CHAPTER 2 ASSESSMENT METHODS

2014 Integrated Report

Contents

CHAPTER 2 ASSESSMENT METHODS

INTEGRATED REPORT

OVERVIEW OF UTAH'S WATER QUALITY ASSESSMENT METHODS

Introduction

Clean Water Act (CWA) federal rules and regulations require the Utah Division of Water Quality (DWQ) to report the condition—or health—of all surface waters to U.S. Congress every other year. Known as the integrated report (IR), this report contains three key pieces of information. First, the report identifies waterbodies that are not meeting their designated uses. These waters are listed as impaired on the 303(d) list of this report (in reference to Section 303(d) of the CWA, which subsequently requires that DWQ develops restoration plans to improve the condition of these waters). Second, the report summarizes the overall condition of Utah's surface waters and estimates the relative importance of key water quality concerns (e.g., pollutants, habitat alteration) and sources of water quality problems. Third, the report contains accompanying methods for the assessment process contained in this chapter. In addition to meeting federal legal requirements such as CWA Section 305(b), these broad statewide summaries help DWQ and the U.S. Environmental Protection Agency (EPA) prioritize resource needs.

The IR combines the 305(b) report on current water quality condition with the 303(d) list of impaired waters.

The following assessment methodology summarizes the methods that DWQ follows when assessing whether water quality is sufficient to support the designated uses assigned to Utah's surface waters. In particular, these methods describe how chemical and biological data are compared against Utah water quality standards (Utah Administrative Code [UAC] R317-2) to identify impaired waters. These methods are often revised in response to new information or to improve their legal or scientific defensibility. In all cases, the aim of assessment methods is to balance the potential for false positive conclusions (conclusion of a degraded use when it is actually supported) and false negative conclusions (failure to identify a degraded use), while remaining consistent with federal regulations and guidance (e.g., *Guidance for 2006 assessment, listing and reporting requirements pursuant to Sections 303(d) and 305(b) of the Clean Water Act* [EPA, 2005]).

What's New in the 2012-2014 IR Assessment Methods

- DWQ developed a suite of automated database tools to improve data quality, reduce human error, and more efficiently and accurately assess water quality data.
- In concert with the targeted monitoring approach outlined in the DWQ Strategic Monitoring Plan, assessments were performed on individual monitoring locations to more accurately define the extent of impairments within an assessment unit (AU).
- Statewide assessments integrated biological, chemical, and physical data collected as part of the probabilistic survey sampling design to better identify environmental stressors and responses in the biological communities of rivers and streams.
- DWQ incorporated data from external sources such as the Utah Division of Oil, Gas and Mining (DOGM) and publically submitted datasets.

Designated Uses and Water Quality Standards

The CWA's central objective is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (CWA Section 101). To meet this objective, the CWA and associated regulations developed the concept of "designated uses." Designated uses describe key attributes of waters that should be maintained to ensure that all surface waters provide important services to humans and other organisms. The creation of use classes allows different waterbodies (e.g., river segments, lakes) to be classified into similar classes (groups), which can then be used to develop numeric criteria that describe pollutant concentrations that must not be exceeded to ensure protection of the use class. Under federal regulations, each state is required to establish use classes, which can include as many classes as are needed to ensure protection; however, at a minimum, the classes must ensure protection of aquatic life and recreation uses for all surface waters (40 Code of Federal Regulations [CFR] 131.10(a)).

DWQ has designated use classes to the rivers, streams, lakes, and reservoirs of Utah. Utah's designated uses include domestic use sources, recreation uses, aquatic life uses, and agricultural uses (Table 2-1); these uses are defined for specific waterbodies throughout Utah in UAC R317-2-6. Specific uses (i.e., Class 5) were recently established for different ecosystems associated with Great Salt Lake to assist with the development of additional numeric criteria for this ecosystem. Each of the designated uses—and associated subclasses—actually protects numerous activities (e.g., recreation, agriculture) or organisms (e.g., aquatic life, Great Salt Lake). For each designated use, numeric criteria are established to ensure protection of the most sensitive of these activities or organisms. A summary of designated use and associated criteria can be found in UAC R317.2.

Table 2-1. Designated uses protected under Utah's water quality standards. Column 1 depicts use codes. Numbers in use codes differentiate major use classes: 1 = drinking water, 2 = recreation, 3 = aquatic life, 4 = agriculture, and 5 = Great Salt Lake. Letters in use classes indicate subclasses of uses, each with different numeric criteria. Use descriptions provide a narrative to describe each use as described in UAC R317-2-6. Emphasis (bold and italic text) indicates the names commonly used to describe uses in the IR and elsewhere.

Use Class	Use Description
1C	Protected for domestic purposes with prior treatment by treatment processes as required by the Utah Division of ***Drinking Water***.
2A	Protected for frequent ***primary contact recreation*** such as swimming.
2B	Protected for infrequent primary contact recreation and ***secondary contact recreation*** such as boating, wading, or similar uses.
3A	Protected for ***cold water*** species of game fish and other cold water ***aquatic life***, including the necessary aquatic organisms in their food chain.
3B	Protected for ***warm water*** species of game fish and other warm water ***aquatic life***, including the necessary aquatic organisms in their food chain.
3C	Protected for ***nongame*** fish and other ***aquatic life***, including the necessary aquatic organisms in their food chain.
3D	Protected ***for waterfowl, shorebirds***, and other ***water-oriented wildlife*** not included in subclasses 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain.
3E	***Severely habitat-limited waters***. Narrative standards will be applied to protect these waters for aquatic wildlife.
4	Protected for ***agricultural uses*** including irrigation of crops and stock watering.
5A	***Great Salt Lake Gilbert Bay***. Protected for infrequent primary and secondary contact recreation, waterfowl, shorebirds, and other water-oriented wildlife, including their necessary food chain.
5B	***Great Salt Lake Gunnison Bay*** (see 5A).
5C	***Great Salt Lake Bear River Bay*** (see 5A).
5D	***Great Salt Lake Farmington Bay*** (see 5A).
5E	***Great Salt Lake Transitional Waters*** (see 5A).

Assessment Units

DWQ segments waters into relatively homogenous units called Assessment Units (AUs). The physical, chemical, or biological conditions of the waters in an AU are more similar to each other than to the conditions in adjacent AUs. Segments that have any different beneficial uses than an adjacent segment are always classified as different AUs. A stream may be divided into several AUs, even when beneficial uses are the same, because of different watershed characteristics. Factors such as flow, channel morphology, substrate, riparian condition, adjoining land uses, confluence with other waterbodies, and potential sources of pollutant loading are considered when delineating AUs (EPA, 2005). AUs for streams and rivers are established for defined stream segments or watersheds (see the Assessment Unit Delineations section), whereas lakes or reservoirs are typically considered to be single and distinct AUs. Although the AU is the smallest unit of watershed area available for reporting purposes, DWQ has modified its approach to data compilation and summary by performing assessments at the monitoring location level. In this way, data can demonstrate more specifically which sites and segments of an AU are impaired and which are not.

Assessment Methods

Pursuant to CWA requirements, DWQ developed water quality standards, including narrative and numeric criteria, to help ensure that the designated uses of Utah's waterbodies are supported. The methods in this chapter describe how DWQ compares site-specific analytical data to these standards to assess whether waterbodies are meeting their designated uses. In general, chemical data assess support against numeric criteria, whereas biological data assess support against narrative criteria. For each AU, available chemical data are compared against the specific uses and criteria assigned to the waterbody. If two criteria exist for two different uses assigned to the AU, the more protective criterion is used to make assessments.

The threat to designated uses posed by various water quality stressors depends on the stressor itself and the specific designated use. This chapter describes how conventional parameters (e.g., pH, dissolved oxygen [DO]), toxic pollutants, and bacteriological data are compared to the water quality standards (UAC R317-2). A separate section of this chapter is used to describe assessment procedures for phosphorous and nitrogen. Because numeric criteria do not currently exist for nutrients, DWQ acknowledges that human-caused eutrophication can threaten designated uses and should be considered when making assessment decisions.

In addition, biological assessment methods are also described. These relatively new assessment procedures quantify—with empirical models— the extent to which human-caused activities have altered the biological composition of streams and rivers. These biological assessments are then used to assess support of aquatic life designated uses. These assessments represent an objective interpretation of aquatic life uses based on Utah's narrative criteria. Because both biological and chemical data are used to assess aquatic life use support, this chapter also describes how both sources of information are used to make final assessment decisions. Although some of these methods are directly applicable to lakes and reservoirs, others are not. Water chemistry data naturally differ with lake depth, which must be accounted for when interpreting lake and reservoir data. Also, monitoring data differ significantly among streams and rivers and lakes and reservoirs. Although lakes and reservoirs are sampled less frequently, they are often sampled at multiple depths, and monitoring protocols specify collecting additional information to provide more accurate designated use assessments for these waters. Given these differences, a separate section of these methods describes a separate process for assessing support of the designated uses assigned to lakes and reservoirs.

The Overall Assessment Process

Creating the IR is a multi-year process that requires careful coordination of DWQ staff, external sister state and federal agencies, and other interested stakeholders. Federal rules and regulations require these reports to be prepared on a biennial basis and submitted to EPA for approval of the 303(d) list on April of even numbered years. Whenever possible, revisions to assessment methods are made available for public comment during odd numbered years. Federal regulations (40 CFR 130.7(b)(5)) also require DWQ to examine all existing and readily available data when making assessment decisions, which includes consideration of data collected by DWQ and others. DWQ typically sends a formal request for data and information approximately 1 year before the reports are to be completed, because DWQ must have sufficient time to compile and organize the information to facilitate subsequent analysis. In addition, sufficient time must be provided for adequate review of the assessments within DWQ and then with its stakeholders. Informal comments outside of formal comment periods are always encouraged.

Data Compilation for Assessments

Pursuant to EPA's guidance and regulations (40 CFR 130.7(b)(5)), DWQ actively pursues all water quality information and data to assist with making informed impairment decisions. DWQ encourages the submission of any data, reports, or water quality observations that can help the agency make more informed decisions. Chemical samples collected following rigorous field and laboratory methods can often be directly combined with those collected by DWQ. Even completely subjective water quality observations (e.g., fish kills, algal blooms) often help agency scientists interpret more quantitative data.

All water quality data submitted to DWQ are used to help the agency make more informed assessment decisions, but different sources of information are interpreted differently in the context of assessing support of designated uses. Considerations regarding the use of data in the IR include the following:

- How frequently were the samples collected? When were the samples collected?
- Where were the samples collected? Is the location representative of the AU?
- Were rigorous field and laboratory methods followed? Are these methods comparable to those followed by DWQ or our federal cooperators?
- What quality assurance/quality control (QA/QC) procedures were followed? Were QA/QC results and procedures documented? What are the precision and accuracy of water quality data?
- Were sufficient metadata collected to allow DWQ to interpret the information in an assessment context?

Answers to these questions help DWQ determine how different data sources and information are used to make designated use assessment decisions. All readily available sources of data and information are reviewed when making assessment decisions. Data submitted that were collected following rigorous, well-documented QA/QC procedures will be directly analyzed as if the information was collected by DWQ. Other sources of information may not be directly used for an assessment decision, but they will still be used to augment other assessment analyses.

Many scientific investigations collect similar types of data. However, the specific QA/QC procedures followed when collecting and analyzing data frequently differ among studies for many reasons. Different studies require varying degrees of accuracy and precision or entirely unique methods, depending on the questions being investigated. DWQ does not require that outside data be collected following identical methods. Yet, the methods that are followed must be sufficiently documented so that DWQ can ascertain the precision and accuracy of the information. Also, DWQ must have sufficient information to interpret the data in an appropriate spatial and temporal context.

For outside entities interested in submitting data for use in developing the IR, recommendations are described for data submission. These recommendations include data elements (metadata) that should be submitted to DWQ along with datasets or reports. DWQ acknowledges that it may not be possible to obtain all of the elements described in this chapter when submitting water quality information. In such cases, DWQ encourages stakeholders to submit whatever information is readily available. Some submissions may lack sufficient information to directly augment assessment analyses; however, the information will still be used qualitatively as DWQ weighs all of the information available to make a final determination of beneficial use support.

Types of Data Used to Make Assessment Decisions

Many types of data are used to make assessment decisions, including chemical data, biological and habitat data, and technical reports/manuscripts. Each source of information is used differently to inform assessment decisions, and each requires a unique suite of QA/QC considerations. This section summarizes some of these unique considerations.

Chemical Data

Most assessment decisions are based on chemical data, in part because these data are most easily linked to numeric criteria. DWQ uses different assessment methods for toxicant and conventional (nontoxic) chemical data. In addition, different assessment methods are followed when using chemical data to assess streams and rivers than are used for lakes and reservoirs. Generally speaking, it is much easier to combine chemical data from multiple data sources than other types of information, because field and laboratory methods are less variable and are often better documented. However, water chemistry is also highly spatially and temporally variable, which can complicate interpretation of the information.

Biological and Habitat Data

Biological and habitat data can be useful sources of information when interpreting aquatic life beneficial use support. However, both field and laboratory methods for these data are less standardized than they are for chemistry data. Differences among protocols complicate directly incorporating biological and habitat data obtained from different sources. As a result, it is often more useful for DWQ to receive summary data and information that interpret biological or habitat information in the context of aquatic life use support. In such cases, it is particularly important that ancillary information is supplied that describes how the data were collected and details of subsequent analyses. The scientific rigor employed to obtain information that describes the physical and biological integrity of waters varies extensively; DWQ will apply varying weights to information submitted based on the confidence it has with collection and analytical techniques, and its confidence that the data are representative of watershed conditions.

Manuscripts and Reports

Reports, articles from refereed journals, and other scientific publications are evaluated for applicability to water quality standards, both numeric and narrative. Sometimes these studies are difficult to interpret in an assessment context. In other cases, the results and conclusions are contrary to other sources of data and information. These difficulties are not surprising because these studies are almost never conducted with the aim of assessing support of water quality standards. Nonetheless, all of these investigations provide insight into how various biological and biogeochemical processes influence the designated uses of Utah's aquatic ecosystems. In the end, DWQ makes formal impairment decisions based on the overall weight of evidence derived from all sources of data and information, which include research conducted to address indirectly related scientific questions.

Quality Assurance Considerations

DWQ has established numerous quality assurance procedures. These procedures include a quality assurance project plan (QAPP) that documents data accuracy objectives and defines protocols for the storage and delivery of analytical results and the associated QA/QC data (DWQ 2014a). In addition, field and laboratory methods (standard operating procedures [SOPs]) have been established that describe specific procedures to be followed when collecting and analyzing data. Whenever possible, all established methods conform to standard practices and procedures. Details of these procedures are available at DWQ's water quality monitoring website.[1] This section provides a summary of several key QA/QC considerations that DWQ uses when evaluating data to be used to make designated use support decisions.

Are the data representative of the AU being assessed?

Assessments are predicated on the assumption that samples capture representative conditions of watersheds or entire lakes and reservoirs at the level of established AUs. Efforts are made to ensure that the sample location provides a representative sample. For instance, samples used for assessing the effects of a point source discharge are generally not collected directly from the effluent, but from the receiving water outside of the mixing zone. In some situations, data sources suggest that AU boundaries are inappropriate, in which case the AU boundaries are adjusted. (see the Assessment Unit Delineations section).

Are the data representative of current conditions?

Designated use assessments should reflect current conditions. Assessments are generally based on data collected within the most recent 5 years. For the 2012-2014 IR, the most recent data generally considered were collected by December 31, 2012. Data collected up to 10 years ago were occasionally used for assessment purposes in situations where insufficient data existed in the last 5 years. Data older than 10 years are not used to determine beneficial use support.

Were appropriate laboratory methods used to obtain analytical results?

All water quality samples should be analyzed in a state- or EPA-certified laboratory or in a U.S. Geological Survey (USGS)–approved laboratory. If the samples are analyzed in a noncertified laboratory or with a nonstandard method, a QAPP should accompany the data, which should include the QA/QC data used in quality control checks within the laboratory. These data should include quality assurance data such as results from field blanks, duplicate samples, spiked samples, and samples with a known concentration for each of the parameters submitted to DWQ. A citation of the method used to analyze the samples should be included to assist DWQ in evaluating the data. If the method was developed by the laboratory, the method validation documentation should be submitted along with the data for evaluation.

There are numerous laboratory methods for processing biological data, all of which are acceptable provided that data are internally consistent. Detailed QA/QC documents for processing biological samples have been developed by DWQ or its contractors; these documents can be provided upon request.

Submission of Data from Outside Sources

Early in the process of developing the IR, DWQ formally and informally requests data and information from as many sources as possible. In many cases, DWQ has worked with outside partners for many years, and has developed routine processes for sharing data. These partnerships are symbiotic, helping both DWQ and its partners make more informed management decisions. This section of these methods is intended to be a guide for others interested in submitting data and information for use in making IR assessment decisions.

[1] http://www.deq.utah.gov/Compliance/monitoring/water/qaqc.htm

DWQ routinely obtains data from numerous outside partners, including the U.S. Forest Service, Bureau of Land Management, National Park Service, DOGM, Davis County, Salt Lake County, and Salt Lake City.

For the most part, field collections following standard state or federal field procedures, coupled with chemical analyses done in a state- or federally certified lab, are of sufficient quality to allow standard beneficial use analyses. For example, DWQ routinely obtains and analyzes data collected and processed by USGS, DOGM, and local municipalities. Data quality procedures for these programs are well documented, and DWQ has already conducted the work necessary to ensure sample comparability. Data collected by other outside entities that have not previously collaborated with DWQ are evaluated on a case-by-case basis to determine how they will be used to make beneficial use support decisions. This section of the report discusses how DWQ solicits data and information, how "outside" data sources are evaluated, how data of varying quality are used to make assessment decisions, and recommendations for submission of data to ensure that they are used to the greatest extent possible.

Public Notification

Each IR cycle, DWQ makes a formal public notification—through newspaper ads, website postings, and email list servers—requesting data and information that can be used to inform designated use assessments. Whenever possible, the aim of DWQ is to obtain all data and information with sufficient time to compile the information by April of odd years. This allows staff sufficient time to obtain clarification where necessary, which ensures that outside sources of information are used to the greatest extent possible for IR assessments. Following each public notice, interested stakeholders have a minimum of 30 days to submit water quality information to DWQ.

External Data Submission

Whenever possible, all datasets should be submitted electronically, either as spreadsheets or as comma-delimited text files. Each dataset is unique, and DWQ will work with interested stakeholders on formatting issues to ensure that the datasets are as compatible as possible to those used by DWQ for IR assessment analyses. Direct communication with outside investigators is necessary to ensure that outside data sources are properly interpreted. However, DWQ requests that electronic data submissions also be accompanied with sufficient metadata to provide documented spatial, temporal, and analytical context to the information. Guidance on desired metadata elements is available and was made public in conjunction with the external data request. The following list provides a few examples of metadata that are crucial for interpreting water quality data:

- The latitude and longitude, and datum, of the monitoring site
- The date and time when the sample was collected
- The type of waterbody (e.g., river, stream, reservoir)

- The type of sample represented by the data (e.g., grab sample, composite, profile)
- The analytical laboratory and methods used
- Detection and reporting limits
- Units of measurement used (e.g., milligrams per liter, parts per billion)

Considerations for the Use of External Data

Data are sometimes submitted to DWQ with the expectation that they will be analyzed following the assessment methods outlined in this chapter to make assessment decisions. In some cases, DWQ does not receive sufficient information to interpret these data to make assessment decisions. In other cases, QA/QA procedures are questionable or are poorly documented. All data used to make assessment decisions, whether collected by DWQ or anyone else, are screened following similar procedures (Figures 2-1 and 2-2). Data that fail to pass these requirements are not used for direct analytical assessments. In such cases, the data are summarized and used to augment other data sources in a weight-of-evidence approach to make assessment decisions.

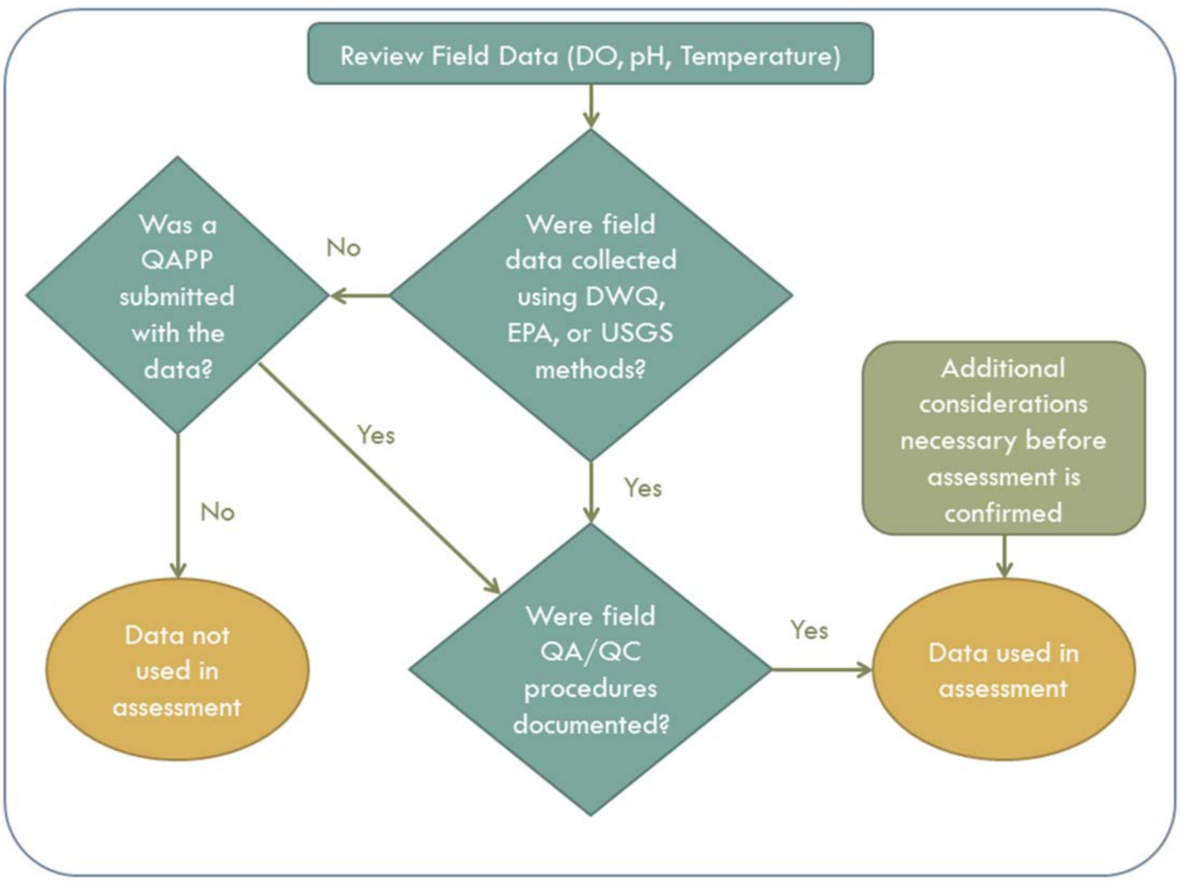

Figure 2-1. An outline of the process that DWQ follows when determining if field-based datasets are of sufficient quality for making assessment decisions. Datasets that fail QA/QC objectives are summarized and used to augment other sources of data and information available for each AU.

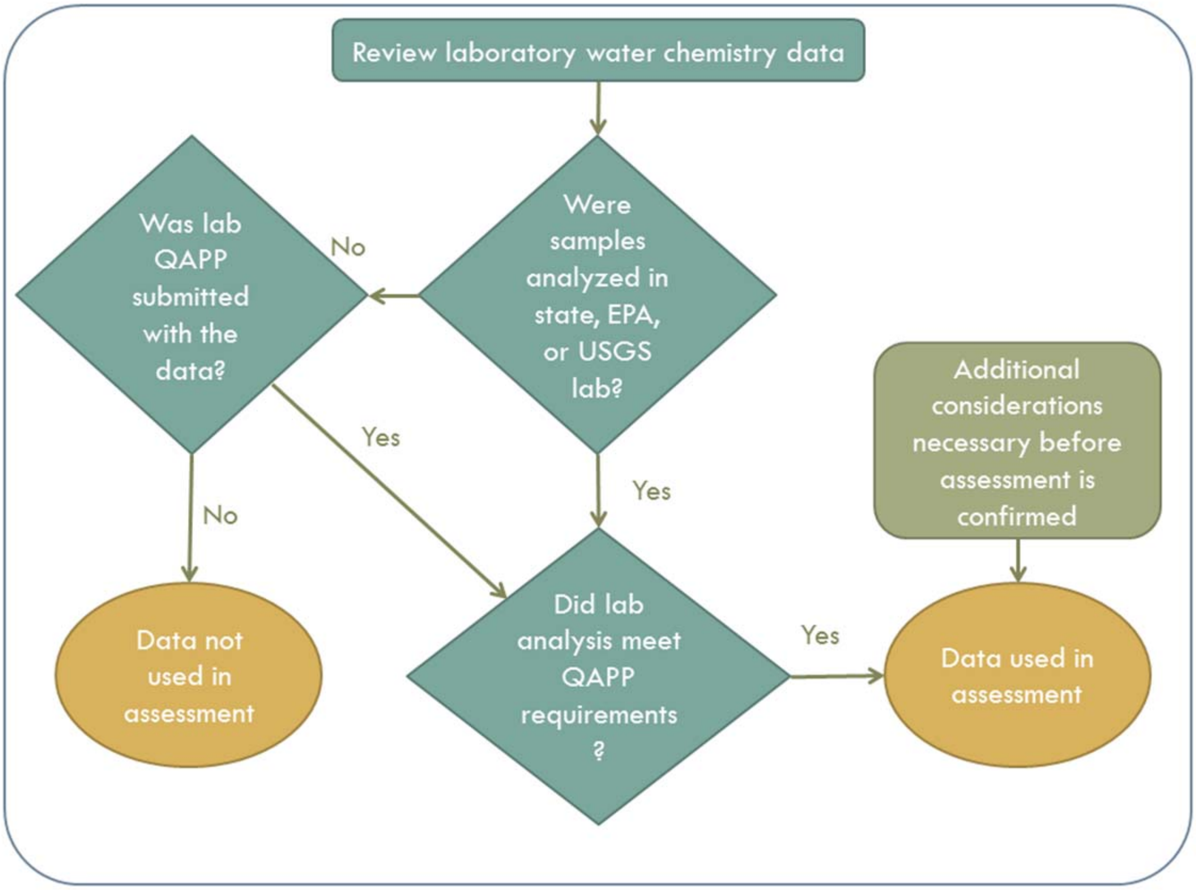

Figure 2-2. An example of the process that DWQ follows when determining if chemistry datasets are of sufficient quality for making assessment decisions. For datasets that fail QA/QC objectives, DWQ will work directly with researchers, on a case-by-case basis, to evaluate data comparability and data quality.

ASSESSMENT UNIT DELINEATIONS

Introduction

DWQ's goal is to assess Utah's rivers and streams on a watershed scale. However, for pragmatic reasons, the watersheds are further subdivided into AUs for assessment. Discrete AUs are DWQ designated decision units on which beneficial use attainments are determined. Lakes and reservoirs are usually delineated as individual AUs, and their size is reported in acres. Rivers and streams are delineated by specific river, river or stream reach, or several stream reaches in subwatersheds. When using subwatersheds to delineate stream AUs, the new USGS 5th-level (10-digit) and 6th-level (12-digit) watershed units for Utah are used to delineate the AUs. These watershed units allow for the aggregation of stream reaches into individual AUs that are of similar size and have similar physical, chemical, and ecological characteristics. The 5th- and 6th-level hydrological units (HUC) were developed by individuals representing state and federal agencies, and have been certified by the Natural Resource Conservation Service.

Assessment results apply to AUs that are defined watersheds, lakes, or reservoirs with similar chemical and physical conditions.

These hydrological units are a starting point for developing AUs, which are subsequently screened further, using geographic information system (GIS) data and field-derived data, to determine if these watersheds' other characteristics (e.g., major changes in surrounding vegetation, hydrologic diversions) warrant further AU division into smaller watersheds. This section of the document outlines the methods that DWQ follows when delineating AUs.

Guidelines for Delineating Stream and River Assessment Units

When delineating river and stream AUs, DWQ follows the guidelines listed below and consistently adheres to the first two guidelines.

- The AU is within an 8-digit USGS HUC.
- Each river and stream in an AU has the same designated beneficial use classifications. For instance, if a stream segment has designated use Classes 1C, 2B, and 3A, whereas an adjacent segment has Classes 2B and 3B, then the watershed would have at least two AUs.
- Large rivers, such as the Green River, Colorado River, and portions of other large rivers (Bear River, Weber River, etc.), are delineated into "linear" or "ribbon" AUs. For these rivers, AU boundaries are established at the point of entry of major tributaries, or at other significant hydrologic boundaries (e.g., dams).
- AUs for smaller rivers and streams are delineated primarily using the 5th- and 6th-level HUCs.
- Some AUs are split into smaller segments than those established for 5th- or 6th-level watersheds if changes in the AU are observed, such as hydrology (e.g., entry of tributary streams, changes in stream power), stream size, geology, soils, vegetation, or human land use.
- With the exception of Great Salt Lake, lakes and reservoirs are currently considered single AUs.

All AUs have been georeferenced (indexed) to the National Hydrologic Database using a reach-indexing tool that provides the capability of using GIS techniques to display information and data for each AU (Figure 2-3). Beneficial use classifications and assessments for individual AUs can be mapped or displayed to provide visual representation of assessment results. Individual stream AUs were assigned a unique identification code for indexing, which includes the 8-digit HUC number with the prefix UT and followed by a 3-digit code to identify each unique AU in an HUC. Lake and reservoir AUs were identified by adding the prefix UT-L- to the 8-digit HUC follow by a 3-digit code.

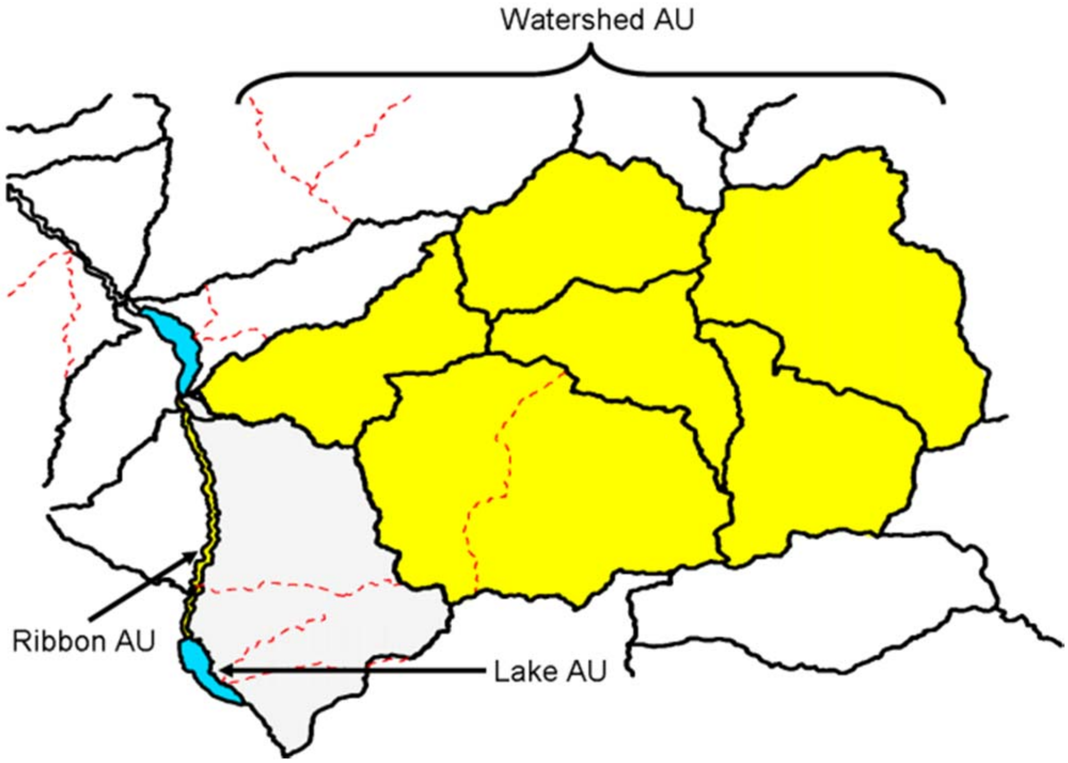

Figure 2-3. An illustration of the three primary types of AUs used in Utah's IR. Watersheds are the most common AU for streams, but "ribbon" AUs are sometimes used when the surrounding landscape has little influence on stream conditions relative to other factors (e.g., a section of stream between two reservoirs). In most situations, an entire lake or reservoir is considered a separate and unique AU.

Changes to Assessment Units

With each IR cycle established, AUs are refined based on DWQ's continually expanding knowledge of the ambient conditions of Utah's streams and rivers. Whenever DWQ changes AU boundaries, DWQ documents the rationale for making these changes and submits this information as part of the IR to EPA.

REPORTING ASSESSMENT RESULTS

Introduction

Beginning in 2002, EPA recommends five categories for reporting results of designated use assessments. EPA developed these five categories to clearly summarize a state's water quality status. Each category is also associated with specific management actions to protect and restore waters to meet Utah's water quality standards and to support their designated uses. DWQ summarizes assessment results using these five categories, along with state-derived subcategories for internal tracking and planning purposes. This section describes each category.

Designated Use Assessment: Categorical Results

EPA reporting categories for assessment results were developed to improve national consistency among states and to avoid conveying to stakeholders that water quality is not better—or worse—than it actually is. However, there are overlaps among assessment categories that may be confusing to stakeholders. First, AUs are assessed independently for each of their designated uses, and assessment results are reported accordingly. As a result, several different assessment results—one for each use—are possible for a single AU. Second, assessment result reporting Categories 1 and 2 summarize assessment results across all uses, whereas Categories 3–5 summarize results independently for each use. Finally, it is possible that a designated use exceeds numeric criteria for more than one pollutant, and total maximum daily loads (TMDLs) are pollutant-specific. Hence, Categories 4 and 5, which track impaired waters, are both pollutant-specific. The following definitions provide details of the meaning of each reporting category:

Category 1: All designated uses are attained.

AUs are reported as Category 1 if all beneficial uses have been assessed against one or more numeric criterion ***and*** each use is found to be fully supporting all uses.

Category 2: Some of the designated uses are attained, but there are insufficient data to determine beneficial use support for the remaining designated uses.

AUs are reported as Category 2 if some but not all designated uses have been evaluated, ***yet*** those uses that have been assessed are found to be supporting designated uses.

Category 3: There are insufficient data to make a determination, or the lakes and reservoirs show indication of impairment for a single monitoring cycle.

For each designated use, AUs are reported as Category 3 if some data and information are available to evaluate one or more of an AU's designated uses, yet available data are insufficient to make a conclusive assessment determination. Inconclusive decisions result from datasets that fail to meet data quality objectives that DWQ has established for making IR assessment decisions. Examples of situations where AUs are reported as Category 3 include the following: datasets with an insufficient number of samples available for analysis, situations where there were contradictory conclusions from multiple data sources, or situations where QA/QC procedures were improper or poorly documented.

By reporting an AU as Category 3, versus simply reporting the AU as not assessed, DWQ is making a commitment to prioritize future monitoring to make a final assessment determination. In part due to this intrinsic commitment to prioritize monitoring, DWQ uses six Category 3 subcategories for planning purposes, which are defined as follows:

- **Category 3A**: AUs are listed in Category 3A if there are insufficient data and information to make an assessment, or in some cases, multiple datasets reveal inconsistent and conflicting information. This category includes sites where data include violations of water quality criteria but insufficient sample counts to make a determination of attainment of standards. These sites will be prioritized for future monitoring and evaluation.

- **Category 3B**: Lakes and reservoirs that have been assessed as not supporting a beneficial use for one monitoring cycle are included in Category 3B. If a lake or reservoir is assessed as impaired for two consecutive monitoring cycles, it is listed on the 303(d) list.

- **Category 3C**: This category is currently used for Great Salt Lake (Designated Use Class 5). Assessment of this ecosystem with traditional approaches is complicated by the current lack of numeric criteria, with the exception of a selenium standard applicable to bird eggs. Also, the lake is naturally hypersaline, so traditional assessment methods are not appropriate. DWQ is working toward developing both numeric criteria and assessment methods for this ecosystem. In the interim, the IR documents the progress that was made in the most recent 2-year reporting cycle.

- **Category 3D**: Further investigations are required. For example, AUs with potential impairments for nutrients and biochemical oxygen demand were placed in Category 3D until such time that numeric nutrient criteria are developed.

- **Category 3E:** This category includes AUs with insufficient data to make a determination of use support. However, the data at these sites and AUs do not include exceedances of water quality criteria and will be assigned a lower priority than Category 3A for future monitoring.

- **Category 3F:** These include sites that were not assessed because they had no uses assigned to them. Sites and AUs in this category will be assigned appropriate beneficial uses and assessed in the next reporting cycle.

Category 4: Impaired for one or more designated uses, but does not require development of a TMDL.

For each designated use, AUs are reported as Category 4 if water quality remains insufficient to support the designated use, yet a TMDL is not required.

- **Category 4A: TMDL has been completed for any pollutant.**

AUs are listed in this subcategory when any TMDL(s) has been developed and approved by EPA, that when implemented, is expected to result in full support of the water quality standards or support the designated uses. Where more than one pollutant is associated with the impairment of an AU, the AU and the parameters that have an approved TMDL are listed in this category. If it has other pollutants that need a TMDL, it is also listed in Category 5. Therefore, an AU can be listed in Category 4A and 5.

- **Category 4B: Other pollution control requirements are reasonably expected to result in attainment of the water quality standard in the near future.**

Consistent with the regulation under 40 CFR 130.7(b)(I) (ii) and (iii), AUs are listed in this subcategory where other pollution control requirements (e.g., best management practices required by local, state, or federal authority) are stringent enough to meet any water quality standard or support any beneficial use applicable to such waters.

- **Category 4C: The impairment is not caused by a pollutant.**

AUs are listed in this subcategory if the impairment is not caused by a pollutant (e.g., habitat alteration, hydromodification).

Category 5: The concentration of a pollutant—or several pollutants—exceeds numeric water quality criteria, or quantitative biological assessments indicate that the biological designated uses are not supported (narrative water quality standards are violated).

Waters reported as Category 5 are impaired, which means that they are not meeting their designated uses. The list of Category 5 waters is sometimes called the "303(d) list" in reference to this section of the CWA, which among other things, requires states to identify impaired waters. There are several sources of data and information that are used when making impairment decisions. First, chemical assessments evaluate designated use support for an AU by comparing pollutant concentrations against numeric criteria that have been established to protect the use. A designated use of an AU is reported as Category 5 if any of the following apply:

- The concentration of any pollutant exceeds—as defined by the methods described in this chapter—a numeric water quality criterion.
- Quantitative biological assessment results for streams and rivers are statistically different than the reference site conditions.
- Weight of evidence assessments for lakes and reservoirs indicate that designated uses are not being supported.

The specific methods used by DWQ to make any of the above conclusions are documented in detail throughout the remaining sections of this chapter.

Exceptions Based on Unusual Hydrologic or Climatic Conditions

Severe or extreme natural conditions, such as a drought, can be considered during the beneficial use assessment. During severe to extreme drought conditions, streams can have temperatures greater than the standard but are rare in occurrence if the normal hydrological regime occurs. In this case, DWQ reserves the right to identify these waters, but not list the AU on the 303(d) list. A rationale for not listing will be provided whenever this occurs. The AU will be assessed again when normal flow conditions return.

As noted in Utah's water quality standards (UAC R317-2), numeric standards can be modified based on natural conditions for temperature, total dissolved solids (TDS), and pathogens. Per the standards, site-specific standards will be developed for temperature and TDS but not for pathogens in these instances. Short-term (5 years or less) climatic influences on temperature and TDS such as drought are also considered for the beneficial use assessments. During drought conditions, streams can have temperatures or TDS greater than the standard but are rare in occurrence under normal conditions. If the condition persists for a longer term, DWQ will modify the water quality standards to take into account the natural conditions. DWQ commits to revising the water quality standards to identify the criteria that will be used to identify these transient excursions (e.g., ambient air temperatures greater than the 90^{th} percentile for 10 years of data). In the interim, these waters will be placed in Category 3A, and the rationale for not listing will be provided.

Criteria for Removing an AU from the 303(d) List (Category 5)

There are various reasons for removing an AU from the 303(d) list (Category 5 waters). Any AU can be removed from the 303(d) list based on the criteria listed below. An AU may be moved in another assessment category due to a delisting, e.g., an AU is moved to Category 4A if a TMDL has been completed and approved by EPA. As a result of a delisting, an AU could be placed in multiple assessment categories.

The following list provides circumstances where it may be appropriate to move an AU that was assessed as impaired (Category 5) in a previous IR to another assessment category:

1. The AU was placed on the list due to an error in assessment or because an AU was listed incorrectly in place of another AU or any other error not based on water quality assessment.
2. The most recent data assessment indicates that the AU is now meeting Utah water quality standard or is supporting the designated beneficial use support for all of its designated uses that were assessed.
3. A TMDL analysis for any pollutant(s) has been completed and approved by EPA. The AU with an approved TMDL and the pollutant(s) are automatically moved to Category 4A. Any pollutant(s) remaining on the 303(d) list for which a TMDL has not been completed and approved for that AU will remain on the 303(d) list (Category 5). Therefore, an AU may be listed in both Categories 4A and 5 for individual pollutants.
4. An existing AU delineation has changed, as follows:
   1) An AU has been changed by dividing it into several AUs.
   2) The AU boundaries have been changed and it is now a part of a different AU or portions of the AU are included in newly defined AUs.
5. The method(s) of determining beneficial use support has changed. The methodology change may cause the assessment to result in all of the designated uses being assessed as fully supported.
6. The state water quality standards or pollution indicator values have changed, which may change the assessment to fully supporting for all designated uses that have sufficient data to be assessed (e.g., AUs with recently established site-specific standards).
7. A determination is made that insufficient amounts of data were collected to place the AU on the list originally, e.g., too few samples were collected to make a reliable determination of beneficial use support.

DWQ exercises discretion in using data or information that go beyond the criteria listed above in determining whether to delist an AU, and they can include other types of information and best professional judgment (BPJ). All changes from Category 5 to any other assessment category are subject to EPA approval. The rationale for removing any AU from Category 5 is documented in a “Request for Removal” table that accompanies the IR.

WATER CHEMISTRY ASSESSMENTS OF STREAMS AND RIVERS

Introduction

For each monitoring location, DWQ compiles and screens all available water quality data and compares these parameters to the numeric criteria assigned to all designated uses for all monitoring locations. These parameters are then evaluated, one-by-one, against the assigned criterion for a waterbody's designated uses. Each designated use is considered to be fully supported (Category 1) once any of its associated parameters are found to be meeting their numeric criteria. Similarly, once any parameter is found to exceed its numeric criteria, the designated use is considered to not be meeting the applicable designated use(s) for that parameter, and the site, and subsequently the AU, will be listed as impaired (303(d) list).

One of the systematic changes to the assessment methods, compared to past IR analysis, is the assessment of water quality parameters at the site level rather than the AU as a whole. This approach results in a more direct comparison of site-specific data to water quality criteria. Because many of Utah's AUs contain multiple monitoring locations, this approach results in a more accurate analysis of the data on a site-specific basis and provides greater resolution across sites for comparison and specification of the water quality impairments within an AU. However, for reporting purposes in populating EPA's Assessment Database, states are required to report use support at the AU level because it is the smallest unit of measure for individual waterbodies. Therefore, if any site with sufficient data in an AU is not meeting water quality standards (i.e. Category 5 at the site level), the AU will be listed as Category 5. Similarly, all sites must be meeting uses for an AU to be listing as Category 1 (fully supporting all uses). Despite this limitation, DWQ still reports on the 303(d) list at the resolution of the site level, which will assist staff in defining areas of future focus of watershed restoration and planning. Figure 2-4 summarizes the decisions made to determine the final EPA categorization for populating the Assessment Database.

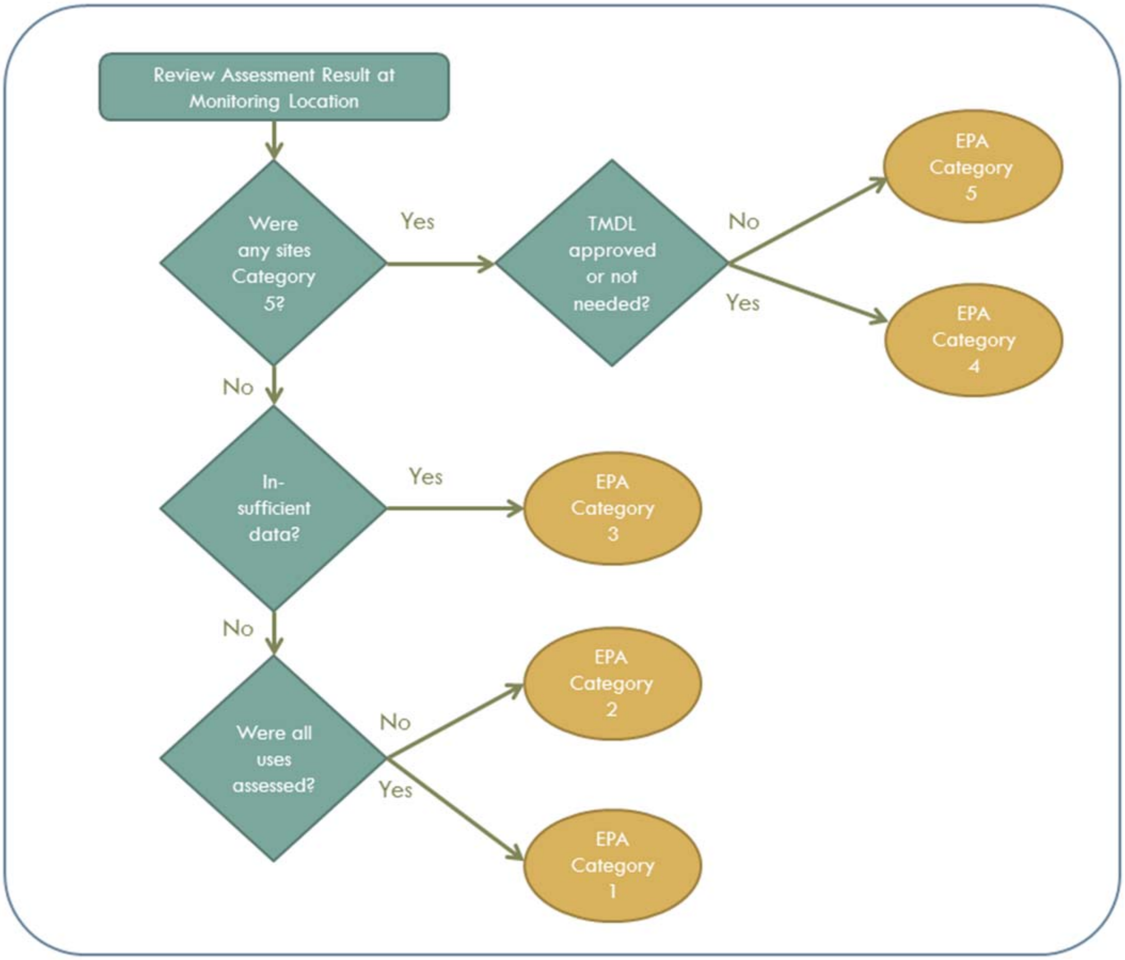

Figure 2-4. Method for populating EPA assessment categories based on site-level assessment results. Note that DWQ establishes multiple subcategories depending on available data and assessment results (see below).

Given that sites are assigned multiple uses, both within and among designated use classes, it is not uncommon for a site to have several numeric criteria for a single chemical parameter. To ensure that the uses are appropriately assessed, DWQ evaluates all applicable numeric criteria. If a parameter has criteria assigned to different designated use classes (e.g., ammonia criteria for drinking water and aquatic life uses), then the criteria are evaluated independently to determine designated use support of each use.

This section provides the methods that DWQ follows for interpreting designated use support from chemical analytical results. Assessment procedures are described for both conventional and toxic parameters.

Sample Size Requirement

As a general rule, DWQ requires at least 10 samples (conventional parameters) or four samples (toxic parameters) collected at a monitoring location within the most recent 5 years to make an assessment of designated use support. Sites that do not meet basic data requirements are considered “insufficient data” for the applicable designated use, unless data quality objectives are met for another parameter associated with that use. This rule helps ensure that assessment decisions are not made from small or sporadic datasets.

However, because DWQ considers all existing and readily available data when making assessments, smaller numbers of samples may be used along with other sources of data and information to make impairment decisions. In the end, any observation that numeric criteria have been exceeded will be used to either conclude impairment or prioritize the AU for follow-up monitoring to obtain the data necessary to make conclusive assessment decisions.

Conventional Parameters

Conventional parameters of chemical condition (Table 2-2) have high temporal variation—daily, seasonally, and yearly. Also, these parameters are not acutely toxic and tend to degrade designated uses via exposure over relatively long time periods. When interpreting designated use support, DWQ follows the "10% rule" (UAC R317-2-7.1), which allows less than or equal to 10% of the samples at a monitoring location to exceed numeric criteria before it would be considered impaired (Figure 2-5).

The following rules generally apply for evaluations of conventional chemical parameters to determine support of applicable uses:

> **Beneficial Use Supported:** For each parameter, if 10 or more samples are available for a monitoring location within the most recent 5 years, then the site is considered to be supporting its designated use(s) if less than 10% of the samples exceed the numeric criterion.
>
> **Beneficial Use Not Supported:** For each parameter, if 10 or more samples are available for a monitoring location within the most recent 5 years, then the sites are considered to be impaired—not supporting its designated uses—if 10% or more of the samples exceed the numeric criterion.

In circumstances where insufficient observations exist in the 5-year dataset to make a determination, 10 years of data are evaluated following the same assessment rule.

Table 2-2. Conventional parameters and associated designated uses as identified for assessment purposes (UAC R317-2-7.1). The notes column provides important considerations for interpretation of assessment results.

Parameters	Designated Uses	Notes
DO	Aquatic life	Numerous recurrence intervals are listed. Minimum and 30-day averages are used for assessments based on grab samples.
Maximum temperature	Aquatic life (3A, 3B, 3C)	Many site-specific standards have been generated, which are used for assessment purposes.
pH	Domestic (1C) Recreation (2A, 2B) Aquatic life (3A, 3B, 3C, 3D) Agriculture (4)	Criteria are identical across uses.

Escherichia coli	Domestic (1C) Recreation (2A, 2B)	Recreation uses have more protective criteria than domestic.
TDS	Agriculture (4)	Many site-specific standards have been generated, which are used for assessment purposes.
Sulfate	Agriculture (4)	Site-specific criterion associated with TDS

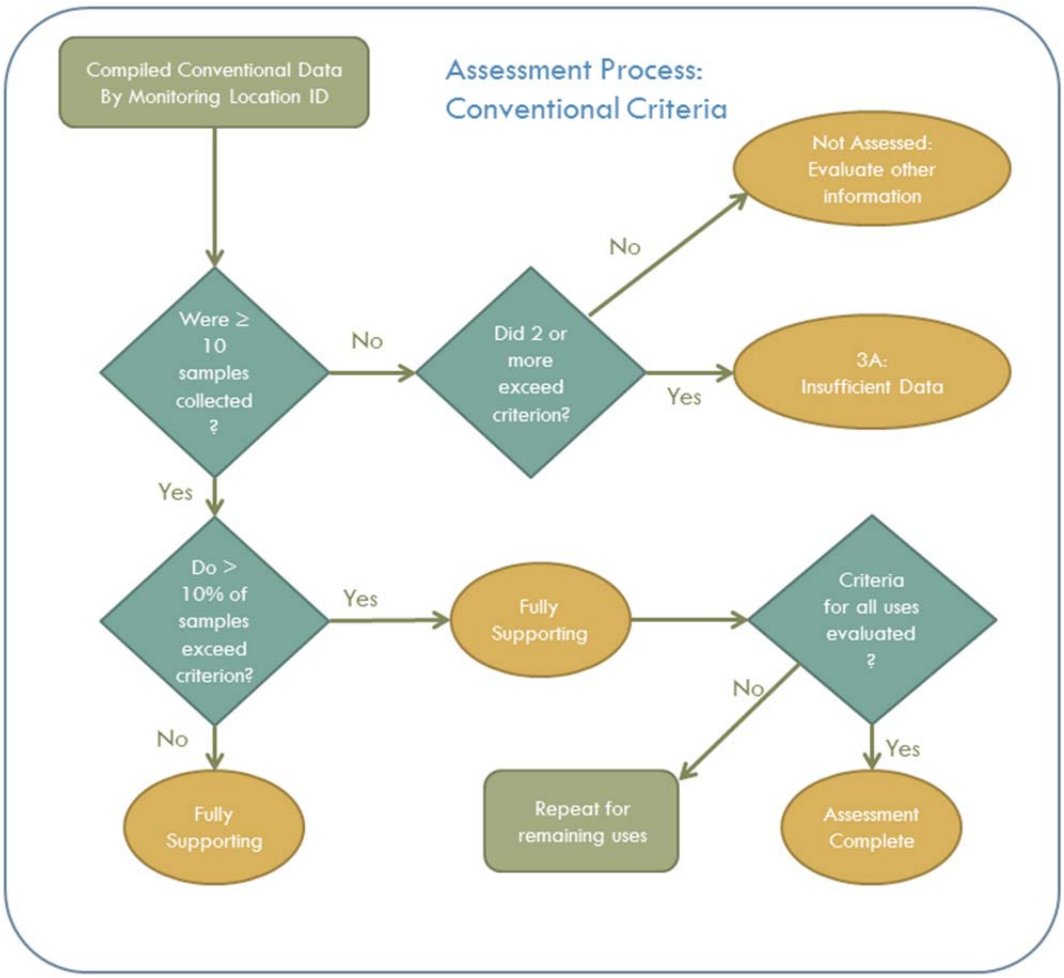

Figure 2-5. This flowchart depicts DWQ's process for assessing designated use support from each conventional water quality parameter for each site. The assessment process begins following a compilation of all available data that meet data quality objectives. A minimum of 10 samples collected from a site during the most recent 5–10 years is required. Assessments from small sample sizes typically result in a conclusion of insufficient data; however, if there is clear indication of an impairment, DWQ will list the site as impaired. Sites are generally considered to be meeting their designated uses if less than 10% of the conventional data samples are below applicable numeric criteria, and impaired otherwise.

Toxic Parameters

Assessment procedures for toxicants are more conservative than conventional parameters: sample size requirements are smaller and sites are considered degraded with two or more criterion violation. These measures are necessary to ensure protection of designated uses for a few reasons. First, many toxic substances accumulate in the tissue of aquatic organisms and become increasingly toxic with prolonged exposure to high pollutant concentrations. Similarly, many toxic substances biomagnify, or increase in tissue concentration from lower to higher trophic levels. Finally, high concentrations of many of these substances can lead to the direct mortality of many species at numerous life stages.

In some cases, designated uses may have both acute and chronic criteria for a given toxic parameter. In other cases, a single acute or chronic criterion is applied. The use-specific criteria are detailed in UAC R217.2 (DWQ, 2005). Sites will be assessed as not meeting standards when two or more exceedance of the acute or chronic criteria is observed (Figure 2.6). The minimum sample size to make a determination is four or more samples in the past 5 years. In cases where insufficient data exist in the past 5 years, 10-year datasets will be evaluated by the same method.

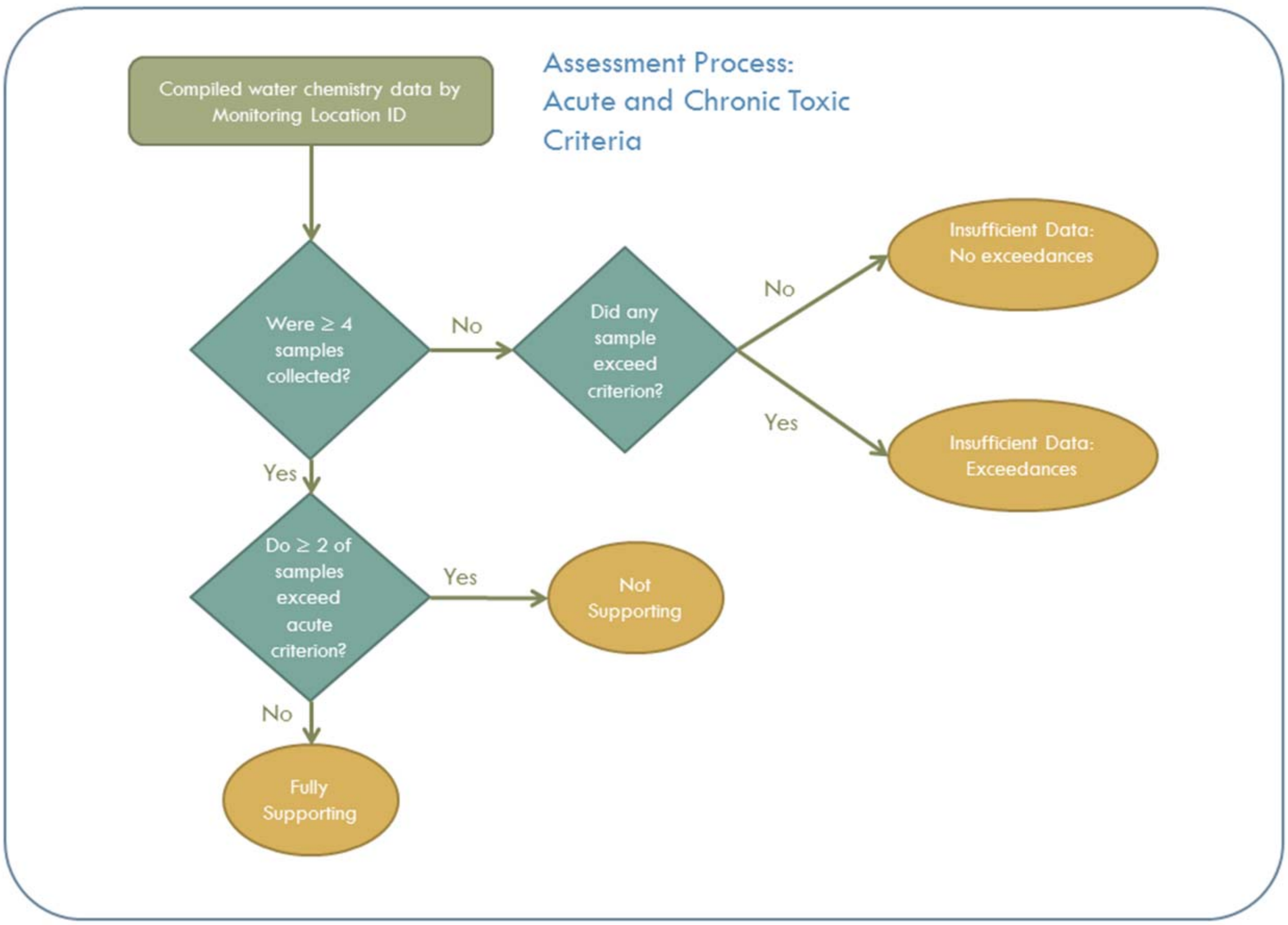

Figure 2-6. Assessment process for toxic substances with chronic and/or chronic criteria.

Additional Considerations

Drinking Water Closures

If Utah's Division of Drinking Water—or other local municipality—issues an advisory or closure for a surface drinking water source, DWQ will assess the site as impaired for 1C uses, unless data show that the problem has been solved. DWQ works in collaboration with the Department of Health, who issues consumption advisories at sites where high mercury concentrations are observed in animal tissues. Figure 2-7 depicts waters that currently have consumption advisories for fish (red dots) or birds (yellow dots). For additional information, please visit the Utah Fish Advisories website.[2]

[2] http://www.fishadvisories.utah.gov

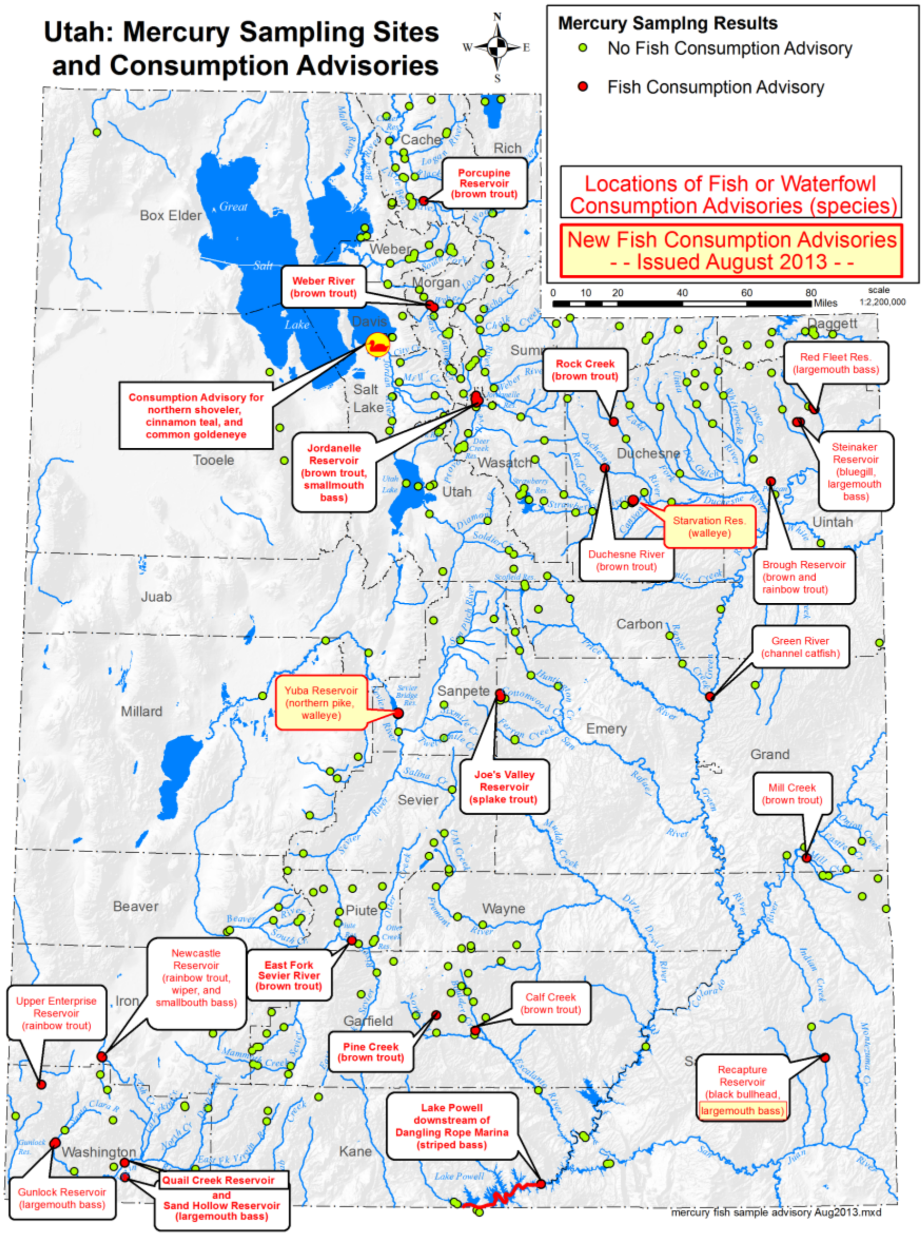

Figure 2-7. Waters that currently have consumption advisories for fish (red dots) or birds (yellow dots).

Fish Kills

DWQ requests information on reported fish kills from Utah's Division of Wildlife Resources (DWR) and other stakeholders. These data are used in concert with water quality data to make final assessment decisions. For example, sites that would generally not be assessed due to small sample sizes may be listed as impaired if fish kills have also been observed at the waterbody.

Beneficial Use Assessment Based on Tissue Consumption Health Advisories

Human health consumption advisories are issued by the Utah Department of Health (UDOH) in conjunction with DWQ, DWR, and local health departments. DWQ and UDOH developed a sampling protocol based on statistical analyses to determine how many fish are required to be collected to use in an advisory. The statistical parameters are as follows:

- The probability of a Type I error is set at 10%. A type I error is when the average concentration in fish is concluded to be greater than the screening level when the actual average concentration is equal to, or lower than, the screening level.
- The probability of a Type II error is set at 20%. A type II error is when the average concentration in fish is concluded to be equal to, or less than, the screening level when the actual average concentration actually exceeds the screening level by more than the minimum detectable difference (see next bullet).
- The minimum detectable difference is set at 0.15 milligram per kilogram (mg/kg). For instance, for mercury health advisories, the screening levels for consumption advisories are 0.3 mg/kg, so under the minimum conditions described above, the average concentration would have to be 0.45 mg/kg before the desired level of confidence in the results is achieved.

If the required confidence is not achieved, additional samples are required. Type I and Type II errors are inversely proportional when the number of samples and minimum detectable difference are held constant. For instance, achieving a reduction in the Type II error probability would require a corresponding acceptance of an increase in the Type I error probability. If the average contaminant concentrations in fish are greater than 0.45 mg/kg, then both Type I and Type II error probabilities are reduced.

Mercury

The current approach for making assessments of aquatic life use support from mercury consumption advisories is different for advisories based on birds than for those based on fish (Figure 2-8). Fish are constant residents of the waterbodies where they are collected, whereas waterfowl migrate across large areas. As a result, it is difficult to directly tie waterfowl tissues higher in mercury directly to an AU.

Although advisories for human health help guide decisions regarding attainment of aquatic life uses, they are not equivocal. Currently, health advisories are issued if the mercury concentration in fish tissue is 0.3 parts per million (0.3 mg/kg wet weight, or 0.3 micrograms per gram [µg/g]). This concentration is recommended by EPA, but it is less than the U.S. Food and Drug Administration value of 1.0 mg/kg. The U.S. Food and Drug Administration set the consumption concentration at 1.0 mg/kg, which correlates to the water column mercury concentration of 0.012 µg/liter (L) in previous studies by EPA (EPA, 1985). Utah's water quality standard for mercury is 0.012 µg/L as a 4-day average. Therefore, the corresponding fish tissue concentration of 1.0 mg/kg is used for assessment.

Beneficial Use Supported: No fish consumption advisories for mercury, or the fish tissue mercury concentration is less than or equal to 1.0 mg/kg.

Beneficial Use Not Supported: Fish consumption advisory for mercury is in place, and fish tissue mercury concentration is greater than 1.0 mg/kg.

DWQ will evaluate the applicability of waterfowl consumption advisories for beneficial use assessments independently for each waterbody. The first step is to link the contaminants in waterfowl tissue to the waterbody being assessed, but a specific methodology has not been established. Only waterfowl collected from Great Salt Lake currently have consumption advisories, and the methodology for assessing mercury in Great Salt Lake is presented in Chapter 7 of the 2010 IR.

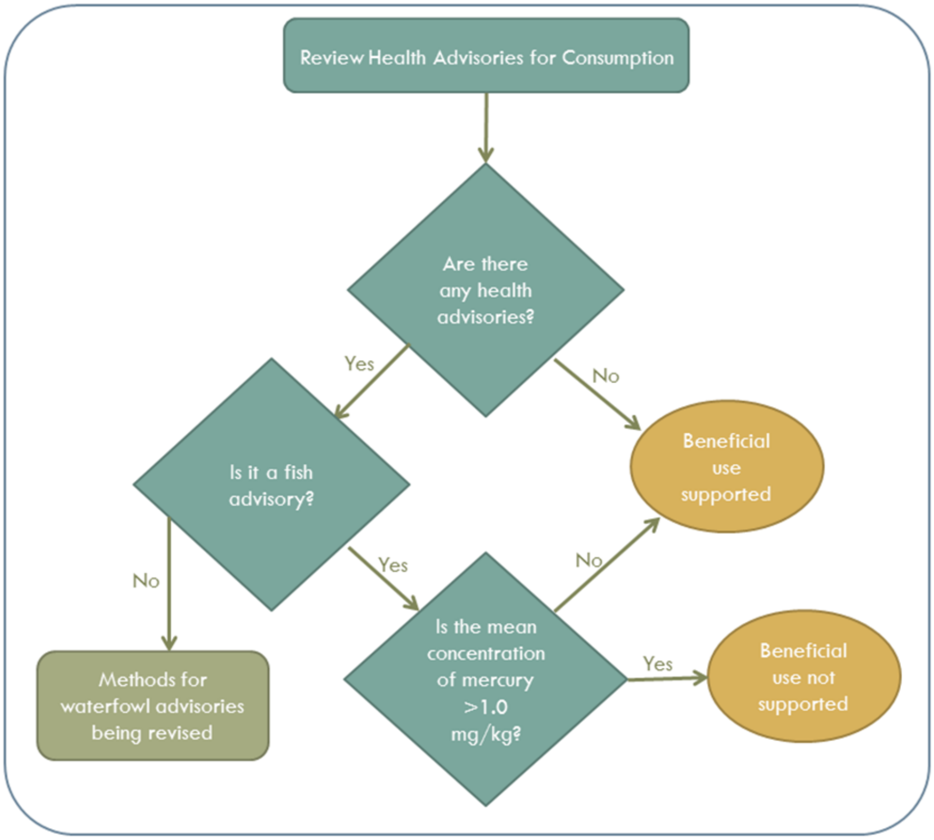

Figure 2-8. Methods used to determine support of aquatic life based on consumption health advisories for mercury.

NUTRIENT EVALUATIONS

Nitrogen and Phosphorus Pollution

The nutrients nitrogen and phosphorus occur naturally and are necessary to support aquatic food webs. However, excessive levels of nitrogen and phosphorus degrade lakes and streams. At very high concentrations, ammonia and nitrate can become toxic. Other deleterious effects are frequently observed at much lower concentrations. These lower concentration effects result from numerous interwoven paths between nutrients and designated uses. For simplicity, these responses can be roughly grouped into two categories: excess production and excess respiration in aquatic ecosystems, excessive production results in nuisance and sometimes toxic algae blooms. These blooms can cause several problems, including alteration of food webs and degraded habitat. The carbon produced by these blooms is consumed by microorganisms that consume oxygen and cause low nighttime oxygen levels. These excess respiration problems essentially choke aquatic biota. Local extinctions are one important consequence of production and respiration problems, which among other things, make aquatic ecosystems less resilient to natural and human-caused disturbances.

There are several ways that DWQ assesses the potentially deleterious effects of excess nutrients. In all cases, toxic concentrations of nitrate are evaluated to ensure protection of drinking water (1C) uses. Similarly, ammonia toxicity is evaluated to ensure protection of aquatic life uses. In lakes, the potentially deleterious effects of nontoxic nitrogen and phosphorus concentrations are evaluated with the trophic state index (TSI) and by examining the relative abundance of cyanobacteria—an important nuisance algae. In streams, nutrient responses are evaluated indirectly with pH (excess production) and DO (excess respiration) numeric criteria. These assessments continue to help DWQ identify waterbodies with nutrient-related problems in the IR.

Several years ago, DWQ determined that the current assessment approaches for nutrients were necessary but insufficient. In response, a program was established to develop more robust assessments of nutrient pollution problems. The result of these efforts has been the development of several new water quality indicators (Figure 2-9). Some of these indicators can be obtained from water chemistry, and include new nitrogen and phosphorus concentrations that are based on ecological risk. Other indicators are based on production or respiration ecosystem processes that measure direct responses to excess nutrient inputs. Still, other efforts defined indicators that are based on relationships between nutrients and direct measures of recreation or aquatic life. Together, these indicators will help DWQ more efficiently and effectively identify and resolve nutrient-related problems.

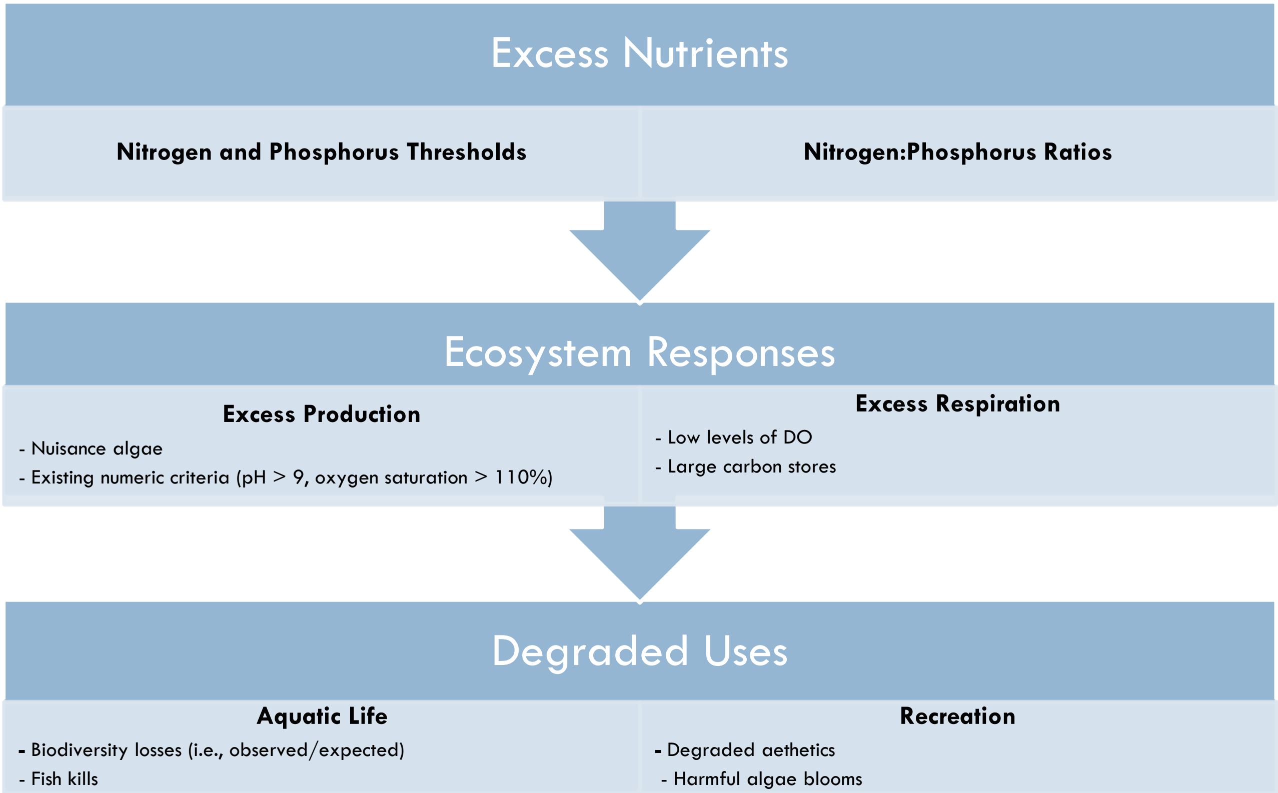

Figure 2-9. Responses to any given concentration of nitrogen and phosphorus vary from waterbody to waterbody. Natural nutrient sources vary, and human sources are numerous. Untangling these complexities is important in defining assessment methods that are neither over- nor under-protective of designated uses. To this end, several new water quality indicators have been developed. DWQ is collaborating with several scientists to derive new assessment methods from these indicators that will be incorporated into the 2016 IR.

Concurrent with the development of these nutrient indicators, DWQ also established stakeholder workgroups to explore policies that could most efficiently and effectively resolve nutrient pollution problems (DWQ, 2014b). Scientists representing several sectors are developing recommendations about the application of newly derived nutrient indicators to monitoring, assessment, and water quality standards programs. DWQ anticipates that these recommendations will result in new and improved nutrient assessments for the 2016 IR. Another group, the Nutrient Core Team, has proposed several water quality programs to be implemented in phases following adaptive management—learn by doing—principles. The first of these programs is currently being implemented.

In the interim, DWQ has developed a screening technique to determine if an AU needs further study to determine whether total phosphorus is degrading aquatic life uses. AUs that exceed these total phosphorus screening criteria are identified and placed on a list of waters that need further evaluation, unless the AU is currently part of an ongoing or completed TMDL analysis for total phosphorus.

Additional evaluations of AUs with high total phosphorus can be conducted in many ways. At a minimum, these AUs may be evaluated by doing a DO diurnal study to determine if DO concentrations are low enough, over a long enough time period, to cause impairment to the designated aquatic life uses. Also, biological assessments are conducted on high total phosphorus waters to quantify the extent of biologically degradation that may be attributable to eutrophication.

The assessment methodology to determine the need for further studies was based on the potential impact of total phosphorus, nitrate, and biochemical oxygen demand to aquatic life uses. The exception to this approach was the evaluation of nitrate for drinking water support and ammonia for aquatic life support. For all other uses, the data were screened against the criteria for sample sizes of four or more samples, and those sites found to exceed the criteria will be prioritized for future nutrient assessment and monitoring. For the 2012-2014 IR, all sites identified with potential nutrient issues were placed in Category 3D for further study.

BIOLOGICAL ASSESSMENTS OF RIVERS AND STREAMS

Introduction

Utah's biological beneficial uses require the protection of fish (e.g., cold water or warm water species) and the organisms on which they depend. In the past, DWQ has assessed these beneficial uses via water chemistry sampling and associated standards that assume to protect aquatic organisms. However, DWQ has developed an empirical model that directly assesses attainment of biological beneficial uses by quantifying the 'health' of macroinvertebrate assemblages. Measuring biological communities directly has the advantage that it integrates the combined effects of all pollutants, which allows a direct examination of how pollutants are interacting to affect the condition of a stream ecosystem (Karr, 1981). Moreover, because aquatic macroinvertebrates spend most of their life in aqueous environments, they are capable of integrating the effects of stressors over time, providing a measure of past, transient conditions (Karr and Dudley, 1981).

Biological assessments are often conducted by comparing the biological assemblage observed at a site with the expected biological assemblage in the absence of human-caused disturbance. Ideally, these comparisons are made using historical data to measure changes to the current biological community. However, in most cases, historical data are not available. As a result, biological conditions representing an absence of human-caused stress are typically set using reference sites as controls, or benchmarks, to establish the biological condition expected in the absence of human-caused disturbance. The biological integrity of sites can be evaluated by comparing the biological composition observed at a site against a subset of physically similar reference sites. Collectively, such comparisons are referred to as biological assessments.

In aquatic biological assessments, reference sites are selected to represent the best available condition for streams with similar physical and geographical characteristics (see Hughes et al., 1986, Suplee et al., 2005, and the Western Center for Monitoring and Assessment of Freshwater Ecosystems website[3] for more details). When reference sites are selected for water quality programs, conditions vary regionally depending on adjacent historical land use. For example, reference sites in Utah mountains are generally more pristine than in valleys. As a result, biological benchmarks are higher in areas of the state that receive less human-made disturbance than those with more disturbances.

A numeric index is a useful tool that quantifies the biological integrity, or biological beneficial use, of stream and river segments. Data obtained from biological collections are complex, with hundreds of species found throughout Utah that vary both spatially and temporally. Similarly, the physical template on which biota

[3] http://www.cnr.usu.edu/wmc/

depend also varies considerably across streams. A robust index of biological integrity should simultaneously account for naturally occurring physical and biological variability and summarize these conditions with a single, easily interpretable number.

River Invertebrate Prediction and Classification System Models

DWQ uses the River Invertebrate Prediction and Classification System (RIVPACS) model approach (Wright, 1995) to quantify biological integrity. RIVPACS is a classification of freshwater sites based on macroinvertebrate fauna; it was first derived in 1977 and has subsequently been used in numerous biological assessment programs worldwide. In the early 1970s, scientists and water managers recognized a need to understand the links between the ecology of running waters and macroinvertebrate communities. This began some of the very early biological assessment work in Europe. A 4-year project was initiated to create a biological classification of unpolluted running waters in Great Britain based on the macroinvertebrate fauna (Furse et al., 1984; Wright, 1995; Clarke et al., 1996; Moss et al., 1999). Over the past 30 years, equivalent RIVPACS models have been developed for aquatic ecosystems throughout the world, including Australia (Metzeling et al., 2002; Marchant and Hehir, 2002; Davies et al., 2000) and Indonesia (Sudaryanti et al., 2001). In the United States, scientists have developed RIVPACS models to assess the biological integrity of the country's aquatic habitats (Hawkins et al., 2000, Hawkins and Carlisle, 2001). Recently, many western states have adapted the RIVPACS model to determine beneficial uses of aquatic life in the rivers of state's such as Colorado (Paul et al., 2005), Montana (Feldman, 2006; Jessup et al., 2006), and Wyoming (Hargett et al., 2005).

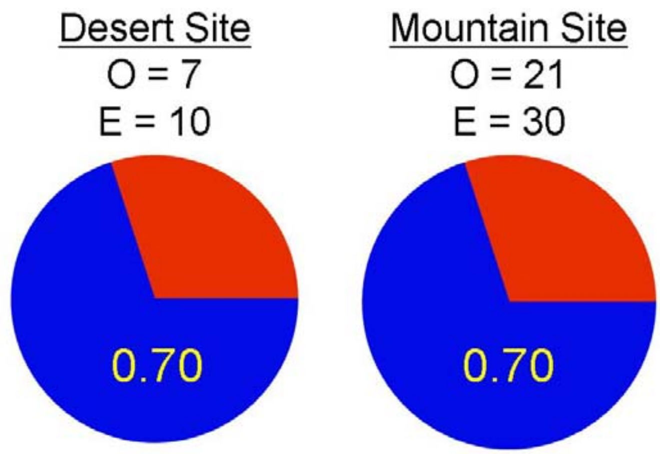

Figure 2-10. A hypothetical example of O/E as a standardization of biological assessments in different natural environments using numbers benthic macroinvertebrate taxa. In the desert site, 7 taxa were observed (O) from an expected number (based on reference) of 10 taxa (E). Thus, the O/E score was 0.70 or a loss of 30% of the taxa expected at the site.

To quantify biological condition, RIVPACS models compare the list of taxa (the lowest practical taxonomic resolution to which taxonomic groups are identified) that are observed (O) at a site to the list of taxa expected (E) in the absence of human-caused stress. Predictions of E are obtained empirically from reference sites that together are assumed to encompass the range of ecological variability observed among streams in the region where the model was developed. In practice, these data are expressed as the ratio O/E, the index of biological integrity.

Interpretation of RIVPACS models requires an understanding of the O/E ratio. In practice, O/E quantifies loss of predicted taxa. However, it is not a measure of raw taxa richness because O is constrained to include only those taxa that the model predicted to occur at a site. The fact that O/E only measures losses of native taxa is an important distinction because the stream ecological template changes in response to human-caused disturbance, and taxa richness can actually increase as conditions become more advantageous to taxa that are more tolerant of the degraded condition. Despite the mathematical complexities of model development, O/E is easily interpreted because it simply represents the extent to which taxa have become locally extinct as a result of human activities. For example, an O/E ratio of 0.40 implies that, on average, 60% of the taxa have become locally extinct as a result of human-caused alterations to the stream.

O/E has some very useful properties as an index of biological condition. First, it has an intuitive biological meaning. Species diversity is considered the ecological capital on which ecosystem processes depend; therefore, O/E can be easily interpreted by researchers, managers, policy-makers, and the public. Second, O/E is universally spatial, which allows direct and meaningful comparison throughout the state (Figure 2-10). This is particularly important for Utah where streams vary considerably from high-altitude mountain environments to the arid desert regions of the state. Third, its derivation and interpretation do not require knowledge of stressors in the region; it is simply a biological measuring tool. Finally, the value of O/E provides a quantitative measure of biological condition.

Model Construction and Performance

Construction of a RIVPACS model for Utah began in 2002, which involved developing and evaluating dozens of models. Details of model development procedures can be found elsewhere (Wright et al., 1993; Wright 1995; Clarke et al., 1996; Moss et al. 1999). Additionally, specific detailed instructions can be viewed on Western Center for Monitoring and Assessment of Freshwater Ecosystems' website[4] and EPA's website[5]. A brief summary is provided here to help the reader better understand Utah's model results and subsequent assessments.

As mentioned earlier, predictions of E are obtained empirically from reference site collections made throughout Utah. Reference sites are selected using experienced DWQ scientists who identified sites that represented the reference conditions in different biogeographical settings throughout Utah. The initial list of candidate reference sites is independently ranked by different scientists familiar with the streams. Only reference sites with a consensus representing best available conditions are used in model development. Subsequent reference sites are added using scores from reference scoring metrics developed during site visits and averaging with independent rankings from field scientists.

Some of the calculations involved in obtaining E are complex. A heuristic description of the steps involved in predicting E provides some context of the assessment methodology. The first step in model development is to classify reference sites into groups of sites with similar taxonomic composition using a cluster analysis. Next, models are developed based on watershed descriptors (e.g., climatic setting, soil characteristics, stream size) to generate equations that predict the probability of a new site falling within each group of reference sites. These equations account for environmental heterogeneity and ensure that when a new site is assessed, it is compared against ecologically similar reference sites. When a new site is assessed, predictions of group membership are then coupled to the distributions of taxa across groups of reference sites to estimate the probability of capturing (Pc) each taxon from the regional pool of all taxa found across all reference sites. E is then calculated as the sum of all taxa Pcs that had a greater than 50% chance of occurring at a site given the site's specific environmental characteristics. Using a Pc limit set at greater than 50% typically results in

[4] http://cnr.usu.edu/wmc/htm/predictive-models/predictive-models-primer
[5] http://www.epa.gov/wed/pages/models/rivpacs/rivpacs.htm

models that are more sensitive and precise which results in a better ability to detect biological stress (Hawkins et al., 2000; Simpson and Norris 2000).

The accuracy and precision of RIVPACS models depend in part on the ability of the models to discriminate among groups of biologically similar reference sites. An extensive list of 74 GIS-based watershed descriptors is evaluated as potential predictor variables in models that predict the probability of membership within biological groups for sites not used in model construction. GIS-based predictor variables, such as soils, meteorology, and geography, instead of field-derived descriptors, are evaluated for a couple of reasons. First, GIS-based descriptors are unlikely to be influenced by human disturbance and are therefore unlikely to bias estimates of expected conditions (Hawkins, 2004). Second, these predictors are easily obtained for any site that allows inclusion of additional macroinvertebrate samples collected by others. Various subsets of potential predictors are evaluated in an iterative, analytical process that explores different combinations of predictors able to explain the biological variability among reference sites. The final analysis selected six variables that resulted in the most precisely predictive model (Table 2-3).

Table 2-3. Final predictor variables used in model construction.

General Category	Description
Geology	Weighted average percentage calcium content of geology in the watershed
Geographical	Mean watershed elevation (meters) from National Elevation Dataset
Geographical	Watershed area in square kilometers
Weather	Watershed average of the mean day of year (1–365) of the last freeze derived from the PRISM data
Weather	Watershed average of the annual minimum of the predicted mean monthly precipitation (millimeters) derived from the PRISM data
Weather	Watershed average of the annual mean of the predicted mean monthly air temperature derived from PRISM data

The RIVPACS model used for the 2014 assessments was reconstructed to accommodate broader spatial and temporal data. Models used earlier were limited to samples from streams ranging from second to fifth order and were collected during a 'fall' window of September–November. The updated model accepts data collected from first- to eighth-plus order rivers and streams with no limitations on season of collection. In addition, new predictor variables were tested, and new and updated reference site data were included. However, to include data collected from agencies using different taxonomic laboratories, the taxon levels required adjustment, which resulted in a more coarse resolution of taxonomy. However, the resulting model was capable of scoring nearly 1,500 samples collected across the state by various agencies.

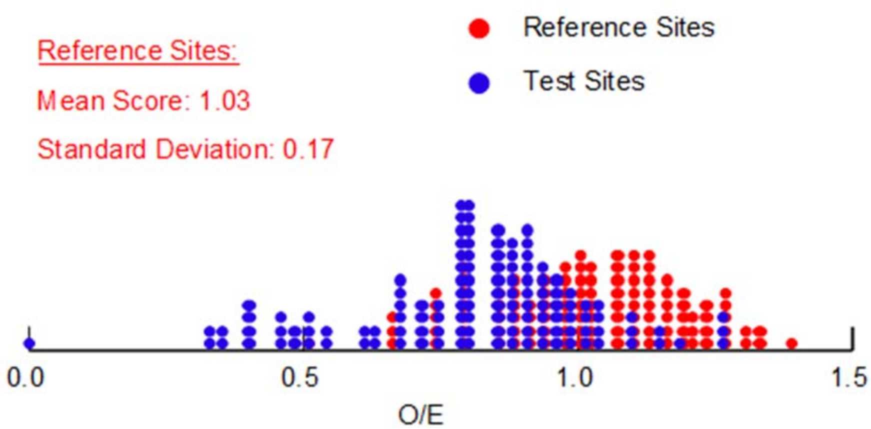

Figure 2-11. Distribution of reference site and test site O/E scores. As expected, sites that were not previously classified in reference condition had O/E values lower than 1, indicating local extinctions resulting from human-caused perturbations to these stream ecosystems. Conversely, the reference sites showed a roughly normal distribution centered on 1, indicating that the model was globally accurate.

The updated model is nearly as accurate and precise as previous models. If the model was perfectly accurate and precise, the O/E score for all reference sites would equal 1. Instead, reference O/E values are typically spread in a roughly normal distribution centered on 1 (Wright, 1995). Model precision is often expressed as the standard deviation (SD) of reference O/E values with lower SDs indicating higher model precision. The RIVPACS model used for the 2012-2014 IR assessments had an SD of 0.19, which is within the range of "accepted" water quality models. The precision was likely affected by the more coarse resolution of taxonomy and the inclusion of a few, large river sites as reference. The average reference O/E score for the current model is 1.03, which means that the model is slightly biased to generate higher O/E values than expected (see Figure 2-11). The accuracy of the model was evaluated by examining the distribution of reference O/E scores across environmental settings and determined that reference O/E values are not biased by stream size, elevation, or ecoregion.

Assessing Biological Use Support

DWQ does not have numeric biological criteria. However, DWQ has narrative biological criteria (UAC R317-2-7.3) that specify how quantitative model outputs are used to guide assessments. To make the narrative assessments as rigorous as possible, a systematic procedure was devised to use the RIVPACS model O/E values to determine aquatic life beneficial use support (Figure 2-12). The goal of this assessment process is to characterize each AU as fully supporting or not supporting aquatic life beneficial uses.

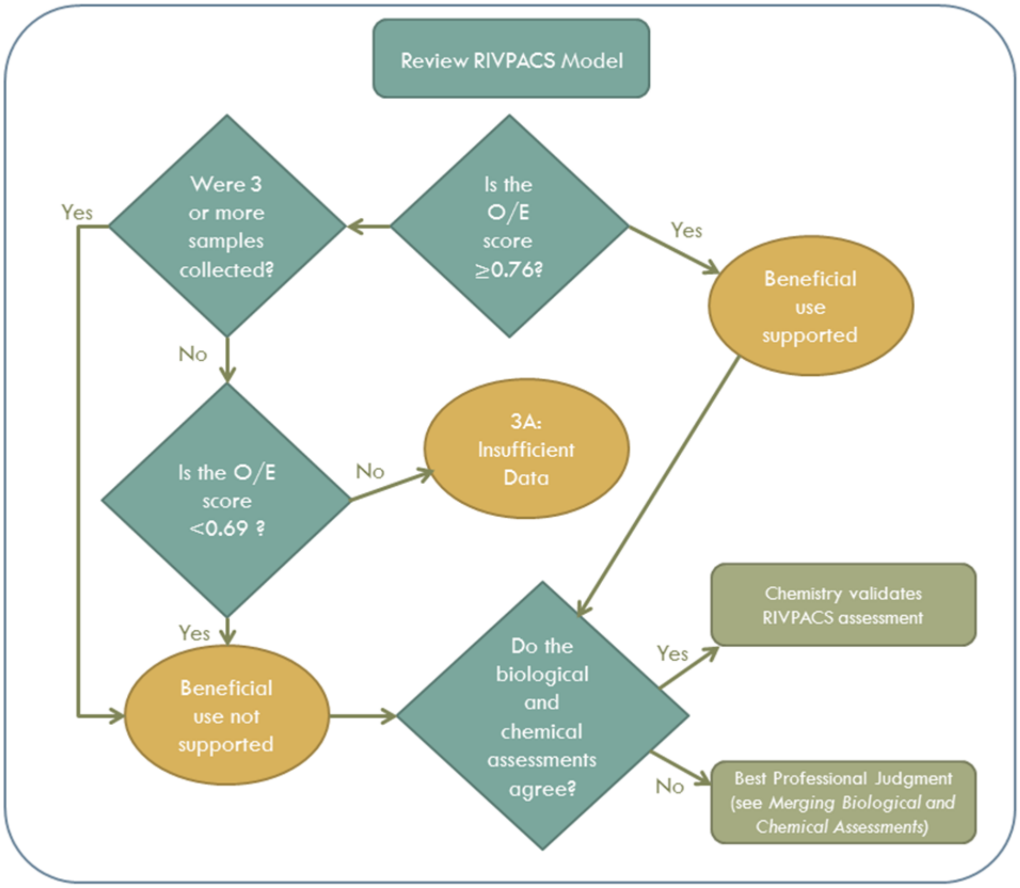

Figure 2-12. Flow diagram depicting the decision tree for making biological assessment decisions.

Utah currently assesses watersheds based on established AUs. Although many AUs contain a single biological monitoring location some AUs contain multiple sites. In such instances, DWQ staff examines available data to determine if multiple sites in an AU score similarly. When comparisons suggest that sites in one AU are ecologically similar, O/E scores from all sites in an AU are averaged for assessment purposes, provided that conclusions of biological condition are similar. If O/E scores differ appreciably among multiple sites in an AU, DWQ will investigate possible explanations for such discrepancies. If DWQ finds multiple sites within an AU from different environmental settings, AUs are subdivided into smaller watershed units whenever clear boundaries can be identified (e.g., political/land use boundaries, tributary confluence). Additionally, if only one site is sampled in an AU, it is examined whether it is an appropriate representation of the AU.

To translate the O/E values into assessment categories, it is necessary to devise impairment thresholds, or O/E scores that indicate whether or not a site is meeting biological beneficial uses (Table 2-4). For these assessments, the 10th and 5th percentiles of reference were used. Essentially, the data used for the 2014 assessment calculate the threshold based on 5th percentile at 0.69, whereas the 10th percentile is 0.76. These thresholds will provide the bounds according to sample strength. The data were averaged across 5 years since the most recent sample was collected. Multiple years are preferred for assessments because O/E scores can vary from year to year and assessments are based on average conditions. Assessments based on the average condition of three or more samples reduces the probability of making an error of biological beneficial use support as a result of an unusual sampling event (e.g., following a flash flood, improperly preserved sample).

Table 2-4. Beneficial use support determination for O/E values obtained from different sample sizes.

Sample Size	**O/E Threshold**	**Use Determination**	**Comments**
≥ 1 sample collected over 5 years	Mean O/E score ≥ 0.76	Fully supporting	Threshold based on 10th percentile of reference sites
≥ 3 samples collected over 5 years	Mean O/E score < 0.76	Not supporting	Threshold based on 10th percentile of reference sites
< 3 samples	Mean O/E score ≥ 0.76	Fully supporting	Threshold based on 10th percentile of reference sites
< 3 samples	Mean O/E score ≥ 0.69–≤ 0.76	Category 3A (insufficient data)	Lower threshold based on 5th percentile of reference sites
< 3 samples	2 of 2 O/E scores < 0.69	Not supporting	Threshold based on 5th percentile of reference sites
< 3 samples	< 2 O/E scores < 0.69	Category 3A (insufficient data)	Threshold based on 5th percentile of reference sites

These errors can be costly to DWQ by increasing staff time and resources, which requires follow-up assessments on misclassified AUs. Conversely, AUs not meeting these thresholds will be assessed as nonsupporting, or they will be required for follow-up sampling if additional information is needed. Assessments of more than three samples with average O/E scores of greater than or equal to 0.76 have a low probability of being misclassified as nonsupport. Alternatively, assessments with fewer than three samples with an average O/E score of less than 0.69 have a 5% probability of being misclassified as nonsupport. However, to ensure that one sample was not incorrectly misapplied and to begin reducing the need for BPJ criteria, at least two samples with a score of 0.69 or less will be required to consider an AU not meeting the aquatic life use. Assessments with fewer than three samples that have a mean O/E score of greater than or equal to 0.69 and less than 0.76 will be placed in impairment Category 3A, which indicates that there are insufficient data to make an assessment. All sites listed as 3A will be given a high priority for future biological monitoring.

Merging Biological and Chemical Assessments

For years, DWQ has assessed biological beneficial use attainment with water chemistry standards that are assumed to be protective of stream biota. Before making final decisions about biological beneficial use support, a comparison is made between impairment assessments obtained from stream biota with those obtained from stream chemistry. The primary goal behind these evaluations is to further limit both false positive and false negative assessments beyond what is considered in the biological assessment. There are four potentially confounding factors that warrant a more careful scrutiny of incongruous biological and chemical assessments. These factors are summarized in a BPJ framework (Figure 2-13) wherein disagreements between chemistry and biology assessments are objectively and systematically evaluated on a case-by-case basis.

These judgment decisions are based in part on EPA's *Consolidated Assessment and Listing Methodology*[6] guidance published in 2002. The guidance provides a framework to weigh multiple types of data used for waterbody assessment. Specifically, the guidance refers to the policy of independent applicability, which stresses that if any one type of applicable data indicates that water quality standards are not supported, the waterbody shall be identified as impaired. Finally, if an AU results in a 3A listing for either biological or chemical assessment, the assessment type with sufficient data to determine the listing will be used. For example, if the biological data of an AU indicate full support, whereas the chemical data indicates 3A, the AU will be listed as full support. The decision framework rectifying situations where chemical and biological data suggest different conclusions about overall water quality is discussed in this section.

[6] http://water.epa.gov/type/watersheds/monitoring/calm.cfm

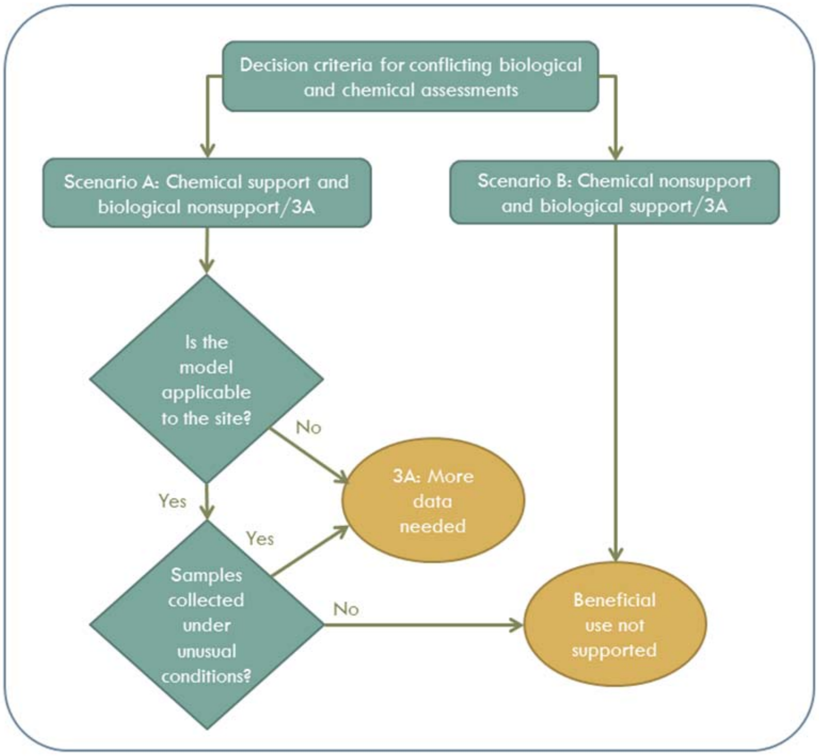

Figure 2-13. Decision criteria for conflicting biological and chemical assessments.

Scenario A: Chemically Support and Biologically Nonsupport/3A

Under this scenario, the AU is meeting water quality standards according to chemical criteria. However, the biological assessment indicates there is impairment or not enough information to make a confident decision (i.e., more data is needed). Two more questions need to be answered before deciding on the appropriate method for the final assessment decision:

1. Is the model applicable to the site? One of the fundamental assumptions of RIVPACS models is that the suite of reference sites used in model construction encompasses the range of environmental conditions observed in the sites that are to be assessed. All sites are evaluated using a Chi-square test to determine whether this assumption is met before a final assessment is made. In instances where model results fall significantly outside of the distribution (i.e., fail the test), the biological assessment is null and therefore the chemical assessment takes precedence.

2. Were the chemical or biological samples collected during unusual environmental conditions? Conclusions of impairment can potentially be biased when samples are collected during unusual environmental conditions. For instance, both biological composition and chemical criteria are known to be altered by drought, and data collected under these conditions may be suspect. Similarly, the composition of stream assemblages is known to be altered by flash floods, and samples collected following these events are suspect. In these situations, the biological data are not indicative of average conditions, and the chemical assessment will be used. Alternatively, if the biological samples were collected under average conditions, the biological assessment shall take precedence.

Scenario B: Chemically Nonsupport and Biologically Support/3A

Under this scenario, the AU is NOT meeting water quality standards according to chemical criteria. However, the biological assessment indicates that the biological beneficial use is fully supported. Under this scenario, due to independent applicability, the results of the chemical assessment shall take precedence.

ESCHERICHIA COLI ASSESSMENTS

Introduction

The World Health Organization (WHO) reports that 80% of all sicknesses can be attributed to inadequate water supplies and poor sanitation. To ensure the protection of public health, routine monitoring and assessment programs are needed. For Utah's bacteriological monitoring program, surface waters will be routinely monitored for pathogens that originate from fecal pollution from both human and animal waste. It is not feasible to monitor all pathogens in water, but by analyzing indicator organisms, such as *Escherichia coli (E. coli)*, the overall potential health risks from water exposure can be quantified.

Using indicator organisms as a means of assessing pathogens' presence in surface waters has been adopted by WHO, EPA, and the European Union. *E. coli* is the most abundant coliform bacteria present in human or animal intestines, numbering up to 1 billion individuals per gram of feces. It is the only true fecal coliform bacteria in that its presence can be exclusively attributed to a fecal origin. *E. coli* is not the only pathogenic organism that presents a potential health threat in surface waters; however, the concentration of *E. coli* is strongly correlated with other pathogenic species, and more importantly, to sickness rates in people exposed to contaminated water. The presence of *E. coli* in water is a strong indication of recent sewage or animal waste contamination. Fecal contamination sources are not just limited to raw sewage. Other fecal sources include grazing pasture, confined feedlots, wildlife, or dog parks. These bacteria may be washed into surface waters during precipitation events such as rainfall or snow melts. When these waters are consumed without proper treatment or are used recreationally, they can pose a threat to human health.

E. coli **standards and associated assessment methods are relatively new for Utah. A stakeholder group has been formed to help inform the public of immediate health concerns. More information can be found at the E. Coli Workgroup website.[7] In each case,** ***E. coli*** **criteria have been established as a result of these newly established criteria. DWQ, in cooperation with its volunteer cooperators, has been implementing an aggressive monitoring program to collect** ***E. coli*** **data to assess these uses. The 2010 IR represents the first formal evaluation data collected from both rivers and lakes through this newly developed program. DWQ anticipates that this program will be modified as it develops.**

WQ recently modified Utah's water quality standards to include numeric *E. coli* criteria (UAC R317-2-6). All surface waters in Utah are assigned *E. coli* numeric criteria to protect recreation uses, and some of these waters have also been assigned numeric criteria to protect domestic (drinking water) uses. Recreation use classes are divided into two subclasses: 1) primary contact (e.g., swimming, water skiing) recreation uses (Class

[7] www.ecoli.utah.gov.

2A), or 2) recreation activities (e.g., fishing, hunting) that result in infrequent primary contact and secondary contact with waters (Class 2B).

Beneficial Use Classifications

All rivers, streams, and irrigation canals and ditches in Utah are designated—explicitly or implicitly—as Class 2B waters, protected for infrequent primary contact and secondary contact recreation such as boating, wading, or similar uses. Some lakes and reservoirs have also been designated as Class 2A, waters protected for primary contact recreation such as swimming and water skiing. These beneficial uses apply to all lakes and reservoirs greater than 20 acres (UAC R317-2-13.12). All lakes and reservoirs not designated in the standards as 2A are designated as Class 2B waters by default. Lakes or reservoirs not listed in the standards are assigned uses by default to the classification(s) of their tributary streams. Some of these waters are also protected as domestic water sources (Class 1C).

E. coli Numeric Criteria

Two *E. coli* numeric criteria, with different frequency and recurrence intervals, have been developed to protect both Class 2 and Class 1C designated uses as follows:

> **Class 2A:** A maximum (not to exceed) concentration of 409 most probable number (MPN) per 100 milliliter (ml) or a five-sample geometric mean of 126 MPN.
>
> **Class 2B and Class 1C:** A maximum (not to exceed) concentration of 668 MPN per 100 ml or a five-sample geometric mean of 206 MPN.

Recreation Period

To evaluate recreation (Class 2) uses, *E. coli* sampling will be conducted in the recreation period (May 1 through September 30). This time period is of greatest risk because this is when most of the recreation occurs on Utah's waters. In addition, this period also coincides with higher *E. coli* concentrations due to warmer water temperatures, which increases the growth and reproduction rates of these organisms.

The summer index period may not adequately protect recreation uses of southern Utah waterbodies, which sometimes have relatively high water temperatures throughout the year. As additional data are available, DWQ will reevaluate—on a site-by-site basis—the index period for southern Utah waters. In the interim, the statewide summer index period will be used for assessment purposes.

Assessment Methods

EPA's Beaches Environmental Assessment and Coastal Health Act was passed in October 2000. The act's primary goal is to reduce the risk of disease to users of the nation's recreational waters. The act provides considerations for interpreting bacteriological criteria when assessing support of recreation (2A/2B) and drinking water (1C) uses, yet it still provides some flexibility by providing a range of approaches to accommodate different monitoring strategies and environmental settings. EPA recommends that the monitoring and assessment methods must match the numeric standards set for *E. coli*. These assessment procedures were developed to be congruous with both federal guidance and Utah's *E. coli* criteria. DWQ's assessment methods based on these recommendations aim to ensure protection of recreation and drinking water uses, while simultaneously considering the need to balance false positive (erroneous conclusion of impairment, Type I error) and false negative (missing an impairment, Type II error) assessments.

In general, the likelihood of becoming ill when recreating in waters increases with increasingly high *E. coli* concentrations. EPA recently published guidance (*Recreational Water Quality Criteria* [EPA, 2012]) that recommends both a geometric mean criterion and a statistical threshold value for assessing recreational waters. These values, which correspond with DWQ's criteria outlined below, are based on an estimated illness rate of 36 illnesses per 1,000 primary contact recreators. Although *E. coli* is an indicator method and does not directly measure pathogenic strains of *E. coli*, it is a strong indicator of fecal and viral contamination of surface water, which may pose a risk to human health. The overarching goal of this assessment approach is to define criteria that ensure protection of recreation and drinking water uses in both rivers and lakes, while simultaneously considering both false positive and false negative assessments. The following rules discuss how these criteria are interpreted for varying numbers of samples collected during the 5-year period prior to making assessment decisions. Monitoring locations that fail to meet any of these criteria will generally be listed as failing to meet recreation—or drinking water— designated uses on Utah's 303(d) list of impaired waters.

Analytical Methods: Data Preparation

Before making any assessment decision, DWQ first compiles information about any beach closures or health advisories, and all existing and available *E. coli* data collected from Utah's waters during the five most recent recreation seasons (May 1 through September 30). These data are summarized by monitoring location as follows:

1. Calculate Geometric Mean of Replicates: Samples collected on the same day are considered replicates. In such situations, the geometric mean of these samples is used to represent a single collection event to avoid overweighing a single spike in high *E. coli* concentrations when assessing support of designated uses.

2. Tally Collection Events for each Recreation Season: The number of collection events (n) for each recreation season is counted (following the rule that samples collected on the same day are considered replicates and represent a single collection event).

3. Calculate Rolling Geometric Means: Calculate rolling geometric means for monitoring locations with 10 or more collection events in the recreation season. Rolling geometric means are calculated by ordering all samples by date and then calculating a series of moving five-sample geometric means, starting with the first five samples, then samples 2–6, then samples 3–7, etc. for all samples within each recreation season.

4. Consider Closures or Health Advisories (lakes only): A tally of the lake or reservoir closures issued for the waterbody during each recreation season.

Assessment of Recreation and Drinking Water Uses with *E. coli* Data

DWQ applies the following rules to perform assessments, depending on the data available at each monitoring location in the dataset:

- **Rule 1**: For each monitoring location with 10 or more samples in any recreation season, all five-sample rolling geometric means of samples collected from May 1through September 30 should not exceed either 126 MPN/100 ml for 2A waters or 206 MPN/100 ml for 1C/2B waters throughout the most recent 5 years.

- **Rule 2**: For each monitoring location with five or more samples in any recreation season, no more than 10% of the samples collected from May 1 through September 30 should exceed 409 MPN/100 ml for 2A waters or 668 MPN/100 ml for 1C/2B waters throughout the most recent 5 years.

- **Rule 3**: Monitoring locations with four or fewer samples in any recreation season will not be assessed for support of recreation uses. These sites will be prioritized for future sampling, particularly if limited data suggest a potential problem exists in the waterbody.

Based on the summary of all *E. coli* data, a waterbody will be assessed using the subsequent assessment considerations:

Fully Supporting (Category 1 or 2)

A waterbody is considered to be fully supporting its beneficial use if

- there is no evidence of impairment from Rule 1 or 2 for all recreation seasons over the most recent 5 years. Years with four or fewer samples will not be considered when deciding if a waterbody is fully supporting or not supporting.

Insufficient Data or Information Assessment Considerations (Category 3A)

- Sites with four or fewer samples in all seasons evaluated will be listed as not assessed, provided that the impairment is not suggested by Rule 1 (three or more health advisories).

All Category 3A sites will be prioritized for future monitoring, especially if limited data suggest impairment.

Not Supporting but No TMDL Required (Category 4)

AUs are reported as Category 4 if water quality remains insufficient to support the designated use, yet a TMDL is not required.

Not Supporting (Category 5)

A waterbody is considered to be impaired (not meeting its designated uses) if any of the following impairment considerations suggest that problems with *E. coli* represent a threat to human health.

i. Any of the five-sample rolling geometric mean calculations exceed the 30-day, five-sample geometric mean criterion (not supporting Rule 1). Monitoring locations are not assessed with Rule 1 unless the analysis is based on 10 or more samples, which should be done during a single recreation season for Class 1 and 2 designated uses.

ii. Any monitoring location where less than 10% of the samples exceed the not-to-exceed criterion shall be considered impaired (not supporting Rule 2). Monitoring locations are not assessed with Rule 2 unless the analysis is based on five or more collection events, which should be done during a single recreation season for Class 1 and 2 designated uses.

iii. Any monitoring location with violations of Rule 1 or 2 during the five most recent recreation seasons shall be considered not supporting. When assessments at a single site contradict one another (e.g., some years supporting, others not fully supporting), the presence of a not supporting assessment shall outweigh the fully supporting, and the site shall be considered not supporting.

iv. A lake or reservoir that has three or more posted health advisories or beach closures during any recreation season shall be considered impaired (not supporting recreation uses). In many cases, sites will also be designated as impaired following the other assessment rules; however, because health advisory rules are conservative—by using the five-sample, 30-day geometric mean criteria without the 10% exceedance exception— this captures sites with repeated moderately high *E. coli* concerns. Although not explicitly required by Utah's water quality standards, UDWQ believes that listing based on health advisories is consistent with the intent of recreation use protection.

LAKE AND RESERVOIR ASSESSMENT METHODS

Introduction

Lakes and reservoirs are defined as waters of Utah, which are protected by beneficial use designations. Each lake and reservoir has been designated as an AU for purposes of assessment. The terms lake, reservoir, and AU are used interchangeably in this chapter.

UAC R317-2-14 contains the standards established for both toxic and conventional parameters, including TDS. Lakes and reservoirs greater than 20 acres are listed along with their beneficial use classifications. Lakes or reservoirs not specifically listed in UAC R317-2-13.12 are assigned designated uses by default to the classification(s) of their tributary stream(s).

GREAT SALT LAKE

Great Salt Lake is divided into five AUs (UAC R317-2-5). With the exception of a selenium standard for the Gilbert Bay AU, no numeric standards are available for any of the AUs. In the absence of numeric standards, the designated uses of GSL are assessed with the Narrative Standard (UAC R317-2-7.2).

Reservoir and Lake Assessments

When DWQ started to monitor lakes and reservoirs, 132 lakes based on size and public interest were selected to make lake and reservoir assessments for the IR, i.e., the 305(b) report and 303(d) list of impaired waters. These lakes and reservoirs account for 93% of the water surface acres in Utah. The lakes were divided into two groups, one group being sampled during even years, and the other group during the odd years. Monitoring for each lake and reservoir is done twice each year.

DWQ transitioned to a watershed-intensive approach where routine sampling is focused in a watershed with more intensive sampling. High-priority lakes and reservoirs, e.g., TMDL or special projects, will continue to be sampled in other watersheds. The TMDL and special studies lakes and reservoirs are monitored four times during the monitoring season. The change to a watershed-intensive approach necessitated changes to the assessment methodology. The 2012 and 2014 assessments are based on the last 5 years of data (for instance, the 2012 data used data from 2005 to 2010). If data for this time period were unavailable, data from the previous 5 years (total of 10 years) were assessed. At least two sample events are required to assess support for lakes.

Water column profile data are collected at the surface and at every meter of the water column depth. The collection is completed when the probe is 1 meter above the bottom. Surface samples are collected from a depth of 0.5 meter. All water chemistry samples, except dissolved metals and algal samples, are collected at the surface, 1 meter above the thermocline, 1 meter below the thermocline, and near the bottom. The dissolved metals sample is collected 1 meter above the bottom at the deepest site on the lake or reservoir. The algal sample is collected as a composite sample from three times the depth of the Secchi disc reading to the surface. The algal sample is collected once at the deepest monitoring site on the lake or reservoir.

The assessment of reservoirs and lakes consists of two tiers:

- Tier I assessment is the preliminary determination of support status based on conventional parameters, such as DO, temperature, pH, toxicants, etc.

- Tier II assessment looks further into the weighted evidence criteria (TSI, fish kills, and blue-green algal dominance) using BPJ. The Tier I preliminary support status may be modified through an evaluation of the TSI, winter DO conditions with reported fish kills, and the presence of significant blue-green algal populations in the phytoplankton community. The Tier II evaluation could adjust the preliminary support status ranking if at least two of the three criteria indicate a different support status.

Tier I Assessments

Total Dissolved Solids

Data collected on individual AUs from all monitoring locations are used to determine the beneficial use support based on TDS. If TDS data are unavailable but conductivity data are available, the conductivity data are used to estimate TDS (USGS 2006). An exceedance using conductivity as a surrogate will result in a Category 3A listing, and the lake will be targeted for TDS sampling.

The following rules are used to determine whether a lake or reservoir is supporting its agricultural designated uses (Figure 2-14):

Beneficial Use Supported: The beneficial use is supported if the standard is exceeded one or fewer times in two consecutive monitoring cycles, e.g., 2002 and 2004 for even-numbered years, or 2001 and 2003 for odd-numbered years.

Beneficial Use Not Supported: The beneficial use is not supported if the TDS standard is exceeded two or more times in two consecutive monitoring cycles.

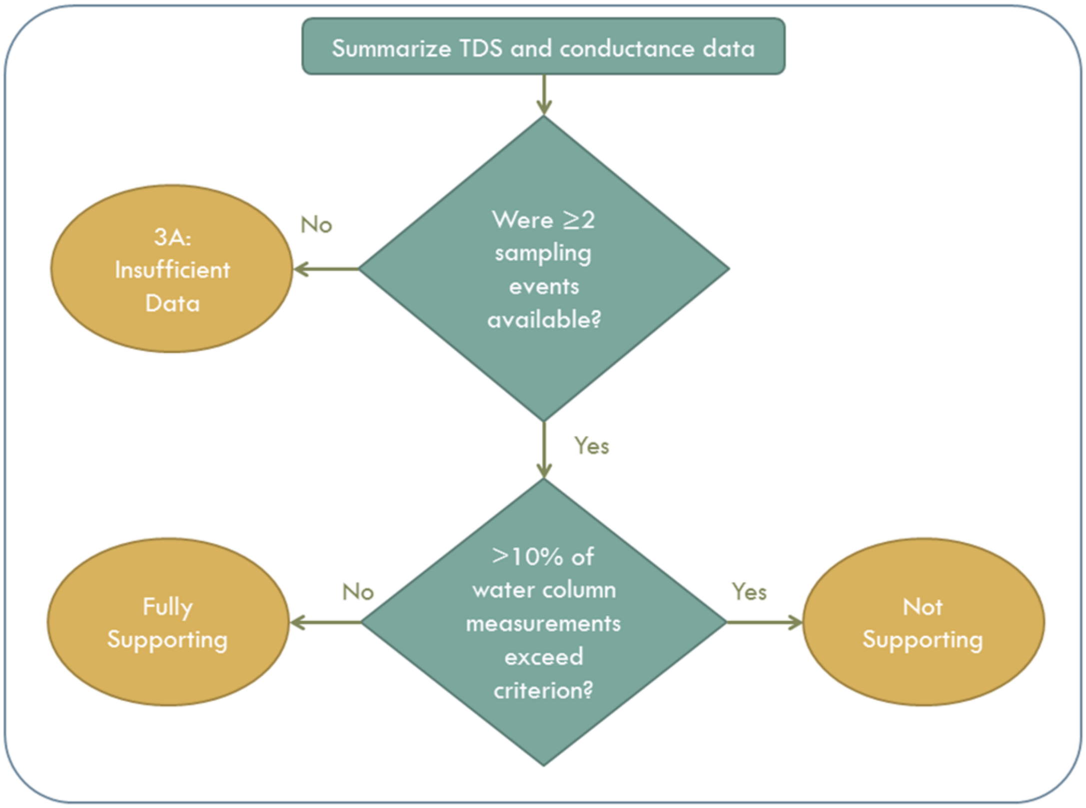

Figure 2-14. The assessment process that DWQ follows to determine support of a lake's designated agricultural uses with TDS data.

Lake Profile Data: pH, Temperature, and Dissolved Oxygen

Lake and reservoir monitoring routinely involves collecting pH, temperature, and DO measurements at 1-meter intervals through the water column—from surface to the lake bottom. These water column measurements are compared against Utah water quality standards to assess beneficial use support (Figure 2-15). If more than one site is sampled in a lake, the profile measurements collected at the deepest site are used for assessment calculations, unless there is sufficient reason to use the profile data from other locations on the lake or reservoir.

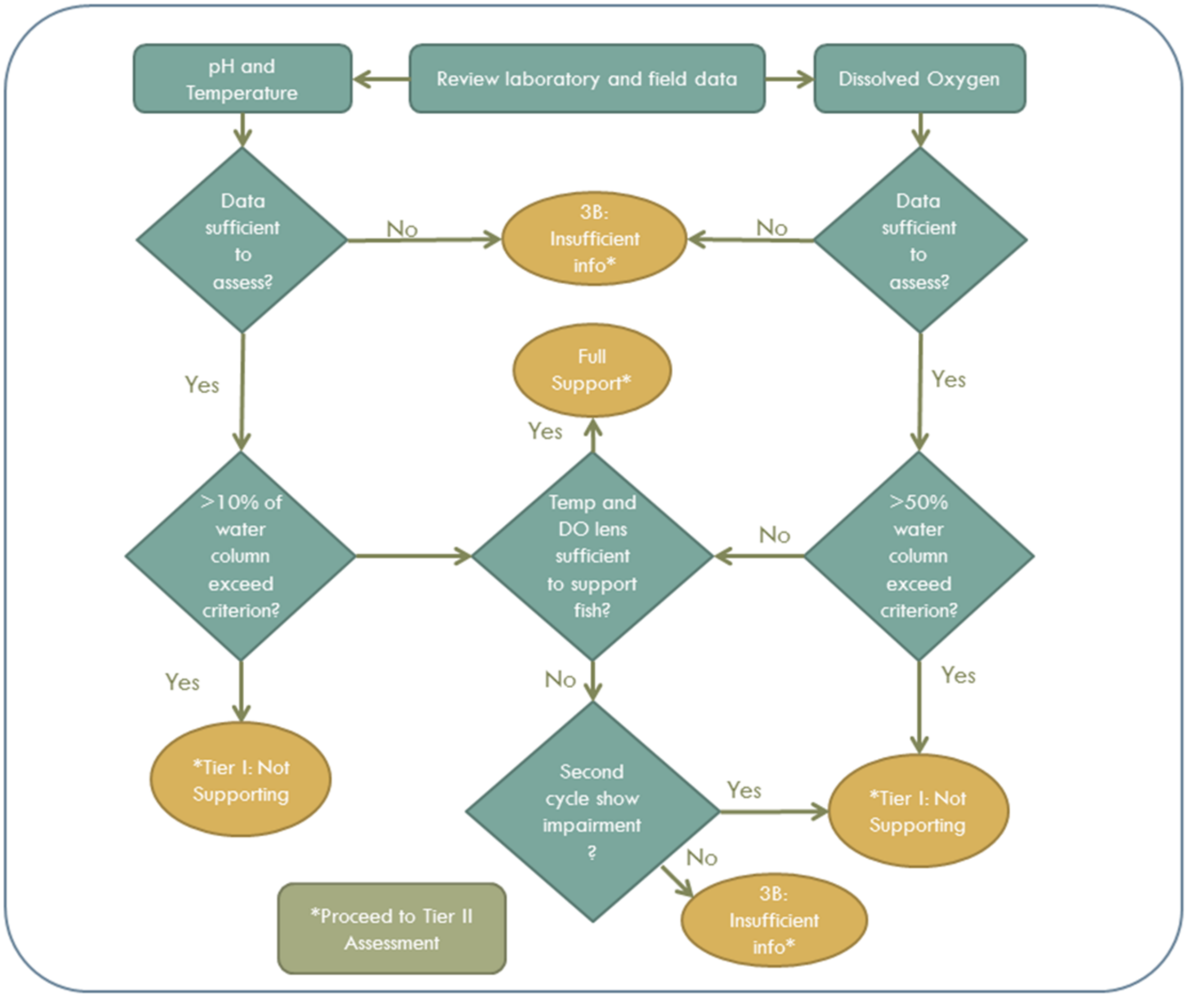

Figure 2-15. This flowchart depicts the process that DWQ follows when using conventional (nontoxic) parameters to assess Utah's lakes. In the case of temperature and DO a second test follows the primary water quality screen to evaluate whether fish have sufficient habitat by looking at the area of the water column that fails to meet both DO and temperature criteria. In all cases, these assessments are followed by a second, Tier II, assessment process.

pH Data

Two pH criteria, maximum and minimum, are used to assess support of designated uses as follows:

Beneficial Use Supported: The beneficial use is supported if the number of violations are less than or equal to 10% of the measurements (e.g., Figure 2-16, Panel A).

Beneficial Use Not Supported: The beneficial use is not supported if greater than 10% of the measurements violate the pH standard (e.g., Figure 2-17, Panel B).

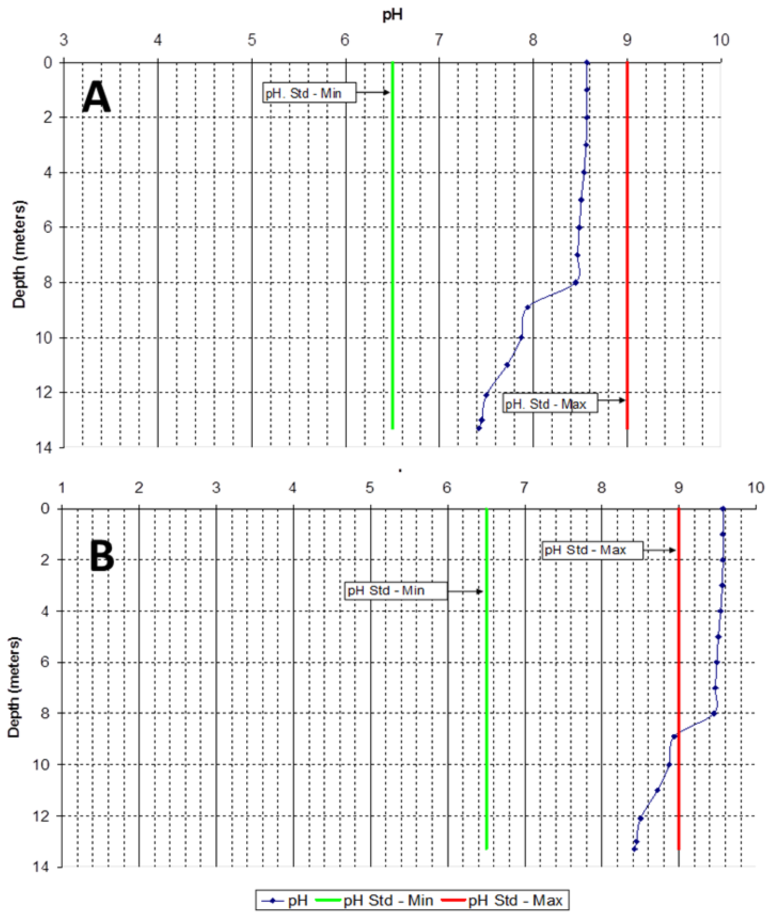

Figure 2-16. Plots of pH measurements (blue dots) against reservoir depth for two reservoirs as an example of assessment procedures. Two pH criteria are depicted, a minimum criterion of 6.5 (green line) and a maximum criterion of 9 (red line). Panel A (top) provides an example of a reservoir meeting its designated use because all of the pH measures are between the two pH criteria. Panel B (bottom) provides an example of an impaired reservoir because greater than 10% of the pH measures are higher than the maximum pH criterion.

Temperature Data

The criteria for assessing the beneficial use support for lakes and reservoirs using temperature data are based upon profile data collected at the surface and then at 1-meter intervals. Data collected from the deepest site during the spring through fall monitoring periods are used to calculate the percentage of violations for each sampling date. For a lake or reservoir to be placed on the 303(d) list, the temperature standard must be exceeded in two consecutive monitoring cycles, e.g., in the 2002 and 2004 monitoring cycles, the temperature was exceeded in more than 10% of the measurements from any individual sampling event.

Beneficial Use Fully Supported: The beneficial use is supported if the number of violations is less than or equal to 10% of the measurements (see Figure 2-17, Panel A).

Beneficial Use Not supported: The beneficial use is not supported if more than 10% of the measurements violate the temperature standard (see Figure 2-17, Panel B).

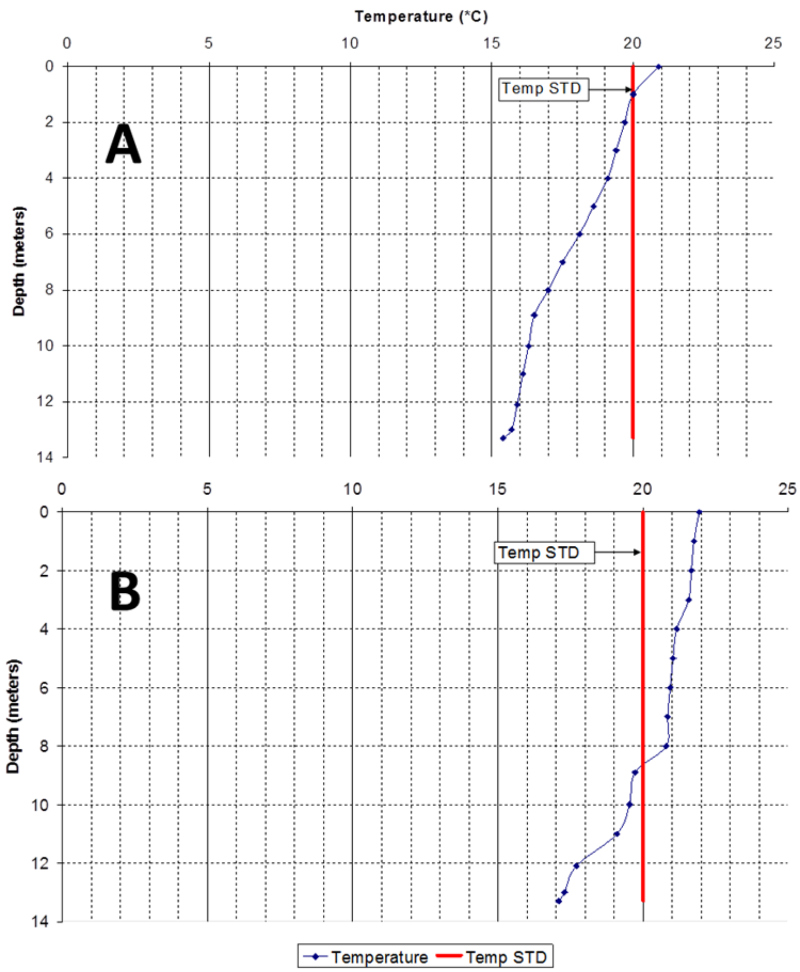

Figure 2-17. Plots of temperature measurements (blue dots) against reservoir depth for two reservoirs to provide an example of assessment procedures. The red line illustrates a temperature criterion of 20 degrees Celsius—Class 3A designated use. Panel A (top) illustrates a reservoir meeting its designated use because less than 10% of the temperature measures are greater than the criterion, whereas Panel B (bottom) illustrates an impaired reservoir because greater than 10% of the temperature measures exceed the criterion.

Dissolved Oxygen Data

The DO assessment uses the DO standard of 4.0 mg/L for Class 3A waters and 3.0 mg/L for Class 3B waters (UAC R317-2-14). State standards account for the fact that anoxic or low DO conditions may exist in the bottom of deep reservoirs.

Beneficial Use Supported: For lakes, the beneficial use is supported if at least 90% of the oxygen measurements are greater than the DO standard for the entire water column depth.

Beneficial Use Not Supported: For lakes, the beneficial use is not supported if more than 10% (greater than 10%) of the oxygen measurements are below the DO standard for the entire water column depth.

Assessments Based on Dissolved Oxygen Concentration and Temperature above the Thermocline

If the temperature profile indicates that the habitat is reduced by high temperatures at or near the surface, an assessment of the thickness of the lens is made to determine if there is sufficient habitat for the fishery. If the data indicates insufficient habitat for the fishery, the lake or reservoir shall be listed. This assessment is largely based on BPJ because of the variability in the size and depth of the lake or reservoir. In the case of reservoirs that are subject to human-controlled operations, drawdown is taken into consideration. Drawdown can change from year to year based on the spring runoff and how full they were at the end of the previous irrigation season or how much water was needed for culinary purposes. Figure 2-18 provides an example of supporting and not supporting the beneficial use based on the DO and temperature data above the thermocline. The rationale for a conclusion of fully supporting based on the existence of a lens will be clearly documented.

Beneficial Use Supported: Sufficient habitat for fish based on DO and temperature above the thermocline.

Beneficial Use Not Supported: Insufficient habitat for fish based on DO and temperature above the thermocline.

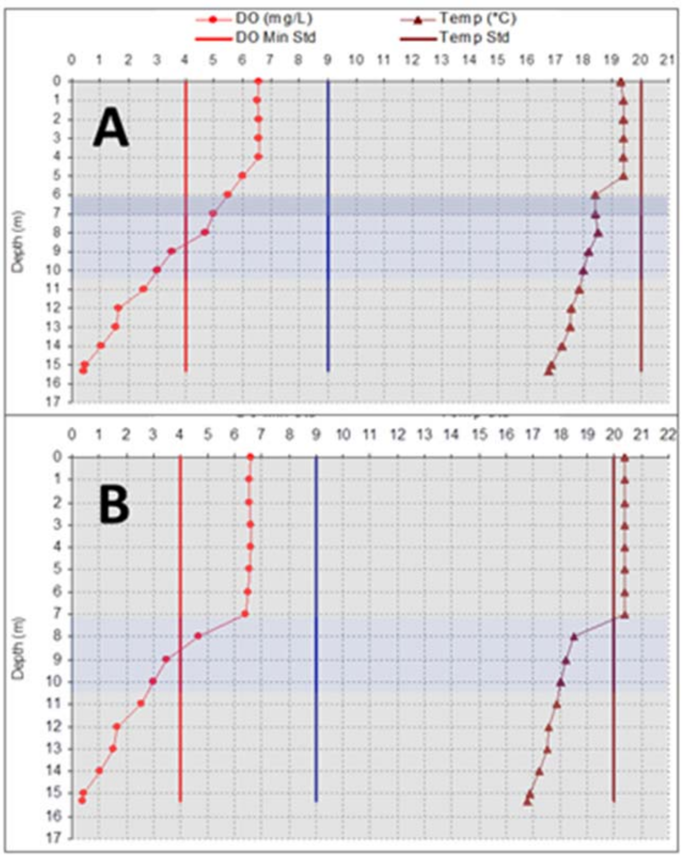

Figure 2-18. These images illustrate the concept of an ecological lens, which is a zone where both DO and temperature are suitable for fish. The reservoir depicted on the top (Panel A) would be considered supporting because the lens where both temperature and DO violate water quality criteria is small. Conversely, the reservoir on the bottom would be considered impaired due to the large area of unsuitable conditions for fish.

Toxicants: Dissolved Metals, Ammonia, and Gross Alpha Data

To obtain toxicant data, one sample is collected near the bottom of the lake at the deepest point in the lake or reservoir. These samples are obtained at the deepest point because this area generally has the highest dissolved metal, ammonia, and gross alpha concentrations. If the concentration of these pollutants exceeds the standard, DWQ will return to the site to conduct follow-up sampling. In some cases, this may occur the following year.

Beneficial Use Supported: The beneficial use is supported if there are less than two exceedances of the chronic or acute standard.

Beneficial Use Not Supported: The beneficial use is not supported if the concentration exceeds the chronic or acute standard two or more times.

Tier II Assessments

Weighted Evidence Criteria

The weighted evidence criteria consist of the following three data types. These evaluations are based to a large extent on BPJ, but efforts are made to be as consistent as possible (Figure 2-19).

- There is an increasing TSI trend over a long-term period or a TSI greater than 50.
- There are winter fish kills or low winter DO when it is measured.
- There is a dominance of green algae or cyanobacteria.

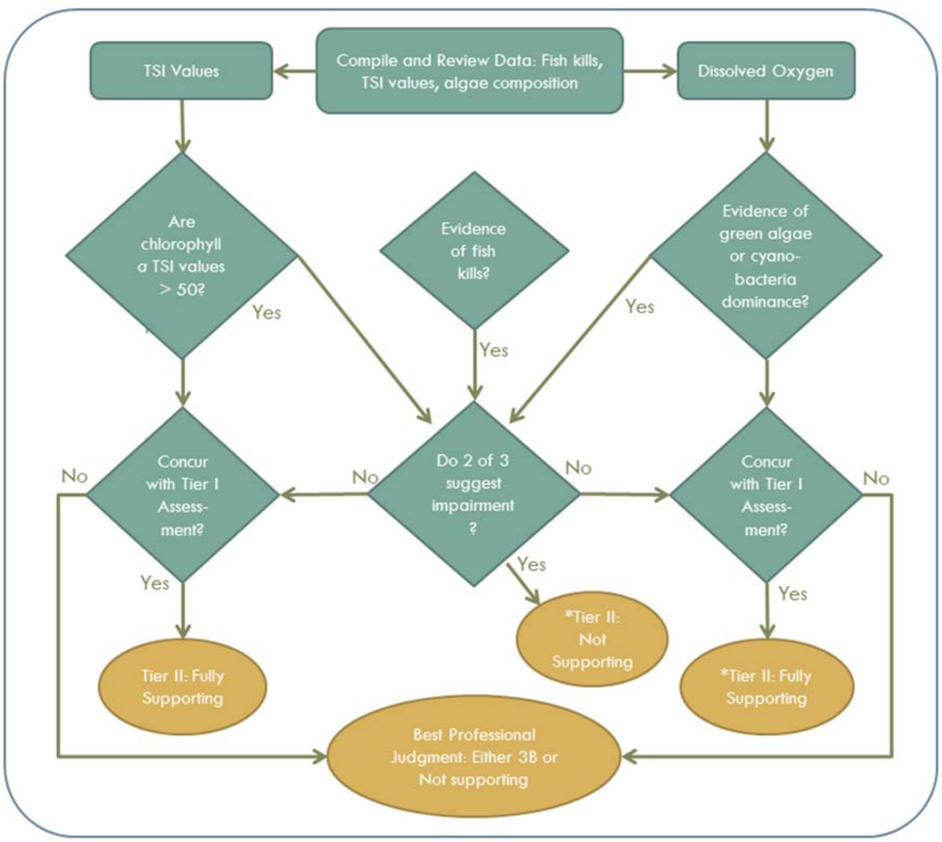

Figure 2-19. A flow chart that describes the Tier II assessment process for lakes and reservoirs. These assessments allow DWQ to use key lines of evidence in making assessments that would be ignored by exclusively focusing on chemical water quality parameters.

Carlson's Trophic State Index

The Carlson's TSI is calculated using Secchi disk transparency, total phosphorus, and chlorophyll *a*. TSI value ranges from 0 to 100, with increasing values indicating a more eutrophic condition, as follows (Table 2-5):

Carlson's TSI estimates are calculated using the following equations:

Trophic Status Based on Secchi Disk (TSI-SD):

TSI-SD = 60 - 14.41 ln (SD), where SD = Secchi disk transparency in meters.

The abbreviation "ln" indicates the natural logarithm.

Trophic Status Based on Total Phosphorus (TSI-TP):

TSI-TP = 14.20 ln (TP) + 4.15, where TP = total phosphorus concentration in µg/L.

Trophic Status Based on Chlorophyll *a* (TSI-Chl-*a*):

TSI-Chl-a = 9.81 ln (Chl-*a*) + 30.60, where TC = chlorophyll *a* concentrations in µg/L.

Once calculated, these independent TSI indicators can be used to interpret how various factors interact to influence lake production (see Table 2-5). In each case, each TSI value can also be used to generalize the overall trophic state of the lake or reservoir as follows:

TSI Index value less than 40: oligotrophic

TSI Index value 40–50: mesotrophic

TSI Index value 51–70: eutrophic

TSI Index value greater than 70: hypereutrophic

Table 2-5. Conditions likely limiting production derived from interpretations of the relationships among the three TSI calculations: chlorophyll *a* (Chl-a), Secchi disc water clarity (SD), and total phosphorous (TP) (EPA, 2000).

Relationship Between TSIs	Conditions Limiting Algae Production
TSI (Chl-a) = TSI (SD) = TSI (TP)	Algae conditions dominate light attenuation.
TSI (Chl-a) > TSI (SD)	Large particulates, such as *Aphanizomenon* flakes, dominate.
TSI (TP) = TSI (SD) > TSI (Chl-a)	Nonalgal particulates or color dominate light attenuation.
TSI (SD) = TSI (Chl-*a*) > TSI (TP)	Phosphorus limits algal biomass (TN/TP ratio greater than 33:1).

TSI (TP) > TSI (Chl-*a*) = TSI (SD)	Zooplankton grazing, nitrogen, or some factor other than phosphorus limits algal biomass.

TSI's were calculated independently for each indicator (e.g., Secchi disk and total phosphorus) but were not averaged. Per Carlson (1977), the most reliable indicator of trophic status is chlorophyll *a* (TSI-Chl-*a*), followed by Secchi disk (TSI-SD), and total phosphorus (TSI-TP). In some lakes, the TSIs for each index are similar. For other lakes, large differences may be observed.

For this reporting cycle, the average TSI (May through September) for each measure is reported. Large discrepancies between TSIs can be suggestive of specific lake conditions that may provide additional context for interpreting the TSI.

Fish Kill Observations

Most lake monitoring data occur in summer months, yet winter fish kills can result from poor water quality, which is an important line of evidence that a lake or reservoir is not meeting its designated uses. To obtain this information DWQ contacts regional biologists at DWR to obtain fish kill records. Reliable winter fish kill data are not available for most lakes and reservoirs. As a result, the lack of fish kill observations generally cannot be used to infer support of aquatic life uses. However, reported fish kills are a compelling source of corroborating information that a lake or reservoir is not supporting its aquatic life uses.

Blue-Green Algae Abundance

DWQ routinely samples to evaluate the composition and relative abundance of algae and cyanobacteria. These data are used as an additional line of evidence to determine if a lake or reservoir is impaired due to human-caused eutrophication.

Phytoplankton (algal) data are used in the Tier II assessment process, because they reflect nutrient abundance and nutrient ratios. Although there is seasonal variability, diatoms dominate lakes that have relatively low nutrient concentrations and have nitrogen:phosphorus ratios that are typical of natural aquatic ecosystems (16:1 respectively). Lakes that meet these conditions are classified as oligotrophic (meaning low food or nutrients). An observation that a lake or reservoir has diverse and abundant diatoms relative to other algae or cyanobacteria taxa is used as a line of evidence that the waterbody is supporting its designated uses.

On the other end of the scale, nutrient loading often leads to an imbalance of nutrients. Such lakes are classified as eutrophic or even hypereutrophic (meaning true or high food or nutrients, respectively). This high and imbalanced nutrient ratio favors another group of algae known as cyanobacteria (sometimes called blue-green algae). This group is unusual in that it can "fix" or convert atmospheric nitrogen to biologically available organic forms. This can allow explosive growth of the algal biomass, which may coat the surface of lakes or wetlands with algal films unless the nutrient ratio in the algal cells once again approaches 16:1. Excessive growth of cyanobacteria can lead to taste and odor problems, which increases drinking water treatments costs. Some species of cyanobacteria produce substances—cyanotoxins—that are toxic to people and animals. Finally, excessive cyanobacteria growth can result in DO conditions that are deleterious to fish. Although daytime DO may be very high in lakes with high cyanobacteria concentrations, evening oxygen depletion from respiration and biodegradation of cyanobacteria cells sometimes causes DO concentrations to fall below values needed to support aquatic life. For these reasons, high concentrations of cyanobacteria are used as a line of evidence that the lake or reservoir is not meeting its designated uses.

Assessment Result

Beneficial Use Supported: To be assessed as supporting, these lakes must be assessed as supporting for two consecutive assessment cycles.

Beneficial Use Not Supported: To be assessed as not supporting, these lakes must be assessed as not supporting for two consecutive assessment cycles.

Insufficient Data and Information: Unless overwhelming evidence suggests otherwise, lakes or reservoirs with a single sampling event are assessed as Category 3B (insufficient data and information). Lakes with no data available are not assessed. Lakes with no new data remain in the same category from previous reporting cycles.

Whenever possible, DWQ will prioritize lakes and reservoirs for subsequent monitoring so that conclusive beneficial use assessments can be made.

LITERATURE CITED

Carlson, R.E. 1977. A Trophic Status Index for Lakes. *Limnology and Oceanography* 22:361–364.

Clarke, R.T., M.T. Furse, J.F. Wright, and D. Moss. 1996. Derivation of a biological quality index for river sites: comparison of the observed with the expected fauna. *Journal of Applied Statistics* 23:311–332.

Davies, N.M, R.H. Norris, and M.C. Thoms. 2000. Prediction and assessment of local stream habitat features using large-scale catchment characteristics. *Freshwater Biology* 45:343–369.

DWQ. 2005. Standards of quality for waters of Utah, R317-2, Utah Administrative Code, Utah Department of Environmental Quality, Utah Division of Water Quality.

———. 2014a. *Quality Assurance Program Plan For Environmental Data Operations*. Final Plan. Available at: http://www.deq.utah.gov/Compliance/monitoring/water/docs/2014/05May/DWQ_QAPP_5.1.14_Rev0.pdf. Accessed September 19, 2014.

———. 2014b. Nutrients in Utah's Waters. Available at: http://www.nutrients.utah.gov/. Accessed September 19, 2014.

EPA. 1985. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses*. EPA-PB85-227049.

_____. 2000. *Nutrient Criteria Technical Guidance Manual Lakes and Reservoirs*. EPA-822-B00-001, April 2000. Available at: http://www2.epa.gov/sites/production/files/documents/guidance_lakes.pdf. Accessed September 19, 2104.

———. 2005. *Guidance for 2006 assessment, listing and reporting requirements pursuant to Sections 303(d) and 305(b) of the Clean Water Act*. Available at: http://www.epa.gov/owow/tmdl/2006IRG/report/2006irg-report.pdf. Accessed September 19, 2014.

_____. 2012. *Recreational Water Quality Criteris*. EPA-820-F-12-058. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/RWQC2012.pdf

Feldman, D. 2006. *A Report to the DEQ Water Quality Planning Bureau on the Proper Interpretation of Two Recently Developed Bioassessment Models*. Helena, Montana: Montana Department of Environmental Quality.

Furse, M.T., D. Moss, J.F. Wright, and P.D. Armitage. 1984. The influence of seasonal and taxonomic factors on the ordination and classification of running-water sites in Great Britain and on the prediction of their macro-invertebrate communities. *Freshwater Biology* 14:257–280.

Hargett, E.G., J.R. ZumBerge, and C.P. Hawkins. 2005. Development of a RIVPACS Model for Wadable Streams of Wyoming. Wyoming Department of Environmental Quality, Water Quality Division.

Hawkins, C.P. 2004. Predictive Model Assessments: A Primer. The Western Center for Monitoring and Assessment of Freshwater Ecosystems, Utah State University, 29 September 2004. Available at: http://129.123.10.240/wmcportal/DesktopDefault.aspx.

Hawkins, C.P., and D.M. Carlisle. 2001. Use of Predictive Models for Assessing the Biological Integrity of Wetlands and Other Aquatic Habitats. In *Bioassessment and Management of North American Freshwater Wetlands*, edited by Russell B. Rader, Darold P. Batzer, and Scott A. Wissinger. Hoboken, New Jersey: John Wiley & Sons, Inc.

Hawkins, C.P, R.H. Norris, J.N. Hogue, and J.W. Feminella. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. *Ecological Applications* 10:1456–1477.

Hughes, R.M., D.P. Larsen, and J.M. Omernik. 1986. Regional reference sites: a method for assessing stream potential. *Environmental Management* 5:629–635.

Jessup, B., C.P. Hawkins, and J. Stribling. 2006. *Biological Indicators of Stream Condition in Montana Using Benthic Macroinvertebrates*. Tetra Tech. Technical report prepared for the Montana Department of Environmental Quality, Helena, Montana.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6:21–27.

Karr, J.R., and D.R. Dudley. 1981. Ecological perspectives on water quality goals. *Environmental Management* 5(1):55–68.

Marchant, R., and G. Hehir. 2002. The use of AUSRIVAS predictive models to assess the response of lotic macroinvertebrates to dams in south-east Australia. *Freshwater Biology* 43:1022–1050.

Metzeling, L., D. Robinson, S. Perris, and R. Marchant. 2002. Temporal persistence of benthic invertebrate communities in south-eastern Australian streams: taxonomic resolution and implications for the use of predictive models. *Marine and Freshwater Research* 53:1223–1234.

Moss, D. J.F. Wright, M.T. Furse, and R.T. Clarke. 1999. A comparison of alternative techniques for prediction of the fauna of running-water sites in Great Britain. *Freshwater Biology* 41:167–181.

Paul, M. J., J. Gerritsen, C.P. Hawkins, and E. Leppo. 2005. *Development of Biological Assessment Tools for Colorado*. Tetra Tech. Technical report prepared for the Colorado Department of Public Health and Environment, Water Quality Control Division – Monitoring Unit, Denver, Colorado.

Simpson, J.C., and R.H. Norris. 2000. Biological assessment of river quality: development of AusRivAS models and outputs. In *Assessing the Biological Quality of Fresh Waters*, edited by J.F. Wright, D.W. Sutcliffe, and M.T. Furse, pp. 125–142. Ambleside, United Kingdom: Freshwater Biological Association.

Sudaryanti, S., Y. Trihadiningrum, B.T. Hart, P.E. Davies, C. Humphrey, R.H. Norris, J. Simpson, and L. Thurtell. 2001. Assessment of the biological health of the Brantas River, East Java, Indonesia using the Australian River Assessment System (AUSRIVAS) methodology. *Aquatic Ecology* 35(2):135–146.

Suplee, M., R. Sada de Suplee, D. Feldman, and T. Laidlaw. 2005. *Identification and Assessment of Montana Reference Streams: A Follow-Up and Expansion of the 1992 Benchmark Biology Study*. Helena, Montana: Montana Department of Environmental Quality. Available at: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CB4QFjAA&url=http%3A%2F%2Fdeq.mt.gov%2Fwqinfo%2Fstandards%2FPDF%2FRefsites_writeup_FINALPrintReady.pdf&ei=KmMcVMyzA9DgoASZ_4HoCw&usg=AFQjCNHS63p2dYBFuItDKPsz9AspHt9wGg.

USGS. 2006. *Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting*. Available at: http://pubs.usgs.gov/tm/2006/tm1D3/pdf/TM1D3.pdf. Accessed September 19, 2014.

Wright, J.F. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. *Australian Journal of Ecology* 20:181–197.

Wright, J.F., M.T. Furse, and P.D. Armitage. 1993. RIVPACS: a technique for evaluating the biological water quality of rivers in the UK. *European Water Pollution Control* 3:15–25.