CITIZEN SCIENCE

HANDBOOK

Quality Assurance & Documentation

"Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it is the only thing that ever has."

–Margaret Mead

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Handbook for Citizen Science Quality Assurance and Documentation

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Note to Reader

Dear Citizen Scientist,

Thank you for picking up this document. You are probably curious about the natural world or have concerns about threats to your health (such as air pollution) or to the environment (such as algal blooms in a nearby lake). You are part of a growing contingent of citizen scientists collecting data and reporting it to the public or to government agencies. With new technologies, it is easier than ever to collect, analyze and report environmental data. New sensors and smart phones make scientific research or environmental monitoring fun and interesting. Sometimes, however, the quality and utility of the data you generate may be questioned. To be more confident in your results, you should first ask a few questions such as: Are your sampling locations representative of your study area? Do you think another volunteer can replicate how you collected the data?

In applying the concepts presented in this handbook, you are taking an important step in planning a successful project. A Quality Assurance Project Plan, or QAPP, is a tool that scientists in government agencies, academia, research organizations and others have used for decades. Although a QAPP is an imposing acronym, don't panic! Most of the information in this handbook is common sense. Some of the quality assurance activities included here you may already be doing and not all the information in this document may be applicable to your specific project. We hope, however, that in documenting the quality assurance activities for your environmental projects, you will be more confident in the results as you present them at a public meeting, in an annual report, or in a meeting with government agencies.

Good luck!

Introduction

With the advent of new technologies for environmental monitoring and tools for sharing information, citizens are more and more engaged in collecting environmental data, and many environmental agencies are using these data. A major challenge, however, is that data users, such as federal, state, tribal and local agencies, are sometimes skeptical about the quality of the data collected by citizen science organizations. One of the keys to breaking down this barrier is a Quality Assurance Project Plan (QAPP).

What is a Quality Assurance Project Plan? A QAPP is a document that explains how organizations ensure, using quality assurance and quality control activities, that the data they collect can be used for its intended purpose. By writing and applying a QAPP, an organization builds data quality procedures into the project from the beginning and will be more confident that the data will meet the specific needs of the project. Importantly, the individuals interested in the project, or the agencies that make decisions based on the data and information from the project, will have a better understanding of the quality of the underlying data.

Audience: Citizen science has been defined as follows: "when the public participates voluntarily in the scientific process, addressing real-world problems in ways that may include formulating research questions, conducting scientific experiments, collecting and analyzing data, and interpreting results" (NACEPT, 2016). This Handbook is targeted to organizations that are starting or growing a citizen science project, and where transparency in the scientific methods for collecting the data are central to the outcome of the project. Examples of citizen science include: organizations that collect water quality data to report to a state agency; programs that collect air sensor data to post online; or groups that document the presence of invasive species. There is detailed information in this Handbook and the companion Templates that more established organizations will find useful.

Purpose: The Handbook has two companion documents, *Templates for Citizen Science Quality Assurance and Documentation" and "Compendium of Examples."* These documents provide tools and procedures to help citizen science organizations properly document the quality of data. In doing so, this Handbook is meant to convey common expectations for quality assurance and documentation; and best management practices to level the playing field for organizations that train and use volunteers in the collection of environmental data.

Background: The Handbook and the companion documents are derived from an earlier EPA document the Citizen Science Quality Assurance Project Plan originally developed for water projects by EPA Region 2 (EPA, 2013). That document's scope has been expanded here to broaden its use in other media, such as air. This Handbook also contains elements from the Uniform Federal Policy for Quality Assurance Project Plans (IDQTF, 2012), and from a national consensus standard (ASQ/ANSI, 2014). And, we include strategies employed by citizen scientist programs to increase the credibility of their monitoring data (EPA, 1996, Freitag et al., 2016, and Williams et al., 2015).

Applicability: The Handbook and companion documents are applicable to the collection and use of environmental data for three broad categories of citizen science projects: *increasing public understanding; scientific studies and research;* and *legal and policy action*.

This document is not intended for projects funded by EPA. If funded by EPA, Quality Assurance (QA) documentation is required by federal regulations (for example, 2 CFR 1500.11 for grants and 48 CFR 46.202 for contracts). QA Documentation must be completed and approved prior to conducting data collection activities. EPA's Quality Directives (provided in references) must be consulted for QA documentation.

Data used in regulatory and policy decision making and standard setting often must be collected using approved methods, which may include acceptance testing to demonstrate equivalence to these methods. Applicable Part(s) of Title 40, Protection of Environment, of the Code of Federal Regulations (CFR) should be consulted to ensure the study meets sampling, siting, quality assurance and all other requirements.

How to Use This Document

This Handbook should be used with the two companion documents – the Templates and the Compendium of Examples. This Handbook explains the purpose of each of the templates. The Templates provide instructions, tables and questions that should be filled in or responded to, and the Compendium provides specific examples of quality assurance documentation. Together, these documents will help organizations complete a QAPP and provide information for data users to evaluate the quality of data collected by citizen scientists. The Templates are recommended but not required. Federal, state, local, tribal, or other organizations may also be contacted for more assistance or guidance. The following are steps to consider when writing a QAPP.

1. Frame the Project's Purpose

Citizen science and crowdsourcing are terms describing diverse activities involving a range of organizations, uses and outcomes. Projects can span different environmental media (e.g. water, air, or biota) and different levels of participant engagement and responsibility. Some citizen science projects are designed for educational or community engagement purposes only, whereas others are designed to scientifically evaluate environmental exposure, to perform legally-defensible measurements, or to affect policy. **Table 1** lists data uses by EPA and other organizations, organized by broad categories and specific project purposes (NACEPT, 2016).

We recommend that your organization design a QAPP that matches the intended purpose of the project, as listed in **Table 1**. Determining where a project fits within the spectrum of project purposes can help characterize the necessary level of quality assurance documentation.

Table 1. Categories of data use associated with project purposes.

Categories of Data Use	Intended Project Purpose
Increasing public understanding	Community engagement
	Education
Scientific studies and research	Environmental condition indicators (screening, exposure)
	Studies and research
Legal and policy action	Regulatory decisions

2. Define the Level of Quality Assurance and Documentation

Once you have identified the project's intended purpose, you should consider the activities you should perform to meet the needs and expectations of the data user. These activities are the basis of Quality Assurance (EPA, 2002) and may include: designing a plan to sample at representative locations; identifying the volume of air needed to meet appropriate levels of detection; or creating Standard Operating Procedures (SOPs) to ensure that volunteers record data uniformly. Quality assurance planning ensures that participants agree to roles and responsibilities, and that data can be used to answer the questions posed by the project, with a defined level of confidence to meet the intended use of the data.

A citizen science organization should consider the project purpose and use of data as it selects the appropriate level of quality assurance and documentation. With this **graded approach**, data collected for *legal and policy action* would require more extensive quality assurance and documentation than data collected for *increasing public understanding*. Below, we provide additional information on these broad categories so that your organization can better determine the activities required to meet the appropriate level of quality assurance and documentation.

Increasing Public Understanding (light shade)
Projects in this category include studies on basic phenomena or issues, and often have as a primary or supporting objective to engage communities in environmental monitoring. Common objectives may center around educating citizens about their environments, scientific processes, and STEM (science, technology, engineering and mathematics) activities. These projects may result in more qualitative, or descriptive outcomes, such as presence or absence of specific species. In these projects, sampling locations may be more dependent on availability of volunteers, rather than based on a rigorous sampling scheme.

Scientific Studies and Research (medium shade)
Projects in this category are aimed at providing data useful for research, feasibility studies, or to identify baseline conditions or trends in exposure from water or air pollutants. Many projects in this category determine the effectiveness of environmental decisions, such as evaluating the number of fish traveling upstream after a dam has been removed. Many organizations in this category conduct screening studies for ecological or public health assessments and utilize risk assessment tools for prioritizing community-based actions.

Legal and Policy Action (dark shade)

Projects requiring the most rigorous level of quality assurance and documentation fall into this category. The purposes of these projects may include regulatory decision-making at a local, state or national level, and often use approved federal methods, or acceptance testing to demonstrate equivalence to these methods.

The overall project purpose may include specific objectives for individuals, communities, and institutions (such as government agencies or universities). Also, the purpose of a project may evolve, or fall into more than one category of data use. A project may start as a community-based educational project but evolve into a more rigorous scientific study that evaluates baseline conditions. For example, an effort to engage local communities in measuring water quality may produce information indicating a need to curb pollution from specific sources. In these situations, more stringent quality assurance and documentation may be needed and pursuing the highest level of quality assurance that will meet a project's intended purpose is recommended. A QAPP is not a static document and should be updated whenever an aspect of the project changes.

3. Factors to Consider

How do you determine the right level of quality assurance and documentation? One factor is whether the data collected are *qualitative* or *quantitative*. In general, quantitative projects (i.e. how much?), as well as projects using statistical hypothesis tests, require a higher level of quality assurance than qualitative projects (**Table 2**).

Table 2. Level of detail of quality assurance and documentation for different project purposes. The darker the shading, the more rigorous the quality assurance level of detail.

Categories of Data Use	Intended Project Purpose	Quantitative	Qualitative	Level of Detail
Increasing public understanding	Community engagement			
	Education			
Scientific studies and research	Environmental condition indicators (screening, exposure)			
	Studies and research			
Legal and policy action	Regulatory decisions			

Projects whose primary purpose is to engage the public might be collecting qualitative information. The environmental question might address presence or absence of specific classes of plants or animals at targeted geographic locations or in a watershed. Or, citizen scientists might collect quantitative data on abundance of certain species, but summarize the data using descriptive measures, such as "low", "medium" or "high".

In contrast, projects that provide information for measuring exposure, or for regulatory decision-making, typically require a quantitative estimation of an important condition indicator. For these projects, the study question often includes a statistic, such as the mean or median, and a measure of variability, estimated from the collected data, which can be visually displayed on a graph or map. These projects are often conducted in a well-defined study area that represents a potentially impacted population (EPA, 2006). Suppose that citizen scientists are interested in the effectiveness of a pollution control device at a nearby smelter. The lead project scientist should establish a statistical hypothesis test to measure, estimate, and compare the median concentrations of air toxicants at specific locations (e.g. upwind and downwind) before and after a new pollution control device has been installed.

Again, you should pursue the highest level of quality assurance and documentation that will meet your project's intended purpose.

4. Link the Intended Use of Data to Recommended Quality Assurance Templates[1]

Like all scientific projects, citizen science projects employ specific strategies, or activities, to improve the credibility of data. These activities are grouped into 24 distinct elements found in standard EPA guidance (EPA, 2001; EPA, 2002). For this Handbook, however, we have consolidated these into 19 key elements shown in **Table 3** (and **Figure 1**). The companion document, *Templates for Citizen Science Quality Assurance and Documentation,* helps organizations complete these elements. Your organization should fill out the templates based on how the data are intended to be used and on guidance received from a state and/or EPA regional office, if applicable.

For each template, it is important that you also choose the right level of quality assurance and documentation to match the project purpose. So, projects addressing regulatory decision-making would require more quality control (QC) activities, such as more frequent instrument calibrations. Similarly, all projects require some level of training of volunteers, but projects to address regulatory decision-making would require more intensive training.

5. Just Getting Started?

The guidance and concepts in the Handbook and Templates can be applied to citizen science projects at any scale, but we recognize that some groups may be in the early stages of learning how to document data quality or may be new to data collection entirely. Even at an early stage, EPA recommends projects provide some level of data quality documentation to help you make use of your data.

As a coordinator of a citizen science project, you may be involved in many aspects of project planning, sample collection, laboratory analysis, data review, and data assessment and data management. Therefore, it is important to consider quality assurance (e.g. planning activities you perform to manage the project and collect, assess, and review data) and quality control (e.g. technical activities you conduct to limit error from instruments or in measurements) in every stage of your project. But, this doesn't need to be overwhelming. You can address the essential elements of quality assurance and documentation by answering these key questions:

1) What is the purpose of the project, and the question you want to answer?
2) How and where are you planning to collect samples, data, or other information?
3) How are you training the volunteers to collect samples, data or other information?
4) How will you control for errors in the field, in the laboratory, or during data analysis?
5) How will you check your data and determine if it is useful?
6) Where do the data go and who will look at the data?

[1] The distribution of quality assurance documentation for each of the data uses follows the alignment from tiered guidance of the EPA Office of Air Quality Planning and Standards, 2017.

Science is great! Collecting data for a big project is fun and valuable but to make conclusions from the data, you need to carefully document these activities. We think that as you answer these questions by filling out the templates in this Handbook, you will be able to better communicate the quality and utility of your project's data.

Table 3. EPA QAPP elements and quality assurance templates recommended for citizen science projects. The templates are organized into four major Quality Assurance Project Plan element listed in EPA guidance documents.

Template	Increase Public Understanding	Science/Research	Legal/Policy
A. Managing the Project			
1. Title and Preparer Page	X	X	X
2. Table of Contents		X	X
3. Problem Definition, Background and Project Description	X	X	X
4. Data Quality Objectives and Indicators	X	X	X
5. Project Schedule		X	X
6. Training and Specialized Experience	X	X	X
7. Documents and Records	X	X	X
B. Collecting the Data			
8. Existing Data		X	X
9. Sampling Design and Data Collection Methods	X	X	X
10. Sample Handling and Custody		X	X
11. Equipment/Instrument Maintenance, Testing Inspection and Calibration		X	X
12. Analytical Methods	X	X	X
13. Field and Laboratory Quality Control	X	X	X
14. Data Management		X	X
C. Assessing the Data			
15. Reporting, Oversight and Assessments	X	X	X
D. Reviewing the Data			
16. Data Review and Usability	X	X	X
Managing the Project (continued)			
17. Organization Chart		X	X
18. Project/Task Organization		X	X
19. Project Distribution List		X	X

Figure 1. Quality assurance and documentation templates recommended for citizen science projects.

Increasing Public Understanding
Community Engagement, Education

Use of Templates 1,3,4,6,7,9,12,13,15,16 is recommended.

Scientific Studies and Research
Environmental Conditions Indicators, Screening, Studies and Research

Use of Templates 1 - 19 is recommended.

Legal and Policy Actions
Regulatory Decisions

Use of Templates 1 through 19 is STRONGLY recommended.

This document does not define, or otherwise limit, the purpose to which citizen scientists may seek to apply their data or information. EPA retains the discretion to determine the extent it will use data or information produced or resulting from use of this document. Please note, however, that data used in regulatory and policy decision making often must be collected using approved methods, which may include acceptance testing to demonstrate equivalence to these methods. To ensure these studies meet the sampling, siting, quality assurance and all other requirements, consult the target data end users for your project.

6. In Summary

This Handbook is meant to convey common expectations for quality assurance process and documentation, and best management practices for organizations that train and use volunteers in the collection of environmental data. This Handbook and its companion Templates and Examples will help the citizen science organization select the appropriate level of quality assurance and documentation to fit the intended use of the data.

For over twenty years, consistent with national consensus standards for collection of environmental data, EPA has encouraged organizations to use the QAPP format to document the transparency of the project's scientific methods, and the quality and usefulness of the collected data or information. The process of developing the QAPP is vital to the success of the project and often just as important as the final written QAPP document. The QAPP gives structure to the development of a project and helps when writing the conclusions reached at the end of the project. In addition, evaluation of the project always involves comparing what was actually done with the requirements in the QAPP.

Instructions for Citizen Science Quality Assurance and Documentation Templates

To develop the QAPP using the templates, complete each of the recommended templates applicable to your project. Templates may also be combined if the information is clearly distinguishable.

Corresponding Template #1: Title and Preparer Page

This page provides a title, an effective date of the plan, and confirms that key parties agree with the plan.

Corresponding Template #2: Table of Contents

For QAPPs longer than a few pages, the Table of Contents helps ensure all the information has been included and is easy to find. The table of contents should include a list (as appendices) of Standard Operating Procedures (SOPs), Instrument Manuals, and any checklists or forms, as applicable.

Corresponding Template #3: Problem Definition, Background and Project Description

A. Problem Definition

This section describes the environmental problem, question or threat to be addressed, explains why this work needs to be done, and provides a framework for determining the project purpose, the use of the data, and the project objectives (see below). As described earlier, the QAPP development process is iterative and the problem definition can be revised as you gather new information (e.g. limitations of available methods, or results from complementary studies).

B. Background

This is an opportunity to describe the history of the project (or environmental problem), relevant previous studies, and how this project fills in a data gap (including from existing data) or complements existing information. If the project is related to other on-going projects, then it is important to show how and why it is related. The more specific you can be, the more favorably it will be received when being considered as an addition to your (or other) datasets. If similar work is being done by others, then collaboration could possibly lead to even stronger results. Working within the scope of existing projects may enable you to build on or possibly use an existing QAPP. A reference to papers or studies that inspired your project are also useful as it may demonstrate that you have researched and identified appropriate methods for collecting data that apply to the environmental problem.

C. Project Description

This section is an opportunity to succinctly describe work to be performed, the data you plan to collect, the technologies or methods used to collect the data, and the decisions you plan to make with the data. For example, you may state that volunteers for your project will visually record the number of fish passing through a fish ladder in two segments of a river during the spring over a three-year period, to determine whether fish passage increases after the removal of a dam. Additional project information as listed below will help your organization plan quality assurance activities to meet the project objectives.

First, you need to identify the **project objectives**. These address the problem or answer the environmental questions <u>and link data results with possible actions</u>. One way to answer this is using "If...then..." statements, such as "If the result for parameter *x* in this area is above the regulatory standard, then we will...". These objectives form the foundation for the entire study. The more precise you are in defining the problem and the project objectives, the more likely it is that the project will successfully meet those objectives.

This section should also include a brief description of the **project site or study area, and locations** as they relate to the environmental questions to be addressed. The definition of a target study area or population ensures that the samples taken are representative of the intended population, and that the locations are selected based on the project objectives.

It is also essential to identify the **time period** for data collection, because your project objectives may apply only to a specific temporal window. For example, a project recording migratory fish through an estuary depends on the timing of the life cycle of the species of interest.

Finally, you should include information on the **data users**. These are the individuals, groups, or agencies who are interested in, or who will make decisions based on, the data and information.

Corresponding Template #4: Data Quality Objectives and Data Quality Indicators

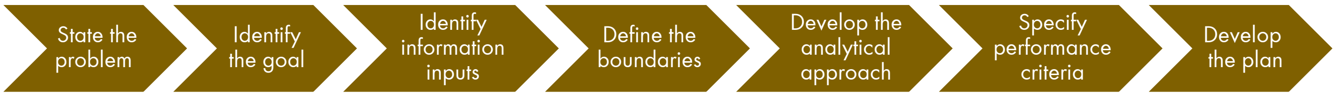
These are key elements of a QAPP and they translate project objectives into specific quality assurance and quality control activities.

A. Data Quality Objectives

Data quality objectives (DQOs) are quantitative or qualitative statements describing the degree of the data's acceptability (i.e. performance criteria) *for making decisions described in the project objective*. For example, if you plan to compare results from a continuous air monitor for ozone to the national 8-hour standard, you can state that the data gathered must be able to measure ozone on an hourly basis, and that variability and uncertainty are minimized (and reduce the likelihood of "decision errors") to determine statistically whether the national standard is being met. (Please note that ozone data collected by a citizen science organization would most likely be used for screening purposes and not for regulatory decision-making.) Qualitative DQOs, however, do not need to make a statistical statement. For example, a community engagement project may provide a DQO that plant species in the study area's impacted wetlands are accurately identified by the volunteers.

The process for setting DQOs can be very involved and relies on the information you provide in Templates 3 and 4. It can be summarized in the flowchart in **Figure 2**.

Figure 2. The DQO Planning Process.



For more information on DQO planning, refer to EPA 2006 as found in the References at the back of the Handbook.

B. Data Quality Indicators

To determine whether the data quality objectives are being met, you should evaluate **Data Quality Indicators** (DQI) for each parameter measured. These DQIs are more typical for projects where quantitative measurements of parameters, such as bacteria or particulate matter in air, or abundance of species, are collected. DQIs are attributes of the data being collected, specifically related to minimizing the uncertainty for each measurement or set of measurements. They are listed below:

> **Precision** is the ability of a measurement to consistently be reproduced. Repeated measurements are usually used to determine precision. In the case of repeated measurements, one would see how close those measurements agree. Precision is often measured as the relative percent difference or the relative standard deviation.
>
> **Bias** is any influence in the project that might sway or skew the data in a particular direction. Taking samples from one location where a problem is known to exist, instead of taking samples evenly distributed over a wide area, is one example of how data can be biased. Bias can result from a non-representative sampling design, calibration errors, unaccounted-for interferences and chronic sample contamination.
>
> **Accuracy** is a degree of confidence in a measurement. The smaller the difference between the measurement of a parameter and its "true" or expected value, the more accurate the measurement. Also, the more precise or reproducible the result, the more reliable or accurate the result. Accuracy can be determined by comparing an analysis of a chemical standard to its actual value.
>
> **Representativeness** is how well the collected data depict the true system.
>
> **Comparability** is the extent to which data from one data set can be compared directly to another data set. The data sets should have enough common ground, equivalence or similarity to permit a meaningful analysis.
>
> **Completeness** is the amount of data that must be collected to achieve the goals and objectives stated for the project. It is determined by comparing the amount of valid, or usable, data you collected to what you originally planned to collect.
>
> **Sensitivity** is essentially the lowest detection limit of a method, instrument or process for each of the measurement parameters of interest.
>
> **Measurement range** is the range of reliable readings of an instrument or measuring device, or a laboratory method, as specified by the manufacturer or the laboratory.

Each DQI has an associated *activity*, such as a *Quality Control (QC) check*. For example, volunteers recording pH in water using an electronic pH meter typically perform a calibration of the instrument before and after a sampling event with known standards. Or, an analytical instrument has a defined sensitivity, or detection limit. And, all DQIs have a quantitative *goal*. For an instrument measuring a specific analyte, a rule of thumb is that the detection limit should be at least three times less than the regulatory action level for that analyte.

If the project has a single use, or is limited in scope, then the data quality objectives will apply to just your project. If, however, data from your project contributes to a team or network of similar projects, then you should take into account the data quality objectives for the other projects as well.

More information on selecting and calculating these indicators are available in many of the documents listed in the references including: EPA, 1996 (The Volunteer Monitor's Guide to Quality Assurance Project Plans); EPA, 2002a (Guidance for Quality Assurance Project Plans. EPA QA/G-5); National Water Quality Monitoring Council (NWQMC), 2006; and Williams, et al., 2015 (Citizen Science Air Monitor (CSAM) Quality Assurance Guidelines).

Corresponding Template #5: Project Schedule

A project schedule helps identify timeframes necessary for planning sampling events, including preparing or procuring equipment, informing participants about timing of data collection, and expectations for distribution of data for review and reporting. Signing off on the QAPP implies that the participants agree to the planned schedule.

Corresponding Template #6: Training and Specialized Experience

The training of citizen data collectors is a very important part of a project. Training ensures consistency and should be recorded and documented. Note that records of training can be as simple as an email summarizing what was taught, by whom and for whom. Training records are essential to evaluate whether procedures are performed correctly and to document the qualifications of the people involved. Some projects rely on professional scientists or trainers with specialized experience that greatly assist the project.

Corresponding Template #7: Documents and Records

It is critical that the key project personnel are aware of the location and status of important documents (e.g. QAPPs, Standard Operating Procedures (SOPs), field data sheets and records (e.g. databases, quality control (QC) checklist). By attaching copies of procedures and checklists to the QAPP, you can provide consistency for the whole project. This also assists in training, data analysis and reporting.

Corresponding Template #8: Existing Data and Data from Other Sources

It is often valuable (or necessary) for projects to use existing data. Existing data can include sampling and testing data collected during previous investigations; historical data, background information; interviews; modeling estimates; photographs; aerial photographs; topographic maps; and published literature, including from Federal and State agencies. The project team should determine whether the quality of the data collected (even by reliable sources or reported in a peer reviewed journal article) are acceptable for the objectives of your project. You should consider the source of the data, the time period during which the data were collected, data collection methods, potential sources of uncertainty, and the type of supporting documentation available including quality assurance documentation such as precision, bias, representativeness, comparability, and completeness. Some of this information may not be available, and you will need to make a judgement on the limitations of the use of the data. Note that there are many sources of existing data that are recognized as reliable, such as National Weather Service data, or other national monitoring networks (e.g. United States Geological Survey).

You should complete this template if your project will be using existing data. If there are no existing data being used, state "no existing data is being used".

Corresponding Template #9: Sampling Design and Data Collection Methods

A. Sampling Design

You need to design a sampling regime that meets the project objectives. For example, you might consider a statistical, or probability-based design to make inferences over a large geographic area, a watershed, or a community. Or you may want to target specific areas using a judgmental design to identify "hot-spots" and contrast "reference" versus "impacted" populations. And, you need to consider the sampling methods or technologies you will employ, e.g. discrete sampling, *in situ* sensors, continuous monitoring, or vegetation transects.

Details about the sampling design and quality control activities should also be documented so that if other organizations repeat the project, they would generate similar results. Some of this information may occur elsewhere in the QAPP and can be referenced here.

This template should also list the quantity and type of **quality control** (QC) samples collected during the project. QC samples are needed to evaluate whether your data quality objectives and indicators are met (see Template #4). For example, contamination is a common source of error in both sampling and analytical procedures, so blank samples are collected to identify when and how contamination might occur. An organization should always document that blanks are consistently free of contamination. A general rule is that 10 to 20% of field collected samples should be QC samples. The laboratory must also run its own QC samples (such a positive and negative controls for microbiological analysis) because they also need to document that their operations do not cause increases in error. For a new monitoring project or for a new analytical procedure, it is a good idea to increase the number of QC samples (up to 20%) until you have full confidence in the procedures you are using. Types of QC samples are described in **Table 4**. Projects that collect qualitative information, such as general abundance of specific species, can evaluate quality by having more than one individual make the same assessment. Vegetation surveys that rely on correct identification of species often send voucher specimens to regional experts.

Note that most of these QC samples are designed primarily for discrete water samples and other types of samples may be required for air or water continuous monitoring. For air monitoring projects, the organization should co-locate sensors at or near sites where reference instruments have been deployed by regulatory agencies. If you are mapping vegetation, or conducting a faunal survey, it is good practice to perform replicate transects to evaluate field variability or have more than one person evaluate the same transect. To assess accuracy of your taxonomic identification, some scientists recommend use of voucher specimens. A voucher specimen is any specimen that serves as a basis of study and is retained as a reference. It should be in a publicly accessible scientific reference collection.

Table 4. Typical QC sample types, descriptions and uses for discrete sampling

QC Sample Type	**Description**	***Useful for (examples)***
Field Blank	A "clean" sample, produced in the field, used to detect or document contamination during the whole process (sampling, transport, and lab analysis). Examples include clean sampling containers, blank filters, etc. that are treated the same as field samples, except no sample is collected in/on them.	Water, sediment and soil sampling; air sampling onto filters
Equipment or rinse blank	This type of blank is used to evaluate if there is carryover contamination from reuse of the same sampling equipment. A sample of distilled water (or other solvent, per the method) is collected in a sample container using regular collection equipment and analyzed as a sample.	Water, sediment and soil sampling equipment; filter air sampling equipment
Split sample	Sample that is divided equally into two or more sample containers and then analyzed by different analysts or laboratories. Used as a measure of precision or to measure the variability in results between laboratories or samples independently analyzing the same original sample.	Water, sediment, soil and fish tissue sampling
Co-located samples	Applicable to air and water sampling. For air sampling, two or more sample collection devices, located together in space and operated simultaneously, to supply a series of duplicate or replicate samples for estimating precision of the total measurement system/process and verification with established methods. Co-located samples must be exposed to the same environment and exposed to the same air. For water sampling, discrete sampling could be applied to compare with continuous monitoring stations.	Water, sediment and soil
Replicate Samples	Obtained when two or more samples are taken from the same site, at the same time, using the same method, and independently analyzed in the same manner. When only two samples are taken, they are sometimes referred to as duplicate samples. These types of samples are representative of the same environmental condition. Replicates (or duplicates) can be used to detect both the natural variability in the environment and that caused by field sampling methods.	Water, sediment and soil
Spiked Samples	Samples to which a known concentration of the analyte of interest has been added. Spiked samples are used to measure accuracy. If this is done in the field (which is unusual), the results reflect the effects of matrix, preservation, shipping, laboratory preparation, and analysis. If done in the laboratory, they reflect the effects of the analysis from the point when the compound is added, e.g. just prior to the measurement step. Percent recovery of the spike material is used to calculate analytical accuracy.	Water, sediment and soil

B. Data Collection Methods

A successful project relies on a consistent protocol for sample collection. Organizations should be able to train their volunteers in these methods so that data collection is feasible and repeatable. Information on recommended sample collection methods, specialized containers, or technologies for ambient water and air, drinking water, and vegetation sampling, may be found in the references and at the following resources:

- Stream, estuary and lake monitoring: https://www.epa.gov/nps/nonpoint-source-volunteer-monitoring
- Drinking water monitoring: https://www.epa.gov/sites/production/files/2015-11/documents/drinking_water_sample_collection.pdf
- New England States Drinking Water Monitoring: https://www.epa.gov/sites/production/files/2015-06/documents/NE-States-Sample-Collection-Manual.pdf
- Air Sensor Monitoring: https://www.epa.gov/air-sensor-toolbox
- Continuous water quality monitoring: https://pubs.usgs.gov/tm/2006/tm1D3/pdf/TM1D3.pdf

Additional resources are available at the following resources targeted for citizen scientists:

- https://www.citizenscience.gov/toolkit/resource-library/
- http://citizenscience.org/

If there are Standard Operating Procedures (SOPs) used, either attach them to the QAPP or cite the publication where they can be found.

When possible, obtain the exact position (using GPS or smartphone applications) of where the sample came from, including sample depth, height, and air or water temperature (if appropriate). If during data review, the reported value appears to be a potential outlier, it may be possible to resample exactly at that point where the initial sample was taken. It could be that it really was an anomaly, but it could be that something else was interfering with the physical conditions at that particular point, for example, an unexpected "hot spot" that should be considered differently from the other values.

Corresponding Template #10: Sample Handling and Custody

To ensure that the sample is not altered after collection or meets the laboratory holding time requirements, this template describes your efforts to have each collected sample retain its original physical form and chemical composition through collection to final disposal. It also identifies maintenance of custody (or possession) of the sample. These principles also apply to continuous monitoring measurements. Chain-of-custody procedures are especially critical for projects where the data may be used in court as evidence or for making regulatory decisions. A chain-of-custody log (which may be composed of shipping manifests or receipts, as long as a person is identified at the point of shipping and receipt at the lab) may be vital to defend the integrity of the data in the case of suspected tampering. Some methods include seals or other configurations to detect tampering.

Corresponding Template #11: Equipment List, Instrument Maintenance, Testing, Inspection and Calibration

Many citizen scientists use electronic (*in situ*) sensors in water and air matrices and these instruments need to be calibrated. All calibrations for a project should be planned for and documented. Calibration records should be kept on calibration data sheets specific to each piece of equipment and include date, time, name of individual doing calibration, and the calibration results themselves. **Acceptance criteria** for calibration checks should also be included on the data sheets. Acceptance criteria are usually quantitative measures and goals that evaluate whether the results can be used. For example, you may check your instrument after sampling many sites against a calibration standard. This is a QC check and called **verification** (see Template #16). If the difference is within the acceptance criteria (or DQI goals, see Template #4), usually expressed as a percentage, you can accept the results.

Calibration is important because it helps prevent bias. Depending on the specifications of the equipment manufacturers, some equipment needs more attention than others and this template helps in making sure equipment does not 'drift' over time. This applies especially to continuous monitoring instruments in water and air. Water sensors are especially prone to drift caused by biofouling and is often distinct from sensor drift.

Analytical and field instruments differ in precision and sensitivity (i.e. lower limit of detection). To compare or merge datasets, or if instruments are changed during the course of a project, it is critical to document these specifications.

Corresponding Template #12: Analytical Methods

This template lists in one place all the specifications for the laboratory or field measurement method organized by each parameter, or analytical group (such as metals, or nutrients). It also helps establish the criteria, such as reporting limits, needed for the project, based on the data quality objectives identified in Template #4. Often, the most important specifications here are the actual sample volume the laboratory needs to make the appropriate analysis and the holding time for the sample. To complete this template, an organization should consult with the analytical laboratory, or field method manufacturer or authorized representative to ensure that the amount of material, water, or air sampled is sufficient to meet the target detection (or reporting) limits. Most information regarding limits and sample volumes for methods can be found online, for both laboratories using standard methods and for field measurement equipment.

Corresponding Template #13: Field and Analytical Laboratory Quality Control Summary

The tables in this template summarize information from Template #s 4 and 9 on the types of quality control (QC) samples that will be collected in the field and by the laboratory.

Corresponding Template #14: Data Management

As was done for sample handling, the information in this template traces the path of the data, from field collection and laboratory analysis to final use or storage. This ensures that project personnel use data of known status or of a defined stage of review or validation. You will need to describe record-keeping procedures, your document control system, and the approach used for data storage and retrieval on electronic media. Any forms or checklists should also be included as attachments.

Corresponding Template #15: Reporting, Oversight and Assessments

Assessments and project oversight include reviews (if possible, by an outside reviewer) to identify shortcomings or departures from the QAPP, corrective actions taken, and limitations of the use of the data. Reporting of results is critical for ensuring that any deviations are corrected if possible, and if none are found, to document the successful implementation of procedures. It is also important to report results and interpretations so that project participants are engaged, and understand the project's progress and results, and limitations or setbacks, if found. Data and interpretive reports might be distributed to project partners and government agencies, but also posted to web sites for public access.

Corresponding Template #16: Data Review and Usability

Use this section to describe how your organization will review, verify, and validate data to determine whether your project objectives were met, and that your data are fit for use. The level of detail and frequency for performing data review depends on the intended use of the data. You should describe how project personnel (such as the project coordinator and the Quality Assurance Manager, if available) will review data as they are obtained and documented (e.g., in checklists, logbooks, emails, and QA reports).

Although data verification and validation are typically conducted sequentially, it may be beneficial (and more cost effective) for smaller projects to combine steps. For example, the personnel conducting the verification could also conduct the first step of the validation process concurrently. When multiple people are involved in a project, the initial data collector typically conducts the first verification at the time of collection and later, if a QA Manager is available (see Template #17), he or she should review the QC checks recorded on the data sheets.

The first step in review is verification. Verification is *determining whether an activity conforms to the stated requirements, (such as acceptance criteria) for that activity*. For example, if you are using a hand-held multi-meter to determine pH and conductivity at certain points in a stream, you should have established calibration procedures and QC checks (associated with data quality indicators) for those two parameters. While you are collecting your data, you would record the results (e.g. on a datasheet or in a notebook) and then review them to ensure that QC checks such as blanks and calibration checks are within the goals (or acceptance criteria) that you have set (see Template #s 4, 9 and 11). This verification process indicates that your multi-meter is operating correctly. Verification also applies if your data are qualitative, such as checking to see if a fish or plant species identification was performed correctly.

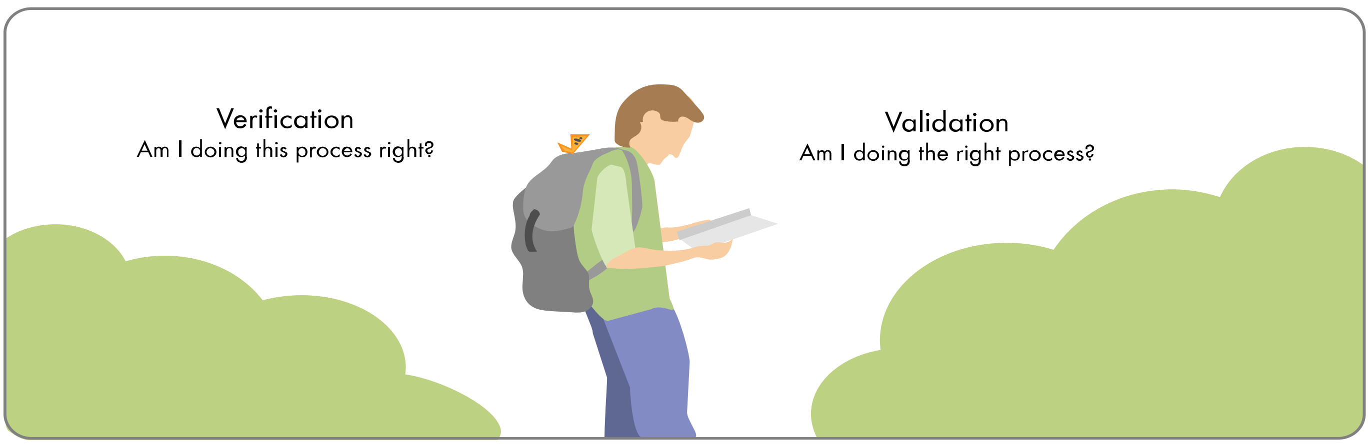
The next step in review is validation. Validation is *determining whether the activities conform to the user needs for the overall project.* This step is a higher-level activity that introduces additional (mostly quality assurance) activities such as reviewing sampling locations, training, chain-of-custody, documentation, and appropriate methods. These activities tie back to the Data Quality Objectives to determine whether the data can be used. (See **Figure 3** below for the distinction between verification and validation.)

Regarding the example used above, if you were measuring conductivity in a stream to evaluate the impacts of road salt, you might consider the following questions:

1. Did we collect the right types of data? Can we make a decision based on pH and conductivity alone, or should we have also taken other measurements such as temperature, nitrate, or dissolved oxygen?
2. Did we collect data from the right locations in the stream(s)? If we had planned to collect data from all the appropriate locations, did we meet our completeness goal? Can we compare our results statistically to a regulatory standard?
3. Did all the datasets meet 100% of the QC criteria? If not, what is the impact to the overall study? Are data qualifiers needed to describe certain specific QC issues that did not meet their planned QC acceptance criteria but do not necessitate complete rejection of the dataset?

All data issues, such as outliers, or batches of samples that do not meet acceptance criteria, should be discussed with the project lead or QA Manager (if available) and explained in project reports. In some cases, data qualifiers may be needed to "flag" data that do not meet QC acceptance criteria, but do not require rejection of the full dataset.[2]

Figure 3. The distinction between verification and validation.



[2] Data qualifiers (sometimes informally called "flags") are a set of codes that are applied to your data to describe various aspects of an analysis that did not meet the QC goals (or acceptance criteria) described in the QAPP or SOPs. Typical flags are for high blanks, low check standards, or measurements below the detection limit. For additional information about common types of data qualifiers, see Appendix C of EPA QA/G-8 Guidance (EPA, 2002b) on Environmental Data Verification and Data Validation.

Finally, you should ensure that your review will evaluate whether you have met the project objectives, and the data are usable, or whether you have identified and documented limitations in the use of the data. You may identify significant departures from the QAPP, or incorrect assumptions established in the planning phase of data collection. You may have uncovered unique qualities of the sample matrix; use of non-standard analytical methods; or a sampling design that is not representative or does not allow for planned statistical comparisons. Any potential limitations of the data should be documented in records associated with these data (i.e., metadata) and included in the final project report.

Corresponding Template #17: Project Organization Chart

The organization chart shows the lines of communication and reporting for the project, like a chain of command. The chart should represent the personnel responsible for ensuring data quality, such as the project lead, trainers, and field data collectors. Some projects require a team of people with differing responsibilities and titles; others may require the services of a single person on a part-time basis. In general, organization charts are not needed for small projects.

We recommend that you identify one person responsible for the overall integrity of the project, sometimes referred to as the Quality Assurance Manager (QAM). To ensure the inadvertent introduction of bias, this person should be independent of the staff working on the project and should have sufficient knowledge of the methodologies of the project, and the confidence to ask questions. The role of the QAM is to evaluate the project activities, methods and results and determine whether the data collected are meeting the project objectives. Many small projects may not have the capability to employ an independent person, so a qualified, experienced, and trained individual can fill this role.

Corresponding Template #18: Project Organization

This shows everybody's role in the development of the project. The responsibilities section provides an outline of the work that will be done for the project. Project-specific details are addressed in many of the other templates.

Corresponding Template #19: Project Distribution List

The distribution list ensures everyone involved with the project receives a copy of the QAPP or other documents and is aware about the work being conducted. It also provides the contact information for those involved with the project, so everyone is aware if changes to the project are made.

Definitions[3]

Acceptance criteria. Quantitative measures and goals that evaluate whether the results can be used.

Accuracy. A data quality indicator, accuracy is the extent of agreement between an observed value (sampling result) and the accepted, or true, value of the parameter being measured. High accuracy can be defined as a combination of high precision and low bias.

Analyte. Within a medium, such as water, an analyte is a property or substance to be measured. Examples of analytes would include pH, dissolved oxygen, bacteria, and heavy metals.

Assessment. The evaluation process used to measure the performance or effectiveness of a system and its elements. As used here, assessment is an all-inclusive term used to denote any of the following: audit, performance evaluation, management systems review, peer review, inspection, or surveillance.

Audit (quality). A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements are implemented effectively and are suitable to achieve objectives.

Bias. Often used as a data quality indicator, bias is the degree of systematic error present in the assessment or analysis process. When bias is present, the sampling result value will differ from the accepted, or true, value of the parameter being assessed.

Blind sample. A type of sample used for quality control purposes, a blind sample is a sample submitted to an analyst without their knowledge of its identity or composition. Blind samples are used to test the analyst's or laboratory's expertise in performing the sample analysis.

Calibration. 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.

Chain-of-custody. An unbroken trail of accountability that ensures the physical security of samples, data, and records.

Citizen science. When the public participates voluntarily in the scientific process, addressing real-world problems in ways that may include formulating research questions, conducting scientific experiments, collecting and analyzing data, and interpreting results.

Contractor. Any organization or individual that contracts to furnish services or items or perform work; a supplier in a contractual situation.

[3] EPA, 2001 - EPA Requirements for Quality Assurance Project Plans, March 2001: QA/R-5. EPA/240/B-01/003. Office of Environmental Information. U.S. Environmental Protection Agency. Washington, DC 20460. https://www.epa.gov/sites/production/files/2016-06/documents/r5-final_0.pdf

Comparability. A data quality indicator, comparability is the degree to which different methods, data sets, and/or decisions agree or are similar.

Completeness. A data quality indicator that is generally expressed as a percentage, completeness is the amount of valid data obtained compared to the amount of data planned.

Data quality assessment. A statistical and scientific evaluation of the data set to determine the validity and performance of the data collection design and statistical test, and to determine the adequacy of the data set for its intended use.

Data quality indicators. Attributes of the data being collected, specifically related to minimizing the uncertainty for each measurement or set of measurements. These typically include precision, bias, accuracy, representativeness, comparability, completeness, sensitivity and measurement range.

Data quality objectives (DQOs). Data quality objectives are quantitative and qualitative statements describing the degree of the data's acceptability or utility to the data user(s). They include indicators such as accuracy, precision, representativeness, comparability, and completeness. DQOs specify the quality of the data needed to meet the monitoring project's goals. The planning process for ensuring environmental data are of the type, quality, and quantity needed for decision making is called the **DQO process.**

Data usability. The process of ensuring or determining whether the quality of the data produced meets the intended use of the data.

Data users. The group(s) that will be applying the data results for some purpose. Data users can include the monitors themselves as well as government agencies, schools, universities, businesses, watershed organizations, and community groups.

Detection limit. Applied to both methods and equipment, detection limits are the lowest concentration of a target analyte that a given method or piece of equipment can reliably ascertain and report as greater than zero.

Duplicate sample. Used for quality control purposes, duplicate samples are two samples taken at the same time from, and representative of, the same site that are carried through all assessment and analytical procedures in an identical manner. Duplicate samples are used to measure natural variability as well as the precision of a method, monitor, and/or analyst. More than two duplicate samples are referred to as replicate samples.

Environmental conditions. The description of a physical medium (e.g., air, water, soil, sediment) or biological system expressed in terms of its physical, chemical, radiological, or biological characteristics.

Environmental data. Any measurements or information that describe environmental processes, location, or conditions; ecological or health effects and consequences; or the performance of environmental technology. Environmental data also includes information collected directly from measurements, produced from models, and compiled from other sources such as data bases or the literature.

Environmental sample. An environmental sample is a specimen of any material collected from an environmental source, such as water or macroinvertebrates collected from a stream, lake, or estuary.

Equipment or rinse blank. Used for quality control purposes, equipment or rinse blanks are types of field blanks used to check specifically for carryover contamination from reuse of the same sampling equipment (see field blank).

Field blank. Used for quality control purposes, a field blank is a "clean" sample (e.g., distilled water) that is otherwise treated the same as other samples taken from the field. Field blanks are submitted to the analyst along with all other samples and are used to detect any contaminants that may be introduced during sample collection, storage, analysis, and transport.

Instrument detection limit. The instrument detection limit is the lowest concentration of a given substance or analyte that can be reliably detected by analytical equipment or instruments (see detection limit).

Matrix. A matrix is a specific type of medium, such as surface water or sediment, in which the analyte of interest may be contained.

Measurement range. The measurement range is the extent of reliable readings of an instrument or measuring device, as specified by the manufacturer.

Metadata.[4] The simplest definition of metadata is "structured data about data." Metadata is structured information that describes, explains, locates, or otherwise makes it easier to retrieve, understand, use or manage an information resource.

Method detection limit (MDL). The MDL is the lowest concentration of a given substance or analyte that can be reliably detected by an analytical procedure (see detection limit).

Performance evaluation (PE) samples. Used for quality control purposes, a PE sample is a type of blind sample. The composition of PE samples is unknown to the analyst. PE samples are provided to evaluate the ability of the analyst or laboratory to produce analytical results within specified limits.

Precision. A data quality indicator, precision measures the level of agreement or variability among a set of repeated measurements, obtained under similar conditions. Precision is usually expressed as a standard deviation in absolute or relative terms.

Protocols. Protocols are detailed, written, standardized procedures for field and/or laboratory operations.

Quality assurance (QA). QA is an integrated management system designed to ensure that a product or service meets defined standards of quality with a stated level of confidence. QA activities involve planning quality control, quality assessment, reporting, and quality improvement.

[4] EPA Classification No.: CIO 2135-S-01.0 - Enterprise Information Management (EIM) Minimum Metadata Standards

Quality Assurance Manager (QAM). The individual designated as the principal manager within the organization having management oversight and responsibilities for planning, documenting, coordinating, and assessing the effectiveness of the quality system for the organization.

Quality assurance project plan (QAPP). A QAPP is a formal written document describing the detailed quality control procedures that will be used to achieve a specific project's data quality requirements.

Quality control (QC). QC is the overall system of technical activities designed to measure quality and limit error in a product or service. A QC program manages quality so that data meets the needs of the user as expressed in a quality assurance project plan.

Relative standard deviation (RSD). RSD is the standard deviation of a parameter expressed as a percentage and is used in the evaluation of precision.

Relative percent difference (RPD). RPD is an alternative to standard deviation, expressed as a percentage and used to determine precision when only two measurement values are available.

Replicate samples. See duplicate samples.

Representativeness. A data quality indicator, representativeness is the degree to which data accurately and precisely portray the actual or true environmental condition measured.

Sensitivity. Related to detection limits, sensitivity refers to the capability of a method or instrument to discriminate between measurement responses representing different levels of a variable of interest. The more sensitive a method is, the better able it is to detect lower concentrations of a variable.

Spiked samples. Used for quality control purposes, a spiked sample is a sample to which a known concentration of the target analyte has been added. When analyzed, the difference between an environmental sample and the analyte's concentration in a spiked sample should be equivalent to the amount added to the spiked sample.

Split sample. Used for quality control purposes, a split sample is one that has been equally divided into two or more subsamples. Splits are submitted to different analysts or laboratories and are used to measure the precision of the analytical methods.

Standard reference materials (SRM). An SRM is a certified material or substance with an established, known and accepted value for the analyte or property of interest. Employed in the determination of bias, SRMs are used as a gauge to correctly calibrate instruments or assess measurement methods. SRMs are produced by the U. S. National Institute of Standards and Technology (NIST) and characterized for absolute content independent of any analytical method.

Standard deviation(s). Used in the determination of precision, standard deviation is the most common calculation used to measure the range of variation among repeated measurements. The standard deviation of a set of measurements is expressed by the positive square root of the variance of the measurements.

Standard operating procedures (SOPs). An SOP is a written document detailing the prescribed and established methods used for performing project operations, analyses, or actions.

True value. In the determination of accuracy, observed measurement values are often compared to true, or standard, values. A true value is one that has been sufficiently well established to be used for the calibration of instruments, evaluation of assessment methods or the assignment of values to materials.

Validation. Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled. In design and development, validation concerns the process of examining a product or result to determine conformance to user needs.

Variance. A statistical term used in the calculation of standard deviation, variance is the sum of the squares of the difference between the individual values of a set and the arithmetic mean of the set, divided by one less than the numbers in the set.

Verification. Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled. In design and development, verification concerns the process of examining a result of a given activity to determine conformance to the stated requirements for that activity.

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