from major WQ monitoring programs (USGS, EPA,

and a number of States). The matrix document is publicly available at
http://www.watersensors.org/qamatrix.html or
http://acwi.gov/methods/sensors/qa/ASW_QA_Matrix_web.pdf
(or search “aquatic sensors workgroup QA Matrix”)

This basic organization of quality assurance actions can be easily adapted to a variety a measurement systems in response to specific project’s needs.

3. Categories of Quality Checks

Actions to check quality, both in agencies’ guidance and in Table 1 above, are dispersed by monitoring phase, data quality aspect, or programmatic considerations (e.g, the 24 elements of the QAPP). **Table 2** shows an arrangement of quality checks by categories and types based on their mechanism (or function). This arrangement highlights categories that are common to multiple areas of inquiry. In fact, quality checks pertinent to biological and physical habitat assessments are included in three of the major categories (comparisons, repeats, and inspections/verifications).

The breakdown into quality check categories and types highlights another important distinction, between (a) quality checks that describe the monitoring results (e.g., matrix spike recovery), and (b) quality checks that ascertain the functionality of the **measurement system** itself. Measurement systems are devices and/or procedures used for quantitation or evaluation of environmental characteristics, including instruments used for field measurements, sampling & analysis processes, physical habitat assessments, and biological assessments. Many descriptors of the measurement system are common to all areas of inquiry, and some are specific to a particular kind of measurement system.

Validity, which depends on the functionality of the measurement system, can be confirmed in a number of ways: (a) be actively tested for (e.g., by running reference toxicant test to ascertain that the batch of test organism responds “properly”, i.e., within the lab control chart for a particular test species and toxicant combination), or (b) gleaned from the measurement system performance (e.g., lab control sample recovery, or survival and reproduction of test organisms in the negative control of the toxicity test), or (c) recorded from the instrument (e.g., sensors diagnostics such as electrode voltage, which needs to be within a certain range for the electrode to function properly). Data from a dysfunctional measurement system are not valid.

Where experts are indispensible

In the realm of categorical observations and estimated values, the field operator’s brain is the measurement system, and it requires training and calibration as actions that affect data quality. Physical habitat assessments include activities like canopy cover categorization (numeric range, e.g., 50% to 75% cover), estimates of flow habitat percentages (one number, e.g., riffle 40%), etc. Effective trainers know how to impart consistent decision rules, understanding of plot delineation and layering, and useful visualization techniques to the trainees. An integral part of the training should include “calibration” of the operator’s perception to align with the trainer’s expertise and experience. As in any kind of monitoring activity, training success should be ascertained by proficiency checks.

Proficiency checks, perhaps better termed "perception checks", are an important part of quality assurance, but they cannot replace the need for routine repetitions of assessments by the same operator and/or comparisons of values generated by two operators walking together and looking at the same thing, as well as periodic comparisons with experts. Such quality checks were not written in any of the monitoring plans or QAPPs read by this author thus far; however, implementation of some of them does happen informally in many Programs.

Biota sampling

Another (very) gray area of quality assurance is sampling biota such as benthic macroinvertebrates (BMI) or fish. Techniques for obtaining representative water samples for chemical analyses abound, but many of them are not applicable to anything that moves (or, for that matter, does not move and is distributed in a very patchy pattern, like benthic algae). Moreover, there is no Standard for organisms' densities, nor is there a meaningful quality check for reproducibility of the sampling and analysis process (because each sampling plot may represent a different BMI or benthic algal community).

Most BMI/periphyton collection protocols assume that sampling is exhaustive (i.e., all organisms in the sampling plot have been captured and recovered into the sample jar) and that there was no introduction of organisms from elsewhere into the sample; however not much is done to check these assumptions.

Once a biota sample is brought to the lab for identification and counts, there are several types of quality checks that can and should be done, e.g., Taxonomic ID check or split-sample counts (Table 2). A note about split samples: Result unit defined as "Count", without a unit of reference, is missing a grand opportunity of data sharing; BMI counts are very useful if related to area (e.g, abundance of benthic Coleoptrea larvae expressed as number of individuals per square foot). This also applies to other biological and physical assessments where counts need to have a unit of reference such as volume (e.g., 26 rotifers per cubic meter), or length (21 pieces of large woody debris per river mile).

4. Data elements that describe quality checks

Table 3 shows the data elements (i.e., the bits of information) that are relevant for quality checks. This list has been extracted from the Integrated List of Data Elements for environmental monitoring (Katznelson 2010). Again, these elements are common to multiple areas of inquiry. The core unifying concept in this case is the expected value versus the observed value, a concept that is used widely in the scientific world. Every expected/observed pair generates an outcome, which tells us about the quality of a given "batch". All batch descriptors – whether the batch is represented by Instrument ID, Sample Batch ID, Lab Batch ID, IDEXX Run ID, ELISA run, or tailgate NH_3 kit – are essential for connecting the quality check outcomes with the monitoring results they support.

5. A common data structure for quality checks outcomes

Table 4 is, essentially, a transposition of selected data elements from Table 3 above to create a data table populated with several real-life examples. Data management systems have employed a variety of approaches and data structures to capture QA/QC outcomes, and many of them provide a clear link between these outcomes and the results they pertain to. However, most systems work well for one or two areas of inquiry.
In contrast, the structure suggested in Table 4 – due to the use of expected/observed data fields - can accommodate many categories and types of quality checks from a variety environmental monitoring disciplines.

6. The Take-Home message(s)

- People are doing the same things and calling them by different names. The first step in an effective QA/QC program is definition of terms.

- QA/QC is a finite set of actions, but what people do to affect the quality of their data is different from what they need to do to check the quality; they need to do both and they also need to record and report.

- It is possible to assess the quality of evaluative (a.k.a. qualitative, or visually-based) results that are generated by estimates or by selection of numeric range categories.

- In quality checks, everything boils down to the comparison of expected values to observed values.

- It is very easy to capture the results of quality checks in a spreadsheet that works with any database.

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Disclaimer

The content of this paper does not necessarily reflect the views and policies of the agencies mentioned above, nor does mention of commercial products constitute endorsement or recommendation for use.

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[See a few definitions at the end of this manuscript below the tables]

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Table 1: Actions to Affect and Check the Quality of Monitoring Data

Activity	**Data Quality Aspect**	**Affect** *(act to influence outcome)*	**Check** *(test to evaluate or verify)*
All	Operator's competence	train, refresh, supervise	run proficiency tests, conduct audits, review work products
Field Measurements & assessments	Accuracy *(Note 1)*	calibrate (adjustable-reading instruments)	conduct accuracy check (all instruments)
	Precision	use consistent procedures under same conditions	repeat measurements
	Reproducibility	calibrate scoring & categorical observations made by different physical habitat assessors	repeat habitat value scoring by different operators (to calculate % match)
Sample collection & handling	Reproducibility	use consistent procedures under same conditions	collect and analyze field duplicates (exact same time & place)
	Lack of contamination	decontaminate, seal & wrap samples; apply 'clean-hands-dirty-hands' technique; use sterile vessels for bacteria	collect and analyze blanks (Trip, Field, Equipment)
	Lack of deterioration	ship cold; preserve if appropriate	measure shipping temperature and pH upon arrival
	Lack of organism loss	collect BMI at appropriate depth and velocity, gather meticulously from D-net	deploy 2nd D-net behind 1st, examine content *(Note 2)*
Laboratory analyses & tests	Accuracy (or validity)	calibrate, use certified calibrator Standards; use appropriate BMI key	run spikes, reference toxicant tests, and positive/negative controls, BMI vouchers
	Precision	use consistent procedures under same conditions	run replicates/duplicates; split BMI samples
	Lack of contamination	decontaminate lab ware	analyze lab Blanks (method, reagent, etc.)
	Lack of deterioration	analyze within holding time	calculate actual holding time

Note 1: General ways to affect accuracy:
* use certified Standards for calibration and accuracy checks
* clean the instrument, kit, test tube, or lab ware before and after each use
* protect all field and lab equipment from extreme temperature, sunlight, excessive humidity, harmful liquids or vapors
* maintain acceptable water quality conditions in toxicity test chambers

Note 2: Assumption: Quality checks for benthic macroinvertebrates (BMI) were done during method development

Table 2: Categories and Types of Quality Checks

Quality Check Category	Quality Check Type	Data quality aspect addressed	Where (Field, Lab, shipping)
Comparison to a 'Standard'	Accuracy Check of measurement (a.k.a. post calibration check)	accuracy	F, L
	Reference Check (another instrument)	accuracy	F
	Taxonomic ID check	"accuracy"	L
Survey Loop	Loop closure	accuracy	F
Repeats	Repeated field measurement	precision	F
	Repeated estimate (one number)	reproducibility	F
	Repeated categorical observations (many characteristics)	% match	F
	Field duplicates	reproducibility	F, L
	Lab replicates/split samples	precision	L
	Matrix Spike/MS Duplicate	precision	L
Inspections /verifications	Sample custody seal	sample integrity - lack of tampering	SHIP
	Sample in cooler temperature	sample integrity - lack of deterioration	SHIP
	Arrival temperature	(same)	L
	Storage temperature	(same)	SHIP, L
	Holding time	(same)	SHIP, L
	Preservative concentrations	(same)	F, L
	Instrument diagnostics	results' validity	F, L
Blanks	Bottle blank	sample integrity - lack of contamination	F
	Equipment rinsate	(same)	F
	Field blank	(same)	F
	Trip blank	(same)	F
	Method blank	(same)	F
	Filter blank	(same)	F
	Reagent blank	signal-to-noise-ratio	F, L
	GFC filter weight loss blank	signal-to-noise-ratio	F, L
Spikes	Lab control sample (LCS) or Standard	batch validity	L
	Certified reference material (CRM)	percent recovery	L
	Surrogate	percent recovery	L
	Matrix spike	percent recovery	L
	Internal standard	percent recovery	L
	Field spike	percent recovery	F
Positive/negative controls	Reference toxicant test	test validity	L
	Bacterial culture	test validity	L

Table 3: Data Elements Common to All Quality Checks

Group	Data Element	Content Examples, pick list *[or unique value]*
Descriptors	Quality Check Category	Comparison; Repeat; Spike; Blank;
	Quality Check Type	Accuracy Check; repeated field measurement;
	Quality Check Date	*[2003-03-21]*
	Quality Check Time	*[13:00]*
	Quality Check Operator	*[Smith, J.]*
	Batch Type	samples [one team one Trip], analytical lab batch, tailgate kit/in-house lab run, instrument, Toxicity test
	Batch Entity Name	Instrument ID, Sample Batch ID or Trip ID, Lab Batch ID, IDEXX Run ID, ELISA, tailgate wet chemistry kit,
	Batch Entity ID	*[TB-STB12 (a thermometer); NO3-WP-07312003 (a lab batch)]*
	Batch Date or Period	*[deployment episode 2005-04-21 to 2005-05-13]*
	Data Quality aspect (DQ Indicator Name)	accuracy (bias), reproducibility, repeatability, percent recovery, lack of contamination
	Characteristic	*[dissolve oxygen, Nitrate as N]*
	Result unit (Unit of reference)	*[mg/l, mg/kg, individuals/sq.meter]*
	Measurement basis	dry weight, wet weight
	spiked test medium	Environmental sample; lab water; clean sand
	(Spiked sample ID)	*[SLC-T1V3,WP-40049588]*
Quality Check Results	**Expected or 1st Value Type**	nominal concentration, value of Standard, NIST thermometer reading, Natural point
	Expected or 1st Result	*[10 mg/l]*
	Observed or 2nd Value type	measured concentration, survey loop closure, Repeated measurement result, analytical result
	Observed or 2nd Result	*[10.5 mg/l]*
	differential or drift	*[0.5 mg/l]*
	QC outcome computation	*[percent recovered]*
	QC Outcome	*[105]*
	QC Outcome unit	*[percent]*
Quality check Conditions	Quality Check environment property	liquid temperature, barometric pressure, salinity
	Quality Check environment property Unit	*[degree C, mmHg]*
	Quality Check environment property Value	*[25, 752]*
Instrument Functionality	Instrument Performance Diagnostic Attribute	*[pH electrode voltage]*
	Instrument Performance Diagnostic Attribute Value	*[68 mV]*
	Instrument Performance Diagnostic Attribute	*[60 to 80 mV]*
	Instrument Performance Diagnostic Attribute Value	*[yes]*
All	Quality check comment	!

Table 4: Examples of Various Quality Checks Records in a Common Data Structure

Quality Check Type	Batch Type	**character -istic**	Result unit	**Expected or 1st Value Type**	**Expected or 1st Result**	**Observed or 2nd Value type**	**Observed or 2nd Result**	Differential or drift
certified reference material	analytical lab batch	Aluminum	ug/L	nominal conc.	56	measured conc.	49	7
matrix spike	ELISA run	diazinon	ng/l	sample content plus spike nominal conc.	210+80	measured conc.	260	30
QC Standard solution	Tailgate kit reagents batch	ammonia as N	mg/L	nominal conc.	0.8	measured conc.	0.9	0.1
loop closure	survey run	elevation	decimal ft	survey loop origin	532.32	survey loop closure	532.29	0.03
repeated field measurement	instrument	pH	pH units	primary measurement result	7.5	repeated measurement result	7.7	0.2
repeated estimate (one number)	field operator	flow discharge	cfs	primary estimate	30	repeated estimate	40	10
split sample	BMI lab batch	Baetis sp. Adults	count/sq.m (calculated)	primary count	12	secondary count	14	2
Field Blank	sample batch [one team one Trip]	methyl-mercury	ng/g	zero	<1 (MDL)	analytical result	1.2	n/ap

From the USEPA Glossary

QA/QC - "A system of procedures, checks, audits, and corrective actions to ensure that all EPA research design and performance, environmental monitoring and sampling, and other technical and reporting activities are of the highest achievable quality" (EMAP 2002).

Quality assurance (QA) - An integrated system of activities involving planning, quality control, quality assessment, reporting and quality improvement to ensure that a product or service meets defined standards of quality with a stated level of confidence (EMAP, 2002).

Quality control (QC) - The overall system of technical activities whose purpose is to measure and control the quality of a product or service so that it meets the needs of users. The aim is to provide quality that is satisfactory, adequate, dependable, and economical (EMAP, 2002).

Quality Assurance Project Plan - Documents the planning, implementation, and assessment procedures for a particular project, as well as any specific quality assurance and quality control activities. It integrates all the technical and quality aspects of the project in order to provide a "blueprint" for obtaining the type and quality of environmental data and information needed for a specific decision or use. (EMAP, 2002).

Quality assessment - The evaluation of environmental data to determine if they meet the quality criteria required for a specific application (EMAP, 2002).