March 8, 2024

TO:	Members of the Water Pollution Control Advisory Council and the public
FROM:	Katie Makarowski, Montana DEQ, Standards and Modeling Section Supervisor
MEETING DATE:	March 15, 2024
SUBJECT:	Proposal of Rules to Implement Senate Bill 358 and § 75-5-321, MCA: Narrative Nutrient Standards and the Adaptive Management Program

ACTION REQUESTED OF COUNCIL:

The council is requested to review the attached rulemaking documents in advance of the meeting on March 15, 2024, and provide comment as they see fit. The department's Water Quality Division will present a rulemaking summary and answer questions about the rulemaking that members may have.

BACKGROUND:

The department is initiating rulemaking to fulfill requirements of Senate Bill 358, adopted by the 67th Montana Legislature (2021). SB 358 requires the department to adopt rules related to narrative nutrient standards in consultation with the nutrient work group, including an adaptive management program for incrementally protecting and maintaining water quality. Senate Bill 358 also requires the department to delete all references to Department Circular DEQ-12A and base numeric nutrient standards. Nutrients, in this context, refers to total phosphorus and total nitrogen concentrations in state surface waters.

The department convened the nutrient work group to address requirements of Senate Bill 358 and has held forty-five nutrient work group meetings since August 2020 and forty meetings since passage of the bill in April 2021. The department has also met extensively with individuals and groups representing various stakeholder interests, hosted multiple listening sessions, informational meetings, and technical subcommittee meetings, provided opportunity for informal public comment at each nutrient work group meeting, and shared periodic updates with the Water Pollution Control Advisory Council throughout this process.

To fulfill requirements of Senate Bill 358, the department is proposing to adopt two new rules and a new Circular:

- NEW RULE I describes translation of existing narrative nutrient standards for implementation by department water quality programs.
- New Rule II describes the implementation of an Adaptive Management Program within the Montana Pollutant Discharge Elimination System (MPDES) permitting program. The Adaptive Management Program provides a new compliance option for point source dischargers with added flexibility to address nutrients within a specific watershed, and allows for the prioritization of phosphorus reduction, where appropriate.
- Department Circular DEQ-15 details procedures and requirements associated with both new rules. Part I includes translators applicable to different beneficial uses, regions, and waterbodies to be used when determining if beneficial uses are protected and narrative nutrient standards

are achieved. Part II details the requirements and procedures for both the department and permittee participants of the Adaptive Management Program.

The department also proposes to amend and repeal existing rules to:

- Delete all references to Department Circular DEQ-12A and base numeric nutrient standards, as directed by SB 358,
- Modify the permit fee structure to account for the Adaptive Management Program,
- Add or modify definitions,
- Provide additional clarity for implementation of narrative nutrient standards,
- Amend 17.30.715 (nondegradation) to reflect the transition from numeric to narrative nutrient standards and enhance clarity in implementation of nondegradation policy for various parameters related to nutrients,
- Repeal ARM 17.30.1388, a framework rule adopted in the interim between adoption of SB 358 and this comprehensive rulemaking, and
- Repeal ARM 17.30.660 as an administrative update following the direct repeal of this rule by SB 358.

RECOMMENDATION:
The recommendation being sought from the Council is to proceed with the rulemaking under the Water Quality Act (Title 75, Chapter 5, MCA).

Please contact us with any questions:

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Attachments:

1. Draft proposed rule adoptions, amendments, and repeals
2. Draft Department Circular DEQ-15
3. Draft Guidance Document in Support of Department Circular DEQ-15
4. Narrative Nutrient Standards: Summary Technical Support Document (Suplee, 2023)
5. An Analysis of Daily Patterns of Dissolved Oxygen Change in Flowing Waters of Montana (Suplee, 2023)
6. Eutrophication Thresholds Associated with Benthic Macroinvertebrate Conditions in Montana Streams (Schulte and Craine, 2023)

Nutrient Rulemaking

Rules to Implement Senate Bill 358 and § 75-5-321, MCA: Narrative Nutrient Standards and the Adaptive Management Program

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March 8, 2024

Proposed Rule Adoption, Amendment, and Repeal

This document contains the rules proposed to be adopted, amended, and repealed by the Department of Environmental Quality to implement Senate Bill 358 and § 75-5-321, MCA, related to narrative nutrient standards and the Adaptive Management Program. This document is being shared with Water Pollution Control Advisory Council (WPCAC) members prior to first publication to provide an opportunity for council members to comment on the proposed action (75-5-301(1), MCA).

The rules as proposed to be adopted provide as follows:

NEW RULE I TRANSLATION OF NARRATIVE NUTRIENT STANDARDS (1) The narrative standard that applies to nutrients is found at ARM 17.30.637(1)(e). The department translates the narrative standards at ARM 17.30.637(1)(e) as provided in Part I of Department Circular DEQ-15 (March 2024 edition).

(2) The department adopts and incorporates by reference Department Circular DEQ-15, entitled "Translation of Narrative Nutrient Standards and Implementation of the Adaptive Management Program" (March 2024 edition), which provides procedures and requirements for the translation of narrative nutrient standards and implementation of the Adaptive Management Program. Copies of Department Circular DEQ-15 may be obtained from the Department of Environmental Quality, P.O. Box 200901, Helena, MT 59620-0901.

NEW RULE II IMPLEMENTATION OF THE ADAPTIVE MANAGEMENT PROGRAM FOR NARRATIVE NUTRIENT STANDARDS (1) Any person who applies for or holds an MPDES permit issued pursuant to Subchapter 13 of these rules may choose to enter the Adaptive Management Program to achieve nutrient standards and to address nutrients in a specific watershed. To enter the Adaptive Management Program, the owner or operator of a point source must provide an Adaptive Management Plan (AMP) to the department for review and approval.

(2) MPDES permits shall include limitations and conditions consistent with the assumptions and elements of department-approved AMPs. Related MPDES permit limitations and conditions must be derived to achieve narrative nutrient standards as provided in NEW RULE I.

(3) Adaptive management requirements for wadeable streams and medium rivers.

(a) The AMP must contain, at a minimum, the following:

(i) monthly effluent monitoring for total phosphorus (TP) and total nitrogen (TN) concentrations;

(ii) a monitoring plan for assessing near field response variables and causal variables downstream and upstream of the facility, consistent with Department Circular DEQ-15;

(iii) a plan for examining those pollutant minimization activities that have the potential to reduce nutrient concentrations in the effluent and watershed, such as:

(A) documentation, to be included in the Operations and Maintenance Manual, of process control strategies identified and implemented through optimization of the existing wastewater treatment facility;

(B) training of operations staff in advanced operational strategies;

(C) minor changes to infrastructure to complement and further advance operational strategies; and

(D) implementation of any pollutant trading, nutrient reduction activities, or the reuse of effluent, identified for potential implementation in the AMP;

(iv) documentation of any nutrient reduction activities implemented by the permittee in the watershed; and

(v) A plan for annual reporting to the department. The annual report must be submitted to the department by March 31st of each year and shall include, at a minimum:

(A) A description of any deviations from the AMP, and proposed corrective actions;

(B) A summary of near field monitoring data;

(C) A description of any facility upgrades and/or reductions achieved in nutrient effluent concentrations resulting from pollutant minimization activities; and

(D) A description of actions to further reduce effluent and watershed nutrient concentrations proposed for implementation in the current year.

(b) Before an AMP is approved by the department, and as necessary thereafter, the department shall determine if prioritization of phosphorus reduction is appropriate for both the point source and the receiving water body. To determine if it is appropriate to prioritize phosphorus reductions from a point source and in a receiving water body, the department may consider:

(i) existing controls on point and nonpoint sources of pollution;

(ii) the presence and variability of the pollutant(s) in the effluent;

(iii) dilution of the effluent in the receiving water, if appropriate;

(iv) monitoring and assessment information for the receiving waterbody collected by the department or the permittee;

(v) whether phosphorus or nitrogen limits plant and algal growth in the waterbody;

(vi) the ratio of nitrogen to phosphorus in the effluent and instream; and

(vii) any other credible, pertinent data available, including data provided in the AMP.

(c) If the department determines prioritization of phosphorus reduction is appropriate under (3)(b), then the department shall develop and implement TP effluent limits in accordance with NEW RULE I. TP effluent limits apply during a growing season as provided in Department Circular DEQ-15, unless a lake or reservoir is affected by the point source, or another downstream use requires protection in which case the limits may apply year-round.

(d) The department may find, based on TP reductions required under (3)(c), associated water quality and response variable monitoring, or other credible data, that the narrative nutrient standards in NEW RULE I are met.

(e) If the department concludes under (3)(b) and (c) that the prioritization or limitation of phosphorus alone is not appropriate and that a discharge causes, has reasonable potential to cause, or contributes to an in-stream excursion above the narrative nutrient standards in NEW RULE I, then the department shall:

(i) Develop effluent limits for TN and/or TP in accordance with NEW RULE I and consistent with the assumptions and elements of the department approved AMP under 3(a); and

(ii) Require a permittee or multiple permittees who have chosen to enter into the Adaptive Management Program to develop and include in their AMP a watershed plan describing how nutrients may be reduced in the watershed. To achieve the effluent limits developed under (e)(i), the watershed plan must:

(A) identify and quantify, to the extent feasible, all major sources of nutrient contributions in the watershed in which the facility is located;

(B) identify all partners that will assist in implementing the nutrient reductions including each partner's level of support;

(C) document action items for the reduction of nutrients in the watershed and specific goals for reductions including expected timelines to achieve the reductions and anticipated load reduction based on sound scientific and engineering practices;

(D) demonstrate the ability to fund the watershed plan either individually, or in conjunction with other permittees and nonpoint sources, or other partners, including municipal and county governments, in the watershed;

(E) if partners are used to implement nutrient reduction actions in lieu of permittees, the watershed plan must include written agreements, enforceable by the permittee, reflecting commitments by partners to implement nutrient reduction actions and must identify the period of commitment;

(F) include continued or expanded monitoring of response variables and water quality as performance indicators to determine if the plan is effective in achieving compliance with narrative nutrient standards;

(G) identify the timeframes for completing and submitting each component of the watershed plan under (3)(e)(ii)(A) through (F);

(H) be submitted to the department annually by March 31st, along with the annual report in (3)(a)(v), documenting progress and effectiveness of the watershed plan;

(I) be approved by the department; and

(J) in addition to this rule, be subject to requirements contained in Department Circular DEQ-15.

(f) Compliance with the narrative nutrient standards shall be determined at a point or points downstream of the permitted facility established consistent with the requirements in Department Circular DEQ-15.

(4) Adaptive management requirements for large rivers. The AMP must meet the requirements in (3)(a) above and, as appropriate, additional requirements in (4)(a) below.

(a) The department or permittee(s) may develop a mechanistic water quality model for a large river. A calibrated and validated model may be used to derive phosphorus limits for use in MPDES permits that achieve narrative nutrient standards and achieve other applicable water quality standards related to nutrients (dissolved oxygen and pH) along the modeled reach. Permittee-developed mechanistic models must be documented in the AMP. Based on modeling, MPDES permit limits will be allocated considering each facility’s relative load, its current treatment for nutrients, estimated cost for projected facility upgrades, the limits of technology, and other considerations as appropriate.

(b) For large rivers where a model has not been developed, the department shall derive MPDES permit limits for phosphorus and/or nitrogen, where necessary, based on best available information regarding the protection of beneficial uses, achieving narrative nutrient standards, and achieving other applicable water quality standards related to nutrients (dissolved oxygen and pH).

(c) TP effluent limits apply during a growing season as provided in Department Circular DEQ-15, unless a lake or reservoir is affected by the point source(s) or another downstream use requires protection in which case the limits may apply year-round.

(d) The nutrient reductions required under (4)(a) and (4(b) will be evaluated using data collected in each river by the department and/or permittee(s) to confirm that beneficial uses are protected, applicable water quality standards are achieved, and to determine if further reductions for phosphorus and/or nitrogen are needed. Sampling methods must be documented in the AMP consistent with requirements in Department Circular DEQ-15.

(e) A permittee or multiple permittees who have chosen to enter the Adaptive Management Program shall develop a watershed plan for the reduction of nutrients in the watershed if, based on data and information in (4)(a) and/or updated modeling, the department concludes that phosphorus control alone is insufficient to protect beneficial uses and if additional nutrient controls are needed to comply with applicable water quality standards. The watershed plan must:

(i) identify and quantify, to the extent feasible, all sources of nutrient contributions in the watershed in which the facility or facilities are located;

(ii) identify all partners that will assist in implementing the nutrient reductions including each partner's level of support;

(iii) document action items for the reduction of nutrients in the watershed and specific goals for reductions including expected timelines to achieve the reductions and an anticipated load reduction based on sound scientific and engineering practices;

(iv) demonstrate the ability to fund the watershed plan either individually, or in conjunction with other permittees and nonpoint sources, or other partners, including municipal and county governments, in the watershed;

(v) if partners are used to implement nutrient reduction actions in lieu of permittees, the watershed plan must include written agreements, enforceable by the permittee, reflecting commitments by partners to implement nutrient reduction actions and must identify the period of commitment;

(vi) include continued or expanded monitoring of the response variables as performance indicators to determine whether the plan is effective in achieving compliance with the narrative nutrient standards;

(vii) identify the timeframes for completing and submitting each component of the watershed plan under (4)(e)(i) through (vi);

(viii) be submitted to the department annually by March 31st, along with an annual report documenting progress and effectiveness of the watershed plan;

(ix) be approved by the department; and

(x) in addition to this rule, be subject to requirements contained in Department Circular DEQ-15.

(f) Compliance with the narrative nutrient standards, and other applicable water quality standards per (4)(a) and (b), shall be determined at a point or points downstream of the facility or facilities established consistent with the requirements in Department Circular DEQ-15.

(5) A permittee under the adaptive management program is not precluded from pursuing, at any time, other regulatory compliance options including, but not limited to variances, compliance schedules, reuse, trading, recharge, land application, or authorizations to degrade.

(6) The department adopts and incorporates by reference Department Circular DEQ-15, entitled "Translation of Narrative Nutrient Standards and Implementation of the Adaptive Management Program" (March 2024 edition), which provides procedures and requirements for the translation of narrative nutrient standards and the implementation of the adaptive management program. Copies of Department Circular DEQ-15 may be obtained from the Department of Environmental Quality, P.O. Box 200901, Helena, MT 59620-0901.

The proposed adoption of new Circular DEQ-15 (draft document has been provided to WPCAC members along with this summary):

CIRCULAR DEQ-15: TRANSLATION OF NARRATIVE NUTRIENT STANDARDS AND IMPLEMENTATION OF THE ADAPTIVE MANAGEMENT PROGRAM

The rules as proposed to be amended provide as follows, new matter underlined, deleted matter interlined:

17.30.201 PERMIT APPLICATION, DEGRADATION AUTHORIZATION, AND ANNUAL PERMIT FEES (1) The purpose of this rule is to provide fee schedules for use in determining fees to be paid to the department under 75-5-516, MCA. The types of fees provided under this rule are:

(a) remains the same.

(b) application fees for non-storm water general permits (Schedule ~~1~~I.B);

(c) application fees for storm water general permits (Schedule ~~1~~I.C);

(d) application fees for other activities (Schedule ~~1~~I.D);

(e) through (f) remain the same.

(g) annual fees for non-storm water permits (Schedule III.B); ~~and~~

(h) annual fees for storm water general permits (Schedule III.C)~~.~~; and

(i) annual fees for adaptive management program participation (Schedule III.D).

(2) through (5) remain the same.

(6) The fee schedules for new or renewal applications for, or modifications of, a Montana pollutant discharge elimination system permit under ARM Title 17, chapter 30, subchapter 11 or 13, a Montana ground water pollution control system permit under ARM Title 17, chapter 30, subchapter 10, or any other authorization under 75-5-201, 75-

5-301, or 75-5-401, MCA, or rules promulgated under these authorities, are set forth below as Schedules I.A, I.B, I.C, and I.D. Fees must be paid in full at the time of submission of the application. For new applications under Schedule I.A, the annual fee from Schedule III.A for the first year must also be paid at the time of application. For new applications under Schedule I.B and I.C, the annual fee is included in the new permit amount and covers the annual fee for the calendar year in which the permit coverage becomes effective.

(a) through (h) remain the same.

Schedules I.A and I.B remain the same.

(i) through (n) remain the same.

Schedule I.C remains the same.

(o) remains the same.

(p) The authorization fee for individual MPDES permittees who elect to participate in the adaptive management program for implementing nutrient standards in Schedule I.D is assessed upon submission of an adaptive management plan under [NEW RULE II] for each 5-year permit cycle the permittee is eligible for participation in the adaptive management program.

Schedule I.D Application Fee for Other Activities

Category	Amount
Short-term water quality standard, turbidity "318 authorization"	$ 250
Short-term water quality standard, remedial activities and pesticide application "308 authorization"	250
Federal Clean Water Act section 401 certification	See ARM 17.30.201(6)(o)
Review plans and specifications to determine if permit is necessary, pursuant to 75-5-402(2), MCA	2,000
Authorization for adaptive management program participation pursuant to [NEW RULE II]	5,000
Major modification	Renewal fee from Schedule I.A
Minor modification, includes transfer of ownership	500
Resubmitted application fee	500
Administrative processing fee	500

(7) remains the same.

Schedule II remains the same.

(8) (a) remains the same.

Schedule III.A III.B remain the same.

8 (b) through (d) remain the same.

Schedule III.C remains the same.

8 (e) through (11) remain the same.

(12) The annual fee for individual MPDES permittees who elect to participate in the adaptive management program for implementing nutrient standards in Schedule III.D is assessed upon submission of an adaptive management plan annual report, as required in [NEW RULE II], for each year the permittee is eligible for participation in the adaptive management program, excepting the year in which the application fee is assessed.

Schedule III.D Annual Fee for Adaptive Management Program Participation

Category	Minimum Fee	Fee Per Million Gallons of Effluent per Day (MGD)
Annual fee for adaptive management program participation pursuant to [NEW RULE II]	$3,000	$3,000

17.30.507 SPECIFIC RESTRICTIONS FOR SURFACE WATER MIXING ZONES (1) Mixing zones for surface waters are subject to the following water quality standards:

(a) narrative water quality standards, standards for harmful substances, numeric acute and chronic standards for aquatic life;~~, standards in Department Circular DEQ-12A;~~ and standards based on human health must not be exceeded beyond the boundaries of the surface water mixing zone;

(b) through (3) remain the same.

17.30.516 STANDARD MIXING ZONES FOR SURFACE WATER (1) and (2) remain the same.

(3) Facilities that meet the terms and conditions in (a) through (e) qualify for a standard mixing zone as follows:

(a) Facilities that discharge a mean annual flow of less than one million gallons per day (MGD) to a stream segment with a dilution ratio greater than or equal to 100:1. For purposes of this procedure, the stream dilution ratio is defined as the seven-day, ten-year (7Q10) low flow of the stream segment without the discharge, divided by the mean annual flow of the discharge. For total nitrogen, total phosphorus, or nutrient parameters identified in Department Circular DEQ-7, the stream low flow used in calculating the dilution ratio is based on the seasonal 14-day, five-year (14Q5) low flow, which is the lowest average 14 consecutive day low flow, occurring from July through October, with an average recurrence frequency of once in five years. In this case discharge limitations will be based on dilution with the applicable low flow value, the 7Q10, or the seasonal 14Q5.

(b) Facilities that discharge a mean annual flow less than one MGD to a stream segment with a dilution less than 100:1. In cases where dilution is less than 100:1, discharge limitations will be based on dilution with 25 percent of the 7Q10 (or 100 percent of the seasonal 14Q5 for total nitrogen, total phosphorus, or nutrient parameters identified in Department Circular DEQ-7).

(c) remains the same.

(d) Facilities whose discharge results in a nearly instantaneous mixing zone. Discharge limitations shall be based on dilution with the 7Q10 (or the seasonal 14Q5 for total nitrogen, total phosphorus, or nutrient parameters identified in Department Circular DEQ-7)~~seven-day, ten-year~~ low flow of the receiving water except as limited by consideration of the factors listed in ARM 17.30.506. For surface waters, nearly instantaneous mixing will be assumed when there is an effluent diffuser which extends across the entire stream width (at low flow), or when the mean daily flow of the discharge exceeds the 7Q10 ~~seven-day, ten-year~~ (or the seasonal 14Q5 for total nitrogen, total phosphorus, or nutrient parameters identified in Department Circular DEQ-7) low flow of the receiving water. A discharge may also be considered nearly instantaneous if the discharger so demonstrates in accordance with a study plan approved by the department. For the purposes of this demonstration nearly instantaneous mixing will be assumed when there will be not more than a ten percent difference in bank-to-bank concentrations at a downstream distance less than two stream/river widths.

~~(e) Facilities that discharge the parameters found in Department Circular DEQ-12A to surface water. Discharge limitations must be based on dilution with the entire seasonal 14-day, five-year (seasonal 14Q5) low flow of the receiving water without the discharge.~~

(4) The length of a standard mixing zone for flowing surface water, other than a nearly instantaneous mixing zone, must not extend downstream more than the one-half mixing width distance or extend downstream more than ten times the stream width, whichever is more restrictive. For purposes of making this determination, the stream width as well as the discharge limitations are considered at the 7Q10 or seasonal 14Q5 low flow. The seasonal 14Q5 low flow may be used only in conjunction with total nitrogen, total phosphorus, or the nutrient parameters identified in Department Circular DEQ-7. ~~The seasonal 14Q5 low flow may be used only in conjunction with base numeric nutrient standards in Department Circular DEQ-12A.~~ The recommended calculation to be used to determine the one-half mixing width distance downstream from a stream bank discharge is described below.

(a) remains the same.

(b) L = CDU, where:

(i) C = channel irregularity factor immediately downstream of the discharge, where:

(A) remains the same.

(B) C = ~~O~~0.3 for channelized streams;

(C) through (6) remain the same.

17.30.602 DEFINITIONS In this subchapter the following terms have the meanings indicated below and are supplemental to the definitions given in 75-5-103, MCA:

(1) through (40) remain the same.

~~(41) "DEQ-12A" means the department circular that is adopted and incorporated by reference in ARM 17.30.619 and is entitled "Montana Base Numeric Nutrient~~

~~Standards." This circular contains numeric water quality standards for total nitrogen and total phosphorus in surface waters.~~

~~(42) "DEQ-12B" means the department circular that is adopted and that is entitled "Montana Base Numeric Nutrient Standards Variances." This circular describes procedures for receiving a variance from the standards and will document recipients of individual variances.~~

17.30.619 INCORPORATIONS BY REFERENCE (1) The board adopts and incorporates by reference the following state and federal requirements and procedures as part of Montana's surface water quality standards:

(a) through (c) remain the same.

(d) 40 CFR 131.10(g), (h) and (j) (2000), which establishes criteria and guidelines for conducting a use attainability analysis; and

~~(e) Department Circular DEQ-12A, entitled "Montana Base Numeric Nutrient Standards" (July 2014 edition), which establishes numeric water quality standards for total nitrogen and total phosphorus in surface waters; and~~

(f) remains the same but is renumbered (e).

~~(2) If a court of competent jurisdiction declares 75-5-313, MCA, or any portion of that statute invalid, or if the United States Environmental Protection Agency disapproves 75-5-313, MCA, or any portion of that statute, under 30 CFR 131.21, or if rules adopted pursuant to 75-5-313(6) or (7), MCA, expire and general variances are not available, then (1)(e) and all references to DEQ-12A, base numeric nutrient standards and nutrient standards variances in ARM 17.30.201, 17.30.507, 17.30.516, 17.30.602, 17.30.622 through 17.30.629, 17.30.635, 17.30.702, and 17.30.715 are void, and the narrative water quality standards contained in ARM 17.30.637 are the standards for total nitrogen and total phosphorus in surface water, except for the Clark Fork River, for which the standards are the numeric standards in ARM 17.30.631.~~

(3) remains the same but is renumbered (2).

17.30.622 A-1 CLASSIFICATION STANDARDS (1) and (2) remain the same.

(3) No person may violate the following specific water quality standards for waters classified A-1:

(a) through (g) remain the same.

(h) Concentrations of carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters may not exceed the applicable standards set forth in Department Circular DEQ-7 ~~and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~.

(i) Dischargers issued permits under ARM Title 17, chapter 30, subchapter 13, shall conform with ARM Title 17, chapter 30, subchapter 7, the nondegradation rules, and may not cause receiving water concentrations to exceed the applicable standards contained in Department Circular DEQ-7 ~~and,unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

(j) and (k) remain the same.

17.30.623 B-1 CLASSIFICATION STANDARDS (1) remains the same.

(2) No person may violate the following specific water quality standards for waters classified B-1:

(a) through (g) remain the same.

(h) Concentrations of carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters may not exceed the applicable standards set forth in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~.

(i) Dischargers issued permits under ARM Title 17, chapter 30, subchapter 13, shall conform with ARM Title 17, chapter 30, subchapter 7, the nondegradation rules, and may not cause receiving water concentrations to exceed the applicable standards specified in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

(j) and (k) remain the same.

17.30.624 B-2 CLASSIFICATION STANDARDS (1) remains the same.

(2) No person may violate the following specific water quality standards for waters classified B-2:

(a) through (g) remain the same.

(h) Concentrations of carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters may not exceed the applicable standards set forth in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~.

(i) Dischargers issued permits under ARM Title 17, chapter 30, subchapter 13, shall conform with ARM Title 17, chapter 30, subchapter 7, the nondegradation rules, and may not cause receiving water concentrations to exceed the applicable standards specified in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

(j) and (k) remain the same.

17.30.625 B-3 CLASSIFICATION STANDARDS (1) remains the same.

(2) No person may violate the following specific water quality standards for waters classified B-3:

(a) through (g) remain the same.

(h) Concentrations of carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters may not exceed the applicable standards set forth in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~.

(i) Dischargers issued permits under ARM Title 17, chapter 30, subchapter 13, shall conform with ARM Title 17, chapter 30, subchapter 7, the nondegradation rules, and may not cause receiving water concentrations to exceed the applicable standards specified in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

(j) and (k) remain the same.

17.30.626 C-1 CLASSIFICATION STANDARDS (1) remains the same.

(2) No person may violate the following specific water quality standards for waters classified C-1:

(a) through (g) remain the same.

(h) Concentrations of carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters may not exceed the applicable standards specified in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~.

(i) Dischargers issued permits under ARM Title 17, chapter 30, subchapter 13, shall conform with ARM Title 17, chapter 30, subchapter 7, the nondegradation rules, and may not cause receiving water concentrations to exceed the applicable standards specified in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

(j) and (k) remain the same.

17.30.627 C-2 CLASSIFICATION STANDARDS (1) remains the same.

(2) No person may violate the following specific water quality standards for waters classified C-2:

(a) through (g) remain the same.

(h) Concentrations of carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters may not exceed the applicable standards specified in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~.

(i) Dischargers issued permits under ARM Title 17, chapter 30, subchapter 13, shall conform with ARM Title 17, chapter 30, subchapter 7, the nondegradation rules, and may not cause receiving water concentrations to exceed the applicable standards specified in Department Circular DEQ-7~~ and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

(j) and (k) remain the same.

17.30.628 I CLASSIFICATION STANDARDS (1) remains the same.

(2) No person may violate the following specific water quality standards for waters classified I:

(a) through (i) remain the same.

(j) Beneficial uses are considered supported when the concentrations of toxic, carcinogenic, nutrient or harmful parameters in these waters do not exceed the applicable standards specified in Department Circular DEQ-7 ~~and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the flows specified in ARM 17.30.635(2) or, alternatively, for aquatic life when site-specific criteria are adopted using the procedures given in 75-5-310, MCA. The limits shall be used as water quality standards for the affected waters and as the basis for permit limits instead of the applicable standards in Department Circular DEQ-7.

(k) Limits for toxic, carcinogenic, or harmful parameters in new discharge permits issued pursuant to the MPDES rules (ARM Title 17, chapter 30, subchapter 13) are the larger of the applicable standards specified in Department Circular DEQ-7 ~~and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~, site-specific standards, or one-half of the mean in-stream concentrations immediately upstream of the discharge point.

<u>17.30.629 C-3 CLASSIFICATION STANDARDS</u> (1) remains the same.

(2) No person may violate the following specific water quality standards for waters classified C-3:

(a) through (g) remain the same.

(h) Concentrations of carcinogenic, bioconcentrating, toxic, radioactive, nutrient, or harmful parameters may not exceed the applicable standards set forth in Department Circular DEQ-7 ~~and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~.

(i) Dischargers issued permits under ARM Title 17, chapter 30, subchapter 13, shall conform with ARM Title 17, chapter 30, subchapter 7, the nondegradation rules, and may not cause receiving water concentrations to exceed the applicable standards specified in Department Circular DEQ-7 ~~and, unless a nutrient standards variance has been granted, Department Circular DEQ-12A~~ when stream flows equal or exceed the design flows specified in ARM 17.30.635(2).

(j) and (k) remain the same.

<u>17.30.635 GENERAL TREATMENT STANDARDS</u> (1) through (1)(e) remain the same.

(2) For design of disposal systems, stream flow dilution requirements must be based on the minimum consecutive seven-day average flow which may be expected to occur on the average of once in ten years <u>(7Q10)</u>. When dilution flows are less than the above design flow at a point discharge, the discharge is to be governed by the permit conditions developed for the discharge through the waste discharge permit program. If the flow records on an affected surface water are insufficient to calculate a <u>7Q10 low flow</u> ~~ten-year seven-day low flow~~, the department shall determine an acceptable stream flow for disposal system design. For total nitrogen, ~~and~~ total phosphorus, <u>and the nutrient parameters identified in DEQ-7,</u> the stream flow dilution requirements must be based on the seasonal 14Q5, which is the lowest average 14 consecutive day low flow, occurring from July through October, with an average recurrence frequency of once in five years.

(3) remains the same.

17.30.702 DEFINITIONS The following definitions, in addition to those in 75-5-103, MCA, apply throughout this subchapter (Note: 75-5-103, MCA, includes definitions for ~~"base numeric nutrient standards,"~~ "degradation," "existing uses," "high quality waters," "mixing zone," and "parameter"):

(1) through (18) remain the same.

(19) "Nutrients" means inorganic phosphorus and total inorganic nitrogen.

(19) and (20) remain the same but are renumbered (20) and (21).

(~~21)~~(22) "Required Reporting values (RRV)" means the detection level that must be achieved in reporting surface water or ground water monitoring or compliance data to the department unless otherwise specified in a permit, approval, or authorization issued by the department. The RRV is the board's best determination of a level of analysis that can be achieved by the majority of commercial, university, or governmental laboratories using EPA approved methods or methods approved by the department. The RRV is listed in Department Circular DEQ-7.~~, Department Circular DEQ-12A, and in the definition of "total inorganic phosphorus."~~

(22) through (26) remain the same but are renumbered (23) through (27).

(~~27)~~(28) The department adopts and incorporates by reference:

(a) remains the same.

~~(b) Department Circular DEQ-12A, entitled "Montana Base Numeric Nutrient Standards" (December 2013 edition), which establishes numeric water quality standards for total nitrogen and total phosphorus in surface waters;~~

(c) through (e) remain the same but are renumbered (b) through (d).

17.30.715 CRITERIA FOR DETERMINING NONSIGNIFICANT CHANGES IN WATER QUALITY (1) The following criteria will be used to determine whether certain activities or classes of activities will result in nonsignificant changes in existing water quality due to their low potential to affect human health or the environment. These criteria consider the quantity and strength of the pollutant, the length of time the changes will occur, and the character of the pollutant. Except as provided in (2), changes in existing surface or ground water quality resulting from the activities that meet all the criteria listed below are nonsignificant, and are not required to undergo review under 75-5-303, MCA:

(a) through (c) remain the same.

(d) changes in the concentration of nitrate in ground water which will not cause degradation of surface water if the sum of the predicted concentrations of nitrate at the boundary of any applicable mixing zone will not exceed the following values:

(i) through (iii) remain the same.

(iv) 7.5 mg/L for domestic sewage effluent discharged from a conventional septic system in areas where the ground water nitrate level exceeds 5.0 mg/L primarily from sources other than human waste.

For purposes of this subsection (d), the word "nitrate" means nitrate as nitrogen; ~~and~~

(e) changes in concentration of ~~total~~ inorganic phosphorus in ground water if water quality protection practices approved by the department have been fully implemented and if an evaluation of the phosphorus adsorptive capacity of the soils in the area of the activity indicates that phosphorus will be removed for a period of 50 years prior to a discharge to any surface waters;

(f) changes in the quality of water for any harmful parameter, and ~~nutrients~~ total nitrogen and total phosphorus for reaches of the Clark Fork River listed at ARM 17.30.631, ~~and parameters listed in Department Circular DEQ-12A,~~ except as specified in (1)(g), for which water quality standards have been adopted other than carcinogenic, bioconcentrating, or toxic parameters, in either surface or ground water, if the changes outside of a mixing zone designated by the department are less than ten percent of the applicable standard and the existing water quality level is less than 40 percent of the standard;

(h) changes in the quality of water for any parameter for which there are only narrative water quality standards, including those addressed by NEW RULE I, if the changes will not have a measurable effect on any existing or anticipated use or cause measurable changes in aquatic life or ecological integrity.

(3) remains the same.

~~(4) If a court of competent jurisdiction declares 75-5-313, MCA, or any portion of that statute invalid, or if the United States Environmental Protection Agency disapproves 75-5-313, MCA, or any portion of that statute under 30 CFR 131.21, or if rules adopted pursuant to 75-5-313(6) or (7), MCA, expire and general variances are not available, then the significance criteria contained in (1)(g) are the significance criteria for total nitrogen and total phosphorus in surface water.~~

17.30.1304 DEFINITIONS In this subchapter, the following terms have the meanings or interpretations indicated below and shall be used in conjunction with and are supplemental to those definitions contained in 75-5-103, MCA.

(1) remains the same.

(2) "Adaptive management plan" means a watershed-specific plan developed under the adaptive management program to achieve the narrative nutrient standards and address nutrients in a specific watershed. ~~An adaptive management plan includes a watershed monitoring plan and, if required, an implementation plan.~~

(3) through (83) remain the same.

The department proposes to repeal the following rules:

17.30.1388 DEVELOPMENT OF AN ADAPTIVE MANAGEMENT PROGRAM IMPLEMENTING NARRATIVE NUTRIENT STANDARDS

17.30.660 NUTRIENT STANDARDS VARIANCES

Circular DEQ-15

Translation of Narrative Nutrient Standards and Implementation of the Adaptive Management Program

March 2024 Edition

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Document Number

Table of Contents

ACRONYMS

AMP	Adaptive Management Plan
ARM	Administrative Rules of Montana
ARP	Advance Restoration Plan
DO	Dissolved Oxygen
DSS	Decision Support System
EPA	United States Environmental Protection Agency
HUC	Hydrological Unit Code
LA	Load Allocation
MCA	Montana Code Annotated
MPDES	Montana Pollutant Discharge Elimination System
TDG	Total Dissolved Gas
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USGS	United States Geological Survey
WLA	Wasteload Allocation

GENERAL INTRODUCTION TO CIRCULAR DEQ-15

In 2021 the 67th Montana Legislature adopted Senate Bill 358, which described a new process for implementing narrative standards for nutrients in permits. The Montana Legislature also directed the Department of Environmental Quality (department) to eliminate the numeric nutrient criteria that had been adopted for total phosphorus (TP) and total nitrogen (TN) in Circular DEQ-12A. The numeric criteria in Circular DEQ-12A applied to wadeable streams and medium-sized rivers across Montana as well as portions of the Yellowstone River. Circular DEQ-12A criteria were not applicable to Montana's remaining large rivers, lakes, reservoirs, or other state surface waters, all of which remained subject to Montana's narrative nutrient standards.

The narrative standards at Administrative Rules of Montana (ARM) 17.30.637(1)(e) — "State surface waters must be free from substances attributable to municipal, industrial, agricultural practices or other discharges that will: (e) create conditions which produce undesirable aquatic life" — are the primary narrative standards the department uses to regulate the impacts of excess phosphorus and nitrogen in state waters. Narrative nutrient standards apply to all state surface waters, including those previously covered under Circular DEQ-12A. This circular provides methods to interpret the narrative nutrient standards and provides additional requirements related to the implementation of an adaptive management program.

While the narrative nutrient standards remain unchanged, Section 75-5-321, Montana Code Annotated (MCA), now requires the department to adopt rules allowing for the use of an adaptive management program as one option for achieving the narrative nutrient standards. The adaptive management program is an incremental, watershed-based approach for protecting and maintaining water quality affected by excess nutrients. An important element of the adaptive management program is that it allows different nutrients (phosphorus vs. nitrogen) and nutrient sources to be addressed separately and incrementally over time by incorporating flexible decision-making which can be adjusted as management actions, their effects, and other factors become better understood in each watershed.

Circular DEQ-15 has two parts. **Part I** contains details associated with translating the narrative nutrient standards, in accordance with NEW RULE I, to determine if a waterbody is achieving the standards or not. **Part II** addresses the implementation of the adaptive management program per NEW RULE II.

DEFINITIONS

Adaptive Management Plan (AMP) means a watershed-specific plan developed under the adaptive management program to achieve the narrative nutrient standards and address nutrients in a specific watershed.

Adaptive Management Program means a watershed-scale program that protects water quality from the impacts of nutrient sources by: (a) prioritizing phosphorus reduction, as appropriate, while accounting for site specific conditions; (b) allowing for nutrient sources to be addressed incrementally over time by incorporating flexible decision-making which can be adjusted as management actions and other factors become better understood; (c) reasonably balancing all factors impacting a waterbody while considering the relative cost of treatment options, their feasibility, and their expected water quality improvement; (d) identifying specific nutrient reduction requirements, and (e) setting as its goal the protection and achievement of beneficial uses of the waterbody.

Ecoregion means a mapped region of relative homogeneity in ecological systems derived from perceived patterns of a combination of causal and integrative factors including land use, land surface form, potential natural vegetation, soils, and geology.

Far Field Sites means, for purposes of an adaptive management plan, instream sampling locations placed throughout the adaptive management plan watershed for the primary purpose of characterizing nutrient loads entering and exiting the watershed.

Large River means a perennial waterbody which has, during summer and fall baseflow (August 1 to October 31 each year), a wadeability index (product of river depth [in feet] and mean velocity [in ft/sec]) of 7.24 ft^2 /sec or greater, a depth of 3.15 ft or greater, or a baseflow annual discharge of 1,500 ft^3 /sec or greater. See also, **Table 1-1**.

Medium River means a perennial waterbody in which much of the wetted channel is unwadeable by a person during baseflow conditions.

Near Field Sites means, for purposes of an adaptive management plan, instream sampling locations near a point source discharge that (a) downstream of the point source represent segments of the stream directly under the influence of the point source's effluent and (b) upstream of the point source represent segments of the stream uninfluenced by the point source and having similar physical characteristic to the downstream location(s) in terms of gradient, flow, baseflow water depth, substrate, and stream shading.

Total Nitrogen means the sum of all nitrate, nitrite, ammonia, and organic nitrogen, as N, in an unfiltered water sample. Total nitrogen in a sample may also be determined via persulfate digestion or as the sum of total Kjeldahl nitrogen plus nitrate plus nitrite.

Total Phosphorus means the sum of orthophosphates, polyphosphates, and organically bound phosphates, as P, in an unfiltered water sample. Total phosphorus may also be determined directly by persulfate digestion.

Wadeable Stream means a perennial or intermittent stream in which most of the wetted channel is safely wadeable by a person during baseflow conditions.

PART I: TRANSLATION OF THE NARRATIVE NUTRIENT STANDARDS

Part I of **Circular DEQ-15** provides translations of the narrative nutrient standards, descriptions of causal and response variables and associated thresholds, and tables to interpret the various combinations of causal and response results. Collectively, this is a weight-of-evidence framework in which each data type (total nitrogen/total phosphorus, and response variables) provides key information; however, it is the response variables—which are direct measures of the biological community or its effects—which have the greatest weight. Achievement (or non-achievement) of the narrative nutrient standards requires that all the specified causal and response variables associated with a beneficial use have been collected and are available for evaluation. If they are not all available, the department will provide a reasonable amount of time for their collection prior to making a decision regarding achievement of the narrative nutrient standards.

The daily curve of dissolved oxygen (DO) change in flowing waters is the response variable with the widest geographic application in this process. Daily DO change, referred to as DO delta, is the daily maximum DO concentration minus the daily DO minimum concentration, expressed in mg DO/L.

Biological assemblages (floral and faunal) and DO patterns are affected by environmental factors besides total nitrogen and total phosphorus concentrations and **Part I** includes options—based on demonstrated effects and within reasonable limits—for addressing such circumstances. These options may result in modified thresholds and site-specific criteria being applied to specific waterbodies or waterbody segments. Site specific modifications must be approved by the department, reviewed and approved by the U.S. Environmental Protection Agency (EPA), and then be made easily accessible to the public via the department's website.

Translators found in **Part I** do not apply to ephemeral waterbodies, but they do apply to intermittent and perennial waterbodies.

1.0 Identify Waterbody Size

To translate the narrative nutrient standards per NEW RULE I, each waterbody must first be identified as a wadeable stream, medium river, or large river (for permittees discharging to or affecting a lake or reservoir, see **Section 3.0** in **Part II**). **Figure 1-1** is a guide to sections in **Part I** depending upon waterbody size; each section provides details on the indicated subjects.

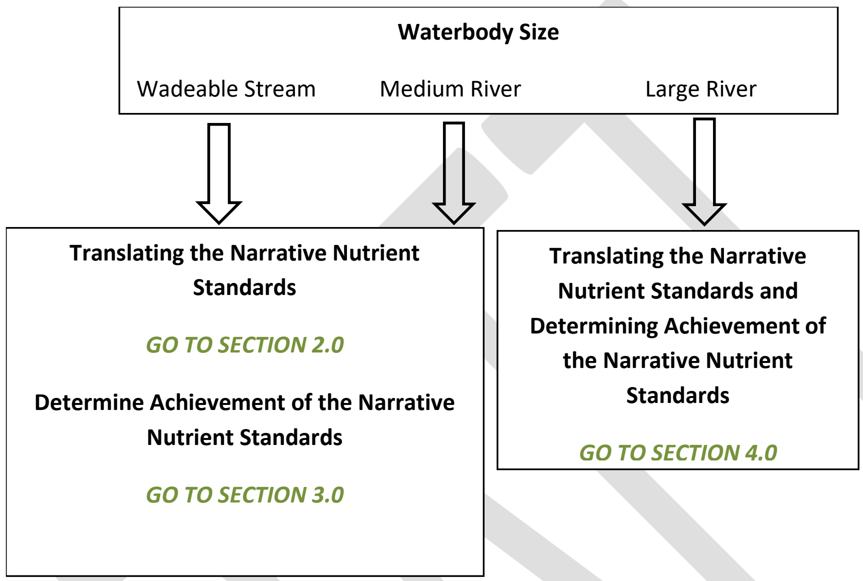

Figure 1-1. Guide to Sections in Part I Depending on Waterbody Size.

Readers should refer to definitions in the **General Introduction to Circular DEQ-15** (above), the list of large rivers in **Table 1-1** below, and any other current department guidance when determining the size of a receiving water body.

Table 1-1. Large River Segments within the State of Montana

River Name	Segment Description
Big Horn River	Yellowtail Dam to mouth
Clark Fork River	Bitterroot River to state-line
Flathead River	Origin to mouth
Kootenai River	Libby Dam to state-line
Madison River	Ennis Lake to mouth
Missouri River	Origin to state-line
South Fork Flathead River	Hungry Horse Dam to mouth
Yellowstone River	State-line to state-line

2.0 WADEABLE STREAMS AND MEDIUM RIVERS: THE NARRATIVE NUTRIENT STANDARDS TRANSLATOR

Table 2-1 shows instream nutrient causal and instream response variable parameters, applicable to different beneficial uses and regions of the state, that must be measured to translate the narrative nutrient standards for wadeable streams and medium rivers. Department programs (e.g., Montana Pollutant Discharge Elimination System (MPDES) Permitting, Monitoring and Assessment, Total Maximum Daily Load (TMDL)) must use these parameters to translate the narrative nutrient standards but may have program-specific data compilation and analysis methods appropriate for their purposes and documented in their respective work units.

Table 2-1. The Narrative Nutrient Standards Translator. An "X" indicates the parameter applies and is required to be measured at monitoring sites to translate the narrative nutrient standards per NEW RULE I.

Benefical Use and Applicable Zone			Causal Variable	Response Variable (threshold)			
Beneficial Use	**Stream Slope Zone***	**Macroinvertebrate Zone***	**TP, TN (*see* ecoregional nutrient concentrations in Table 2-3)**	**DO Delta†**	**Benthic Chl*a* ; AFDW**	**% filamentous algae bottom cover**	**Macroinvertebrates**
Recreation	Western and transitional ecoregions, <u>all</u> stream/medium river water surface slopes	n/a	**X**		**X** (150 mg Chla/m^2; 35 g AFDM/m^2)	**X** (30% cover)	
Aquatic Life	Western and transitional ecoregions, streams/medium rivers with >1% water surface slope	Mountains	**X**				**X** Beck's Biotic Index v3 (35.1)
Aquatic Life	Western and transitional ecoregions, streams/medium rivers with ≤1% water surface slope	Low Valleys and Transitional[a]	**X**	**X** (3.0 mg DO/L)			**X** Beck's Biotic Index v3 (18.7)
Aquatic Life	Eastern ecoregions, <u>all</u> streams/medium rivers	Plains	**X**	**X** (6.0 mg DO/L)[b]			

*Ecoregions comprising these zones are provided in **Table 2-2**.

† The allowable exceedance rate of a dataset of weekly average DO delta values is 10% in the Low Valleys and Transitional and 15% in the Plains.

[a] With the exception of Big Spring Creek, spring creeks are exempt from this narrative translation. Stream and medium river reaches below dams may be given special consideration. See **Section 2.3** for details and applicable criteria.

[b] Data collected during drought periods may be excluded from analysis. See department guidance for definition of drought.

Ecoregions associated with the stream slope and macroinvertebrate zones are shown in **Table 2-2**. A map of the three macroinvertebrate zones is shown in **Figure 2-1**. Stream slope and macroinvertebrate zones in **Table 2-1** largely correspond; for example, western and transitional ecoregions with water surface slope >1% are largely restricted to the ecoregions in the Mountains macroinvertebrate zone, and conversely, western and transitional ecoregions with water surface slope <1% are largely restricted to ecoregions which form the Low Valleys and Transitional macroinvertebrate zone. However, cases will arise—usually near western ecoregion borders—where, for example, a stream may have ≤1% water surface slope but is located in the Mountains macroinvertebrate zone. **Case-by-case evaluations may be appropriate in such situations, using stream slope as the primary criterion to determine which parameters should apply**. Causal and response variables (and their thresholds) should be kept together; in other words, for the example just given, if the stream is to be evaluated as a waterbody with ≤1% slope it should be evaluated using DO delta (and its corresponding threshold of 3.0 mg/L) and the Beck's Biotic Index (v3) and its corresponding threshold of 18.7. Translator parameters modified from what is shown in **Table 2-1** and applied to a waterbody must be approved by the department and submitted to EPA for review and approval as site specific criteria.

Table 2-2. Ecoregions associated with the Stream Slope Zone and Macroinvertebrates Zone from the Narrative Nutrient Standards Translator in Table 2-1. Level IV (small-scale) ecoregions are those shown as a number-letter combination.

Beneficial Use	Stream Slope Zone	Stream Slope Zone Ecoregions	Macroinvertebrate Zone	Macroinvertebrate Zone Ecoregions
Recreation	Western and transitional ecoregions, all streams/medium rivers regardless of water surface slope	15. Northern Rockies	n/a	n/a
		16. Idaho Batholith		
		17. Middle Rockies		
		41. Canadian Rockies		
		42l. Sweetgrass Uplands		
		42n. Milk River Pothole Upland		
		42q. Rocky Mountain Front Foothill Potholes		
		42r. Foothill Grassland		
		43s. Non-calcareous Foothill Grassland		
		43t. Shield-Smith Valleys		
		43u. Limy Foothill Grassland		
		43v. Pryor-Bighorn Foothills		
		43o. Unglaciated Montana High Plains		
Aquatic Life	Western and transitional ecoregions, streams/medium rivers with >1% water surface slope **OR** with ≤1% water surface slope	15. Northern Rockies	Mountains	15. Northern Rockies (excl. 15c Flathead Valley)
		16. Idaho Batholith		16. Idaho Batholith
		17. Middle Rockies		17. Middle Rockies (excl. Level IV Ecoregions in Low Valleys and Transitional)
		41. Canadian Rockies		41. Canadian Rockies
			Low Valleys and Trasitional	15c. Flathead Valley
				17s. Bitterroot-Frenchtown Valley
				17u. Paradise Valley
				17w. Townsend Basin
				17aa. Dry Intermontane Sagebrush Valleys
				17ac. Big Hole
				17ak. Deer Lodge-Philipsburg-Avon Grassy Intermontane Hills and Valleys
		42l. Sweetgrass Uplands		42l. Sweetgrass Uplands
		42n. Milk River Pothole Upland		42n. Milk River Pothole Upland
		42q. Rocky Mountain Front Foothill Potholes		42q. Rocky Mountain Front Foothill Potholes
		42r. Foothill Grassland		42r. Foothill Grassland
		43s. Non-calcareous Foothill Grassland		43s. Non-calcareous Foothill Grassland
		43t. Shield-Smith Valleys		43t. Shield-Smith Valleys
		43u. Limy Foothill Grassland		43u. Limy Foothill Grassland
		43v. Pryor-Bighorn Foothills		43v. Pryor-Bighorn Foothills
		43o. Unglaciated Montana High Plains		43o. Unglaciated Montana High Plains
	Eastern ecoregions, all streams/medium rivers	18. Wyoming Basin	Plains	18. Wyoming Basin
		42. Northwestern Glaciated Plains (excl. Level IV Ecoregions listed above)		42. Northwestern Glaciated Plains (excl. Level IV Ecoregions in Low Valleys and Transitional)
		43. Northwestern Great Plains (excl. Level IV Ecoregions listed above)		43. Northwestern Great Plains (excl. Level IV Ecoregions in Low Valleys and Transitional)

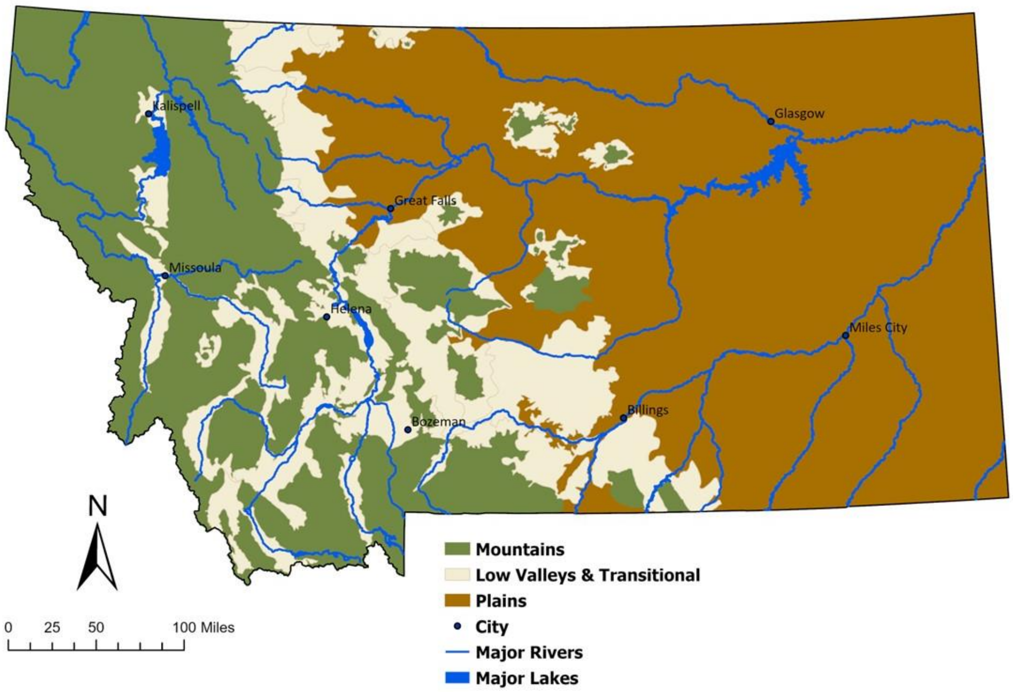

Figure 2-1. Map of Montana showing the Geographic Extent of the Mountains, Low Valleys and Transitional, and Plains Macroinvertebrate Zones.

2.1 TOTAL PHOSPHORUS (TP) AND TOTAL NITROGEN (TN): THE CAUSAL VARIABLES

Table 2-3 provides TP and TN concentrations—the causal variables that must be measured as part of the narrative nutrient standards translation—organized by ecoregion. The department compiled and reviewed scientific literature and carried out its own studies[1,2,3,4,5] which demonstrate that TP and TN concentrations protective of aquatic life and recreation beneficial uses vary across the state (ecoregion by ecoregion). The highest TP and TN concentrations which protect the most sensitive beneficial use in each ecoregion or ecoregion group are shown in **Table 2-3**; harm to beneficial uses (e.g., aquatic life) at lower TN and TP concentrations are documented in the scientific literature. Simultaneous realization of paired TN and TP concentrations in **Table 2-3** could also affect beneficial uses, i.e., either the TN or the TP value may need to be at a lower concentration than shown in the table to ensure full protection. The department also uses stream hydrograph and biological patterns to identify appropriate index periods (i.e., time periods during which variables should be measured/data collected) applicable to wadeable streams and medium rivers for each ecoregion[3,4]. Montana streams and rivers are generally most vulnerable to excess nutrient impacts during the summer and early fall baseflow months, therefore values in **Table 2-3** shall be applied seasonally, at a minimum, per the time periods in the table. To identify the ecoregion applicable to a point source or monitoring location, start at the smallest geographic scale (column three from the left) and determine if the point source/monitoring location is situated in one of the listed level IV ecoregions. If it is not, then the nutrient concentration applicable to the larger-scale level III ecoregion (column two) applies.

Table 2-3. Ecoregional TP and TN Concentrations Protective of Aquatic Life and Recreation Beneficial Uses. The most sensitive beneficial use associated with the ecoregional concentrations is shown. Also shown are the minimum time periods when the concentrations should be applied.

Region	Ecoregion (Level III)	Ecoregion (Level IV)	Upper Threshold: Total Phosphorus (µg/L)	Upper Threshold: Total Nitrogen (µg/L)	Most Sensitive Beneficial Use Threshold is Associated With	Applicable Time Period: Start of Growing Season	Applicable Time Period: End of Growing Season
Western	Northern Rockies (15)	all	40[a]	640[a]	Aquatic Life	July 1	September 30
Western	Canadian Rockies (41)	all	60[b]				
Western	Idaho Batholith (16)	all					
Western	Middle Rockies (17)	all except 17i					
Western	Middle Rockies (17)	Absaroka-Gallatin Volcanic Mountains (17i)	117[c]	Apply concentrations less than Middle Rockies (17) ecoregion threshold above	Aquatic Life	July 1	September 30
Transitional	Northwestern Glaciated Plains (42)	Sweetgrass Upland (42l), Milk River Pothole Upland (42n), Rocky Mountain Front Foothill Potholes (42q), and Foothill Grassland (42r)	226[d]	640[a]	Aquatic Life	July 1	September 30
Transitional	Northwestern Great Plains (43)	Non-calcareous Foothill Grassland (43s), Shields-Smith Valleys (43t), Limy Foothill Grassland (43u), Pryor-Bighorn Foothills (43v), and Unglaciated Montana High Plains (43o)[a]	41[e]	640[a]	Aquatic Life	July 1	September 30
Eastern	Northwestern Glaciated Plains (42)	all except those listed above as transitional for 42	150[f]	1300[g]	Aquatic Life	June 16	September 30
Eastern	Northwestern Great Plains (43) and Wyoming Basin (18)	all except for those listed above as transitional for 43, and 43c below				July 1	September 30
Eastern	Northwestern Great Plains (43)	River Breaks (43c)	Narrative Nutrient Standards Apply	Narrative Nutrient Standards Apply		June 16	September 30

[a]See endnote 6.
[b] Based on maintaining TP concentration below saturation (per Dodds et al. (2006) which is cited in the document in endnote 3). Concentration is <90 th percentile of Middle Rockies reference streams.
[c]Based on the 90th percentile of the reference stream concentrations for this level IV ecoregion. Aquatic life are adapted to naturally higher TP concentrations in this ecoregion.
[d] Based on these streams' origins in the Canadian Rockies; equal to the 90th percentile of natural background for these ecoregions.
[e]Based on upper concentrations observed in the Elk Creek reference site.
[f]Per Heiskary et al. (2010) cited in the document in endnote 3. Concentration is below the 90th percentile of these ecoegions' reference streams.
[g]Based on protection of regional DO standards for aquatic life (see page 3-18 of the document in endnote 3).

2.2 Response Variables

See Table 2-1. Response variables in **Table 2-1** (e.g., benthic algae density, DO delta, Beck's Biotic Index (v3)) were selected because they respond to eutrophication (i.e., excess nutrient concentrations)[4,5,7], are readily measured, and have been linked by the department to the specified beneficial uses indicated.

2.3 The Narrative Nutrient Standards Translator: Site Specific Considerations

Some waterbodies have characteristics which may be given special consideration when applying the narrative nutrient standards translator. These cases are detailed in this section.

2.3.1 Wadeable Streams and Medium Rivers in Western and Transitional Ecoregions: Influence of Dams

In Montana, conditions resulting from the reasonable operation of dams on July 1, 1971, are natural (§ 75-5-306(2), MCA). Dense macrophyte beds are sometimes found downstream of dams; this is often due to the hydrologic modifications caused by the dam that result in more favorable conditions for macrophyte growth. Reaches immediately downstream of dams having dense macrophyte beds may have DO delta and Beck's Biotic Index (v3) values that do not meet the thresholds in **Table 2-1**. Adjustment to **Table 2-1** thresholds may be appropriate in these situations if the department is satisfied that dam operations are done in the best practicable manner to minimize harmful effects (ARM 17.30.636(1)), to be evaluated by the department on a case-by-case basis. The extent of the reach downstream of a dam affected in such a manner needs to be identified, and updated translator thresholds applied to the reach must be approved by the department and submitted to EPA for review and approval under factor 4 of 40 CFR 131(10)(g).

2.3.2 Western and Transitional Ecoregions: Spring Creeks

Spring creeks commonly have dense, naturally occurring macrophyte beds resulting in DO delta and Beck's Biotic Index (v3) values that may not meet the thresholds in **Table 2-1**; therefore, they are exempt from the narrative nutrient translator. Montana's spring creeks are inventoried[8] and this inventory must be used to identify these waterbodies. Unlisted but verified spring creeks may be evaluated and assessed on a case-by-case basis; these waterbodies must be approved as spring creeks by the department. The narrative nutrient standards (NEW RULE I) apply to spring creeks but will require development of site-specific causal and response variable criteria on a case-by-case basis. Such criteria must be approved by the department and submitted to EPA for review and approval.

Big Spring Creek (from its headwaters at 46.999211, -109.33704, to its mouth at the Judith River) is not included among the spring creeks described in this section (Big Spring Creek is influenced by 23 non-spring tributaries). **Instead, use the translator in Table 2-1 for Big Spring Creek.**

2.3.3 Wadeable Streams and Medium Rivers in the Low Valleys and Transitional Macroinvertebrate Zone: Effects of Specific Conductance

Department analysis[5] shows that streams and rivers whose specific conductivity (a measure of the dissolved salts in water) is below 200 µS/cm will likely have higher-than-expected Beck's Biotic Index (v3) scores and, conversely, those whose specific conductivity is above 200 µS/cm will likely have lower-than-expected Beck's Biotic Index (v3) scores. If the natural background specific conductance of a waterbody is less than or greater than 200 µS/cm, consideration may be given to the applicable Beck's Biotic Index (v3) threshold, subject to department review and approval. The department will require data and analysis indicating the specific conductivity is natural and the extent of the affected reach in question. Permittees and others are advised to consider any current guidance developed by the department. Site-specific Becks Biotic Index (v3) thresholds developed for a waterbody reach must be approved by the department and submitted to EPA for review and approval.

2.3.4 Waterbodies which are Atypical for the Ecoregion

It is possible that permittees and others may find that although they discharge to or are assessing a waterbody in the geographic areas described in **Table 2-2**, the waterbody does not appear to fit the general stream characteristics outlined here:

Western and Transitional Ecoregion streams are those that are usually perennial and generally clear during summer/fall base flow, have high-to-low gradient, are mostly gravel-to cobble-bottomed but whose substrate becomes finer in their lower extents, comprise a pool-riffle-run series longitudinally, have limited macrophyte populations (with exceptions, e.g., below dams and spring creeks), and generally support a salmonid fish population. This zone has a high degree of geographic overlap with Montana's A-1 and B-1 waterbody classifications (see ARM 17.30.607 through 614).

Eastern Ecoregion streams are those that are low-gradient and which may become intermittent during summer/fall baseflow, often have deep pools even when intermittent, commonly have a mud bottom, may be quite turbid, are often very sinuous, frequently have substantial macrophyte populations including near-bank emergent macrophytes, often have filamentous algae but sometimes only phytoplankton algae (i.e., as evidenced by a green color to the stream water), and generally support warm-water fish species (e.g., green sunfish, black bullheads, silvery minnows, etc.). This zone has a high degree of geographic overlap with Montana's B-3 and C-3 waterbody classifications (see ARM 17.30.607 through 613).

When a waterbody in one of these geographic areas does not appear to fit these general ecoregional patterns, permittees and others are advised to contact the department early in the process of establishing their monitoring sites and before collecting causal and response variable data. Permittees and others are advised to consider any current guidance developed by the department. A Use Attainability Analysis (ARM 17.30.602(39)) may be in order; these use classification changes must be approved by the department and submitted to EPA for review and approval under one or more of the six factors at 40 CFR 131(10)(g).

2.4 Data Collection Index Period, Minimum Data Collection

This section covers the index period during which nutrient and response variable data should be collected and provides minimum data collection requirements. If appropriate for a waterbody, the index period may be adjusted to include earlier or later dates on a case-by-case basis, subject to department review and approval. Permittees and others are advised to consider any current department guidance on this subject.

2.4.1 Nutrient, Response Variable, and Other Monitoring Data for Western and Transitional Ecoregions

Table 2-4 provides details on minimum data collection requirements for wadeable streams and medium rivers in western and transitional ecoregions. When implementing sampling methods for purposes of meeting the requirements in **Table 2-4**, permittees and others are advised to consider any current department guidance.

Table 2-4. Minimum Data Collection Requirements for Monitoring Sites in the Western and Transitional Ecoregions

Parameter	Associated Beneficial Use	Site Type	Annual Index Period	Minimum Annual Sampling Requirements	Threshold
1. Physical Variables					
Water Surface Slope (%)	Recreation, Aquatic Life	Near-field, far-field, and other monitoring sites	n/a	Determined once, generally at the time the sampling reach is established	1%
2. Response Variables					
Reach average benthic algal chlorophyll *a* (Chl*a*)	Recreation	Near-field, far-field, and other monitoring sites	July 1 to September 30	Twice during the index period, with a minimum of 4 weeks between sampling events	150 mg Chla/m^2
Reach average benthic algal ash free dry weight (AFDW)					35 g AFDW/m^2
% Bottom cover by filamentous algae, reach average				Monthly during the index period; two of the events must pair with the Chl*a* /AFDW sampling	30% bottom coverage
Dissolved Oxygen* Delta (daily maximum minus daily minimum)	Aquatic Life			Instruments deployed annually for at least 14 continuous days which must be in August; longer datasets may include July and September. Logging must occur at least every 15 minutes. Deployment sites must correspond to reaches used to collect other response variable data.	Western and transitional ecoregions, streams/medium rivers with ≤1% water surface slope: 3.0 mg/L
Macroinvertebrates (reach-wide composite)				Once per annual index period, corresponding to one of the other sampling events	Beck's Biotic Index (v3): Mountains = 35.1 Low Valleys and Transitional = 18.7
3. Nutrient Concentrations					
Total P, Total N	Recreation, Aquatic Life	Near-field, far-field, and other monitoring sites	July 1 to September 30	Twice during the index period, with a minimum of 4 weeks between sampling events	Concentration are greater than applicable ecoregional values in **Table 2-3**
Total P, Total N		Tributaries		At a sufficient frequency to characterize tributary loads as established in an AMP	

*Dissolved oxygen concentration standards in Circular DEQ-7 also apply, and must be examined using the instrument datasets.

For data collection bracketing point source discharges, data collection may not exceed 24 hours between upstream and downstream site sample collections.

Water surface slope is required for waterbodies in western and transitional ecoregions and should be determined using a laser level over the longitudinal extent of each monitored sampling reach. Permittees and others are advised to consider any current guidance developed by the department. Alternatively, a GIS may be used to determine slope subject to department review and approval.

Extraction of Chl*a* from samples, and the subsequent determination of Chl*a* concentration, must be performed in an analytical laboratory by a qualified laboratory technician or chemist. Benthic Chl*a* must be reported as milligrams chlorophyll *a* per square meter of stream bottom (mg Chl*a*/m^2). Chlorophyll *a* may be analyzed spectrophotometrically or by high-performance liquid chromatography (HPLC). If using spectrophotometric methods, use of the monochromatic equation for phaeopigment-corrected Chl*a* is required. **For both spectrophotometric and HPLC methods, Chl*a* extraction must be undertaken using warmed ethanol.** Analysis of benthic algae ash free dry weight (AFDW) must be undertaken using standard methods. Benthic algal AFDW must be reported as grams ash free dry weight per square meter of stream bottom (g AFDW/m^2). Percent bottom cover of the stream bottom may be assessed visually by trained personnel or via the use of aerial drone technology (subject to review and approval by the department). Permittees and others are advised to consider any current guidance developed by the department.

Dissolved oxygen must be measured using logging instruments deployed instream that have been properly calibrated in accordance with the manufacturer's instructions. When selecting instruments and evaluating different instrument deployment options, permittees and others are advised to consider any current guidance developed by the department. DO delta values must be expressed as a 7-day moving average however, for datasets ≥30 days long, DO delta values may—alternatively—be expressed as a calendar weekly average (n=4 weekly averages, minimum).

Macroinvertebrates must be collected using a reach-wide composite method using a D-frame kick net, sampling from downstream to upstream along the reach and collecting a sample at each of 11 transects; the 11 kick samples are composited to obtain a single sample which is representative of the entire reach. Permittees and others are advised to consider any current guidance developed by the department.

2.4.2 Nutrient, Response Variable, and Other Monitoring Data for Eastern Montana Ecoregions

Table 2-5 provides details on minimum data collection requirements for wadeable streams and medium rivers in eastern Montana ecoregions. When developing and implementing sampling methods to meet the requirements in **Table 2-5**, permittees and others are advised to consider any current department guidance.

Table 2-5. Data Collection Requirements for Different Types of AMP Monitoring Sites in Eastern Montana Ecoregions

Parameter	Associated Beneficial Use	Site Type	Annual Index Period	Minimum Annual Sampling Requirements	Threshold
1. Response Variables					
Dissolved Oxygen* Delta (daily maximum minus daily minimum)	Aquatic Life	Near-field, far-field, and other monitoring sites	Northwestern Glaciated Plains(42): 6/16-9/30 Northwestern Great Plains(43): 7/1-9/30	Instruments deployed annually for at least 14 continuous days which must be in August; longer datasets may include June, July, and September. Logging must occur at least every 15 minutes. Deployment sites must correspond to reaches used to collect causal variable data.	6.0 mg DO/L†
2. Nutrient Concentrations					
Total P, Total N	Aquatic Life	Near-field, far-field, and other monitoring sites	Northwestern Glaciated Plains(42): 6/16-9/30 Northwestern Great Plains(43): 7/1-9/30	Twice during the index period, with a minimum of 4 weeks between sampling events	Concentration are greater than applicable ecoregional values in **Table 2-3**
Total P, Total N		Tributaries		At a sufficient frequency to characterize tributary loads as established in the AMP	

*Dissolved oxygen concentration standards in Circular DEQ-7 also apply, and must be examined using the instrument datasets.
† Data collected during drought periods may be excluded from analysis. See department guidance for definition of drought.

For data collection bracketing point source discharges, data collection may not exceed 24 hours between upstream and downstream sample collection.

Dissolved oxygen must be measured using logging instruments deployed instream that have been properly calibrated according to the manufacturer's instructions. When selecting instruments and evaluating different instrument deployment options, permittees and others are advised to consider any current guidance developed by the department. DO delta values must be expressed as a 7-day moving average however, for datasets ≥30 days long, DO delta values may—alternatively—be expressed as a calendar weekly average (n=4 weekly averages, minimum).

3.0 Wadeable Streams and Medium Rivers: Use of Data for Determining if Beneficial Uses are Protected and Narrative Nutrient Standards are Achieved

This section provides decision tables pertaining to causal and response data collected per the Narrative Nutrient Standards Translator (**Table 2-1**). The department shall use such data, along with other relevant, credible data, to determine if beneficial uses are protected and narrative nutrient standards are achieved. These data may also inform if a phosphorus control focused strategy has resulted in the protection of beneficial uses in the waterbody.

If it is concluded that narrative nutrient standards are not achieved or depending on other circumstances, it may be necessary for the department to use a TP and/or TN concentration from **Table 2-3** for use in MPDES permits and for other department water quality work. See **Section 4.0**, **Part II** of this circular for additional information.

3.1 Expression of Nutrient Concentration and Response Variable Data

Data collected for purposes of determining if the narrative nutrient standards are achieved must be reduced and expressed as described in **Table 3-1**. The table provides information on how to express the data for individual sampling events/months and for larger datasets which have been collected over multiple years. The department has concluded that datasets 3-5 years in length will be necessary to accurately evaluate achievement/non-achievement of the narrative nutrient standards for waterbodies receiving discharge from an MPDES permit.

Table 3-1. Expression of Nutrient Concentration and Response Variables, and Associated Thresholds, for Purposes of Determining Achievement of the Narrative Nutrient Standards in Wadeable Streams and Medium Rivers

Applicable Ecoregions	Parameter	How the Parameter is Expressed	How the Parameter is Assessed across Time (2-5 years or longer)	Threshold
Western and Transitional, Eastern	Instream nutrient concentrations	Monthly arithmetic average	Long-term arithmetic average	Applicable ecoregional concentrations in **Table 2-3**
Western and Transitional	Benthic algal chlorophyll *a* (Chl*a*)	Weighted average of replicates (normally 11) collected across a reach	One sampling event exceedence is allowed every three years	150 mg Chla/m^2
Western and Transitional	Benthic algal ash free dry weight (AFDW)	Weighted average of replicates (normally 11) collected across a reach	One sampling event exceedence is allowed every three years	35 g AFDW/m^2
Western and Transitional	% Bottom cover by filamentous algae	Arithmetic average of replicates (normally 11) visually assessed across a reach	One sampling event exceedence is allowed every three years	30% bottom coverage
Western and Transitional	Macroinvertebrates	A single metric score generated from a reachwide composite sample	Arithmetic average of sampling-event metric scores	Beck's Biotic Index (v3) Mountains: 35.1 Low Valleys and Transitional: 18.7
Western and Transitional, Eastern	Dissolved Oxygen Delta (daily maximum minus daily minimum)	7-day average of daily DO deltas	All available 7-day average DO deltas compared to the applicable exceedence rates in **Table 2-1**.	Western and TransitionaL: 3.0 mg DO/L. Eastern: 6.0 mg DO/L during non-drought periods

3.2. Determining if Narrative Nutrient Standards are Achieved in Wadeable Streams and Medium Rivers

Tables 3-2 through **3-5** below provide all result combinations for the **Table 3-1** parameters and their associated thresholds. The tables apply to the specific beneficial uses and the geographic region(s) indicated. **For a site, "Meets" means the parameter value is less than or equal to the threshold in Table 3-1, "Exceeds" means the parameter is greater than the threshold—however the reverse applies to Beck's Biotic Index (v3). Higher Beck's Biotic Index (v3) scores are better, therefore "Exceeds" for this parameter means a site score is lower than (less than) the threshold.** Different result combinations inform achievement or non-achievement of the narrative nutrient standards. This construct is a weight-of-evidence approach in which each data type (nutrients and response variables) provides key information, however it is the response variables which provide the most important information.

Some data combination outcomes may warrant further investigation (e.g., scenario two in **Table 3-3**). If additional scientific investigation reveals an underlaying cause for the outcome that is not related to nutrient concentrations, the department may consider alternatives for determining more appropriate response variable threshold(s) for the waterbody or waterbody reach.

Table 3-2. Evaluation of Narrative Nutrient Standards for the Recreational Use in the Western and Transitional Ecoregions—All Wadeable Streams and Medium Rivers

Parameter			
Nutrient Causal Variables	**Benthic Chlorophyll *a*, Ash Free Dry Weight***	**% Filamentous Algae Cover**	**Are Narrative Nutrient Standards Achieved?**
Meets	Meets	Meets	Yes
Meets	Meets	Exceeds	No
Meets	Exceeds	Meets	No
Meets	Exceeds	Exceeds	No
Exceeds	Meets	Meets	Yes
Exceeds	Meets	Exceeds	No
Exceeds	Exceeds	Meets	No
Exceeds	Exceeds	Exceeds	No

*If either benthic chlorophyll *a* or ash free dry weight exceed their respective thresholds on more than one sampling event every three years, the conclusion is "Exceeds."

Table 3-3. Evaluation of Narrative Nutrient Standards for the Aquatic Life Use in the Western and Transitional Ecoregions for Wadeable Streams and Medium Rivers with Water Surface Slope ≤1%

Parameter			
Nutrient Causal Variables	**Dissolved Oxygen Delta**	**Macroinvertebrate Metric (Beck's Biotic Index v3)**	**Are Narrative Nutrient Standards Achieved?**
Meets	Meets	Meets	Yes
Meets	Meets	Exceeds	No*
Meets	Exceeds	Meets	No
Meets	Exceeds	Exceeds	No
Exceeds	Meets	Meets	Yes
Exceeds	Meets	Exceeds	No
Exceeds	Exceeds	Meets	No
Exceeds	Exceeds	Exceeds	No

*Investigation of other factors that may be depressing the macroinvertebrate metric may be warranted. Coordinate investigations with the department's Adaptive Management Program Scientist.

Table 3-4. Evaluation of Narrative Nutrient Standards for the Aquatic Life Use in the Western and Transitional Ecoregions for Wadeable Streams and Medium Rivers with Water Surface Slope >1%

Parameter		
Nutrient Causal Variables	**Macroinvertebrate Metric (Beck's Biotic Index v3)**	**Are Narrative Nutrient Standards Achieved?**
Meets	Meets	Yes
Meets	Exceeds	No
Exceeds	Meets	Yes
Exceeds	Exceeds	No

Table 3-5. Evaluation of Narrative Nutrient Standards for the Aquatic Life Use in the Eastern Ecoregions—All Wadeable Streams and Medium Rivers. ***See text for important caveat*****.**

Parameter		
Nutrient Causal Variables	**Dissolved Oxygen Delta**	**Are Narrative Nutrient Standards Achieved?**
Meets	Meets	Yes
Meets	Exceeds	No
Exceeds	Meets	Yes
Exceeds	Exceeds	No

Important Caveat for Table 3-5. Based on patterns observed in eastern ecoregion reference sites, average weekly dissolved oxygen delta values during drought periods will increase above the threshold in **Table 3-1** (6.0 mg/L) strictly as a result of drought. Therefore, data compared to the threshold and used for **Table 3-5** should be collected during non-drought periods only. For a definition of drought and a website where drought data can be derived, permittees and others are advised to consider any current guidance developed by the department.

3.3 Dataset Reset

Nutrient reduction activities undertaken in a watershed, including a watershed in an AMP, may justify a reset of the nutrient and response variable dataset used to evaluate nutrient control effectiveness and achievement of the narrative nutrient standards. Datasets must properly represent current conditions. A dataset reset means establishing a new period of record for evaluating instream nutrient and response variable data which begins after nutrient reduction activities have been implemented and these changes have had the potential to affect response variables at the monitoring sites. Changes could come from improvement in the facility discharge, nonpoint source controls, or both. Permittees may request that a dataset be reset. The department will determine if and when a dataset reset is appropriate, in accordance with an AMP and the conditions of the MPDES permit.

4.0. Large Rivers: The Narrative Nutrient Standards Translator *and* Data Evaluation to Determine if Beneficial Uses are Protected and Narrative Nutrient Standards are Achieved

Protection of beneficial uses and achievement of narrative nutrient standards in large rivers must be evaluated using the translator in **Table 4-1**. The department has completed its most detailed data collection and mechanistic modeling work on the lower Yellowstone River[9] and therefore the translator is more specific for it than for other large river segments where modeling work is unfinished or has not commenced.

Table 4-1. The Narrative Nutrient Standards Translator for Large Rivers. An "X" indicates the parameter applies and is required to be measured at monitoring sites to translate the narrative nutrient standards per NEW RULE I.

Benefical Use, Applicable River, Reach				Causal Variable and Threshold	Response Variable (threshold)		
Beneficial Use	**River**	**Reach**	**Applicable Time Period**	**TP, TN Concentration***	**DO Delta**	**Benthic algal Chl*a*†; AFDW†**	**% filamentous algae bottom cover†**
Recreation	Yellowstone River mainstem	From the Bighorn River confluence to the Power River confluence	August 1 to October 31	**X** TP: 55 µg/L **X** TN: 655 µg/L	n/a	**X** (150 mg Chla/m²; 35 g AFDM/m²)	**X** (30% cover)
Aquatic Life	Yellowstone River mainstem				**X** (4.1 mg/L)	n/a	n/a
Recreation	Yellowstone River mainstem	From the Powder River confluence to the Stateline		**X** TP: 95 µg/L **X** TN: 815 µg/L	n/a	**X** (150 mg Chla/m²; 35 g AFDM/m²)	**X** (30% cover)
Recreation	Other Large River Reaches (see **Table 1-1**)	Variable		**X** TP‡ **X** TN‡	n/a	**X** (150 mg Chla/m²; 35 g AFDM/m²)	**X** (30% cover)

*Allowable exceedance rate is 20% of reach-specific TP or TN criteria. For causal variables shown as ranges, an allowable 20% exceedance rate will apply to any site-specific TP or TN concentration identified.

†Along shore areas at river transects where approximatly 10% or more of the river transect is wadeable.

‡ No specific concentrations are provided; site specific criteria will need to be determined case-by-case, generally using mechanistic modeling methods.

Mechanistic modeling work may be underway for other large river segments; check with the department's Water Quality Standards & Modeling Section for status. Field data collected to support model development may be used to assess if the narrative nutrient standards are achieved and a use-support assessment may be completed even before a model is completed.

For large river reaches where thresholds have not been provided in **Table 4-1**, mechanistic modeling and field data collected to support model development may be used to identify causal variable concentration thresholds, as well as DO delta thresholds for aquatic life use protection. Site-specific thresholds are subject to department review and approval and must be submitted to EPA for review and approval.

Dissolved oxygen must be measured using in-river deployed logging instruments that have been properly calibrated in accordance with the manufacturer's instructions. When selecting instruments and evaluating different instrument deployment options, permittees and others are advised to consider any current guidance developed by the department. Instruments are to be deployed for at least 14 continuous days which must be in August; longer datasets may include September. Logging must occur at least every 15 minutes. DO delta values must be expressed as a 7-day moving average however, for datasets ≥30 days long, DO delta values may—alternatively—be expressed as a calendar weekly average (n=4 weekly averages, minimum).

4.1. Evaluation of Data to Determine if Large River Beneficial Uses are Protected and Narrative Nutrient Standards are Achieved

Data collected for purposes of determining if the narrative nutrient standards are achieved in large rivers must be reduced and expressed as described in **Table 3-1** of the previous section.

Tables 4-2 and **4-3** below provide all result combinations for the parameters in the large river narrative nutrient standards translator (**Table 4-1)**. **Tables 4-2** and **4-3** apply to the specific beneficial uses indicated. **For a monitoring location, "Meets" means the parameter is less than or equal to the threshold provided in Table 2-1, "Exceeds" means the parameter is greater than the threshold.** Different result combinations inform achievement or non-achievement of the narrative nutrient standards.

Table 4-2. Evaluation of Narrative Nutrient Standards for the Recreational Use in Large Rivers

Parameter			
Nutrient Causal Variables	**Benthic Chlorophyll *a*, Ash Free Dry Weight***	**% Filamentous Algae Cover**	**Are Narrative Nutrient Standards Achieved?**
Meets	Meets	Meets	Yes
Meets	Meets	Exceeds	No
Meets	Exceeds	Meets	No
Meets	Exceeds	Exceeds	No
Exceeds	Meets	Meets	Yes
Exceeds	Meets	Exceeds	No
Exceeds	Exceeds	Meets	No
Exceeds	Exceeds	Exceeds	No

*If either benthic chlorophyll *a* or ash free dry weight exceed their respective thresholds on more than one sampling event every three years, the conclusion is "Exceeds."

Table 4-3. Evaluation of Narrative Nutrient Standards for the Aquatic Life Use in Large Rivers

Parameter		
Nutrient Causal Variables	**Dissolved Oxygen Delta**	**Are Narrative Nutrient Standards Achieved?**
Meets	Meets	Yes
Meets	Exceeds	No
Exceeds	Meets	Yes
Exceeds	Exceeds	No

The dataset reset principles outlined in **Section 3.3** above also apply to large rivers.

4.1.1 Large Rivers: Influence of Dams

In Montana, conditions resulting from the reasonable operation of dams on July 1, 1971, are natural (§ 75-5-306(2), MCA). Dense macrophyte beds are sometimes found downstream of dams; this is often due to the hydrologic modifications caused by the dam that result in more favorable conditions for macrophyte growth. Reaches immediately downstream of dams having dense macrophyte beds may have DO delta values that do not meet the thresholds in **Table 4-1**. Adjustment to **Table 4-1** DO delta thresholds are allowed in these situations if the department is satisfied that dam operations are done in the best practicable manner to minimize harmful effects (ARM 17.30.636(1)), to be evaluated by the department on a case-by-case basis. The extent of the reach downstream of a dam affected in such a manner needs to be identified, and updated translator parameters for the reach must be approved by the department and submitted to EPA for review and approval under factor 4 of 40 CFR 131(10)(g).

5.0 OTHER WATER QUALITY STANDARDS LINKED TO NUTRIENTS

In addition to the narrative nutrient standards, there are several water quality standards closely linked to nutrient-induced effects; these include the following response variables: (1) dissolved oxygen concentrations, (2) pH, (3) turbidity (as a function of increased phytoplankton biomass), and (4) total dissolved gas (TDG). Water quality standards and thresholds associated with these response variables are found in: (1) for dissolved oxygen, Circular DEQ-7; (2) for pH, within specific water-use classifications found in ARM Title 17, chapter 30, subchapter 6; (3) for turbidity, within specific water-use classifications found in ARM Title 17, chapter 30, subchapter 6; and (5) for TDG, in Department Circular DEQ-7, but accounting for the fact the dissolved oxygen is only a fraction of TDG. Achievement/non-achievement of these water quality standards are evaluated independently in accordance with other department procedures and guidance.

6.0 NONDEGRADATION

When determining whether activities will result in nonsignificant changes in existing water quality for TN and TP in surface waters, the criteria applicable for parameters for which there are only narrative water quality standards at ARM 17.30.715(1)(h) will apply. ARM 17.30.715(1)(h) indicates that changes in the quality of water for any parameter for which there are only narrative water quality standards are nonsignificant, and are not required to undergo review under 75-5-303, MCA, if the changes will not have a measurable effect on any existing or anticipated use or cause measurable changes in aquatic life or ecological integrity. When implementing the nondegradation policy at 17.30.715(1)(h), an evaluation of response variables through the use of a model or models must be undertaken to evaluate whether measurable changes in aquatic life or ecological integrity will be likely to result from a proposed activity.

PART II: IMPLEMENTATION OF THE ADAPTIVE MANAGEMENT PROGRAM

1.0 INTRODUCTION TO THE ADAPTIVE MANAGEMENT PROGRAM

Implementation of narrative nutrient standards via the adaptive management program and other regulatory pathways is shown in **Figure 1-1**. The adaptive management program is a long-term compliance schedule with interim performance milestones to be evaluated annually and at each permit renewal cycle. These performance milestones will be based on the principles of improving facility operations, understanding waterbody response variable characteristics, and reducing nonpoint source nutrient loading as soon as possible given each permittee's unique circumstances. Performance milestones must be based on the considerations listed in **Section 1.1, Part II**, specific to individual permittees and waterbodies, and must be consistent with the requirements in ARM 17.30.1350.

The department will evaluate each point source with nutrients as a pollutant of concern for reasonable potential to cause or contribute to an exceedance of the narrative nutrient standards. For point sources with reasonable potential, adaptive management can be used by the department to prioritize phosphorus reduction, where appropriate. Reduction of phosphorus is an initial requirement of adaptive management and will be implemented if appropriate (see decision point in the upper left part of **Figure 1-1**). At a minimum, nitrogen limits will be implemented per state and federal regulations for anti-backsliding (e.g., ARM 17.30.1344(2)(b)). If phosphorus control is successful in protecting receiving water body beneficial uses and downstream uses, additional controls will not be necessary. However, regardless of the success of phosphorus control, ongoing monitoring will continue to be required. If phosphorus-focused control is not successful in protecting water quality and beneficial uses, then phosphorus *and* nitrogen controls are implemented. Nitrogen sources in watersheds are often dispersed among different sources and adaptive management at this stage allows permittees to examine the potential for effective reduction of nutrients in their watershed in an iterative manner (see circular component in lower right area of **Figure 1-1**). The entire process is adaptive in that it allows for an incremental approach (phosphorus focus first, then nitrogen) and incorporates flexible decision-making which can be adjusted as management actions and other factors become better understood in each watershed. Note that adaptive management is a complex, iterative process with the potential for feedbacks which may not all be presented in **Figure 1-1**.

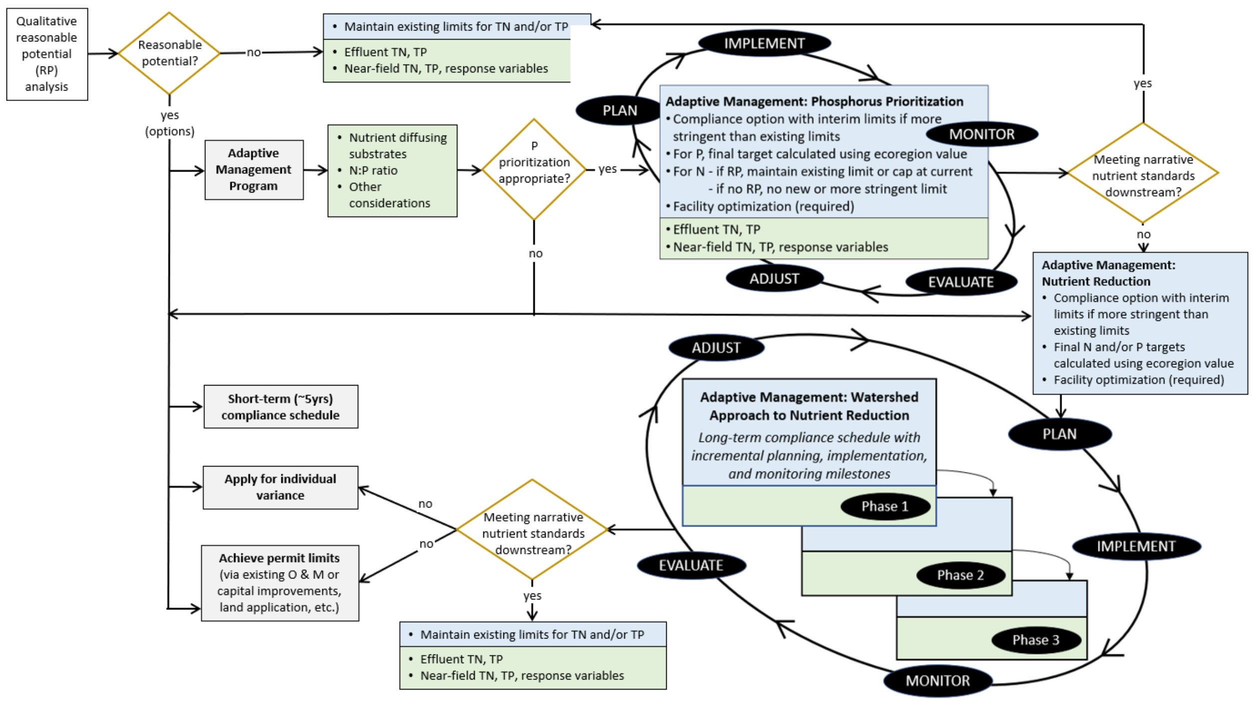

Figure 1-1. Flowchart Outlining Implementation of Narrative Nutrient Standards and Steps in the Adaptive Management Program and Other MPDES Permit Compliance Options. In the colored boxes blue areas describe permit limits and conditions, green areas indicate monitoring requirements. Key decision points in the figure are diamond shaped.

Figure 1-1 also addresses permittees who need or choose to select other regulatory pathways instead of adaptive management to achieve the narrative nutrient standards. Additional pathways include, for example, water quality standard variances and more traditional compliance schedules that do not include an AMP. *These options have separate and distinct rules and requirements that are not included in this circular.*

The department adopted this circular in conformance with the statutory requirements found in Section 75-5-321, MCA. This circular contains adaptive management implementation requirements for Montana's narrative nutrient standards found at ARM 17.30.637(1)(e) for point sources whose discharges contains total phosphorus and/or total nitrogen that has the reasonable potential to cause or contribute to an exceedance of the narrative nutrient standards. This circular is applicable only to the implementation of these narrative nutrient standards. The methods, implementation process, and department approach described in this circular are not applicable to any other department circular water quality standards including but not limited to nitrate + nitrite and ammonia.

1.1 Program Eligibility Requirements

Point source permittees choosing to enter the adaptive management program must satisfy the following program eligibility requirements:

- It must be demonstrated that the point source has a reasonable potential to cause or contribute to an exceedance of the narrative nutrient standards due to discharges of total nitrogen (TN) and/or total phosphorus (TP);

- The point source permittee(s) must submit an adaptive management plan (AMP) with monitoring and implementation elements, to be approved by the department; and
- Applicable program fees must be submitted to the department.

In developing an AMP, each permittee will consult with the department's adaptive management program scientist to determine initial milestones while taking into consideration the following:

- Status of the treatment facility's performance and optimization;
- Appropriateness of phosphorus prioritization (see **Section 2.0**);
- Characterization of nutrient causal and response variables in the receiving waterbody;
- Existence of prior nutrient source assessment studies in the watershed;
- Attaining water quality goals as soon as possible; and
- Opportunities for watershed-scale nonpoint source project implementation.

An AMP may continue for multiple permit cycles if the department considers interim milestones to be achieved and that the permittee continues to be eligible. Requirements for AMPs are the same for wadeable streams, medium rivers, and large rivers, and are covered in **Section 6.0** here in **Part II**. Other considerations for entering the adaptive management program are provided in department guidance.

1.2 Identify Waterbody Size

For purposes of entering the adaptive management program and applying the correct narrative nutrient standards translator, each receiving waterbody must be identified as a wadeable stream, medium river, or large river. Please see **Section 1.0** of **Part I** of this circular for instructions on this.

1.3 Organization of the Rest of Part II

For the purpose of implementing the adaptive management program, NEW RULE II contains requirements specific to the department and requirements for AMPs which are the responsibility of permittees (to be later reviewed and approved by the department). As such, the remainder of **Part II** of this Circular is organized as follows:

- **Sections 2.0, 3.0, 4.0, and 5.0 address requirements specific to the department regarding AMPs it may receive (permittees are advised to review these sections).**
- **Section 6.0 addresses requirements for AMPs; this section should be reviewed by permittees and others developing AMPs for submittal to the department.**
- **Section 7.0 addresses large rivers and water quality modeling; this section should be reviewed by permittees discharging to large rivers or those planning on developing a mechanistic or conceptual water quality model for inclusion in an AMP.**
- **Section 8.0 addresses integration of the Adaptive Management Program and Total Maximum Daily Load (TMDL) Program.**

2.0. DETERMINING IF PHOSPHORUS PRIORITIZATION IS APPROPRIATE FOR THE POINT SOURCE AND THE WATERBODY

Section 75-5-321, MCA, requires that the department prioritize the minimization of phosphorus where appropriate, accounting for site-specific conditions. NEW RULE II provides factors the department may consider when evaluating if phosphorus prioritization is appropriate for a discharge facility. This section provides additional details to support requirements in the rule.

2.1 TECHNIQUES FOR IDENTIFYING THE LIMITING NUTRIENT IN A WATERBODY

Nutrient diffusing substrates (NDS) provide a mechanism to determine if phosphorus, nitrogen, or both control algae growth and primary productivity in a location of a stream or river. Nutrient diffusing substrates may be deployed in flowing waterbodies for the purpose of determining the limiting nutrient(s). A limiting nutrient is the one present in the least quantity; this is an important factor in controlling algae growth in a waterbody. The ratio of TN to TP (i.e., the Redfield Ratio) of ambient water samples from the waterbody may also be used to inform this analysis, but water TN:TP ratios should be used in conjunction with (not as an alternative to) NDS.

Nutrient diffusing substrates may be deployed upstream and downstream of a facility in the same sites where other instream data are collected (more on these sites in **Section 6.0**). Results from NDS deployed downstream of a point source should be considered together with the status of phosphorus and nitrogen treatment and effluent concentrations from the facility. Downstream of a discharge, a receiving waterbody (via NDS data) could show nitrogen limitation but, rather than reducing nitrogen concentrations in the effluent, it might be effective (from a cost and engineering perspective) for a permittee to first lower facility effluent phosphorus concentrations and—as a result—move the waterbody towards P limitation and achievement of the narrative nutrient standards. Readers are advised to consider any current department guidance on this subject.

In areas where nitrogen is the primary limiting nutrient (e.g., in the Absaroka-Gallatin Volcanic Mountains level IV ecoregion in **Table 2-3** in **Part I**, where natural background phosphorus is already at saturating concentrations), nitrogen control will likely be required in addition to phosphorus control. Some MPDES permits regulate activities where total nitrogen is present in the effluent while total phosphorus is absent. For these circumstances, the department shall limit total nitrogen rather than total phosphorus.

The department may find that phosphorus-focused control at a point source is not protecting beneficial uses nor achieving the narrative nutrient standards based on sufficient credible data, including response variable data collected from downstream near field sites. For such cases, if a permittee would like to continue under the adaptive management program, the department will require the permittee to develop a watershed-scale plan for inclusion in their AMP that will include actions for addressing nitrogen (see **Section 6.6**).

3.0 MPDES DISCHARGES THAT MAY AFFECT A LAKE, RESERVOIR, OR A DOWNSTREAM WATERBODY

Loading of nutrients to lakes and reservoirs occurs year-round and, in northern temperate regions like Montana, spring runoff normally constitutes the bulk of the annual loading. Although the bulk of nutrient loading to lakes and reservoirs occurs in spring, undesirable aquatic life (e.g., phytoplankton algae blooms) can occur in lakes and reservoirs later, during summer and fall, if annual nutrient load is excessive or elevated nutrient concentrations persist through those seasons. The department must consider elements in this section when developing MPDES permit limits for nutrients, if nutrients will affect a lake, reservoir, or downstream waterbody.

3.1 DISCHARGES DIRECTLY TO A LAKE OR RESERVOIR

Permittees discharging nutrients directly to a lake or reservoir will be required to have year-round monitoring for TP and/or TN. Where MPDES effluent limits are required for direct discharges of nutrients to a lake or reservoir, the department may apply these effluent limits year-round. In addition, and in consultation with the department and under their AMP (if applicable), permittees must determine the proportion of their TP and/or TN load relative to the total annual load to the lentic waterbody. This data must be collected over at least two calendar years. Depending upon the permittee's proportion of the annual load, the department may require the permittee to undertake in-lake response variable monitoring (e.g., phytoplankton chlorophyll *a*), to be determined in consultation with the department. AMP actions to protect, maintain, and potentially improve the lake condition shall be determined on a case-by-case basis. In determining their contribution to the annual load, permittees and others are advised to consider any current department guidance.

3.2 DISCHARGES TO A FLOWING WATERBODY THAT MAY AFFECT A DOWNSTREAM LAKE OR RESERVOIR

Permittees whose discharge is likely to affect a downstream lake or reservoir will be informed of this situation by the department. The department may determine year-round TP and/or TN permit limits are necessary, to be determined on a case-by-case basis.

3.3 DISCHARGES TO A FLOWING WATERBODY THAT MAY AFFECT BENEFICIAL USES IN A DOWNSTREAM REACH

Beneficial uses downstream of point source discharges must be protected. A reach of a wadeable stream, medium river, or large river downstream from an MPDES discharge may have beneficial uses sensitive to phosphorus and/or nitrogen concentrations from the upstream point source. In these cases, the department may carry out case-by-case evaluations for each applicable MPDES permit. These evaluations may lead to MPDES nutrient limits adjusted to protect a downstream waterbody.

4.0. NUTRIENT CONCENTRATIONS FOR USE IN MPDES PERMITS AND OTHER DEPARTMENT PROGRAMS

The translators in **Sections 2.0** and **4.0** of **Part I**, together with the decision tables in **Sections 3.0** and **4.0** of **Part I** provide the means to determine if narrative nutrient standards are achieved. When it is concluded that narrative nutrient standards are not achieved, or depending on other circumstances, it may be necessary for the department to identify a TP and/or TN concentration protective of recreation and aquatic life beneficial uses for application in MPDES permits and other department programs. TP and/or TN concentrations must be selected from **Tables 2-3** and **4-1** of **Part I** unless compelling waterbody-specific scientific information indicates a concentration or concentrations greater than the table values is protective of the most sensitive beneficial use. If waterbody-specific information indicates TP and/or TN concentrations greater than those in **Tables 2-3** and **4-1** of **Part I** are more appropriate for protection of beneficial uses**,** the department may initiate a formal rulemaking process, including submission to EPA for review and approval. Permittees and others are advised to consider any current guidance developed by the department.

Different department work units may have program-specific guidance on how they collate TP and/or TN concentration data, and how they evaluate and apply these data in relation to **Tables 2-3** and **4-1** of **Part I**. Methods used by a department work unit for evaluating and applying **Tables 2-3** and **4-1** nutrient concentration data must be communicated to other department work units working in the same subject area. This communication must occur prior to any program-specific application of the nutrient concentrations.

5.0 DEPARTMENT FIELD AUDITS OF MONITORING LOCATIONS

This circular requires the implementation of complex field data-collection methods. To ensure high quality data are collected, the department shall carry out field audits to ensure all data collection protocols are being properly adhered to. The department shall audit a minimum of 10% of permittees under the adaptive management program per year. Audits will be performed in the field by department staff having expertise in the applicable data collection methods and who will accompany the data-collection entity (permittee, their consultant, or other responsible agent) to observe the data collection event as it proceeds. The department shall prepare an annual report summarizing audit findings and permittees not properly adhering to protocols established in their AMP will be informed in writing and required to correct the issue prior to the next field sampling event.

6.0 REQUIREMENTS FOR ADAPTIVE MANAGEMENT PLANS: WADEABLE STREAMS, MEDIUM RIVERS, AND LARGE RIVERS

Per NEW RULE II, permittees entering the adaptive management program are required, at a minimum, to (1) collect monthly effluent data for TP and TN, (2) submit an AMP which includes causal and response variable monitoring, (3) examine pollutant minimization activities which may reduce nutrient concentrations in their facility's effluent and the watershed, and (4) report annually on progress. This section provides details related to these activities. Applicable, credible data collected prior to the adoption of this circular may be used to inform an AMP including watershed activities whose goal is to reduce nutrient loadings.

6.1 Identify Waterbody Beneficial Use Classification, Watershed, and Applicable Translator

Permittees should refer to ARM 17.30.607 through 613 and identify their receiving waterbody's beneficial use classification, then review the associated beneficial uses described in ARM 17.30.621 through 631.

AMPs are based on United States Geological Survey (USGS) hydrologic unit code (HUC) watershed boundaries. Different ecoregions may exist within a single watershed because ecoregion boundaries are not watershed-based. This could result in a permittee identifying, for example, both transitional and eastern ecoregion nutrient concentrations and response variables as being applicable to their watershed.

An AMP submitted to the department must describe the applicable use class of the waterbody, which translator best applies to them (**Sections 2.0** and **4.0**, **Part I**), and which response variables will be measured, along with a justification; this is subject to department review and approval. Permittees are advised to consider any current department guidance to address such situations, and to select parameters most appropriate for their near field sites.

The department acknowledges that there may be streams that do not fit the typical ecoregional patterns; if a permittee or other entity believes this situation applies, see **Section 2.3.4** in **Part I.**

6.2 Types of Sites in an Adaptive Management Plan (AMP)

Sampling site locations in a submitted AMP are subject to department review and approval. **At a minimum, an AMP must comprise one near field site upstream and one near field site downstream of each point source discharge** (**Figure 6-1**). The department expects a permittee to establish the sampling sites in an approved AMP as long-term monitoring locations. A permittee may request modifying the monitoring locations. The downstream near field site (or sites) is the point of compliance for determining if the narrative nutrient standards are achieved. Permittees are advised to consider any current guidance on locating these sites that has been developed by the department.

Data collected at the near field sites under the AMP, as well as other credible data (if available), will be used by the department to determine if phosphorus prioritization has been successful in protecting beneficial uses and achieving the narrative nutrient standards. Other credible data include chemical and biological information from locations in the watershed that are useful for evaluating point source P-control effectiveness and beneficial use support. Sources for such data might be, for example, a conservation district, a water quality protection district, or similar entity.

For permittees in the early phase of the adaptive management program, two near field sites may be all that is necessary (see example, **Figure 6-1**) to determine achievement of standards for purposes of permit compliance. However, downstream far field sites may be required by the department to ensure attainment of water quality standards of the entire receiving waterbody or downstream waterbodies (far field sites are further discussed in **Section 6.6**).

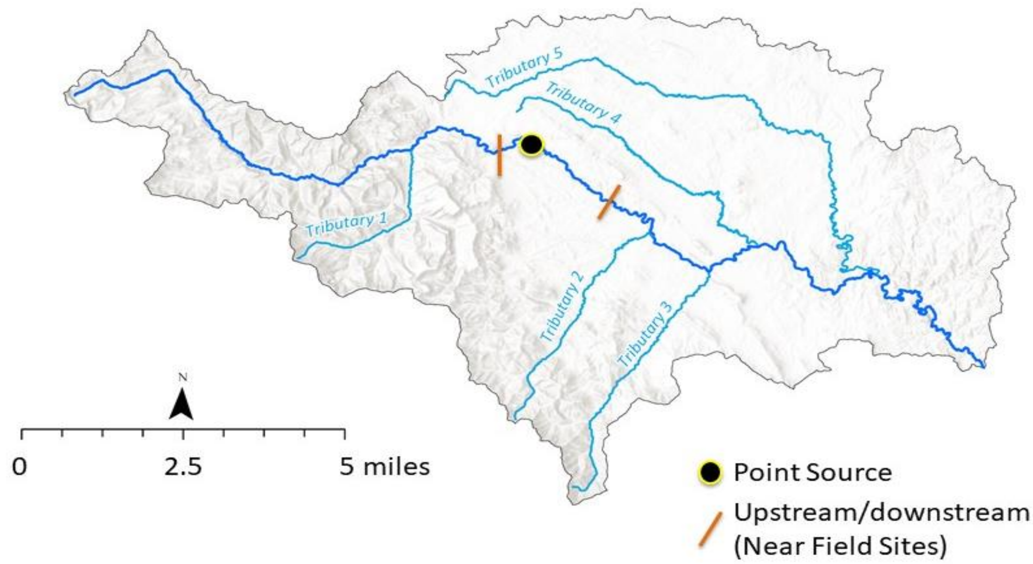

Figure 6-1. Example of an AMP Watershed with Near Field Sites Bracketing a Single Point Source.

6.3 Nutrient Concentration Data Requirements

A permittee must monitor TP and TN in the effluent, and at all near field and far field department-approved sites. Instream TN and TP data must be collected at least at the same frequency and during the same monitoring events as the instream response variables. Nutrient data will be used to characterize nutrient concentrations and loads in the near field area upstream and downstream of the point-source discharge point. At a minimum, TP and TN must be measured, however soluble forms (e.g., nitrate, and soluble reactive phosphorus (SRP)) can provide important information about sources and the department encourages their collection during monitoring events for TN and TP.

Table 6-2 provides the required reporting values (RRVs) for TP and TN, the RRVs for nitrogen that can be used to compute total nitrogen from its constituents, and the RRV for SRP. Permittees are also advised to consider any current department guidance on collecting instream nutrient samples.

Table 6-2. Required Reporting Values[a,b] for Phosphorus and Nitrogen Measurements

Nutrient		Method of Measurement	Required Reporting Value
Total phosphorus		Persulfate digestion	3 µg/L
Total nitrogen		Persulfate digestion	70 µg/L
Total nitrogen	Sum of:	(a) total kjeldahl nitrogen	225 µg/L
		(b) nitrate + nitrite	See RRVs below
Nitrate- as N			20 µg/L
Nitrite- as N			10 µg/L
Nitrate + Nitrite-as N			20 µg/L
Soluble reactive phosphorus (SRP)		Sampled filtered, 0.45 µm	1 µg/L

[a] See definition for required reporting values found in footnote 19 of Department Circular DEQ-7.

[b]The total nitrogen persulfate method is used for instream measurements only and cannot be used for effluent. Persulfate digestion is not a 40 CFR Part 136 approved method.

6.4 Pollutant Minimization Activities for Point Sources, including Optimization

Permittees are required to examine pollutant minimization activities which may reduce nutrient concentrations in the effluent. Nutrient reductions may be achieved by optimization, conventional capital improvements, or both. The department offers technical support and training to municipal wastewater treatment plant operators to achieve nutrient reductions through operational optimization. This section provides requirements, recommendations, and resources for undertaking this work. Permittees are advised to consider any current department guidance on these topics.

A strong optimization effort should begin with monitoring of the influent, effluent, and internal points within the system such as between cells, tanks, or zones. The permittee should monitor ammonia, nitrate, nitrite, dissolved oxygen, alkalinity, pH, and oxidation-reduction potential at each location to assess the wastewater chemistry in each treatment phase. This chemistry can inform decision making regarding nitrification or denitrification (modify anaerobic and aerobic zones) in the system. The department recommends consultation with its technical assistance staff through the department's optimization program or with qualified third-party wastewater optimization experts.

For lagoons, the department recommends regular sludge depth recording and sludge removal when needed to ensure proper health and function of the lagoon. Proper sludge maintenance increases retention time and thus treatment effectiveness.

6.5 Information Provided by Changes Upstream and Downstream of a Point Source

Near field site datasets collected upstream and downstream of a point source provide important information about relative changes in nutrient concentrations and response variables and the effectiveness of phosphorus-focused point source control (as well as other watershed nutrient-control work). Data from near field sites, along with other relevant information, shall be used to inform next steps in adaptive management. Based on the outcomes of the upstream- and downstream-near field sites, different scenarios will be encountered; these are outlined in **Table 6-3**. The implications/actions in the table's right column should be used to guide next steps.

Table 6-3. Scenarios Resulting from the Outcome of Analyses Undertaken in Part I Section 3.2. Achieving/not achieving refers to whether beneficial uses are protected/the narrative nutrient standards are achieved at the near field monitoring locations indicated.

Scenario	Upstream Site(s)	Downstream Site(s)	Implications/Actions
A	Achieving	Achieving	Uses are supported/the narrative nutrient standards are achieved. Continue to monitor.
B	Achieving	Not Achieving	Uses are not supported/the narrative nutrient standards are not achieved. Evaluate further phosphorus control and potentially nitrogen control for the point source, and/or implement an AMP watershed plan to address phosphorus and nitrogen control at the watershed scale
C	Not Achieving	Achieving	Uses are supported/the narrative nutrient standards are achieved below the point source; continue to monitor. Upstream of the point source, the department should encourage/coordinate nutrient reduction work in the upstream watershed.
D	Not Achieving	Not Achieving	Uses are not supported/the narrative nutrient standards are not achieved. Evaluate further phosphorus control and potentially nitrogen control for the point source, and/or implement an AMP watershed plan to address phosphorus and nitrogen control upstream of the point source, downstream of the point source, or both.

6.6 Developing a Watershed-scale Plan for Inclusion in an Adaptive Management Plan

If the department concludes that prioritization/limitation of phosphorus alone is insufficient to achieve the narrative nutrient standards, a permittee's continued participation in the adaptive management program will require the inclusion, in the AMP, of a watershed-scale plan for the reduction of nutrients ("watershed plan"). All elements in this section must be incorporated into an AMP watershed plan. For large rivers, outputs from a mechanistic model may also be used to inform the AMP watershed plan (large rivers and modeling are described in **Section 7.0** here in **Part II**). A watershed plan may be developed and included in an AMP prior to a department finding that P prioritization has not been successful in supporting beneficial uses and achieving the narrative nutrient standards.

6.6.1 Identification, Quantification, and Characterization of Sources of Nutrient Contributions in the AMP Watershed

To the extent feasible, the permittee(s) must identify, quantify, and characterize major nutrient sources in their watershed and provide them and their locations in the AMP. Established watershed restoration plans and total maximum daily load documents (**Section 8.0**) should be consulted to synchronize sampling and reduce redundant efforts.

Robust monitoring within the watershed will be necessary for a successful AMP. Existing scientific information concerning algal growth dynamics, applicable scientific data specific to the region, locally collected data from the waterbody, and characterization of the point source effluent(s) and the nonpoint sources may all be used by the permittee to quantify and describe nutrient sources and loads in the watershed. Consideration should be given to the magnitude and extent of nonpoint source nutrients already in the receiving waterbody and the degree to which the point source(s) alone can reduce nutrient concentrations below algal growth saturation concentrations. Nutrient control projects downstream of a point source can be undertaken and may be credited to the point source's permitted load so long as no hot spots (localized areas of water quality exceedances) remain downstream of the facility after the projects have been completed.

For small watersheds with a single point source (**Figure 6-2**), the two near field sites, a downstream far field site, and strategically selected tributary sites may be all that are necessary to adequately characterize nutrient loads in the watershed. A downstream far field site should normally be placed near the terminus of the AMP watershed (i.e., the point where the waterbody flows into the next watershed) but may be placed further upstream subject to department review and approval. Tributary sites are used to track tributary nutrient loading and, as illustrated in **Figure 6-2**, may be used to monitor the effect of nonpoint source nutrient reduction projects (see Tributary 4 in **Figure 6-2**).

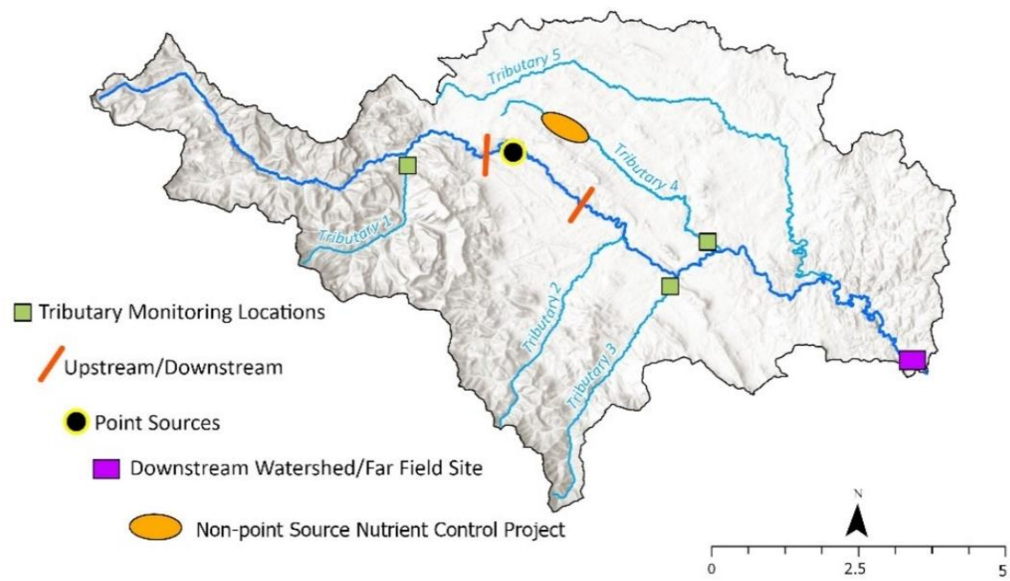

Figure 6-2. Example of a Simple AMP Watershed. Monitoring sites include near field sites, a downstream far field site, and tributary sites. In this example a tributary site is placed on Tributary 4 so effects of an upstream nonpoint source nutrient control project on that tributary can be tracked.

In complex watersheds, such as those with multiple dischargers and various types of non-point sources of nutrients, multiple sampling sites will be needed. These include near field sites bracketing the point sources, far field sites, tributary sites, and mainstem monitoring sites (**Figure 6-3**). Tributary sites may be used to characterize nutrient concentrations and loads from principal tributaries, while far field sites characterize nutrient concentrations and loads at the far upstream and downstream extent of an AMP watershed (**Figure 6-3**), and response variables where applicable. One downstream far field site is required, at a minimum. When locating sites for an AMP watershed, permittees are advised to consider any current department guidance.

A downstream far field site should normally be placed at the terminus of the AMP watershed (i.e., at the point where the waterbody flows into the next watershed; see the downstream far field site in **Figure 6-3**), although there may be exceptions subject to department review and approval. Far field sites may be used to assess achievement of the narrative nutrient standards at a larger waterbody or watershed (multiple waterbody) scale, provided the permittee identifies this as an objective in the AMP and coordinates with the department to select sites for this objective. Upstream far field sites provide data on nutrient concentrations and loads entering the AMP watershed, and inform AMP loading calculations, TMDLs, and other water quality planning work. Upstream sites do not necessarily have to be placed at the very upper-most boundary of the HUC; they may be placed further downstream within the HUC if appropriate.

Site locations should be strategically located to monitor the effect of any nonpoint source control activities. For illustration, there are two nonpoint source nutrient control projects in the watershed in **Figure 6-3**. The effects of the nonpoint source project on Tributary 2 are tracked at the monitoring site at the mouth of that tributary. Similarly, changes resulting from the nonpoint source project on the mainstem are tracked using a mainstem site (red square, **Figure 6-3**).

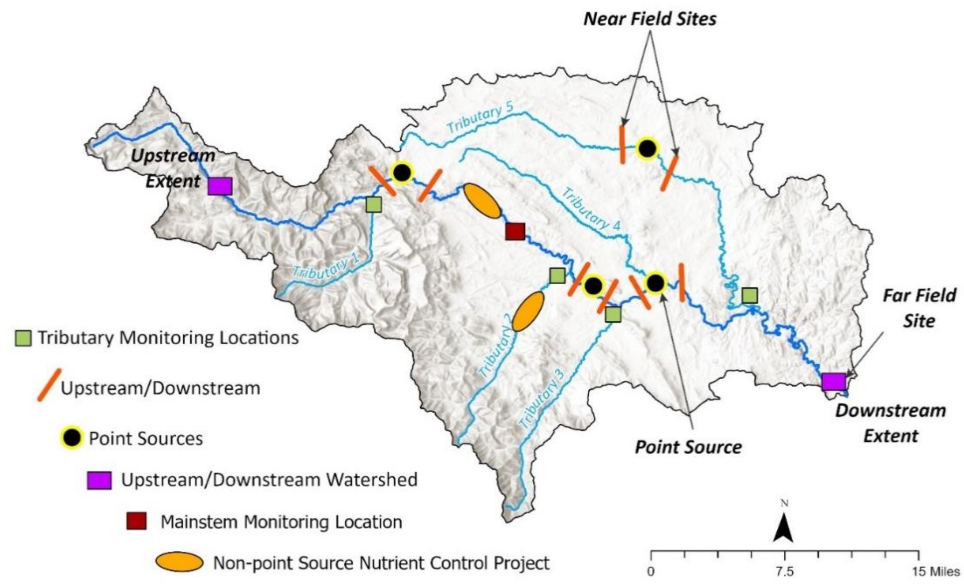

Figure 6-3. Example of a Complex AMP Watershed, Showing Different Types of Monitoring Sites.

6.6.2 Identifying All Partners that will Assist in Implementing Nutrient Reductions

Permittees must identify partners, including landowners, conservation districts, watershed groups, water quality districts, municipalities, counties, and others. Permittees and partners must work to target point and nonpoint sources of nutrients to minimize their overall fiscal outlays while achieving compliance with narrative nutrient water quality standards and improving water quality.

6.6.3 Develop and Document Action Items for the Reduction of Nutrients in the Watershed

As part of the watershed plan to achieve nutrient reductions, permittees must develop action items and milestones in accordance with the compliance schedule required in their permit. Evaluation of information from the near field upstream and downstream monitoring sites (**Section 6.5**, **Part II**, above) should be used to inform these decisions. A permittee may choose to improve their facility and/or proceed with a broader nitrogen (or nitrogen and phosphorus) focused watershed approach to address nonpoint sources and meet necessary nutrient reductions and achieve compliance.

6.6.3.1 Implementing Nonpoint Source Projects

A permittee may achieve nutrient reductions in the watershed through nonpoint source project implementation. A TMDL wasteload allocation, or WLA (more on TMDLs in **Section 10**), requires reasonable assurance that the load reduction expected will in fact be achieved. Permittees are advised to consider any current department best management practice guidance on this subject. All significant pollutant sources—including natural background, permitted point sources, and nonpoint sources—need to be quantified at the watershed scale so that the relative pollutant contributions and reductions can be determined. Because the effects of pollutants on water quality can vary throughout the year, assessing pollutant sources must include an evaluation of the seasonal variability of the pollutant loading in relation to the period that nutrient controls are in place (most commonly, the summer/fall index period). This loading and reduction analysis may be done using a department approved watershed-loading model and, in all cases, must be based on sound scientific and engineering practices.

Once necessary reductions have been calculated and allocated to nutrient sources, a permittee must select nonpoint source projects that will reduce nutrients to a level which will achieve the narrative nutrient standards in the waterbody point of compliance. Established watershed restoration plans and total maximum daily load documents (**Section 8.0**) should be consulted to synchronize sampling and reduce redundant efforts.

6.6.3.2 Nutrient Trading

A permittee may achieve nutrient reductions through nutrient trading. *See* **Department Circular DEQ-13**. Trading is an approach to achieving water quality standards in which a point source acquires pollutant reduction credits from another point source or a nonpoint source in the applicable trading region; these credits are then used to meet the source's pollutant discharge obligations.

6.6.4. Demonstrate the Ability to Fund and Implement Nutrient Reductions via a Watershed Plan

A permittee must demonstrate reasonable assurance through secured funding and landowner/partner agreements to implement nonpoint source projects in the watershed. Permittees who choose to invest in nonpoint source projects in the watershed to reduce nutrient loading must provide funding documentation in the AMP. This documentation must include enforceable written agreements—enforceable by the permittee—that document a commitment to fund, implement, and complete projects with stakeholders. The documentation must identify all stakeholders participating, include cost estimates, assign specific contribution amounts to each stakeholder, and identify timelines for project completion that include responsibilities for each project implementation step. The agreement must also specify the period nonpoint source controls will be maintained. If partners implement nutrient reduction actions in lieu of permittees, AMPs must include or reference enforceable written agreements reflecting commitments by partners to implement actions. Enforceable written agreements are the responsibility of permittees and will not be enforced by the department; however, permittees are responsible for the load reductions or other permit-limit adjustments made as a result of these agreements. Failure to implement agreed-upon projects according to AMP timelines must be reported in annual reports, may be considered a permit violation under Section 75-5-605, MCA, and may result in the department re-evaluating continued permittee eligibility in the program.

6.6.5 Continued Data Collection for Response Variables as Performance Indicators

Ongoing and potentially expanded collection and monitoring of response variables and thresholds, as well as nutrient concentrations, are the principal means by which the department will conclude if a waterbody is achieving the narrative nutrient standards. Data collection locations, frequency, and types must be linked to the action items and on-the-ground activities planned for a permittee's AMP; these actions in turn must inform any updates to the AMP watershed monitoring objectives, subject to department review and approval.

Data collection at the near field sites must be on-going and remain relatively consistent. However, data collection that best supports an AMP needs to be adaptive. For example, potential nutrient sources identified during a watershed inventory may prompt the selection of new or additional monitoring sites to quantify nutrient loads or isolate potential nutrient reduction projects. Initial characterization at tributary sites may clarify which tributaries contribute greater or lesser nutrient loads to the receiving waterbody and therefore may lead to tributary sites being added or discontinued. Additional or different monitoring sites—particularly far field sites—may be required to demonstrate effectiveness of nonpoint source reduction projects or to affirm achievement of the narrative nutrient standards. Far field sites may be required to demonstrate protection of downstream beneficial uses and to monitor changes over time.

6.6.6 Timeframes for Completing and Submitting Items in Sections 6.6.1 through 6.6.5; Annual Reports

Subject to department approval, a permittee, or multiple permittees collaborating on a single AMP, must identify the timeframe for completing and submitting to the department each of the components in **Sections 6.6.1** through **6.6.5** as part of their AMP (or updated AMP). Annual progress reports must be submitted to the department by March 31st and must address all relevant actions taken under the AMP implementation plan in the year prior to the report. Annual reports are required to maintain communication and accountability between the permittee(s) and the department. Additionally, annual reports provide the permittee(s) with the opportunity to modify their adaptive management strategy. Adjusted plans and accompanying justifications should be submitted with the annual report. Annual reporting must include electronic data submittal of collected biological, chemical, and physical measurements in a format provided by the department.

7.0 Large Rivers and Water Quality Models: Data Collection, Model Calibration and Validation, Simulating the Effect of Potential Management Activities

Permittees discharging to a large river should consult with the department as to the status of mechanistic modeling on the river segment where they discharge. Where models are developed or are nearing completion, modeling shall be used to examine the effects simulated point- and nonpoint source pollution management activities will have on a waterbody's beneficial uses and water quality.

Permittees on wadeable streams and medium rivers are not precluded from developing and using a mechanistic water quality model as part of their AMP. However, please note that developing water quality models is resource intensive.

For large rivers where a mechanistic model has not been developed and a model is not currently under development, NEW RULE II(4)(b) provides for a process similar to that for wadeable streams and medium rivers (phosphorus control first); however, there are applicable water quality causal variables and response variables specific to large rivers (see **Section 4.0** in **Part I**). Also, considerations about where to place monitoring sites will be different from smaller waterbodies. The department encourages permittees on large rivers where models are not developed nor are currently under development to undertake modeling work, but they should first consult the department and consider any current department guidance on the topic. Permittees pursuing a mechanistic model must conform with the requirements in this section.

The department may develop mechanistic water quality models for the state's large rivers (listed in **Table 1-1** in Part I), where feasible. Once calibrated and validated, the models must be used to derive phosphorus limits for MPDES permits that protect beneficial uses and achieve water quality standards along the modeled reach.

Field data to support model development serves multiple purposes. The data inform and constrain the range of model parameters. The data must be collected at a sufficient number of strategically selected sites to ensure that the built model can properly simulate the effect of different management options and their resulting effects on water quality. The data may also be used to determine if the narrative nutrient standards (and other water quality standards) have been achieved, per **Section 4.0** in **Part I**.

Figure 7-1 (reproduced from Chapra 2003)[10] shows the overall methodology for developing and using a mechanistic model in an AMP watershed. Once developed, the model becomes a decision support system (DSS) which involves the integration of science and data for waterbody and water quality management. AMPs for nutrient management that are model-based must follow the water-quality modeling process identified in **Figure 7-1**. The process starts with problem specification (i.e., nutrient management), and includes the water-quality modeling process (model selection, data collection for modeling, calibration and confirmation procedures, uncertainty analysis, and decision support, as detailed in the right side of the figure), and finally, use of the model-based DSS to evaluate beneficial use support and achievement of water quality standards. Since the DSS can directly simulate (1) management activity impacts on surface water and (2) hypothetical load reduction(s) necessary to achieve the narrative nutrient standards and other applicable water quality standards (dissolved oxygen and pH), the department will use the modeling results to inform MPDES permit limits. Simulation of potential management activities within the DSS must reasonably balance all factors impacting a waterbody while considering the feasibility of treatment options and the expected water quality improvements.

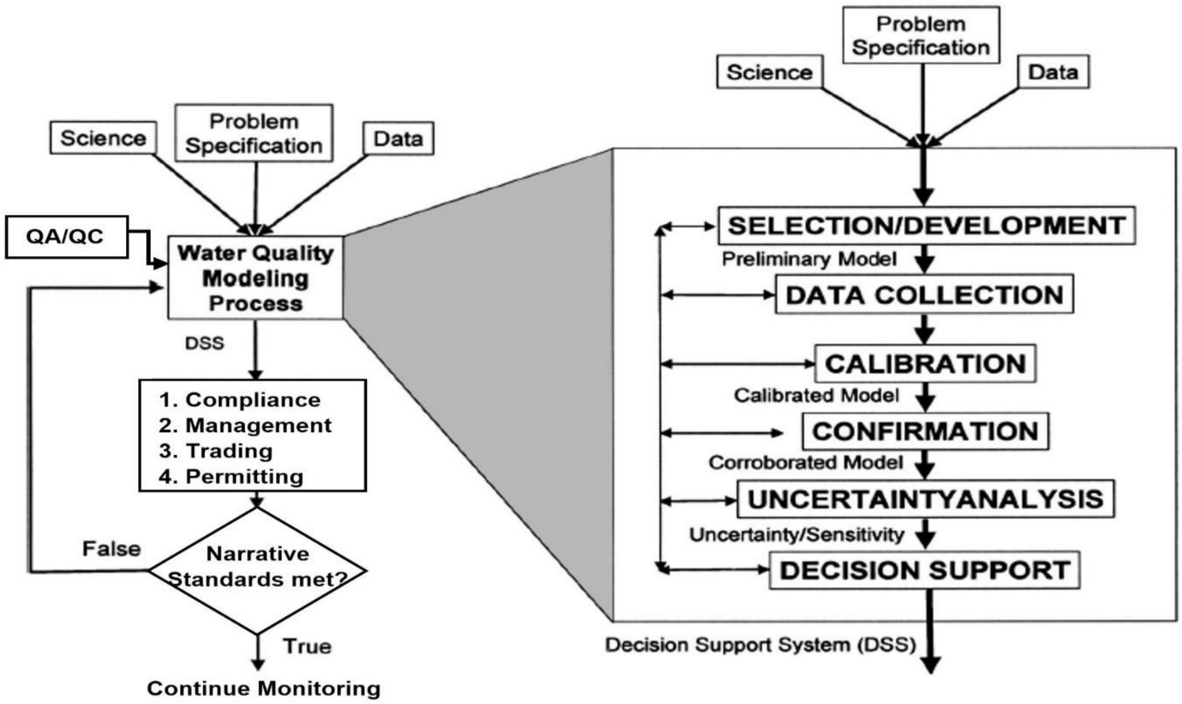

Figure 7-1. Process for Applying Water Quality Modeling in an AMP Watershed. The principal components for developing, calibrating, and confirming a model are contained in the break-out box shown on the right-hand side of the figure. The developed model then becomes a decision support system (DSS) for evaluating the effect of different management options, determining potential compliance pathways, and establishing permit limits.

7.1. TYPES OF MODELS AND MODELING REPORT REQUIREMENTS

The department and permittees shall use non-proprietary modeling tools for AMPs. This means using only standardized modeling applications that are readily available to the public, are widely supported by federal agencies, and are also well known through both professional and academic literature. In selecting a non-propriety modeling tool, permittees are advised to consider any current department guidance.

Once modeling activities are completed, the modeling process and application of its results must be documented in a report and referenced in the AMP. Reporting requirements will be project-specific but must include the following: (1) an executive summary; (2) numeric table of contents; (3) project information and background; (4) model overview; (5) model construction overview; (6) model parameterization section; (7) model calibration; (8) model confirmation; and (9) the final modeling results. The report must have sufficient detail to document all phases of the modeling project so that the process could be completed by an experienced user to generate similar modeling results. In developing models and the associated report, permittees are advised to consider any current department guidance.

7.2. Conceptual Water Quality Models

An alternative modeling approach to the mechanistic modeling methods described above is the development of a conceptual water quality model. Conceptual water quality models are a formal and rigorous process to identify stressors causing biological impairments in aquatic ecosystems (i.e., impacts to aquatic life beneficial uses), and a structure for organizing the scientific evidence supporting the conclusions. However, they do not provide for carrying out "what if" scenarios (e.g., "what will be the effect on diel pH fluctuations if the phosphorus load from source X is reduced by 25%?"), which is a distinct advantage of mechanistic models. The department must review and approve the use of a conceptual water quality model prior to inclusion in an AMP.

Permittees may develop conceptual water quality models to assess the array of factors which may be affecting their receiving waterbody and AMP watershed. This can include analysis of physicochemical factors which enhance or mute the effects of nutrients, analysis of conditions that may impact the macroinvertebrate community, etc. In developing conceptual models and the associated report, permittees are advised to consider any current department guidance.

8.0 Integration of the Adaptive Management Program with the Total Maximum Daily Load Program

When a waterbody or waterbody segment is not achieving the narrative nutrient standards and it is considered impaired by a pollutant, a total maximum daily load (TMDL) must be developed. To calculate the TMDL load allocations and wasteload allocations, the department will translate the narrative nutrient standards to TP and/or TN target values from the TN and TP concentrations derived from relevant studies (see translators in **Part I)** and nutrient concentrations in **Tables 2-3**and **4-1** in **Part I**. Once the TMDL is determined, reductions will be allocated to the significant source(s) of the pollutant to meet the TMDL.

Pollutant sources are characterized as either point sources, which receive a wasteload allocation (WLA), or as nonpoint sources, which receive a load allocation (LA). For purposes of assigning WLAs, point sources include all sources subject to regulation under the MPDES program. To the extent possible, the department shall coordinate TMDL development or revision in conjunction with active AMPs to promote robust data collection and analysis, detailed source assessment, and implementation efficiency and consistency. The department must then ensure that any effluent limits developed in MPDES permits are consistent with the requirements and assumptions of any available TMDL wasteload allocation.

8.1. TMDL Revisions

In situations where a permittee opts into the adaptive management program and a nutrient TMDL already exists, any TMDL revision must be based on 3-5 years of data collected through a department-approved AMP (this may include applicable, credible data collected after the TMDL was completed but before adoption of this circular). If response variable data indicate a different nutrient target concentration than used in the approved TMDL is more appropriate for achieving the narrative nutrient standards, the TMDL may be revised using the new target concentration. In this situation, any WLA will also be revised and the MPDES permit limit would subsequently be modified to reflect the new WLA, as appropriate. Revised TMDLs would be periodically evaluated based on AMP data collection efforts and subsequent reassessments.

Any changes or re-allocation between the WLA and LA or changes in the TMDL's loading capacity will be released for public comment and submitted to EPA for review and approval as a revised TMDL according to the same procedures as for a new TMDL. TMDL revisions shall be prioritized by the department in accordance with Section 75-5-702, MCA, through consultation with the Statewide TMDL Advisory Group, and based on data collected via an approved AMP.

Previously approved nutrient TMDLs with WLAs will remain in place until new data is acquired that could inform a new target value or values. For permittees opting into the adaptive management program in these areas, information may be added to the existing TMDL to outline options for implementation of the WLA. These document edits will take place in the form of an erratum that does not require public comment or resubmittal to EPA for approval.

Previously approved nutrient TMDLs without WLAs would not be prioritized for revision as part of the adaptive management program process, but they could be addressed if prompted by subsequent monitoring and assessment activities.

8.2. The Adaptive Management Program and Advance Restoration Plans

Under the EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act (CWA) Section 303(d) Program, EPA recognizes that there are cases in which pursuing advance restoration plans (ARPs) before developing a TMDL may provide a more immediate and practicable path to restore water quality. An ARP is a near-term plan for water quality improvement with a schedule and milestones that is accepted by EPA. Impaired waters for which the department pursues an ARP would remain on the CWA 303(d) list and still require a TMDL until all beneficial uses are attained. If beneficial uses are attained, the relevant waterbody-pollutant pairing would be removed from the CWA 303(d) list and a TMDL would no longer be required.

The department may submit AMPs to EPA for acceptance (but not under a formal approval process) as ARPs in watersheds impaired for nutrients with no existing TMDL. Acceptance of an AMP as an ARP may prompt the department to lower the priority ranking of TMDL development for the waterbody-pollutant pairing in question, in accordance with Section 75-5-702, MCA. Accepted ARPs would be evaluated on the same schedule as their accompanying AMPs to ensure they are still the most practicable path toward achieving water quality standards. If the ARP is determined not to be the most immediate and practicable approach to attain all beneficial uses, the department would require updates to the AMP and/or increase the priority ranking of TMDL development for the waterbody-pollutant pairing.

9.0 ENDNOTES

(1) Suplee, M.W., A. Varghese, and J. Cleland. 2007. Developing Nutrient Criteria for Streams: An Evaluation of the Frequency Distribution Method. *Journal of the American Water Resources Association* 43: 453-472.

(2) Suplee, M.W., V. Watson, A. Varghese, and J. Cleland. 2008. Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers. Helena, MT: Montana Dept. of Environmental Quality. *For more specificity, refer to scientific citations within the document*.

(3) Suplee, M.W., and V. Watson. 2013. Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers—Update 1. Helena, MT: Montana Dept. of Environmental Quality. *For more specificity, refer to scientific citations within the document*.

(4) Suplee, M.W., V. Watson, M. Teply, and H. McKee. 2009. How Green Is Too Green? Public Opinion of What Constitutes Undesirable Algae Levels in Streams. *Journal of the American Water Resources Association* 45: 123-140.

(5) Schulte, N.O., and J.M. Craine. 2023. Eutrophication Thresholds Associated with Benthic Macroinvertebrate Conditions in Montana Streams. Prepared for the MT Dept. of Environmental Quality by Jonah Ventures. October 5, 2023.

(6) *See* Gravelle, J.A., G. Ice, T.E. Link, and D.L. Cook. 2009a. Nutrient Concentration Dynamics in an Inland Pacific Northwest Watershed Before and After Timber Harvest. *Forest Ecology and Management* 257: 1663-167; and, Gravelle *et al.* 2009b. Effects of Timber Harvest on Aquatic Macroinvertebrate Community Composition in a Northern Idaho Watershed. *Forest Science* 55(4): 352-366. TN value was derived from post-harvest water-year averaged TN concentrations (NO_{2+3} + TKN) coupled with no observed detrimental effects on stream macroinvertebrates.

(7) Suplee, M.W. 2023. An Analysis of Daily Patterns of Dissolved Oxygen Change in Flowing Waters of Montana. Helena, MT: Montana Department of Environmental Quality.

(8) Decker-Hess, J. 1989. An Inventory of the Spring Creeks in Montana. Kalispell, MT; Montana Department of Fish, Wildlife, and Parks.

(9) Suplee, M.W., K.F. Flynn, and S.C. Chapra. 2015. Model-Based Nitrogen and Phosphorus (Nutrient) Criteria for Large Temperate Rivers: 2. Criteria Derivation. *Journal of the American Water Resources Association* 51: 447-470.

(10) Chapra, S.C. 2003. Engineering Water Quality Models and TMDLs. *Journal of Water Resources Planning and Management* 129: 247-256.

Montana Department of Environmental Quality

Guidance Document in Support of Circular DEQ-15

Translation of Narrative Nutrient Standards
and
Implementation of the Adaptive Management Program

Version 1.0 (*Draft*)

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Document Revision and Version History

Revision(s) and Date	Version number	Summary of change(s)	Revised sections(s)	Revised by

Executive Summary

This guidance document has been prepared in support of **Department Circular DEQ-15** (March 2024 edition). **Part I** of this document provides guidance for interpreting the narrative nutrient standards, while **Part II** offers guidance on developing and implementing adaptive management plans (AMPs) under the broader adaptive management program (§75-5-321, MCA). This document provides links to important department standard operating procedures (SOPs) and includes specific procedures which will help users in implementing their AMPs. It also provides detailed guidance pertaining to the development of mechanistic water quality models and guidance on conceptual models. Two example case studies have been provided in the document's appendices; one outlining a mechanistic modeling scenario, the other describing a more conventional data collection and assessment approach for implementing an AMP.

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Acronyms

AMP	Adaptive Management Plan
ARM	Administrative Rules of Montana
ARP	Advance Restoration Plan
BMP	Best Management Practice(s)
DMI	United States Drought Monitor Index
DO	Dissolved Oxygen
DSS	Decision Support System
EPA	United States Environmental Protection Agency
FWP	Montana Department of Fish, Wildlife & Parks
HUC	Hydrologic Unit Code (*of the* United States Geological Survey)
LA	Load Allocation
MCA	Montana Code Annotated
MOS	Margin of Safety
NSC	Normalized Sensitivity Coefficient
NSE	Nash and Sutcliffe Efficiency
PB	Percent Bias
QAPP	Quality Assurance Project Plan
RMSE	Root Mean Squared Error
SAP	Sampling and Analysis Plan
SC	Specific Conductivity
SOP	Standard Operating Procedure
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USGS	United States Geological Survey
WLA	Wasteload Allocation

GENERAL INTRODUCTION TO CIRCULAR DEQ-15'S SUPPORTING GUIDANCE DOCUMENT

In 2021 the 67th Montana Legislature adopted Senate Bill 358 (now 75-5-321, Montana Code Annotated (MCA)) which described a new process for implementing narrative standards for nutrients in Montana Pollutant Discharge Elimination Systems (MPDES) permits. Nutrients, in this context, refers to total phosphorus (TP) and total nitrogen (TN) concentrations in state surface waters. The narrative nutrient standards at Administrative Rules of Montana (ARM) 17.30.637(1)(e) — "State surface waters must be free from substances attributable to municipal, industrial, agricultural practices or other discharges that will: (e) create conditions which produce undesirable aquatic life" — are the main narrative standards the department has used to regulate the impacts of excess phosphorus and nitrogen in state waters. However, throughout the ARMs there are other standards that address unwanted water quality changes which link to excess nutrients (e.g., ARM 17.30.623(2)(c), which narratively describes allowable pH changes).

This guidance has been developed by the Department of Environmental Quality (department) to provide additional details in support of NEW RULE I, NEW RULE II, and **Department Circular DEQ-15**, which were adopted to conform with statutory requirements at 75-5-321, MCA. Like **Circular DEQ-15**, this guidance has two parts; **Part I** of this guidance addresses translation of the narrative nutrient standards, **Part II** addresses the adaptive management program. Some topics cross-over between the two parts and therefore, where appropriate, reference is made to the applicable sections of Part I and Part II in **Circular DEQ-15**.

Note: hyperlinks to web pages are provided throughout this document, however websites are frequently modified and may render these links outdated.

PART I: TRANSLATION OF THE NARRATIVE NUTRIENT STANDARDS

1.0 GUIDANCE SUPPORTING PART I, SECTION 1.0 OF CIRCULAR DEQ-15 (IDENTIFY WATERBODY SIZE)

To apply the correct translator in **Circular DEQ-15**, each waterbody must be identified as a wadeable stream, medium river, or large river. The department has identified large river segments in Montana (Flynn and Suplee, 2010) and they are presented in **Table 1-1**.

Table 1-1. Large River Segments within the State of Montana

River Name	Segment Description
Big Horn River	Yellowtail Dam to mouth
Clark Fork River	Bitterroot River to state-line
Flathead River	Origin to mouth
Kootenai River	Libby Dam to state-line
Madison River	Ennis Lake to mouth
Missouri River	Origin to state-line
South Fork Flathead River	Hungry Horse Dam to mouth
Yellowstone River	State-line to state-line

Some Montana waterbodies are not large (i.e., they are not listed in **Table 1-1** above) but they do not readily lend themselves to wadeable stream or medium river data collection methods. Segments of the Milk River are a good example (it frequently has steep banks and becomes unwadeable close to each bank). If a permittee discharges to such a waterbody and it is evident that wadeable data collection methods in this guidance and **Circular DEQ-15** cannot be performed safely and/or realistically, permittees should contact the department's Adaptive Management Program Scientist to decide on the best path forward for AMP monitoring and to discuss possible modifications to data collection methods (the department has experience with case-specific method modifications). Modeling may also be appropriate, as most data collection for modeling can be undertaken from boats or from shore.

2.0 GUIDANCE SUPPORTING PART I, SECTION 2.0 OF CIRCULAR DEQ-15 (WADEABLE STREAMS AND MEDIUM RIVERS: THE NARRATIVE NUTRIENT STANDARDS TRANSLATOR)

This section provides details pertaining to Section 2.0, Part I of **Circular DEQ-15**. In addition, some sections of **Part II** of the circular are addressed as well, as indicated.

2.1 Guidance Related to Allowable Exceedance Rates

Tables 2-1 and 4-1 in **Circular DEQ-15** provide allowable exceedance rates for specified response and causal variables found in the tables. These exceedance rates should be applied using the U.S. Environmental Protection Agency's (EPA's) Raw Score Method (EPA, 1997a). EPA's guidelines require a waterbody to be listed as impaired only if a specified percentage of collected samples violate a standard (EPA, 1997a). If the allowable exceedance rate were, for example, 10%, EPA's guidelines imply that a violation of the numeric criterion is acceptable for 10% of the samples taken.

See **Table 2-1** below. If, for example, a dataset contained 18 samples, and the allowable exceedance rate is 15%, up to three excursions above the threshold are allowed and the dataset will still be considered "Meets" per the attainment decision tables in Section 3.0 of **Circular DEQ-15**. Use **Table 2-1** below and the applicable exceedance rates in **Circular DEQ-15** to assess datasets. A minimum of four samples per dataset is recommended.

Table 2-1. Raw Score Critical Values for 10%, 15%, and 20% Allowable Exceedance Rates as Found in Circular DEQ-15.

Raw score allowable exceedence frequencies, n=4 minimum.			
Sample Size	10% Allowable Exceedence: Conclusion is "Exceeds" if excursions are greater than:	15% Allowable Exceedence: Conclusion is "Exceeds" if excursions are greater than:	20% Allowable Exceedence: Conclusion is "Exceeds" if excursions are greater than:
1-5	1	1	1
6-10	1	2	2
11-15	2	3	3
16-20	2	3	4
21-25	3	4	5
26-30	3	5	6
31-35	4	6	7
36-40	4	6	8
41-45	5	7	9
46-50	5	8	10

2.2 Guidance Related to Identifying Appropriate Response Variables and Thresholds (Addressing Elements of Part I, Section 2.0, and Part II, Section 6.1 of Circular DEQ-15)

2.2.1 Identifying the Most Suitable Translator for Waterbody Segments near the Boundaries of Stream Slope and Macroinvertebrate Zones

As discussed in **Circular DEQ-15**, near the boundaries of some western and transitional ecoregions there are wadeable stream and medium river reaches that—due to their water surface slope being ≤1%—may be better assessed using the translator for the ≤1% Stream Slope/Low Valley and Transitional macroinvertebrate zones. For such cases, stream slope in the reach should be measured in the field via laser level using methods in **Part I**, **Section 2.3.2** of this guidance. In addition to water surface ≤1%, other characteristics that may justify a near-ecoregion boundary waterbody being viewed as a low gradient site are:

- Stream substrate more dominated by small gravels and sand rather than gravels and cobbles;
- Presence of sparse macrophyte (aquatic vascular plant) populations; and
- Glides with minimal water surface disturbance interspersed between more turbulent riffles and runs in the longitudinal geomorphic pattern.

The opposite situation, although less likely, could occur as well. A reach of stream in an ecoregion of the Low Valleys and Transitional macroinvertebrate zone could have water surface slope >1%, substrate dominated by gravels and cobbles, no macrophytes, have turbulent riffles and few or no glides. It would be more suitable to apply the >1% Stream Slope/Mountains translator to this reach.

Data supporting these considerations needs to be documented and provided to the department's Adaptive Management Program Scientist and will, per Circular DEQ-15, require department review and approval as site specific standards, followed by EPA review and approval.

2.2.2 Identifying Waterbody Beneficial Use Classification, Watershed, and Applicable Translator

Per Section 6.1, Part II of **Circular DEQ-15,** upon submittal, an AMP must describe which stream slope and macroinvertebrate zone apply to the AMP watershed, along with a justification. AMPs are based on watershed hydrologic unit codes (HUCs); however, data collection requirements are based on ecoregions (**Circular DEQ-15**). Ecoregions are mapped regions of relative homogeneity in ecological systems derived from perceived patterns of a combination of causal and integrative factors including land use, land surface form, potential natural vegetation, soils, and geology (Omernik, 1987). The department uses ecoregions to describe regions of relative ecological uniformity for data collection and application of stream macroinvertebrate populations, diatom algae populations, and ambient stream nutrient concentrations (Teply, 2007, 2010a, 2010b; DEQ, 2012; Suplee et al., 2008; Suplee and Watson, 2013). Ecoregions are based on the 2002 version (version 2) of the U.S. Environmental Protection Agency map, found at: https://www.epa.gov/eco-research/ecoregion-download-files-state-region-8#pane-24 .

HUC information is provided by the U.S. Geological Survey (USGS) and can be found at https://nas.er.usgs.gov/hucs.aspx . Because AMPs are based on HUCs and data collection requirements are based on ecoregions cases may arise where, for example, data collection requirements for both the transitional and the eastern ecoregional zones may apply in the same watershed.

In such cases, permittees and others should carry out a geographic information system (GIS) analysis and establish which ecoregions encompass most of the area in their watershed. For permittees, the location of the point source in the watershed in relation to the ecoregional zone boundaries in the watershed and the areal proportion of each ecoregion upstream of that site should be considered. This work should be coupled with an on-the-ground reconnaissance in the AMP watershed to ensure that the waterbody reach generally reflects the underlaying expectation of the region as described in Section 2.3.4 of **Circular DEQ-15**.

Field reconnaissance should also consist of site visits documented by a longitudinal series of stream photographs. Additional data (e.g., stream substrate D_{50}, Rosgen and Silvey, 1996; rapid visual assessments per the department's Aquatic Plant Visual Assessment Form in the standard operating procedure at https://deq.mt.gov/files/Water/WQPB/QAProgram/Documents/WQPBWQM-011v8.pdf) will also be helpful. These data, along with the geospatial analysis described above, will greatly aid the department's review of the submitted justification. Note in particular: does the waterbody tend to develop long algal streamers (filaments) but has only very few macrophytes? If so, the response variables for the western and transitional ecoregions are probably the better fit. Some transitional ecoregions are known, based on department reference sites (Suplee et al., 2005), to have naturally higher benthic algae density than is typically found in the ecoregions to the west (e.g., the Rocky Mountain Front Foothill Potholes [42q]; Suplee and Watson, 2013). In such cases, if benthic algae measurements are the most appropriate response variables for the AMP watershed, a higher benthic chlorophyll *a* (Chl*a*) threshold may be justified.

Additional data, for example the receiving waterbody's fisheries population from Montana Fish, Wildlife, and Park's online database, will be very helpful and the department highly recommends that they be reviewed. Please see their searchable database at https://myfwp.mt.gov/fishMT/reports/surveyreport to determine the type of fish which have been documented in the stream. See **Appendix A** for a case study using stream fish.

2.3 Guidance Supporting Section 2.3.3 of Circular DEQ-15 (Wadeable Streams and Medium Rivers in the Low Valleys and Transitional Macroinvertebrate Zone: Effects of Specific Conductivity)

Adjustments to the Low Valley and Transitional Beck's Biotic Index (v3) threshold in Table 2-1 of **Circular DEQ-15** may be carried out as follows. For a given Beck's Biotic Index (v3) score in the Low Valleys and Transitional zone, add the y-axis value corresponding to a site's natural background specific conductivity (SC) from the residual plot (per **Figure 2-1** below) to the applicable Beck's threshold (18.7). **Appendix B** contains a SC vs. Beck's residuals look-up table which can be used to identify incremental Beck's adjustment values in the natural background SC range of 80-810 µS/cm. The relationship is the most well defined to the right of a log10Conductance of ~1.9 (80 µS/cm), and then up to ~2.91 (812 µS/cm), therefore adjustments should only be considered for natural background SC values in this range. Starting at log10(Conductance) = 2.3 (equal to 200 µS/cm), expected values of Beck's would be less than the values from the logistic model. How much less depends on the y value at a site's natural background SC. At SC of ~562 µS/cm (log10[conductance] = 2.75), the expected Beck's score from the logistic plot is reduced by ~5 (residual plot y = -5), allowing the threshold to drop from 18.7 to 13.7 at a natural background SC of 562 µS/cm.

Data supporting site-specific adjustments, including an analysis of the natural background SC, needs to be documented and provided to the department's Adaptive Management Program Scientist, and will require department review and approval followed by EPA review and approval as site specific standards.

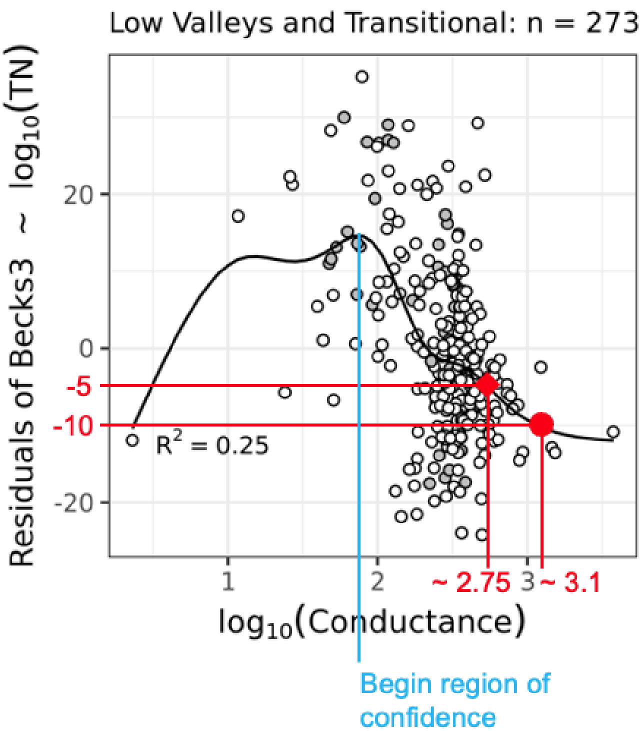


Figure 2-1. Use of Residual Analysis Plot to Identify Candidate Adjustment Values for the Beck's Biotic Index (v3) Based on a Site's Specific Conductivity. See also, Appendix B.

2.4 Guidance Supporting Section 2.4 of Circular DEQ-15 (Data Collection Index Period, Minimum Data Collection)

2.4.1 Adjustments to a Data Collection Index Period

The index period (aka growing season) during which AMP response variable data are collected has a maximum range of June 16 to September 30 annually and varies by ecoregion. Per **Circular DEQ-15**, the index period may be modified to include earlier or later dates on a case-by-case basis, subject to department review and approval.

Index period start and end dates were based on average regional biological and hydrograph patterns as described in Suplee et al. (2007), but individual streams may depart from the average. If a permittee believes it may be necessary to adjust the data collection index period for their receiving waterbody, the department recommends using flow from a stream gage as close to and on the same waterbody as the point source. Data should reflect conditions over the past 10 years. The data can be used to estimate what the best—on average—sampling period may be for the waterbody. For example, as can be seen from the 10-year hydrograph from the East Gallatin River in **Table 2-2**, the first two weeks of July have higher flows (about 2.5 times higher) compared to later in July, August, and September (see dark gray days in **Table 2-2**). In this case, commencing July sampling sometime after July 14 would exclude the higher flows and lead to better baseflow data collection more consistent with the bulk of the index period. (Note that for this example no department approval would be required to alter the initiation of sampling, as sampling would still fall within the annual index period of July 1 to September 30 applicable to this ecoregion.) To move the sampling season earlier than July 1, the department would need to be presented with a site-specific hydrograph similar to that in **Table 2-2** but showing that stable and representative base flows are already achieved in June. Further, if the request included an extension into the first half of June, water temperature data would also need to be provided to confirm that water temperatures were not unusually low at that time (due to it being early in the season) compared to later in the index period.

Sampling might also extend into the first two weeks of October, if temperatures remain moderate and base flow conditions remain reasonably stable (Suplee and Sada de Suplee, 2016). Local flow and water temperature data, and nearby weather station data would be needed to support such a change, subject to department review and approval per **Circular DEQ-15**.

Table 2-2. Discharge (ft3/sec) for USGS gage 06048700 "East Gallatin River at Bozeman, Mont." Values shown are the average daily flows over the 2001 to 2011 period. Darker gray areas show time periods within the index period when flows are still elevated relative to the rest of the sampling index period.

Day of month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	42	47	45	118	283	433	164	52	43	40	55	47
2	44	43	44	128	267	441	155	51	42	41	55	47
3	44	42	46	124	268	453	147	53	39	42	57	47
4	41	43	48	112	297	433	142	53	37	44	56	47
5	43	44	47	121	295	418	141	51	39	48	55	47
6	43	47	46	148	328	425	130	52	42	50	53	47
7	41	44	46	139	364	479	124	51	43	51	55	46
8	46	44	52	140	379	461	118	52	41	51	62	43
9	44	42	54	149	376	440	108	54	43	52	60	43
10	42	42	56	157	380	443	102	52	50	52	56	44
11	41	42	58	155	373	513	101	49	45	52	56	46
12	42	42	70	164	373	501	97	46	41	53	56	46
13	43	42	88	182	377	465	94	45	42	52	57	45
14	44	42	88	218	404	436	90	45	42	52	56	45
15	43	41	80	232	439	420	84	47	43	55	52	45
16	42	41	80	212	442	404	81	44	42	59	55	43
17	44	41	81	229	464	390	78	44	44	61	54	42
18	46	41	86	239	484	359	75	47	45	59	53	41
19	51	42	89	235	509	335	73	46	44	59	53	43
20	48	40	88	231	528	310	68	42	44	66	52	44
21	47	41	93	254	523	299	66	41	46	63	49	45
22	44	41	94	279	505	277	66	41	47	58	47	44
23	44	41	94	324	495	264	67	45	48	56	48	46
24	44	41	90	315	500	247	62	43	49	56	46	44
25	43	41	89	290	615	237	63	41	46	57	48	45
26	43	42	95	293	540	228	64	41	43	55	50	46
27	47	43	93	270	502	209	63	39	42	55	48	44
28	46	43	95	266	475	195	61	39	42	55	47	44
29	44	41	91	274	490	183	55	41	42	57	46	46
30	45		97	295	466	175	51	41	44	57	47	44
31	43		104		444		50	43		56		43

2.4.2 Measuring Water Surface Slope

Once a monitoring reach has been established, a series of 11 transects within the reach are set at a distance 1/10th the length of the study reach. To measure water surface slope a laser level is placed on the bank in a mid-reach location where it is visible to the largest proportion of the reach possible. The rod person establishes an elevation (water surface to laser plane) at the most downstream transect that can be picked up by the laser. The rod person then moves upstream to the next visible transect flag, or even further upstream to the next (or beyond) if the laser will pick it up. Ideally the entire reach (most downstream transect to most upstream transect) can be picked up by the laser, but interference from trees/brush will likely limit the number of transects measured; a minimum distance of three contiguous transects within the reach should be shot with the laser. The contiguous transects encompassing the most downstream to most upstream laser rod measurements provide the longitudinal distance (run).

Water surface slope is determined as in the following example. In this example, trees and brush obscured the laser readings from transect E and further upstream.

Downstream Distance (transect A) = 0.0 ft
Upstream Distance (transect D) = 150.0 ft
Total Distance (run) = 150. ft
Downstream Water Surface to laser elevation = 10.87 ft
Upstream Water Surface to laser elevation = 6.22 ft
Elevation Change (rise) = 4.65 ft

$$SLOPE\ (\%) = \frac{rise}{run}\ x\ 100 = \frac{4.65ft}{150.0ft}\ x\ 100 = 0.031\ x\ 100 = 3.1\%$$

2.4.3 Standard Operating Procedures for Collecting Nutrient Concentration, Response Variable, and Other Data

Table 2-3 provides links to department standard operating procedure (SOP) documents associated with the collection and evaluation of nutrient and response variable data. The SOPs provide detailed instructions on all aspects of collecting data associated with each parameter and should be followed in their entirety.

In addition, the department's Water Quality Planning Bureau maintains a list of water quality sample parameters (e.g. nutrients, metals, common ions, etc.) and their associated sample bottle type, preservation, allowable holding times, analytical reporting limits, etc. This list is periodically updated as reporting limits change, etc. Users of this guidance document should contact the department's Adaptive Management Program Scientist to get the latest version of this list to ensure their data-collection work corresponds to the current department protocols.

Table 2-3. Hyperlinks to Department Standard Operating Procedures (SOPs) Addressing each of the Parameters Shown

Parameter	Applicable Ecoregions	Standard Operating Procedure (SOP) Hyperlink
Water Surface Slope (%)	Western and Transitional	See **Section 2.4.2** of this document
Benthic Algal Chlorophyll *a* (Chl*a*), Benthic Algal Ash Free Dry Weight	Western and Transitional	https://deq.mt.gov/files/Water/WQPB/QAProgram/Documents/WQPBWQM-011v8.pdf
% Bottom Cover by Filamentous Algae	Western and Transitional	https://deq.mt.gov/files/Water/WQPB/QAProgram/Documents/WQPBWQM-011v8.pdf
Instream Dissolved Oxygen Data	Western, Transitional, and Eastern	https://deq.mt.gov/files/Water/WQPB/QAProgram/Documents/SOP_SmallDataLoggers_WQDWQPBFM-07_Final.pdf
Macroinvertebrates	Western and Transitional	https://deq.mt.gov/files/Water/WQPB/QAProgram/Documents/WQPBWQM-009_rev3_Final.pdf
Nutrient Concentrations	Western, Transitional, and Eastern	https://deq.mt.gov/files/Water/WQPB/QAProgram/Documents/SOP_ChemistrySampling_WQDWQPBFM-02_2019_Final.pdf

2.4.4 Reducing a Continuous Dissolved Oxygen (DO) Dataset to Daily DO Delta Values and Computing a 7-day Moving Average DO Delta

The department recommends the PME MiniDOT dissolved oxygen (DO) and temperature logger for continuous monitoring of DO. Other instruments (e.g., YSI EXO2 or EXO3 sondes) are also excellent for this work, but they are larger and more expensive because they can collect many more water quality variables than are needed here, and their data files will require more manipulation to use the department's Delta Calculator.

Continuous DO datasets must undergo quality control with data flags applied according to applicable department SOPs. Continuous DO datasets can then be reduced to daily DO delta values (i.e., daily DO maximum minus the daily DO minimum) using an Excel spreadsheet tool ("Delta Calculator") available from the department (check with the Adaptive Management Program Scientist). To use the Delta Calculator, continuous data files need to be formatted as shown in **Figure 2-2** or the Delta Calculator will not function. Critical components are:

- Provide a Staton ID name in cell B1.
- The instrument's logging interval (minutes) must be entered in cell B5 as a number.
- Launch, deployment, and retrieval times must be entered in cells B6 to B8 formatted as shown.
- The order of the columns (see headers in rows 19, 20) from left to right <u>must be as shown</u>. Mountain Standard Time (column C) must be formatted as shown; the program uses this time column to compute daily DO delta.
- You will need to have added the two flag columns to the spreadsheet, they are not part of any instrument output.
- The first row of continuous data must begin on row 21.
- When finished, the formatted tab must be the tab furthest to the left in the Excel file, or be the only tab in the file, and the file must be saved as a Microsoft Excel Worksheet.

	A	B	C	D	E	F	G	H	I	J	K
1	Station ID:	C03BLACR01									
2	Activity ID:	S4711	S6207								
3	Serial Number:	176381									
4	Logger Make/Model:	MiniDOT									
5	Interval (min):	10									
6	Launch Date/Time:	8/6/2023 9:23									
7	Deployment Date/Time:	8/6/2023 9:35									
8	Retrieval Date/Time:	8/31/2023 15:36									
9	Retrieval Comments:	Sensor face is clear, some algae on housing body. Still in flowing water, does not seem to be disturbed.									
10											
11											
12	FLAG CODES										
13	R: Data rejected (same general definition in modern STORET).										
14	BD: Calibration Drift was beyond QAPP criteria.										
15	DX: Deployed YSI 6600 data differed from the cross-check YSI 6600 instrument.										
16	II: Interference with instrument readings from material (e.g., filamentous algae) caught on YSI or deployer.										
17											
18											
19	Unix Timestamp	UTC_Date_&_Time	Mountain Standard Time	Temperature		Dissolved Oxygen	Dissolved Oxygen Saturation		Q	Battery	
20	(Second)	(none)	(none)	(deg C)	TEMP FLAG	(mg/l)	(%)	DO FLAG	(none)	(Volt)	
21	1691336040	2023-08-06 15:	2023-08-06 09:34:00	17.972	R	8.197	86.537308	R	0.957	3.55	
22	1691336640	2023-08-06 15:	2023-08-06 09:44:00	15.789		8.208	82.786644		0.956	3.55	
23	1691337240	2023-08-06 15:	2023-08-06 09:54:00	15.635		8.284	83.279233		0.958	3.54	
24	1691337840	2023-08-06 16:	2023-08-06 10:04:00	15.584		8.335	83.700694		0.958	3.54	
25	1691338440	2023-08-06 16:	2023-08-06 10:14:00	15.549		8.378	84.069574		0.958	3.54	
26	1691339040	2023-08-06 16:	2023-08-06 10:24:00	15.541		8.408	84.356177		0.958	3.54	

BlackfootR

Figure 2-2. Screenshot of a Correctly Formatted Continuous DO Dataset.

The Delta Calculator spreadsheet has an input tab (Control) with a run button, and an Output tab (**Figure 2-3)**. The file path to where the formatted, continuous datasets are located on your computer must be provided in cell B2. File names to be processed must be listed starting in cell B3 (provide at least two files) and the names must include the suffix after the period (.xlsx). When all files are ready, click the run button and all daily DO delta values will be computed and pasted in the Output tab. Daily DO deltas that did not pass QC (e.g., there were too many flagged data during a particular day) will be shown as -99999.00 in the Output tab; these values should later be deleted. The Output tab will include additional data besides DO delta (e.g., daily DO minimum, daily average water temperature).

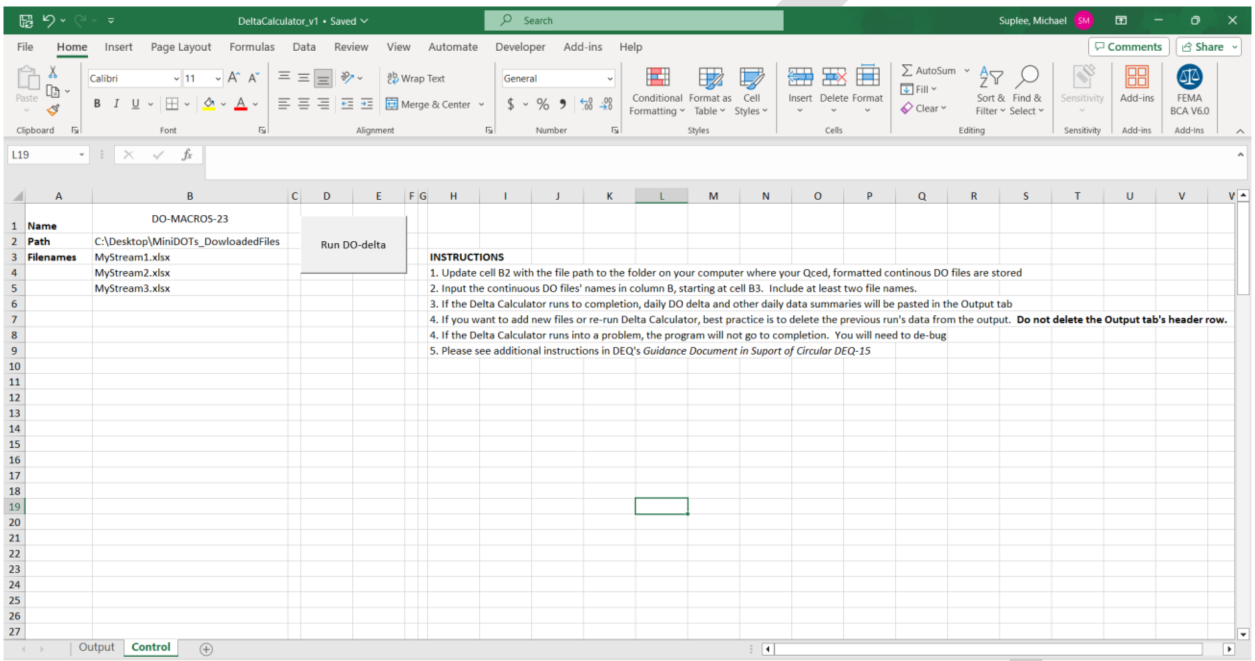
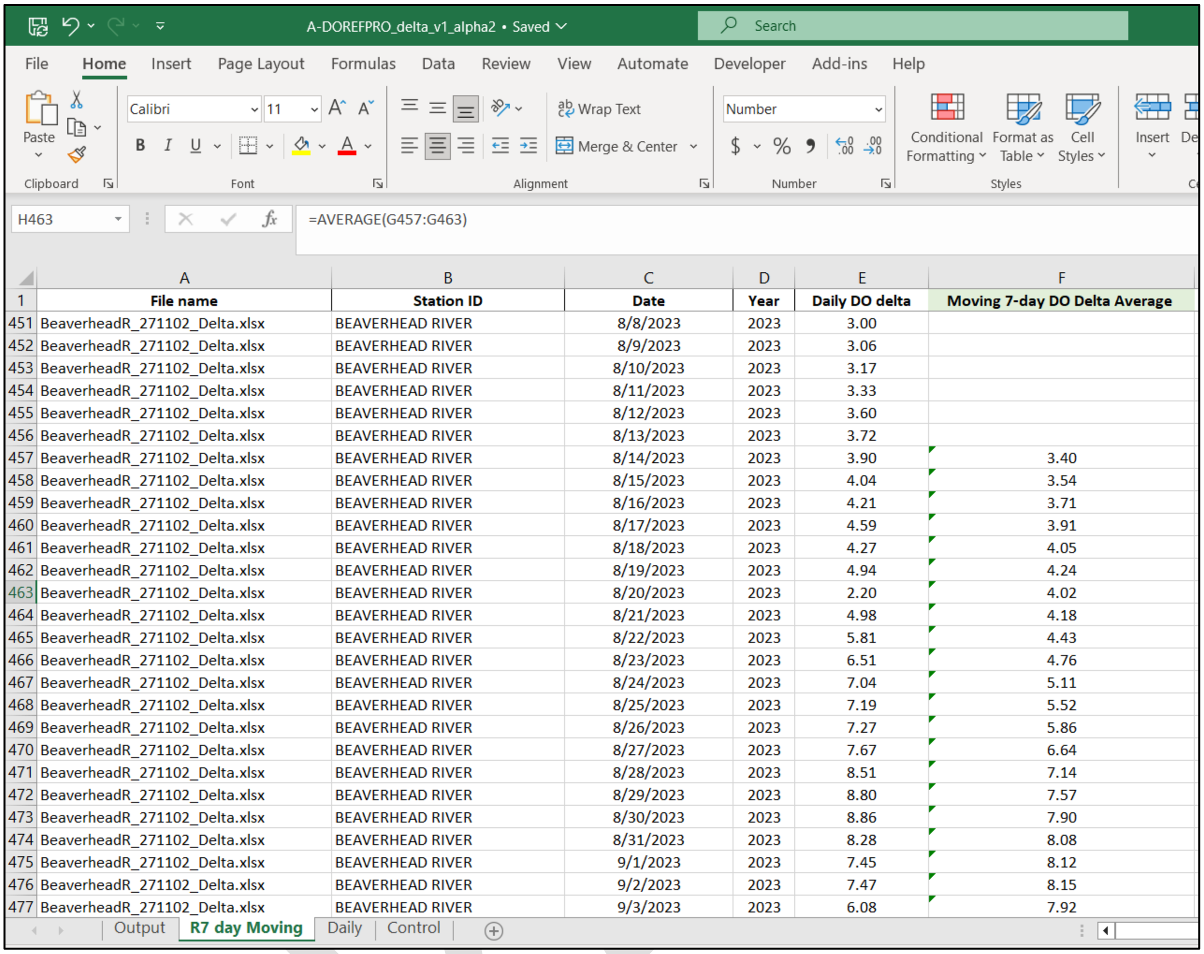


Figure 2-3. Screenshot of the Delta Calculator's Control Tab.

2.4.4.1 Computing a 7-day Moving Average DO Delta

A 7-day moving average is computed from daily DO deltas (**Figure 2-4**, column F). The daily DO delta dataset will require a minimum of eight days of data to compute more than a single 7-day moving average.



	File name	Station ID	Date	Year	Daily DO delta	Moving 7-day DO Delta Average
451	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/8/2023	2023	3.00	
452	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/9/2023	2023	3.06	
453	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/10/2023	2023	3.17	
454	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/11/2023	2023	3.33	
455	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/12/2023	2023	3.60	
456	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/13/2023	2023	3.72	
457	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/14/2023	2023	3.90	3.40
458	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/15/2023	2023	4.04	3.54
459	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/16/2023	2023	4.21	3.71
460	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/17/2023	2023	4.59	3.91
461	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/18/2023	2023	4.27	4.05
462	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/19/2023	2023	4.94	4.24
463	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/20/2023	2023	2.20	4.02
464	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/21/2023	2023	4.98	4.18
465	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/22/2023	2023	5.81	4.43
466	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/23/2023	2023	6.51	4.76
467	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/24/2023	2023	7.04	5.11
468	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/25/2023	2023	7.19	5.52
469	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/26/2023	2023	7.27	5.86
470	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/27/2023	2023	7.67	6.64
471	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/28/2023	2023	8.51	7.14
472	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/29/2023	2023	8.80	7.57
473	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/30/2023	2023	8.86	7.90
474	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	8/31/2023	2023	8.28	8.08
475	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	9/1/2023	2023	7.45	8.12
476	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	9/2/2023	2023	7.47	8.15
477	BeaverheadR_271102_Delta.xlsx	BEAVERHEAD RIVER	9/3/2023	2023	6.08	7.92

Figure 2-4. Screenshot of 7-Day Moving Average Computed from a Dataset of Daily DO Deltas.

2.4.5 Macroinvertebrates: Calculating Beck's Biotic Index (version 3)

Beck's Biotic Index (v3) is calculated based on taxa tolerance values ("TOLVAL") which are found in Appendix A of DEQ (2012) available at: https://deq.mt.gov/water/Programs/Monitoring.

Beck's Biotic Index (v3) is computed as follows:

Beck's Biotic Index (v3) = 3•TV0 + 2•TV1 + 1•TV2

Where TV0 is the number of taxa (*not* individuals) in the sample with tolerance value 0 (zero), TV1 is the number of taxa (*not* individuals) in the sample with tolerance value 1, and TV2 is the number of taxa (*not* individuals) in the sample with tolerance value of 2.

3.0 Guidance Supporting Part I, Section 3.0 of Circular DEQ-15 (Wadeable Streams and Medium Rivers: Use of Data to Determine if Beneficial Uses are Protected and Narrative Nutrient Standards are Achieved)

Per Table 3-5 in **Circular DEQ-15**, a drought index is used in eastern Montana ecoregions to identify time periods when DO delta datasets may be excluded from use in the narrative nutrient standards translator. Details are provided below.

3.1 Background on the Drought Index

Agencies within National Oceanic and Atmospheric Administration (NOAA) and the US Department of Agriculture (USDA) teamed with the National Drought Monitoring Center (NDMC) to produce a weekly US Drought Monitor Index (DMI) product that incorporates climatic data and professional input from all levels (Svoboda, 2000). Since no single definition of drought works in all circumstances, the DMI authors rely on the analyses of several key indices and ancillary indicators from different agencies to create a final index (Heim, 2002). Key parameters (**Table 3-1**) include the Palmer Drought Index (PMDI), the Crop Moisture Index, soil moisture model percentiles, daily streamflow percentiles, percent of normal precipitation, topsoil moisture (percent short and very short) generated by the USDA, and a satellite-based Vegetation Health Index. The ancillary indicators include the Surface Water Supply Index, the Keetch–Byram Drought Index, the Standardized Precipitation Index, snowpack conditions, reservoir levels, groundwater levels determined from wells, USDA reported crop status, and direct *in situ* soil moisture measurements.

GLEC (2021) shows that drought affects DO delta and that a useful drought index is the "number of consecutive weeks at a drought severity of D_{ZERO}" (first row, **Table 3-1**). GLEC (2021) showed the break point between drought and non-drought periods is six consecutive weeks at D_{ZERO}. **That is, ≤6 consecutive weeks at D_{ZERO} are non-drought periods, while >6 consecutive weeks at D_{ZERO} are drought periods; this drought criterion should be used for compliance with Circular DEQ-15 requirements.**

Table 3-1. Key Parameters Comprising the US Drought Monitor Index D0 through D4 Categories along with Possible Impacts

			Ranges				
Category	Description	Possible Impacts	Palmer Drought Severity Index (PDSI)	CPC Soil Moisture Model (Percentiles)	USGS Weekly Streamflow (Percentiles)	Standardized Precipitation Index (SPI)	Objective Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	Going into drought: ▪ short-term dryness slowing planting, growth of crops or pastures Coming out of drought: ▪ some lingering water deficits ▪ pastures or crops not fully recovered	-1.0 to -1.9	21 to 30	21 to 30	-0.5 to -0.7	21 to 30
D1	Moderate Drought	▪ Some damage to crops, pastures ▪ Streams, reservoirs, or wells low, some water shortages developing or imminent ▪ Voluntary water-use restrictions requested	-2.0 to -2.9	11 to 20	11 to 20	-0.8 to -1.2	11 to 20
D2	Severe Drought	▪ Crop or pasture losses likely ▪ Water shortages common ▪ Water restrictions imposed	-3.0 to -3.9	6 to 10	6 to 10	-1.3 to -1.5	6 to 10
D3	Extreme Drought	▪ Major crop/pasture losses ▪ Widespread water shortages or restrictions	-4.0 to -4.9	3 to 5	3 to 5	-1.6 to -1.9	3 to 5
D4	Exceptional Drought	▪ Exceptional and widespread crop/pasture losses ▪ Shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0 to 2	0 to 2	-2.0 or less	0 to 2

3.2 Determining the Area- and Time-weighted Drought Index

As discussed in **Section 3.1** above, ≤6 consecutive weeks at D_{ZERO} are non-drought periods, while >6 consecutive weeks at D_{ZERO} are drought periods; this drought criterion should be used for compliance with **Circular DEQ-15** requirements.

Drought severity and longevity data can be downloaded as a comma-separated Excel file at https://droughtmonitor.unl.edu/DmData/DataDownload/WeeksInDrought.aspx . Make sure to select D0 (D_{ZERO}) and a time-period corresponding to the period when the DO measuring instrument was deployed instream; all Montana counties will be downloaded for the period you select.

In some cases, the watershed you are evaluating will be contained within one or more counties which are all experiencing the same drought level (i.e., they all have either ≤6 consecutive weeks at D0 or >6 consecutive weeks at D0). **In this case no further geospatial analysis is necessary, you can conclude that the prevailing drought conditions for those counties and times apply to your dataset during the time period identified.**

However, in some cases a watershed will be split between counties experiencing different drought conditions during the same time period and a more sophisticated GIS method is needed. Data need to be aggregated over different areal extents and time periods relative to the sampling station and their associated drainage areas, as detailed next.

The number of consecutive weeks at drought severity level D0 in a watershed is computed as a weighted sum where the weights represent the percent area of the specified county existing within the drainage basin polygon. This integration is represented as:

 # consecutive weeks at drought severity level $D0_{AMP}$ = [% $area_{AMP}$ in $CNTY_a$ × # consecutive weeks at drought severity level $D0_{CNTYa}$] + [% $area_{AMP}$ in $CNTY_b$ × # consecutive weeks at drought severity level $D0_{CNTYb}$] + [% $area_{AMP}$ in CNTYc × # consecutive weeks at drought severity level $D0_{CNTYc}$]

where **# consecutive weeks at drought severity level $D0_{AMP}$** is the weighted drought index for a specific AMP watershed, and CNTY a, b, and c are three counties that intersect the boundary of the AMP watershed. Further, % $area_{AMP}$ in $CNTY_a$ is the percent of the AMP watershed total area in $CNTY_a$ and so on for $CNTY_b$ and $CNTY_c$. Also note that $\sum$ % $area_{AMP[a,b,c]}$ = 100.

The resulting spatial-temporal integrated number of consecutive weeks in the watershed at drought severity level D0 can then be compared to the 6-week cutoff.

PART II: IMPLEMENTATION OF THE ADAPTIVE MANAGEMENT PROGRAM

1.0 GUIDANCE SUPPORTING PART II, SECTION 1.0 OF CIRCULAR DEQ-15 (INTRODUCTION TO THE ADAPTIVE MANAGEMENT PROGRAM)

1.1 PROGRAM ELIGIBILITY REQUIREMENTS

Permittees opting to enter the adaptive management program must meet the eligibility requirements outlined in **Circular DEQ-15**. In addition, before entering the program there are key considerations to consider:

- Resources: Does the point source have the financial and personnel resources to conduct the required monitoring and implementation?

- Measurable impacts: Are there multiple nonpoint sources within the watershed with which a partnership could be formed and result in a measurable reduction in nutrient loads?

- Fees: If a permittee chooses to withdraw from the adaptive management program, but then decides to re-enter, the permittee must reapply and resubmit fees.

To assist in determining if the adaptive management program is feasible for a point source, the department's Adaptive Management Program Scientist is available for consultation.

2.0 GUIDANCE SUPPORTING PART II, SECTION 2.0 OF CIRCULAR DEQ-15 (DETERMINING IF PHOSPHORUS PRIORITIZATION IS APPROPRIATE)

Readers should refer to the department's SOP for preparing, deploying, recovering, and analyzing nutrient diffusing substrates (NDS), found at:

---PLACEHOLDER FOR WEB HYPERLINK WHEN DOCUMENT IS POSTED---

Examples of results from NDS racks deployed in Montana rivers and streams are shown in **Figure 2-1**. The figure shows (in **Figure 2-1A**) a case where no clear indication of nutrient limitation is indicated because the overlap of error bars of all treatments is substantial (statistical tests confirms this), and (in **Figure 2-1B**) a case where strong N and P co-limitation is documented.

If results from a deployed nutrient diffusing rack were to show that the +P and +NP had similar chlorophyll *a* (Chl*a*) magnitudes and were significantly higher in Chl*a* than the Control and +N treatments, this would constitute a demonstration of P limitation. In contrast, if the rack were to show that the +N and +NP treatments had similar chlorophyll *a* (Chl*a*) magnitudes and were significantly higher in Chl*a* than the Control and +P treatments, this would constitute a demonstration of N limitation. Bear in mind that nutrient limitation can vary spatially and temporally and therefore the goals of an AMP should be carefully considered when selecting sites for deploying nutrient diffusers.

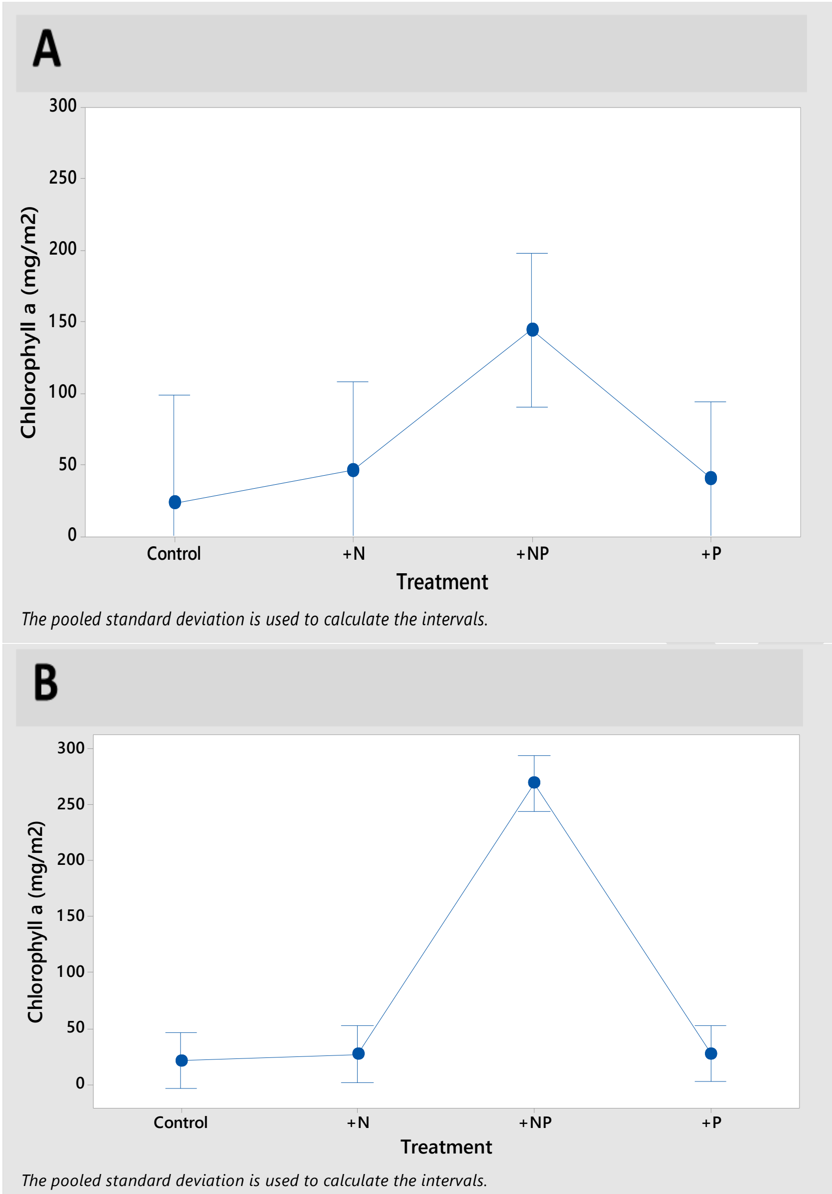


Figure 2-1. Examples of Different Nutrient Diffusing Substrate Results (n = 4 Replicates per Treatment; "Control" Means no Nutrients were Added to the Diffusing Replicates). A. A scenario in which no clear indication of nutrient limitation is indicated in the waterbody. B. An example where strong N- and P- co-limitation is indicated.

The ratio of TN to TP (i.e., the Redfield Ratio; Redfield (1958)) of water samples may also be used to inform the analysis of the limiting nutrient in the watershed. The Redfield Ratio is 7.2:1 by mass. In general, studies of benthic algae show that it is necessary to move some distance above or below the Redfield ratio in order to be strongly convinced that a lotic waterbody is P or N limited (Dodds, 2003). When a benthic algal Redfield ratio (by mass) is 10, P limitation is indicated (Hillebrand and Sommer, 1999). Thus, there is a range of N:P values between about 6 and 10 where one can state, for practical purposes, that algal growth is co-limited by N and P. When submitting findings on these topics to the department, permittees should provide graphs and tables as part of their reporting.

3.0 Guidance Supporting Part II, Section 3.0 of Circular DEQ-15 (MPDES Discharges that May Affect a Lake, Reservoir, or a Downstream waterbody)

Guidance is provided below for several scenarios which may be encountered in AMP watersheds.

3.1 Permittees Discharging Directly to a Lake or Reservoir

Per **Circular DEQ-15**, permittees discharging directly to a lake or reservoir are required to determine their proportion of the total annual nutrient load (TP, TN, or possibly both) to the lentic waterbody. In northern temperate regions like Montana, the majority of nutrient loading to a lake or reservoir typically occurs during spring runoff. As such, data collection should focus on that period. A stream hydrograph gage (maintained by the USGS or others) on the principal tributary flowing into the lake or reservoir of concern should be reviewed to determine the period of greatest inflow. Select a gage as near to the lake/reservoir inlet as possible. Nutrient data collection (at a minimum, TP and TN) should then be undertaken in the principal inflowing waterbody (or waterbodies) to the lake/reservoir. Equal depth- and width-integrated (EWI) sampling is highly recommended, although mid-stream grab samples may be adequate. Nutrient data collection should target the rising and falling limb of the hydrograph, as well as the peak. Approximately two weeks to a month prior to the commencement of spring runoff, data collection at lower intensity (e.g., bi-weekly) should commence. With the rising limb of the hydrograph, sampling intensity should increase to weekly, if possible, until the falling limb has come down in early summer. Minimal sampling can then occur for the remainder of the year (monthly or every 6 weeks).

At the same time, the permittee will need to have records of their discharge volume and nutrient concentrations throughout this entire period. These data can then be compiled with the inflow data described above to determine the relative load contribution of the point source to the lake/reservoir.

If, as a result of the loading calculations, a permittee is required to monitor in-lake response variables like phytoplankton chlorophyll *a*, the department recommends establishing a monitoring site near mid lake. If a reservoir, consult with the department on the most appropriate location. Data should be routinely collected throughout the summer (the time period of greatest concern for algae blooms, etc.). A deployed sonde that continuously measures chlorophyll *a* is a good option if a buoy or other deployment platform can be arranged.

3.2 Permittees Discharging to a Flowing Waterbody which May Affect a Downstream Lake or Reservoir

Determining when a point source discharge to a flowing waterbody is affecting a downstream lake or reservoir can be complicated. The potential for an effect varies depending on distance between the lentic waterbody and the point source, the size of the discharge and the lake/reservoir, etc. The department will carry out this analysis on a case-by-case basis and permittees should contact the permit writer assigned to their permit or the department's Adaptive Management Program Scientist.

Permittees should also determine if there is an existing Total Maximum Daily Load (TMDL) load allocation (LA) in the watershed assigned to the lake or reservoir.

4.0 Guidance Supporting Part II, Section 4.0 of Circular DEQ-15 (Identifying Nutrient Concentrations for Use in MPDES Permits and Other Programs)

Application of nutrient concentrations in Tables 2-2 and 4-1 in Part I of **Circular DEQ-15** may be guided by internal department program policies specific to each program; these should be consulted, as appropriate. Another good resource to consult is Suplee and Watson (2013). This document is a compendium of scientific dose-response studies (nutrients as dose, response variable impacts as response) applicable to specific Montana ecoregional zones. The document also includes descriptive statistics from regional reference sites, water Redfield ratios, etc., and includes recommendations regarding most-appropriate nutrient criteria for each ecoregional zone.

5.0 Guidance Supporting Part II, Section 5.0 of Circular DEQ-15 (Department Field Audit of Monitoring Locations)

Per **Circular DEQ-15**, the department will carry out field audits on a minimum of 10% of permittees under the adaptive management program each year to ensure all data collection protocols are being properly adhered to. Audits may include, but are not limited to:

- AMP records review
    - Field forms
    - Contract laboratory review
    - Records retention
    - Sampling data
- Review of compliance schedule
    - Conformance
    - Progress towards next interim or final limit
- Monitoring
    - Monitoring locations
    - Department Adaptive Management Program Scientist or other staff will accompany the data collection entity to observe the data collection event
- Implementation
    - Optimization
    - Review of secured funding and landowner/partner agreements
- The department may sample/deploy data loggers downstream of permittee's monitoring location

The department will prepare an annual report summarizing audit findings and permittees not properly adhering to protocols established in their AMP will be informed in writing. Corrections to monitoring deficiencies will need to be addressed prior to the next field sampling event. All other corrections related to AMP records review, review of compliance schedule, and/or implementation will need to be addressed prior to submittal of the permittee's annual adaptive management program report.

6.0 Guidance Supporting Part II, Section 6.0 of Circular DEQ-15 (Requirements for Adaptive Management Plans: Wadeable Streams, Medium Rivers, and Large Rivers)

6.1. Identifying Sites for an Adaptive Management Plan

There may be several types of sampling/monitoring sites in an AMP watershed (**Figure 6-1**). The location of the near field site(s) downstream of the point source should be identified by first carrying out nutrient spiraling calculations (Mulholland et al., 2002; Ensign and Doyle, 2006; Kohler et al., 2008). **The department has An Excel spreadsheet available called "SpiralingCalcs_DistanceEstimates_v2.xls" to provide the distance estimates. Instructions are provided in the spreadsheet in cell I2.** The spreadsheet requires input of average stream <u>water velocity</u> and stream <u>depth</u> to compute a series of approximate downstream distances for emplacing the site or sites. The range of downstream distances should provide for a number of candidate site locations. The selected site should be placed downstream of (not within) any normal mixing zone for other pollutants that may be in place.

Average stream velocity can be computed from average index period base flow data and average channel cross sectional area if such data are available from a nearby gage on the receiving waterbody. If no gage data are available, index period flow, width, and depth measurements need to be made in the reach around the site, and then (in turn) the cross-sectional area and water velocity can be computed.

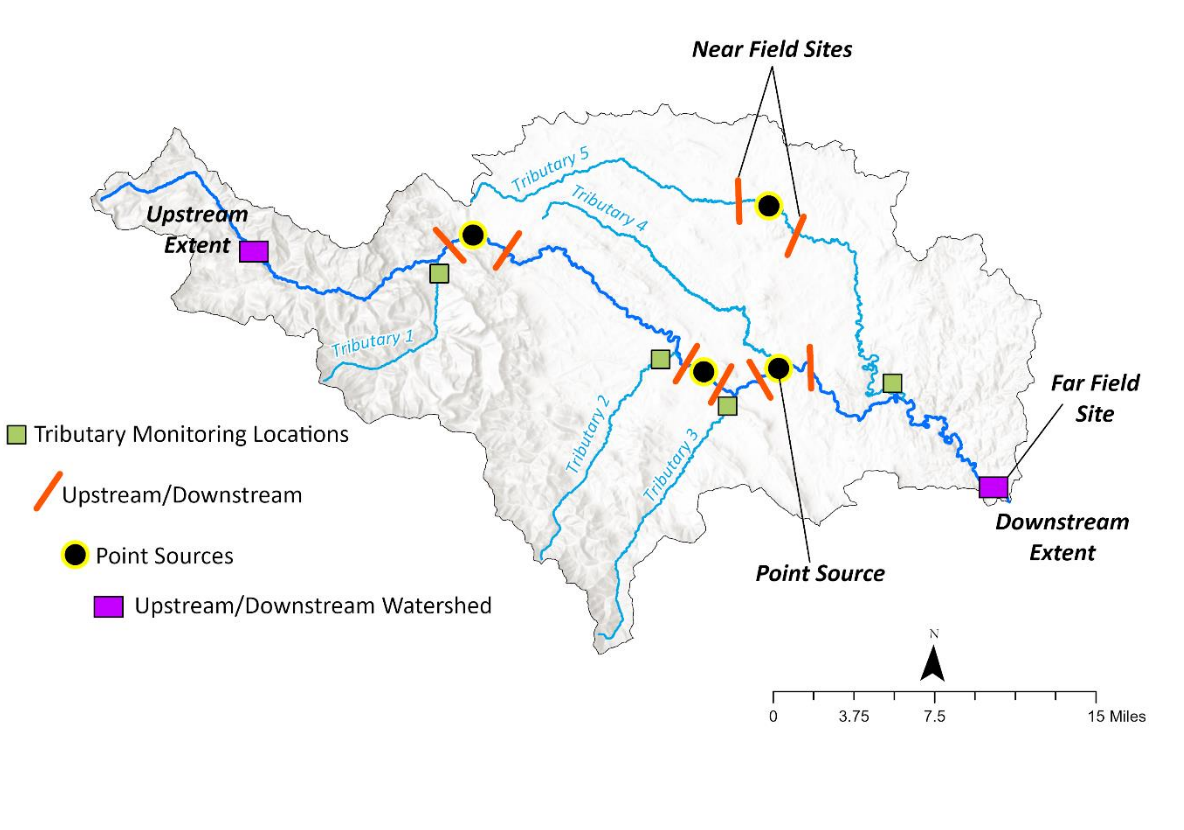


Figure 6-1. Example AMP Watershed, Showing Different Types of Monitoring Sites. This is an example of a large, complex watershed with multiple point sources.

Once the average index period stream velocity and depth are known, the spreadsheet will provide the minimum, maximum, median, and average downstream distance estimates (i.e., a range) for where data-collection sites could be placed (see **Summary of Computations** in cells C52 to F55). An example of the spreadsheet's use is provided in **Appendix A**. To locate the most suitable site, the department recommends that reconnaissance be carried out at the indicated locations (min, max, median, and average distance downstream from the discharge), as well as at locations in between these points.

Photographs should be taken and later provided to the department to support the justification for the site(s) selected; photos will allow the department to evaluate the suitability of the selected site(s). Monitoring at the near field sites is expected to remain relatively consistent over time, therefore site access now and into the future is a critical consideration. Using sites on public land (if possible) helps ensure access, or if private land access is necessary the landowner should be aware of the long-term nature of the data collection. If the landowner is not comfortable with this type of arrangement a different site should be selected.

Upstream- and downstream- near field sites should be as similar as possible regarding gradient, flow, baseflow water depth, substrate, and stream shading.

Far field and tributary sites should be adaptive to the needs of the AMP. For example, potential nutrient sources identified during a watershed inventory may prompt the selection of new or additional monitoring sites to quantify nutrient loads or isolate potential nutrient reduction projects. Initial characterization at tributary sites may clarify which tributaries contribute greater or lesser nutrient loads to the receiving waterbody and therefore may lead to tributary sites being added or discontinued. Additional or different monitoring sites may also be necessary to demonstrate effectiveness of nonpoint source reduction projects or to affirm compliance with narrative nutrient standards. Downstream far field sites should generally be located near the end of the AMP watershed so that nutrient loads exiting the watershed can be documented. Please see the case study in **Appendix A** for an example of locating far field and tributary sites.

6.2 Data Submittal to the Department

All nutrient effluent and downstream analytical results from laboratories for the adaptive management program will be uploaded as two separate Discharge Monitoring Reports (DMRs) via EPA's NetDMR in accordance with the permit requirements. All data submitted to the department for the adaptive management program from analytical laboratories and others must adhere to the most current NetDMR submittal requirements in the EPA support portal. To submit DMR data Go to NetDMR Production Site. All site information, field measurements, and analytical results from laboratories for response variables for the adaptive management program will be uploaded into DEQ's EQuIS Montana EQuIS Water Quality Exchange (MT-eWQX). Data uploaded to MT-eWQX is submitted to EPA's National WQX Warehouse and accessible via the Water Quality Portal. All data submitted to DEQ for the adaptive management program from analytical laboratories and others must adhere to the most current Electronic Data Deliverable (EDD) and submittal requirements in the MT-eWQX EDD Guidance available on DEQ's Lakes, Streams & Wetlands webpage under "Submit Data": https://deq.mt.gov/water/Programs/sw. See **Table 6-1** for parameters broken down by the database submittal locations.

Table 6-1. Nutrient and Response Variable Database Submittal

<table>
<tr><th>Effluent DMR</th><th>Downstream DMR</th><th>EQuIS (Raw Data)</th></tr>
<tr><td>TP</td><td>TP</td><td>Benthic Algal Chlorophyll a</td></tr>
<tr><td>TN (calculated)</td><td>TN</td><td>Benthic Algal Ash Free Dry Weight</td></tr>
<tr><td colspan="2" rowspan="6">---</td><td>% Bottom cover by filamentous algae</td></tr>
<tr><td>DO blobs (these are used to calculate DO delta)</td></tr>
<tr><td>Macroinvertebrate raw taxa counts</td></tr>
<tr><td>Orthophosphate (downstream raw data) - Optional or as needed for AMP</td></tr>
<tr><td>Nitrate + Nitrite (downstream raw data) - Optional or as needed for AMP</td></tr>
<tr><td>Total Kjeldahl Nitrogen (TKN) (downstream raw data) - Optional or as needed for AMP</td></tr>
</table>

6.3 Municipal Plant Pollutant Minimization Activities

A permittee may achieve nutrient reductions through conventional capital improvements or through Montana's optimization program. Montana offers technical support and training to municipal wastewater treatment plant operators to achieve nutrient reductions through operational optimization. Pollutant minimization activities which may reduce TN and TP in the effluent are typically centered around optimization as this can be a very cost-effective approach. Some of these activities include adding external or in-plant carbon sources, using internal recycle streams, temperature considerations, solids and hydraulic retention times, and phosphorus removal process considerations. Further discussion of these activities and activities not discussed in this guidance can be found in the *Municipal Nutrient Removal Technologies Reference Document: Volume 1 – Technical Report* (Tetra Tech, Inc., 2007).

There are two types of carbon sources – in-plant and external (Tetra Tech, Inc., 2007). Methanol is often used as an external carbon source because of its low cost and ease of handling. Companies have also used molasses or brewery waste as a supplemental carbon source (Tetra Tech, Inc., 2007). In-plant sources include primary effluent, which can be step-fed to the activated-sludge process, and fermentation of primary sludge to obtain volatile fatty acids and other readily used carbon compounds (Tetra Tech, Inc., 2007).

Internal recycle streams can help promote denitrification. The internal recycle streams return nitrates in the aeration basin to the anoxic zone for denitrification. With the anoxic zone at the beginning of the process, carbon source addition is not generally necessary (Tetra Tech, Inc., 2007). An anoxic basin with an internal recycle stream can achieve reasonable rates of total nitrogen removal in the range of 6 to 8 mg/L (Tetra Tech., Inc., 2007).

Solids and hydraulic retention times affect the nitrification/denitrification process. The aerobic zone(s) of nitrification/denitrification processes must be large enough to allow most of the carbonaceous biological oxygen demand (CBOD) to be consumed before nitrification can begin (Tetra Tech, Inc., 2007). The size of the anoxic zone(s) must be sufficient to allow denitrification to occur without consuming the entire carbon source that might be needed for biological phosphorus removal. The microorganisms responsible for nitrification have a slower growth rate than other heterotrophic bacteria, therefore, a longer retention time is needed. It is also important to consider temperature. At lower temperatures, the nitrification and denitrification kinetics decrease, leading to poorer performance in the winter, if operational changes are not made to compensate for the decreased kinetic rates (Tetra Tech, Inc., 2007).

Phosphorus can be removed from wastewater by biological uptake. Biological phosphorus removal promotes the growth of phosphate-accumulating organisms, which then go through anaerobic conditions and then to aerobic conditions. Under anaerobic conditions, the microorganisms break the bonds in internally accumulated polyphosphate, resulting in the release of phosphate and the consumption of organic matter in the form of volatile fatty acids or other easily biodegraded organic compounds (Tetra Tech, Inc., 2007). When the microbes are then put under aerobic conditions, the microorganisms perform uptake of phosphate, forming polyphosphate. When these organisms are wasted, the contained phosphate is also removed.

Secondary release of phosphorus is of concern in certain types of plants. Secondary phosphorus release can be reduced by minimizing the retention time that the mixed liquor or sludge return lines are held before they return to the secondary process, reducing return flows from sludge-handling operations, or treating the sludge-handling return lines before introduction to the secondary process (Tetra Tech, Inc., 2007).

6.4 Lagoon Pollutant Minimization Activities

Proper maintenance and optimization of wastewater lagoons promotes total phosphorus and nitrogen removal. Pollutant minimization activities which may reduce nutrient concentrations in the effluent include sludge removal, vegetation control (aquatic and terrestrial), burrowing animal control, infiltration/inflow, organics loading, and others (WET-Geum, 2015).

Ensuring proper sludge depth and health is important for the biological decay of the settled material. Accumulation of solids in wastewater lagoons can affect the treatment efficiency and effluent quality by reducing capacity and creating preferential flow paths (Harris, 2003). Periodic sludge removal is required. Creating an aerobic cover over the sludge blanket has also been shown to slow the release of phosphorus from sediments (WET-Geum, 2015). Aerobic conditions can reduce the amount of phosphorus leaching back to the lagoon water column. Mechanical removal techniques are proven technologies that are fully scalable, easy to implement, and are 100% effective at removing solids.

Burrowing animals can cause seepages and weaknesses in dikes. Dikes should be checked daily for signs of leakage. Wet spots, seepage, and depression points may indicate weaknesses in the lagoon dike (WET-Geum, 2015). One method for controlling burrowing animals is to remove a burrowing animal's food source (cattails, bullrush, smartweed, water lily, sedges, young willows, and other plants). Rip-rap or sections of chain link fence placed a couple of feet above and below the water line will help prevent animal burrowing.

Conducting an Infiltration & Inflow (I&I) study can help to identify problems with hydraulic overloading. Various I&I reduction techniques and approaches can be implemented to reduce non-sewage inflows to the wastewater system. Replacement of leaking infrastructure and several slip lining technologies are available that are effective in reducing non-sewage influent (WET-Geum, 2015).

Low organic loading promotes nitrogen removal. Some activities that reduce organic loading include parallel operation of ponds; effluent recirculation; and sludge removal. Running the ponds in parallel helps to reduce the load to a particular pond. Effluent recirculation from lower loaded ponds downstream to heavier loaded primary ponds upstream can help dilute incoming wastewater and add dissolved oxygen (Harris, 2003).

Other pollutant minimization activities not discussed here can be found in *USER GUIDE – Optimization Methods and Best Management Practices for Facultative Lagoons* (WET-Geum, 2015) and *Wastewater Lagoon Troubleshooting: An Operators Guide to Solving Problems and Optimizing Wastewater Lagoon Systems* (Harris, 2003).

6.5 Information Provided by Changes Upstream and Downstream of a Point Source

Permittees and others should use Table 6.3 in Part II of **Circular DEQ-15** as a guide for next steps. These steps may include developing a watershed-scale plan for nutrient reductions for inclusion in an AMP; details on preparing a watershed plan are next, in **Section 6.6** below.

6.6 Developing a Watershed-scale Plan for Inclusion in an Adaptive Management Plan

Subsections here provide guidance pertaining to activities to be carried out in a watershed once it has been determined that a watershed is not achieving the narrative nutrient standards and an AMP watershed plan is required (per **Circular DEQ-15,** Part II, Section 6.6). Note that a watershed plan may be developed and included in an AMP even prior to a department finding that P prioritization has not been successful; guidance provided here applies to this situation as well.

6.6.1 Quantification and Characterization of Major Sources of Nutrient Contributions

To the extent feasible, existing scientific information concerning algal growth dynamics, applicable scientific data specific to the region, locally collected data from the waterbody, and features of the point source effluent(s) and the nonpoint sources should all be used to quantify and characterize the nutrient sources and loads in the watershed. Consideration should be given to the magnitude and extent of nonpoint source nutrients already in the receiving waterbody and the degree to which the point source(s) alone can reduce concentrations below algal growth saturation concentrations. Saturating phosphorus concentrations in rivers and streams are low (5-30 µg/L) and considerable reduction in TP may be necessary to achieve controlling concentrations.

Phosphorus is very commonly associated with suspended sediment in flowing waters (Grayson et al., 1996; Uusitalo et al., 2000). Therefore, control actions which limit soil erosion from developed lands (e.g., row crops) can be very effective in lowering P loading to rivers and streams. Usually, the greatest sediment and P loading occurs during spring runoff and controlling such loads in spring may not necessarily have a large bearing on stream and river algal growth during the summer index period. However, reduction of soil erosion can be effective for summer rain events, and thus aide in reducing P loading at that critical time. Not all phosphorus associated with suspended sediment or highly-treated wastewater is necessarily bioavailable, and analytical methods are available to distinguish bioavailable from non-bioavailable P if necessary (Uusitalo et al., 2000; Ekholm and Krogerus, 2003; Suplee, 2021); the department is continuing to examine technical and regulatory aspects of distinguishing bioavailable from non-bioavailable P.

6.6.2 Identifying All Partners that will Assist in Implementing Nutrient Reductions

Individuals and organizations from which to solicit participation may include, if applicable:

- Landowners
- Local irrigation districts
- Conservation or environmental organizations
- Watershed groups
- Water quality districts
- Municipalities
- Counties (planning department, sanitarian/environmental health)
- USDA Natural Resources Conservation Service (district conservationist)
- Federal land management agencies (U.S. Forest Service, Bureau of Land Management, U.S. Fish and Wildlife Service wildlife refuges, etc.)

- State land management agencies (MT Department of Natural Resources and Conservation; MT Fish, Wildlife & Parks)
- Timber companies
- Hydroelectric industry
- Other point source dischargers of nutrients in the watershed
- Tribal nations

6.6.2.1 Implementing Nonpoint Source Projects

A permittee may achieve nutrient reductions in the watershed through nonpoint source project implementation. Nonpoint source implementation projects vary in scope and scale based on land use practices and site conditions. Appendix A of the Montana Nonpoint Source Management Plan includes a list and description of widely accepted BMPs used to address different nonpoint source pollution categories and causes of water quality impairment. The department's Load Reduction Estimation Guide provides a description of methods for estimating pollutant load reductions from different nonpoint source pollution categories, applicable BMPs, and causes of water quality impairment. The TMDL WLA requires reasonable assurance that the load reduction expected will be achieved. All significant pollutant sources, including natural background, permitted point sources, and nonpoint sources, need to be quantified at the watershed scale so that the relative pollutant contributions and reductions can be determined. Because the effects of pollutants on water quality can vary throughout the year, assessing pollutant sources must include an evaluation of the seasonal variability of the pollutant loading. This loading and reduction analysis will be done using a department approved watershed-loading model.

Once necessary reductions have been calculated and allocated to sources, the permittee needs to select nonpoint source projects that will reduce nutrients to a level that will meet the narrative standard in the waterbody and demonstrate reasonable assurance by having secured funding and landowner/partner agreements to implement nonpoint source projects either individually, or in conjunction with other permittees and nonpoint sources, or other partners, including municipal and county governments, in the watershed must be included in the plan. Plans should include any contracts/landowner agreements reflecting commitments by partners to implement applicable actions.

6.6.2.2 Nutrient Trading

A permittee may achieve nutrient reductions through nutrient trading. Trading is a market-based approach to achieving water quality standards in which a point source purchases pollutant reduction credits from another point source or a nonpoint source in the applicable trading region that are then used to meet the source's pollutant discharge obligations. **Circular DEQ-13**, Montana's Policy for Nutrient Trading, should be followed if trading is pursued, which states all trades that involve point source discharges will be monitored and enforced under an MPDES permit.

Permittees should consult with the department on whether an established stakeholder group exists for the watershed and obtain assistance identifying stakeholders. Specifically, the department may have created a TMDL watershed advisory group if TMDLs have been completed, or are under development, for the watershed, per 75-5-704, MCA.

6.6.3 Continued or Expanded Monitoring of Response Variables and Water Quality as Performance Indicators

Data collection at the near field sites must remain relatively consistent in perpetuity. However, data collection that best supports an AMP plan needs to be adaptive. Each watershed will be different and case-by-case customization of tributary and far field monitoring sites will be necessary, especially as watershed plans evolve over time.

The department has a sampling and analysis plan (SAP) template which can be used to describe expansions of an AMP watershed plan beyond the basic near field sites. This document can be requested from the department. In addition, the department has completed numerous SAPs for projects across the entire state; these describe specific sampling projects, their objectives, and the corresponding sampling sites and data types. Examples can be provided upon request—contact the department's Adaptive Management Program Scientist.

6.6.4 Annual Reporting

Annual progress reports must be submitted to the department and must address all the relevant actions taken under the AMP watershed plan in the year prior to the report. Annual reports are required, per **Circular DEQ-15**, to maintain communication and accountability between the point source and the department. Additionally, annual reports provide the permittee with the opportunity to modify their adaptive management strategy. The department has put together a list of annual report requirements that will allow the permittees and contractors to format the report how they would like. The report may contain more than the minimum elements that are listed below:

1. State what stage of the AMP process the permittee is in based on implementation phases:
   - Monitoring and facility optimization.
   - Source assessment.
   - Watershed scale nutrient-reduction implementation.
2. State whether the permittee is working with other permittees:
   - Number of other permittees.
   - Permit numbers.
   - Name of facilities.
   - Receiving waterbody(ies).
3. Implementation Summary:
   - Optimization efforts – Plan, Do, Study, Act
     - **Plan:** Describe how operators might make operational changes that can promote nutrient reductions.
     - **Do**: Implement the planned changes then monitor the results. Describe which changes were implemented and which were not.
     - **Study:** Assess the monitored results; determine if optimization efforts were successful; determine changes that did not work and additional changes that might further drive nutrient reduction. Describe reductions that were achieved.
     - **Act:** Eliminate ineffective changes, institute new changes; or maintain status quo if reduction efforts are successful.
     - Compare annual optimization reductions to previous years.
     - Show reductions have been maintained–this should be presented as a rolling annual average and expressed as both concentration and mass reduction.
     - Describe any technical assistance you received:
       - What were the recommendations?

        - What is being monitored to achieve reductions (e.g., oxidation reduction potential, ammonia, etc.)?
        - What has been done to achieve the reductions (e.g., cycling blowers on and off, etc.)?
    - Describe what efforts have been made to maintain reductions (e.g., training new people).
    - Describe areas for improvement.
    - Nonpoint source agreements (if in watershed-scale nutrient reduction implementation).
        - Progress on nonpoint source work or potential nonpoint source projects that are being considered.
        - Expected timeline for completion.
        - Expected and realized reductions.
    - Upgrades (if performed)
        - Planned completion date or if already completed, when?
        - What upgrades were made?
        - Expected and realized reductions.
4. Monitoring Summary – Post Sampling Plan:
    - Summarize near field monitoring:
        - Up/down stream summary of nutrient statistics.
        - Up/down stream summary of response variable statistics.
            - Including DO delta and HBI data
    - Watershed – For modeling or nonpoint source implementation/trading.
    - Summary of DMR and EQuIS data.
    - If response variables are not met, develop a plan of action.
    - At least in the first annual report, results from nutrient diffusing substrates.
    - Deviations from the adaptive management sampling plan.
        - Annual % completeness by measurement.
        - Description of problems encountered (lab/field issues).
        - Flagged data summary.
        - Corrective measures for next year.
        - A plan to overcome lacking/lagging data to meet adaptive management program. Timelines if annual monitoring expectation not fully completed.
5. Overall summary:
    - Plan for meeting the interim limit or final effluent limit.
    - Present site-specific data.
    - Highlight the successes.
    - Adherence to adaptive management plan and deviations.
    - Next steps.

Per NEW RULE II, annual reporting, which must include electronic data submittal of collected biological, chemical, and physical measurements, is due by March 31st of each year.

7.0 Guidance Supporting Part II, Section 7.0 of Circular DEQ-15 (Large Rivers and Water Quality Models: Data Collection, Model Calibration and Validation, Simulating the Effects of Potential Management Activities)

This section covers water quality modeling. **Sections 7.1** through **7.6** address mathematical (mechanistic) water quality models, while **Section 7.7** covers conceptual water quality models.

7.1 Introduction to Mechanistic Water quality Models

The development of nutrient management AMPs for Montana's large rivers requires an understanding of the individual waterbody response to nutrient loadings including the most limiting nutrient, the magnitude of point and non-point sources at various locations in the watershed, the amount of controllable nutrient load, as well as the fate and transport of nutrients in the receiving water, both upstream and downstream of the point of discharge. As such, this guidance has been prepared should permittees choose or be required to use model-based approaches for demonstrating compliance in meeting narrative nutrient water quality standards, and for watershed-based nutrient management.

Although no single modeling tool is appropriate or useful for every situation, it is recognized that water-quality models may be needed to address nutrient management requirements in large rivers or complex watersheds. This section has been drafted to outline a quasi-standard approach for numerical model selection, development, and application for nutrient AMP implementation purposes. Considerable research has already been devoted to the use of modeling tools for site-specific nutrient management (Bierman et al., 2013), with the premise that properly conducted process-based load-response modeling approaches are effective in accounting for unique water body-specific characteristics along with resolving the effects of multiple confounding factors on ecological responses. Furthermore, simulation models have been increasingly required in water quality planning and management as engineering controls become more costly to implement, and the penalties of judgment errors become more severe (EPA, 1997b).
Accordingly, nutrient modeling guidance for Montana's adaptive management program is contained herein. It is assumed the reader is already familiar with modeling terminology and engineering or natural sciences concepts and processes. For background information see Chapra (1997), Chapra (2003), Shoemaker et al. (2005), Borah et al. (2006), and Bierman et al. (2013). Specifically, the guidance outlines the following topics relative to the nutrient AMP process for large waterbodies: (1) the overall modeling approach including problem specification and definition of appropriate modeling scales and domains and quality planning procedures, (2) indicator/endpoint definition, (3) model selection, (4) model calibration and confirmation, and (5) general guidance and caveats for model application. These are presented in the remaining portions of the guidance section. **Appendix C** provides a simple applied case study example for the mechanistic model approach.

7.2 Use of Water Quality Models for AMP Implementation – Overall Approach

The primary purpose for models in AMP implementation is to develop a decision support system (DSS) which can be used for regulatory purposes including the following: (1) demonstrating compliance with

Montana's narrative nutrient standards, (2) evaluating water quality as a function of nutrient management actions to predict water quality changes in negatively impacted watersheds, (3) using models *vis-à-vis* nutrient trading to manage controllable point and non-point source nutrient contributions (DEQ, 2012; Rutherford and Cox, 2009; Ribaudo and Gottlieb, 2011), and (4) establishing permit limits for point source discharges in the context of AMP planning.

A flowchart for nutrient modeling is found in **Figure 7-1** (reproduced from Bierman et al., 2013). As differentiated in this guidance, both model-based and non-modeling approaches can be applied and regardless of which approach is used, the most important up-front consideration is the water-quality indicators/endpoints upon which nutrient control decisions will be made. Modeling processes are then initiated for the purpose of making management or regulatory decisions. Finally, there is an adaptive management component (circular arrows shown as "monitoring and iterative improvement") that requires the collection of additional data for post-audits or iterative model refinement or improvement.

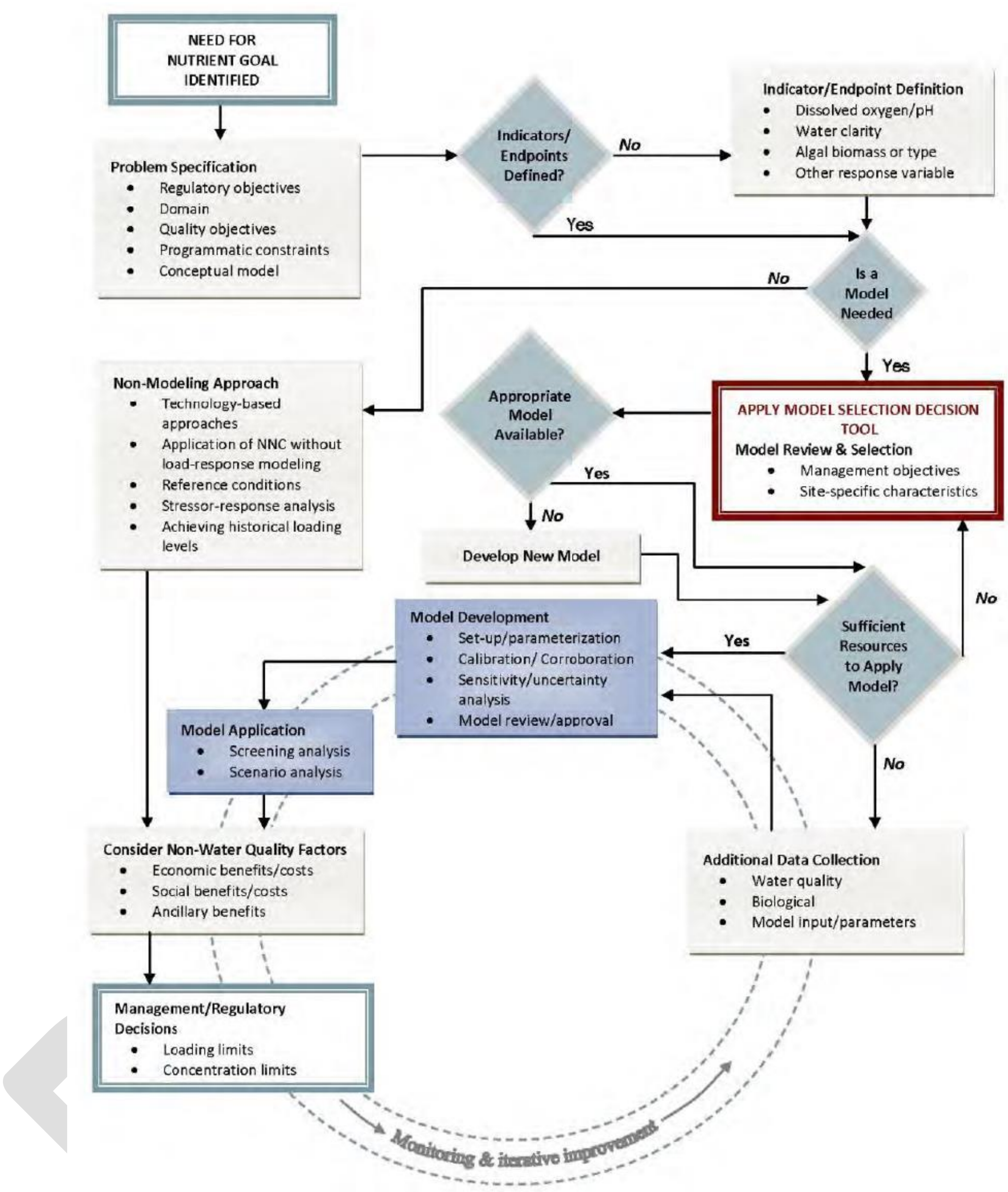


Figure 7-1. Process for Setting Site-specific Nutrient Goals (from Bierman et al., 2013).

7.3 Rationale for Modeling

The primary impetus for water-quality modeling in an AMP is to build an understanding of water quality problems including where and how they occur. This may include evaluating beneficial use support or compliance with the narrative nutrient standards, understanding the extent and severity of a problem such as a potential impact or the anticipated level of stress from a particular management activity on a response variable of interest, extrapolating from current conditions to potential future conditions, or evaluating the outcome of various management measures and strategies or for evaluating trends or system responses. Anticipated nutrient related AMP questions and actions that can be addressed through modeling will likely include the following:

- Are narrative nutrient standards currently being achieved in the waterbody based on response variables/indicator endpoints of concern?
- Would an increase in wastewater treatment for a particular nutrient (i.e., nitrogen or phosphorus) result in meeting the narrative nutrient standards?
- How can different spatial areas of the watershed be prioritized and managed for water-quality improvement (i.e., hot spot identification)?
- Identifying agricultural or other best management practices (BMPs) that are likely to be the most effective, or most cost-effective in controlling nutrient loads on a watershed basis.
- Determining what combinations of nutrient management options are likely to be most effective in terms of both nutrient load reduction and cost.

More specific discussions about AMP nutrient management modeling are covered in subsequent sections after first discussing types of models and AMP objectives.

7.4 Types of Water Quality Models and AMP Objectives

Widely used water-quality models have been developed by government agencies, universities, and private entities since the advent of modernized computing in the late 1960s. Most of these tools use mathematical (deterministic) and mechanistic relationships that estimate time series of pollutant loads or waterbody responses to pollutants for a variety of spatial or temporal scales. It is important to recognize that models can range in complexity from simple assessments where pollutants are calculated as a function of land use (e.g., export models) to mechanistic simulation models that explicitly describe processes of pollutant export or fate and transport in receiving waters.

For this document, models are broken into two functional categories that reflect overall objectives in the water-quality modeling process. These are: (1) watershed-loading models and (2) receiving-water quality models. The former simulates the export of pollutants from the land surface in some fashion with an emphasis on nutrient loadings from all locations in a watershed, whereas the latter characterize the response of the waterbody to the same pollutant loadings in a very detailed way. Further descriptions of each of these categorical types of water-quality models are provided below.

7.4.1 Watershed-Loading Models

Watershed-loading models simulate the generation and movement of pollutants from the land surface to lakes, rivers, or streams, with simplified in-stream transport (EPA, 1997b). They are primarily designed to predict pollutant movement over large watershed scales, thus providing an understanding of the allocation (i.e., where pollution is generated from, and how much) of nutrient sources in a watershed. Such models range in complexity from simple Geographic Information System (GIS) loading estimates to complex simulation tools that explicitly describe the processes of runoff and nutrient transport. Loading models typically operate at the watershed or subbasin scale, although field-scale simulations are possible. Most loading models have been developed for the purpose of nonpoint source estimation with an emphasis on agricultural cropland or forestland, but they have been adapted to other land use categories as well (Donigian and Huber, 1991). For AMP purposes, watershed-loading models would most frequently be used to address the following management questions:

- What spatial areas in the watershed generate the highest nutrient loads?
- What is the overall contribution of point and non-point sources in a watershed?

- How does an agricultural management practice in an upstream location result in a reduction in nutrient loading at a permitted discharge?
- What is the nutrient source loading contribution of an unmonitored tributary?

One caveat is that watershed-loading models incorporate many empirical parameters that cannot be measured directly (e.g., buildup and washoff parameters, soil/chemical characteristics, partition coefficients, and reaction rates). Hence, they require calibration and appreciable data requirements exist for modeling. A general AMP rule of thumb is that the larger the AMP watershed is (spatially), the more likely a watershed-loading model will be needed to understand nutrient management. Such models will subsequently require calibration at multiple spatial locations.

7.4.2 Receiving-Water Models

Receiving-water models explicitly simulate chemical and biological responses of a waterbody to nutrient loadings. In essence, they attempt to reproduce the mechanistic relationship between forcing functions, boundary conditions, and state variables, reflecting the key waterbody response from nutrient stressors. Broad categories of receiving-water models include steady-state (constant flow and loadings) and hydrodynamic (time-variable flow and loadings). Each develop a mass balance for one or more interacting constituents over different spatial domains and temporal scales considering: (1) nutrient inputs to the system, (2) transport through the system, and (3) transformations or reactions within the system. Questions that receiving-water models could be used to answer for AMP purposes include:

- What is the site-specific chemical and biological response (e.g., benthic algal biomass, pH variation, dissolved oxygen minima, or other response variable/endpoint indicators of interest) of the waterbody to nutrient inputs at a variety of spatial locations or temporal scales?
- What is the limiting nutrient, or how does the limiting nutrient change over a given spatial extent given known nutrient sources and loadings?
- How does the waterbody respond to different nutrient inputs at various flow and environmental conditions, and where is the critical response located?
- What is the holistic system response from different actions at different points in the waterbody?

Receiving-water models require considerable site-specific data to calibrate model kinetic processes, and therefore require well thought out data collection and modeling approaches. Receiving-water models can be developed standalone or be used in concert with a watershed-loading model to provide additional insight to dynamic processes, chemical interactions, and biological processes.

7.5 Level of Effort in Modeling

Beyond the type of model being applied, the level of effort in AMP modeling should consider the complexity of the watershed being evaluated and importance of the decision required. Decision-based and data-driven modeling approaches are preferred for AMP studies, where robust data and modeling techniques are incorporated into the modeling process to match the rigor and importance of the planning process. This is typically referred to as the graded approach (EPA, 2002). Nutrient AMP modeling efforts can be broken into three levels of detail, each of which will depend on site-specific characteristics of the AMP watershed:

- Simple Methods – Basic techniques or screening/scoping tools require minimal user experience and are adequate for "back of the envelope" modeling computations. They typically are applied with either a hand calculator or spreadsheet and are sufficient in certain circumstances. A simple watershed-loading method is described in DEQ (2005). A good receiving-water example is the Clark Fork River Voluntary Nutrient Reduction Program (VNRP; Tri-State Implementation Council, 1998)[1].

- Moderate Methods – Moderate methods require mid-range user experience and are more data and computer intensive than simple methods. They find a balance between the simplistic and detailed computational methods. A good example of a mid-range watershed model for nutrient evaluation planning is the use of event-mean concentrations in EPA (2006) and DEQ (2008). Flynn et al. (2015) and Suplee et al. (2015) describe a suitable application of a steady-state receiving-water model for nutrient management.

- Detailed Methods – More sophisticated tools are needed for studies having high resource value, socio-political exposure, or controversial/complex nutrient AMP implementation. Detailed methods require a large effort by experienced professionals to simulate the physical processes over large spatial or temporal scales, either in a watershed or river system. Examples include two- or three-dimensional[2] receiving water models, or linked watershed and receiving-water modeling applications such as those described in EPA (2007).

The primary guiding factors in determining the level of effort in AMP nutrient management include: (1) the number of point source facilities on a large river segment, (2) the complexity of the watershed (i.e., a watershed having multiple nutrient point or non-point sources is considerably more difficult to manage when compared to one that has only a few), and (3) the magnitude of the controllable point and non-point source loads in the watershed, giving deference to the use of reasonable land, soil and water conservation practices.

7.5.1 Preliminary Level of Effort Requirements for Montana Waterbodies

Large river segments for Montana are defined in **Table 9-1** below (from Flynn and Suplee, 2010), shown in conjunction with the number of Montana Pollutant Discharge Elimination System (MPDES) nutrient permits in both the reach of interest, and upstream. Based on inspection, several watersheds are heavily permitted and contain dozens of permits (e.g., Clark Fork, Missouri, and Yellowstone rivers). These will require complex AMP approaches. Several have only a single MPDES permit, however, and will require a lower level of effort. It is important to recognize that the distributed spatial nature of larger watersheds may require careful consideration of the level of modeling detail, effort, and

[1]The VNRP used a steady-state spreadsheet mass balance model for nutrient target setting in the watershed (constant flow and concentration data from point sources, tributary inflows during 30Q10 critical streamflow conditions, and an assumed nutrient gain/loss factor to represent algal uptake of nutrients and groundwater and tributary changes along with a flow increment factor). The primary management goal of the VNRP was to improve water quality and control nuisance algae in the river, noting the nuisance algal goal in that efforts is analogous to the narrative state water quality standard.

[2] Zero-dimensional models reflect completely mixed systems and therefore have no spatial variation. One-dimensional models consider only on spatial representation, typically linear or longitudinal in nature (like a river). Two- and three-dimensional models consider water quality gradients in two- or three- spatial dimensions and are useful in lakes and reservoirs where stratification occurs, or within incompletely mixed rivers.

approach, sometimes involving multi-jurisdictional headwaters extending either into Canada or Wyoming. Moreover, several of the large river segments confluence together such they could potentially be addressed in one master AMP planning effort. Prior to selecting a nutrient AMP modeling approach, discussions should be made collectively with the department to select an appropriate methodology for a given watershed.

Table 7-1. Large River Segments of Montana and Anticipated Level of Effort for Water-quality Modeling

River Name	Segment Description	Permitted Nutrient Facilities [a]		Anticipated Water-Quality Modeling Effort
		Within	Up-stream	
Bighorn River	Yellowtail Dam to mouth	0	0	Simple
Clark Fork River	Bitterroot River to state-line	6	13[b]	Detailed
Flathead River	Origin to mouth	8	2	Detailed
Kootenai River	Libby Dam to state-line	2	0	Simple
Madison River	Ennis Lake to mouth	1	5	Moderate
Missouri River	Origin to state-line	26	34	Detailed
SF Flathead River	Hungry Horse Dam to mouth	1	0	Simple
Yellowstone River	State-line to state-line	19	0	Detailed

[a] Nutrient permit only including contributing watersheds; excludes federal NPDES permits
[b] Not including Flathead River

7.6 Technical Guidance and Considerations for Nutrient Modeling in AMP Watersheds

As noted in Bierman et al. (2013), the use of process-based models for nutrient management requires careful consideration of a range of technical and management issues. While the primary technical challenge of water-quality modeling is to develop useful quantitative linkages between nutrients and environmental endpoints of concern, the principal management challenge is to ensure that the model will support the AMP regulatory requirements. To meet each objective, it is recommended that planning and modeling steps identified in **Figure 9-1** and in Figure 9-1 of Circular DEQ-15 be carefully followed when conducting AMP nutrient modeling. Guidance for key steps is described in the following sections, generalized to any kind of modeling effort. Critical to project success is early engagement and coordination with the department, along with planning agency check points during each phase of the modeling process.

7.6.1 Problem Specification

7.6.1.1 Quality Planning and Modeling Objectives

Prior to AMP modeling, project planning activities should include the development of a Quality Assurance Project Plan (QAPP) that outlines the rationale and objectives for modeling in the context of the AMP. The U.S. Environmental Protection Agency (EPA) addressed environmental models as part of the quality assurance (QA) planning process under Order 5360.1 A2, “Policy and Program Requirements for the Mandatory Agency-wide Quality System” (EPA, 2000a), requiring a QAPP for projects where simulation data are used to interpret measured data. The following elements should be included:

- Project management and administration,
- Measurement and data acquisition,

- Assessment and oversight, and
- Data validation and model usability.

The QAPP should outline the project management structure, document the type and quality of data needed to employ an effective modeling approach, establish model setup and calibration methods consistent with the established objectives and project-specific requirements, and ensure that managers and planners make sound and defensible scientific decisions based on modeling results. Further information can be found in EPA (2002). The department also has QAPP templates upon request. Higher planning standards are required for projects that involve multiple point or nonpoint source complexities recognizing that QA activities should be adapted to meet the rigor needed for the project at hand. At a minimum, modeling objectives for the AMP QAPP should incorporate the value of the resource(s) considered, project management details, data needs and monitoring requirements, and accuracy required from model output. It is important to recognize in some cases, objectives will best be met by using a combination of models.

7.6.1.2 Model Extent/Domain

Nutrient AMP modeling will require specification of an appropriate modeling extent or domain. This will depend on site-specific circumstances and hinge on the AMP regulatory question being considered. Only generalized guidance can be offered here, but two generic model domains and types of modeling approaches are envisioned, with flexibility for unique situations. These are as follows:

1. Case 1: Receiving-Water Model. If modeling is solely conducted to demonstrate compliance with the narrative nutrient standards, and one or more MPDES permits are present on the same river segment, and only if point source nutrient management is being considered in the AMP, the model domain can be constrained to MPDES discharge location and downstream extent for a single permit, or alternatively the collective river extent for multiple discharges, in both instances continuing the modeling downstream to the most distal point of waterbody impact.
2. Case 2: Watershed Model/Receiving-Water Model. If both point and non-point source management is being considered as part of the AMP, as would be done in watershed-based nutrient management or nutrient trading, and knowledge of upstream sources and their fate and transport through the watershed are required, the model domain must include the entire contributing watershed of interest, incorporating watershed-loading models, and possibly a linked receiving-water model.

A hypothetical illustration of Case 1 for a single MPDES permit is shown in **Figure 7-2a,** where facility ABC Inc. discharges into a free-flowing river called Pristine Creek (modified from EPA, 2010). In this instance, downstream concentrations are predicted as a function of the upstream load or concentration, noting the model only includes the upstream boundary of the environmental domain of interest (flow and nutrient concentration), the MPDES facility contributions of those same constituents, and computes downstream conditions far enough to observe the most limiting biological response. A similar circumstance is envisioned for multiple MPDES permits on the same river, but over a continuous modeling reach, incorporating multiple permits, with consideration of Montana’s use-class boundaries, locations of principal tributaries or irrigation exchanges, groundwater inputs, and other important waterbody features or processes.

For Case 2, it is recognized that near-field sources or management actions closer to an area of interest have a greater influence on localized water quality than far-field sources or management actions because nutrients are not conservative and are subject to transformations such as nutrient spiraling as well as temporary incorporation into fixed and floating algal assemblages along the waterway. Additionally, loading sources are often spatially distributed. Therefore, if permitting or trading were to be done over large spatial scales for AMP nutrient management with multiple source types, the entire watershed will likely have to be evaluated for collective watershed management purposes since nutrient loads could originate from an upstream community or agricultural area (**Figure 7-2b**), or anywhere in between. In this case, watershed-loading and possibly receiving-water models will possibly be needed for AMP nutrient planning over large and complex watershed scales.

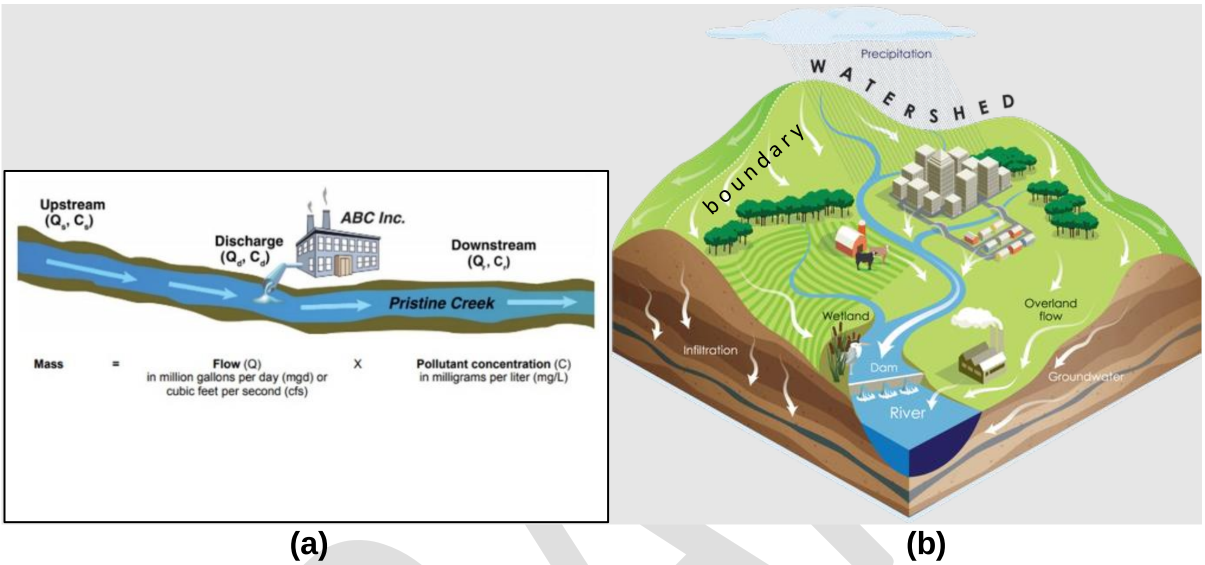


Figure 7-2. Example Model Domains for Nutrient AMP Management. (a) Case 1. A single MPDES discharge permit on a segment of a river in a watershed where conditions immediately upstream and then downstream past the point of impact are modeled. (b) Case 2. A watershed-based nutrient AMP domain that must include the hydrologic (watershed) boundary, contributing tributaries, and multiple point and non-point sources.

It important to recognize that the situations above are idealized. Some blending of approaches may be needed. For example, it is unreasonable to expect AMP watershed-loading models to be developed for an entire river basin if only a few distal sources exist upstream and contribute minimally to water quality at a particular location. As such, the model extent or domain should be truncated in these cases and consider only proximal sources to the AMP reach. Lakes and reservoirs may also serve as appropriate breakpoints, depending on nutrient management objectives. For the sake of simplicity, if a particular far-field nutrient source (point or nonpoint) contributes <5% to the overall load of a limiting nutrient at a downstream location when not accounting for instream transport/uptake, its influence is likely minimal and the Case 1 approach would be most relevant.

Moreover, due to the imperfect nature of the approach, and for practicality's sake, preliminary guidance for AMP model domains and breakpoints for Montana's large rivers are provided in **Table 7-2**. Again, the most important considerations are that (1) the upstream study limit is well-understood and extends at least as far upstream as the most upstream permitted discharge in the reach (unless demonstrated that it is not an important contributor) and (2) downstream evaluations should extend far enough so that management actions based on model results do not lead to degradation of downstream waters.

Table 7-2. Large River Segments of Montana and Recommended Modeling Approaches and Domains

River Name	Segment Description	Recommended Model Approach and Domain [a, b]
Bighorn River	Yellowtail Dam to mouth	No model needed
Clark Fork River	Bitterroot River to State-line	Linked watershed-loading and receiving-water model accounting for point and non-point sources for the entire Clark Fork watershed
Flathead River	Origin to mouth	Linked watershed-loading and receiving-water model(s) that account for point and non-point sources upstream to the Glacier National Park Boundary on the NF and MF of the Flathead River and Hungry Horse Dam on the SF
Kootenai River	Libby Dam to state-line	Simple receiving-water model from dam to state-line, recognizing phosphorus additions are being made in this section of the river
Madison River	Ennis Lake to mouth	Include in Missouri River approach
Missouri River	Origin to state-line	Linked watershed-loading and receiving-water model(s) that account for point and non-point sources for the entire Missouri River watershed to Canyon Ferry Reservoir. Downstream from Canyon Ferry Reservoir, the downstream impoundments and river segments should be considered on a case-by-case basis
SF Flathead River	Hungry Horse Dam to mouth	Use Flathead River approach
Yellowstone River	State-line to state-line	Linked watershed-loading and receiving-water model(s) that account for point and non-point sources from Yellowstone National Park Boundary to the state-line, with the possibility to only focus on the lower river downstream of the Stillwater River (e.g., accounting for Clarks Fork and Laurel-Billings urban complex).

[a] AMP model planning consultations should be made with the department early on in a project to select an approach and level of effort that is consistent with watershed complexity and project requirements. Any AMP approach or domain requires final approval by the department, recognizing that model domains can transcend local, state, and national political boundaries (e.g., multi-jurisdictional watersheds).
[b] Some planning tools may already exist that were developed as part of the Total Maximum Daily Load (TMDL) program.

Finally, modeling domains should be of a manageable size to allow for integration and coordination of water quality program data collection activities within the permitting process, should consider stakeholder involvement or established watershed working groups, and consider funding capabilities and/or requirements.

7.6.1.3 Model Indicator/Endpoint Selection

AMP nutrient modeling applications require *a priori* specification of endpoints affected by nutrients that represent attainment of beneficial uses. These have been defined in Circular DEQ-15 for large rivers to include: (1) dissolved oxygen concentrations, (2) pH, (3) chlorophyll *a* (as bottom-attached [benthic] biomass), (4) turbidity (as a function of increased phytoplankton biomass), and (5) total dissolved gas. Endpoints must be identified to determine compliance with the narrative nutrient standards prior to the model selection process, to ensure the model includes the correct state-variables representing those responses. Indicators should be framed so that (1) odors, colors, or nuisance conditions, (2) materials that are toxic or harmful to human, animal, plant, or aquatic life; and (3) undesirable aquatic life can all be appropriately represented in the model. To the extent that AMP nutrient concentration and load goals are evaluated, models subsequently provide a site-specific translator relating nutrient inputs to quantitative waterbody responses (Bierman et al., 2013). Endpoints to be used in AMP nutrient modeling should be specified in the modeling QAPP.

7.6.2 Model Selection/Development

Model selection is dependent on AMP project requirements in conjunction with the indicators or endpoints discussed previously. The department advocates using the model selection toolbox (MST) from Bierman et al. (2013) as an initial reference for model selection as it has extensive guidance on types of models available, model selection, and application procedures for nutrient management modeling. It also provides a useful tool in developing a candidate list of models depending on the problem specification and project objectives. Because of this, we only briefly address model selection in this guidance document. Important considerations in the model selection process may include:

- Developing an appropriate conceptual model regarding system processes relative to the problem of interest (regarding conceptual models, see Section 9.3 in Circular DEQ-15 and **Section 7.7** in this document). This should include determining potential stressors and key state variables that represent the linkage between the stressor and beneficial use indicators/endpoints.
- Determining the appropriate model complexity with respect to spatial, temporal, and processes of interest. This includes choosing appropriate spatial context (0-, 1-, 2-, or 3-dimensional), grid resolution, temporal characteristics (steady-state *vs*. dynamic model), state-variables (i.e., nutrient forms as causal variables and associated response variables), and sediment interactions, growth kinetics, and source/sink terms.

Off-the-shelf public domain models have the following advantages:

- Comprehensive documentation including a user's manual, conceptual representation of the model process, explanation of theory and numerical procedures, data needs, data input format, and description of model output.
- Technical support in the form of training, use-support, and continual development from federal or academic research organizations.
- A proven track record providing validity and defensibility when faced with legal challenges.
- They are readily available to the public (non-proprietary).

An abbreviated list of process-based models that could potentially be used in nutrient AMP planning are shown in **Table 7-3**. The list is not comprehensive, nor well explained, and the reader should consult Shoemaker et al. (2005), Borah et al. (2006), and Bierman et al. (2013) for a complete compendium of modeling tools, including details about selection and application procedures. EPA (1999) also provides useful guidance in terms of selecting potential model endpoints and model selection.

It is important to point out that pre-existing tools have been developed by the department and others, and these may be useful for nutrient evaluations at the large-watershed scale. For example, the USGS SPARROW (SPAtially Referenced Regressions On Watershed attributes) model provides nutrient load estimates across the conterminous U.S. (Wise, 2019; Robertson and Saad, 2019) under long-term average hydrologic conditions over the period 1999 through 2014, with point source inputs that occurred in 2012. Contributions of municipal wastewater treatment discharge, farm fertilizer, nitrogen fixing crops, urban lands, manure, and atmospheric deposition are estimated at the 8-digit hydrologic unit code (HUC) scale.

Additionally, the implementation of the Hydrologic and Water Quality System (HAWKS, 2020) provides similar functionality in modeling nutrients at the 8-digit HUC level, providing daily, monthly, and annual estimates of water quality across large geographic areas. HAWKS currently is supported by the EPA Office of Water and the Texas A&M University Spatial Sciences Laboratory. None of the above tools (short of those developed by the department) have been verified for Montana's agricultural practices or with site-specific data.

Table 7-3. List of Watershed-loading and Receiving-water Models Useful for Nutrient AMPs

Watershed-Loading Models	Receiving-Water Models
Generalized Watershed Loading Functions (GWLF)	AQUATOX
Hydrologic Simulation Program Fortran (HSPF)	BATHTUB
Loading Simulation Program in C++ (LSPC)	CE-QUAL-RIV1
Pollutant Load–Bank Erosion Hazard Index (PLOAD-BEHI)*	CE-QUAL-W2
Spreadsheet Tool for Estimating Pollutant Loads (STEPL)*	Environmental Fluid Dynamics Code (EFDC)
Soil Water Assessment Tool (SWAT)	Stream Water Quality Model (QUAL2K)
Stormwater Management Model (SWMM)	Water Quality Analysis Simulation Program (WASP)

*Simple method; requires department review and approval.

7.6.3 Data Collection

To accurately calibrate or confirm water-quality models for AMP planning, it is necessary to measure factors that either directly or indirectly influence water quality processes in the river, or that are used in the calibration process. These include forcing functions such as meteorology and hydrology, boundary conditions (i.e., tributary or point source inputs), state-variables for calibration, and rate data (if possible), which are described in subsequent sections. Direct measurement of key parameters will increase the confidence in the model predictions and reduce the uncertainty in calibrated model parameters and coefficients (Barnwell et al., 2004).

7.6.3.1 Data Requirements for AMP Modeling

AMP modeling will typically require a preliminary evaluation of existing data (data compilation) prior to data collection to identify the extent and availability of information to support model development. In most circumstances, complete data will not be available to support AMP modeling; however, in some cases sufficient data may be identified. Even with a considerable number of models available to choose from, many of the basic data requirements will be similar. Input requirements coarsely fall into three general categories: (1) model geometry, (2) forcing functions/boundary conditions, and (3) calibration requirements. These each are described below.

Model Geometry includes the model grid or network representing how the system is subdivided spatially into segments for which water quality predictions will be made. At the heart of the geometry is the computational unit of the model (i.e., elements or cells) over which water and pollutant mass balances are developed. As part of AMP planning, the model network must be defined so that water quality gradients are appropriately described, model stability requirements are met (e.g., Courant condition), and the location of important boundary conditions are adequately delineated. Once the geometry is established, forcing function and boundary condition information must be specified using available data to describe energy, water, and pollutant fluxes into or out of the system.

Forcing Functions quantify major inputs of energy, water, and pollutants into, out of, or along the model boundaries. Types of forcing functions for water-quality models include meteorological data (e.g., solar radiation, air temperature, humidity, wind speed, and atmospheric loadings), hydrologic or hydrodynamic (flow) information, and tributary or point source loadings. Everything outside of, and crossing, a boundary in a receiving-water model, is treated as an external forcing, meaning the user must know how those boundaries change over time, including changes or variation in flow or loading contributions. As an example, watershed models are driven solely by meteorological data whereas boundaries for lake or river receiving water models would consist of the inflows or upstream and downstream boundary conditions, air-water/water-sediment interfaces, and any tributary or point source inflows. In branched river systems, it may be necessary to decide whether to explicitly model a tributary or consider it as a point input (Bierman et al., 2013).

Calibration Data reflect the real-world data necessary to constrain model coefficients or kinetics to ensure the model reasonably reflects actual watershed or waterbody processes. Data for calibration take the form of observations within the river or system being modeled and will include measured flow and water quality constituents (with an emphasis on nutrients), diurnal state-variable observations that are representative of system biological or chemical responses, and any other observation required to constrain the model. Calibration data are ideally collected in a condition similar to that envisioned for the problem being evaluated and ideally cover multiple spatial locations of importance, as well as temporal conditions of significance.

Dilks et al. (2019) describe procedures for nutrient water-quality model data collection. They consider the following steps, which should be adopted for AMP planning:

- Compiling existing physical description, hydrologic information, climate, external loads, ambient data, and process measurement data.
- Developing and applying a scoping/strawman[3] model as a simple framework that accounts for important spatial and temporal processes.
- Defining sampling parameters, locations, and frequency for the system of interest based on the scoping model evaluation.

Beyond this guidance, monitoring recommendations for larger, deeper rivers and lakes and impoundments are shown in **Table 7-4**. The reader is referred to Dilks et al. (2019) for complete information, noting any data collection efforts should define appropriate spatial sampling locations, monitoring frequency, constituents, and number of monitoring events. Outside of this generalized guidance, it is difficult to specify minimum data requirements given the range and breadth of models considered for AMP planning. The reader is encouraged to consult a model-specific user manual for any model being considered. Generally, a higher level of effort will be required for dynamic models or those that compute mass transport in multiple dimensions beyond steady-state or zero or one-dimensional models. This is because considerably more data is required to calibrate a dynamic water quality model over a range of different flow and water quality loading conditions than a steady state model that represents only the critical waterbody condition.

[3] It is noted that for AMP planning, it is recommended, but not required to develop a scoping model. However, this may be a useful preliminary step to understand data gaps and areas of model sensitivity.

Table 7-4. Nutrient Model Monitoring Guidance by Waterbody Type (from Dilks et al. 2019)

Waterbody Type		Spatial Coverage [a]	Temporal Frequency & Extent	Constituents [b]	Number of Events [c]
Large rivers	Forcing Functions	• Upstream boundary or boundaries for branched systems (flow, chemistry, sonde data) • Each tributary/point source that will change instream concentration by more than 5% • Samples above/below mixing zone of major inputs	• Sufficient frequency to capture variability in forcing functions • Sufficient temporal extent to capture nutrient loads important to condition being modeled • If no watershed model available, wet weather events possibly should be considered	• All nutrient forms and organic carbon in model • Flow • All water quality state variables considered in model that are appropriate to beneficial uses	• Continuous meteorology over modeled period • Boundary conditions as required for specific model approach
Large rivers	Calibration Data	• Sufficient resolution to capture >10% change in water quality • < 0.5 days travel time apart • Resource areas of concern	• Sufficient frequency to capture variability in forcing functions and nutrient loads important to condition being modeled • Continuous sonde data (DO, pH, etc.)	• All state variables considered by model	• Minimum two years (one near critical preferably)
Lakes or impoundments	Forcing Functions	• At any input that will change in-lake concentration >1% in water quality (flow, chemistry, sonde data) • < 0.5 days travel time apart • Resource areas of concern	• Sufficient frequency to capture variability in forcing functions • Sufficient temporal extent to capture nutrient loads important to condition being modeled • Continuous sonde data (DO, pH, etc.)	• All nutrient forms and organic carbon in model • Flow • All water quality state variables considered in model that are appropriate to beneficial uses	• Continuous meteorology over modeled period • Boundary conditions as required for specific model approach
Lakes or impoundments	Calibration Data	• Sufficient resolution to capture >10% change in water quality • Resource areas of concern	• Sufficient frequency to capture variability in forcing functions and nutrient loads important to condition being modeled • Continuous sonde data (DO, pH, etc.)	• All state variables considered by model • Elevations	• Minimum two years (one near critical preferably)

[a] Model segmentation and boundaries should be discrete enough to capture the water balance, major hydrogeometric features (i.e., changes in flow or geometry), water quality processes, spatial water-quality gradients, areas of water quality concern, characteristics of control structures (e.g., dams, weirs, etc.), and locations of both point and major nonpoint sources.

[b] Nutrient data should include inorganic, organic, and dissolved forms. The same holds true with other water-quality data that influence dissolved oxygen, total carbon, or other response variables related to beneficial uses.

[c] Forcing functions (meteorological data) and deployed instrument data should be collected at high frequency, such as hourly or less to aid in understanding diurnal cycling and for calibration and confirmation of the model.

7.6.3.2 Data Quality
Data of known and documented quality are essential for implementing a successful modeling project. The department recommends that Data Quality Objectives (DQOs) be developed for all AMP modeling projects as part of the planning process to specify the acceptance criteria for model input, calibration, or confirmation. DQOs identify the (1) type and quality of data that will be appropriate for use in modeling, (2) spatial and temporal input data coverage requirements, (3) data quality and currency, and (4) technical soundness of the collection methodology. A bullet list of requirements are shown below:

- All input and calibration data for modeling will be of a known and documented quality,
- Data will be collected from as many sources as are available/practicable, and provide the maximum temporal and spatial coverage for the type of model being used,
- The data will be comparable with respect to previous and future studies, and
- Data will be representative of the parameters being measured with respect to time and space, and the conditions from which the data are obtained.

DQOs can be further refined to define performance criteria that limit the probability of making decision-based errors. They should address the data validity and reliability of the modeling effort and can be described in the context of completeness, representativeness, and comparability. In each AMP effort, the final decision about quality planning will be made in consultation with the department. The higher the risk to the resource value or areal extent, the more comprehensive modeling rigor is required.

7.6.4 Model Calibration
Model calibration includes the set of procedures whereby model parameters are adjusted iteratively to provide a better fit between predicted values and observations. Ideally, calibration is an iterative process where deficiencies in the initial parameterization are reviewed and constrained by refining the calibration through the adjustment of uncertain parameters via a feedback loop with observed data. General information related to model calibration and confirmation can be found in Thomann (1982), Donigian (1982), ASTM (1984), and Wells (2005). Once an acceptable calibration is reached, the model parameterization can then be confirmed on an independent data set to judge the extent to which the model is able to predict water quality conditions over time. Both calibration and confirmation have become increasingly important due to the need for valid and defensible nutrient management models. Water quality model calibration should consider the most important response variables and processes of interest in the AMP watershed. A complete watershed-loading model calibration involves a successive examination of the following characteristics of the watershed hydrology and water quality: (1) annual and seasonal water balance and streamflow, (2) sediment, and (3) nutrients. Simulated and observed values for reach characteristic are examined, and critical parameters are adjusted to attain acceptable levels of agreement. The refinement of calibration parameters should reflect the scientific literature and not exceed reasonability.

Receiving water models are often calibrated globally, although spatially specific kinetics are sometimes used. Calibration should focus on the water balance, temperature, hydrodynamics, and state variables of importance to nutrient management like algal biomass, dissolved oxygen, pH, or other indicators/endpoints deemed critically important in initial AMP planning. A much greater emphasis is placed on the kinetic aspects of biological or chemical processes in the waterbody of interest in a receiving-water model. Appropriate initial conditions or model “warm-up” periods should be used during modeling and decisions made during model calibration and confirmation should be sufficiently documented so that an experienced user could complete the calibration process and obtain similar modeling results.

Ideally, both high and low flow years, and the anticipated range of conditions and scenarios for which the AMP management will be evaluated should be considered in calibration. The deterministic ability to predict conditions over the entire range of observed data is important, along with documenting comparisons of simulated and observed state variables for daily, monthly, and annual values (as appropriate). Calibration should be completed in sequential order, using the most upstream point first and then moving downstream to the next point of calibration, noting important parameters or files associated within the area upstream of a calibrated point should not be changed during subsequent downstream calibration steps.

7.6.4.1 Sensitivity Analysis

Parameter sensitivity has a considerable influence on the uncertainty of the model. As such, a sensitivity analysis is recommended as part of the calibration process in AMP modeling. This helps determine the effect of a change in a model input on the model outcome and is of great benefit in guiding the calibration process. Model sensitivity is typically evaluated to identify sensitive parameters that are unknown, are conversely sensitive ones that are known, in order to constrain the calibration. The sensitivity of a given model parameter should be expressed as a normalized sensitivity coefficient (NSC; Brown and Barnwell, 1987), as shown below:

$$NSC = \frac{\Delta Y / Y}{\Delta X / X} \qquad \text{(Eq-1)}$$

where ΔY = change in the output variable Y and ΔX = change in the input variable X. The results of the sensitivity analysis should be documented in final AMP model report documentation. At a minimum, a one-at-a-time sensitivity analysis should be completed with ΔX of ±25% to evaluate the sensitivity of model inputs or calibration coefficients.

7.6.4.2 Performance Metrics

Performance metrics should be used to evaluate the calibration of an AMP nutrient model. Deviations between models and observed data result from: (1) incorrect estimation of model parameters, (2) erroneous observed model input data, (3) deficiencies in model structure or forcing functions, or (4) error of numerical solution methods (Donigian and Huber, 1991). Numerous statistical tests exist for model performance evaluation and a suitable review of error statistics, correlation or model- fit efficiency coefficients, and goodness-of- fit tests is provided by Moriasi et al. (2015). At a minimum, the following performance metrics should be considered in AMP modeling:

Root Mean Squared Error (*RMSE*) is a commonly used objective function for hydrologic or water quality model calibration. It compares the difference between the observed and predicted ordinates and uses the squared differences as the measure of fit. Thus, a difference of 10 between the predicted and observed values is one hundred times worse than a difference of 1. Squaring the differences also treats both overestimates and underestimates by the model as undesirable. These are then summed and divided by the number of observations. The equation for calculation is:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2} \qquad \text{(Eq-2)}$$

where O_i = observed variable and P_i= predicted variable

Percent Bias (*PB*) measures the average tendency of the simulated data to be larger or smaller than observed data and expresses the value on a percentage basis. It reflects consistent or systematic deviation of results from the "true" value. Percent bias is calculated as the difference between an observed (true) and predicted value as shown below:

$$PB = \frac{\sum_{i=1}^{n}(P_i - O_i)}{\sum_{i=1}^{n} O_i} \times 100 \qquad \text{(Eq-3)}$$

Low-magnitude values indicate an accurate model simulation. Positive values indicate overestimation bias, whereas negative values indicate underestimation bias.

Nash and Sutcliffe Efficiency (*NSE*) is a dimensionless performance measure often used in watershed modeling. It provides a statistical measure of the variability between measured and predicted model values. It is calculated as below:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \qquad \text{(Eq-4)}$$

A *NSE* value of one indicates a perfect fit between measured and predicted values for all events. *NSE* values between zero and one suggest a positive relationship between observed and predicted values, thus allowing for the use of predicted values in lieu of observed data. A value of zero indicates that the fit is as good as using the average value of all the measured data.

Graphical comparisons of model performance can also be made through time series plots of observed and simulated variables, residual scatter plots (observed versus simulated values), or spatially oriented plots. When observed data are adequate, or uncertainty estimates are available, confidence intervals should be provided so they can be considered in the model performance evaluation. For water quality data, model performance may at times rely primarily on visual and graphical presentations because the frequency of observed data is often inadequate for computing accurate statistical measures.

7.6.4.3 Acceptance Criteria for AMP Models

Acceptance criteria should be defined as part of the initial project planning and should be considered in the calibration process. Thomann (1982) and Arhonditsis and Brett (2004) provide suitable guidance for defining model acceptance criterion and general recommendations applied in this guidance are provided in **Table 9-5**. Final criteria for AMP modeling acceptance criteria will be project specific and should be discussed with the department before finalizing.

Table 7-5. Candidate Acceptance Criteria for AMP Nutrient Models

State-variable	Relative Error (±%)[a, b]	Units
Temperature	10	°C
Dissolved oxygen	15	mg/L
Nutrients	25	µg/L
Benthic Algae	35	mg/m^2
Phytoplankton	35	µg/L

[a]Arhonditsis and Brett (2004), 153 aquatic modeling studies in lakes, oceans, estuaries, and rivers.

[b]Thomann (1982), studies on 15 different waterbodies (rivers and estuaries).

Model performance evaluations should consist of comparison of model results with observed historical data, and general evaluation of model behavior. At the end of the calibration, AMP managers and project stakeholders should be able to assess the ability of the model to simulate water quality responses based on the following criteria:

- Modeling input and output validity,
- Model calibration and validation performance determination,
- Sensitivity and uncertainty analysis assessment, and
- Parameter deviation and post-simulation validation.

This will ensure that model predictions are reasonable, and that all work is consistent with the requirements of the project.

7.6.4.4 Modeling Journal

A modeling journal is recommended for calibration of nutrient AMP models to keep a log of the internal parameters that were adjusted during the calibration process. Each time that changes are made to the model, or a model calibration run is completed, adjustments should be documented to provide a record of the modeling process. The level of detail in the model calibration journal should be sufficient that another modeler could duplicate the calibration given the same data and model. The modeling journal should include complete recordkeeping of each step of the modeling process. Documentation should consist of the following information:

- Model assumptions.
- Parameter values and sources.
- Input file notations.
- Output file notations and model runs.
- Calibration and validation procedures and results from the model.
- Intermediate results from iterative calibration runs.
- Changes and verification of changes made in code.

These files should be retained over the long term for post-auditing or project reuse. The credibility of a modeling approach hinges on the ability to provide this information.

7.6.5 Model Confirmation

Following calibration, the AMP model should be confirmed using an independent dataset to ensure that it is sufficiently credible for decision making. The purpose of model confirmation is to assure that the calibrated model properly assesses the range of variables and conditions expected within the simulation. Although there are several approaches to confirming a model, perhaps the most effective is to use only a portion of the available observations for calibration. The remaining portion of the dataset is then used for confirmation. Once final calibration parameters are developed, a simulation is performed, and the same performance metrics used in the calibration are reassessed for the confirmation data. This type of split-sample approach should be used when possible. However, it is important to recognize that confirmation is, in reality, an extension of the calibration process (Reckow, 2003; Wells, 2005). In this regard, if the confirmation is not initially successful, the AMP should not be abandoned. Rather the remaining data should be used for recalibration of the model and then the utility of the model should be evaluated in consultation with the department for decision-making purposes.

7.6.6 Uncertainty Analysis

Research has shown that uncertainty analysis should be completed to examine how the lack of knowledge in model parameters, variables, and processes propagates through the model structure as model output or forecast error. Uncertainty stems from our limited ability accurately describe complex processes. As such, an uncertainty analysis should be considered for AMP modeling. Potential sources of model uncertainty include:

- Estimated model parameter values.
- Observed model input data.
- Model structure and forcing functions.
- Numerical solution algorithms.

It is recommended, although not required, that AMP modeling projects include an uncertainty analysis. This decision should be made jointly with the department during project planning.

7.6.7 Decision Support and Simulating AMP Objectives

Objectives envisioned for AMP nutrient management modeling include: (1) assessing support of beneficial uses and water quality impacts in the modeled watershed and (2) using the model(s) to simulate potential changes in phosphorus and/or nitrogen management to best manage water quality through BMPs, permitting, and nutrient trading. General guidance for completing these decision support activities is provided below for flowing waters and lentic waterbodies, each which necessitate different approaches.

To assess whether narrative nutrient standards are being achieved in large rivers (i.e., if beneficial uses are being supported), the models developed using the approach described in this guidance document should be used to simulate water quality during critical low flow conditions. For nutrients, this corresponds to the summer growing season when algal growth is at its peak and water quality impacts are maximal. Selection of a critical condition should consider a low-flow duration and frequency corresponding to the 14Q5 (14-day 5-year) in the receiving water for steady-state models (representing the time it takes to grow nuisance algal biomass, with an excursion frequency that allows for the waterbody to recover from impacts) along with critical meteorological and boundary conditions expected during the same time. For dynamic models[4], selection of a year corresponding to a critical flow condition hydrograph is required. Both are envisioned to be done under maximum MPDES permit load limits for any facility in the modeled reach, or perhaps under current load limits.

Predefined water-quality indicators/endpoints are then assessed through the model output to ascertain whether narrative nutrient standards are being achieved. This would include examining algal biomass, dissolved oxygen, pH, and other model response endpoints that reflect beneficial use support as defined in Montana's water quality standards (e.g., ARM 17.30.627(1)(e); ARM 17.30.623(2)(c)), the AMP, and the modeling QAPP) over the entire spatial domain of the AMP planning area. When appropriate, diurnal indicators should be evaluated at the same time (e.g., DO minima, pH maxima), with the most limiting indicator being used as the decision-point of whether the waterbody is compliant with the narrative nutrient standards. In essence, the model is used as a translator between the nutrient stressor and waterbody response to determine beneficial use attainment under critical conditions.

In lakes or impoundments, a slightly different approach is required as the response during critical conditions (again during summer growing season when the lake is stratified and surface temperatures are warm), is contingent mainly on the nutrient loading during spring runoff rather than summer months. In this case, AMP modeling will need to account for loadings over the entire year, necessitating watershed-loading and time-variable receiving-water modeling. Critical loads could be developed with the watershed model to simulate loadings to the lake from all tributary sources and groundwater during a high flow year, in conjunction with loadings at maximum MPDES permit limit levels over the simulation period. The lake/reservoir receiving-water model would then be used to evaluate how the waterbody processes those loadings over the summertime period in terms of algal response, Secchi depth, harmful algal bloom (HAB) frequency or other indicators of importance.

AMP modeling of complex watersheds may require the use of linked models to simulate integrated effects of various management practices at the basin scale. One model may be necessary to predict loading to a waterbody from nonpoint sources and a second to predict fate and transport of pollutants in the waterbody. This combination of linked models may be useful for:

- Characterizing runoff quantity and quality including the temporal and spatial detail of concentrations or load ranges from non-point sources.
- Estimating load reductions needed to meet a water quality standard.
- Providing input or boundary conditions to a receiving water quality analysis, e.g., drive a receiving water quality model.
- Distinguishing between the effects of different management strategies, including the magnitude and most effective combinations of BMPs.
- Determining if management criteria can be met by a proposed strategy.

[4] Specific guidance has not been developed to determine at what condition a dynamic flow model should be used. Generally, if streamflow in the receiving water is not varying by more than 10% over the critical condition period, a steady-state model should suffice provided loadings are also not varying in time considerably.

- Performing frequency analysis on quality parameters to determine the return periods of concentrations and loads for a given site.
- Providing input to cost-benefit analyses.
- Nutrient trading.

Two scenarios are envisioned for nutrient AMP modeling: (1) simulating baseline conditions which reflect existing conditions for the waterbody and (2) one or more scenarios in which nutrient management is contemplated. By comparing simulated results between the existing modeled condition and proposed BMPs, or future growth scenarios, changes in water quality can be evaluated to guide stakeholder decisions and assist in the development of AMPs. This may include consideration of management techniques to regulate the most limiting nutrient, or BMPs that will have the greatest impact on pollutant reduction and potential for reaching desired nutrient levels to attain beneficial uses. A final factor in AMP modeling is that a margin of safety (MOS) should be considered. The MOS could be addressed through an uncertainty analysis discussed previously, or by directly specifying a value based on conservative analytical assumptions. Should protective assumptions be relied on to provide an MOS, they should be appropriately described and documented. From a regulatory perspective, the allowable pollutant load to a specific waterbody would consist of the sum of: (1) waste load allocations from point sources, (2) load allocations for nonpoint sources, and (3) the MOS sufficient to account for uncertainty and lack of knowledge (EPA, 1999).

7.6.8 Best Practices for Modeling

A summary of best practices for modeling are provided below as outlined in Donigian and Huber (1991). They are expounded upon with specificity to AMP planning.

- Have a clear statement of project objectives. Verify the need for water quality modeling. Can objectives be satisfied without water quality modeling? Define the following:
    - Will the department require a water quality model for my AMP watershed?
    - How can a model help address the questions and problems relevant to AMP decisions?
    - How can a model be used to link stressors or management actions to quantitative measures (endpoints) of waterbody condition?
    - Is modeling appropriate for examination of the stressors of concern in this situation?
- Use the simplest model that will satisfy the project objectives. Often a screening model, e.g., regression or statistical, can determine whether more complex simulation models are needed. Consider the spatial and temporal scale and resolution of the application in defining model complexity, recognizing it may be necessary to use multiple models or link models to address nutrient management problems. Because of this consideration, it is important to choose models with compatible input and output data.
- To the extent possible, utilize a quality prediction method consistent with available data. Data availability should be evaluated before beginning the model selection process.

- Only predict the quality parameters of interest and only over a suitable time scale. For AMP planning, this will primarily be the water-quality indicators/endpoint of interest. It is important to define carefully which model state-variables correspond to those indicators.
- Perform a sensitivity analysis on the selected model and familiarize yourself with the model characteristics.
- Calibrate and confirm the model results. Use one set of data for calibration and another independent set for confirm. If no such data exist for the application site, formulate data collection plans that meet modeling objectives.
- Use the linkage between model input and output to support management/decision-making for AMP decision making.

The above practices essentially reiterate the workflow described at the beginning of this guidance document, outlining a framework for systematic application of water-quality modeling for nutrient AMP support. It is important to recognize models are tools and should be used in combination with other assessment techniques, when possible, to reflect our understanding of watershed systems. It is useful to recognize the AMP modeling approach in a large way parallels the EPA NPDES watershed strategy initiative developed in the early 1990s (EPA, 1994). That framework provided a basis for management decisions using an ecosystems approach through watershed-based permitting where NPDES permits are issued to point sources on a geographic or watershed basis to enhance permitting efficiency, improve coordination among programs, and provide greater consistency and responsiveness[5]. This would enable a greater focus on watershed goals and allow consideration of multiple pollutant sources and stressors, including the level of nonpoint source control that is practicable (EPA, 2015).

7.7 Guidance Related to the Development of a Conceptual Model

Permittees intending to build a conceptual water quality model should refer to EPA's Stressor Identification Guidance Document (EPA, 2000b). The document provides a base flow chart for a conceptual model, instructions on developing candidate causes and casual pathways, and guidance on identifying relevant biological responses. The stressor identification process—which is at the heart of the conceptual model—consists of five basic steps: (1) define the case, (2) list candidate causes, (3) evaluate data from the case, (4) evaluate data from elsewhere, and (5) identify probable cause. Additional information pertaining to the development of a conceptual model is found in Cormier and Suter (2008) and Cormier et al. (2010).

Conceptual models are developed from global and local information about stressors and their relationships to biological assemblages and beneficial uses of a waterbody. The process of creating a conceptual model can aid in identifying unknown elements in a waterbody (e.g., the source of observed excess sediment). The complexity of the conceptual model depends on the complexity of the watershed and its impairments. In some cases (i.e., rural streams with limited non-point impacts) the same basic conceptual model could be used repeatedly.

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[5] The most common watershed-based permitting approach is to re-issue NPDES permits according to a five-year rotating basin schedule. Each source receives an individual permit, and the permits are issued based on basin or watershed management areas. This process allows permittees to compare their permits with other dischargers in the same area and facilitates sharing data to arrive at the most appropriate limits.

Conceptual models are presented as flow diagrams with boxes and arrows to illustrate presumed relationships. These diagrams provide a graphic representation that can be presented to stakeholders and to help to guide the subsequent planning/data collection process. Often there will be more than one pathway between cause and effect. An example of a conceptual model is shown below in **Figure 7-3**.

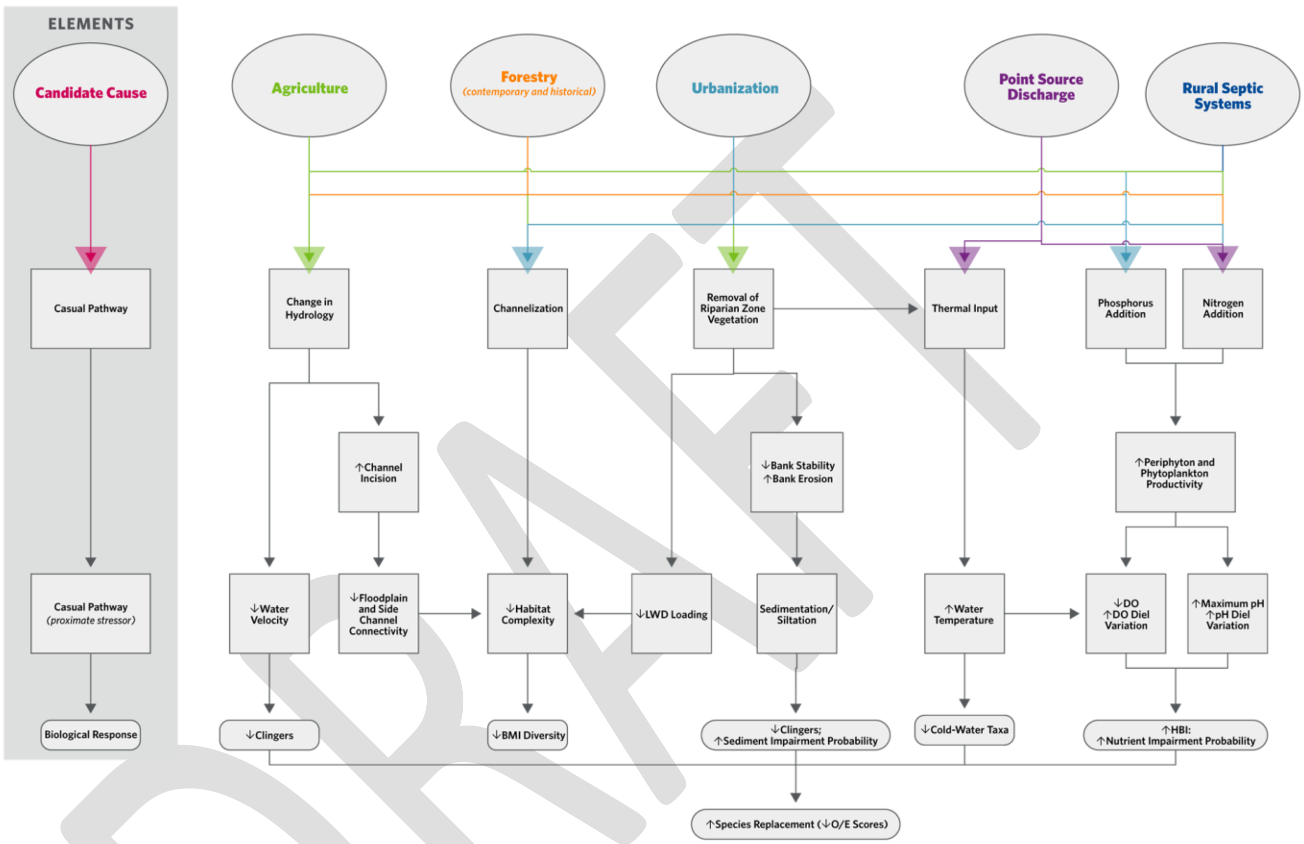

Figure 7-3. Example Conceptual Model. The far branches (those near the bottom of the figure) show the biological responses presumed to occur via the relationships (connections) to candidate causes shown near the top.

Conceptual models have two main parts. First, a set of risks that are known or may be affecting the waterbody. Second, the flow diagram illustrates these risks and their presumed relationships within the waterbody to the endpoints—the biological responses. The conceptual model can be used to start identifying relationships between the possible causes and sources of impacts seen in a waterbody, and their relative importance. In fact, the conceptual model can help to identify what types of data you need to collect as part of the characterization process.

Conceptual models can be a working and dynamic representation of the workings of a waterbody. The model can be used to explore ways of addressing a problem before selecting a solution or as an approach to guide data collection or analysis. The conceptual model text should describe what is known and rank levels of uncertainty and variability, if possible. Identify and describe key assumptions made in the model because of lack of knowledge, simplification, approximation, or extrapolation.

Causal pathways are eliminated, diagnosed, or weighted relative to the other causal pathways as data are collected and analyzed (see Chapter 4 in EPA (2000b)). Each causal pathway may be ranked relative to the others based on the consistency and coherence of the considerations, or lines of evidence. Consistency among the lines of evidence is ranked. Inconsistencies are evaluated and ranked, according to whether the inconsistencies can be explained or not. For example, an inconsistent line of evidence may be the result of a paucity of data or another causal pathway masking its effects. The result of this process is a qualitative ranking of causal pathways that indicates primary and secondary stressors. The relative importance of each causal pathway should be considered for action/restoration priorities.

8.0 Guidance Supporting Part II, Section 8.0 of Circular DEQ-15 (Integration of the Adaptive Management Program with the Total Maximum Daily Load Program)

A total maximum daily load (TMDL) is the maximum amount of a pollutant a waterbody can receive and still meet water quality standards. A TMDL calculation is the sum of the load allocations (LAs), wasteload allocations (WLAs), and an implicit or explicit margin of safety. Once the TMDL is determined, reductions are allocated to each identified significant source in order to meet the TMDL.

8.1 AMP in Watersheds Where an EPA-Approved TMDL Exists

Implementation of the AMP will be coordinated across the department with other relevant programs by the Adaptive Management Program Scientist. This effort will include the coordination of AMP development with MPDES permitting cycles and, when appropriate, revisions to existing TMDLs. AMPs (see **Section 6.0**) will not supplant or immediately prompt revision of existing TMDLs and corresponding WLAs. Required load reductions must demonstrate the potential to attain beneficial uses and be consistent with the existing TMDL.

The department will evaluate the need for TMDL revisions when 3-5 years of AMP monitoring data are available. Based on response variable data, the appropriate target concentration for phosphorus and/or nitrogen will be determined in accordance with Section 4.0, Part II of **Circular DEQ-15**. Target concentrations may be lower, higher, or the same as the numbers used in existing TMDLs. In instances where the target concentration is the same as the existing TMDL, no revisions would be made unless the assumptions about LAs and WLAs are demonstrated to be inaccurate. In the other instances, TMDLs would be revised according to the appropriately determined target concentration. Other changes to the TMDL document could be made at this time as necessary.

8.2 AMP in Watersheds Where an EPA-Approved TMDL Does Not Exist

In areas where a TMDL has not been completed and an AMP is developed, the department may submit an AMP as an Advance Restoration Plan (ARP) to EPA. EPA acceptance of an AMP as an ARP would acknowledge work being done in the watershed to attain beneficial uses without following the traditional TMDL development pathway. Although the waterbody-pollutant pairing would remain in category 5 of the 303(d) list, indicating that a TMDL is still required, acceptance of an AMP as an ARP may result in the department assigning a lower priority ranking for TMDL development to allow time for AMP implementation to take effect while continuing monitoring to evaluate progress toward attainment of beneficial uses. This will be done in accordance with 75-5-702, MCA and consultation with the Statewide TMDL Advisory Group.

In preparing an AMP for submittal as an ARP, the following elements should be included/addressed:

- Identification of specific impaired waterbodies (i.e., assessment units) addressed by the advance restoration approach, and identification of all sources contributing to the impairment.
- Analysis to support why the permittee believes implementation of the AMP/advance restoration approach is expected to achieve water quality standards.
- An action or implementation plan to document: a) the actions to address all sources – both point and nonpoint sources, as appropriate – necessary to achieve water quality standards (this may include a list of nonpoint source conservation practices or BMPs to be implemented); and, b) a schedule of actions designed to meet water quality standards with clear milestones and dates, which includes interim milestones and target dates with clear deliverables.
- Identification of available funding opportunities to implement the AMP/advance restoration plan.
- Identification of all parties committed, and/or additional parties needed, to take actions that are expected to meet water quality standards.
- An estimate or projection of the time when water quality standards will be met.
- Plans for effectiveness monitoring to: demonstrate progress made toward achieving water quality standards following implementation; identify needed improvement for adaptive management as the project progresses; and evaluate the success of actions and outcomes.
- Commitment to periodically evaluate the advance restoration approach to determine if it is on track to be more immediately beneficial or practical in achieving water quality standards than pursuing the TMDL approach in the near-term.

Because the adaptive management program is a permittee-centric program, development of an AMP and submittal as an ARP would be done for the relevant waterbody assessment unit-pollutant pairings only. In watersheds or TMDL planning areas where the department has assigned a medium or high priority to TMDL development, the AMP will be coordinated and implemented into TMDL development to the extent possible. In these watersheds, AMPs would be incorporated into new TMDL documents to present a comprehensive water quality planning document. Individual assessment units would have corresponding TMDLs or ARPs, depending on which permittees opt into the adaptive management program. Once established and approved, the water quality planning document would be evaluated in accordance with **Section 8.1**.

9.0 ACKNOWLEDGEMENTS

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10.0 REFERENCES

Arhonditsis, G.B., and M.T. Brett. 2004. Evaluation of the Current State of Mechanistic Aquatic Biogeochemical Modeling. *Marine Ecology Progress Series* 271: 13-26.

ASTM. 1984. Standard Practice for Evaluating Environmental Fate Models of Chemicals. Designation E978-84. American Society of Testing and Materials. Philadelphia, PA. 8 p.

Barnwell, T.O., C.B. Linfield, and R.C. Whittemore. 2004. Importance of Field Data in Stream Water Quality Modeling Using QUAL2E-UNCAS. *Journal of Environmental Engineering* 130(6): 643-647.

Bierman, V.J., DePinto, J.V., Dilks, D.W., Moskus, P.E., Slawecki, T.A.D., Bell, C.F., Chapra, S.C., and Flynn, K.F. 2013. Modeling Guidance for Developing Site-specific Nutrient Goals. Water Environment Research Foundation Report LINK1T11. 336 p.

Borah, D. K., Yagow, G., Saleh, A., Barnes, P.L., Rosenthal, W., Krug, E.C., and Hauck, L.M. 2006. Sediment and Nutrient Modeling for TMDL Development and Implementation. *Transactions of the ASABE* 49(4): 967-986.

Brown, C.L., and T.O. Barnwell, Jr. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS – Documentation and User's Manual. Environmental Research Laboratory. EPA/600/3-87/007. Athens, GA.

Chapra, S.C. 1997. Surface Water-quality Modeling. Waveland Press, Inc. Long Grove, IL.

Chapra, S.C. 2003. Engineering Water Quality Models and TMDLs. *Journal of Water Resources Planning and Management* 129(4): 247-256.

Cormier, S.M., and G.W. Suter. 2008. A Framework for Fully Integrated Environmental Assessment. *Environmental Management* 42: 543-556.

Cormier, S.M., Suter, G.W., and S.B. Norton. 2010. Causal Characteristics for Ecoepidemiology. *Human and Ecological Risk Assessment* 16: 53-73.

DEQ. 2005. Appendix E – Big Springs Creek Watershed Water Quality Restoration Plan and Total Maximum Daily Loads. Version 1.1. Helena, MT.

DEQ. 2008. Appendix G – Big Hole River Watershed Nutrient TMDL GWLF Modeling Documentation. TMDL Technical Report DMS-2008-10. Helena, Montana.

DEQ. 2012. Sample Collection, Sorting, Taxonomic Identification, and Analysis of Benthic Macroinvertebrate Communities Standard Operating Procedure. WQPBWQM-009. Helena, MT: Montana Department of Environmental Quality.

DEQ. 2012. Circular DEQ-13. Montana's Policy for Nutrient Trading. December 2012. Helena, MT.

Dilks, D., Redder, T., Chapra, C., Moscus. P., Bierman, V.J., DePinto, J.V., Schlea, D., Rucinski, D., Hinz, S.C., Tao, H., Flynn, K.F., Clements, N. 2019. Evaluation of Data Needs for Nutrient Target-setting using the Nutrient Modeling Toolbox. LINK3R16/4814. Water Research Foundation.

Dodds, W.K. 2003. Misuse of Inorganic N and Soluble Reactive P Concentrations to Indicate Nutrient Status of Surface Waters. *Journal of the North American Benthological Society* 22(2): 171-181.

Donigian, Jr., A.S. 1982. Field Validation and Error Analysis of Chemical Fate Models. In: Modeling Fate of Chemicals in the Aquatic Environment. Dickson et al. (Editors.), AnnArbor Science Publishers, Ann Arbor, MI. 303-323 p.

Donigian Jr., A.S. and W.C. Huber. 1991. Modeling of Nonpoint Source Water Quality in Urban and Non-urban Areas. EPA-600/3-91-039, USEPA, Athens, GA, 78 p.

Ekholm, P., and K. Krogerus. 2003. Determination of Algal-available Phosphorus of Differing Origin: Routine Phosphorus Analysis versus Algal Assays. *Hydrobiologia* 492: 29-42.

Ensign, S.H., and M.W. Doyle. 2006. Nutrient Spiraling in Streams and River Networks. *Journal of Geophysical Research* 111: 1–14. https://doi.org/10.1029/2005JG000114

EPA, 1994. Moving the NPDES Program to a Watershed Approach. Office of Waste Management Permits Division. Washington, DC.

EPA. 1997a. Guidelines for Preparation of the Comprehensive State Water Quality Assessments. Office of Water. Washington, DC. https://www.epa.gov/waterdata/guidelines-preparation-comprehensive-state-water-quality-assessments-305b-reports-and

EPA. 1997b. Compendium of Tools for Watershed Assessment and TMDL Development. EPA841-B-97-006. Office of Water. Washington, DC 20460.

EPA. 1999. Protocol for Developing Nutrient TMDLs. First edition. EPA 841-B-99-007. Office of Water. Washington, D.C.

EPA. 2000a. Policy and Program Requirements for the Mandatory Agency-wide Quality System. CIO 2105.0 (formerly 5360.1 A2). Approval Date: May 5, 2000.

EPA. 2000b. Stressor Identification Guidance Document. EPA/822/B-00/025. Office of Research and Development, Washington, D.C.

EPA. 2002. Guidance for Quality Assurance Project Plans for Modeling. EPA QA/G-5M. EPA/240/R-02/007. Office of Environmental Information. Washington, D.C.

EPA. 2006. Appendix C – GWLF/BATHTUB Modeling: Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area: Volume II – Final Report. Prepared for the Montana Department of Environmental Quality with Technical Support from Tetra Tech, Inc.

EPA. 2007. Modeling the Tongue River Watershed with LSPC and CE-QUAL-W2. U.S. Environmental Protection Agency.

EPA. 2010. NPDES Permit Writers' Manual. EPA-833-K-10-001. Office of Wastewater Management, Water Permits Division. Washington, D.C.

EPA. 2015. Watershed-based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation Guidance.

Flynn, K.F., and M.W. Suplee. 2010. Defining Large Rivers in Montana using a Wadeability Index. Helena, MT: Montana Department of Environmental Quality, 14 p.

Flynn, K.F., Suplee, M.W., Chapra, S.C., and H. Tao. 2015. Model-based Nitrogen and Phosphorus (Nutrient) Criteria for Large Temperate Rivers: 1. Model Development and Application. *Journal of the American Water Resources Association* 51(2): 421-446.

GLEC (Great Lakes Environmental Center, Inc.). 2021. Dissolved Oxygen Spatial Analysis, Technical Progress Report —Phase II. Prepared by Dale White, Principal Research Scientist.

Grayson, R.B., Finlayson, B.L., Gippel, C.J., and B.T. Hart. 1996. The Potential of Field Turbidity Measurements for the Computation of Total Phosphorus and Suspended Sediment Loads. *Journal of Environmental Management* 47: 257-267.

Harris. 2003. Wastewater lagoon troubleshooting: An Operators Guide to Solving Problems and Optimizing Wastewater Lagoon Systems. H&S Environmental, L.L.C.

HAWQS. 2020. HAWQS System and Data to Model the Llower 48 Conterminous U.S. using the SWAT Model, doi.org/10.18738/T8/XN3TE0, Texas Data Repository Dataverse, V1.

Heim, R.R. 2002. A Review of Twentieth-century Drought Indices used in the United States. *Bulletin of the American Meteorological Society*, 83(8): 1149-1166.

Hillebrand, H. and U. Sommer. 1999. The Nutrient Stoichiometry of Benthic Microalgal Growth: Redfield Proportions Are Optimal. *Limnology and Oceanography* 44: 440-446.

Kohler, A.E., A.T. Rugenski, and D. Taki. 2008. Stream Food Web Response to a Salmon Carcass Analogue Addition in Two Central Idaho, U.S.A. Streams. *Freshwater Biology* 53: 446–60. https://doi.org/10.1111/j.1365-2427.2007.01909.x.

Mills, W.B., G.L. Bowie, T.M. Grieb, and K.M. Johnson. 1986. Handbook: Stream Sampling for Waste Load Allocation Applications. U.S. Environmental Protection Agency, Office of Research and Development, EPA/625/6-86/013. September 1986.

Moriasi, D.N., Gitau, M.W., Pai, N. and P. Daggupati. 2015. Hydrologic and Water Quality Models: Performance Measures and Evaluation Criteria. *Transactions of the ASABE* 58: 1763-1785.

Mulholland, P.J., J.L. Tank, J.R. Webster, W.B. Bowden, W.K. Dodds, S.V. Gregory, N.B. Grimm et al. 2002. Can Uptake Length in Streams Be Determined by Nutrient Addition Experiments? Results from an Interbiome Comparison Study. *Journal of the North American Benthological Society* 21: 544–60.

Omernik, J.M. 1987. Ecoregions of the Conterminous United States. *Annals of the Association of American Geographers* 77:118-125.

Ribaudo, Marc O. and J. Gottlieb. 2011. Point-Nonpoint Trading – Can It Work? *Journal of the American Water Resources Association* 47(1): 5-14. DOI: 10.1111/j.1752-1688.2010.00454.x

Reckow, K.H. 2003. On the Need for Uncertainty Assessment in TMDL Modeling and Implementation. *Journal of Water Resources Planning and Management* 129 (4): 247-256.

Redfield, A.C. 1958. The Biological Control of Chemical Factors in the Environment. *American Scientist* 46:205-221.

Robertson, D.M. and D.A. Saad. 2019. Spatially Referenced Models of Streamflow and Nitrogen, Phosphorus, and Suspended-sediment Loads in Streams of the Midwestern United States. Scientific Investigations Report 2019-5114. U.S. Geological Survey.

Rosgen, D., and H.L. Silvey. 1996. Applied River Morphology, 2nd Edition. Wildland Hydrology, Pagosa Springs, CO.

Rutherford, K. and T. Cox. 2009. Nutrient Trading to Improve and Preserve Water Quality. *Water & Atmosphere* 17(1): 12-13.

Schulte, N.O., and J.M. Craine. 2023. Eutrophication Thresholds Associated with Benthic Macro-invertebrate Conditions in Montana Streams. Prepared for the MT Dept. of Environmental Quality by Jonah Ventures. October 5, 2023.

Shoemaker, L., T. Dai, J. Koenig, and M. Hantush. 2005. TMDL Model Evaluation and Research Needs. EPA/600/R-05/149. Cincinnati, Ohio: U.S. EPA, National Risk Management Research Laboratory.

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, MT: Montana Department of Environmental Quality, 41 p.

Suplee, M.W., A. Varghese, and J. Cleland. 2007. Developing Nutrient Criteria for Streams: An Evaluation of the Frequency Distribution Method. *Journal of the American Water Resources Association* 43: 453-472.

Suplee, M.W., V. Watson, A. Varghese, and J. Cleland. 2008. Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers. Helena, MT: MT DEQ Water Quality Planning Bureau.

Suplee, M.W., and V. Watson. 2013. Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers—Update 1. Helena, MT: Montana Department of Environmental Quality.

Suplee, M.W., Flynn, K.F., and S.C. Chapra. 2015. Model-based Nitrogen and Phosphorus (Nutrient) Criteria for Large Temperate Rivers: 2. Criteria Derivation. *Journal of the American Water Resources Association* 51(2): 447-470.

Suplee, M.W., and R. Sada. 2016. Assessment Methodology for Determining Wadeable Stream Impairment due to Excess Nitrogen and Phosphorus Levels. Helena, MT: Montana Dept. of Environmental Quality.

Suplee, M.W.. 2021. Determination of Bioavailable Phosphorus from Water Samples with Low Suspended Sediment Using an Anion Exchange Resin Method. *MethodsX 8*: 1010343. https://doi.org/10.1016/j.mex.2021.101343

Svoboda, M. 2000. An Introduction to the Drought Monitor. *Drought Network News*, 12: 15–20.

Tetra Tech, Inc. 2007. Municipal Nutrient Removal Technologies Reference Document Volume 1 – Technical Report. Prepared for the U.S. Environmental Protection Agency by Tetra Tech, Inc.

Teply, M. and L. Bahls. 2007. Statistical Evaluation of Periphyton Samples from Montana Reference Streams. Larix Systems Inc. and Hannaea. Helena, MT: Montana Department of Environmental Quality.

Teply, M. 2010a. Interpretation of Periphyton Samples from Montana Streams. Cramer Fish Sciences. Helena, MT: Montana Department of Environmental Quality.

Teply, M. 2010b. Diatom Biocriteria for Montana Streams. Cramer Fish Sciences. Helena, MT: Montana Department of Environmental Quality

Thomann, R.V. 1982. Verification of Water Quality Models. *Environmental Science*, a Journal of Environmental Engineering Division (EED) Proc. ASCE, 108: EE5, October.

Tri-State Implementation Council. 1998. Clark Fork River Voluntary Nutrient Reduction Program. Nutrient Target Subcommittee. Sandpoint, ID.

Uusitalo, R., Yli-Halla, M., and E. Turtola. 2000. Suspended Soil as a Source of Potentially Bioavailable Phosphorus in Surface Runoff Waters from Clay Soils. *Water Research* 34: 2477-2482.

Wells, S. 2005. Surface Water Hydrodynamic and Water Quality Models: Use and Misuse. 23rd Annual Water Law Conference, San Diego, CA. February, 24-25, 2005.

WET-Geum. 2015. USER GUIDE — Optimization Method and Best Management Practices for Facultative Lagoons. Prepared for Montana DEQ by Water & Environmental Technologies and Geum Environmental Consulting, Inc.

Wise, D.R. 2020. Spatially Referenced Models of Streamflow and Nitrogen, Phosphorus, and Suspended-sediment Loads in Streams of the Pacific Region of the United States. Scientific Investigations Report 2019-5112. U.S. Geological Survey. https://pubs.usgs.gov/sir/2019/5112/sir20195112.pdf

APPENDIX A CASE STUDY: USING CONVENTIONAL DATA COLLECTION AND ASSESSMENT METHODS TO UNDERTAKE AN AMP IN A SIMPLE WATERSHED

Introduction

Data collection in the point source receiving waterbody is a required component of each Adaptive Management Plan (AMP). Data collection is conducted to represent the extent to which permitted dischargers are affecting beneficial uses of their receiving waters, to evaluate compliance with permit limits, and to identify opportunities for water quality improvements. This case study presents a hypothetical example of how an AMP watershed monitoring plan could be developed without using a water quality model in a less complex watershed which has a limited number (probably no more than two) permitted facilities discharging to a receiving water.

Watershed Overview

The Redwater River watershed (4th code, 8-digit HUC 10060002) (**Figure A-1**) is in northeastern Montana, in McCone, Dawson, Prairie, and Richland counties. The watershed is in the Northwestern Great Plains ecoregion and the waters within it are classified as C-3, meaning they are "to be maintained suitable for bathing, swimming, and recreation, and growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl, and furbearers," and their "quality is naturally marginal for drinking, culinary, and food processing purposes, agriculture, and industrial water supply" (ARM 17.30.629).

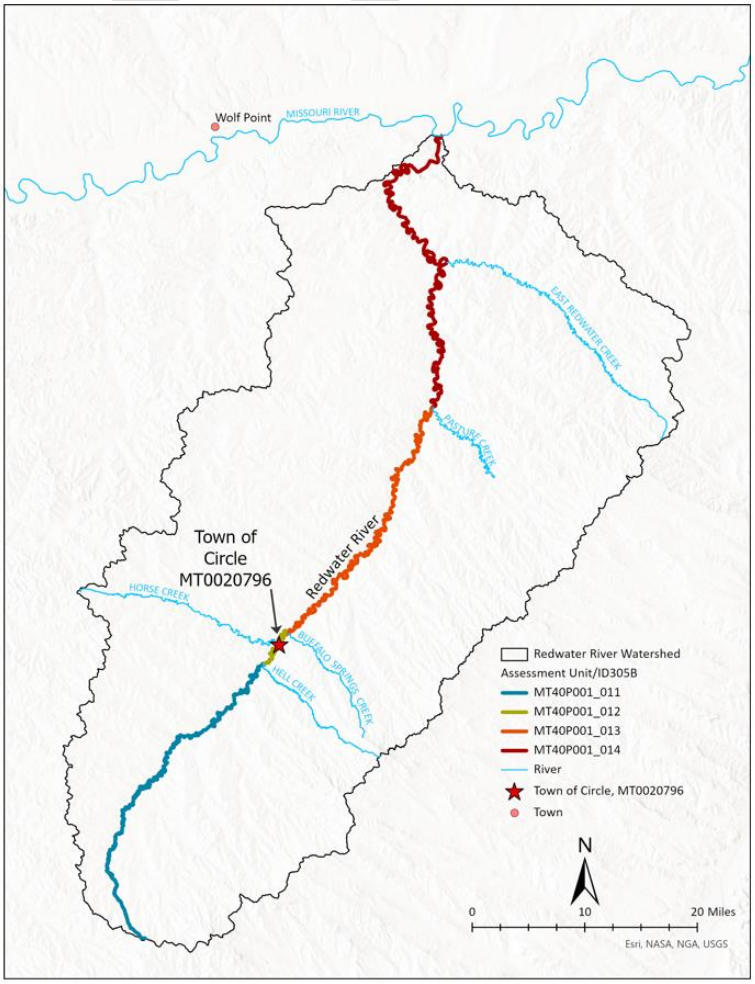

Figure A-1: Redwater River Watershed.

The Redwater River, for the purposes of this case study, is the receiving water for the Town of Circle domestic wastewater treatment facility per the facility's MPDES individual permit. The Redwater River flows 170 miles northeast from its headwaters to its confluence with the Missouri River downstream from Wolf Point. It is a low gradient, mostly wadeable medium river in the eastern prairie region. Tributaries to the Redwater River include Hell, Buffalo Springs, Horse, Pasture, and East Redwater creeks. The Redwater River consists of four assessment units which are unique segments used by the department for administrative and assessment purposes.

The AMP: Evaluating Relative Change Upstream and Downstream

In this case study, the basic AMP data collection focuses on a response variable and nutrient concentrations at near field sites upstream and downstream from the point source discharge. The primary objective of this work is to evaluate whether the watershed is negatively impacted by nutrients.

Each data parameter is evaluated relative to its respective threshold, collectively resulting in one of several possible combinations of outcomes. This will inform the department's determination of achievement/non-achievement of the narrative nutrient standards (per Section 3.0 in **Circular DEQ-15**).

If evaluation of the data concludes that the watershed is achieving narrative nutrient standards, the department may agree that it is sufficient to continue implementing a sampling plan to meet minimum annual monitoring requirements until other changes occur. Alternately, if evaluation of the data determines the watershed is not achieving the narrative nutrient standards, the permittee could implement an AMP watershed plan (see "**AMP Watershed Plan**" below), which entails an expanded monitoring strategy, and would initiate a watershed inventory to quantify and characterize nutrient sources and identify partners to assist in implementing nutrient reductions.

Site Selection

Near field monitoring sites should be located on the mainstem of the receiving waterbody. Efforts will be made to select sites that are adequately comparable in character in terms of slope, water volume, depth, substrate, and shading.

The upstream near field site will be located upstream from the point of discharge at a location that is as near as possible to the discharge point without water quality being influenced by the discharge itself. This site is intended to capture water quality conditions immediately prior to the input of the permitted facility's discharge (**Figure A-2**) and should have characteristics similar to the downstream site.

The downstream near field site is selected after carrying out nutrient spiraling calculations. Nutrient spiraling calculations use water velocity and channel depth data plus literature values for uptake velocity (v_i) to estimate the distance that nutrients travel before being taken up by organisms (e.g., microorganisms, algae). The downstream near field site is selected within this uptake distance so that data collection for nutrient and response variables occurs where nutrient impacts are likely to manifest. Downstream near field sites should also be downstream from the permit-defined mixing zone.

Nutrient spiraling calculations using the recommended Nutrient Spiraling Spreadsheet yield a range of uptake distance estimates for nitrate and phosphate. When selecting the downstream near field site, both the mean and the median of the downstream distance estimates, plus the stream or river segment between these two distances, as well as the minimum and maximum, should be visited for reconnaissance purposes to identify the most appropriate sampling location. Once a candidate downstream near field site is located, confirm that its basic characteristics match those of the upstream near field site. If they do not reasonably correspond, then it will be necessary to reposition one or both sites until site characteristics are reasonably comparable.

Data from the United States Geological Survey (USGS) gage station on the Redwater River at Circle, MT (USGS 06177500) is used in nutrient spiraling calculations. Uptake distances are based on mean channel depth (calculated from area and width) and mean water velocity measurements (n = 35) collected during the summer growing season (July 1 through September 30) from 1986 to 2021. In this case study, the downstream near field site should be located approximately 800 to 2400 meters downstream from the point source discharge (**Table A-1**; **Figure A-2**).

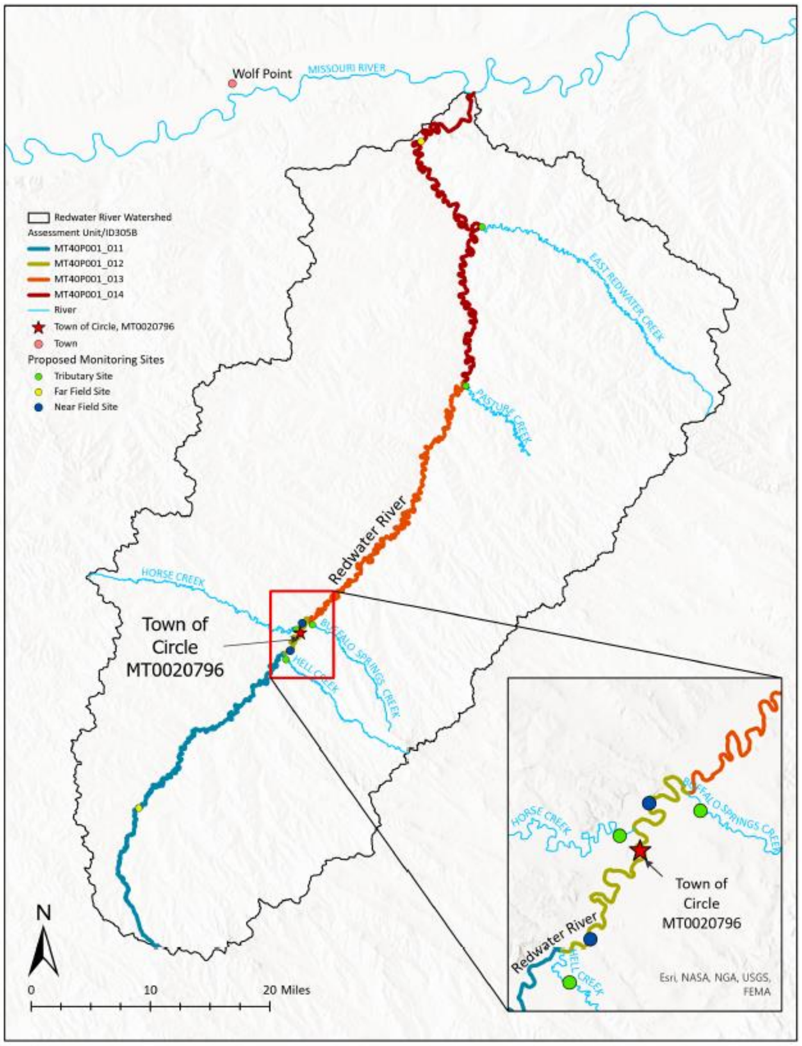

Figure A-2. Near-field and Far-field Monitoring Sites in an AMP Watershed. The figure includes sites that should be included in a basic AMP and sites for a more advanced AMP Watershed Plan.

Table A-1: Nutrient Uptake Distance Estimates for the Redwater River

Summary Statistic	Uptake Distance* (S_w) (meters)	
	Nitrate	Phosphate
Minimum	756	545
Mean	878	813
Median	2368	1472
Maximum	6562	3631

*Based on 139 studies (Ensign and Doyle, 2006) with an additional correction factor

Note: if a tributary confluences with the receiving waterbody between the point source discharge and the near field downstream site location identified via nutrient spiraling calculations, a monitoring site near the mouth of this tributary should be included in the monitoring plan. Nutrient concentration data should be collected at this site so that tributary loads can be considered when evaluating upstream/downstream change.

Ecoregion Zone

GIS analysis confirms that the Redwater River watershed lies wholly within the Northwestern Great Plains level III ecoregion. Observations of waterbody characteristics during on-the-ground reconnaissance confirm that the Redwater River reflects the underlaying expectation of the eastern ecoregion zone as described in Section 2.3.4 of **Circular DEQ-15**. Further, a search of fish survey and inventory data in the Montana Department of Fish, Wildlife and Parks (FWP) MFISH database for the Redwater River yields a list of 34 fish species which are indicative of a warm-water fishery expected in this eastern ecoregion zone; the ten most common species are shown in **Table A-2**. These factors confirm that the ecological characteristics and monitoring requirements that correspond to the eastern ecoregional zone (see Section 2.4.2, **Circular DEQ-15**) are appropriate to apply in this watershed.

Table A-2: Ten Most Common Fish Species Inventoried in the Redwater River since 2000

Species	Count
Fathead Minnow	10,451
Sand Shiner	8,857
White Sucker	2,845
Flathead Chub	1,570
Emerald Shiner	984
Longnose Dace	909
River Carpsucker	341
Common Carp	322
Brassy Minnow	293
Green Sunfish	258

Data Collection Strategy

Grab samples of ambient water will be collected from each upstream and downstream near field site and submitted to an analytical laboratory for analysis of nutrient (TN and TP) concentrations twice between July 1 and September 30 with at least 30 days between sampling events.

The response variable appropriate for the eastern ecoregion zone—dissolved oxygen (DO) delta—will be monitored at each near field site.

Continuous DO will be measured via deployment of MiniDOT data logger instruments deployed for at least 14 days, all of them in August—a longer dataset may include July and September. Given the prevalence of fine sediment substrate and intermittent pools, a fencepost or rebar is expected to be the best deployment platform (pending review of site-specific conditions) (**Figure A-3**). The instrument will be attached using zip-ties to a metal fencepost or rebar that has been pounded securely into the substrate of the channel in a location near a bank where the instrument is likely to remain submerged. To limit interference of the instrument's DO sensors, copper wire mesh is secured over the sensor face to limit fouling, and the deployment location will be free from macrophytes (removed manually as needed). The DO delta (daily maximum minus daily minimum) will be calculated for each day of deployment and weekly average DO delta will also be calculated.

NOAA's Climate Prediction Center forecasts wet conditions for the upcoming summer, so DO data will have a good chance of being collected during non-drought conditions.

Figure A-3. Dissolved Oxygen Sonde Deployment.

Once the DO data is collected, and checked to ensure it was collected during non-drought, the DO delta weekly averages are compared against the threshold (Section 3.0, **Circular DEQ-15**), also considering the allowable exceedance rate. In combination with the nutrient concentration data, achievement or non-achievement of the narrative nutrient standards can then be determined (Table 3-5, **Circular DEQ-15**).

AMP Watershed Plan: Characterizing Nutrient Sources and Identifying Water Quality Improvement Opportunities

In this case study, if evaluation of the initial monitoring data from near field sites indicates the watershed is not achieving the narrative nutrient standards, the permittee could initiate an AMP watershed plan. The primary objectives of this plan are:

- To quantify nutrient loads throughout the watershed to understand the magnitude and extent of nutrient sources in the watershed and identify opportunities for implementing nutrient reductions.
- To continue collecting data for nutrient concentration and response variables as performance indicators of the effectiveness of implemented AMP actions in achieving compliance with narrative nutrient water quality standards.

Site Selection

The near field sites monitored during the AMP implementation plan will be the same sites as those monitored during the initial data collection effort (see "**AMP Monitoring Plan**" above) (**Figure A-2**).

The far field sites will be selected to characterize the upstream and downstream extents of the watershed. The Redwater River is the mainstem waterbody draining the watershed and is the point source receiving waterbody. The far field site representing the furthermost upstream extent of the watershed will be as near to the headwaters of the Redwater River as is practical, in a reach of the river that is accessible for sampling purposes and is upstream of any substantial tributary inflows and other nutrient contributions.

The purpose of the far field downstream extent site is to quantify nutrient loads from the receiving waterbody to the waterbody it confluences with downstream, and to characterize water quality conditions (including response variables) at a point that represents the cumulative impacts of all watershed activities upstream. This site should be downstream from tributary inflows that may contribute nutrient loads to the mainstem and downstream from substantial nutrient sources along the mainstem. The site should be located downstream from areas where nutrient reduction actions may be implemented so that the data can be useful while evaluating effectiveness of water quality improvement activities throughout the AMP process.

In this case study, the far field downstream extent site will be as near to the Redwater River's confluence with the Missouri River as is accessible while avoiding backwater influence from the Missouri River (**Figure A-2**).

<u>Tributaries</u>

One monitoring site should be selected near the mouth of each principal tributary to the receiving waterbody. Data from tributary sites can be used to quantify and compare nutrient loads among tributaries for consideration when developing and prioritizing action items for the reduction of nutrients in the watershed. Tributary sites are also useful when monitoring how effective water quality improvement projects that are implemented in the tributary's watershed were at reducing nutrient loads. In this case study, one site is selected near the mouth of Hell, Buffalo Springs, Horse, Pasture, and East Redwater creeks (**Figure A-2**).

Ecoregion Zone

The same eastern ecoregion zone applies (See "**AMP Watershed Monitoring Plan: Ecoregion Zone**" above).

Data Collection Strategy

At each site (near field, far field, and tributaries), grab samples of ambient water will be collected and submitted to an analytical laboratory for analysis of nutrient (TN and TP) concentrations twice between July 1 and September 30 with at least four weeks between sampling events.

The response variable appropriate for the eastern ecoregion zone—dissolved oxygen (DO) delta—will be monitored at each site.

Continuous DO will be measured via deployment of MiniDOT data logger instruments deployed for at least 14 days, all of them in August, with a longer dataset that might include July and September. The DO delta (daily maximum minus daily minimum) will be calculated for each day of deployment and the weekly average DO delta—if collected outside of drought conditions—will be compared against the weekly average threshold in Table 3-1, **Circular DEQ-15**.

Discharge (flow) measurements will be paired with each nutrient concentration sampling event to enable loading calculations. Calculating nutrient loads will allow for relative comparisons of nutrient contributions between tributary inflows to the Redwater River, thereby informing action items in the AMP implementation plan. Tributaries in this watershed may be intermittent and periodically not flowing or dry during sampling events; efforts will be made to capture tributary flow events during the index period to represent tributary nutrient sources to the Redwater River. Alternatively, and if found to be necessary, flow can be measured up- and downstream of intermittent tributaries to determine any flow additions that are occurring below the surface.

Implementation

AMP Watershed Plan

Monitoring planning is often an iterative process in which the results of the data collection efforts are compiled, analyzed, and used to refine the monitoring strategy. The basic watershed plan will help to establish future monitoring needs throughout the AMP process. Monitoring at the near field sites is expected to remain relatively consistent in perpetuity. However, monitoring planning during the AMP watershed plan phase also needs to be adaptive. For example, potential nutrient sources identified during a watershed inventory may prompt the selection of new or additional monitoring sites to quantify nutrient loads or isolate potential nutrient reduction projects. Initial characterization at tributary sites may clarify which tributaries contribute greater or lesser nutrient loads to the receiving waterbody and therefore may lead to tributary sites being added or discontinued. Additional or different monitoring sites may also be necessary to demonstrate effectiveness of nonpoint source reduction projects or to affirm achievement/non-achievement of narrative nutrient standards.

Watershed Inventory

To develop and implement an AMP watershed plan, a permittee will need to inventory the point and nonpoint source contributions of nutrients throughout the watershed. The watershed inventory may entail geospatial analysis or other desktop exercises, coordination with partners in the watershed, and data collection. Quantifying these sources may entail collecting data for nutrient concentrations and discharge to calculate loads. The watershed inventory, including relative comparisons of nutrient loads from each, will help to identify and prioritize opportunities for nutrient reductions.

Partnerships

The AMP process highlights the benefits of forming partnerships to achieve cumulative water quality improvements in a watershed. Partnerships will be necessary to facilitate the implementation of best management practices or other watershed improvement projects aimed at reducing nonpoint nutrient sources. Decreasing nutrient loads from nonpoint sources upstream from the point source could help to increase the assimilative capacity of the receiving waterbody, while reducing nonpoint nutrient sources downstream from the point source discharge may provide pollutant credit trading opportunities. All improvement actions will lead to cumulative improvements in water quality in the receiving waterbody. To identify partners that will assist in implementing AMP action items, the permittee may contact, for example, counties and municipalities, conservation districts, watershed groups, conservation organizations, and landowners.

Monitoring partnerships may also be possible to reduce or leverage resources to meet water quality monitoring requirements through time. Point source dischargers may be able to identify entities that already have proficiency in similar water quality monitoring methods who may be willing to partner to achieve data collection. For example, entities that administer monitoring programs include watershed groups, conservation districts, water quality districts, and non-governmental organizations, some of which enlist community volunteers to become trained and participate in data collection.

APPENDIX B SPECIFIC CONDUCTIVITY VS. BECK'S BI (V3) LOOK-UP TABLES

logConductance	Specific Conductivity (µS/cm)	Residual (add this value to Beck's Biotic Index (v3) Threshold)
1.90855	81.0	14.52
1.91855	82.9	14.44
1.92855	84.8	14.34
1.93855	86.8	14.22
1.94855	88.8	14.08
1.95855	90.9	13.91
1.96855	93.0	13.72
1.97855	95.2	13.51
1.98855	97.4	13.28
1.99855	99.7	13.02
2.00855	102.0	12.74
2.01855	104.4	12.44
2.02855	106.8	12.12
2.03855	109.3	11.78
2.04855	111.8	11.42
2.05855	114.4	11.04
2.06855	117.1	10.64
2.07855	119.8	10.23
2.08855	122.6	9.80
2.09855	125.5	9.37
2.10855	128.4	8.92
2.11855	131.4	8.46
2.12855	134.4	7.99
2.13855	137.6	7.52
2.14855	140.8	7.04
2.15855	144.1	6.57
2.16855	147.4	6.09
2.17855	150.9	5.62
2.18855	154.4	5.15
2.19855	158.0	4.68
2.20855	161.6	4.23
2.21855	165.4	3.78
2.22855	169.3	3.35
2.23855	173.2	2.93
2.24855	177.2	2.52
2.25855	181.4	2.14
2.26855	185.6	1.77
2.27855	189.9	1.42
2.28855	194.3	1.08
2.29855	198.9	0.77
2.30855	203.5	0.48
2.31855	208.2	0.21
2.32855	213.1	-0.04
2.33855	218.0	-0.28
2.34855	223.1	-0.49
2.35855	228.3	-0.68
2.36855	233.6	-0.85
2.37855	239.1	-1.00
2.38855	244.7	-1.14
2.39855	250.4	-1.26
2.40855	256.2	-1.36
2.41855	262.2	-1.45
2.42855	268.3	-1.52
2.43855	274.5	-1.59
2.44855	280.9	-1.64
2.45855	287.4	-1.69
2.46855	294.1	-1.74
2.47855	301.0	-1.78
2.48855	308.0	-1.82
2.49855	315.2	-1.85
2.50855	322.5	-1.90
2.51855	330.0	-1.94
2.52855	337.7	-1.99
2.53855	345.6	-2.05
2.54855	353.6	-2.12
2.55855	361.9	-2.20
2.56855	370.3	-2.28
2.57855	378.9	-2.38
2.58855	387.8	-2.49
2.59855	396.8	-2.60
2.60855	406.0	-2.73
2.61855	415.5	-2.87
2.62855	425.2	-3.01
2.63855	435.1	-3.17
2.64855	445.2	-3.33
2.65855	455.6	-3.50
2.66855	466.2	-3.67
2.67855	477.0	-3.85
2.68855	488.1	-4.04
2.69855	499.5	-4.22
2.70855	511.2	-4.42
2.71855	523.1	-4.61
2.72855	535.2	-4.81
2.73855	547.7	-5.01
2.74855	560.5	-5.21
2.75855	573.5	-5.40
2.76855	586.9	-5.60
2.77855	600.6	-5.80
2.78855	614.5	-5.99
2.79855	628.9	-6.19
2.80855	643.5	-6.38
2.81855	658.5	-6.56
2.82855	673.8	-6.75
2.83855	689.5	-6.93
2.84855	705.6	-7.11
2.85855	722.0	-7.28
2.86855	738.8	-7.45
2.87855	756.1	-7.62
2.88855	773.7	-7.78
2.89855	791.7	-7.94
2.90855	810.1	-8.10

APPENDIX C MECHANISTIC MODELING CASE STUDY

A hypothetical mechanistic modeling case study is provided below to better illustrate the approach proposed in this guidance document. For real world examples, the reader is referred to Bierman et al. (2013) who detail the use of nutrient models for setting site-specific nutrient goals. Included in that work is a demonstration of the application of all modeling concepts discussed in this document, along with judgement decisions made along the way for the development of nutrient decision support.

Pristine River Case Study. The Pristine River is in a large multi-HUC watershed that has three large tributaries entering it (**Figure C-1**). Tributary 1 (T1) enters from the northeast and contains a small, single MPDES nutrient permit (City 1). Tributary T2 enters from the southeast and is pristine. Along the path of the Pristine River and downstream of the confluence of T1 and T2 enters a single nutrient point source discharge at midpoint of the watershed at City 2. Downstream of this location, Tributary 3 (T3) enters and is primarily agriculturally dominated. A third MPDES nutrient permit (City 3) is located downstream of T3. To characterize water quality, each city was bracketed by appropriately placed near-field sampling sites both upstream and downstream of each point of discharge, as well far-field sites near the upper and at the lower end of the watershed, along with tributary confluences and key mainstem monitoring locations. The overall load (W, in kg/day) of the most limiting nutrient during the most recent synoptic sampling is detailed in the figure.

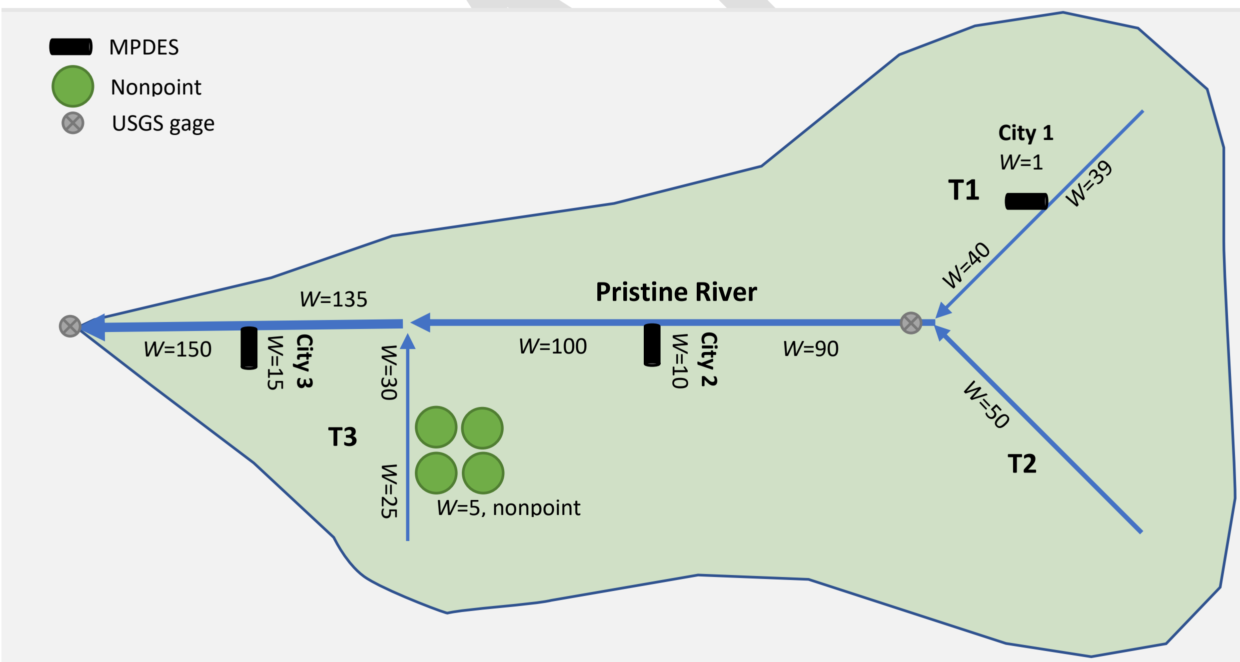

Figure C-1. Schematic of Pristine River Associated with the Hypothetical Case Study.

To complete watershed nutrient management, an AMP stakeholder group has formed in the lower, more urbanized part of the Pristine River consisting of Cities 2 and 3, and several of the agricultural producers. They have agreed to share costs to model the river to assess whether narrative nutrient standards are currently being achieved. Primary questions the group has is whether beneficial uses are being supported and to understand whether agricultural BMPs in T3 will have any benefit to watershed management during the next permitting cycle. At the same time, City 1 has decided to conduct their own independent effort. Both stakeholder groups have hired independent consultants that will follow the AMP modeling guidance.

Based on the problem specification, the consultant for City 1 concludes that a simple receiving-water model could be used on T1. Modeling would require knowledge of the upstream boundary condition above City 1, the City 1 load contribution, and then several calibration points downstream to evaluate the water-quality response, extending downstream as far as impacts from the point source are observed. All nutrient-related state variables, response variables, and applicable information such meteorological data should be monitored for the modeling.

The consultant for the lower watershed has concluded that nutrient management activities are only feasible in the lower portion of the watershed. However, they also recognize that City 1 is an upstream nutrient loading source. From review of available loading data, it is identified that City 1 contributes approximately 1% of the overall nutrient load upstream of City 2, not accounting for instream processing. Because of this, and following the AMP guidance, the effect of nutrients from this location can be ignored, and the lower river can be examined on its own.

To define the model domain in the lower river, the consultant for the lower Pristine River stakeholder group decided that the Pristine River water-quality model would begin immediately upstream of City 2, extending downstream to include T3 and all downstream sources. However, a more complex approach is required since multiple point sources and influent tributaries exist, and agricultural practices are widespread in T3. Two potential modeling approaches were conceived by the consultant for AMP water-quality modeling. They comprised:

- A receiving-water model of Pristine River extending from just upstream of City 2 to the most downstream point in the watershed where nutrient planning is desired, recognizing the following:
    - In this case, boundary conditions would need to be established upstream of City 2, and at the mouth of T3 and the City 2 and City 3 MPDES discharge.
    - Just as was proposed for City 1 further upstream, locations for model calibration should be established periodically along the river, upstream of the City 3 point of discharge, and downstream of the points of discharge near the estimated critical impact point (e.g., near field sites), and extending downstream to the project terminus (far field).
    - The relationship between agricultural practices in T3 and the T3 boundary condition are not understood. Therefore, empirical estimation of how agricultural BMPs would affect water quality at the T3 boundary condition is required.
- A second and more detailed approach was also considered by the consultant which was to develop a watershed-loading model to aid in BMP calculations and to better understand nutrient processes within the modeled reach. In deliberating, the watershed model could be constructed to encompass one of the following:
    - The entire watershed, integrating the point source in T1 and associated fate and transport of nutrients downstream. This would enable holistic watershed-wide planning and decision making; or

  - For T3 only, for the sole purpose of understanding the relationship between agricultural BMPs and the T3 boundary condition. This information would then be integrated into the lower river's receiving water model to evaluate nutrient AMP scenarios.

In this case, the decision was made to conduct a sensitivity analysis on the influence of the T3 tributary, including the presumed influence of BMPs on the tributary's loadings, to determine if its nutrient contribution has any meaningful influence on the overall model response (i.e., using a strawman model). Based on this outcome it was decided that due to the small size of the agricultural loadings relative to the rest of the loadings in the reach, and minimal in-stream responses from changes in those loadings, watershed modeling would not be required, and empirical estimates would be sufficient. However, it was also recognized that if the agricultural contribution in this watershed were to become large in the context that it was impacting water quality in the Pristine River, T3 would likely need to be modeled using a watershed model. The project approach was discussed with the department and agreed upon. Once formulated and vetted, modeling tool(s) were then chosen by both consultants for the work and the required steps of model calibration, confirmation, and ultimately decision support analysis for AMP purposes was completed. This allowed appropriate AMP decision making for each of the watersheds by modeling nutrient endpoints to assess beneficial use support, as well as using modeling tools to best manage nutrients in the watershed.

As is evident in this brief case study example, each AMP watershed and modeling approach will be site-specific, and will require up-front discussions with the department about project methodology, recognizing that activities might span multiple HUCs and requiring coordination between multiple municipalities or stakeholder groups. The case study should be used for illustrative purposes only.

Montana Department
of Environmental Quality

Narrative Nutrient Standards: Summary Technical Support Document

December 4, 2023

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Executive Summary

This document provides brief summary overviews of causal and response variables found in Part I of **Circular DEQ-15** (December 2023 edition), and the rationale for their use**.** In most cases, technical documents referenced herein contain the important details about the causal and response variables. However, in some cases, important details are provided here if they were not sufficiently covered in the reference materials. This document addresses magnitude, duration, and frequency of the causal and response variables (aka criteria) in **Circular DEQ-15**.

TABLE OF CONTENTS

ACRONYMS

ARM	Administrative Rules of Montana
DEQ	Montana Department of Environmental Quality
DO	Dissolved oxygen
DO Δ	Dissolved oxygen delta (daily maximum minus daily minimum concentration)
EPA	United States Environmental Protection Agency
MCA	Montana Code Annotated

1.0 INTRODUCTION AND BACKGROUND INFORMATION

Changes in Montana law[1] necessitated the development of a structured translation process to interpret the state's narrative water quality standards applicable to total nitrogen (TN) and total phosphorus (TP) concentrations (ARM 17.30.637(1)(e)). DEQ proposed that this translation process include (a) for aquatic life beneficial uses, macroinvertebrate metrics and the daily change in dissolved oxygen (DO Δ) as response variables; and (b) for recreational beneficial uses, benthic algae chlorophyll *a*, benthic algal ash free dry weight, and percent bottom cover by filamentous algae as response variables. The translators for these parameters are found in Part I of **Circular DEQ-15** (December 2023 edition).

This document provides a summary overview of response and causal variables from Part I of **Circular DEQ-15**, and the rationale for their use. In most cases, referenced technical documents contain the important details about the response and causal variables and the reader should refer to them as needed. However, in some cases, important details are provided here if they were not sufficiently covered in the reference materials. This document addresses **magnitude**, **duration**, and **frequency** aspects of the response and causal variables (aka criteria) in **Circular DEQ-15**; these three terms are provided in bold throughout the document to ease identification of the subject.

2.0 TECHNICAL SUMMARIES

Technical summaries regarding causal and response variables and the rationale for their selection are provided below for both the aquatic life and recreation beneficial uses.

2.1 AQUATIC LIFE BENEFICIAL USES

2.1.1 MACROINVERTEBRATE METRICS

- Beck's Biotic Index (version 3)
    - Mountains threshold (**magnitude**): 35.1
    - Low Valleys and Transitional threshold (**magnitude**): 18.7

Rationale: See details in Schulte and Craine (2023) and Suplee (2023). Beck's Biotic Index (v3)—which is based on macroinvertebrate population structure—was the most consistent biological metric across Montana's western and transitional region in terms of correlation with TN and TP concentration gradients. DEQ also considered the multimeric indices that were developed in Schulte and Craine (2023), but concluded that the large increase in complexity, difficulty in interpreting their biological meaning, and modest increase in explanatory power was far outweighed by the simpler and nationally recognized Beck's Biotic Index (v3).

In terms of time, macroinvertebrates generally represent conditions of weeks to months due to the nature of macroinvertebrate life histories (Hering et al., 2006), but even up to years for some taxa.

[1] 75-5-321, MCA

Thus, macroinvertebrates generally represent time periods of intermediate **duration**. Because a macroinvertebrate sample represents an intermediate **duration** of time at a stream site, one might expect a fair degree of across-time stability (all things being equal) in metric scores and this was shown to be the case in Montana streams (Suplee, 2023). Nevertheless, even duplicate field samples will disagree, in terms of indicating stream impairment or non-impairment, about 18% of the time (Stribling et al., 2008). Therefore, averaging results from two or more macroinvertebrate samples from a site will provide a more accurate site assessment. Thus, DEQ recommends that average macroinvertebrate scores be compared to the Beck's Biotic Index (v3) which can then be assessed as "meets" or "exceeds" per section 3.0 in **Circular DEQ-15**.

2.1.2 Dissolved Oxygen Delta (DO Δ)

- Western Montana (streams and medium rivers with water surface slope ≤1%)
    - Threshold (**magnitude**) = 3.0 mg/L
- Eastern Montana (all streams and medium rivers; non-drought periods)
    - Threshold (**magnitude**) = 6.0 mg/L

Rationale**:** See Suplee (2023). The western Montana DO Δ threshold is based on relationships between macroinvertebrate metrics (including Beck's Biotic Index v3) and DO Δ; the eastern Montana threshold is based on the relationship between weekly DO Δ and DO minimum standards (during non-drought periods). DO Δ **duration** (i.e., averaging period) for both western and eastern Montana is recommended to be expressed as the 7-day average (rolling or calendar). This corresponds to the expression of DO minima in adopted water quality standards (**Circular DEQ-7**; DEQ, 2019). Further, GLEC (2021)—after analyzing the DO Δ dataset from DEQ's 5-year study of eastern Montana plains streams—recommends that weekly summary measures are intuitively more stable and find that weekly summaries based on only a day or two's data should be avoided as most outliers (high residuals) in their analysis were likely caused by weekly averages comprising too few days. Thus, weekly averages provide a better, more consistent **duration** for this response variable.

Per the translator in **Circular DEQ-15** (see Table 2-1 of that document), there is a 10% allowable exceedance **frequency** for weekly average DO Δ in western Montana. This is based on the minimum allowable exceedance rate commonly used by states for conventional pollutants such as biochemical oxygen demand (BOD) and pH (California, 2004). DO Δ is generally analogous to these conventional pollutants in terms of its harmful biological effects. For eastern Montana DO Δ, the allowable 15% exceedance **frequency** was derived from an analysis of Montana plains reference sites during non-drought periods (Suplee, 2023).

2.1.3 Consideration of Conditions Downstream of Dams

Rationale: **Circular DEQ-15** allows for adjustments to the DO Δ threshold downstream of dams (note: these must be reviewed and approved by DEQ case-by-case). Scientific research shows that macrophyte abundance is strongly associated with current velocity and flood disturbance (French, 1995; Riis and Biggs, 2003). Velocity and flood disturbance are greatly altered (and usually moderated) below dams. DEQ has observed dense macrophyte mats in the tailrace areas of some Montana rivers (e.g., the Missouri River below Holter dam) whereas dense macrophyte beds are absent in free-flowing rivers like the Yellowstone River. As shown in GLEC (2021) and discussed in Suplee (2023), dense macrophytes beds generally increase DO Δ and for this reason DEQ is providing the option for adjustment to DO Δ.

Beck's Biotic Index (v3) is likely to be affected as well, thus the allowance for potential adjustments to the threshold in areas below dams (again, case-by-case after DEQ review).

2.1.4 Spring Creeks

Rationale: Spring creeks were excluded from the narrative nutrient standards translator in **Circular DEQ-15**, although stand-alone causal criteria for them are included in the circular (see the circular's section 2.3.2). Continuous DO and macroinvertebrate data collected by DEQ in Elk Springs Creek (a low-gradient reference stream in southwestern Montana) showed that neither the DO Δ nor the Beck's Biotic Index (v3) thresholds presented above could be met. Elk Springs Creek is a tier I (nearly pristine; Suplee et al., 2005) reference stream site located in the Red Rock Lakes National Wildlife Refuge with zero percent agriculture in the watershed and no grazing allowed in the refuge (however moose are common). It is extremely sinuous, very low gradient (0.08%), has extensive stands of native macrophytes (61% bottom cover on average), is essentially devoid of filamentous algae (1.5% cover), and has a very fine (mud and fine sand) bottom substrate. These natural conditions lend themselves to quite high DO Δ due to the macrophytes (5.9 mg/L on average, summer/fall 2023) and a low Beck's scores (score = 1). Spring creeks typically have extensive macrophyte stands and very limited (or no) hydrologic flushing events, and DEQ assumes that other spring creeks would similarly not be able to meet DO Δ nor the Beck's Biotic Index (v3) threshold.

Fortunately, Montana spring creeks are inventoried (Decker-Hess, 1989), making it clear which waterbodies the different criteria in **Circular DEQ-15** should be applied to. The ecoregional total phosphorus (TP) criteria recommendations from Suplee and Watson (2013) are applied to the spring creeks and to the best of DEQ's knowledge are of the appropriate **magnitude**. **Duration** should be considered as a monthly average. In **Circular DEQ-15**, DEQ provides an allowable TP exceedance **frequency** of 20%; this is based on long-term analysis of numeric nutrient standards on the Clark Fork River (see appendix A.4.2.3 in Suplee and Sada, 2016).

Nitrogen concentrations in spring creeks, on the other hand, are elevated when compared to streams and medium rivers subject to annual spring runoff. This is especially true for nitrate (NO_3), which has an interquartile range of about 185 to 915 µg/L and an average around 690 µg/L in spring creeks (n>30 spring creeks; see Appendix 2 in Decker-Hess, 1989). Therefore, for nitrogen, DEQ assigned a range of total nitrogen (TN) concentrations within which spring creek nitrogen concentrations will normally fall. The range was based on current scientific understanding of protective TN criteria for Montana (Suplee and Watston, 2013) and the interquartile range of spring creek nitrate concentrations in Decker-Hess (1989). Like TP, **duration** should be considered as a monthly average. The allowable exceedance **frequency** for an identified, site-specific TN concentration is 20%, based on the same rationale provided above for TP in spring creeks.

2.1.5 Large Rivers: Lower Yellowstone River

- Yellowstone River mainstem, Bighorn River confluence to the Power River confluence
  - Causal variables **magnitude**: 55 µg TP/L, 655 µg TN/L
  - DO Δ threshold (**magnitude**): 4.1 mg/L

Rationale: Site-specific analysis undertaken via mechanistic water quality modeling identified the causal variable concentrations for the Yellowstone River reach listed above (Suplee et al., 2015). Regarding the DO Δ threshold of 4.1 mg/L, note in Suplee et al. (2015) that DO Δ increases with each incremental nitrogen or phosphorus dose added to the river in the model (see tables 6 and 7, first half in each, Suplee et al., 2015). DEQ took the average DO Δ of the two modeled dosing scenarios (4.3 mg DO/L and 3.87 mg DO/L) at the point where the model showed impacts to the pH standard—which is what the causal variables are also based on.

For the causal variables (TP, TN), **duration** should be considered as a monthly average with an allowable exceedance **frequency** of 20% based on analyses from the Clark Fork River (see appendix A.4.2.3 in Suplee and Sada, 2016). The **duration** for the response variable DO Δ is a weekly average (rolling or calendar) and the allowable exceedance **frequency** is once in three years, on average, consistent with Stephan et al. (1985).

2.1.6 Large Rivers: Other Large Rivers and Large River Reaches

Rationale: For aquatic life use in other large rivers or river reaches, the causal variable **magnitudes** are provided as ranges in **Circular DEQ-15** (see section 4.0 there) based on DEQ's best scientific understanding from Yellowstone River modeling work (Flynn et al., 2015; Suplee et al., 2015) and other large river criteria work (Smith and Tran, 2010). **Circular DEQ-15** provides that the DO Δ threshold should be determined case-by-case (see footnote in the circular's table 4-1).

DEQ is requiring that the combined criterion method be applied to all large rivers and large river segments, however additional work will be required to derive appropriate causal criteria concentrations and an appropriate DO Δ threshold for other large rivers or large river segments. The work should follow methods DEQ will provide in the guidance document for large river assessment.

2.2 Recreation Beneficial Uses

2.2.1 Western Montana Recreational Use Thresholds (All Streams and Medium Rivers)

- Benthic Chlorophyll a (**magnitude**): 150 mg/m^2
- Ash Free Dry Weight (**magnitude**): 35 g/m^2
- Percent Cover by Filamentous Algae (**magnitude**): 30% cover

Rationale: The benthic (bottom-attached) chlorophyll *a* and ash free dry weight thresholds are based on acceptable levels from public opinion surveys in both Montana and Utah (Suplee et al., 2009; Jakus et al., 2017). Percent filamentous cover is based on public opinion work in Utah (Ostermiller et al., 2019) and is consistent with cover percentages and preferences documented in Montana's public opinion survey in Suplee et al. (2009). **Duration** of these algae-based parameters is typically several weeks, at most, which is why DEQ requires two sampling events per index period (**Circular DEQ-15**). The allowable exceedance **frequency** is once every three years, on average, based on EPA recommendations (Stephan et al., 1985).

No recreation-based criteria are being proposed for eastern Montana plains streams or medium rivers. DEQ has documented that these streams may naturally exceed the 150 mg chlorophyll *a*/m^2 threshold (Suplee et al., 2007). DEQ has no other information regarding appropriate recreation-based thresholds linked to nitrogen and phosphorus for plains streams and medium rivers.

2.2.2 Large Rivers: Lower Yellowstone River

- Yellowstone River mainstem, Power River confluence to State Line (causal variables **magnitude**): 95 µg TN/L, 815 µg TN/L
- Benthic Chlorophyll a (**magnitude**): 150 mg/m^2
- Ash Free Dry Weight (**magnitude**): 35 g/m^2
- Percent Cover by Filamentous Algae (**magnitude**): 30% cover

The causal criteria for the lowest reach of the Yellowstone River (Power River confluence to State Line) were based on impacts to the recreational use by excess benthic algae growth in near-shore areas (Suplee et al., 2015). For the causal variables (TP, TN), **duration** should be considered as a monthly average with an allowable exceedance **frequency** of 20% based on analyses from the Clark Fork River (see appendix A.4.2.3 in Suplee and Sada, 2016).

The recreational thresholds for chlorophyll *a*, ash free dry weight, and percent cover are the same as for wadeable streams and medium rivers except that they apply only to the wadeable region of this lower Yellowstone River reach. The **duration** for these algae-based response variables is typically several weeks at most. The allowable exceedance **frequency** for the response variables is once every three years, on average, based on EPA recommendations (Stephan et al., 1985).

2.2.3 Large Rivers: Other Large Rivers and Large River Reaches

<u>Rationale</u>: For recreation uses in other large rivers or river reaches, the causal variable **magnitudes** are provided as ranges in **Circular DEQ-15** (see the circular's table 4-1) based on DEQ's best scientific understanding from Yellowstone River modeling work (Flynn et al., 2015; Suplee et al., 2015) and other large river criteria work (Smith and Tran, 2010). Additional work will be required to derive appropriate causal criteria concentrations for other large rivers or large river segments and the work should follow methods DEQ will provide in the guidance document for large river assessment. Once identified, **duration** for the causal variables should be considered as monthly averages. The allowable exceedance **frequency** for an identified, site-specific TP or TN concentration should be 20%, based on the same rationale provided in **Section 2.2.2**.

The recreational thresholds for chlorophyll *a*, ash free dry weight, and percent cover are the same as for the lower Yellowstone River in **Section 2.2.2**. The **duration** for these algae-based response variables is typically several weeks at most. The allowable exceedance **frequency** is once every three years, on average, based on EPA recommendations (Stephan et al., 1985).

3.0 REFERENCES

California (CA Environmental Protection Agency State Water Resources Control Board). 2004. *Functional Equivalent Document, Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List - Final*. Division of Water Quality, State Water Resources Control Board.

Decker-Hess, J. 1989. *An Inventory of the Spring Creeks in Montana*. Kalispell, MT; Montana Dept. of Fish, Wildlife, and Parks.

DEQ. 2019. Circular DEQ-7, *Montana Numeric Water Quality Standards*. *June 2019 Edition*. Helena, MT: Montana Dept. of Environmental Quality.

Flynn, K.F., M.W. Suplee, S.C. Chapra, and H. Tao. 2015. Model-based nitrogen and phosphorus (nutrient) criteria for large temperate rivers: 1. Model development and application. *Journal of the American Water Resources Association* 51: 421-446.

French, T.D. 1995. *Environmental Factors Regulating the Biomass and Diversity of Aquatic Macrophyte Communities in Rivers*. Master of Science thesis, Department of Biological Sciences, University of Alberta.

GLEC (Great Lakes Environmental Center, Inc.). 2021. *Dissolved Oxygen Spatial Analysis, Technical Progress Report —Phase II*. Prepared by Dale White, Principal Research Scientist.

Hering, D., R.K Johnson, and A. Buffagni. 2006. Linking organism groups—major results and conclusions from the STAR project. *Hydrobiologia* 566: 109-113.

Jakus, P.M., N. Nelson, and J. Ostermiller. 2017. Using survey data to determine a numeric criterion for nutrient pollution. *Water Resources Research* 53: 1–13.

Ostermiller, J.D., M. Shupryt, M.A. Baker, B. Neilson, E.B. Gaddis, A. J. Hobson, B. Marshall, T. Miller, D. Richards, and N. von Stackelberg. 2019. *Technical Support Document: Utah's Nutrient Strategy.* Utah Department of Environmental Quality, Water Quality Division.

Riis, T., and B.J.F. Biggs. 2003. Hydrologic and hydraulic control of macrophyte establishment and performance in streams. *Limnology and Oceanography* 48: 1488-1497.

Schulte, N.O., and J.M. Craine. 2023. *Eutrophication Thresholds Associated with Benthic Macroinvertebrate Conditions in Montana Streams*. Prepared for the MT Dept. of Environmental Quality by Jonah Ventures. October 5, 2023.

Smith, A.J., and C.P. Tran. 2010. A weight-of-evidence approach to define nutrient criteria protective of aquatic life in large rivers. *Journal of the North American Benthological Society* 29: 875-891.

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman, and W.A. Brungs. 1985. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and*

Their Uses. PB85-227049. U.S. Environmental Protection Agency, Environmental Research Laboratories, Corvallis, Oregon.

Stribling, J.B., B.K. Jessup, and D.L. Feldman. 2008. Precision of benthic macroinvertebrate indicators of stream condition in Montana. *Journal of the North American Benthological Society* 27: 58-67.

Suplee, M.W. 2023. *An Analysis of Daily Patterns of Dissolved Oxygen Change in Flowing Waters of Montana*. Document No. WQDWQSMTECH-05. Helena, MT: Montana Dept. of Environmental Quality.

Suplee, M.W., Sada de Suplee, R., Feldman, D., and T. Laidlaw. 2005. *Identification and Assessment of Montana Reference Streams: A Follow-up and Expansion of the 1992 Benchmark Biology Study.* Helena, MT: Montana Dept. of Environmental Quality.

Suplee, M.W., A. Varghese, and J. Cleland, 2007. Developing nutrient criteria for streams: An evaluation of the frequency distribution method. *Journal of the American Water Resources Association* 43: 456-472.

Suplee, M.W., V. Watson, M. Teply, and H. McKee. 2009. How green is too green? Public opinion of what constitutes undesirable algae levels in streams. *Journal of the American Water Resources Association* 45: 123-140.

Suplee, M.W., and V. Watson. 2013. *Scientific and Technical Basis of the Numeric Nutrient Criteria for Montana's Wadeable Streams and Rivers—Update 1*. Helena, MT: Montana Dept. of Environmental Quality.

Suplee, M.W., K.F. Flynn, and S.C. Chapra. 2015. Model-based nitrogen and phosphorus (nutrient) criteria for large temperate rivers: 2. Criteria derivation. *Journal of the American Water Resources Association* 51: 447-470.

Suplee, M.W. and R. Sada. 2016. *Assessment Methodology for Determining Wadeable Stream Impairment Due to Excess Nitrogen and Phosphorus Levels*. Helena, MT: Montana Dept. of Environmental Quality. https://deq.mt.gov/files/Water/SurfaceWater/UseAssessment/Documents/NtrntAssessMethod_May2016_FINAL.pdf

Montana Department of Environmental Quality

An Analysis of Daily Patterns of Dissolved Oxygen Change in Flowing Waters of Montana

December 4, 2023

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Executive Summary

The daily curve of dissolved oxygen (DO) change in flowing waters is recognized as a key indicator of the balance between aquatic community respiration, plant photosynthetic production, and atmospheric diffusion of oxygen. A simple way to characterize the magnitude of the daily DO curve is to subtract the daily minimum DO concentration from the daily maximum. This daily DO change is referred to as DO Δ. When DO Δ is excessive, demonstrable impacts to aquatic life can occur as shown by work in Ohio, Minnesota, and Montana.

The objective of this report was to identify DO Δ thresholds protective of aquatic life in Montana streams and medium-sized rivers. The report has two parts: **Part I** is applicable to low-gradient western Montana streams and medium rivers, while **Part II** pertains to eastern Montana waterbodies. Each part of the report indicates the specific geographic areas to which the work applies. **Part I** comprises **Part I-A**, an initial investigation using extant data that was available in fall 2022, and **Part I-B** which incorporates field data collected in 2023 for the purpose of augmenting and refining the initial analysis.

Part I relies on bottom-dwelling macroinvertebrates to identify a protective DO Δ threshold. Macroinvertebrate metrics (i.e., quantitative population descriptions) provide a way to determine if Montana's narrative nutrient standards at ARM 17.30.637 are achieved: *(1) State surface waters must be free from substances attributable to municipal, industrial, agricultural practices or other discharges that will: (e) create conditions which produce undesirable aquatic life.* Macroinvertebrate metrics give DEQ a direct means of assessing aquatic pollution effects vis-à-vis this water quality standard. For example, the "EPT" Orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are major components of the aquatic life community and a food source for salmonids in western Montana. A decline in sensitive EPT and a corresponding increase in tolerant taxa (e.g., scuds, Amphipoda) is undesirable, and when linked to a stressor like elevated DO Δ the relationship between the two can be used to identify a DO Δ threshold protective of aquatic life.

Data in **Part I** consistently showed that with increasing DO Δ there is a decline in sensitive macroinvertebrate taxa, including those in the EPT Orders and Families within EPT. There is a corresponding increase in the percent of tolerant taxa—for example the Hydropsychidae. Well established biotic indices (Beck's Biotic Index version 3; Hilsenhoff Biotic Index) responded strongly and in the expected direction to increasing DO Δ and showed that there is a loss of sensitive species and a general decline in water quality as DO Δ goes up. Based on the findings in the **Part I-A** initial investigation and the follow-up analyses in **Part I-B**, DEQ recommends a DO Δ threshold of **3.0 mg/L** which should be protective of aquatic life in low-gradient western Montana streams and medium rivers.

In eastern Montana streams and medium rivers (**Part II**), DEQ assembled findings from a series of studies carried out in the region from 2010 to 2022. A significant relationship between weekly average DO Δ and weekly average DO minimums was shown. This relationship, along with weekly DO minimum standards in **Circular DEQ-7**, was used to identify a DO Δ threshold of **6.0 mg/L** which should be protective of aquatic life in eastern Montana streams and medium rivers. The DO Δ threshold of **6.0 mg/L** will ensure minimum stream DO levels are maintained, and is the same threshold recommended by (and based on a similar relationship used by) the Ohio Environmental Protection Agency. Drought was shown to substantially increase DO Δ independently of other environmental factors, therefore it is recommended that the eastern MT DO Δ threshold only be applied during non-drought periods.

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LIST OF PART II FIGURES

ACRONYMS

ARM	Administrative Rules of Montana
BPJ	Best Professional Judgement
BHWC	Big Hole Watershed Committee
DEQ	Montana Department of Environmental Quality
DO	Dissolved Oxygen
DO Δ	Dissolved oxygen delta (daily maximum minus daily minimum concentration)
EMAP	Environmental Monitoring and Assessment Program (of the EPA)
EPA	United States Environmental Protection Agency
EPT	Macroinvertebrates from the Orders Ephemeroptera, Plecoptera, and Trichoptera
EQuIS	Environmental Quality Information System
HBI	Hilsenhoff Biotic Index
MBMG	Montana Bureau of Mines and Geology
MCA	Montana Code, Annotated
SOP	Standard Operating Procedure
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant

GENERAL INTRODUCTION: DISSOLVED OXYGEN DELTA

The daily curve of dissolved oxygen (DO) change in flowing water (**Figure 1**) has long been recognized as a key indicator of the balance between aquatic community respiration, photosynthetic production, and atmospheric diffusion of oxygen (Odum, 1956). A simple way to characterize the magnitude of the daily DO curve is to subtract the daily minimum DO concentration from the daily maximum. This daily DO change, or DO Δ, can be used as an indicator of overall community productivity and respiration and is more pronounced in lower-gradient streams and rivers where atmospheric reaeration is much reduced. DO Δ integrates all forms of community photosynthesis whether they be from phytoplankton, periphyton (attached algae), macrophytes, or combinations thereof. The same is true for respiration; respiration of DO by plants, algae, bacterial decomposition (in the water and sediment), macroinvertebrates, fish, etc., are all integrated into the daily DO curve.

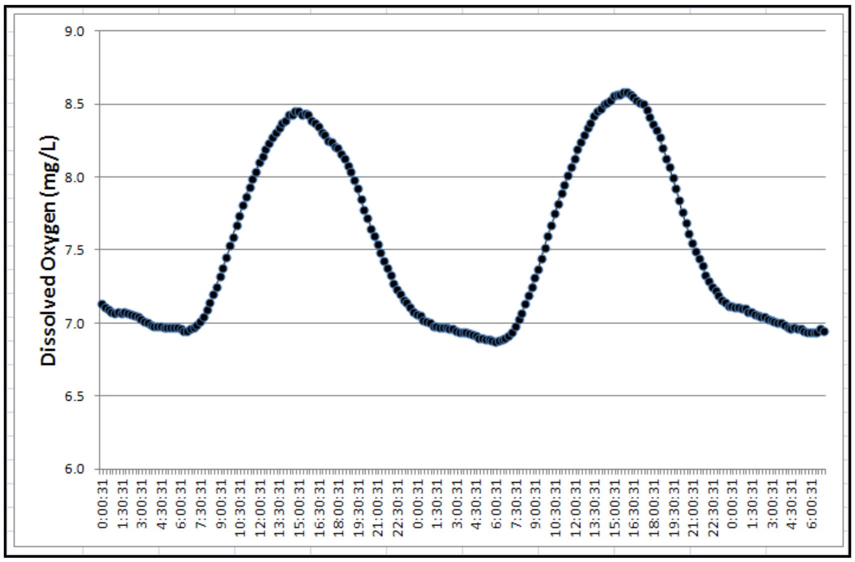

Figure 1. Example of a Daily Curve of DO in a Stream over the Course of Two Days (Time of Day on the Horizontal Axis). In flowing waters, DO is usually at its lowest just before dawn and at its highest in the mid-afternoon.

Work in Minnesota (Heiskary and Bouchard, 2015) shows that when aquatic plant (sestonic or benthic) and microbial growth and biomass are stimulated by excess nutrient (nitrogen and phosphorus) enrichment, stream DO Δ can increase to the point where demonstrable impacts to aquatic life occur (**Figure 2**). These impacts have been shown to affect multiple fish and macroinvertebrate metrics used by Minnesota to evaluate stream health (Heiskary et al., 2013). Work in Ohio links high DO Δ with the co-occurrence of low DO concentrations below their state water quality standard minimum of 4 mg/L (Miltner, 2010). And as found in numerous Ohio-based watershed assessment documents, a primary determinant of the presence of deformities, lesions, and tumors in sampled fish was the frequency of high DO Δs– the higher organisms are stressed by continuous adaptation to changing DO conditions (GLEC, 2021).

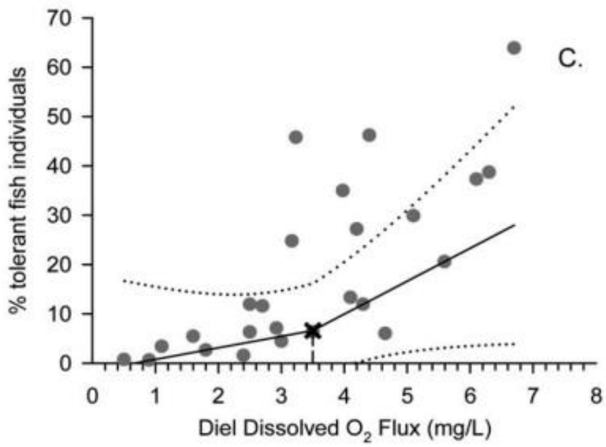

Figure 2. Changes in a Fish Assemblage with DO Δ. As stream DO Δ (or flux, as shown here) increases, more sensitive fish species (e.g., greater redhorse, various shiners) are lost and highly tolerant species (e.g., carp) come to dominate the population. From Figure 3C in Heiskary and Bouchard (2015).

In Montana, Suplee et al. (2019) show that adding low concentrations of inorganic nitrogen and phosphorus to a low-gradient prairie stream led to large increases in benthic algal biomass in summer which, in turn, resulted in large and significant increases in stream DO Δ; when fall arrived, the plants senesced *en masse* and DO concentrations dropped to around 1 mg/L near the stream bottom (**Figure 3**). This work shows that DO problems in streams can occur after peak algal growth has passed and can be delayed until the algae die back later in the year.

Considering the findings from Heiskary et al. (2013), Heiskary and Bouchard (2015), and Suplee et al. (2019) together, a coherent pattern emerges in which elevated nutrient concentrations result in excessive floral biomass that leads to high diel changes in oxygen concentration which can then cause seasonal/episodic crashes in DO; these changes in DO patterns can impact aquatic life. Thus, DO Δ is demonstrated to be a useful indicator of stream eutrophication and, importantly, an indicator of DO problems that may happen in the near future, either episodically or at the onset of a seasonal change. This latter point is important, because Montana's adopted DO standards (DEQ, 2019) might not always be exceeded during a routine, short data collection period (note in **Figure 3** that DO never fell below 5 mg/L—the stream's DO standard—until the very end); in contrast, high DO Δ is indicative of likely future DO problems.

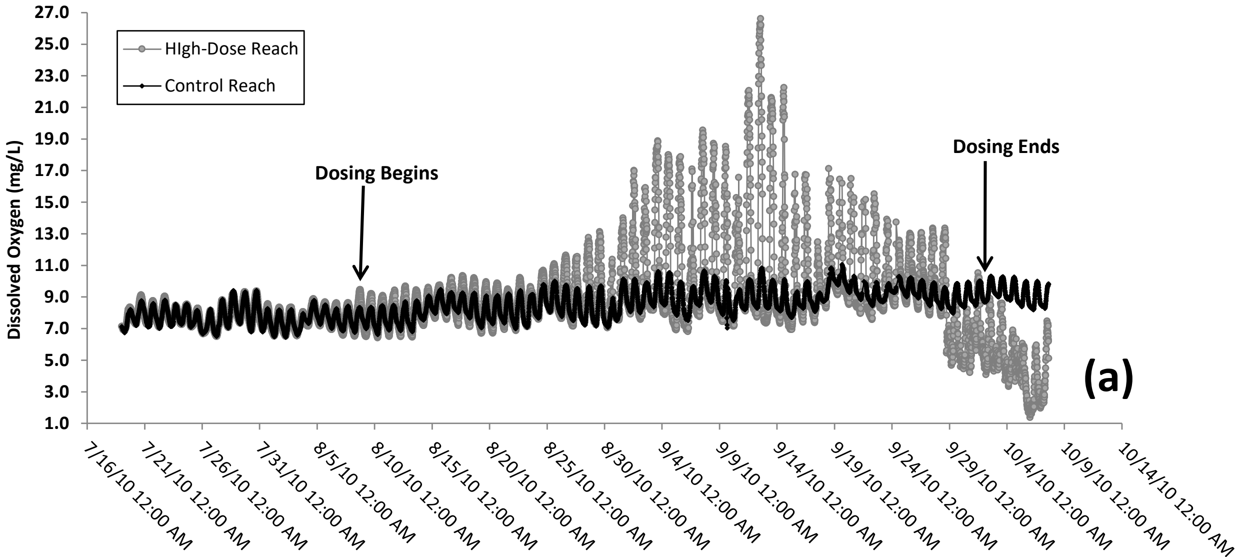

Figure 3. High DO Δ can Indicate Future Low DO Problems. Relative to an upstream control reach where no nutrients were added, an experimental reach (high dose reach) receiving nitrogen and phosphorus additions showed significant increases in DO Δ in summer and then, in fall, DO concentrations crashed (to near 1 mg/L on the bottom) due to senescence of the accumulated benthic algae. The site's DO standard is 5 mg/L. From Figure 6a in Suplee et al. (2019).

DO Δ in the Water Quality Regulatory Setting

DEQ already uses DO Δ to assess eutrophication status of eastern Montana streams (Suplee and Sada, 2016), most or all of which are low gradient and meandering. DEQ has, since 2010, used a DO Δ threshold of 5.3 mg/L to assess prairie stream eutrophication (Suplee and Sada, 2016). Other states also use DO Δ thresholds for the purpose of assessing stream/river eutrophication impacts caused by excess nitrogen and phosphorus concentrations. Minnesota has adopted regulations for streams and rivers for three regions (north, central, and south) each with different DO Δ criteria (values range from 3.0 to 5.0 mg/L; Minnesota administrative rule 7050.0222(2)). Ohio EPA's proposed stream nutrient assessment procedure uses a DO Δ threshold of 6.5 mg/L. And today, with the availability of small, reasonably priced deployable instruments, acquiring continuous DO datasets—essential for calculating DO Δ—is now much easier.

Organization of the Rest of this Document

- **Part I**: Analyses for western Montana pertaining to low-gradient streams and medium rivers.
  - **Part I-A**: An initial investigation to identify a range of candidate DO Δ thresholds protective of aquatic life based on extant data.
  - **Part I-B**: Integration of DEQ's 2023 field data with data from **Part IA** for purposes of improving the analyses, refining conclusions, and recommending a DO Δ threshold protective of aquatic life in western Montana low gradient streams and medium rivers.
- **Part II**: Analyses pertaining to Eastern Montana streams and medium rivers for purposes of recommending a DO Δ threshold protective of aquatic life in those waterbodies.

PART I WESTERN MONTANA

Part I of this document presents work relevant to low gradient streams (stream slope ≤ 1%) in the western part of the state. The overarching purpose of **Part I** is to identify a dissolved oxygen delta (DO Δ) threshold protective of aquatic life in low gradient streams of western Montana. **Part I-A** documents an initial investigation based on extant macroinvertebrate and continuous dissolved oxygen data which were available in 2022. **Part I-B** presents analyses which include data collected during field season 2023 for purposes of augmenting and improving the work undertaken in **Part I-A**. Ecoregions (Woods et al., 2002) comprising the western region discussed in **Part I** of this report are shown in **Table 1**.

Table 1. Ecoregions Comprising the Region Under Investigation in Part I of this Report.

Ecoregions (Whole number prefix: Level III. Number-letter prefix: Level IV)
15. Northern Rockies
16. Idaho Batholith
17. Middle Rockies
41. Canadian Rockies
42l. Sweetgrass Uplands
42n. Milk River Pothole Upland
42q. Rocky Mountain Front Foothill Potholes
42r. Foothill Grassland
43s. Non-calcareous Foothill Grassland
43t. Shield-Smith Valleys
43u. Limy Foothill Grassland
43v. Pryor-Bighorn Foothills
43o. Unglaciated Montana High Plains

PART I-A: AN INITIAL INVESTIGATION USING EXTANT DATA TO IDENTIFY A DISSOLVED OXYGEN DELTA THRESHOLD PROTECTIVE OF AQUATIC LIFE IN LOW-GRADIENT WESTERN MONTANA STREAMS AND MEDIUM RIVERS

1.0 PROBLEM DEFINITION AND PROJECT BACKGROUND

Changes in Montana law[1] necessitated the development of a structured translation process to interpret the state's narrative water quality standards applicable to total nitrogen and phosphorus concentrations (ARM 17.30. 637(1)(e)). DEQ proposed that this translation process include, among other parameters, the daily change in dissolved oxygen, or DO Δ. Although DEQ had been using DO Δ in eastern Montana for over ten years, the need for the translation process to function statewide required the identification of a DO Δ threshold specific to lower-gradient waterbodies in western Montana.

Work to identify a DO Δ threshold protective of aquatic life for low-gradient western MT streams began in earnest in fall 2022. At that time, the only way to proceed with the analysis was to leverage extant DO and macroinvertebrate data that had been collected for other purposes. **Part I-A** of this document describes this initial investigation to derive a preliminary DO Δ threshold for western Montana wadeable streams and medium rivers using the extant data. The next part of this document, **Part I-B**, presents analysis of DO Δ and macroinvertebrate data collected in summer and fall 2023; the 2023 work was undertaken to support and further advance the initial investigation described here in **Part I-A**.

2.0 METHODS

The investigation in **Part I-A** relied exclusively on extant (found) datasets. Continuous DO datasets, macroinvertebrate samples, and other extant information were all identified and acquired from readily available sources (details on sources below). Use of extant data necessitated the use of careful quality control (QC) procedures to ensure data quality, as well as the implementation of various assumptions necessary to carry the analysis forward. Details on QC methods and assumptions, and analyses undertaken to support them, are provided throughout the document and in appendices.

2.1 FRAMEWORK FOR THE INVESTIGATION

Sample Frame: Low gradient wadeable streams and medium rivers (not large rivers, per Flynn and Suplee, 2010) in the western Montana level III ecoregions Northern Rockies, Middle Rockies, Canadian Rockies and Idaho Batholith, and transitional level IV ecoregions (Suplee and Sada, 2016) along the Rocky Mountain Front that are subcomponents of the Northwestern Glaciated and Great Plains level III ecoregions (**Table 2-1A**).

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[1] 75-5-321, MCA

Table 2-1A. Geographic Regions Comprising the Sample Frame for the Investigation

Ecoregion Scale	Ecoregion Name	Ecoregion Number
Level III	Northern Rockies	15
Level III	Idaho Batholith	16
Level III	Middle Rockies	17
Level III	Canadian Rockies	41
Level IV	Sweetgrass Uplands	42l
Level IV	Milk River Pothole Upland	42n
Level IV	Rocky Mountain Front Foothill Potholes	42q
Level IV	Foothill Grassland	42r
Level IV	Unglaciated Montana High Plains	43o
Level IV	Non-calcareous Foothill Grassland	43s
Level IV	Shields-Smith Valleys	43t
Level IV	Limy Foothill Grassland	43u
Level IV	Pryor-Bighorn Foothills	43v

Sampling Unit: An available continuous DO dataset, macroinvertebrate sample, or other relevant data point from a site that was collected within the sample frame during the summer and fall index period as described in DEQ (2012).

2.2 Dissolved Oxygen Datasets from Western Montana Wadeable Stream and Medium Rivers

In late 2022 and early 2023, DEQ obtained all readily locatable continuous DO datasets which had been collected from western Montana wadeable streams and medium rivers. Sources included DEQ, the Montana Bureau of Mines and Geology (MBMG), the United States Geological Survey (USGS), environmental consulting firms, local Water Quality Districts, a doctoral dissertation, and the peer-reviewed scientific literature. DEQ located thirty stream and medium river sites from which continuous DO data had been collected between 2000 and 2022. Data collection time-steps in the continuous datasets were usually 10 or 15 minutes, a few were 30 minutes. If not already completed, each dataset was screened and data were flagged consistent with Wagner et al. (2016). DO delta (daily maximum minus the daily minimum; Δ), daily DO minimum, daily DO maximum, average and median daily water temperature were extracted for each day in each dataset using a DEQ Excel tool. The Excel tool excludes certain flagged data (e.g., those flagged as "R" for reject) and provides, along with the summary results for each daily time step, the percent completeness of each daily time period. DEQ only carried forward daily values where completeness was ≥95% (i.e., <5% of the data were flagged and excluded for any given day). Some sites had multiple years of DO data, some had as little as a single day's DO data, others had more than a month of daily values over a summer/fall period. One site (Clark Fork above Little Blackfoot-Kohrs Bend) had data which extended into November (beyond the summer and fall index period), and for this site these late-season data were retained for analysis because the daily DO patterns continued to maintain the same general patterns and magnitudes they had earlier in the fall.

For purposes of this work, only sites from locations where water surface slope is ≤1% were analyzed further (consistent with the narrative nutrient standards translator in draft **Circular DEQ-15** (DEQ, 2023, and earlier versions). Water surface slopes based on laser field measurements were used when available, while at other sites slope was calculated using a geographic information system. For the latter, DEQ used USGS's StreamStats online tool[2]. Where they could be cross-checked, slopes obtained from the online USGS tool were, on average, within 9% of field-measured slopes (and thus in reasonable agreement). Five sites which had continuous DO datasets were eliminated due to excess stream gradient; a map of the 26 remaining sites used in this analysis is shown in **Figure 2-1A**.

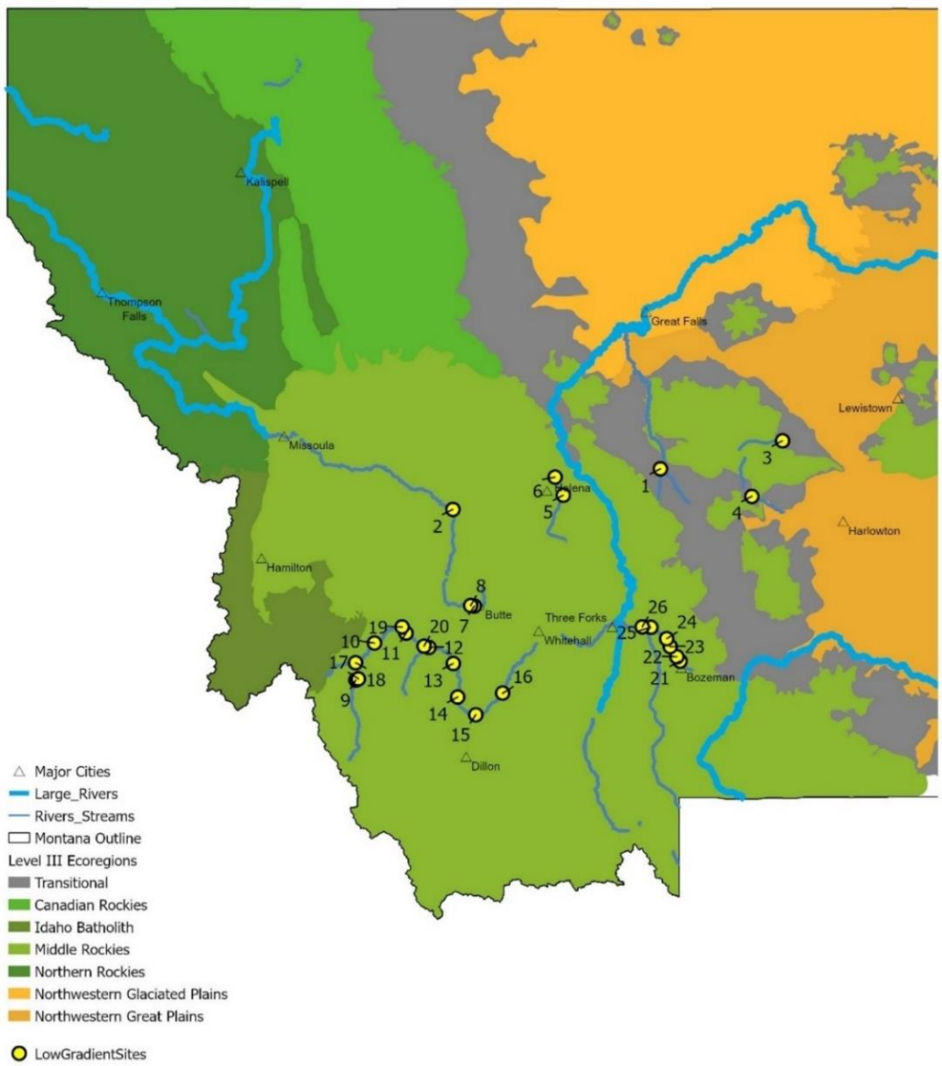

Figure 2-1A. Map of Sites Used in this Analysis. Site numbers correspond to sites listed in Table 2-3A in Section 2.7 below.

[2] https://streamstats.usgs.gov/ss/

2.3 Benthic Macroinvertebrate data

2.3.1 Benthic Macroinvertebrates and Water Quality Standards

Macroinvertebrate metrics are descriptions of specific attributes of the macroinvertebrate community derived from each macroinvertebrate sample. Macroinvertebrate metrics provide a way to determine if Montana's narrative nutrient water quality standards (at ARM 17.30.637) are achieved: *(1) State surface waters must be free from substances attributable to municipal, industrial, agricultural practices or other discharges that will: (e) create conditions which produce undesirable aquatic life.*

Macroinvertebrate metrics give DEQ a direct means of assessing aquatic pollution effects vis-à-vis this water quality standard. For example, the "EPT" Orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are major components of the aquatic life community and a food source for salmonids in western Montana. A decline in EPT, if linked to water pollution (like elevated total nitrogen and total phosphorus) or indictors thereof (like elevated DO Δ), is undesirable. Shifts in macroinvertebrate communities from sensitive clean water taxa (many of which are EPT taxa) to tolerant taxa such as aquatic sow bugs (Isopoda), scuds (Amphipoda), and adult aquatic beetles (Coleoptera) can be assessed with macroinvertebrate metrics and, again, these changes reflect undesirable changes to aquatic life.

2.3.2 Benthic Macroinvertebrate Data in the Extant Dataset

Benthic macroinvertebrate samples collected from study sites (**Figure 2-1A**) were identified in DEQ's EQuIS database. Macroinvertebrate data were available from 22 of the 26 low-gradient sites where continuous DO data were also collected. Population metrics were computed for each macroinvertebrate sample using BioMonTools in R (Leppo et al., 2021; R Core Team, 2022).

Macroinvertebrate samples found in the EQuIS database were collected using one of several protocols (HESS, traveling kick, Jab, EMAP targeted riffle, and EMAP reachwide) and all protocols were retained for purposes of this analysis;[3] a protocol comparison is provided in **Appendix A**. DEQ has assumed for this initial investigation that sampling protocol plays a minor role in the analytical results and that any effects due to sampling protocol will be random in nature.

2.4 Assessing the Usability of Benthic Macroinvertebrate data Not Co-collected with the DO Data

It was common for sites to have multiple macroinvertebrate samples collected over a number of years. However macroinvertebrate data were often, but not always, co-collected with the extant continuous DO datasets. In order to try to retain and evaluate as many sites with continuous DO data as possible (since continuous DO datasets were relatively scarce), DEQ explored whether macroinvertebrate data not co-collected during the same year as the DO data at a site could reasonably be associated with the

[3] Four protocols (travelling kick, jab, EMAP targeted riffle, and EMAP reachwide) were used to collect macroinvertebrates from a site over two consecutive summers; no clear pattern in terms of an effect on the macroinvertebrate metrics due to protocol could be discerned (**Appendix A**), consistent with findings by others (Jessup et al., 2005). Less is known about comparability to the HESS protocol, however Jessup et al. (2005) show the single HESS-collected sample in their analysis grouped tightly with the site it was collected from along with other samples from that site collected using other protocols (see **Appendix A**).

DO data from that site for purposes of carrying out inferential statistics. DEQ posed the following question:

Is a site's multi-year average macroinvertebrate metric score sufficiently similar to the score obtained during a year when macroinvertebrates and DO were co-collected that the multi-year site average score could reasonably serve as a proxy?

To answer, two approaches were undertaken using eight sites where macroinvertebrate data were collected over a number of years and where macroinvertebrate samples were also co-collected at the same time as a continuous DO dataset.

In the first approach, nine key macroinvertebrate metrics[4] known for their consistent responses to perturbations (Davis and Simon, 1994; Bukantis, 1998; Barbour et al., 1999; Suplee and Sada, 2016; S. Sullivan, aquatic ecologist, personal communication 11/30/2022) were computed as (a) an all-data average metric score for a site and as (b) the score only for the year the DO data were collected. The percent % difference between (a) and (b) was calculated as follows:

$[\text{ABS}(\text{METRIC } X_{\text{ALL-DATA AVERAGE}} - \text{METRIC } X_{\text{DO YEAR}})] \div [(\text{METRIC } X_{\text{ALL-DATA AVERAGE}} + \text{METRIC } X_{\text{DO YEAR}}) \div 2]$

where ABS is the absolute value; the final result is expressed as a percent. This was carried out for each of the nine key metrics and for all eight sites, resulting in 72 individual comparisons.

There was an absolute mean percent difference of 18% between the all-data average and the DO-year metric scores; a box and whisker plot of the 72 comparisons is in **Figure 2-2A**. The interquartile range of the differences was 7 to 25% and there were more cases where the percent difference was lower than the mean than higher than the mean.

[4] Total taxa richness, EPT richness, % EPT, number intolerant taxa, number tolerant taxa, % tolerant taxa, % dominant taxa, % clinger taxa, and the MT Hilsenhoff Biotic Index (HBI).

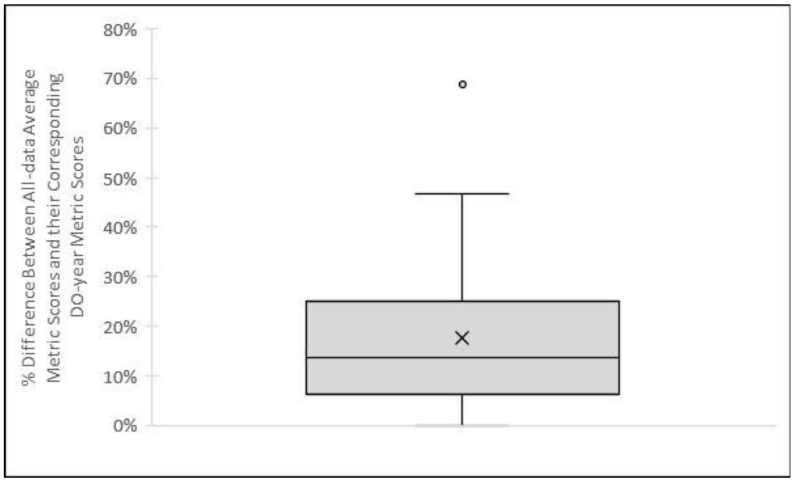

Figure 2-2A. Box and Whisker Plot of the Percent Difference Between the All-data Average Metric Scores and their Corresponding DO-year Metric Scores for Nine Macroinvertebrate Metrics. Horizontal line in the box is the median, the X is the mean.

In the second approach, DEQ again calculated scores for key macroinvertebrate metrics as (a) an all-data average metric score for a site and (b) the score only for the year the DO data were collected. The two scores were then compared to see if a decision made about the health of stream macroinvertebrate populations based on one or the other score would differ substantially. The objective was to see if decision-making would differ strongly between an all-data average vs. a DO-year metric score. DEQ used previously established stream health benchmarks from Bukantis (1998; **Figure 2-3A**) applicable to the intermountain valley and foothills physiographic province[5] to define three decision-making bands; macroinvertebrate scores rated as 3 (i.e., the best macroinvertebrate scores) made up one decision-making band, scores rated from 1-2 comprised the middle band (mid-range), and those rated zero (worst) the third. Bukantis (1998) only reported on five of the nine key metrics under consideration here so the analysis was restricted to them, resulting in (5 metrics X 8 sites) forty individual comparisons.

[5] A geographic region corresponding to the Montana Valley and Foothill Prairies ecoregion of earlier Montana ecoregion maps (Omernik and Gallant, 1987; see also Map 1 and 2 in Bahls et al., 1992); nearly all study sites in the present investigation are located in this geographic region.

SCORE:	3	2	1	0
		PLAINS		
Taxa Richness	>24	24-18	18-12	<12
EPT Richness	>8	8-6	5-3	<3
Biotic Index	<5	5-6	6-7	>7
% Dominant Taxon	<30	30-45	45-60	>60
% Collectors (g+ff)	<60	60-80	80-95	>95
% EPT	>50	50-30	30-10	<10
Shannon Diversity	>3.0	3.0-2.4	2.4-1.8	<1.8
% Scrapers + Shredders	>30	30-15	15-3	<3
# Predator Taxa	>5	4-5	3-4	<3
% Multivoltine	<40	40-60	60-80	>80
		INTERMOUNTAIN VALLEY AND FOOTHILLS		
Taxa Richness	>28	28-21	21-14	<14
EPT Richness	>14	14-13	12-11	<11
Biotic Index	<4	4-5	5-6	>6
% Dominant	<30	30-40	40-50	>50
% Collectors (g+ff)	<60	60-75	75-90	>90
% Scrapers + Shredders	>30	30-20	20-10	<10
% Hydropsychinae of Trichoptera	<75	75-85	85-95	>95
% EPT	>60	60-45	45-30	<30
		MOUNTAIN		
Taxa Richness	>28	28-24	24-19	<19
EPT Richness	>19	19-17	17-15	<15
Biotic Index	<3	3-4	4-5	>5
% Dominant	<25	25-35	35-45	>45
% Collectors (g+ff)	<60	60-70	70-80	>80
% Scrapers + Shredders	>55	55-40	40-25	<25
% EPT	>70	70-55	55-40	<40

Figure 2-3A. Ranges of Macroinvertebrate Metrics from Bukantis (1998) used to Define Decision-making Bands in the Comparative Analysis. Scores (from three, best; to zero, worst) associated with the metric ranges are at the top of the figure. Only the metric ranges from the Intermountain Valley and Foothills (mid-figure) were used to define the decision bands.

For the second approach, the all-data average score and the single-year (DO year) score fell within the same decision-making band in 72.5% of cases. In 27.5% of cases the two scores fell in adjacent bands. In no case did the results fall at opposite ends of the decision bands (best, worst). Thus, most of the time (73%), DEQ's decision about the health of stream macroinvertebrate populations would be the same if it were based on the all-data site average or the single year (DO year) metric score. This result is consistent with Stribling et al. (2008) who show that in Montana duplicate field samples of macroinvertebrates (i.e., those collected the same day at the same site) will agree, in terms of indicating stream impairment or non-impairment, 81.6% of the time, on average.

Appendix B contains all of the case-by-case computations supporting the two approaches just described.

Based on the findings from these two approaches DEQ concluded it was reasonable, where temporally co-collected data were not available, to associate an all-data site average macroinvertebrate score with a continuous DO and temperature dataset at a site where DO and macroinvertebrate data were not collected in the same year. But because co-collected data are preferred, when macroinvertebrate and DO data were collected from a site during the same year only the co-collected macroinvertebrate data will be used even if other years of macroinvertebrate data were available from the site. In this way DEQ is leveraging the most information it can from the extant dataset. DEQ assumed that error introduced by this approach was random in nature and would not skew inferential statistics in any particular direction. For clarity, X-Y scatterplots presented later in Results (**Section 3.0**) will include Y error bars reflecting the average percent difference (18%) between the all-data average and DO-year metric scores identified here, but only for sites where the all-data average macroinvertebrate metric score was used.

Methods used for associating continuous DO and macroinvertebrate data are detailed further in **Section 2.8**.

2.5 Benthic Macroinvertebrate and Continuous DO Data from Low-Gradient Reference Sites

DEQ has eleven western and transitional low-gradient reference sites which meet the ≤1% slope criterion (**Appendix C**). However, only one low-gradient reference stream site (per Suplee et al., 2005)—the Middle Fork Judith River—had extant continuous DO data. Later in the report (**Section 3.0**), this single site will be highlighted in the scatterplots for ease of identification.

2.6 Best Professional Judgement (BPJ) Eutrophication Rating Based Primarily on Floral and Nutrient Concentration Characteristics

Independently from the acquisition and examination of macroinvertebrate data, an assessment—using best professional judgement (BPJ) and based mainly on water chemistry and floral characteristics—was undertaken to assign a eutrophication rating to each site which had continuous DO data; ratings and definitions are in **Table 2-2A.** This approach provided an independent method for assessing eutrophication and its effects on DO Δ and could therefore be used to corroborate or contest the findings based on macroinvertebrates.

As noted, ratings were based mainly on floral characteristics and nutrient concentrations (total nitrogen and total phosphorus) of the waterbodies. For example, a rating of four would be associated with a site showing extensive bottom-attached algal growth (characterized as benthic chlorophyll *a* and ash free dry mass), elevated nutrient concentrations, low DO problems, etc. Ratings reflect, as best possible, the condition of the waterbody at the time the DO data were collected. The rating assessments were completed before the macroinvertebrate metric data were acquired and no ratings were adjusted after the macroinvertebrate data were examined. Generally speaking, sites with ratings of 3 to 4 would be listed as impaired on DEQ's 303(d) list (DEQ, 2021a), but this is only a general statement and exceptions exist.

Table 2-2A. Numeric Ratings Associated with a Gradient of Eutrophication for Low-gradient Western Montana Streams and Medium Rivers

RATINGS	Description
1	No known eutrophication impacts
2	Low eutrophication impacts
3	Medium eutrophication impacts
4	High eutrophication impacts

Information to derive the ratings included assessment records from DEQ's 303(d) list, a doctoral thesis dissertation, peer-reviewed scientific publications, technical reports and data from DEQ, MBMG, and local Watershed Districts, ambient nutrient concentrations in DEQ's EQuIS database, and DEQ staff knowledge. In addition, all of DEQ's eutrophication ratings for sites in the Big Hole River watershed were reviewed by the Big Hole Watershed Committee[6] (personal communication, P. Marques, 2/9/2023). The committee concurred with all of DEQ's scores. Notes on each site's evaluation process and specific citations are in **Appendix D**.

2.7 Final Site List

The final 26 sites used in the analyses, the data available from each site, and the BPJ eutrophication scores are in **Table 2-3A.** Note that macroinvertebrate data were only available for use at 22 of the 26 sites but one of these sites (Big Hole River @ Wisdom Bridge) was not usable due to QC issues with its continuous DO dataset, leaving 21 sites available for DO Δ-macroinvertebrate analysis.

Table 2-3A. Final Sites used in the DO Δ Analyses. See also, Figure 2-1A (map with site numbers).

Number	Site Name	Latitude	Longitude	Water Surface Slope (%)	Continuous DO Data (years)	Macroinvertebrate Data (years)[a]	Eutrophication Rating
1	Camas Creek at mouth	46.70431	-111.19278	0.80	2022	1995 & 2005	2.0
2	Clark Fork River above Little Blackfoot River-Kohrs Bend	46.49687	-112.73715	0.50	2013	Multiple	4.0
3	Judith River Middle Fork near mouth*	46.84650	-110.28600	0.44	2021	2021 & others	1.0
4	Musselshell River North Fork	46.56390	110.51240	0.34	2015	2015 & 2016	2.5
5	Prickly Pear Creek at Kleffner Ranch	46.56931	-111.91540	0.80	2009	None	1.0
6	Prickly Pear Creek at Montana Law Enforcement Acadamy	46.66123	-111.97619	0.04	2009	Multiple	4.0
7	Silver Bow Creek (SBC-2)†	45.99940	-112.57680	0.60	2007, 2008	None	4.0
8	Silver Bow Creek at Rocker-post remediation-old plant (SBC-3)†‡	46.00167	-112.60490	0.60	2007, 2008	2010 to 2016	4.0
9	Big Hole River at Wisdom Bridge	45.61528	-113.45778	0.26	Failed QC	2002	2.5
10	Big Hole River at Mudd Creek Bridge	45.80722	-113.31861	0.22	2000	2002	4.0
11	Big Hole River near Dickie Bridge	45.85972	-113.08361	0.60	2000	Multiple	3.0
12	Big Hole River at Jerry Creek Bridge	45.78472	-112.91389	0.30	2000	2002	2.0
13	Big Hole River at Maiden Rock	45.70139	-112.73444	0.29	2000	2002	2.0
14	Big Hole River at Kalsta Bridge	45.52667	-112.70083	0.50	2000	2002	2.5
15	Big Hole River at Notchbottom	45.43528	-112.56639	0.22	2000	2002	2.5
16	Big Hole River near Twin Bridges	45.54667	-112.36639	0.01	2000	Multiple	2.5
17	Steel Creek	45.62180	-113.43840	0.60	2000	None	2.5
18	North Fork Big Hole River	45.70528	-113.45944	0.14	2000	2003	2.0
19	Deep Creek	45.89080	-113.11330	0.70	2000	None	2.0
20	Wise River	45.79190	-112.95160	1.00	2000	Multiple	1.5
21	East Gallatin Site A	45.71410	-111.04760	0.50	2015	2015 & 2020	2.5
22	East Gallatin Site D	45.73630	-111.07105	0.55	2015	2015 & others	4.0
23	East Gallatin Site G	45.78880	-111.11950	0.54	2015	2015 & others	3.0
24	East Gallatin Site H	45.83059	-111.14617	0.30	2015	2015 & others	4.0
25	East Gallatin Site I	45.88921	-111.26408	0.07	2015	2015 & others	3.5
26	East Gallatin Site J	45.89230	-111.32860	0.15	2015	2015 & 2014	3.5

*DEQ Stream Reference Site (Suplee et al., 2005)
†Site names in parantheses follow the naming convention of Gammons et al. (2011).
‡Remediation was completed at this location in 2003. The wastewater treatment plant was upgraded and operational in 2017.
[a] "Multiple" means ≥ 3 years of samples were available but none of them corresponded to the DO year.

2.8 Spearman Rank Correlation, Scatterplots, and Changepoint Analysis

Average site macroinvertebrate metric scores were joined to their corresponding average daily DO Δ values for 21 sites as follows. When macroinvertebrate data were collected from a site the same year as the DO data, only the average macroinvertebrate metric score from the DO year was joined to the DO data, even if there were other years of macroinvertebrate data available from the site. For sites where

[6] https://bhwc.org/

DO data were not co-collected with the macroinvertebrates, the all-data average site macroinvertebrate score was joined with the corresponding DO Δ data for the site (per **Section 2.4**). This resulted in a flat data table having one average DO Δ value and one average macroinvertebrate metric score for each site, so that each site in the analyses had equal weight. At one site a specific time range was isolated due to known changes in stream conditions resulting from stream remediation work and, later on, a wastewater treatment plant upgrade (see **Table 2-3A,** site number 8, and associated footnote).

Besides the nine key macroinvertebrate metrics discussed already, DEQ had available an additional 208 macroinvertebrate metrics generated via the BioMonTools in R (Leppo et al., 2021; R Core Team, 2022). DEQ analyzed the DO Δ vs. macroinvertebrate metric correlations for all 217 (9+208) metrics using the analytical methods described in the next two paragraphs. The complete list of 217 macroinvertebrate metrics analyzed is in **Appendix E**.

Spearman's rank correlation test (non-parametric; Conover, 1999) was used to identify significant monotonic (linear or non-linear) relationships between DO Δ and the macroinvertebrate metrics as well as DO Δ and the eutrophication ratings. For all 217 available macroinvertebrate metrics, Spearman's rank was run two-sided (more conservatively) with a significance level of <0.01[7]. For any of the 217 metrics which significantly correlated to DO Δ, their scatterplots were further examined to see if the relationship behaved in an ecologically coherent manner (aquatic insect experts were consulted on this)[8]. Locally weighted scatterplot smoothing lines (LOWESS; data not shown) generated in Minitab (v 21) and logarithmic model line fits (Excel) were used for these examinations. All retained, significant relationships were carried forward as candidates for change-point analysis.

A change-point is the point along an environmental or stressor gradient at which there is a high degree of change in a response variable. Change-point analysis divides the data into two groups above and below a threshold, where each of the two groups is internally similar and the difference among the two groups is high. To determine a change-point between site average DO Δ and a site average macroinvertebrate metric, DEQ used mvpart in R (R Core Team, 2022) to run regression tree analysis, setting the tree depth to one (i.e., the root node, which equals the change-point; Qian et al. 2003, King and Richardson 2003). The method always finds a change-point, even in a dataset with a straight-line relationship between X and Y; but because linear relationships represent a gradual continuum of change in Y over X they do not lend themselves well to threshold identification. Therefore, for threshold identification, DEQ only carried out change-point analysis on relationships with a stronger non-linear than linear response[9]. DEQ also eliminated highly redundant metrics (e.g., HBI vs. HBI version 2; HBI version 2 was eliminated) as they do not provide important additional information.

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[7] A Bonferroni adjustment (Cabin and Mitchell, 2000) for 217 tests at significance 0.05 equates to a family-wide adjusted p-value of 0.0002 (note: Bonferroni is considered very conservative). DEQ opted not to institute such a low p value due to the potential for greatly increased type II error (i.e., concluding there are no significant relationships when there truly are). Instead, DEQ opted for a family-wide significance level of <0.01 (i.e., >99% confidence) since each relationship was going to be scrutinized by other criteria (see text).

[8] Running large numbers of correlations can result in some significant correlations occurring purely be chance, especially since DEQ departed from the Bonferroni adjustment. A review of each significant case was undertaken in light of ecological knowledge about the organisms in question in order to screen out possible spurious relationships.

[9] One scatterplot had essentially identical R^2 values for the linear and logarithmic model lines.

DO concentrations are affected by water temperature and DEQ wanted to examine the importance of this co-variable before proceeding. Average site water temperature was calculated by averaging all continuous temperature data co-collected at a site with the DO data using the same data handling methods described earlier for DO Δs. Average site water temperature ranged from 12.2 to 17.8°C, with an interquartile range of 13.7 to 14.8 °C. Temperature effect on DO Δ across these temperature ranges is relatively modest—even at the temperature endpoints of 12.2 and 17.8 °C the effect on DO saturation is only about 1 mg DO/L. Further, average DO Δ did not correlate significantly with average daily water temperature (Spearman's rho, $p > 0.1$). Therefore, water temperature effects were not further considered in this investigation.

3.0 Results

3.1 Spearman Rank Correlations and Threshold analysis

Among the 217 macroinvertebrate metrics examined, 23 significantly correlated with DO Δ. After consultation with a macroinvertebrate ecologist (S. Sullivan, personal communication 2/27/2023) regarding expected or potential behavior of lesser-known metrics to perturbation, examination of the scatterplots to identify those with non-linear relationships, and elimination of highly redundant metrics, DEQ carried seven significant relationships on to change-point analysis.

Table 3-1A shows the seven significant, non-linear relationships and provides the non-parametric inferential statistics and threshold analysis for each. They are ordered by strength of the Spearman's rho coefficient. For these seven relationships, variation in DO Δ explained between 57% and 76% of the variation in the macroinvertebrate metric scores (Spearman's rho, **Table 3-1A**). Change-point analysis on the seven relationships showed DO Δ threshold concentrations ranging from 1.50 to 3.94 mg DO/L, with a mean and median threshold concentration of 3.08 and 3.14 mg DO/L, respectively. Spearman rank correlation statistics for all 217 metrics are found in **Appendix F.**

As expected, the BPJ eutrophication rating (see **Section 2.6**) was significantly and strongly correlated with DO Δ ($p < 0.000$; Spearman's rho =0.827); this was the strongest correlation in the investigation.

Table 3-1A. Macroinvertebrate Metrics and Their Response to DO Δ. Associated inferential statistic values are shown; relationships are ordered by correlation strength (highest to lowest).

Causal Variable	Response Variable - Code	Response Variable - Description	Predicted Response to Increasing purtubation	Spearman Rank Correlation		Change-point Analysis	
				Rho	p-value	DO Δ change-point (mg/L)	Relative Error†
DO Δ	x_Becks3	Beck's Biotic Index v3	decrease	-0.758	<0.000	1.50	0.497
DO Δ	pi_Hydro2EPT	Percent (0-100) individuals - Family Hydropsychidae of Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT)	increase	0.737	<0.000	3.63	0.443
DO Δ	pi_tv_intol4	percent (0-100) individuals - tolerance value - intolerant < 4	decrease	-0.634	0.002	2.75	0.536
DO Δ	nt_ffg_pih	number taxa - Functional Feeding Group (FFG) - piercer-herbivore (PH)	probably increase	0.631	0.002	3.94	0.276
DO Δ	pt_Coleo	percent (0-100) taxa - Order Coleoptera	probably increase	0.574	0.007	3.14	0.537
DO Δ	nt_Ephemerellid	number taxa - Family Ephemerellidae	decrease	-0.572	0.007	3.84	0.689
DO Δ	x_HBI	Hilsenhoff Biotic Index (references the TolVal field) using Montana DEQ values	increase	0.571	0.007	2.75	0.619

†Relative error is 1 – R^2 root mean square error. This is the error for predictions of the data that were used to estimate the model.

3.2 X-Y Scatterplots Between DO Δ and Response Variables

Scatterplots of the seven macroinvertebrate metrics which were best explained by non-linear responses to DO Δ are in **Figures 3-1A** through **3-8A**. A logarithmic model was the best fit to these relationships and is shown in each scatterplot. Y error bars are provided for sites where macroinvertebrate data were not co-collected with the continuous DO data (see details in **Section 2.4**). The Middle Fork Judith River reference site (triangle in the scatterplots) exhibited the lowest average DO Δ in the dataset (1.1 mg/L) and its position in the scatterplots was always in the anticipated region of the plots in relation to the DO Δ stressor gradient. Examples of DO Δ-macroinvertebrate metric scatterplots which significantly correlated with but which were *not* carried forward to change-point analysis are in **Appendix G**.

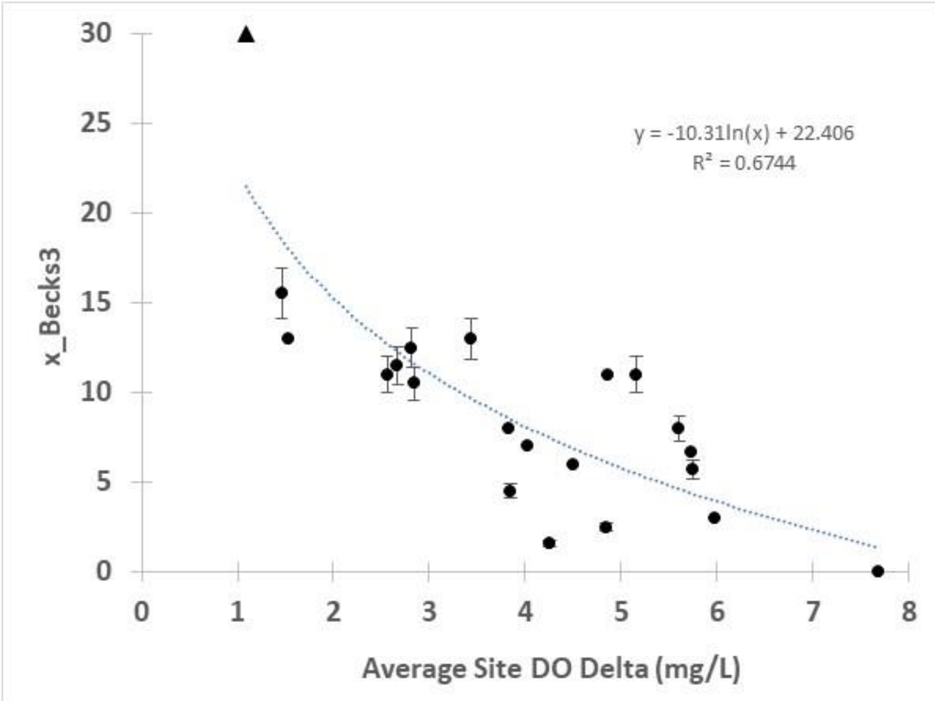


Figure 3-1A. Scatterplot of DO Δ vs. Beck's Biotic Index (version 3). The triangle is the reference site. See text for explanation of error bars.

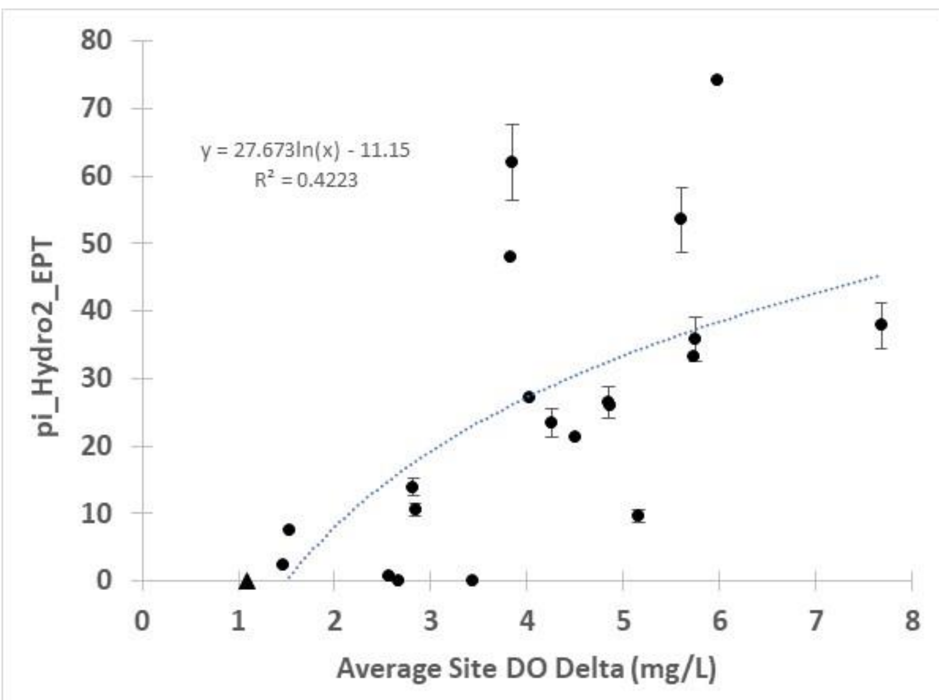


Figure 3-2A. Scatterplot of DO Δ vs. Percent Individuals in the Family Hydropsychidae of the Orders Ephemeroptera, Plecoptera, and Trichoptera. The triangle is the reference site. See text for explanation of error bars.

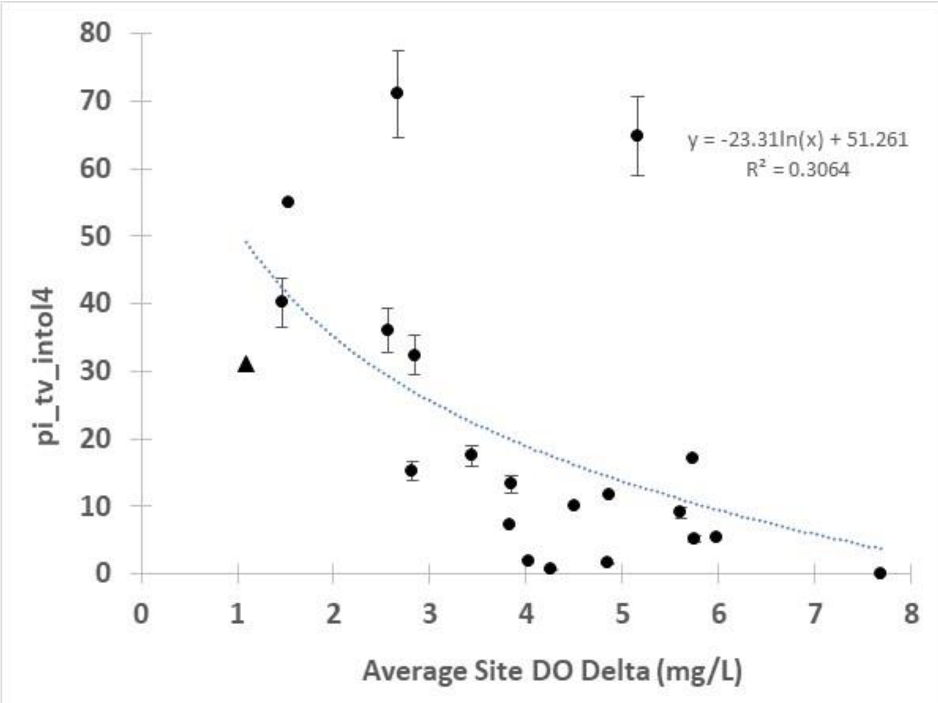


Figure 3-3A. Scatterplot of DO Δ vs. Percent Intolerant Individual (Tolerance Value <4). The triangle is the reference site. See text for explanation of error bars.

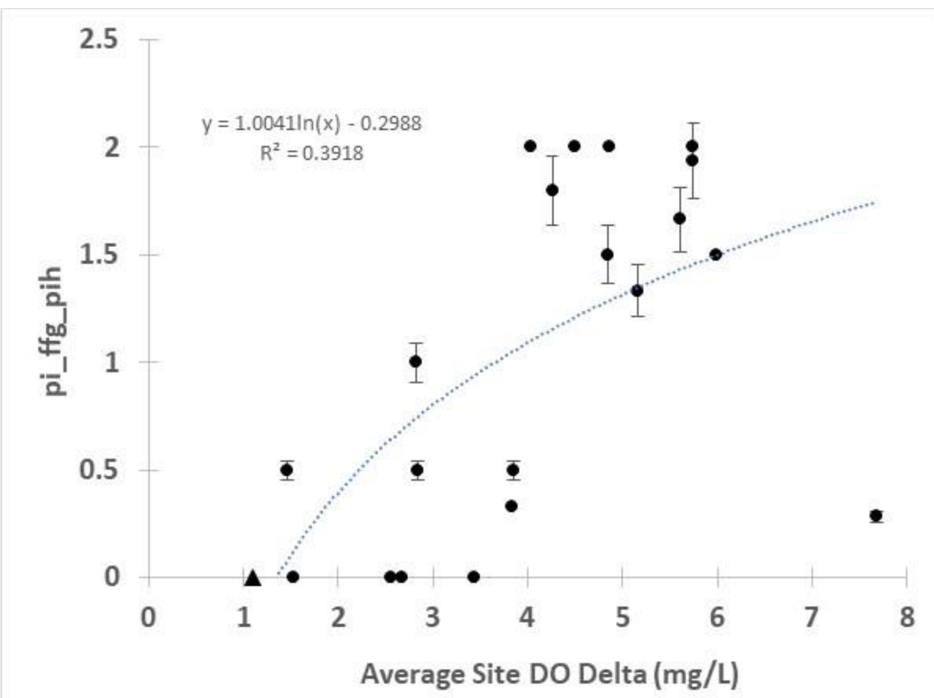


Figure 3-4A. Scatterplot of DO Δ vs. Number of Taxa in the Functional Feeding Group Piercer-Herbivore. The triangle is the reference site. See text for explanation of error bars.

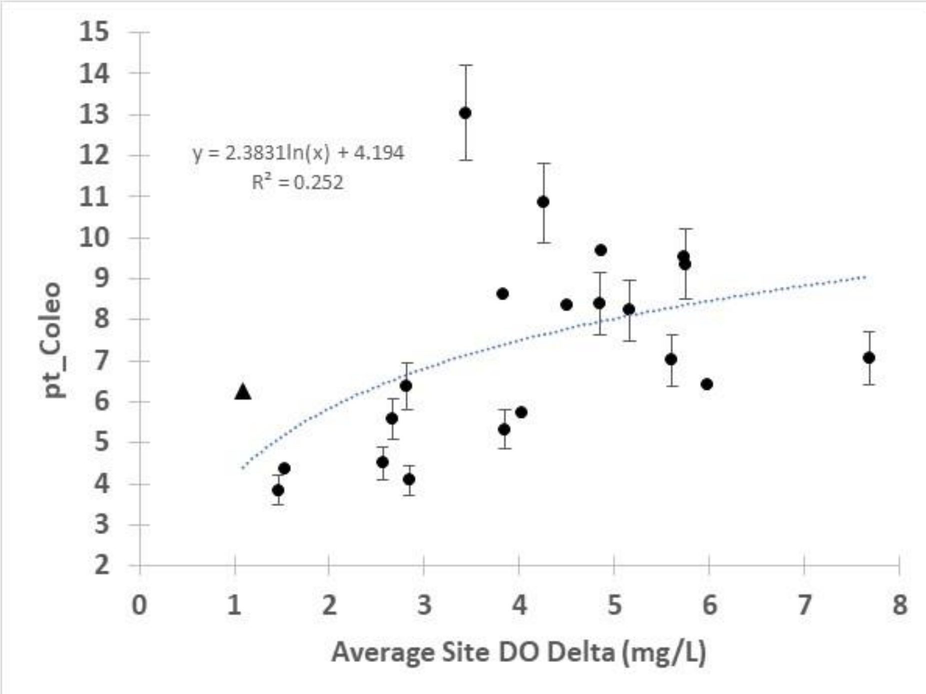


Figure 3-5A. Scatterplot of DO Δ vs. Percent Taxa in the Order Coleoptera (beetles). The triangle is the reference site. See text for explanation of error bars.

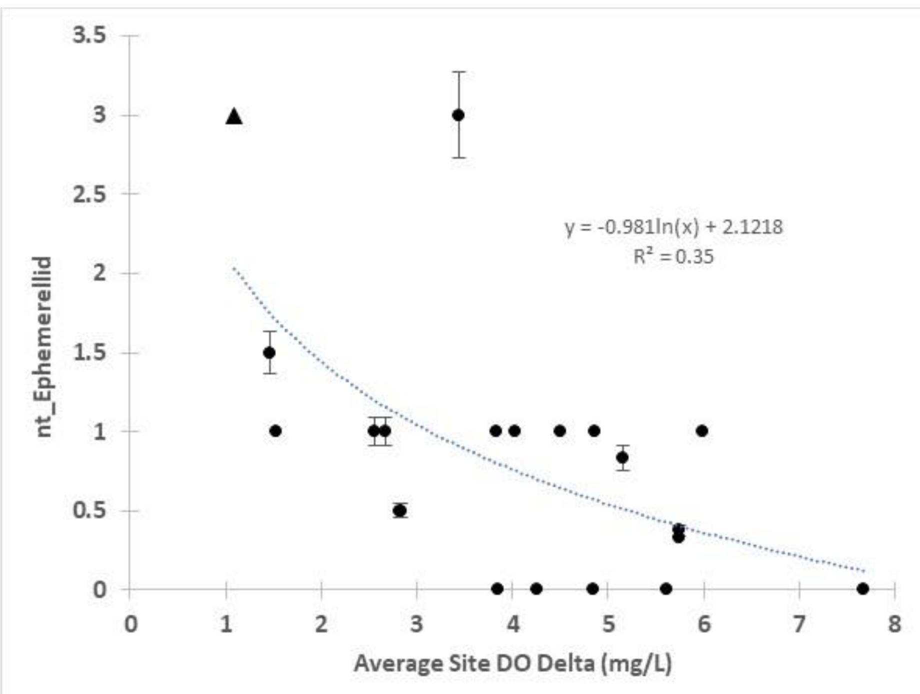


Figure 3-6A. Scatterplot of DO Δ vs. Number of Taxa in the Family Ephemerellidae (spiny crawler mayflies). The triangle is the reference site. See text for explanation of error bars.

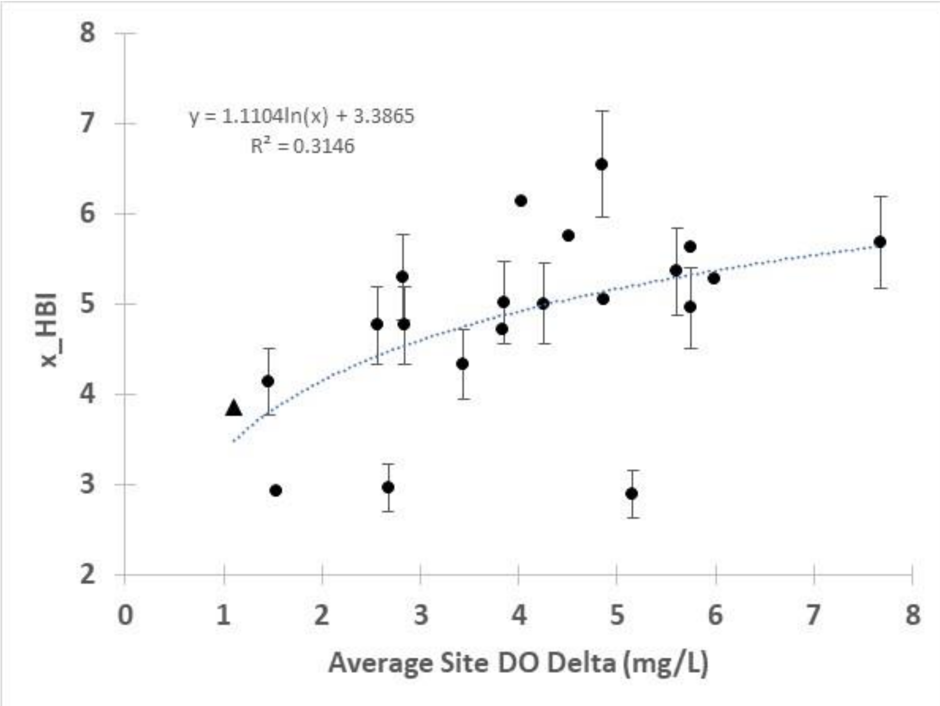


Figure 3-7A. Scatterplot of DO Δ vs. the Hilsenhoff Biotic Index (HBI). The triangle is the reference site. See text for explanation of error bars.

Finally, **Figure 3-8A** shows DO Δ vs. the BPJ eutrophication ratings. It is the only relationship presented in this report that is based on waterbody flora and nutrient concentrations and not exclusively on macroinvertebrate metrics. Its results corroborate the overall patterns manifested between DO Δ and macroinvertebrates.

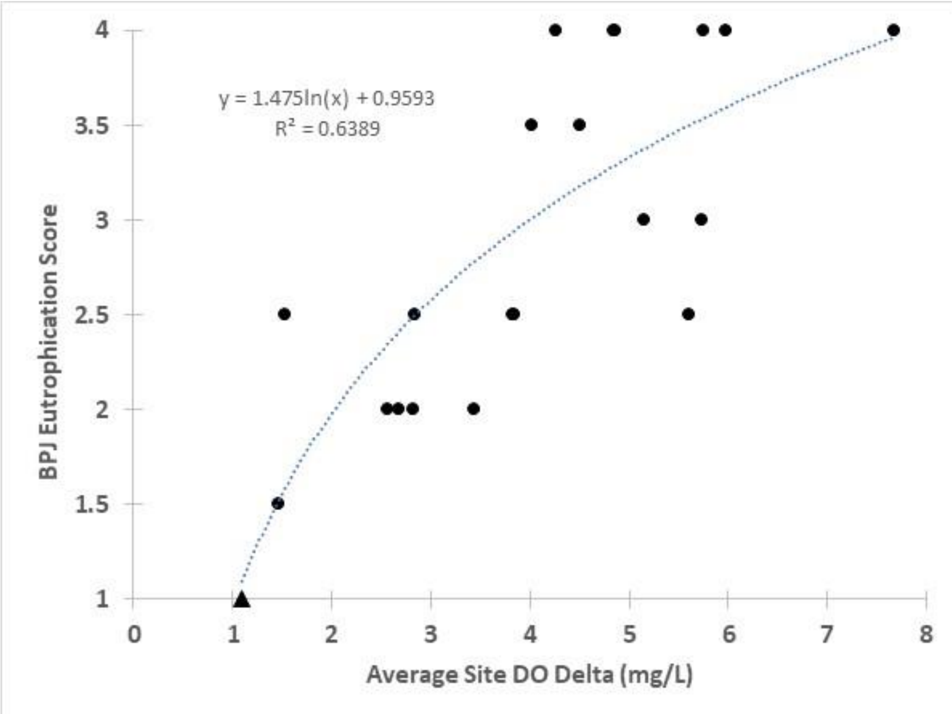


Figure 3-8A. Scatterplot of DO Δ and a Site Eutrophication Rating (1 Least, 4 Most) for the Sites, Based on Best Professional Judgement. The triangle is the reference site.

4.0 DISCUSSION

The data in this initial investigation indicate that with increasing DO Δ there is a general decline in sensitive macroinvertebrate taxa, including those in the EPT Orders and Families within EPT, and a corresponding increase in the percent of tolerant taxa—for example the Hydropsychidae (see Barbour et al., 1999 for details on this group). Biotic indices (Beck's, HBI) responded strongly to increasing DO Δ and show there is a loss of sensitive species and a general decline in water quality as DO Δ goes up.

Work in western Montana low-gradient streams shows that Beck's Biotic Index (v3) is one of the metrics most strongly correlated with nitrogen and phosphorus concentration gradients (Schulte and Craine, 2023). The present work shows Beck's Biotic Index (v3) is strongly, negatively, correlated with DO Δ, whether looked at non-parametrically (Spearman's rho = -0.758; **Table 3-1A**) or parametrically (negative log relationship, R^2 = 0.674; **Figure 3-1A**). DO Δ increases with increasing nutrient concentrations (Suplee et al., 2019) and increasing DO Δ, in turn, strongly effects macroinvertebrate indices like Beck's, as shown here.

The other biotic index is the Hilsenhoff Biotic Index (HBI). HBI has long been used by DEQ to assess western Montana streams and medium rivers (Bahls et al., 1992; Bukantis, 1998; Suplee and Sada, 2016). Like Beck's, it was closely related to DO Δ in this study and, due to its expected behavior under perturbation (its values increase with stress), it is essentially a mirror-image of Beck's (**Figures 3-1A**, **3-7A**). Hilsenhoff (1987) states that transitioning from 4.5 to 5.5 on the HBI scale equates to a change from good water quality (some organic pollution) to fair water quality (fairly significant organic pollution); this nationally applied shift in water quality conditions brackets the identified DO Δ threshold of 2.75 mg/L in the present study (**Table 3-1A; Figure 3-7A**). Bukantis (1998) and McGuire (2004) indicate <4 is the optimal HBI score for intermountain valley and foothill streams, but based on the present analysis this may be to too stringent an expectation given that the reference site had an HBI of 3.85 at a very low DO Δ of 1.1 mg/L. The difference between the earlier work and the current investigation is likely related to more conservative (lower) percentiles of reference used to set the expectation (via the RBP III method (EPA, 1989)) as applied by those earlier authors.

The family Ephemerellidae (spiny crawler mayflies, **Figure 3-6A**) are sensitive to disturbance and their decline with increasing DO Δ is consistent with a decline due to increased DO Δ observed for other sensitive species, such as the intolerant taxa with tolerance values <4 shown in **Figure 3-3A**.

The present study also showed significant, non-linear relationships for macroinvertebrate groups or taxa with less well-documented expectations in terms of response to perturbation (**Figures 3-4A**, **3-5A**). In spite of less being known about these groups, they provided fairly clear patterns in the present study especially when the position of the reference site is considered. The piercer-herbivores (**Figure 3-4A**) are almost certainly responding to the increase in floral biomass which co-occurs with (and causes) increasing DO Δ.

The mean of the DO Δ thresholds for the seven non-linear relationships used in this analysis was 3.1 mg/L. Heiskary and Bouchard (2015) identify similar DO Δ thresholds to protect aquatic life in flowing waters in geographic regions (level III ecoregions Northern Lakes and Forests, North Central Hardwood Forests, and Driftless Area; EPA 2006) which are the closest physiographic analogs to the current investigation. For their ecoregions, Heiskary and Bouchard (2015) recommend DO Δ values from 3.0 to 3.5 mg/L[10].

Overall, the data in this initial investigation—whether considered via parametric or non-parametric statistics—indicate that with increasing DO Δ there is a decline in sensitive macroinvertebrate taxa, including those in the EPT Orders and Families within EPT. There is a corresponding increase in the percent of tolerant taxa—for example the Hydropsychidae. Biotic indices (Beck's, HBI) responded strongly and in the expected direction to increasing DO Δ and show that there is a loss of sensitive species and a general decline in water quality as DO Δ goes up. For low gradient western Montana streams and medium rivers, these changes mean that DO Δ is linked to conditions which produce undesirable aquatic life. Based on this initial investigation using extant data, a DO Δ threshold in the range of 3 to 3.5 mg/L appears to be appropriate for minimizing undesirable changes in aquatic life in low gradient streams of the region.

5.0 Acknowledgements

DEQ would like to acknowledge the assistance of Nick Banish, District Manager with the Gallatin Local Water Quality District, for providing macroinvertebrate and water quality data for the East Gallatin River. DEQ thanks Pedro Marques (Executive Director, Big Hole Watershed Committee) for facilitating his organization's review of DEQ's eutrophication ratings for sites in the Big Hole watershed, and Darrin Kron (DEQ) for his independent review of the same Big Hole sites. Special thanks to Sean Sullivan of Rhithron Associates, Inc. for multiple helpful insights and conversations regarding macroinvertebrate ecology. Thanks to Christy Meredith (DEQ) for assistance with R programming. DEQ very much

[10] These have been adopted into water quality regulations at Minnesota administrative rule 7050.0222(2).

appreciates the time spent by Sean Sullivan (*Rhithron*), Dr. Will Bouchard (Minnesota Pollution Control Agency), Christy Meredith (MT DEQ), and Tina Laidlaw (U.S. EPA) in carrying out peer reviews on an earlier version of this report; their suggestions were very helpful.

PART I-B: AUGMENTING AND ENHANCING THE WORK IN PART 1-A USING 2023 FIELD DATA FOR PURPOSES OF IDENTIFYING A PROTECTIVE DISSOLVED OXYGEN DELTA THRESHOLD

1.0 PROJECT OBJECTIVE, PROBLEM DEFINITION, PROJECT BACKGROUND

The overarching purpose of **Part I** is to identify a dissolved oxygen delta (DO Δ) threshold protective of aquatic life in low gradient streams of western Montana. Here in **Part I-B,** analyses will be presented that incorporate/integrate data collected in field season 2023 with the data from **Part I-A** for purposes of improving the analyses and refining the conclusions. Shortcomings of the **Part I-A** initial investigation were (1) a limited number of continuous DO datasets from low-gradient western MT sites and (2) only a single reference site (per Suplee et al., 2005) having both continuous DO data and macroinvertebrate samples. DEQ set out to correct these issues in 2023 by setting as its goal summer and fall sampling of approximately 20 western MT low-gradient sites, about half of which would be low-gradient reference sites (see list in **Appendix C**). For comparative purposes, two sites were sampled which overlapped with sites analyzed in **Part I-A;** the remaining 2023 sites were new to the project. A sampling and analysis plan (SAP) was finalized in summer 2023 (Suplee, 2023) and is available from DEQ as a separate document.

Part I-A identified a range of candidate thresholds for dissolved oxygen delta (DO Δ) protective of aquatic life. **Part I-B** will present data and analyses supporting a final recommendation for a dissolved oxygen delta (DO Δ) threshold protective of aquatic life for low gradient streams and medium rivers of western Montana.

2.0 METHODS

Table 2-1B and **Figure 2-1B** shows the sites sampled in 2023. Detailed field sampling methodology is provided in Suplee (2023) but in brief:

- Continuous DO meters were deployed at each site starting in early August 2023 and were left *in situ* for a minimum of two weeks, a maximum of 36 days.
- Macroinvertebrate samples were collected per DEQ (2012) upon return to each site to retrieve the DO meters.
- A visual assessment of stream flora was completed per DEQ (2021b).
- Water quality samples for nutrients (total nitrogen, total phosphorus) were collected and field conductivity, temperature, and pH were also measured.

Table 2-1B. Low-gradient Sites Sampled in 2023

Number	Site Name	Site Type	Reference or Non-Reference site	Station ID	Lat (DD)	Long (DD)	Level III Ecoregion	HUC	% Water Surface Slope	Stream Gradient Determination Method
1	Pipe Creek	Stream	Non-reference	K01PIPEC03	48.48895	-115.52419	Northern Rockies	17010101	0.77	USGS StreamStats
2	Deep Creek	Stream	Non-reference	M09DEEPC10	46.33449	-111.17180	Middle Rockies	10030101	0.82	USGS StreamStats
3	Sun River	Medium River	Non-reference	M13SUNR64	47.61764	-112.69146	Northwestern Glaciated Plains (Transitional)	10030104	0.60	USGS StreamStats
4	Beaverhead River	Medium River	Non-reference	M02BVHDR90	45.06626	-112.80031	Middle Rockies	10020002	0.29	USGS StreamStats
5	Red Rock Creek	Stream	Non-reference	M01RDRKC01	44.61604	-111.65712	Middle Rockies	10020001	0.96	USGS StreamStats
6	Little Blackfoot	Medium River	Non-reference	C01LTBLR65	46.43888	-112.46151	Middle Rockies	17010201	0.45	USGS StreamStats
7	West Fork Madison River	Medium River	Non-reference	M05MDWFR05	44.88117	-111.58234	Middle Rockies	10020007	0.71	USGS StreamStats
8	East Fork Bitterroot River	Medium River	Non-reference	C05BITER60	45.89515	-113.82223	Idaho Batholith	17010205	0.79	USGS StreamStats
9	Rock Creek	Stream	Non-reference	C02ROCKC60	46.41035	-113.70605	Middle Rockies	17010202	0.54	USGS StreamStats
10	Monture Creek	Stream	Non-reference	C03MONTC10	47.12479	-113.14748	Middle Rockies	17010203	0.96	USGS StreamStats
11	Prickly Pear Creek	Stream	Non-reference	M09PRPEC01	46.51747	-111.94721	Middle Rockies	10030101	0.66	USGS StreamStats
12	Prickly Pear Creek at Montana Law Enforcement Acadamy*	Stream	Non-reference	M09PREP02	46.66137	-111.97619	Middle Rockies	10030101	0.04	USGS StreamStats
13	Clark Fork River above Little Blackfoot River-Kohrs Bend*	Medium River	Non-reference	C01CKFKR03	46.49829	-112.74309	Middle Rockies	17010201	0.50	USGS StreamStats
14	Belly River	Medium River	Reference	S02BELYR01	48.96806	-113.68263	Canadian Rockies	9040002	0.30	USGS StreamStats
15	Blackfoot River	Medium River	Reference	C03BLACR01	46.89977	-113.75606	Middle Rockies	17010203	0.09	USGS StreamStats
16	Gallatin River	Medium River	Reference	M05GLTNR01	45.05443	-111.15651	Middle Rockies	10020008	0.50	USGS StreamStats
17	Blacktail Deer Creek East Fork in Robb Creek Wildlife Area	Stream	Reference	M02BDEFC01	44.86583	-112.21864	Middle Rockies	10020002	1.00	EMAP
19	Elk Springs Creek	Stream	Reference	M01ELKC01	44.64441	-111.6649	Middle Rockies	10020001	0.08	Laser
19	Middle Fork Judith River*	Medium River	Reference	M22JUDMF01	46.84653	-110.2860	Northwestern Great Plains (Transitional)	10040103	0.44	Laser
20	Sweet Grass Creek	Stream	Reference	Y03SWTGC07	46.15294	-110.18171	Northwestern Great Plains (Transitional)	10070002	0.24	Laser

*A stream or medium river site that provided data and was analyzed in **Part I-A**.

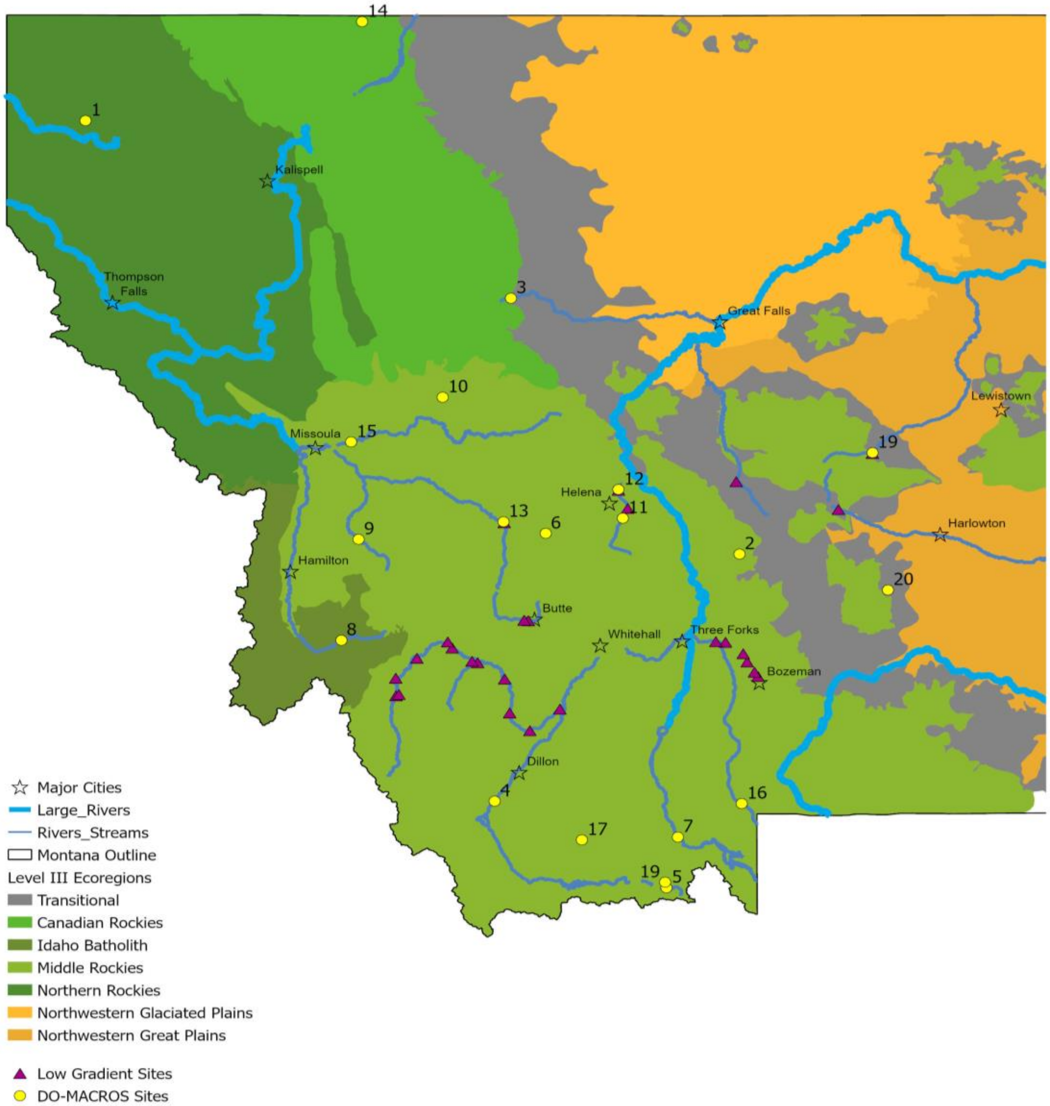


Figure 2-1B. Map of Sites Sampled in 2023. 2023 sites are the yellow circles and the numbers correspond to site numbers in Table 2-1B. Sites which were part of the initial investigation (Part I-A of this report) are shown as purple triangles.

MiniDOT® DO meters (10-minute logging interval) were subject to a pre-deployment calibration check (Suplee, 2023) and then, post-deployment, the continuous DO datasets were QCed and processed per methods in Section 2-2 of **Part 1-A**. The DO meter deployed at the reference site Blacktail Deer Creek East Fork (**Table 2-1B**) failed almost immediately upon deployment and no DO or temperature record could be extracted from it. Macroinvertebrate samples were processed by *Rhithon* Associates consistent with DEQ (2012) and population metrics were computed for each macroinvertebrate sample using BioMonTools in R (Leppo et al., 2021; R Core Team, 2022).

Using the complete daily DO record collected by each instrument (covering early August to mid-September, depending on the site), average site DO Δ and water temperature was computed and then joined with the corresponding macroinvertebrate metric scores to carry out correlation analysis. The

2023 data were then combined with analogous **Part I-A** data to create a “complete dataset.” One 2023 site (Elk Springs Creek, a reference site, Table 2-1) was excluded as it is a spring creek. Montana spring creeks are inventoried (Decker-Hesse, 1989), are ecologically distinct from runoff-influenced streams, and are proposed to have different regulatory requirements; they will be addressed in a separate DEQ document. As a result, the complete dataset comprised 39 sites with one DO Δ value and one score for each macroinvertebrate metric per site.

Relationships with Spearman rank correlation p-values ≤0.01 were considered significant, consistent with **Part I-A**. Analysis here in **Part I-B** was focused on significant DO Δ-macroinvertebrate relationships from **Part 1-A** (see Table 3-1, Section 3.0 of **Part I-A**) for which a meaningful[11] Y-axis threshold could be identified. Y-axis thresholds provide a means of identifying a protective DO Δ threshold from the X-axis based on statistically fitted model lines. Using the complete dataset, significant DO Δ-macroinvertebrate scatterplots meeting the Y-axis criterion were plotted with best-fit parametric model lines (e.g., logarithmic) and non-parametric model lines (LOWESS; smoothing factor = 0.5).

Section 2.4 of **Part I-A** explains the rationale for the error bars shown for some sites in the **Part I-A** scatterplots (the error bars are associated with sites where continuous DO and macroinvertebrate data were not temporally co-collected). Analogous error bars will be associated with the same sites here in **Part I-B**. (No error bars are needed for 2023 data—in all cases continuous DO and macroinvertebrates were temporally co-collected.) The 2023 field work provided six more sites with which the error bar uncertainty analysis in Section 2.4 of **Part I-A** could be augmented. The same methods in Section 2.4 of **Part I-A** were carried out on data from the six new sites and the results were compiled with the earlier tabulations. The updated, augmented analysis shows that, on average, there is an absolute mean percent difference of 13% between an all-data average macroinvertebrate score at a site and the DO-year macroinvertebrate metric score. This is a reduction in uncertainty (previously it was found to be 18%), and highlights what DEQ has observed and the scientific literature (Stribling et al., 2008) supports—that macroinvertebrate metric scores at stream sites tend to be stable over time, barring any known changes (e.g., stream restoration or remediation). But to ensure readers who may be concerned with the inclusion of the “error bar” sites (i.e., sites where continuous DO and macroinvertebrate data were not temporally co-collected), key DO Δ-macroinvertebrate relationships will be re-examined and presented after excluding the “error bar” sites. The reduced dataset, as it will be referred to hereafter, comprised 26 sites.

3.0 RESULTS

Per Spearman rank test, average water temperature was not significantly correlated to average DO Δ for the complete dataset nor for the 2023 dataset. Water temperature effects were not further considered in this analysis.

Meaningful Y-axis relationships were identified for two of the seven macroinvertebrate metrics/indices from **Part I-A**. A threshold for Beck’s Biotic Index version 3 (Beck’s) of 18.68 was derived from a TN-Beck’s logistic relationship for low-gradient western Montana streams and medium rivers (Schulte and Craine, 2023). This threshold is considered by DEQ to be protective of aquatic life and is being proposed

[11] Meaningful in this context means a threshold for the macroinvertebrate metric in question that could be identified in the scientific literature or in DEQ technical reports and that is protective of aquatic life beneficial uses.

for adoption in draft **Circular DEQ-15**. A threshold for the Hilsenhoff Biotic Index (HBI) of 5.0 was identified and represents the general transition from good to fair water quality per Hilsenhoff (1987). In the past DEQ has considered an HBI of 4.0-4.5 for low-gradient western streams as appropriate to protect aquatic life (Bukantis, 1998; McGuire, 2004), but four of six (67%) of the low-gradient reference sites in this dataset exceed 4.0 and one reference site exceeds 5.0. Thus, 4.0 is evidently too conservative based on the current data.

Based on the complete dataset, Beck's and HBI were significantly and strongly correlated to DO Δ (Spearman's rho = -0.792, p <0.000, and Spearman's rho = 0.505, P= 0.001, respectively). The biotic indices' scatterplots, including fitted regression lines, are in **Figure 3-1B** and **3-2B**.

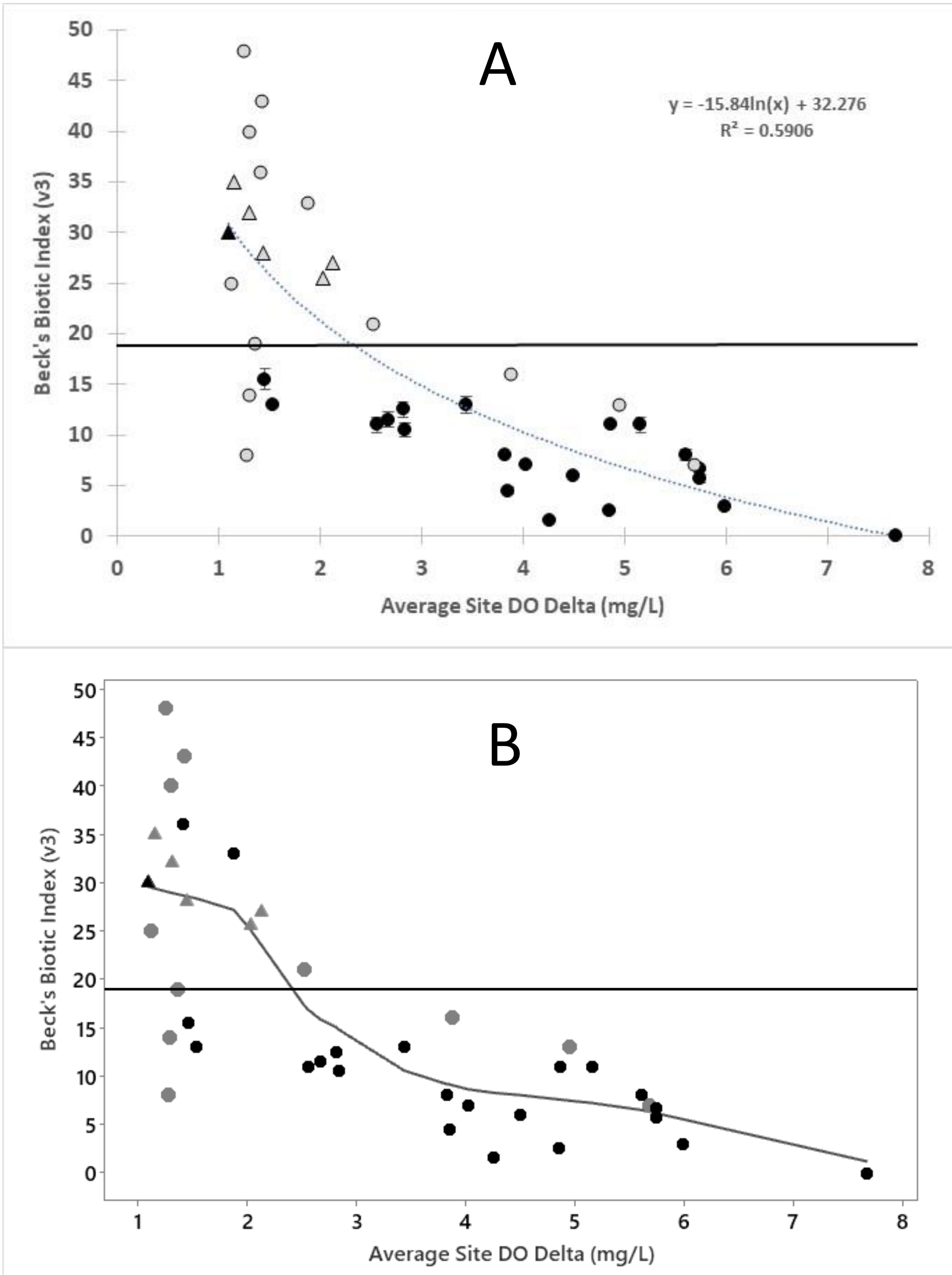


Figure 3-1B. Scatterplots of Beck's Biotic Index (v3) vs. Average Site DO Δ. Black symbols are sites from Part I-A, gray symbols are 2023 field season sites. Triangles are low-gradient reference sites. Horizontal lines are the threshold identified for this biotic index in Schulte and Craine (2023). See text for explanation of error bars. Panel A. Parametric, logarithmic regression line and associated line equation. Panel B. Non-parametric LOWESS line.

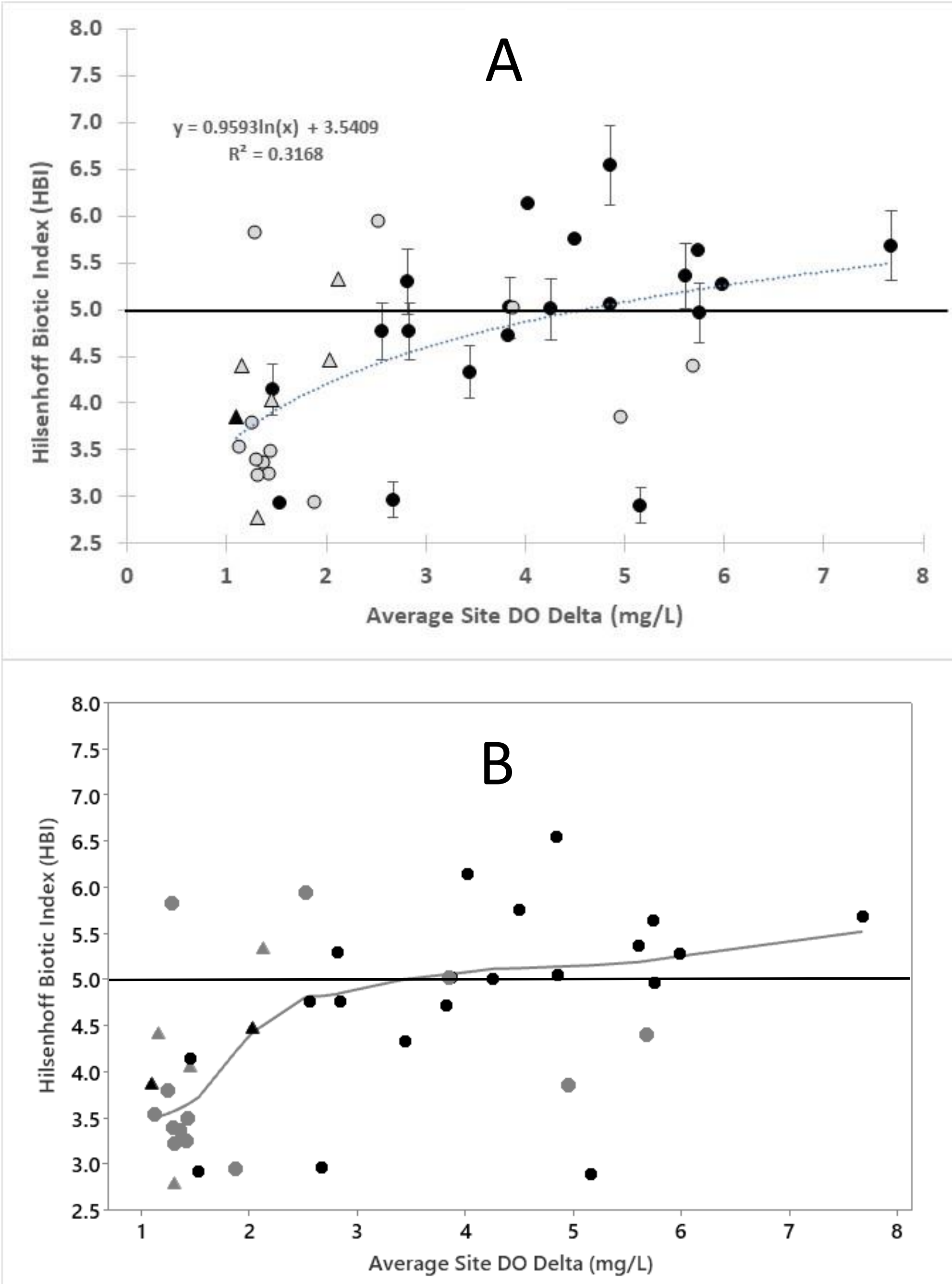


Figure 3-2B. Scatterplots of HBI vs. Average Site DO Δ. Black symbols are sites from Part I-A, gray symbols are 2023 field season sites. Triangles are low-gradient reference sites. Horizontal lines show the threshold identified per Hilsenhoff (1987). See text for explanation of error bars. Panel A. Parametric, logarithmic regression line and associated line equation. Panel B. Non-parametric LOWESS line.

Based on the best-fit logarithmic equation in panel A of **Figure 3-1B**, a Beck's threshold of 18.68 corresponds to a DO Δ value of 2.36 mg DO/L. Similarly, the same scatterplot but based on the LOWESS line (panel B of **Figure 3-1B**) equates to a DO Δ of approximately 2.4 mg DO/L. For HBI, the parametric line equation (panel A **Figure 3-2B**) equals a DO Δ of 4.58 mg DO/L while the LOWESS line in panel B of **Figure 3-2B** equals approximately 3.4 mg DO/L.

The two relationships in **Figures 3-1B** and **3-2B** were then re-examined without the "error bar" sites (i.e., sites where continuous DO and macroinvertebrate data were not temporally co-collected) and these are presented in **Figures 3-3B** and **3-4B**. Based on the reduced dataset (n=26 sites), Beck's and HBI were still significantly and strongly correlated to DO Δ (Spearman's rho = -0.689, p <0.000, and Spearman's rho = 0.506, p = 0.008, respectively). Using the same Y-axis thresholds earlier applied to each relationship, the corresponding DO Δ values are 2.6 mg DO/L (Beck's) and 4.2 mg DO/L (HBI).

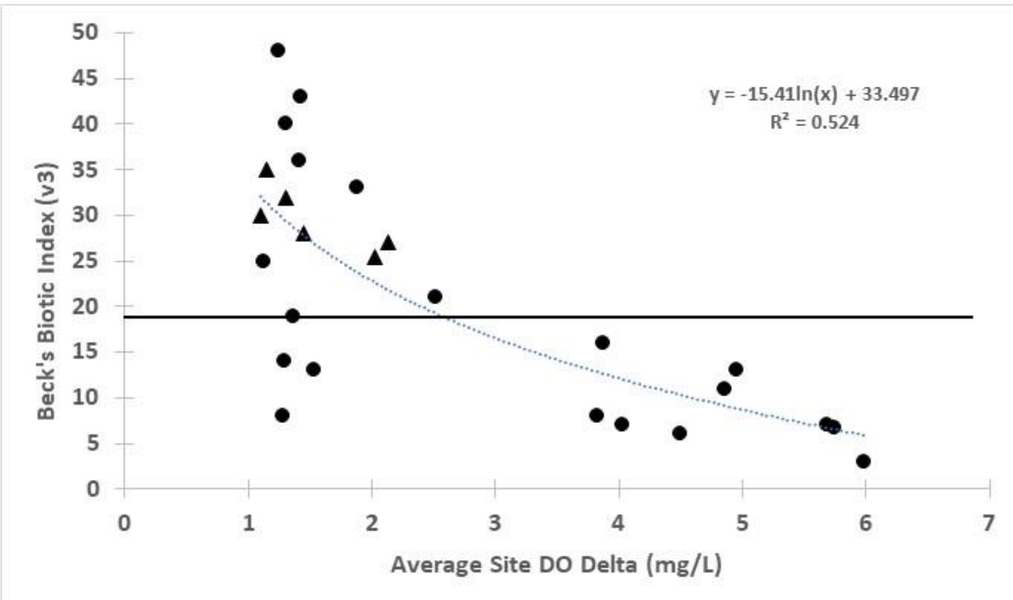


Figure 3-3B. Scatterplot of Beck's Biotic Index (v3) vs. Average Site DO Δ for a Reduced Dataset Comprising 26 Sites (see text for details). Triangles are low-gradient reference sites. The horizontal line is the threshold identified for this biotic index in Schulte and Craine (2023).

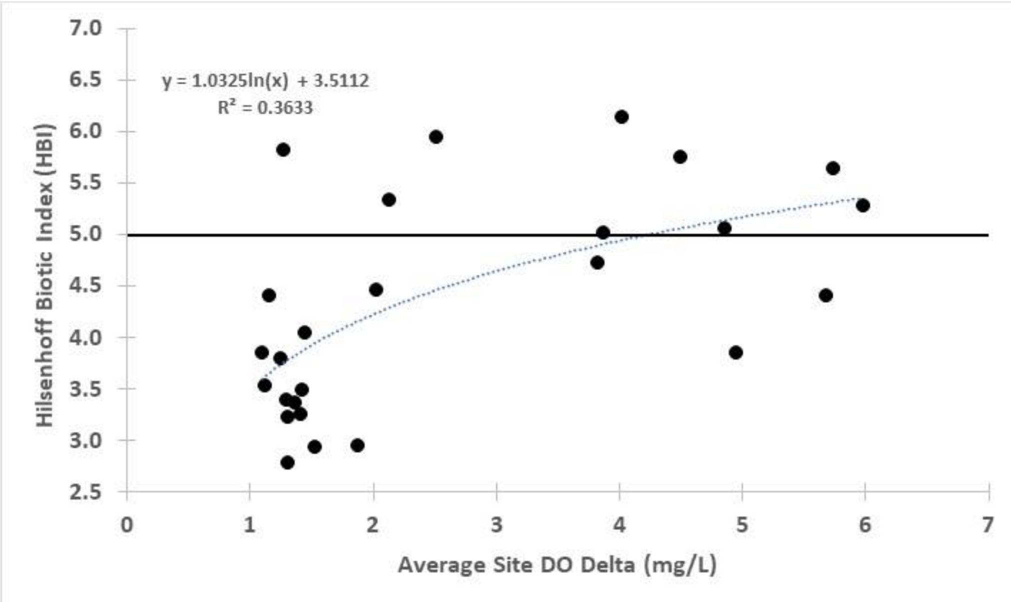


Figure 3-4B. Scatterplot of HBI vs. Average Site DO Δ for a Reduced Dataset Comprising 26 Sites (see text for details). Triangles are low-gradient reference sites. The horizontal line is the threshold identified for this biotic index per Hilsenhoff (1987).

4.0 DISCUSSION

Combining the 2023 dataset with the initial investigation dataset from **Part 1-A** resulted in robust relationships between biotic indices (Beck's, HBI) and DO Δ. These biotic indices were designed by the biologist who made them to respond to organic pollution (Beck, 1955; Hilsenhoff, 1987; Barbour et al., 1999) and their responsiveness here is consistent with this purpose. Hilsenhoff (1987) ties his metric directly to stream water quality, reporting that as HBI values move beyond about 5 there is a shift from some stream organic pollution to fairly significant organic pollution.

After a detailed analysis of the relationship between total nitrogen and total phosphorus concentrations and macroinvertebrate metrics for a 17-year Montana dataset, Schulte and Craine (2023) identified version 3 of Beck's Biotic Index (Beck's) as the representative metric for the low valleys and transitional zone of western Montana. These authors also identified Beck's as the best representative metric for the steeper, mountainous regions of western Montana (although with a different protection threshold than the low valleys and transitional zone). Beck's was found to be strongly correlated with DO Δ in the initial investigation of the present study (**Part 1-A**), and the addition of 19 sites from 2023—five of them reference sites—only further strengthened these findings (**Figures 3-1B**, **3-3B**). Similarly, the well-recognized HBI (Davis and Simon, 1994) correlated well with DO Δ in the initial investigation (**Part IA**), the complete dataset, and the reduced dataset (**Figures 3-2B**, **3-4B**).

By tying the threshold for Beck's (18.68) from Schulte and Craine (2023) and the HBI threshold of 5.0 from Hilsenhoff (1987) back to DO Δ patterns in low gradient western Montana streams and medium rivers, it was possible to identify a protective DO Δ threshold range from 2.36 to 4.58 mg DO/L. The Y-axis threshold method used here in **Part IB** is independent from the change-point analysis method in **Part 1-A**, yet the change-points produced an average DO Δ threshold (3.1 mg DO/L) that falls very centrally in the 2.36 to 4.58 mg DO/L range. In Minnesota, Heiskary and Bouchard (2015) analyzed 14 biological metrics (fish and macroinvertebrates) and, using change point and other methods, identify similar DO Δ thresholds for aquatic life protection. In flowing waters of geographic regions (level III ecoregions Northern Lakes and Forests, North Central Hardwood Forests, and Driftless Area; EPA 2006) which are the closest physiographic analogs to the current investigation, Heiskary and Bouchard (2015) recommend DO Δ values from 3.0 to 3.5 mg/L. Minnesota has adopted these DO Δ thresholds into their administrative rules (MAR 7050.0222(2)) for purposes of protecting aquatic life.

Considering together the work of Hilsenhoff (1987), Heiskary and Bouchard (2015) and Suplee et al. (2019) (discussed in the **General Introduction**), and Schulte and Craine (2023), a coherent ecological pattern emerges. Elevated nutrient concentrations result in excessive floral biomass that leads to high diel changes in oxygen concentration which can then cause nightly or seasonal/episodic crashes in DO; these changes in DO patterns impact aquatic life. A simple conceptual model of this is shown in **Figure 4-1B**. As demonstrated in the present study and by Schulte and Craine (2023), in low-gradient western Montana streams DO Δ correlates more strongly with macroinvertebrates (R^2 = 0.591, Beck's) than with nutrient concentrations (R^2 = 0.26, Beck's); this is because DO Δ is the proximate stressor (as are low DO and food resource changes), whereas excess nitrogen and phosphorus are the ultimate stressors.

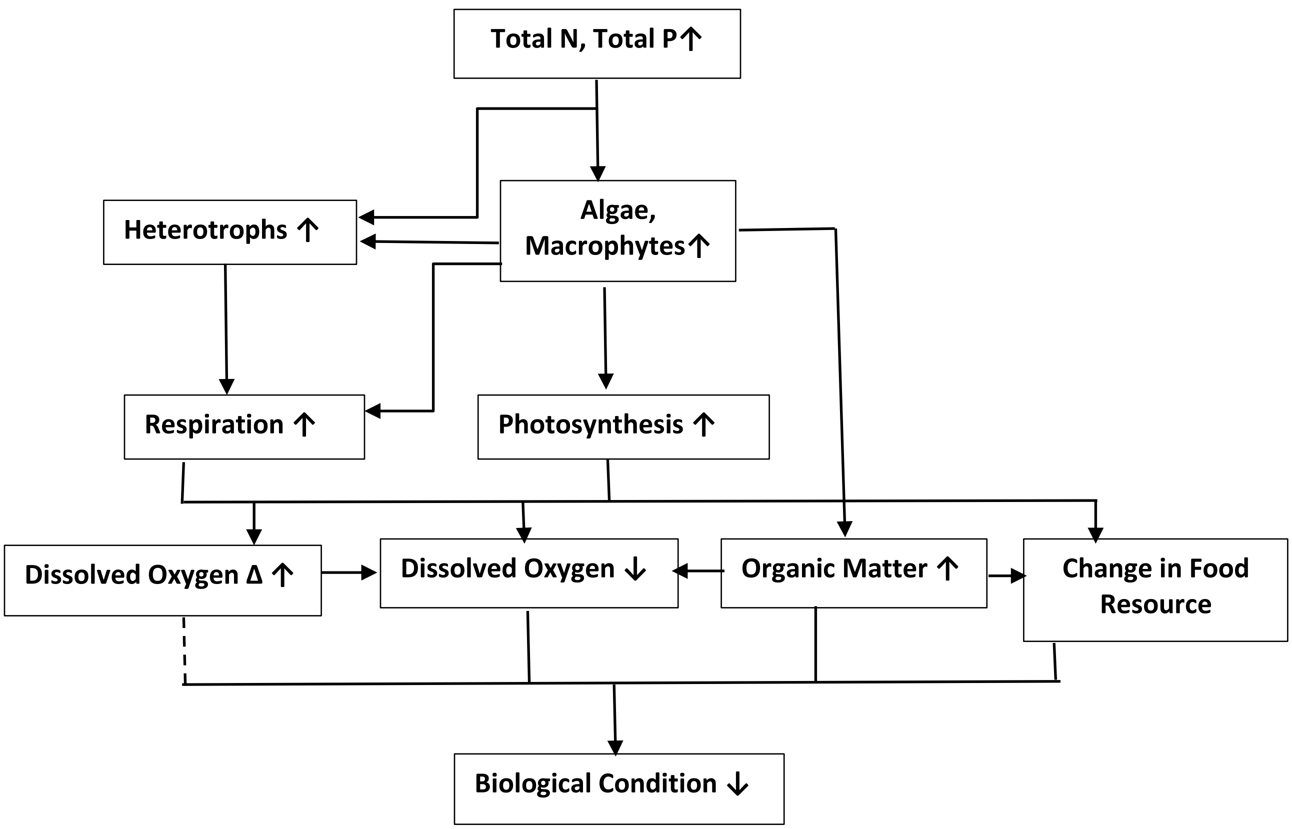


Figure 4-1B. Simplified Conceptual Model of the Impacts of Nutrient Enrichment on Stream and Medium River Biological Condition. Modified from Heiskary and Bouchard (2015).

5.0 Conclusion and Recommendations

It can be concluded from the totality of work presented in **Part I** of this report that excessive DO Δ is linked to undesirable changes in aquatic life in low-gradient western Montana streams and medium rivers. As the objective of the work was to identify a DO Δ threshold protective of aquatic life in low gradient streams and medium rivers of western Montana, **Table 5-1B** provides a summary of candidate DO Δ thresholds for that purpose.

Table 5-1B. Compilation of Identified DO Δ thresholds Protective of Stream Aquatic Life

Source	DO Δ Threshold Derivation Method	DO Δ Range or Value (mg DO/L)
Miltner (2010)	Linkage between high DO Δ and co-occurrence of low DO concentrations falling below Ohio's minimum standard of 4 mg DO/L	<6.0
Heiskary and Bouchard (2015)	Correlation between DO Δ and undesirable changes in Minnesota fish and macroinvertebrate taxa	3.0 to 3.5
Part I-A, Initial Investigation, Present Study	Change-point analysis on seven macroinvertebrate metrics correlated with DO Δ	1.5 to 3.9
Part I-A, Initial Investigation, Present Study	Average of the seven change-point analyses	3.1
Part I-B, Full Dataset, Present Study	DO Δ thresholds identified via statistically modeled line relationships and using Beck's and HBI thresholds from other sources	2.36 to 4.58
Part I-B, Full Dataset, Present Study	Average of DO Δ thresholds identified via statistically modeled line relationships and using Beck's and HBI thresholds from other sources	3.2
Part I-B, Reduced Dataset, Present Study	DO Δ thresholds identified via statistically modeled line relationships and using Beck's and HBI thresholds from other sources	2.6 to 4.2
Part I-B, Reduced Dataset, Present Study	Average of DO Δ thresholds identified via statistically modeled line relationships and using Beck's and HBI thresholds from other sources	3.4

Collectively, the data in **Table 5-1B** suggest a DO Δ value bracketing 3.0 is appropriate. Giving particular consideration to the present work and that of Heiskary and Bouchard (2015), a DO Δ thresholds of **3.0 mg/L** is recommended and should be protective of aquatic life in low-gradient western Montana streams and medium rivers.

6.0 Acknowledgements

Thanks to the Rein Anchor Ranch who granted DEQ access permission to carry out stream sampling on ranch property. A big thanks to Rosie Sada, Brady Grigsby, Nate Gong (all from DEQ), and Guy Mitchell (University of Montana) for help in completing sampling during the challenging 2023 field season.

PART II EASTERN MONTANA

Part II of this document presents work pertaining to streams and medium rivers in the eastern part of the state. The overarching purpose of **Part II** is to update a dissolved oxygen delta (DO Δ) threshold protective of aquatic life in the low gradient streams and medium rivers of eastern Montana. DEQ has for many years been using a DO Δ threshold of 5.3 mg/L as part of its plains streams 303(d) list assessments. However, the threshold was developed from a relatively small dataset and much additional work was carried out in the 2010s and 2020s to further refine the DO Δ threshold and to understand the environmental factors influencing it. **Part II** of this report documents the entire body of work leading to DEQ's updated threshold recommendation for eastern Montana streams and medium rivers.

1.0 PROBLEM DEFINITION, BACKGROUND INFORMATION, PROJECT OBJECTIVES

Ecoregions (Woods et al., 2002) comprising the eastern Montana region addressed here in **Part II** of this report are shown in **Table 1-1**.

Table 1-1. Ecoregions Comprising the Region Under Investigation in Part II of this Report

Ecoregions (Whole number prefix: Level III. Number-letter prefix: Level IV)
18. Wyoming Basin
42. Northwestern Glaciated Plains (excluding level IV ecoregions listed below)
42l. Sweetgrass Uplands
42n. Milk River Pothole Upland
42q. Rocky Mountain Front Foothill Potholes
42r. Foothill Grassland
43. Northwestern Great Plains (excluding level IV ecoregions listed below)
43s. Non-calcareous Foothill Grassland
43t. Shield-Smith Valleys
43u. Limy Foothill Grassland
43v. Pryor-Bighorn Foothills
43o. Unglaciated Montana High Plains

As noted in **Part I** of this report, changes in Montana law[12] necessitated the development of a structured translation process to interpret the state's narrative water quality standards applicable to nitrogen and phosphorus concentrations (ARM 17.30. 637(1)(e)). DEQ proposed in draft **Circular DEQ-15** that this translation process include, among other parameters, the response variable DO Δ.

[12] 75-5-321, MCA

From 2009 to 2011 DEQ carried out a whole-stream nutrient addition study in a reference condition prairie stream (Suplee et al., 2016; Suplee et al., 2019). At the time, the eastern region of the state was less well studied than the western region and DEQ wanted to better understand the behavior of the region's waterbodies when subjected to elevated nutrient concentrations. The study showed that low concentrations of inorganic nitrogen and phosphorus added to the stream led to large increases in benthic algal biomass in summer which, in turn, resulted in large and significant increases in stream DO Δ; when fall arrived, the algae senesced *en masse* and DO concentrations dropped to ~1 mg/L along the reach receiving the highest nutrient dose.

Later, following up on the nutrient-addition study, DEQ identified a DO Δ threshold of 5.3 mg/L based on change-point analysis (Qian et al. 2003, King and Richardson 2003) using the continuous DO datasets collected as part of the dosing study plus other continuous DO datasets from nearby plains streams. DEQ assigned a eutrophication rating to each reach or site using methods described in Section 2.6 of **Part I** of this report, and carried out change-point analysis on the relationship which is shown in **Figure 1-1**. As can be seen, once eutrophication intensity rises to medium to high (ratings 3 to 4), there is a sharp rise in DO Δ.

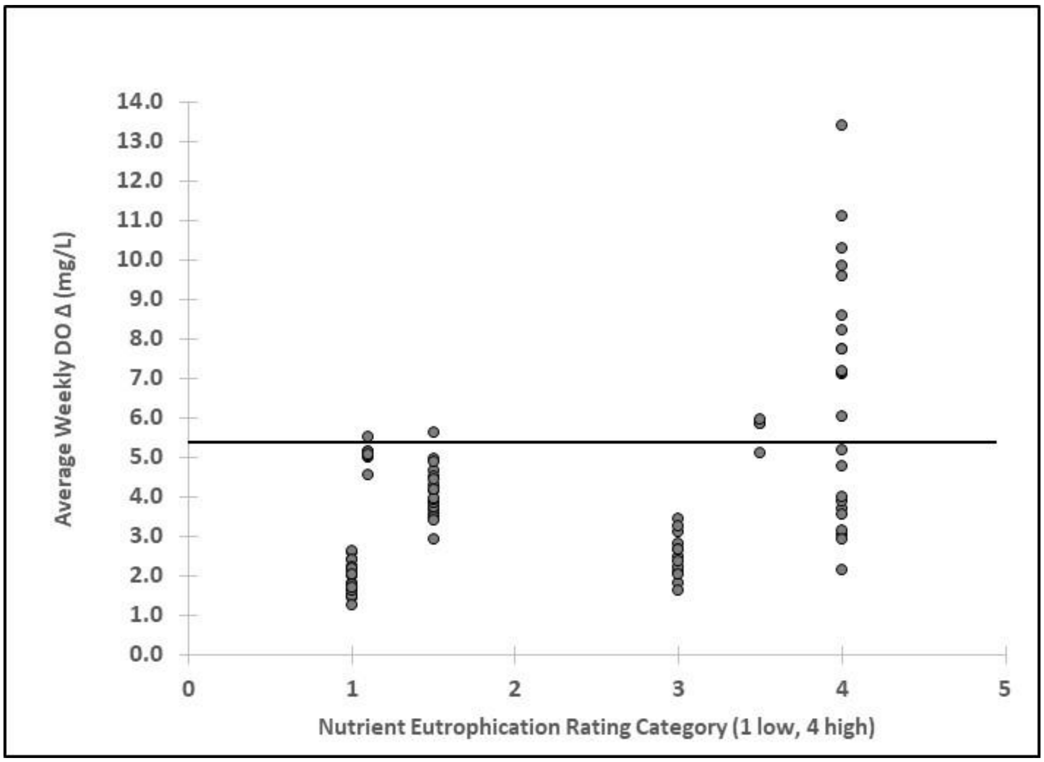


Figure 1-1. Dataset used by DEQ to Undertake Change-point Analysis. A rating of 1 (low eutrophication) was assigned, for example, to the control reach, 3.5 was assigned to the low-dose reach, and 4 to the high-dose reach; see Suplee et al. (2019) for details on each reach. The black horizontal line is the change-point of 5.3 mg/L identified from the relationship.

The 5.3 mg/L DO Δ threshold identified was based to a high degree on the stream (Box Elder Creek) where the controlled nutrient-addition study in Suplee et al. (2019) took place. But DEQ wanted to know more about DO Δ patterns across a wider range of plains streams. Therefore, from 2013 to 2017, DEQ sampled 73 unique plains stream sites, many of which were sampled over multiple years of the five-year study. The complete analytical work carried out on the dataset is documented in GLEC (2021) and germane aspects of the report are detailed here. Finally, in 2021 and 2022, DEQ targeted a number of plains reference sites and collected continuous DO datasets which had not previously been acquired. Collectively, all these studies and data inform the final DO Δ recommendations at the conclusion of **Part II** of this report.

2.0 DO Δ and Environmental Variables in Plains Streams

GLEC (2021) used Classification and Regression Trees (CART) to explore the relationships of watershed stressors and mitigators to a response. The monitoring dataset—collected between 2013 and 2017—was comprised of continuous DO, water chemistry, and aquatic plant metrics for 73 stations located in eastern Montana extending from the north at tributaries to the Missouri River to the south at the Wyoming state border (**Figure 2-1**).

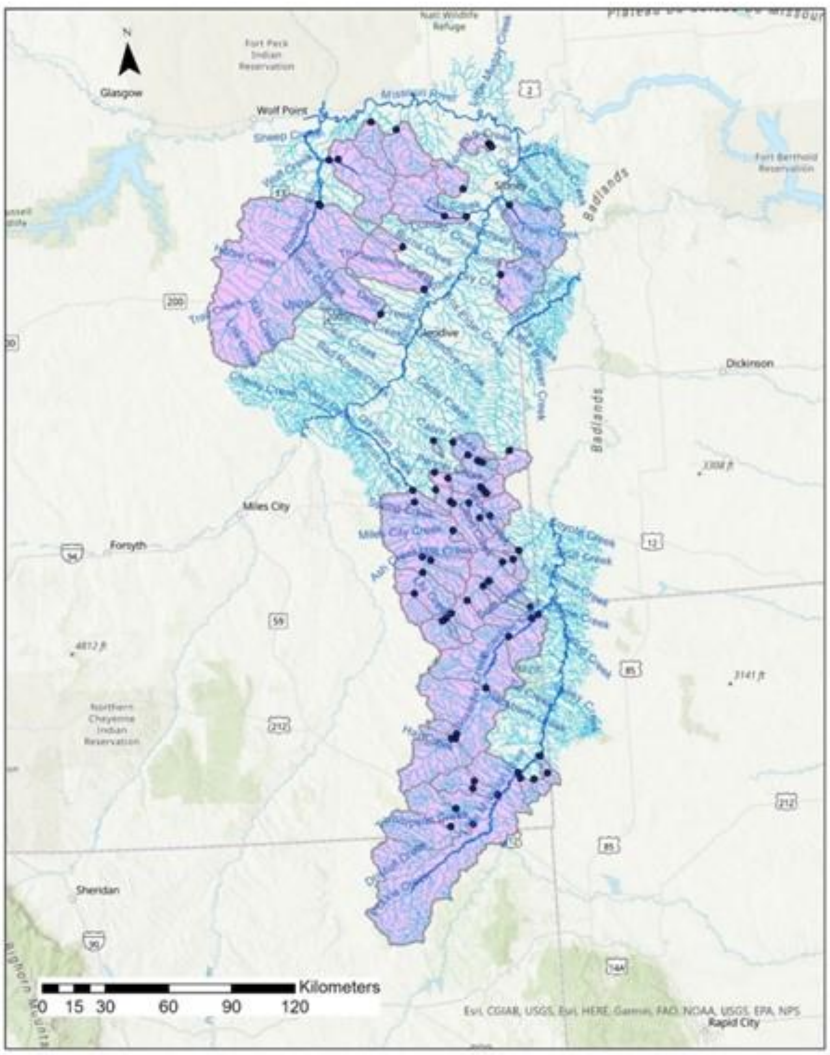


Figure 2-1. Stream Sampling Stations (Black Dots) and their Corresponding Watersheds (in Pink) in the 2013-2017 Study. Major stream segments in each basin are labeled.

The datasets comprise three model categories – predictor variables, pure response variables that are affected by stressors or mitigators, and those that may serve a dual role and behave either as predictor or response variables. Several regression tree models were built and interpreted, for example responses of mean DO Δ, maximum DO Δ, and count/week of days exceeding the DO Δ threshold of 5.3 mg/L (5.3 being based on DEQ's earlier work as described in **Section 1.0**). In each tree, the splits that occur first are for predictor variables that explain the largest amount of variation in the data. Helsel (2019) suggests regression trees as a modern approach to examining relationships in water quality and notes that regression trees are non-parametric and not significantly impacted by outliers. He expounds on the advantages of using regression tree methods, namely:

1. they make use of a machine learning tool to classify data into groups by relating the target variable to cutoffs of explanatory variables;
2. the method is flexible because there are no assumptions of linearity or normality;
3. data at the 'high end' do not affect relationships at the 'low end'; thus, they are not as restricted as are traditional regression methods;
4. evaluation of success is done by cross-validation – the percent of correct predictions of categories for the response variables – rather than by p-values; and
5. predictions are made for individual observations rather than the mean of observations (as done in regression).

Overall, the CART analyses in GLEC (2021) showed that low levels of watershed disturbance and the absence of prolonged drought conditions were the most consistent predictors for optimal stream DO conditions, expressed as either DO Δ or as a DO minimum. Other predictors like conductivity, nutrient concentrations, drainage area, and water temperature were also important. Summary measures of DO (average per week) were found to be the most stable.

2.1 Effect of Drought on DO Δ

The CART model for weekly mean DO Δ is presented in **Figure 2-2**. **Figure 2-2** shows, at the first split, that weekly mean DO Δ is inherently lower (3.28 mg/L) in watersheds with low (<16.3%) land use disturbance[13] compared to watersheds where managed lands dominate; in the latter, DO Δ averages 6.59 mg/L. Managed land use classes include Pasture/Hay, Cultivated Crops, and Introduced Upland Vegetation – Annual and Biennial Forbland. Streams in watersheds with low land disturbance (the left-hand branch) show a range of DO Δ from 2.74 to 6.19 mg/L depending on site specific conductivity (but note that the split occurs at a relatively high specific conductance of 3,923 µS/cm). Under the managed lands (right-hand) branch, the next split in the tree is the number of consecutive weeks at low intensity drought (D_{ZERO} are abnormally dry conditions as indicated by the U.S. Drought Monitor Index[14]; see

[13] Low-disturbance land use classes consisted of individual classes such as the Great Plains Badlands, Great Plains Ponderosa Pine Woodland and Savanna, and Great Plains Wooded Draw and Ravine. All were derived from the Natural Heritage Program for Montana (NHP) and the National Land Cover Dataset (NLCD) of the US Geological Survey. Both datasets were time stamped 2015-2016.

[14] GLEC (2021) examined a number of different drought indices, and several proved to be important predictors of DO. The U.S. Drought Monitor Index compiles results from several drought indices into a single drought metric and was an important factor affecting mean weekly DO Δ; we recommend its use.

https://droughtmonitor.unl.edu and **Figure 2-3**). GLEC (2021) observes that a given region does not experience a higher intensity drought (e.g., D_{THREE} -D_{FOUR}) until some duration of lower intensity drought (D_{ZERO} -D_{ONE}) exists. When weather conditions are wetter (D_{ZERO} ≤6 weeks), plains streams located in watersheds dominated by managed lands will have an average DO Δ of 5.31 mg/L (**Figure 2-2**). But if low intensity drought conditions persist for greater than six weeks, stream DO Δ will increase due to drought alone—to an average of 8.47 mg/L if no further environmental factors in the tree are considered.

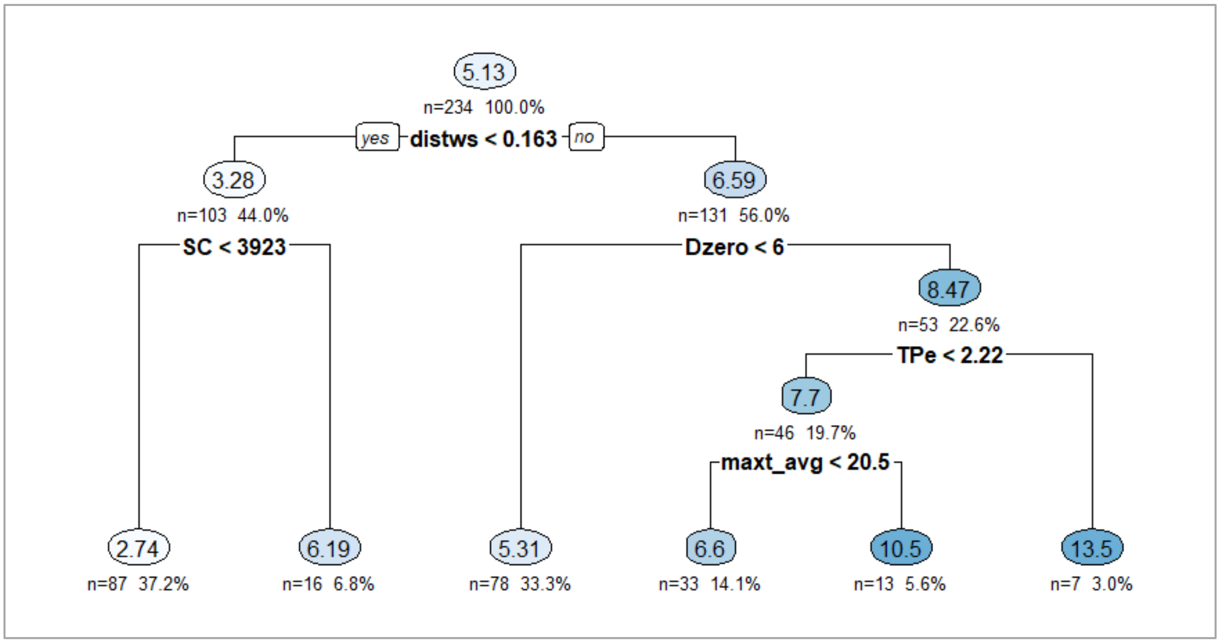


Figure 2-2. Regression Tree for Average Weekly DO Δ (mg/L). The predicted value and the number and percentage of total observations are shown for each node. The decision statement to split is located under each node (in bold) – traverse left if the statement is true (yes), otherwise traverse right (no). Branching to the left of "Dzero ≤ 6" represents wetter conditions (i.e., fewer weeks of Dzero drought, whereas its corollary (Dzero > 6) to the right reflects drier conditions. From Figure 4.1 in GLEC (2021).

			Ranges				
Category	Description	Possible Impacts	Palmer Drought Severity Index (PDSI)	CPC Soil Moisture Model (Percentiles)	USGS Weekly Streamflow (Percentiles)	Standardized Precipitation Index (SPI)	Objective Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	Going into drought: ■ short-term dryness slowing planting, growth of crops or pastures Coming out of drought: ■ some lingering water deficits ■ pastures or crops not fully recovered	-1.0 to -1.9	21 to 30	21 to 30	-0.5 to -0.7	21 to 30
D1	Moderate Drought	■ Some damage to crops, pastures ■ Streams, reservoirs, or wells low, some water shortages developing or imminent ■ Voluntary water-use restrictions requested	-2.0 to -2.9	11 to 20	11 to 20	-0.8 to -1.2	11 to 20
D2	Severe Drought	■ Crop or pasture losses likely ■ Water shortages common ■ Water restrictions imposed	-3.0 to -3.9	6 to 10	6 to 10	-1.3 to -1.5	6 to 10
D3	Extreme Drought	■ Major crop/pasture losses ■ Widespread water shortages or restrictions	-4.0 to -4.9	3 to 5	3 to 5	-1.6 to -1.9	3 to 5
D4	Exceptional Drought	■ Exceptional and widespread crop/pasture losses ■ Shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0 to 2	0 to 2	-2.0 or less	0 to 2

Figure 2-3. The U.S. Drought Monitor Index.

Reference streams (per Suplee et al., 2005) are affected by drought as well. **Figure 2-4** illustrates the effect of drought on a DEQ plains reference stream from the same study. Over the 2013-2017 period, both drought (>6 weeks at D_{ZERO}) and non-drought (≤6 weeks at D_{ZERO}) periods occurred. The site's land ownership and management was unchanged over this time, therefore changes observed in DO Δ are due to drought—which induces reduced water volume, warmer water temperatures, and more flora per unit water volume.

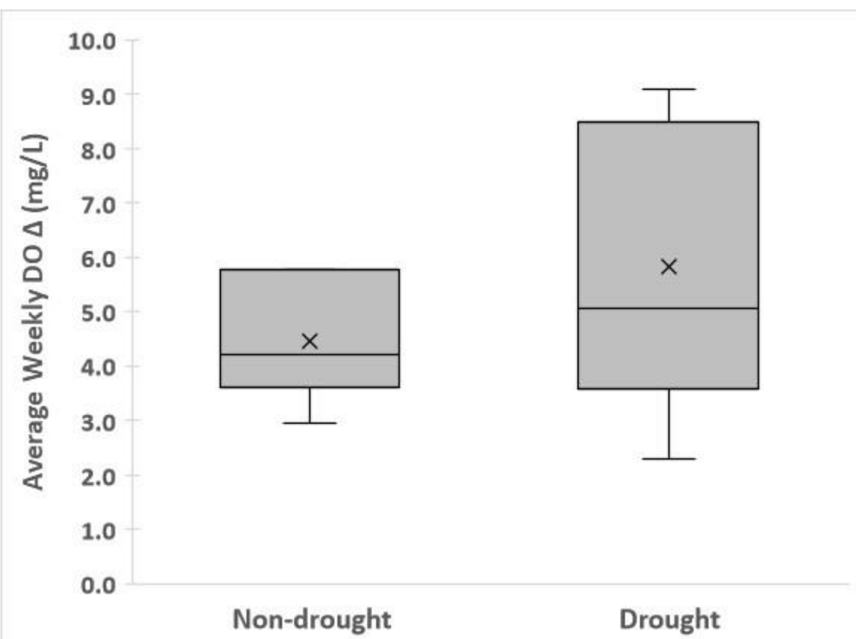


Figure 2-4. Changes in Weekly Average DO Δ During Non-drought and Drought Periods at a Plains Reference Stream. Data were collected over the 2013-2017 period. Drought here is defined as >6 weeks at D_{ZERO} of the U.S. Drought Monitor Index.

2.2 Analysis of Exceedance Frequency in Relation to the 5.3 mg/L DO Δ Threshold

The DO Δ exceedance-rate model from GLEC (2021) is shown in **Figure 2-5.** This model evaluated exceedance frequency of the 5.3 mg/L DO Δ threshold DEQ has used for plains streams assessments. This model counts the number of days per week the threshold is exceeded—and so suggests the number of days the aquatic system is stressed by high DO Δ. Note again that watershed disturbance (splitting at 33% land area in this case) plays a primary role, with fewer exceedances of the 5.3 mg/L threshold in watersheds with a lower % of managed lands (1.61 exceedances/week, on average). Following to the far right-hand branch, note that nearly every day of the week experiences an exceedance (6.84 days on average) when managed land cover in the watershed exceeds 33% of total area and drought is severe. (Note: in this model an alternate drought index was identified. Values of the Palmer Meteorological Drought Index, or PMDI, less than -4.8 are considered extreme drought.) Exceedances are less frequent when drought is less severe in managed watersheds, ranging from 1.87 to 4.22/week (see middle part of **Figure 2-5**). Over on the left-hand branch, where managed land area is <33%, the minimal presence of aquatic vascular plants, i.e., macrophytes (0,1 – the two lowest areal coverage categories) results in the lowest number of exceedances of the 5.3 mg/L threshold in the entire tree (1.3/week), whereas higher macrophyte higher densities nearly doubles this frequency (2.39/week). This finding is consistent with the observation that macrophyte photosynthesis contributes to DO supersaturation and (therefore) more exceedances of the threshold.

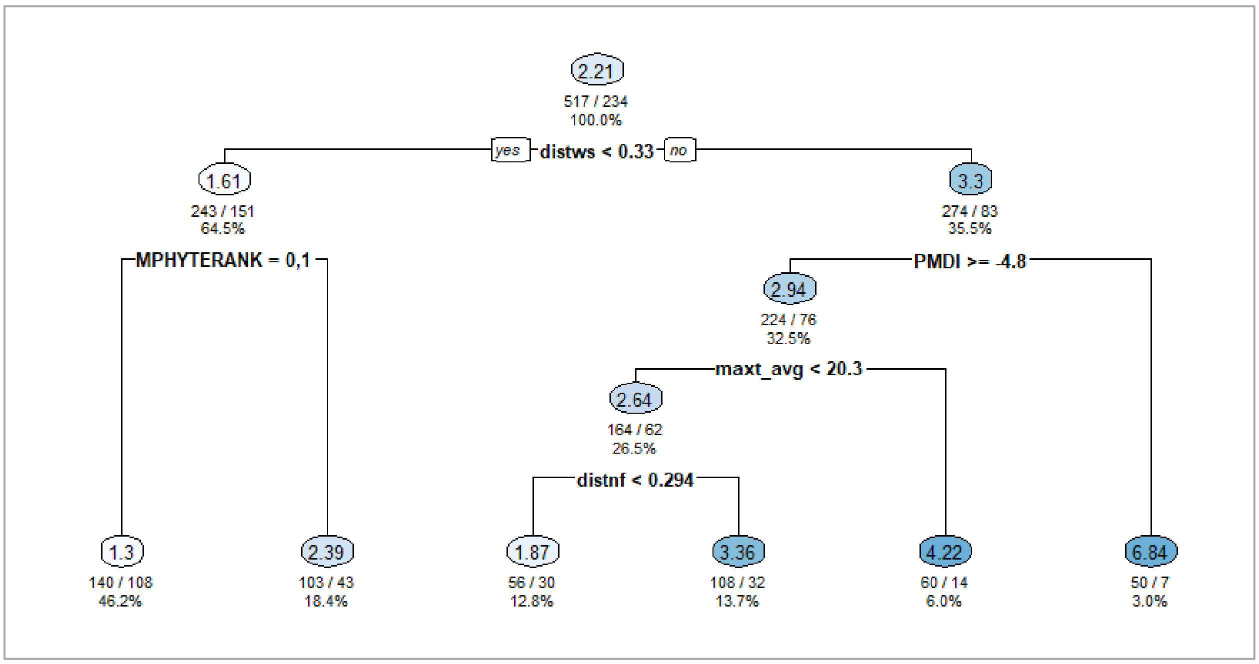


Figure 2-5. Regression Tree for the Number of Exceedances (Days) per Week of DEQ's Earlier DO Δ Threshold of 5.3 mg/L. Shown for each node is the predicted value, then a pair separated by "/" listing the total number of events (1 event = 1 day of exceedance) and the number of observations, and the percentage of total observations. The decision statement to split is located under each node (in bold) – traverse left if the statement is true (yes), otherwise traverse right (no). ***From*** **Figure 4.16 in GLEC (2021).**

The conclusion that can be drawn from **Figure 2-5** is that even plains streams in undisturbed watersheds during non-drought will exceed DEQ's 5.3 mg/L DO Δ threshold once or twice a week (recall that computation of DO Δ results in a single DO Δ value per day). In managed watersheds exceedance is higher, around 3 exceedances per week.

2.3 Relationship between DO Δ and DO Minimum in Eastern Montana Streams

Montana has minimum DO standards for surface waterbodies which are found in DEQ-7 (DEQ, 2019) and these apply to the plains regions as well. Based on the same 2013-2017 dataset discussed above, the relationship between average weekly DO Δ and average weekly DO minimum during non-drought is shown in **Figure 2-6**[15]. This significant relationship (Spearman's rho = -0.521, $p < 0.000$) is presented with its 90% confidence band. Streams in the 2013-2017 study are mostly classified C-3 but one is classified B-2. C-3 streams have a 7-day mean minimum DO of 4.0 mg/L, while for B-2 streams it is 5.0 mg/L (DEQ, 2019); these minimum DO requirements protect aquatic life from low DO and are shown as a gray horizontal band in the figure. The modeled relationship shows that if a minimum of 5 mg/L is to be maintained, weekly average DO Δ should be held to about 6 mg/L. In Ohio, Milter (2010) identified the same basic relationship and it is reproduced below in **Figure 2-7**. Based on his work, Milter (2010) recommends DO Δ of 6.0 mg/L or less.

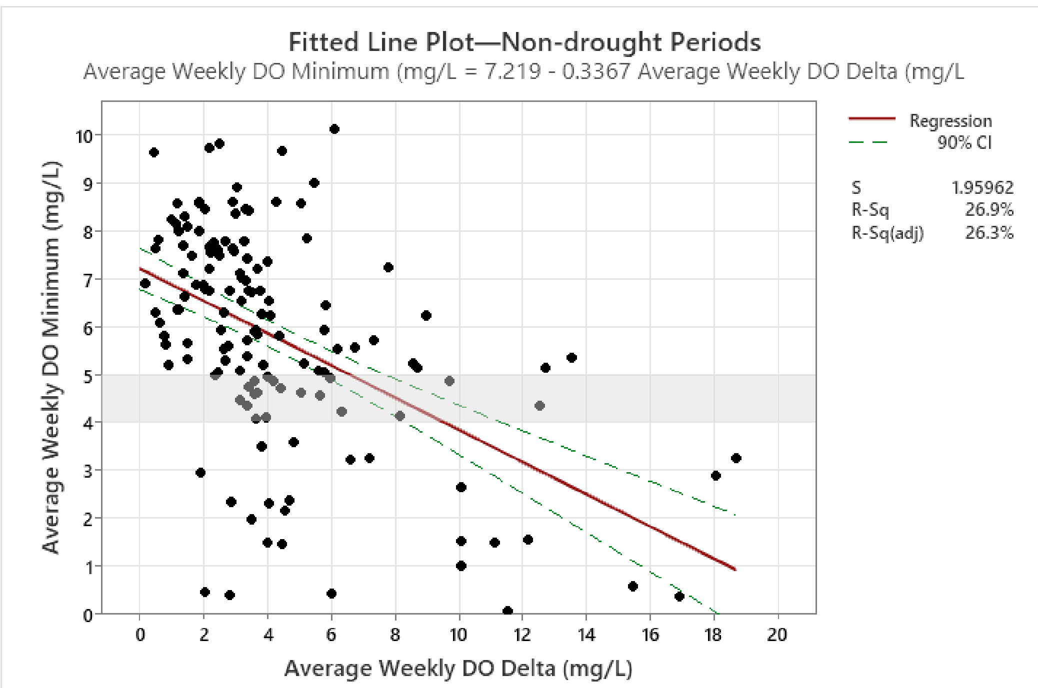


Figure 2-6. Relationship between DO Δ and DO Minimum in Montana Plains Streams. Data are from the 2013-2017 period.

[15] Five datapoints clustered very close to the origin (0,0) were excluded as they were most likely instrument error.

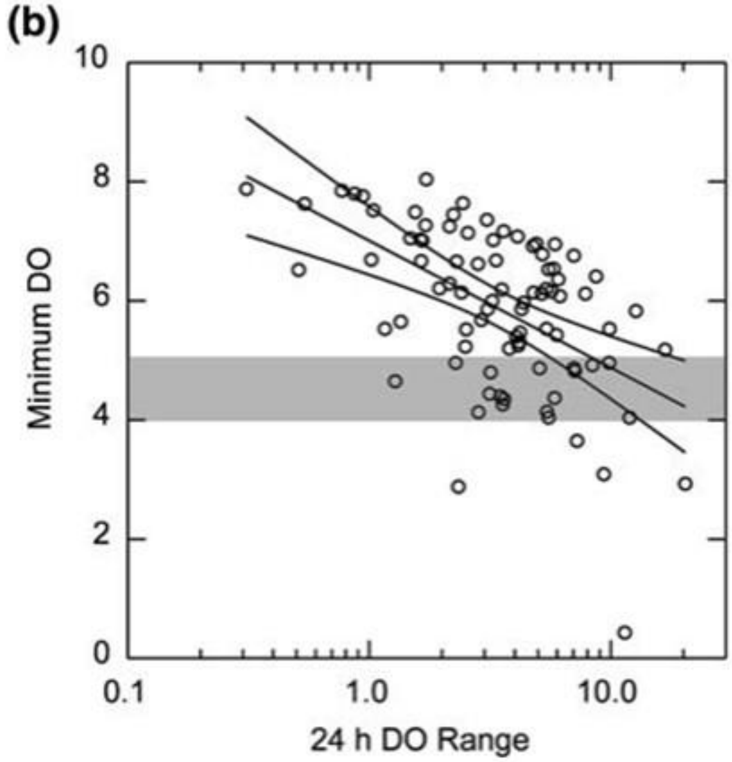


Figure 2-7. Relationship between DO Δ and DO Minimum in Ohio Streams. From Figure 3b in Milter (2010).

2.4 Additional Exceedance Frequency Analysis using 2013-2017 and 2021/2022 Reference Stream Data

2.4.1 Reference Sites During Drought

The effect of drought on streams in minimally disturbed eastern Montana streams was further analyzed using continuous DO datasets collected by DEQ from 14 regional reference streams in 2021 and 2022. All 14 reference sites were experiencing drought (>6 weeks at D_{ZERO}) when the DO instruments were deployed. Although all 14 sites had been reviewed and met reference site criteria per Suplee et al. (2005), an additional criterion of <16.3% managed lands was applied here to better synchronize this analysis with that of GLEC (2021); see also **Figure 2-2**. The extra screening criterion retained ten "best of" plains reference sites. These included ''Rock Creek below Horse Creek, Near Int. Boundary'' which is a USGS Hydrologic Benchmark Network (HBN) site located on the U.S.-Canadian border in the Northwestern Glaciated Plains ecoregion. Much of Rock Creek's watershed upstream of the site is contained within the Grasslands National Park of Canada and only about 7% is used for crop agriculture (U.S. and Canada combined). Also included was the reference site ''Bitter Creek'' (same ecoregion) which has as its immediate upstream drainage a land area that has been described by the Montana Natural Heritage Program as the largest intact grassland in northern Montana, and one of the most extensive naturally functioning glaciated plains grasslands in North America (Cooper et al., 2001).

Among the ten "best of" plains reference sites, during drought, four could meet a DO Δ threshold of 6.0 mg/L all the time. However, the other six (including Bitter Creek) could not meet the threshold within any reasonable exceedance frequency (exceedance frequencies ranged from 24 to 100%). Based on these findings, it can reasonably be concluded that a DO Δ threshold is best applied to all plains streams during drought, not just to those in managed lands >16.3% per findings in GLEC (2021). Otherwise, there is a risk of applying an overly stringent standard, resulting in determinations of standards non-achievement for otherwise healthy waterbodies that were simply experiencing drought-induced effects.

2.4.2 Reference and Comparison Sites During Non-Drought

For the 2013-2017 study, GLEC (2020; 2021) applied a screening process to identify sites with minimal local and watershed-scale disturbance. The process was analogous to the process DEQ uses to identify reference sites. DEQ further screened these sites using best professional judgement to ensure they were consistent with reference-site screening criteria. This resulted in 24 sites referred to here as comparison sites; these were combined with four DEQ plains reference sites sampled over the same period. Weekly average DO Δs for the 28 comparison plus reference sites during non-drought were compiled and the DO Δ exceedance frequency of this dataset was examined. The analysis showed that the sites could achieve a DO Δ threshold of 6.0 mg/L 87% of the time. Based on this, DEQ recommends a 15% allowable exceedance rate to accompany the 6.0 mg/L DO Δ threshold.

3.0 CONCLUSIONS, RECOMMENDATIONS

DEQ's five-year study of DO patterns in eastern Montana plains streams showed that DO Δ is significantly related to DO minimum (**Figure 2-6**) and this relationship provided a means to identify a DO Δ threshold protective of the region's aquatic life. The data indicate that a DO Δ threshold of 6 mg/L (expressed as a weekly average) would be protective of the B-2, B-3, and C-3 streams of the region as it will ensure that weekly DO minima standards (per **Circular DEQ-7**) are attained. Miltner (2010) comes to the same conclusion for Ohio low gradient streams. He states that, "A daily DO range >6.0 mg/l carries a significant risk of minimum concentrations falling below the established water quality standard of 4.0 mg/l (Fig. 4). Conversely, ranges <6.0 mg/l tend to maintain minima >5.0 mg/l (the water quality standard for average daily minimum DO) and, therefore, should be protective of aquatic life based on both water quality standards, and the change points for macroinvertebrate indicators identified in this study…."

As found in numerous Ohio-based watershed assessment documents, a primary determinant of the presence of deformities, lesions, and tumors in sampled fish was the frequency of high DO Δs – higher organisms are stressed by continuous adaptation to changing DO conditions (GLEC, 2021). Thus, it is important to ensure the DO Δ threshold is not exceeded too often but, also, it is important to ensure that otherwise healthy streams are not judged to be impaired when they are not. Based on analyses presented here, DEQ recommends a 15% allowable exceedance frequency accompany the weekly average DO Δ threshold of 6.0 mg/L.

The DO Δ threshold of 6.0 mg/L is just slightly higher than DEQ's earlier assessment threshold of 5.3 mg/L for the plains but is twice that recommended for low-gradient streams of western Montana (see Section 5.0 in **Part I-B**). But it should be borne in mind that plains streams are very different from their low-gradient western counterparts. For one, macrophytes are a ubiquitous component of plains streams, at least in those that don't experience excessive scouring flows (Suplee, 2004). DO Δ increases due to macrophytes (e.g., **Figure 2-5**, left hand branch) and this fact influences the threshold identified for these steams.

DEQ's 5-year study of DO patterns in Montana plains streams also shows that drought alone can increase DO Δ, even in reference streams (**Section 2.4.1**). DEQ recommends that the 6.0 mg/L DO Δ threshold only be applied during non-drought periods, using the U.S. Drought Monitor Index value of ≤6 weeks at D_{ZERO} as the breakpoint between drought and non-drought periods.

4.0 ACKNOWLEDGEMENTS

Many, many thanks to Rosie Sada (MT DEQ) for making sure the five-year plains streams study was completed; that study formed the basis of most of the conclusions in **Part II** of this report. Thanks to the Carter, Little Beaver, Dawson, and Richland County Conservation Districts who assisted us in completing the five-year plains study. Thanks also to Dale White (Great Lakes Environmental Center, Inc.) for valuable conversations regarding approaches to data analysis for the five-year dataset.

PART I AND PART II REFERENCES (SOME CITATIONS ARE FROM THE APPENDICES)

Bahls, L., Bukantis, R., and S. Tralles. 1992. *Benchmark Biology of Montana Reference Streams*. Helena, MT: Montana Dept. of Environmental Quality.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, 2nd Edition*. EPA 841-B-99-002. Office of Water, Washington, D.C.

Beck, W.M. 1955. Suggested method for reporting biotic data. *Sewage and Industrial Wastes* 27: 1193-1197.

BHWC (Big Hole Watershed Committee). 2012. *Big Hole River, Montana Watershed Restoration Plan Part I: Upper & North Fork Big Hole Watershed*.

Bukantis, R. 1998. *Rapid Bioassessment Macroinvertebrate Protocols: Sampling and Sample Analysis SOPs*. *Draft* 1/12/1998. Helena, MT: Montana Dept. of Environmental Quality.

Cabin, R.J., and R.J. Mitchell. 2000. To Bonferroni or not to Bonferonni: when and how are the questions. *Bulletin of the Ecological Society of America* 81: 246-248.

Conover, W.J. 1999. *Practical Nonparametric Statistics* (3rd edition). New York: John Wiley & Sons.

Cooper, S.V., C. Jean, and P. Hendricks, 2001. Biological Survey of a Prairie Landscape in Montana's Glaciated Plains. Report to the Bureau of Land Management. Montana Natural Heritage Program, Helena, Montana. 24 pp. plus appendices

Decker-Hess, J. 1989. *An Inventory of the Spring Creeks in Montana*. Kalispell, MT; Montana Dept. of Fish, Wildlife, and Parks.

DEQ. 2012. *Sample Collection, Sorting, Taxanomic Identification, and Analysis of Benthic Macroinvertebrate Communities Standard Operating Procedure*. Helena, MT: Montana Dept. of Environmental Quality.

DEQ. 2019. Circular DEQ-7, *Montana Numeric Water Quality Standards*. June 2019 Edition. Helena, MT: Montana Dept. of Environmental Quality.

DEQ. 2021a. *Montana 2020 Final Water Quality Integrated Report*. Helena, MT: Montana Dept. of Environmental Quality.

DEQ. 2021b. *Sample Collection and Laboratory Analysis of Chlorophyll-a Standard Operating Procedure. Version 8.0.* Document No. WQPBWQM-011. Helena, MT: Montana Dept. of Environmental Quality.

DEQ. 2023. Circular DEQ-15, *Translation of Narrative Nutrient Standards and Implementation of the Adaptive Management Program*. *Draft 4*. November 2023 Edition. Helena, MT: Montana Dept. of Environmental Quality.

David, W.S., and T.P Simon (Eds). 1994. *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis Publishers, London.

EPA (U.S. Environmental Protection Agency). 1989. *Rapid Bioassessment Protocols for Use in Stream and Rivers: Benthic Macroinvertebrates and Fish.* EPA/440/4-89/001. Office of Water, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 2006. *Level III Ecoregions of the Continental United States*. https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

EPA (U.S. Environmental Protection Agency). 2006. *Framework Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area: Volume II – Final Report*. Prepared for the Montana Dept. of Environmental Quality.

Flynn, K.F. 2014. Methods and Mathematical Approaches for Modeling *Cladophora Glomerata* and River Periphyton. PhD. Dissertation, Tufts University.

Flynn, K.F., and M.W. Suplee. 2010. *Defining Large Rivers in Montana Using a Wadeability Index*. Helena, MT: Montana Dept. of Environmental Quality.

Gammons, C.H., Ridenour, R., and A. Wenz. 2001. *Diurnal and Longitudinal Variations in Water Quality on the Big Hole River and Tributaries During the Drought of August, 2000.* Montana Bureau of Mines and Geology Open File Report 424.

Gammons, C.H., Babcock, J.N., Parker, S.R., and S.R. Poulson. 2011. Diel cycling and stable isotopes of dissolved oxygen, dissolved inorganic carbon, and nitrogenous species in a stream receiving treated municipal sewage. *Chemical Geology* 283: 44-55.

Giorgi, A., C. Feijoo, and G. Tell. 2005. Primary producers in a Pampean stream: temporal variation and structuring role. *Biodiversity and Conservation* 14: 1699-1718.

GLEC (Great Lakes Environmental Center, Inc.). 2020. *Dissolved Oxygen Spatial Analysis DEQ-Contract 22012 Technical Progress Report*. August 10, 2020. Prepared by Dale White, Principal Research Scientist.

GLEC (Great Lakes Environmental Center, Inc.). 2021. *Dissolved Oxygen Spatial Analysis, Technical Progress Report —Phase II*. Prepared by Dale White, Principal Research Scientist.

Heiskary, S.A. and R.W. Bouchard. 2015. Development of eutrophication criteria for Minnesota streams and rivers using multiple lines of evidence. *Freshwater Science* 34: 574–592.

Helsel, D.R., and R.M. Hirsch. 2002. *Statistical Methods in Water Resources*. U.S. Department of the Interior, U.S. Geological Survey.

Helsel, D. 2019. *Forty Years of Water Quality Statistics: What's Changed, What Hasn't?* 60 minute webinar at https://PracticalStats.com

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. *The Great Lakes Entomologist* 20: 31-39.

HydroSolutions Inc., 2019. *Clark Fork River Nutrient Water Quality Status and Trends Report, 1998-2017*. Helena, MT. Prepared for Montana Dept. of Environmental Quality, Helena, MT and Avista, Noxon, MT.

Jessup. B., Feldman, D., Laidlaw, T., Stagliano, D., and J. Stribling. 2005. *Comparability Analysis of Benthic Macroinvertebrate Sampling Protocols in Montana. Final Draft* 11/11/2005. Helena, MT: Montana Dept. of Environmental Quality.

Kerans, B.L., J.R. Karr, and S.A. Ahlstedt. 1992. Aquatic invertebrate assemblages: spatial and temporal differences among sampling protocols. *Journal of the North American Benthological Society* 11: 377-390.

King, R.S., and C.J. Richardson. 2003. Integrating bioassessment and ecological risk assessment: an approach to developing numeric water quality criteria. Environmental Management 31: 795-809.

Leppo, E.W., J. Stamp, and J. van Sickle. 2021. BioMonTools: Tools for biomonitoriong and bioassessment R package version 0.5.0.9039 https://github.com/leppott/BioMonTools.

McGuire, D.L. 2004. *Clark Fork River Macroinvertebrate Community Biointegrity: 2003 Assessments*. Prepared for the Montana Dept. of Environmental Quality by McGuire Consulting.

Miltner, R.J. 2010. A method and rationale for deriving nutrient criteria for small rivers and streams in Ohio. *Environmental Management* 45: 842-855.

Montana DEQ. 2009. *Upper and North Fork Big Hole River Planning Area TMDLs and Framework Water Quality Restoration Approach*. M03-TMDL-01A. Helena, MT: Montana Dept. of Environmental Quality.

Montana DEQ. 2009. *Middle and Lower Big Hole River Planning Area TMDLs and Water Quality Improvement Plan*. M03-TMDL-02A. Helena, MT: Montana Dept. of Environmental Quality.

Odum, H.T. Primary production in flowing waters. *Limnology and Oceanography* 1: 102-117. http://www.jstor.org/stable/2833008

Omernik, J.M., 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77:118-125.

Omernik, J.M., and A.L. Gallant. 1987. *Ecoregions of the West Central United States* (map). EPA/600/D-87/317. United State Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

Qian, S.S., King, R.S., and C.J. Richardson. 2003. Two statistical methods for the detection of environmental thresholds. *Ecological Modelling* 166: 87-97.

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/ [r-project.org].

Package: mvpart, Version: 1.6-2, Date: 2014-06-22; Author: rpart by Terry M Therneau and Beth Atkinson atkinson@mayo.edu, R port of rpart by Brian Ripley ripley@stats.ox.ac.uk, Some routines from vegan -- Jari Oksanen jari.oksanen@oulu.fi ; Extensions and adaptations of rpart to mvpart by Glenn De'ath <g.death@aims.gov.au>. Maintainer: Glenn De'ath g.death@aims.gov.au Description: Multivariate regression trees.

Schade, P. 2019. *Prickly Pear Creek 2019 Rewatering Project Final Report*. Lewis & Clark County Water Quality Protection District, Helena MT.

Schulte, N.O., and J.M. Craine. 2023. *Eutrophication Thresholds Associated with Benthic Macroinvertebrate Conditions in Montana Streams*. Prepared for the MT Dept. of Environmental Quality by Jonah Ventures. October 5, 2023.

Stribling, J.B., B.K. Jessup, and D.L. Feldman. 2008. Precision of benthic macroinvertebrate indicators of stream condition in Montana. *Journal of the North American Benthological Society* 27: 58-67.

Suplee, M.W. 2004. *Wadeable Streams of Montana's Hi-line Region: An Analysis of their Nature and Condition, with an Emphasis on Factors Affecting Aquatic Plant Communities and Recommendations to Prevent Nuisance Algae Conditions.* Helena, MT: Montana Department of Environmental Quality.

Suplee, M.W. 2023. *Sampling and Analysis Plan: Dissolved Oxygen and Macroinvertebrate Sampling in Low-gradient Streams and Medium Rivers in Support of the Narrative Nutrient Standards Translator.* Document ID WQDWQSMSAP-09. Helena, MT: Montana Department of Environmental Quality, Water Quality Planning Bureau.

Suplee, M.W., Sada de Suplee, R., Feldman, D., and T. Laidlaw. 2005. *Identification and Assessment of Montana Reference Streams: A Follow-up and Expansion of the 1992 Benchmark Biology Study.* Helena, MT: Montana Dept. of Environmental Quality.

Suplee, M.W., Watson, V., Dodds, W.K., and C. Shirley. 2012. Response of algal biomass to large-scale nutrient controls in the Clark Fork River, Montana, United States. *Journal of the American Water Resources Association* 48: 1008-1021.

Suplee, M.W., Sada, R.H., Feldman, D., and G. Bruski. 2016. *Whole-stream Nitrogen and Phosphorus Addition Study to Identify Eutropication Effects in a Wadeable Prairie Stream*. Helena, MT: Montana Dept. of Environmental Quality

Suplee, M.W. and R. Sada. 2016. *Assessment Methodology for Determining Wadeable Stream Impairment Due to Excess Nitrogen and Phosphorus Levels*. Helena, MT: Montana Dept. of Environmental Quality, p. C-4 and Table C2-2.

Suplee, M.W., Sada, R. and D.L. Feldman. 2019. Aquatic plant and dissolved oxygen changes in a reference-condition prairie stream subjected to experimental nutrient enrichments. *Journal of the American Water Resources Association* 55: 700-719.

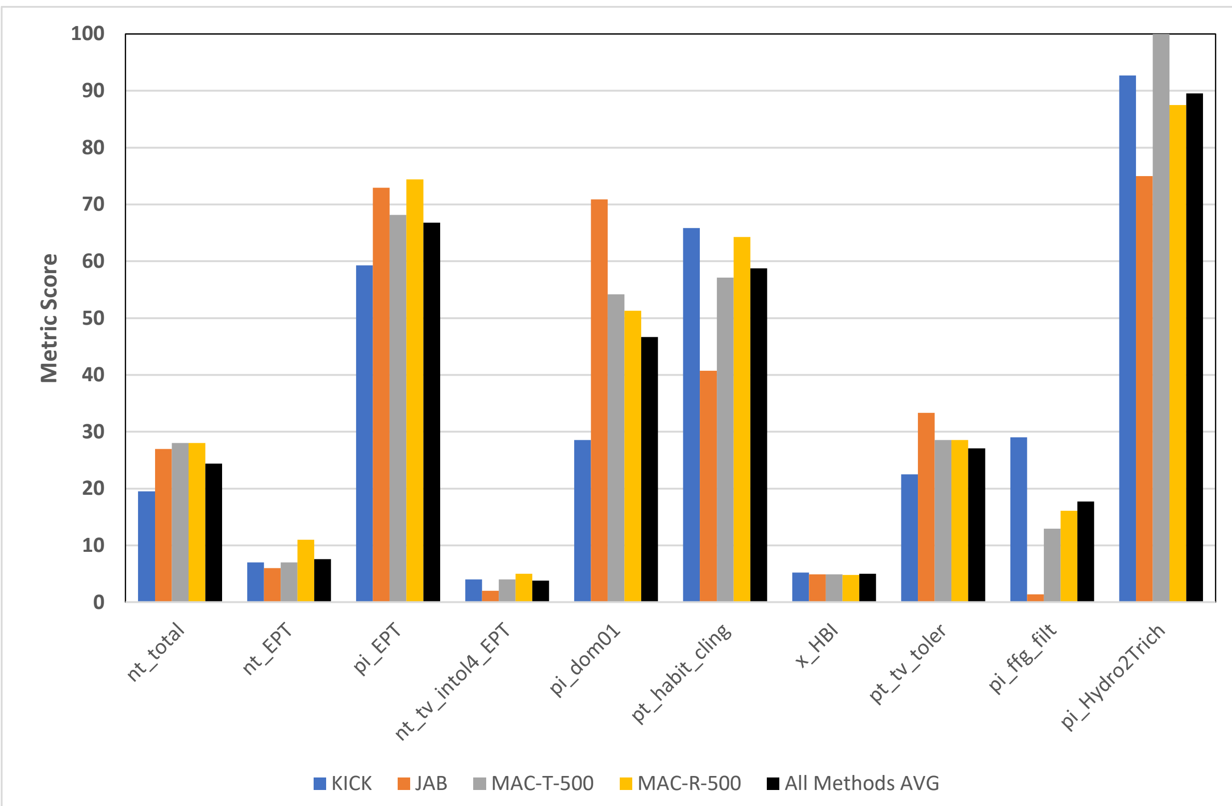
Wagner, R.J., Boulger, R.W., Oblinger, C.J., and B.A. Smith. 2006. *Guidelines and Standard Procedures for Continuous Water-Quality Monitors—Station Operation, Record Computation, and Data Reporting*. U.S. Geological Survey Techniques and Methods 1–D3, Reston, VA. https://pubs.usgs.gov/tm/2006/tm1D3/pdf/TM1D3.pdf

Woods, A.J., Omernik, J.M., Nesser, J.A., Shelden, J., Comstock, J.A., and S.H. Azevedo. 2002. *Ecoregions of Montana, 2nd edition* (color poster with map, descriptive text, summary tables, and photographs). Map scale 1:1,500,000. https://gaftp.epa.gov/EPADataCommons/ORD/Ecoregions/mt/mt_front_1.pdf

APPENDIX A: METHODS COMPARISON

Datasets used in the **Part IA** initial investigation included a site (Prickly Pear Creek at Montana Law Enforcement Academy) which was repeatedly sampled using multiple protocols over two consecutive summers; no method was isolated to a single year. The results of that work are shown in the figure below. **The all-methods average for each metric is shown as the black bar**. No clear protocol effect is apparent; for example, a protocol producing the highest metric score in one metric does not mean that that method will manifest the highest metric score for a different metric. In one case, all four protocols produced nearly identical results (x_HBI, the Hilsenhoff Biotic Index).

The HESS method could not be compared because, in this dataset, it was never collected at a site along with one or more of the other methods. Jessup et al. (2005) show the single HESS-collected sample in their analysis grouped tightly, in a principal components analysis of taxa relative abundance, with the site it was collected from along with other samples from that site collected via other protocols (see blue diamond, site “DOG” in Figure 6 below, which is reproduced from their document). Others find HESS samples provide mixed results in relation to other protocols—no detectable differences as well as consistent differences from them—depending on the metric, site, year, etc. (Kerans et al., 1992).



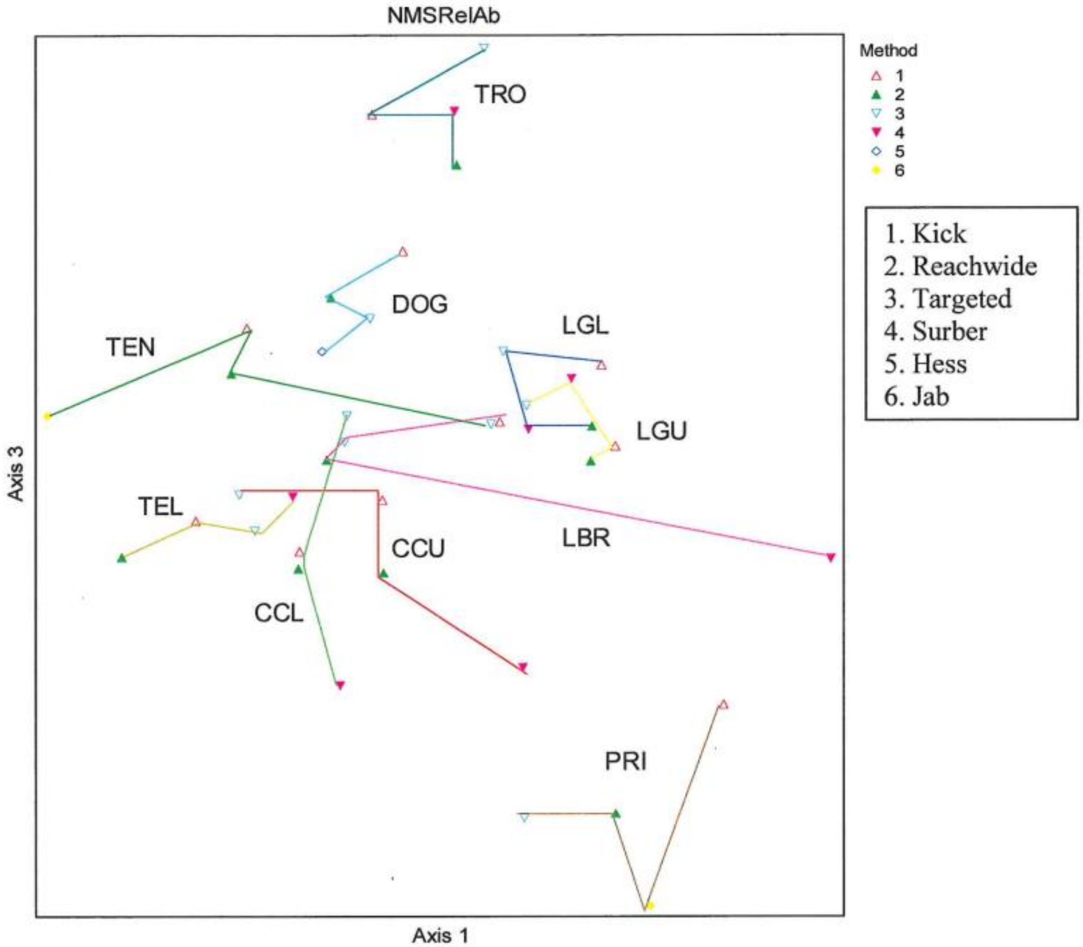


Figure 6. Ordination diagram of samples in taxa space. Three-letter abbreviations are site codes that correspond to the closest grouping of linked samples. Symbols distinguish the protocol used to collect the sample.

Reproduced from Jessup et al. (2005), page 30. The HESS sample is the blue diamond in the “DOG” site cluster.

APPENDIX B: COMPARISON OF MACROINVERTEBRATE METRICS SCORES COMPUTED AS AN ALL-DATA AVERAGE VS. THE SCORE FROM THE YEAR CONTINUOUS DO DATA WERE COLLECTED

Metrics highlighted in green are those which were compared to Bukantis (1998).

Site	Data Type, Decision Correspondance,* and % Difference	Year with both Macro-invertebrate and DO Data	Macroinvertebrate Metric Name and Code: Taxa Richness	EPT Richness	% EPT	Intolerant Taxa Richness	% Dominant Taxa	% Clingers	MT HBI	% Tolerant	Tolerant Taxa Richness
			nt_total	nt_EPT	pi_EPT	nt_tv_intol4_EPT	pi_dom01	pt_habit_cling	x_HBI	pt_tv_toler	nt_tv_ntol
MF Judith River	Metric Score from Year Having Continuous DO Data	2021	48.0	17.0	24.1	16.0	15.5	52.1	3.9	10.4	33.0
MF Judith River	All Data Average Metric Score	n/a	37.3	13.5	17.9	12.8	19.8	49.7	4.3	15.5	24.8
MF Judith River	Decision Correspondance†	n/a	Same	Same	Same		Same		Same		
MF Judith River	Percent Difference	2021	25.0%	23.0%	29.5%	22.0%	24.6%	4.8%	10.0%	39.0%	28.2%
East Gallatin Site I	Metric Score from Year Having Continuous DO Data	2015	36.0	10.0	37.0	5.0	26.3	50.0	5.8	25.0	17.0
East Gallatin Site I	All Data Average Metric Score	n/a	33.3	9.3	53.9	5.0	27.5	52.1	5.1	24.0	17.7
East Gallatin Site I	Decision Correspondance†	n/a	Same	Same	Same		Same		Same		
East Gallatin Site I	Percent Difference	2015	7.7%	6.9%	37.3%	0.0%	4.6%	4.1%	12.3%	4.3%	3.8%
East Gallatin Site J	Metric Score from Year Having Continuous DO Data	2015	35.0	11.0	36.8	6.0	34.6	54.3	6.1	28.6	18.0
East Gallatin Site J	All Data Average Metric Score	n/a	32	11.5	51.1	7.5	28.0	56.5	5.2	17.7	19.5
East Gallatin Site J	Decision Correspondance†	n/a	Same	Same	Same		Close		Close		
East Gallatin Site J	Percent Difference	2015	9.0%	4.4%	32.4%	22.2%	21.1%	3.9%	16.2%	46.8%	8.0%
East Gallatin Site A	Metric Score from Year Having Continuous DO Data	2015	27.0	11.7	67.0	8.3	28.2	55.5	4.7	13.2	18.0
East Gallatin Site A	All Data Average Metric Score	n/a	29.3	11.5	58.9	8.3	28.8	55.5	5.1	16.9	18.8
East Gallatin Site A	Decision Correspondance†	n/a	Close	Same	Close		Same		Same		
East Gallatin Site A	Percent Difference	2015	8.0%	1.4%	12.9%	1.0%	2.2%	0.0%	7.7%	24.2%	4.1%
East Gallatin Site D	Metric Score from Year Having Continuous DO Data	2015	24.5	7.5	52.0	5.0	29.4	49.9	5.3	22.1	13.0
East Gallatin Site D	All Data Average Metric Score	n/a	30.2	10.2	50.6	7.0	25.8	53.9	5.2	20.2	17.6
East Gallatin Site D	Decision Correspondance†	n/a	Close	Same	Same		Same		Same		
East Gallatin Site D	Percent Difference	2015	20.8%	30.5%	2.7%	33.3%	13.1%	7.7%	1.0%	8.8%	30.1%
East Gallatin Site G	Metric Score from Year Having Continuous DO Data	2015	31.7	9.7	36.8	5.7	32.0	55.9	5.6	22.1	17.0
East Gallatin Site G	All Data Average Metric Score	n/a	33.3	12.0	52.0	7.7	35.2	55.6	5.1	18.9	19.5
East Gallatin Site G	Decision Correspondance†	n/a	Same	Close	Same		Same		Same		
East Gallatin Site G	Percent Difference	2015	5.1%	21.5%	34.2%	30.0%	9.5%	0.5%	10.0%	15.5%	13.7%
East Gallatin Site H	Metric Score from Year Having Continuous DO Data	2015	31.0	11.0	53.9	7.0	27.1	51.6	5.1	22.6	18.0
East Gallatin Site H	All Data Average Metric Score	n/a	27.0	9.0	38.4	5.8	41.5	53.6	6.2	24.1	15.3
East Gallatin Site H	Decision Correspondance†	n/a	Close	Same	Same		Close		Close		
East Gallatin Site H	Percent Difference	2015	13.8%	20.0%	33.6%	19.6%	41.9%	3.7%	20.0%	6.4%	16.5%
Musselshell River North Fork	Metric Score from Year Having Continuous DO Data	2015	23.0	7.0	58.4	6.0	31.1	47.8	2.9	21.7	14.0
Musselshell River North Fork	All Data Average Metric Score	n/a	32.0	14.3	42.5	12.3	38.3	54.1	3.6	17.9	22.0
Musselshell River North Fork	Decision Correspondance†	n/a	Close	Close	Same		Same		Same		
Musselshell River North Fork	Percent Difference	2015	32.7%	68.8%	31.4%	69.1%	20.8%	12.2%	21.2%	19.1%	44.4%

*When ≥ 2 macroinvertebrate samples where collected in a year corresponding to a DO year, the average of the macroinvertebrate samples for that year is shown.

†Since Bukantis provided no decimals, standard rounding protocol were used to compare to Bukantis ranges (e.g., a score of 14.1 to 14.4 is ≤14, a score of 14.5 to 14.9 would be >14).

Appendix C: Low Gradient (≤ 1.0 %) Reference Sites (Suplee et al., 2005) in Western Montana and Transitional Level IV Ecoregions

Reference Site Name	Station ID	Latitude	Longitude	Water Surface Slope (%)	Macroinvertebrate and Continuous DO Data Available in 2022?
Blackfoot River	C03BLACR01	46.89944	-113.75610	0.09	no
Flathead River South Fork abv Hungry Horse Reservoir	C08FRSFK01	47.97890	-113.56080	0.05	no
Blacktail Deer Creek East Fork in Robb Creek Wildlife Area	M02BDEFC01	44.86583	-112.21861	1.00	no
Gallatin River	M05GLTNR01	45.05444	-111.15640	0.50	no
Rock Creek near Clinton at mouth	RC-CFR	46.72250	-113.68220	0.30	no
Clear Creek (Nutrient Pilot Project)	REFCC	48.30611	-109.49060	0.25	no
Belly River at 3-mile campsite (Glacier NP)	S02BELYR01	48.96806	-113.68263	0.30	no
Judith River Middle Fork near mouth	M22JUDMF01	46.84650	-110.28600	0.44	yes
Sweet Grass Creek on private ranch	Y03SWTGC07	46.152900	-110.181500	0.24	no
Elk Springs Creek	M01ELKC01	44.64444	-111.66360	0.08	no
Flathead River South Fork abv Hungry Horse and abv Bunker Creek	C08FRSFK03	47.79726	-113.41529	0.9	no

APPENDIX D: ASSESSMENT NOTES FOR EUTROPHICATION RATINGS

Site Name	Review Notes	Final BPJ Site Rating
Camas Creek at mouth	Slope is 0.8% (OK). Rating based on 2019-2022 nutrient sampling near mouth, photos. Nutrients slightly elevated, P in particular.	2.0
Clark Fork River above Little Blackfoot River-Kohrs Bend	Slope 0.5% (OK). Based on Suplee et al. (2012), Flynn (2014), 1998-2017 Clark Fork River trend report (HydroSolutions, 2019), etc.	4.0
Four Mile Creek (Reference Site)	Slope is 2.3%, **ELIMINATED**. DEQ stream reference site.	n/a
Judith River Middle Fork near mouth	Slope is 0.44% (OK). DEQ stream reference site.	1.0
Musselshell River North Fork	Slope 0.34% (OK). Per 303(d) list, no chlorophyll *a* or AFDW exceedences, nitrogen levels (soluble and total) low, but four elevated TP samples (up to 51 ug/L) and sources present. Overall suggests specific nutrient enrichment (P) with limited effects so far.	2.5
Prickly Pear Creek at Kleffner Ranch	Slope is 0.8% (OK). 2020 data shows total nutrients at expected concs., nitrate a bit high (0.16 mg/L). (No earlier nut. data found.) No flow withdrawals here, and no known land use changes here since the DO data were collected. Sources: EQuIS, 303d, and Schade (2019).	1.0
Prickly Pear Creek at Montana Law Enforcement Acadamy	Slope is 0.04% (OK). Rating based on repeated nutrient sampling (concentrations elevated, including at times HIGH ammonia), EPA (2006) TMDL prepared for DEQ.	4.0
Shields River	Slope is 1.3%, **ELIMINATED.** USGS dissolved oxygen data.	n/a
Crooked Creek (Reference Site)	Slope is 5.4%, **ELIMINATED**. DEQ stream reference site.	n/a
Silver Bow Creek (SBC-2)	Slope averages 0.6% (OK). Rating based on Gammons et al. (2011) which was after metals cleanup but prior to upgrades at Butte WWTP.	4.0
Silver Bow Creek at Rocker-post remediation-old plant (SBC-3)	Slope averages 0.6% (OK). Rating based on Gammons et al. (2011) which was after DEQ remediation metals cleanup but prior to upgrades at Butte WWTP in 2017.	4.0
Big Hole River at Wisdom Bridge	Slope 0.26% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document (M03-TMDL-01A), BHWC (2012), and review by the Big Hole Watershed Committee.	2.5
Big Hole River at Mudd Creek Bridge	Slope is 0.22% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document, BHWC (2012) and review by the Big Hole Watershed Committee.	4.0
Big Hole River near Dickie Bridge	Slope 0.6% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document, BHWC (2012) and review by the Big Hole Watershed Committee.	3.0
Big Hole River at Jerry Creek Bridge	Slope is 0.3% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document, BHWC (2012) and review by the Big Hole Watershed Committee.	2.0
Big Hole River at Maidenrock	Slope is 0.29% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document, BHWC (2012) and review by the Big Hole Watershed Committee.	2.0
Big Hole River at Kalsta Bridge	Slope 0.5% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document, BHWC (2012), and review by the Big Hole Watershed Committee.	2.5
Big Hole River at Notchbottom	Slope 0.22% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document, BHWC (2012), and review by the Big Hole Watershed Committee.	2.5
Big Hole River near Twin Bridges	Slope 0.01% (OK). Rating based on Gammons 2001, 2003 303(d) list, 2009 DEQ TMDL document, BHWC (2012), and review by the Big Hole Watershed Committee.	2.5
Steel Creek	Slope is 0.6% (OK). Rating based on 2004 nutrient data, 1999 303(d) list assessment record, and 2009 TMDL document (M03-TMDL-02A), and review by the Big Hole Watershed Committee.	2.5
North Fork Big Hole River	Slope 0.14% (OK). Rating based on 303(d) list, 2003 nutrient data, Upper Big Hole TMDL (M03-TMDL-01A), and review by the Big Hole Watershed Committee.	2.0
Deep Creek	Slope is 0.7% (OK). Rating based 2002 303(d) list assessment record, 2009 TMDL document (M03-TMDL-02A), and review by the Big Hole Watershed Committee.	2.0
Wise River	Slope is right at 1% (OK). Rating based on older nutrient data, 1999 303(d) list assessment record, and 2009 TMDL document (M03-TMDL-02A), and review by the Big Hole Watershed Committee.	1.5
East Gallatin Site A	Slope 0.5% (OK). Rating based on 303(d) list datasets, 2014-2015 data from the Gallatin Local Water Quality District.	2.5
East Gallatin Site D	Slope 0.55%(OK). Rating based on 303(d) list datasets, 2014-2015 data from the Gallatin Local Water Quality District.	4.0
East Gallatin Site G	Slope 0.54% (OK). Rating based on 303(d) datasets, 2014-2015 data from the Gallatin Local Water Quality District.	3.0
East Gallatin Site H	Slope 0.3% (OK). Ratings based on 303(d) list datasets, 2014-2015 data from the Gallatin Local Water Quality District.	4.0
East Gallatin Site I	Slope 0.07% (OK). Ratings based on 303(d) list, 2014-2015 data from the Gallatin Local Water Quality District.	3.5
East Gallatin Site J	Slope 0.15% (OK). Ratings based on 303(d) list, 2014-2015 data from the Gallatin Local Water Quality District.	3.5
Trail Creek nr NF Musselshell confluence	Slope 1.8%, **ELIMINATED**.	n/a

APPENDIX E: COMPETE LIST OF MACROINVERTEBRATE METRICS EXAMINED IN THIS INVESTIGATION

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-1
li_total	natural log number individuals - total
ni_Chiro	number individuals - Family Chironomidae
ni_EPT	number individuals - Orders Ephemeroptera, Plecoptera and Trichoptera (EPT)
ni_total	number individuals - total
ni_Trich	number individuals - Order Trichoptera
nt_Amph	number taxa - Order Amphipoda
nt_Bival	number taxa - Class Bivalvia
nt_Chiro	number taxa - Family Chironomidae
nt_COET	number taxa - Orders Coleoptera, Odonata, Ephemertopera, and Trichoptera (COET)
nt_Coleo	number taxa - Order Coleoptera
nt_CruMol	number taxa - Phylum Mollusca and SubPhylum Crustacea
nt_Deca	number taxa - Order Decapoda
nt_Dipt	number taxa - Order Diptera
nt_ECT	number taxa - Orders Ephemeroptera, Coleoptera, and Trichoptera (EPT)
nt_Ephem	number taxa - Order Ephemeroptera
nt_Ephemerellid	number taxa - Family Ephemerellidae
nt_EPT	number taxa - Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT)
nt_ET	number taxa - Orders Ephemeroptera and Trichoptera (ET)
nt_ffg_col	number taxa - Functional Feeding Group (FFG) - collector-gatherer (CG or GC)
nt_ffg_filt	number taxa - Functional Feeding Group (FFG) - collector-filterer (CF or FC)
nt_ffg_mah	number taxa - Functional Feeding Group (FFG) - macrophyte herbivore (MH)
nt_ffg_omn	number taxa - Functional Feeding Group (FFG) - omnivore (OM)

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-2
nt_ffg_par	number taxa - Functional Feeding Group (FFG) - parasite (PA)
nt_ffg_pih	number taxa - Functional Feeding Group (FFG) - piercer-herbivore (PH)
nt_ffg_pred	number taxa - Functional Feeding Group (FFG) - predator (PR)
nt_ffg_pred_scrap_shred	number taxa - Functional Feeding Group (FFG) - predator (PR), scraper (SC), or shredder (SH)
nt_ffg_scrap	number taxa - Functional Feeding Group (FFG) - scraper (SC)
nt_ffg_shred	number taxa - Functional Feeding Group (FFG) - shredder (SH)
nt_Gast	number taxa - Class Gastropoda
nt_habit_burrow	number taxa - Habit - burrowers (BU)
nt_habit_climb	number taxa - Habit - climbers (CB)
nt_habit_climbcling	number taxa - Habit - climbers (CB) and clingers (CN)
nt_habit_cling	number taxa - Habit - clingers (CN)
nt_habit_sprawl	number taxa - Habit - sprawlers (SP)
nt_habit_swim	number taxa - Habit - swimmers (SW)
nt_Hemipt	number taxa - Order Hempitera
nt_Hepta	number taxa - Family Heptageniidae
nt_Insect	number taxa - Class Insecta
nt_Isop	number taxa - Class Isopoda
nt_Mega	number taxa - Order Megaloptera
nt_Mol	number taxa - Phylum Mollusca
nt_Nemour	number taxa - Family Nemouridae
nt_NonIns	number taxa - not Class Insecta
nt_Odon	number taxa - Order Odonanta
nt_OET	number taxa - Orders Odonanta, Ephemeroptera, and Trichoptera (OET)
nt_Oligo	number taxa - Class Oligochaeta
nt_oneind	number of taxa - one individual
nt_Perlid	number taxa - Family Perlidae
nt_Pleco	number taxa - Order Plecoptera
nt_POET	number taxa - Orders Plecoptera, Odonanta, Ephemeroptera, and Trichoptera (POET)
nt_Ptero	number taxa - Genus Pteronarcys
nt_Rhya	number taxa - Genus Rhyacophila
nt_Tipulid	number taxa - Family Tipulidae
nt_total	number taxa - total

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-3
nt_Trich	number taxa - Order Trichoptera
nt_Tromb	number taxa - Family Trombidformes
nt_Tubif	number taxa - Family Tubificidae
nt_tv_intol4_EPT	number taxa - tolerance value - intolerant < 4 and Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT)
nt_tv_ntol	number taxa - tolerance value - ntol < 6
nt_tv_stol	number taxa - tolerance value - stol ≥ 8
nt_tv_toler	number taxa - tolerance value -tolerant ≥ 7
nt_volt_multi	number taxa - multivoltine (MULTI)
nt_volt_semi	number taxa - semivoltine (SEMI)
nt_volt_uni	number taxa - univoltine (UNI)
pi_Amph	percent (0-100) individuals - Order Amphipoda
pi_AmphIsop	percent (0-100) individuals - Order Amphipoda, Isopoda
pi_Baet	percent (0-100) individuals - Family Baetidae
pi_Bival	percent (0-100) individuals - Class Bivalvia
pi_Caen	percent (0-100) individuals - Family Caenidae
pi_ChCr2Chi	percent (0-100) individuals - Genera Chironomus or Cricotopus of Family Chironomidae
pi_Chiro	percent (0-100) individuals - Family Chironomidae
pi_ChiroAnne	percent (0-100) individuals - Order Chironomidae and Phylum Annelida
pi_COC2Chi	percent (0-100) individuals - Genera Chironomus, Cricotopus, Cricotopus/Orthocladius, or Orthocladius of Family Chironomidae
pi_COET	percent (0-100) individuals - Orders Coleoptera, Odonata, Ephemeroptera, and Trichoptera
pi_Coleo	percent (0-100) individuals - Order Coleoptera
pi_Colesens	percent (0-100) individuals - Order Coleoptera and not Family Hydrophilidae

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-4
pi_Corb	percent (0-100) individuals - Genus Corbicula
pi_CorixPhys	percent (0-100) individuals - Family Corixidae or Physidae
pi_CraCaeGam	percent (0-100) individuals - Genus Crangonyx, Caecidotea, or Gammarus
pi_Cru	percent (0-100) individuals - SubPhylum Crustacea
pi_CruMol	percent (0-100) individuals - SubPhylum Crustacea and Phylum Mollusca
pi_Deca	percent (0-100) individuals - Order Decapoda
pi_Dipt	percent (0-100) individuals - Order Diptera
pi_DiptNonIns	percent (0-100) individuals - Order Diptera OR Class not Insecta
pi_dom01	percent (0-100) individuals - most dominant taxon; max(N_TAXA)
pi_dom02	percent (0-100) individuals - two most dominant taxa
pi_dom03	percent (0-100) individuals - three most dominant taxa
pi_dom04	percent (0-100) individuals - four most dominant taxa
pi_dom05	percent (0-100) individuals - five most dominant taxa
pi_dom06	percent (0-100) individuals - six most dominant taxa
pi_dom07	percent (0-100) individuals - seven most dominant taxa
pi_dom08	percent (0-100) individuals - eight most dominant taxa
pi_dom09	percent (0-100) individuals - nine most dominant taxa
pi_dom10	percent (0-100) individuals - ten most dominant taxa
pi_ECT	percent (0-100) individuals - Orders Ephemeroptera, Coleoptera, and Trichoptera (EPT)
pi_Ephem	percent (0-100) individuals - Order Ephemeroptera
pi_EphemNoCae	percent (0-100) individuals - Order Ephemeroptera and not Family Caenidae
pi_EphemNoCaeBae	percent (0-100) individuals - Order Ephemeroptera and not Family Caenidae or Baetidae
pi_EPT	percent (0-100) individuals - Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT)
pi_EPTNoBaeHydro	percent (0-100) individuals - Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) and not Family Baetidae or Hydropsychidae
pi_EPTNoCheu	percent (0-100) individuals - Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) and not Family Cheumatopsyche
pi_EPTNoHydro	percent (0-100) individuals - Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) and not Family Hydropsychidae
pi_ET	percent (0-100) individuals - Orders Ephemeroptera and Trichoptera (ET)
pi_ffg_col	percent (0-100) individuals - Functional Feeding Group (FFG) - collector-gatherer (CG or GC)
pi_ffg_col_filt	percent (0-100) individuals - Functional Feeding Group (FFG) - collector-gatherer (CG or GC) or collector-filterer (CF or FC)
pi_ffg_filt	percent (0-100) individuals - Functional Feeding Group (FFG) - collector-filterer (CF or FC)
pi_ffg_mah	percent (0-100) individuals - Functional Feeding Group (FFG) - macrophyte herbivore (MH)
pi_ffg_omn	percent (0-100) individuals - Functional Feeding Group (FFG) - omnivore (OM)

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-5
_ffg_par	percent (0-100) individuals - Functional Feeding Group (FFG) - parasite (PA)
_ffg_pih	percent (0-100) individuals - Functional Feeding Group (FFG) - piercer-herbivore (PH)
_ffg_pred	percent (0-100) individuals - Functional Feeding Group (FFG) - predator (PR)
_ffg_scrap	percent (0-100) individuals - Functional Feeding Group (FFG) - scraper (SC)
_ffg_shred	percent (0-100) individuals - Functional Feeding Group (FFG) - shredder (SH)
_ffg_xyl	percent (0-100) individuals - Functional Feeding Group (FFG) - xylophage (XY)
pi_Gast	percent (0-100) individuals - Class Gastropoda
_habit_burrow	percent (0-100) individuals - Habit - burrowers (BU)
_habit_climb	percent (0-100) individuals - Habit - climbers (CB)
pi_habit_climbcling	percent (0-100) individuals - Habit - climbers (CB) and clingers (CN)
_habit_cling	percent (0-100) individuals - Habit - clingers (CN)
pi_habit_cling_PlecoNoCling	percent (0-100) individuals - Habit - clingers (CN) and Order Plecoptera (not clingers)
_habit_sprawl	percent (0-100) individuals - Habit - sprawlers (SP)
_habit_swim	percent (0-100) individuals - Habit - swimmers (SW)
pi_Hemipt	percent (0-100) individuals - Order Hemiptera
_Hydro	percent (0-100) individuals - Family Hydropsychidae
_Hydro2EPT	percent (0-100) individuals - Family Hydropsychidae of Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT)
_Hydro2Trich	percent (0-100) individuals - Family Hydropsychidae of Order Trichoptera
_Insect	percent (0-100) individuals - Class Insecta
_IsopGastHiru	percent (0-100) individuals - Order Isopoda, Class Gastropoda, SubClass Hirudinea
_Mol	percent (0-100) individuals - Phylum Mollusca
_Nemata	percent (0-100) individuals - Phylum Nemata

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-6
_NonIns	percent (0-100) individuals - Class not Insecta
_Odon	percent (0-100) individuals - Order Odonata
_OET	percent (0-100) individuals - Orders Odonata, Ephemeroptera, and Trichoptera
_Oligo	percent (0-100) individuals - Class Oligochaeta
pi_Orth2Chi	percent (0-100) individuals - SubFamily Orthocladiinae of Family Chironomidae
_Ortho	percent (0-100) taxa - SubFamily Orthocladiinae
_Pleco	percent (0-100) individuals - Order Plecoptera
_POET	percent (0-100) individuals - Orders Plecoptera, Odonata, Ephemeroptera, and Trichoptera
_SimBtri	percent (0-100) individuals - Family Simuliidae and Genus Baetis tricaudatus complex
pi_Sphaer	percent (0-100) individuals - (Bivalvia) Family Sphaeriidae
pi_SphaerCorb	percent (0-100) individuals - (Bivalvia) Family Sphaeriidae and Genus Corbicula
_Tanyp	percent (0-100) individuals - SubFamily Tanypodinae
pi_Tanyp2Chi	percent (0-100) individuals - SubFamily Tanypodina of Family Chironomidae
_Tanyt	percent (0-100) individuals - Tribe Tanytarsini
_Trich	percent (0-100) individuals - Order Trichoptera
_TrichNoHydro	percent (0-100) individuals - Order Trichoptera and not Family Hydropsychidae
pi_Tromb	percent (0-100) individuals - Order Trombidiformes
pi_Tubif	percent (0-100) individuals - Family Tibuficidae
_tv_intol	percent (0-100) individuals - tolerance value - intolerant ≤ 3
_tv_intol4	percent (0-100) individuals - tolerance value - intolerant < 4
_tv_ntol	percent (0-100) individuals - tolerance value - ntol < 6
_tv_stol	percent (0-100) individuals - tolerance value - stol ≥ 8
_tv_toler	percent (0-100) individuals - tolerance value - tolerant ≥ 7
_tv_toler6	percent (0-100) individuals - tolerance value - tolerant > 6
_tv2_intol	percent (0-100) individuals - intolerant (tolerance value 2)
_volt_multi	percent (0-100) individuals - multivoltine (MULTI)
_volt_semi	percent (0-100) individuals - semivoltine (SEMI)
_volt_uni	percent (0-100) individuals - univoltine (UNI)
pt_Amph	percent (0-100) taxa - Order Amphipoda
pt_Bival	percent (0-100) taxa - Class Bivalvia
_Chiro	percent (0-100) taxa - Family Chironomidae
_COET	percent (0-100) taxa - Orders Coleoptera, Odonata, Ephemeroptera, Trichoptera

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-7
pt_Coleo	percent (0-100) taxa - Order Coleoptera
pt_Deca	percent (0-100) taxa - Order Decapoda
pt_Dipt	percent (0-100) taxa - Order Diptera
pt_ECT	percent (0-100) taxa - Orders Ephemeroptera, Coleoptera, and Trichoptera (EPT)
pt_Ephem	percent (0-100) taxa - Order Ephemeroptera
pt_EPT	percent (0-100) taxa - Orders Ephemeroptera, Plecoptera, and Trichoptera (EPT)
pt_ET	percent (0-100) taxa - Orders Ephemeroptera and Trichoptera (ET)
pt_ffg_col	percent (0-100) taxa - Functional Feeding Group (FFG) - collector-gatherer (CG or GC)
pt_ffg_filt	percent (0-100) taxa - Functional Feeding Group (FFG) - collector-filterer (CF or FC)
pt_ffg_mah	percent (0-100) taxa - Functional Feeding Group (FFG) - macrophyte herbivore (MH)
pt_ffg_omn	percent (0-100) taxa - Functional Feeding Group (FFG) - omnivore (OM)
pt_ffg_par	percent (0-100) taxa - Functional Feeding Group (FFG) - parasite (PA)
pt_ffg_pih	percent (0-100) taxa - Functional Feeding Group (FFG) - piercer-herbivore (PH)
pt_ffg_pred	percent (0-100) taxa - Functional Feeding Group (FFG) - predator (PR)
pt_ffg_scrap	percent (0-100) taxa - Functional Feeding Group (FFG) - scraper (SC)
pt_ffg_shred	percent (0-100) taxa - Functional Feeding Group (FFG) - shredder (SH)
pt_ffg_xyl	percent (0-100) taxa - Functional Feeding Group (FFG) - xylophage (XY)
pt_Gast	percent (0-100) taxa - Class Gastropoda
pt_habit_burrow	percent (0-100) taxa - Habit - burrowers (BU)
pt_habit_climb	percent (0-100) taxa - Habit - climbers (CB)
pt_habit_climbcling	percent (0-100) taxa - Habit - climbers (CB) and clingers (CN)
pt_habit_cling	percent (0-100) taxa - Habit - clingers (CN)

Macroinvertebrate Metric Code	Macroinvertebrate Metric Description-8
pt_habit_sprawl	percent (0-100) taxa - Habit - sprawlers (SP)
pt_habit_swim	percent (0-100) taxa - Habit - swimmers (SW)
pt_Hemipt	percent (0-100) taxa - Order Hemiptera
pt_Insect	percent (0-100) taxa - Class Insecta
pt_NonIns	percent (0-100) taxa - not Class Insecta
pt_Odon	percent (0-100) taxa - Order Odonata
pt_OET	percent (0-100) taxa - Orders Odonata, Ephemeroptera, and Trichoptera (OET)
pt_Oligo	percent (0-100) taxa - Class Oligochaeta
pt_oneind	percent of taxa - one individual
pt_Pleco	percent (0-100) taxa - Order Plecoptera
pt_POET	percent (0-100) taxa - Orders Plecoptera, Odonata, Ephemeroptera, and Trichoptera (POET)
pt_Trich	percent (0-100) taxa - Order Trichoptera
pt_Tromb	percent (0-100) taxa - Order Tombidiformes
pt_tv_intol	percent (0-100) taxa - tolerance value - intolerant ≤ 3
pt_tv_intol4	percent (0-100) taxa - tolerance value - intolerant < 4
pt_tv_ntol	percent (0-100) taxa - tolerance value - ntol < 6
pt_tv_stol	percent (0-100) taxa - tolerance value - stol ≥ 8
pt_tv_toler	percent (0-100) taxa - tolerance value - tolerant ≥ 7
pt_volt_multi	percent (0-100) taxa - multivoltine (MULTI)
pt_volt_semi	percent (0-100) taxa - semivoltine (SEMI)
pt_volt_uni	percent (0-100) taxa - univoltine (UNI)
x_Becks	Becks Biotic Index
x_Becks3	Becks Biotic Index v3
x_D	Simpson's Index; 1-sum((N_TAXA/ni_total)^2, na.rm = TRUE)
x_D_G	Gleason's Index; (nt_total) / log(ni_total)
x_D_Mg	Margalef's Index; (nt_total - 1)/log(ni_total)
x_Evenness	Peilou's Index (Evenness); x_Shan_e/log(nt_total)
x_HBI	Hilsenhoff Biotic Index (references the TolVal field) THIS IS THE MONTANA DEQ values
x_HBI2	Hilsenhoff Biotic Index 2 (references the TolVal2 field) THIS IS THE RAI values
x_NCBI	North Carolina Biotic Index (references the TolVal2 field)
x_Shan_10	Shannon Wiener Diversity Index (log base 10); -x_Shan_Num/log(10)
x_Shan_2	Shannon Wiener Diversity Index (log base 2); -x_Shan_Num/log(2)
x_Shan_e	Shannon Wiener Diversity Index (natural log); -x_Shan_Num/log (exp(1))

APPENDIX F: SPEARMAN RANK CORRELATION STATISTICS FOR 217 MACROINVERTEBRATE METRICS EXAMINED IN PART IA.

Significant relationships (P ≤ 0.01) are highlighted in green. All tests are two-sided.

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
ni_total	AVG Daily DO delta (mg/L)	21	0.078	(-0.367, 0.494)	0.737

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
li_total	AVG Daily DO delta (mg/L)	21	0.086	(-0.360, 0.500)	0.712

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
ni_Chiro	AVG Daily DO delta (mg/L)	21	0.068	(-0.376, 0.485)	0.771

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
ni_EPT	AVG Daily DO delta (mg/L)	21	0.027	(-0.409, 0.454)	0.907

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
ni_Trich	AVG Daily DO delta (mg/L)	21	0.025	(-0.411, 0.452)	0.915

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_total	AVG Daily DO delta (mg/L)	21	-0.006	(-0.436, 0.427)	0.980

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Amph	AVG Daily DO delta (mg/L)	21	0.165	(-0.290, 0.559)	0.474

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Bival	AVG Daily DO delta (mg/L)	21	0.229	(-0.230, 0.605)	0.317

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Coleo	AVG Daily DO delta (mg/L)	21	0.259	(-0.202, 0.626)	0.257

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_COET	AVG Daily DO delta (mg/L)	21	0.036	(-0.402, 0.461)	0.875

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_CruMol	AVG Daily DO delta (mg/L)	21	0.275	(-0.186, 0.637)	0.228

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Deca	AVG Daily DO delta (mg/L)	21	0.037	(-0.401, 0.461)	0.874

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Dipt	AVG Daily DO delta (mg/L)	21	-0.137	(-0.539, 0.315)	0.553

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ECT	AVG Daily DO delta (mg/L)	21	0.047	(-0.393, 0.469)	0.840

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Ephem	AVG Daily DO delta (mg/L)	21	-0.167	(-0.561, 0.288)	0.468

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Ephemerellid	AVG Daily DO delta (mg/L)	21	-0.572	(-0.817, -0.151)	0.007

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_EPT	AVG Daily DO delta (mg/L)	21	-0.237	(-0.610, 0.223)	0.302

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ET	AVG Daily DO delta (mg/L)	21	-0.038	(-0.463, 0.400)	0.869

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Gast	AVG Daily DO delta (mg/L)	21	0.184	(-0.273, 0.573)	0.425

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Hemipt	AVG Daily DO delta (mg/L)	21	0.611	(0.204, 0.838)	0.003

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Hepta	AVG Daily DO delta (mg/L)	21	-0.178	(-0.569, 0.278)	0.440

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Insect	AVG Daily DO delta (mg/L)	21	-0.095	(-0.507, 0.352)	0.682

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Isop	AVG Daily DO delta (mg/L)	21	0.037	(-0.401, 0.461)	0.874

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Mega	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Mol	AVG Daily DO delta (mg/L)	21	0.275	(-0.186, 0.637)	0.228

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Nemour	AVG Daily DO delta (mg/L)	21	-0.074	(-0.490, 0.370)	0.750

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_NonIns	AVG Daily DO delta (mg/L)	21	0.168	(-0.287, 0.561)	0.467

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Odon	AVG Daily DO delta (mg/L)	21	0.184	(-0.272, 0.573)	0.423

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_OET	AVG Daily DO delta (mg/L)	21	-0.007	(-0.437, 0.426)	0.978

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Oligo	AVG Daily DO delta (mg/L)	21	-0.098	(-0.509, 0.349)	0.672

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Perlid	AVG Daily DO delta (mg/L)	21	-0.361	(-0.694, 0.098)	0.108

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Pleco	AVG Daily DO delta (mg/L)	21	-0.516	(-0.787, -0.079)	0.017

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_POET	AVG Daily DO delta (mg/L)	21	-0.227	(-0.604, 0.232)	0.321

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Ptero	AVG Daily DO delta (mg/L)	21	-0.334	(-0.676, 0.126)	0.138

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Rhya	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Tipulid	AVG Daily DO delta (mg/L)	21	-0.035	(-0.460, 0.403)	0.880

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Trich	AVG Daily DO delta (mg/L)	21	0.327	(-0.134, 0.672)	0.148

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Tromb	AVG Daily DO delta (mg/L)	21	0.091	(-0.356, 0.503)	0.696

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Tubif	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Amph	AVG Daily DO delta (mg/L)	21	0.167	(-0.288, 0.560)	0.470

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_AmphIsop	AVG Daily DO delta (mg/L)	21	0.150	(-0.304, 0.548)	0.517

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Baet	AVG Daily DO delta (mg/L)	21	-0.467	(-0.758, -0.020)	0.033

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Bival	AVG Daily DO delta (mg/L)	21	0.227	(-0.232, 0.604)	0.322

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Caen	AVG Daily DO delta (mg/L)	21	0.111	(-0.338, 0.519)	0.633

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Coleo	AVG Daily DO delta (mg/L)	21	0.114	(-0.335, 0.521)	0.622

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_COET	AVG Daily DO delta (mg/L)	21	-0.187	(-0.575, 0.270)	0.417

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Corb	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_CorixPhys	AVG Daily DO delta (mg/L)	21	0.480	(0.035, 0.766)	0.028

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_CraCaeGam	AVG Daily DO delta (mg/L)	21	0.254	(-0.207, 0.622)	0.267

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Cru	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_CruMol	AVG Daily DO delta (mg/L)	21	0.279	(-0.182, 0.640)	0.221

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Deca	AVG Daily DO delta (mg/L)	21	0.037	(-0.401, 0.461)	0.874

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Dipt	AVG Daily DO delta (mg/L)	21	0.055	(-0.387, 0.475)	0.814

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_DiptNonIns	AVG Daily DO delta (mg/L)	21	0.190	(-0.267, 0.577)	0.410

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ECT	AVG Daily DO delta (mg/L)	21	-0.177	(-0.568, 0.279)	0.444

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Ephem	AVG Daily DO delta (mg/L)	21	-0.140	(-0.541, 0.312)	0.544

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_EphemNoCae	AVG Daily DO delta (mg/L)	21	-0.152	(-0.550, 0.302)	0.511

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_EphemNoCaeBae	AVG Daily DO delta (mg/L)	21	-0.090	(-0.503, 0.357)	0.699

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_EPT	AVG Daily DO delta (mg/L)	21	-0.191	(-0.578, 0.266)	0.407

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_EPTNoBaeHydro	AVG Daily DO delta (mg/L)	21	-0.471	(-0.761, -0.025)	0.031

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_EPTNoCheu	AVG Daily DO delta (mg/L)	21	-0.191	(-0.578, 0.266)	0.407

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_EPTNoHydro	AVG Daily DO delta (mg/L)	21	-0.525	(-0.792, -0.090)	0.015

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ET	AVG Daily DO delta (mg/L)	21	-0.170	(-0.563, 0.285)	0.461

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Gast	AVG Daily DO delta (mg/L)	21	0.204	(-0.255, 0.587)	0.376

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Hemipt	AVG Daily DO delta (mg/L)	21	0.482	(0.038, 0.768)	0.027

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Hydro	AVG Daily DO delta (mg/L)	21	0.593	(0.179, 0.828)	0.005

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Hydro2EPT	AVG Daily DO delta (mg/L)	21	0.737	(0.400, 0.899)	0.000

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Hydro2Trich	AVG Daily DO delta (mg/L)	21	0.579	(0.160, 0.821)	0.006

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Insect	AVG Daily DO delta (mg/L)	21	-0.270	(-0.634, 0.191)	0.236

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_IsopGastHiru	AVG Daily DO delta (mg/L)	21	0.195	(-0.263, 0.581)	0.398

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Mol	AVG Daily DO delta (mg/L)	21	0.279	(-0.182, 0.640)	0.221

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Nemata	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_NonIns	AVG Daily DO delta (mg/L)	21	0.270	(-0.191, 0.634)	0.236

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Odon	AVG Daily DO delta (mg/L)	21	0.184	(-0.272, 0.573)	0.423

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_OET	AVG Daily DO delta (mg/L)	21	-0.166	(-0.560, 0.289)	0.471

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Oligo	AVG Daily DO delta (mg/L)	21	0.238	(-0.222, 0.612)	0.298

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Pleco	AVG Daily DO delta (mg/L)	21	-0.503	(-0.779, -0.063)	0.020

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_POET	AVG Daily DO delta (mg/L)	21	-0.194	(-0.580, 0.264)	0.401

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Sphaer	AVG Daily DO delta (mg/L)	21	0.227	(-0.232, 0.604)	0.322

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value

pi_SphaerCorb	AVG Daily DO delta (mg/L)	21	0.227	(-0.232, 0.604)	0.322

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Trich	AVG Daily DO delta (mg/L)	21	-0.148	(-0.547, 0.305)	0.522

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_TrichNoHydro	AVG Daily DO delta (mg/L)	21	-0.273	(-0.635, 0.188)	0.232

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Tromb	AVG Daily DO delta (mg/L)	21	-0.044	(-0.467, 0.395)	0.850

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Tubif	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Amph	AVG Daily DO delta (mg/L)	21	0.178	(-0.278, 0.569)	0.440

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Bival	AVG Daily DO delta (mg/L)	21	0.227	(-0.232, 0.604)	0.322

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Coleo	AVG Daily DO delta (mg/L)	21	0.574	(0.154, 0.818)	0.007

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_COET	AVG Daily DO delta (mg/L)	21	0.201	(-0.257, 0.585)	0.382

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Deca	AVG Daily DO delta (mg/L)	21	0.037	(-0.401, 0.461)	0.874

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Dipt	AVG Daily DO delta (mg/L)	21	-0.262	(-0.628, 0.199)	0.251

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ECT	AVG Daily DO delta (mg/L)	21	0.188	(-0.269, 0.576)	0.414

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Ephem	AVG Daily DO delta (mg/L)	21	-0.256	(-0.624, 0.205)	0.263

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_EPT	AVG Daily DO delta (mg/L)	21	-0.239	(-0.612, 0.221)	0.297

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value

pt_ET	AVG Daily DO delta (mg/L)	21	0.061	(-0.381, 0.480)	0.793

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Gast	AVG Daily DO delta (mg/L)	21	0.221	(-0.238, 0.600)	0.335

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Hemipt	AVG Daily DO delta (mg/L)	21	0.657	(0.271, 0.861)	0.001

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Insect	AVG Daily DO delta (mg/L)	21	-0.340	(-0.680, 0.120)	0.131

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_NonIns	AVG Daily DO delta (mg/L)	21	0.340	(-0.120, 0.680)	0.131

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Odon	AVG Daily DO delta (mg/L)	21	0.184	(-0.272, 0.573)	0.423

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_OET	AVG Daily DO delta (mg/L)	21	0.043	(-0.396, 0.466)	0.854

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Oligo	AVG Daily DO delta (mg/L)	21	0.023	(-0.413, 0.451)	0.920

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Pleco	AVG Daily DO delta (mg/L)	21	-0.511	(-0.784, -0.072)	0.018

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_POET	AVG Daily DO delta (mg/L)	21	-0.240	(-0.613, 0.220)	0.294

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Trich	AVG Daily DO delta (mg/L)	21	0.075	(-0.369, 0.491)	0.748

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Tromb	AVG Daily DO delta (mg/L)	21	0.115	(-0.334, 0.522)	0.618

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_Chiro	AVG Daily DO delta (mg/L)	21	-0.075	(-0.491, 0.369)	0.748

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Chiro	AVG Daily DO delta (mg/L)	21	-0.138	(-0.539, 0.315)	0.552

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_Chiro	AVG Daily DO delta (mg/L)	21	-0.136	(-0.538, 0.316)	0.556

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Ortho	AVG Daily DO delta (mg/L)	21	-0.347	(-0.684, 0.113)	0.124

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Tanyt	AVG Daily DO delta (mg/L)	21	0.352	(-0.108, 0.688)	0.118

Pairwise Spearman Correlations (Note: no pattern discernable, Y values almost all the same)

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Tanyp	AVG Daily DO delta (mg/L)	21	0.656	(0.269, 0.860)	~~0.001~~

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_COC2Chi	AVG Daily DO delta (mg/L)	21	-0.400	(-0.718, 0.056)	0.072

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ChCr2Chi	AVG Daily DO delta (mg/L)	21	0.134	(-0.318, 0.536)	0.563

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Orth2Chi	AVG Daily DO delta (mg/L)	21	-0.471	(-0.761, -0.025)	0.031

Pairwise Spearman Correlations (Note: no pattern discernable, Y values almost all the same)

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Tanyp2Chi	AVG Daily DO delta (mg/L)	21	0.592	(0.179, 0.828)	~~0.005~~

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ChiroAnne	AVG Daily DO delta (mg/L)	21	0.074	(-0.370, 0.491)	0.750

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_SimBtri	AVG Daily DO delta (mg/L)	21	0.169	(-0.286, 0.562)	0.464

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_Colesens	AVG Daily DO delta (mg/L)	21	0.116	(-0.334, 0.522)	0.618

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_tv_intol	AVG Daily DO delta (mg/L)	21	-0.634	(-0.849, -0.237)	0.002

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_tv_intol4	AVG Daily DO delta (mg/L)	21	-0.634	(-0.849, -0.237)	0.002

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_tv_intol4_EPT	AVG Daily DO delta (mg/L)	21	-0.429	(-0.736, 0.024)	0.052

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_tv_ntol	AVG Daily DO delta (mg/L)	21	-0.280	(-0.640, 0.181)	0.219

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_tv_toler6	AVG Daily DO delta (mg/L)	21	0.117	(-0.333, 0.523)	0.614

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_tv_intol	AVG Daily DO delta (mg/L)	21	-0.630	(-0.847, -0.231)	0.002

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_tv_intol4	AVG Daily DO delta (mg/L)	21	-0.630	(-0.847, -0.231)	0.002

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_tv_toler	AVG Daily DO delta (mg/L)	21	0.312	(-0.150, 0.661)	0.169

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_tv_stol	AVG Daily DO delta (mg/L)	21	0.327	(-0.133, 0.672)	0.147

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_tv_ntol	AVG Daily DO delta (mg/L)	21	-0.245	(-0.617, 0.215)	0.284

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_tv_stol	AVG Daily DO delta (mg/L)	21	0.255	(-0.206, 0.623)	0.265

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_tv_ntol	AVG Daily DO delta (mg/L)	21	-0.481	(-0.766, -0.036)	0.027

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_tv_stol	AVG Daily DO delta (mg/L)	21	0.406	(-0.049, 0.722)	0.067

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_tv2_intol	AVG Daily DO delta (mg/L)	21	-0.617	(-0.841, -0.213)	0.003

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_col	AVG Daily DO delta (mg/L)	21	-0.357	(-0.691, 0.103)	0.113

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_filt	AVG Daily DO delta (mg/L)	21	0.201	(-0.257, 0.585)	0.382

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_pred	AVG Daily DO delta (mg/L)	21	-0.142	(-0.542, 0.311)	0.541

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_scrap	AVG Daily DO delta (mg/L)	21	0.188	(-0.269, 0.576)	0.414

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_shred	AVG Daily DO delta (mg/L)	21	0.025	(-0.411, 0.452)	0.915

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_mah	AVG Daily DO delta (mg/L)	21	0.110	(-0.339, 0.518)	0.635

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_omn	AVG Daily DO delta (mg/L)	21	-0.589	(-0.827, -0.174)	0.005

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_par	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_pih	AVG Daily DO delta (mg/L)	21	0.631	(0.233, 0.848)	0.002

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_ffg_pred_scrap_shred	AVG Daily DO delta (mg/L)	21	0.069	(-0.374, 0.487)	0.766

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_col	AVG Daily DO delta (mg/L)	21	-0.071	(-0.489, 0.372)	0.758

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_filt	AVG Daily DO delta (mg/L)	21	0.774	(0.465, 0.915)	0.000

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_pred	AVG Daily DO delta (mg/L)	21	-0.201	(-0.585, 0.257)	0.382

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_scrap	AVG Daily DO delta (mg/L)	21	-0.017	(-0.445, 0.418)	0.942

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_shred	AVG Daily DO delta (mg/L)	21	0.242	(-0.219, 0.614)	0.291

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_mah	AVG Daily DO delta (mg/L)	21	0.419	(-0.035, 0.730)	0.059

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_omn	AVG Daily DO delta (mg/L)	21	-0.562	(-0.812, -0.138)	0.008

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_par	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_pih	AVG Daily DO delta (mg/L)	21	0.565	(0.141, 0.813)	0.008

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_xyl	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_ffg_col_filt	AVG Daily DO delta (mg/L)	21	0.397	(-0.059, 0.717)	0.074

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_col	AVG Daily DO delta (mg/L)	21	-0.510	(-0.784, -0.072)	0.018

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_filt	AVG Daily DO delta (mg/L)	21	0.429	(-0.025, 0.736)	0.053

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_pred	AVG Daily DO delta (mg/L)	21	-0.243	(-0.615, 0.217)	0.289

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_scrap	AVG Daily DO delta (mg/L)	21	0.342	(-0.119, 0.681)	0.130

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_shred	AVG Daily DO delta (mg/L)	21	0.123	(-0.327, 0.528)	0.594

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_mah	AVG Daily DO delta (mg/L)	21	0.263	(-0.198, 0.628)	0.250

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_omn	AVG Daily DO delta (mg/L)	21	-0.494	(-0.774, -0.051)	0.023

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_par	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_pih	AVG Daily DO delta (mg/L)	21	0.709	(0.352, 0.886)	0.000

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_ffg_xyl	AVG Daily DO delta (mg/L)	21	*	(*, *)	*

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_habit_burrow	AVG Daily DO delta (mg/L)	21	-0.119	(-0.525, 0.331)	0.607

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_habit_climb	AVG Daily DO delta (mg/L)	21	0.217	(-0.242, 0.596)	0.345

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_habit_climbcling	AVG Daily DO delta (mg/L)	21	0.116	(-0.333, 0.523)	0.615

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_habit_cling	AVG Daily DO delta (mg/L)	21	0.070	(-0.373, 0.488)	0.762

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_habit_sprawl	AVG Daily DO delta (mg/L)	21	-0.567	(-0.815, -0.145)	0.007

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_habit_swim	AVG Daily DO delta (mg/L)	21	0.331	(-0.130, 0.674)	0.143

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_habit_burrow	AVG Daily DO delta (mg/L)	21	0.217	(-0.242, 0.597)	0.345

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_habit_climb	AVG Daily DO delta (mg/L)	21	0.034	(-0.404, 0.459)	0.884

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_habit_climbcling	AVG Daily DO delta (mg/L)	21	0.169	(-0.287, 0.562)	0.464

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_habit_cling	AVG Daily DO delta (mg/L)	21	0.242	(-0.219, 0.614)	0.291

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_habit_sprawl	AVG Daily DO delta (mg/L)	21	-0.453	(-0.750, -0.004)	0.039

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_habit_swim	AVG Daily DO delta (mg/L)	21	0.133	(-0.319, 0.535)	0.566

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_habit_burrow	AVG Daily DO delta (mg/L)	21	-0.001	(-0.432, 0.431)	0.998

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_habit_climb	AVG Daily DO delta (mg/L)	21	0.237	(-0.223, 0.611)	0.301

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value

pt_habit_climbcling	AVG Daily DO delta (mg/L)	21	0.309	(-0.152, 0.660)	0.173

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_habit_cling	AVG Daily DO delta (mg/L)	21	0.229	(-0.231, 0.605)	0.319

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_habit_sprawl	AVG Daily DO delta (mg/L)	21	-0.664	(-0.864, -0.281)	0.001

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_habit_swim	AVG Daily DO delta (mg/L)	21	0.391	(-0.066, 0.713)	0.079

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_habit_cling_PlecoNoCling	AVG Daily DO delta (mg/L)	21	0.239	(-0.221, 0.612)	0.297

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_volt_multi	AVG Daily DO delta (mg/L)	21	0.181	(-0.276, 0.570)	0.434

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_volt_semi	AVG Daily DO delta (mg/L)	21	-0.532	(-0.795, -0.098)	0.013

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_volt_uni	AVG Daily DO delta (mg/L)	21	-0.264	(-0.629, 0.197)	0.248

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_volt_multi	AVG Daily DO delta (mg/L)	21	0.197	(-0.260, 0.583)	0.391

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_volt_semi	AVG Daily DO delta (mg/L)	21	-0.055	(-0.475, 0.387)	0.814

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_volt_uni	AVG Daily DO delta (mg/L)	21	-0.122	(-0.527, 0.328)	0.598

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_volt_multi	AVG Daily DO delta (mg/L)	21	0.504	(0.064, 0.780)	0.020

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_volt_semi	AVG Daily DO delta (mg/L)	21	-0.468	(-0.759, -0.020)	0.033

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_volt_uni	AVG Daily DO delta (mg/L)	21	-0.256	(-0.624, 0.205)	0.263

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom01	AVG Daily DO delta (mg/L)	21	0.282	(-0.179, 0.641)	0.216

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom02	AVG Daily DO delta (mg/L)	21	0.166	(-0.289, 0.560)	0.471

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom03	AVG Daily DO delta (mg/L)	21	0.108	(-0.341, 0.516)	0.642

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom04	AVG Daily DO delta (mg/L)	21	0.018	(-0.417, 0.446)	0.938

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom05	AVG Daily DO delta (mg/L)	21	0.006	(-0.426, 0.437)	0.978

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom06	AVG Daily DO delta (mg/L)	21	0.052	(-0.389, 0.473)	0.823

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom07	AVG Daily DO delta (mg/L)	21	0.049	(-0.391, 0.471)	0.832

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom08	AVG Daily DO delta (mg/L)	21	0.096	(-0.351, 0.508)	0.679

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom09	AVG Daily DO delta (mg/L)	21	0.123	(-0.327, 0.528)	0.594

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pi_dom10	AVG Daily DO delta (mg/L)	21	0.151	(-0.303, 0.549)	0.515

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_Becks	AVG Daily DO delta (mg/L)	21	-0.630	(-0.848, -0.231)	0.002

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_Becks3	AVG Daily DO delta (mg/L)	21	-0.758	(-0.908, -0.436)	0.000

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_HBI	AVG Daily DO delta (mg/L)	21	0.571	(0.150, 0.817)	0.007

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_HBI2	AVG Daily DO delta (mg/L)	21	0.590	(0.175, 0.827)	0.005

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_NCBI	AVG Daily DO delta (mg/L)	21	0.590	(0.175, 0.827)	0.005

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_Shan_e	AVG Daily DO delta (mg/L)	21	-0.065	(-0.483, 0.378)	0.780

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_Shan_2	AVG Daily DO delta (mg/L)	21	-0.065	(-0.483, 0.378)	0.780

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_Shan_10	AVG Daily DO delta (mg/L)	21	-0.065	(-0.483, 0.378)	0.780

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_D	AVG Daily DO delta (mg/L)	21	-0.174	(-0.566, 0.282)	0.451

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_D_G	AVG Daily DO delta (mg/L)	21	-0.117	(-0.523, 0.333)	0.614

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_D_Mg	AVG Daily DO delta (mg/L)	21	-0.104	(-0.514, 0.344)	0.654

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
x_Evenness	AVG Daily DO delta (mg/L)	21	-0.160	(-0.555, 0.295)	0.489

Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
nt_oneind	AVG Daily DO delta (mg/L)	21	-0.246	(-0.617, 0.215)	0.283

Pairwise Spearman Correlations

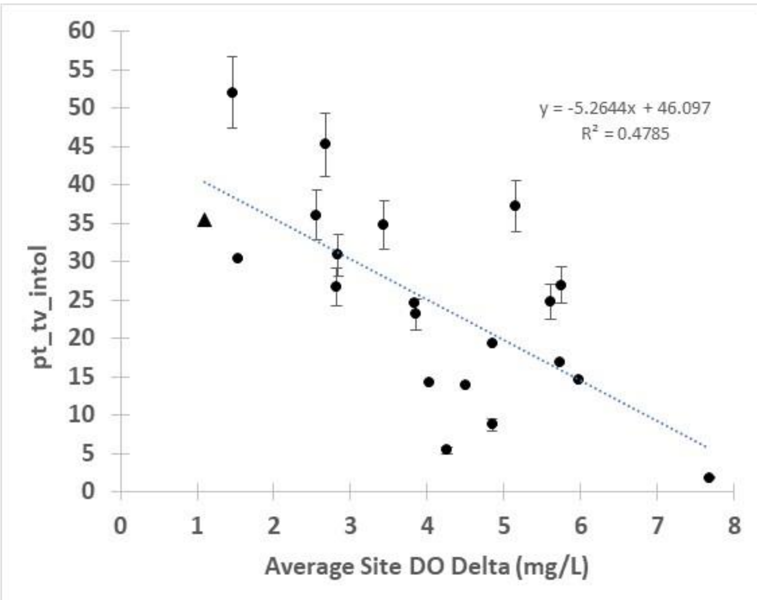
Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
pt_oneind	AVG Daily DO delta (mg/L)	21	-0.194	(-0.580, 0.264)	0.401

Pairwise Spearman Correlations

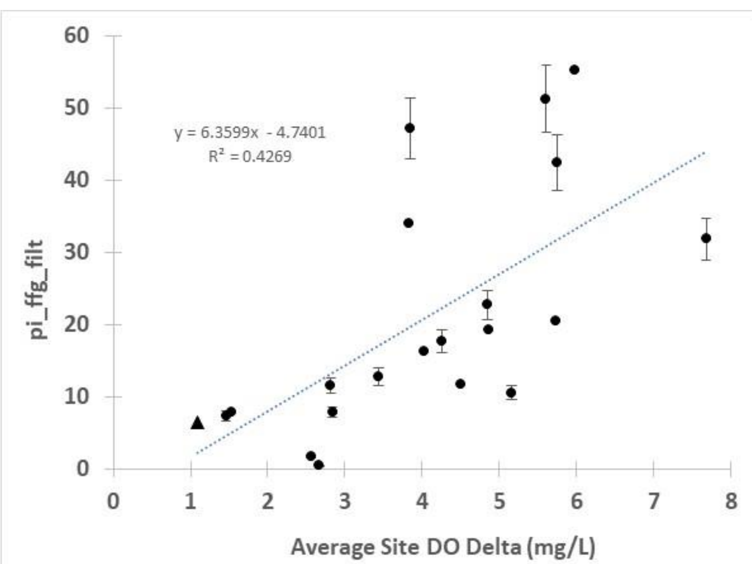
Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
BPJ_Eutrophication_Rating	AVG Daily DO delta (mg/L)	21	0.827	(0.568, 0.937)	0.000

APPENDIX G: THREE SIGNIFICANT SCATTERPLOTS WHICH WERE NOT CARRIED FORWARD TO CHANGE-POINT ANALYSIS

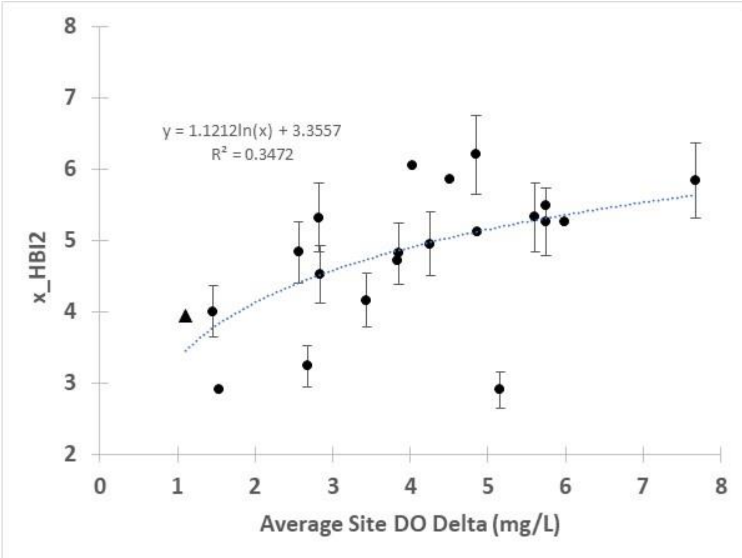
See **Section 2.4** of **Part IA** for explanation of the scatterplot's error bars.



Scatterplot of DO Δ vs. pt_tv_intol (percent of taxa with tolerance value ≤ 3). This is a metric comprising intolerant taxa. **Reason for Exclusion**: Linear relationship.

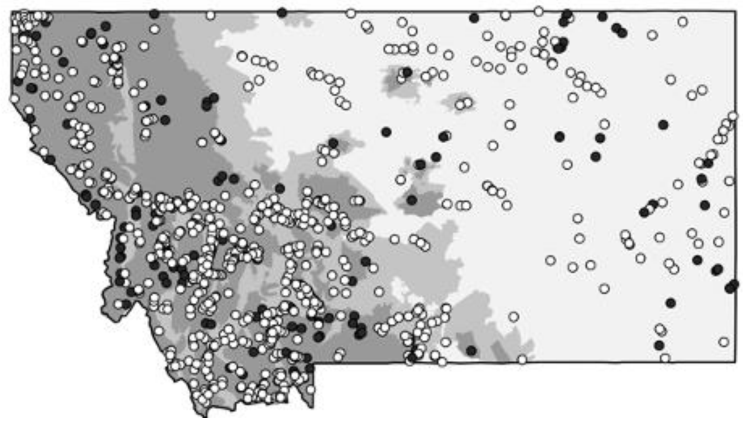


Scatterplot of DO Δ vs. pi_ffg_filt (percent individuals that are collector-filterers). This is a metric comprising generalist taxa. **Reason for Exclusion**: Linear relationship, behavior of the metric under perturbation is described as variable (Barbour et al., 1999).



Scatterplot of DO Δ vs. x_HBI2 (Hilsenhoff Biotic Index version 2). Curvilinear relationship. **Reason for Exclusion**: Redundant information to x_HBI; the plot is nearly identical to **Figure 3-7**.

Eutrophication thresholds associated with benthic macroinvertebrate condition in Montana streams



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1.0 Introduction

The Montana Department of Environmental Quality (DEQ) is developing a translation process for its narrative nutrient standards (Administrative Rules of Montana 17.30.637(1)(e)) that uses the responses of benthic macroinvertebrate community characteristics (i.e., metrics) to causal eutrophication indicators (nitrogen, phosphorus, benthic algal chlorophyll *a*, and benthic algal ash-free dry weight) as part of the process of interpreting the standards.

Benthic macroinvertebrates are often considered to be secondary indicators of nutrient enrichment in wadeable streams (Mazor et al. 2022). Nitrogen and phosphorus are the most common causes of eutrophication in freshwater ecosystems, which often leads to an excess of benthic algae (or periphyton) on the streambed (Poikane et al. 2021). Such algal growth can reduce the quality of food, available habitat, and oxygen availability for macroinvertebrates (Bowman et al. 2007). The community composition of macroinvertebrates (i.e., the relative numbers of taxa and individuals at a location) reflects these responses to nutrient enrichment over time (Chambers et al. 2006). Therefore, macroinvertebrates can be used as robust, integrative indicators of eutrophication and biological condition (Heiskary and Bouchard 2015).

This report documents the analysis of thresholds, or change points, in the relationships between macroinvertebrate metrics and eutrophication indicators to support the translation of Montana's narrative nutrient standards relative to macroinvertebrate condition. This analysis follows a weight-of-evidence, or multiple-lines-of-evidence, approach that is recommended by the U.S. Environmental Protection Agency (EPA) for development of nutrient criteria, which integrates reference site distributions, predictive relationships, existing thresholds, and best professional judgment. The specific objectives of the present study were to:

- Curate water quality data for co-analysis with existing macroinvertebrate metric data,
- Characterize the macroinvertebrate metrics that are most responsive to eutrophication indicators (total nitrogen, total phosphorus, benthic algal chlorophyll *a*, and benthic algal ash-free dry weight),
- Identify candidate thresholds in macroinvertebrate metrics and eutrophication indicators for each of three macroinvertebrate regions in Montana (Mountains, Low Valleys and Transitional, and Plains) using multi-model selection and reference site distributions,
- Determine additional effects of covariates (e.g., temperature, flow, pH, specific conductance) on candidate thresholds after accounting for the influence of eutrophication indicators,
- Test whether multimetric indices (MMIs) yielded higher explanatory power or substantially different causal variable changepoints than single metric models in threshold analysis of macroinvertebrate condition.

2.0 Data preparation

2.1 Macroinvertebrate metrics

Prior to the present analysis, Rhithron Associates, Inc. downloaded all benthic macroinvertebrate count data from the Water Quality Portal (WQP) and also identified all relevant data from its own database that were collected in Montana by DEQ, EPA, and other collaborators. Taxonomy was harmonized, and samples were curated according to macroinvertebrate and site selection criteria: adequate target count, consistent field and laboratory methods, wadeable streams/medium rivers only, and an index period between 2005 and 2021. From the count data, 191 metrics were generated using BioMonTools (Leppo et al. 2021) across 577 harmonized taxa and 1606 curated samples. Most metrics were calculated in four ways: number of taxa (prefix "nt_"), percent of taxa ("pt_"), number of individuals ("ni_"), and percent of individuals ("pi_"). Metrics that represent diversity or tolerance indices were calculated according to the respective formula. This sample-by-metric matrix defined the site and date ranges of the present analysis.

All data processing and analysis in the present work was conducted using R v.4.2.0 (R Core Team 2022). For samples from the same site and date (e.g., from field replicates or methods comparisons), values from each metric were averaged to reduce the influence of patterns caused by the geographic proximity of samples or the date of measurement (i.e., spatial and temporal autocorrelation). Repeat visits to sites between 2005 and 2021 were retained to account for variable water quality conditions and macroinvertebrate assemblages over this 17-year time period. Following deduplication, 1415 samples remained.

2.2 Macroinvertebrate regions

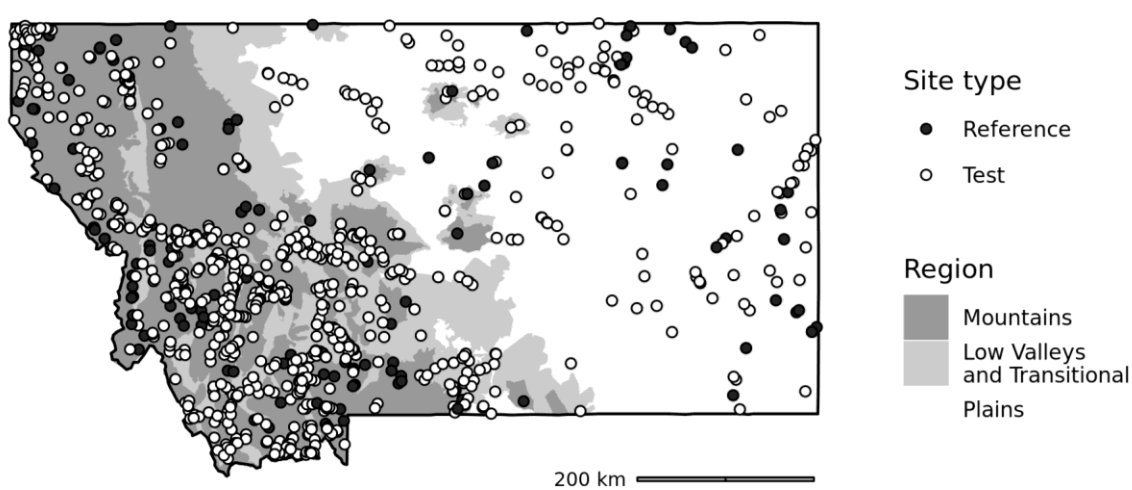

Figure 1. Map of Montana macroinvertebrate regions with reference and test sites used in the present analysis.

During construction of MMIs and observed/expected models for Montana, Jessup et al. (2006) determined that Montana stream macroinvertebrates were best classified according to three site classes that parallel previously defined physiographic and ecological regions: Mountains, Low Valleys, and Plains. Community composition of reference sites strongly differed among these macroinvertebrate regions. Subsequent work showed that transitional regions on the eastern side of the Rocky Mountain front are biologically more similar to western Montana than to the plains further to the east (Teply and Bahls 2007); this pattern is consistent with earlier ecoregion maps which describe a “Montana Valleys and Foothill Prairies” ecoregion (Bahls et al. 1992). Therefore, the present analysis focused on region-specific analyses of Mountains, Low Valleys and Transitional, and Plains – hereafter referred to as macroinvertebrate regions. Jessup et al. (2006) listed a subset of ecoregions and other geographic characteristics belonging to each macroinvertebrate region, but this list was incomplete given the site list used in the present study. In consultation with DEQ, macroinvertebrate regions were defined according to current Level III and IV Ecoregions (Woods et al. 2002) as listed in Table 1.

Table 1. Level II and IV Ecoregions associated with each Montana macroinvertebrate region.

Macro-invertebrate region	Ecoregions
Mountains	15. Columbia Mountains/Northern Rockies (excl. 15c Flathead Valley) 16. Idaho Batholith 17. Middle Rockies (excl. Level IV Ecoregions in Low Valleys and Transitional) 41. Canadian Rockies
Low Valleys and Transitional	15c. Flathead Valley 17s. Bitterroot-Frenchtown Valley 17u. Paradise Valley 17w. Townsend Basin 17aa. Dry Intermontane Sagebrush Valleys 17ac. Big Hole 17ak. Deer Lodge-Philipsburg-Avon Grassy Intermontane Hills and Valleys 42l. Sweetgrass Uplands 42n. Milk River Pothole Upland 42q. Rocky Mountain Front Foothill Potholes 42r. Foothill Grassland 43s. Non-calcareous Foothill Grassland 43t. Shield-Smith Valleys 43u. Limy Foothill Grassland 43v. Pryor-Bighorn Foothills 43o. Unglaciated Montana High Plains
Plains	18. Wyoming Basin 42. Northwestern Glaciated Plains (excl. Level IV Ecoregions in Low Valleys and Transitional) 43. Northwestern Great Plains (excl. Level IV Ecoregions in Low Valleys and Transitional)

2.3 Water quality data

Water quality data were downloaded from the WQP using the following search parameters: *State: Montana, Site Type: Stream, Date Range: 01-01-2005 to 12-31-2021, Data Profiles: Sample Results*. A total of 1606559 observations from 6669 sites were reported. Data were filtered to sites in the metric dataset (column: *MonitoringLocationIdentifier*) and water quality variable (column: *CharacteristicName*), targeting variables associated with four primary eutrophication indicators (nitrogen, phosphorus, benthic algal chlorophyll *a*, and benthic algal ash-free dry weight [AFDW]) and an assortment of background variables or other stressors known to influence macroinvertebrates (alkalinity, aluminum, chloride, dissolved oxygen, flow, hardness, iron, magnesium, mercury, pH, sodium, sulfate, temperature, solids, specific conductance, turbidity, and zinc). Water quality variables were separated by media (e.g., water or sediment) and fraction (e.g., total or dissolved) and converted each variable to consistent units.

For most samples across the index period, benthic chlorophyll *a* and AFDW were sampled from multiple transects using either template, hoop, or sediment core collection methods (DEQ 2021). Biomass values were then calculated as weighted averages of each method (excluding sediment cores for AFDW). In the WQP, most biomass values were reported as final weighted averages, but some were reported as individual transect values or method-specific composite values, each of which required further analysis for harmonization. Processing of benthic algal biomass records was as follows:

- Pre-calculated weighted averages or composite measurements with only a single collection method across all transects (chlorophyll *a*) or non-sediment core transects (AFDW). No further analysis. 68% of samples.
- Individual transect values by collection method (i.e., template, hoop, or core). Weighted average site means were calculated ignoring non-detect transects (including 0.5 * detection limits yielded mean values that were highly correlated to those from ignoring non-detects, Pearson $r = 0.99$) and excluding core transects from AFDW calculations. 20% of samples.
- Chlorophyll *a* measurements from the surface area of a single rock. All records were from 2005. No further analysis. 6% of samples.
- No method reported. All records were from the 2019 National Aquatic Resource Surveys. No further analysis. 6% of samples.

Prior to further data processing, water quality measurements were averaged across multiple samples taken at the same site on the same day, as was done for macroinvertebrate metrics. Accordingly, a sample was defined as a unique site-by-date.

To account for multiple detection limits and/or reporting limits for a given water quality variable across the index period, the 5th percentile of each water quality variable was calculated across all samples, excluding non-detects. If 0.5 * detection limit was less than or equal to the 5th percentile, 0.5 * detection limit was used as the measured value. If 0.5 * detection limit was greater than the 5th percentile, the observation was removed. Among eutrophication indicators, 2% of TN, 0% of TP, 4% of benthic chlorophyll *a*, and 0% of benthic AFDW observations were removed with this approach.

Since macroinvertebrate responses to water quality are integrative over time and water quality measurements were not always collected the day of macroinvertebrate sampling, the water quality values for each sample-by-variable from up to 30 days before and 7 days after macroinvertebrate sampling were averaged. This increased the number of samples with data for eutrophication indicators by ~5 – 20%, depending on the variable.

The most commonly observed fraction of each eutrophication indicator was selected: total nitrogen (TN), total phosphorus (TP), benthic algal chlorophyll *a* (corrected for pheophytin), and benthic algal AFDW. Six other variables had observations in at least 50% of samples and were selected for further analysis: water temperature, flow, pH, hardness, specific conductance, and total suspended solids.

Extreme outliers for each variable were removed based on manual inspection of distributions and consultation with DEQ regarding anomalous events, nontarget sites, and possible equipment malfunction. During outlier removal, 5 sites (each with one sample) were removed, as they represented large rivers. As a result, 1410 samples with macroinvertebrate metric and water quality data were used in further analysis (Table 2, Table S1).

The distribution of each water quality variable-by-region was assessed using histograms (Figure S1). All variables except temperature and pH followed a log-normal distribution. That is, after log10(x) transformation, the variable was approximately normally distributed. Otherwise, each variable was strongly right skewed, with the vast majority of observations clustered at the low end of the variable range and few observations of very large values. Transforming log-normal variables was necessary prior to data analysis to (1) stabilize the variance across the entire range of values, (2) ensure that normality assumptions of the statistical methods used were met, (3) allow models to more sensitively determine relationships between metrics and water quality variables across dynamic response ranges, and (4) decrease the influence of rare, extreme observations. Therefore, all variables except temperature and pH, which were already normally distributed, were log10(x) transformed prior to data analysis. Flow values were log10(x + 1) transformed due to observations of 0 cfs.

Table 2. Water quality variables selected for data analysis. Values are based on samples remaining after outlier removal. Values for each region are mean (standard deviation) across all samples and reference samples.

Variable	Outlier threshold	Samples		Mountains		Low Valleys and Transitional		Plains	
		All	Ref.	All	Ref.	All	Ref.	All	Ref.
Samples		1410	319	689	206	461	47	260	66
Total nitrogen, TN (mg/L)	2	929	298	0.16 (0.25)	0.10 (0.15)	0.38 (0.54)	0.14 (0.07)	0.99 (0.79)	1.21 (0.87)
Total phosphorus, TP (mg/L)	5	1067	297	0.02 (0.04)	0.01 (0.02)	0.04 (0.08)	0.02 (0.02)	0.11 (0.20)	0.10 (0.12)
Benthic chlorophyll *a* (mg/m^2)	1300	733	232	17.02 (20.35)	12.02 (9.79)	29.33 (35.10)	44.59 (42.09)	38.19 (67.42)	31.81 (27.49)
Benthic ash-free dry weight, AFDW (g/m^2)	300	422	168	13.29 (21.66)	5.77 (9.90)	22.53 (35.27)	19.96 (18.26)	17.67 (16.54)	13.67 (12.45)
Water temperature (°C)	*na*	1190	261	11.50 (3.57)	10.42 (3.20)	14.26 (3.38)	13.75 (3.10)	21.46 (4.23)	21.52 (5.00)
Flow (cfs)	2000	922	253	19.16 (65.38)	13.52 (18.60)	49.16 (157.82)	11.25 (17.73)	78.74 (182.16)	2.08 (4.72)
pH	*na*	1095	253	7.92 (0.68)	7.78 (0.62)	8.21 (0.48)	8.14 (0.34)	8.40 (0.53)	8.44 (0.54)
Hardness (mg/L)	2000	750	259	97.74 (89.58)	66.02 (54.46)	164.30 (92.16)	121.60 (67.13)	355.94 (280.80)	382.45 (306.84)
Specific conductance (μS/cm)	11000	1116	215	186.18 (173.65)	150.71 (212.14)	323.56 (268.41)	219.91 (111.52)	1616.84 (1473.60)	2088.10 (1284.90)
Total suspended solids (mg/L)	5000	886	262	4.70 (9.95)	1.06 (1.92)	7.67 (9.34)	3.84 (4.57)	60.10 (102.15)	50.04 (77.14)

2.4 Dataset summary

Following data curation, 1410 discrete samples from 983 wadeable streams and medium rivers were retained for data analysis. Of these, 319 represented reference sites. Nine metrics had 0 standard deviation across these samples and were removed, leaving 182 metrics from 6 categories: diversity, phylogeny, tolerance, functional feeding group, habit, and life history (voltinism). 1291 samples had an observation for at least one eutrophication indicator or water quality variable. For the 4 target eutrophication indicators, TP had the most observations (1067 samples), followed by TN (928), benthic chlorophyll *a* (732), and benthic AFDW (422). Reference sites had significantly lower TN and TP than test sites in the Mountains and Low Valleys and Transitional, but not in the Plains (Figure 2). Meanwhile, benthic chlorophyll *a* in reference sites was lower than that in test sites only in the Mountains, while benthic AFDW was lower in reference sites in the Mountains and Plains.

3.0 Correlation analysis

Correlations among water quality variables, metrics, and water quality variable-metric pairs were calculated to (1) select water quality variables that represented distinct gradients of local conditions, (2) identify groups of highly similar metrics to screen metrics during threshold analysis, and (3) identify metrics that responded strongly to eutrophication indicators.

3.1 Methods: correlation analysis

For each macroinvertebrate region, Spearman rank correlations with significance tests were calculated between each pair of log-transformed water quality variables, macroinvertebrate metrics, and metrics-water quality variables. Samples with missing values for any variable in a given pair were ignored. Correlations were calculated using ‘cor.test’ in the R *stats* package. For metric and metric-water quality correlations, clusters of highly correlated metrics were determined using k-means clustering to identify groups of both highly similar metrics and those metrics that responded similarly to water quality variables. For numbers of clusters between 2 and 10, the within-cluster sum of squares (WCSS) was calculated, which measures the variance within clusters. The optimal number of clusters was then determined as the point at which the rate of decrease in WCSS was lower than the average rate of change across the range of candidate numbers of clusters. This point represents the “elbow” at which adding more clusters does not substantially decrease WCSS, indicating a leveling off in the explained variance.

3.2 Results: correlation analysis

3.2.1 Water quality correlations

In general, eutrophication indicators were moderately correlated across regions, but none so strongly that they were considered to represent the same gradient (Figure 3, Table S2). TN and TP were positively correlated in each region ($\rho > 0.4$), with the strongest correlation in the Plains ($\rho = 0.72$). Benthic chlorophyll *a* was not significantly correlated with nutrients in any region, but was correlated with AFDW across regions (ρ between 0.48 and 0.59). Meanwhile, benthic AFDW was weakly, positively correlated with nutrients in the Mountains and Low Valleys and Transitional but more strongly and negatively correlated with nutrients in the Plains. With regards to other water quality variables, nutrients were moderately, positively correlated with

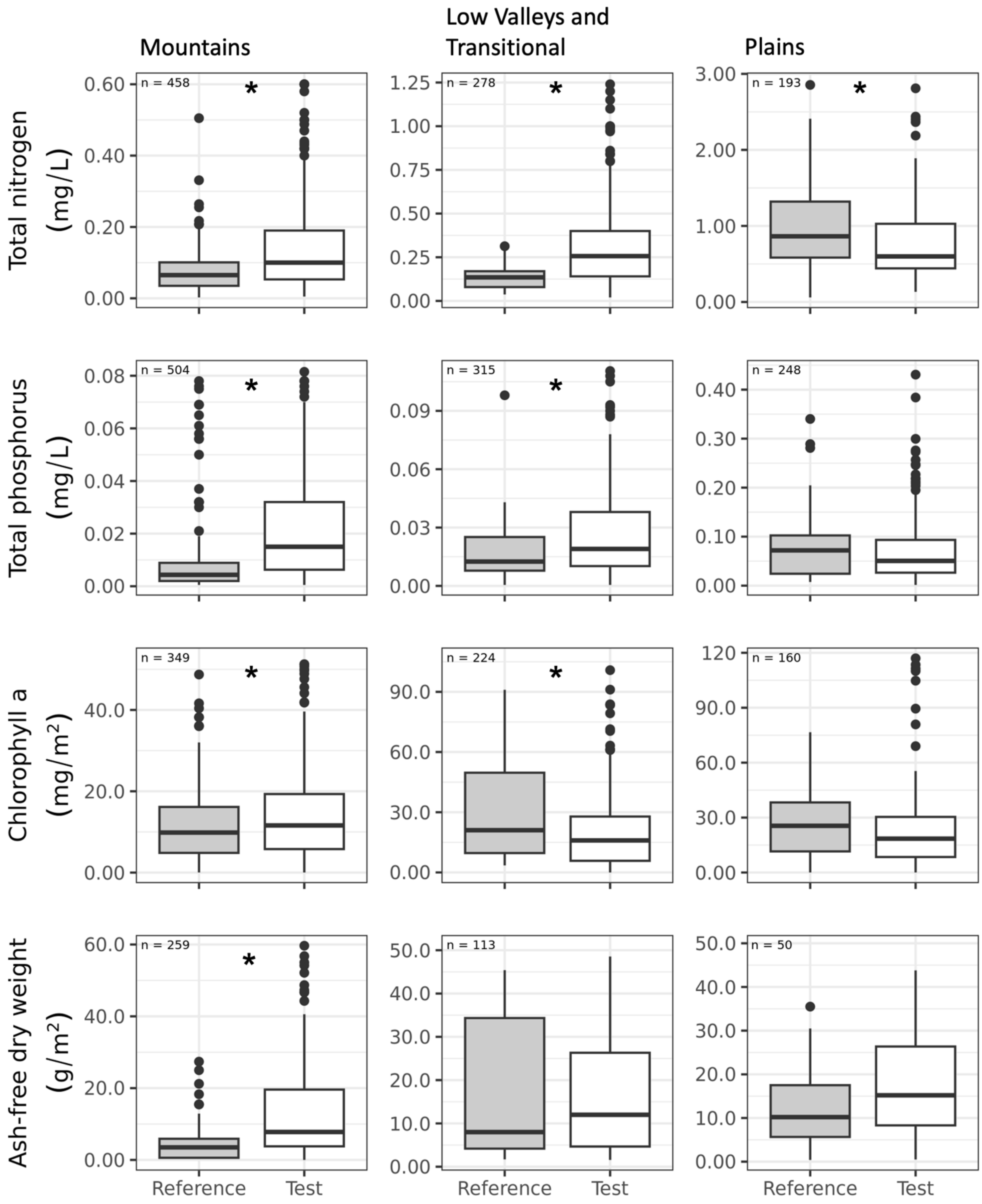

Figure 2. Boxplots of untransformed eutrophication indicators by region and site type (reference or test). The y axes extend only to the 95th percentile of observations to better visualize the contrast between reference and test sites. The n values in the upper left corner of each plot correspond to the number of samples with observations for the given eutrophication indicator-by-region. Asterisks indicate significant differences in means at $p < 0.05$ (Welch's t-tests).

specific conductance and total suspended solids in each region ($\rho > 0.3$). Among water quality variables, hardness and specific conductance were strongly, positively correlated – particularly in the Mountains and Low Valleys and Transitional. Since more observations were available for specific conductance across the dataset, hardness was removed from further analysis. Otherwise, few strong correlations were apparent among water quality variables.

3.2.2 Metric correlations

Spearman correlations among metrics were calculated to assess redundancy among metrics (Figure S2, Table S3). Variations of the same base metric (e.g., pi_EPT, pt_EPT, nt_EPT) were highly correlated regardless of region. In each region, highly correlated metrics were separated into 4 – 5 clusters. Each region contained clusters characterized by Ephemeroptera/Plecoptera/Trichoptera (EPT) taxa, intolerant taxa, Shannon diversity, and Beck's Biotic Index; proportion of dominant or tolerant taxa alongside the Hilsenhoff Biotic Index (HBI); non-insect taxa; and varying combinations of taxa, habits, and/or functional feeding groups. Importantly, correlations among metrics were not used to select metrics for further analysis, as a data-driven, all-metrics approach to threshold analysis was used to harness the power of the dataset. Correlations were used in later analyses to remove MMIs that contained highly correlated metrics. Given the number of comparisons, correlation matrices and heatmaps are provided as supplementary files.

3.2.3 Metric-water quality correlations

Overall, relationships between most metrics and water quality variables followed expected patterns based on historical responsiveness of metrics (Figure S3, Table S4). In general, highly correlated metrics in the metrics-only correlations clustered together in their relationships with water quality variables. In each region, water quality variables were generally clustered into three groupings: flow, total nitrogen and specific conductance with other miscellaneous variables, and temperature and benthic chlorophyll *a* with other miscellaneous variables (Table 3). Metrics that were most responsive to eutrophication indicators were EPT taxa, intolerant taxa, Beck's Biotic Index, and diversity indices (negatively correlated) and tolerant taxa, dominant taxa, and HBI (positively correlated).

Nevertheless, regions differed slightly in the specific groupings of variables and metrics, as well as in the strength of correlations. For example, in the Low Valleys and Transitional, metrics were most strongly correlated with flow, hardness, TN, and AFDW. Meanwhile, there were weaker correlations between EPT taxa and nutrients than in the Mountains. Similarly, there were fewer strong, positive relationships between metrics and nutrients in the Plains than in the Mountains or Low Valleys and Transitional, while metrics were more strongly related to flow and AFDW.

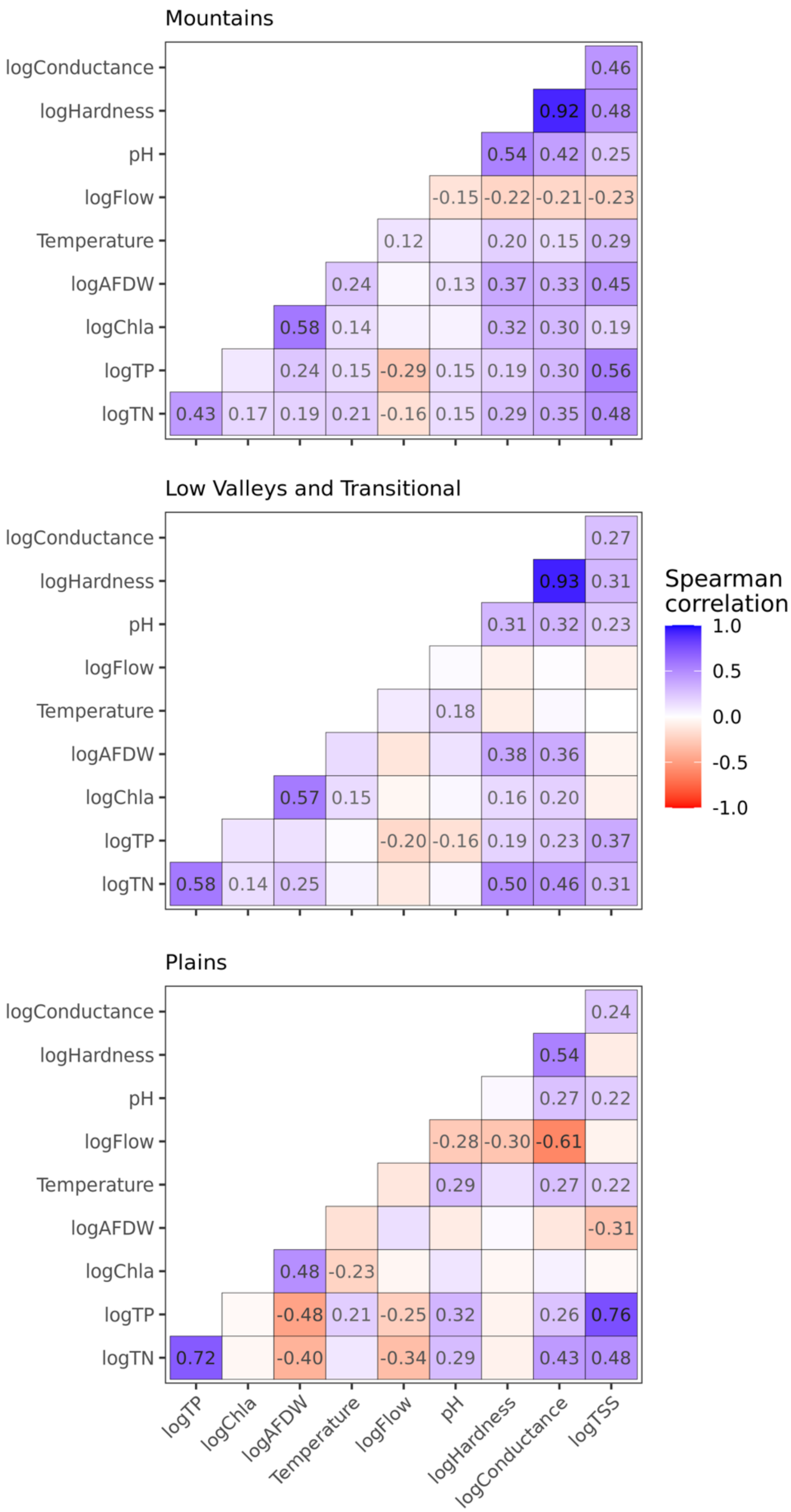

Figure 3. Spearman rank correlations among water quality variables by region. Significant correlations are shown with their correlation coefficients ($p < 0.05$).

Correlations between metrics and water quality variables were used as a preliminary screening of metric responsiveness to eutrophication indicators. However, linear and nonlinear modeling of all metrics was used as a more robust measure of these relationships. Correlation matrices and heatmaps are provided as supplementary files.

Table 3. General direction and strength of Spearman rank correlations between metric clusters and water quality variable clusters across regions. + refers to positive correlation, - to negative correlation. The number of symbols ranges from one (weak) to three (strong) to approximate the absolute strength of correlation.

Metric clusters	Flow	Total nitrogen/ Specific conductance/ Others	Temperature/ Chlorophyll *a*/ Others
Tolerant taxa, HBI	-	+++	+
Dominant taxa	-	++	+
EPT taxa, intolerant taxa, Becks, Shannon	++	- -	-
Total individuals, scrapers, omnivores, predators	+	-	-/+
Various groups, incl. non-insects, Hydropsychidae, Isopoda, Chironomidae, Coleoptera	-/+	+/-	+/-

4.0 Threshold analysis

4.1 Methods: threshold analysis

The goal of threshold analyses was to identify relationships between metrics and eutrophication indicators from which thresholds or change points could be determined using piecewise linear regression and/or nonlinear regression models. Analysis followed an all-metrics procedure with iterative model selection based on multiple lines of evidence. The next section provides an overview of the process. Subsequent sections describe each step in further detail.

4.1.1 Workflow

For each metric-eutrophication indicator pair, multiple models were computed - including linear regression, piecewise linear regressions (i.e., segmented regression), and nonlinear regressions. These models were univariable: that is, composed of a single metric as the response variable and a single eutrophication indicator as the explanatory variable. Rather than target a subset of metrics from correlation analyses, all metrics were considered in separate models. Models with multiple eutrophication indicators or water quality variables as explanatory variables (i.e., multiple regressions or multivariable models), were not considered because the focus was on determining thresholds associated with eutrophication. "Controlling" for variation in background variables at the outset can reduce the ability to detect relationships with target variables and reduce the sample dataset due to differential data collection. Potential independent effects of non-target variables like temperature or specific conductance were later accounted for via analysis of model residuals.

For each macroinvertebrate region, the top models of each eutrophication indicator were selected as those with the highest variation explained (R^2 values) and best model quality (Akaike Information Criterion, AIC). Across metrics, models from each of the four eutrophication indicators were compared, and the indicator with the highest variation explained was used to calculate thresholds of eutrophication impact. Thresholds were calculated as the regions of substantial change in the regression model. Each candidate threshold was validated by the distribution of reference sites.

Next, the extent to which other eutrophication indicators, background variables, and other stressors - together referred to as covariates - explained additional variation in the metric-eutrophication indicator relationships was assessed. This was done by calculating the residuals of the univariable model (i.e., the differences between observed metric values and the metric values predicted by the single eutrophication indicator model) and using the residuals as the response variable in univariable models that used each covariate as an explanatory variable.

4.1.2 Step 1: Selecting the strongest models between metrics and eutrophication indicators

First, the relationships between each metric and log-transformed eutrophication indicator (TN, TP, benthic chlorophyll *a*, and benthic AFDW) were characterized by six separate models (Figure 4):

- **Simple linear regression** - a straight line. If its R^2 was greater than or within 0.01 of another model, the relationship was considered linear, and no threshold could be determined. Calculated using 'lm' in *stats*.
- **Single breakpoint piecewise linear regression** - a "hockey stick" model with a single inflection point between two straight lines, each with different slopes. If its R^2 was within 0.05 of a nonlinear asymptotic or logistic regression, the nonlinear model was selected because of its relative simplicity of construction and interpretation. Calculated using 'segmented' in *segmented*, with npsi = 1, which forces the starting value of the breakpoint to be internally computed based on quantiles.
- **Double breakpoint piecewise linear regression** - a "broken stick" model with two inflection points between three straight lines, each

with different slopes. If its R^2 was within 0.05 of a nonlinear logistic regression, the logistic model was selected because of its relative simplicity of construction and interpretation. Calculated using ‘segmented’ in *segmented*, with npsi = 2, which forces the starting values of the breakpoint to be internally computed based on quantiles (Muggeo 2003).

- **Asymptotic regression** - a nonlinear model resembling a growth curve or exponential decay towards an asymptote. If its R^2 was within 0.05 of a logistic regression, the logistic model was selected because of its ability to characterize three potential thresholds (see below) instead of using the minimum or maximum value of the eutrophication indicator as a threshold. Calculated using ‘SSasymp’ in *stats*, a ‘selfStart’ model that internally calculates the starting values for model parameters (horizontal asymptote, response when input is 0, and natural log of the rate constant).
- **Four parameter logistic regression** - a nonlinear model resembling a sigmoid or S-shaped curve that has an upper and lower asymptote. If its R^2 was greater than that of linear regression and within 0.05 of any other model, this model was selected because of its ability to characterize three potential thresholds: initialization (change from asymptote to exponential change), maximum change (midpoint of curve representing linear change), and saturation (change from exponential change to another asymptote). Calculated using ‘SSfpl’ in *stats*, a ‘selfStart’ model that internally calculates the starting values for model parameters (left and right horizontal asymptotes, input value at the inflection point of the curve, and a numeric scale parameter).
- **Generalized additive models (GAMs)** - a nonlinear model that resembles a flexible, smooth curve that captures complex relationships. These models are superficially similar to the nonparametric locally weighted scatterplot smoothing (LOWESS) in that a “wiggly” line is fit to the relationship, but GAMs can be used to generate an R^2 value. GAMs were used to approximate the maximum amount of explicable variation between a metric and eutrophication indicator. If the R^2 of the GAM was greater than 0.05 of piecewise, asymptotic, and logistic regressions, the relationship was considered too complex for thresholds to be characterized, and the metric was removed from consideration for the given indicator. Given the complexity of GAMs relative to other modeling approaches, GAMs were not used to estimate

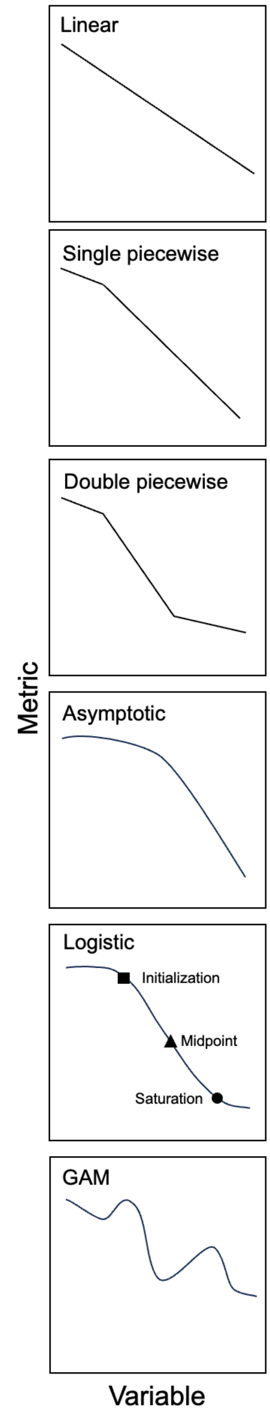

Figure 4. Conceptual plots of curves from linear and nonlinear models

potential thresholds of change. Calculated using 'gam' in *mgcv* with 'family' = Gaussian and the eutrophication indicator as a smooth term using the default number of knots, 'k' (Wood 2011).

For each eutrophication indicator, the 95th percentile of GAM R^2 values across metrics was used as the minimum R^2 required for a piecewise, asymptotic, and/or logistic model to be considered as sufficiently explanatory for the metric-indicator relationship. In each region, at least 10 metrics met this 95th percentile cutoff, so model selection for each metric proceeded.

For each region and each metric-by-indicator, the logistic model was selected as the most explanatory model (or had functionally equivalent explanatory power as other models).

4.1.3 Step 2: Selecting the most responsive eutrophication indicator

The second step was to determine which eutrophication indicator yielded the strongest relationship with candidate metrics. The 95th percentiles of R^2 values from logistic models for each eutrophication indicator were compared.

In each region, the relationships between metrics and TN were the strongest (i.e., the 95th percentile of R^2 for the top metrics and TN was greater than the 95th percentile of R^2 for the top metrics and TP, benthic chlorophyll *a*, or benthic AFDW). Therefore, TN was used as the explanatory variable in the initial models used to determine thresholds prior to modeling covariate relationships. For each region, all metric-TN logistic models with R^2 values within 75% of the top metric-TN logistic model R^2 were selected for further analysis.

4.1.4 Step 3: Determining metric and total nitrogen thresholds

For the third step, threshold values for the metric and TN were determined from logistic models. Three thresholds were estimated: initialization (the point of change from the first asymptote to exponential change), maximum change (the midpoint of the curve representing linear change), and saturation (the point of change from exponential change to the second asymptote). Initialization and saturation thresholds were calculated as the point on either side of the midpoint at which the slope was 50% of that at the midpoint.

Following consultation with DEQ and based on EPA guidance (EPA 2000), the distribution of reference sites was used to determine which, if any, threshold to set based on the model. If 75% of reference sites had TN concentrations below and metric values above (for metrics that decreased with TN) or below (for metrics that increased with TN) the initialization point of the curve, the initialization point would be the candidate threshold. If 75% of reference sites were between the initialization and midpoints of the curve, the midpoint of the curve would be the candidate threshold. If 75% of reference sites exceeded the midpoint, the metric was considered to be overly responsive and a poor indicator of the effects of eutrophication (i.e., reference sites were characterized by too high of TN and/or too low or high of metric values) (Figure 5). Additionally, the candidate threshold was considered to be the threshold value from the curve instead of the 75th reference site percentile point along the curve, because the 75th reference percentile value is being used primarily as a benchmark for threshold decision making and is more representative of the underlying dataset rather than the overall shape of the distribution.

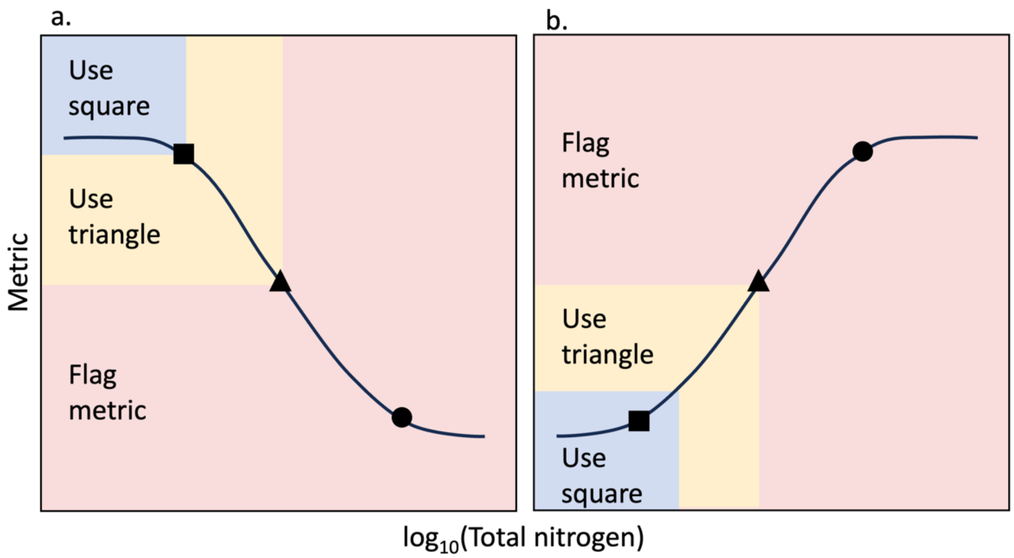

Figure 5. Conceptual plots of reference thresholds in logistic curves for (a) metrics that decrease with total nitrogen (i.e., high metric values are generally associated with good biological condition) and (b) metrics that increase with total nitrogen (i.e., low metric values are generally associated with good biological condition). If 75% of reference sites had metric and total nitrogen values in a given colored polygon (i.e., the point of intersection between hypothetical vertical and horizontal lines denoting the 75^{th} percentile of reference sites for each axis), the denoted point of change in the curve was considered the candidate threshold point.

For illustrative purposes only, a top performing metric-TN model was selected from each region as a representative metric for which to report logistic model biplots, residual model biplots, and multimetric index (MMI) models.

4.1.5 Step 4: Estimating independent influences of other water quality variables

Following the calculation of region-specific thresholds in macroinvertebrate metrics relative to TN, the fourth step was to estimate additional variation of the metric that could be explained by other eutrophication indicators (TP, benthic chlorophyll *a*, and benthic AFDW) and other water quality variables (temperature, flow, pH, and specific conductance). To this end, the residuals of each metric-TN logistic model (i.e., the difference between observed metric values and predicted metric values) were calculated using ‘residuals’ in *stats*. These residuals were then used as the response variable in individual GAMs for each covariate (e.g., a GAM for residuals-by-TP, a GAM for residuals-by-AFDW, etc.). GAMs were used for this analysis because of their flexibility to model a variety of shapes between the residuals and covariates and, therefore, estimate the maximum amount of explicable variation. If the R^2 value of a residual-covariate

GAM was greater than 0.20, the covariate was considered to explain additional independent variation in the metric beyond that explained by TN alone.

4.1.6 Step 5: Comparing multimetric indices to single metric models

In addition to single metrics as the response variable in the initial metric-TN models, the extent to which MMIs increased the explanatory power of models over single metric models was tested. In general, MMIs operate on the principle that different metrics reflect different characteristics of the biological community, which in turn respond to different sources of water quality degradation. Therefore, MMIs are typically constructed and validated based on their ability to distinguish reference sites and disturbed sites, which are generally differentiated by a variety of stressors that represent general disturbance. Since the present analysis focused on the effects of eutrophication indicators on macroinvertebrate metrics, MMIs may have limited benefit over single metrics since multiple metrics must respond in complementary ways to only a single eutrophication indicator.

Nevertheless, MMI values were calculated using the methods of van Sickle (2010) - but MMI performance was not tested in the traditional way of differentiating reference and disturbed sites. Briefly, each metric was converted to a 0 - 10 scale, with values less than the 5th percentile set to 0 and values greater than the 95th percentile set to 10. For metrics with which reference sites had lower values, the metric was flipped (e.g., 10 became 0 and 0 became 10) so that all metrics shared the same scale and direction. It was expected that conducting region-specific analyses controlled for the strongest sources of variation in natural characteristics among sites. Therefore, so-called predictive MMIs were not generated, in which the influences of natural background variables like temperature, flow, or pH or landscape variables like watershed area, precipitation, soil lithology, and forest cover on a metric are "modeled out" (i.e., by using the residuals of a multivariable model between each metric and the landscape variables as the metric value).

For the representative metric of single metric models for each region, all 2- 4-metric combinations were determined regardless of metric category (e.g., Becks3 + nt_EPT, Becks3 + pt_ffg_pred, Becks3 + nt_EPT + pt_ffg_pred, etc.) - resulting in over 350000 MMI combinations for each region. For each of these MMIs, if the maximum correlation between scaled metrics was > 0.7 or < -0.7, the MMI was removed from consideration to reduce metric redundancy. For all other MMIs, scaled metric values were summed, divided by the number of metrics, and multiplied by 10 to get MMI scores that then spanned a 0 - 100 scale. Then, linear regressions, logistic regressions, and GAMs were calculated, with MMI scores as the response variable and TN (the top eutrophication indicator from single metric models) as the explanatory variable. The R^2, AIC, and TN threshold values from the top performing MMIs were compared to those of the top performing single metric models to determine if MMIs substantially increased the variation explained over single metric models and could be used to determine thresholds.

4.2 Results: threshold analysis

Detailed tables of model performance and logistic regression biplots for all top metrics are provided in supplementary files (Table S5, Figure S4).

4.2.1 Mountains

In the Mountains, 21 single metric models passed model selection and quality filtering, including removing logistic R^2 values less than 75% of that of the maximum. The 95th percentile of GAM R^2 values was 0.29, and logistic R^2 values ranged from 0.24 - 0.32. The maximum logistic R^2 was for the pt_tv_intol metric (0.32) and was greater than R^2 values of linear (0.26) and single breakpoint piecewise models (0.30) and comparable to double breakpoint piecewise (0.33) and GAM (0.34) values. Following the removal of redundant metrics (e.g., removing nt_tv_intol when pt_tv_intol had higher R^2), 8 metrics remained (Table 4). Of these, three metrics increased with TN (HBI, pt_tv_toler, pt_tv_stol).

Table 4. Top metrics and corresponding thresholds for the Mountains, arranged by logistic model R^2. Representative metric is bolded. Becks3 was selected as the representative metric instead of pt_tv_intol because it yielded comparable model performance and threshold values of TN and was also the top model in the Low Valleys and Transitional.

Metric	Description	Logistic R^2	Linear R^2	GAM R^2	TN threshold (mg/L)	Metric threshold
pt_tv_intol	Percent of intolerant taxa	0.32	0.26	0.34	0.155	42.16
Becks3	**Beck's Biotic Index v3**	**0.31**	**0.27**	**0.33**	**0.139**	**35.09**
nt_Pleco	Number of Plecoptera taxa	0.29	0.25	0.31	0.132	4.84
nt_EPT	Number of EPT taxa	0.28	0.24	0.29	0.139	18.13
HBI	Hilsenhoff Biotic Index	0.27	0.23	0.30	0.133	3.52
pt_tv_toler	Percent of tolerant taxa	0.26	0.21	0.29	0.159	12.31
nt_tv_ntol	Percent of mostly intolerant taxa	0.25	0.22	0.26	0.139	29.72
pt_tv_stol	Percent of semi-tolerant taxa	0.25	0.19	0.28	0.164	8.49

In each model except pt_tv_toler and pt_tv_stol, the intersection of the 75th percentile of TN (0.11 mg/L) and the 75th percentile of the metric was between the initialization point and midpoint of the curve (Figure 6). Therefore, based on the criteria discussed with DEQ, the TN and metric values at the midpoint of the curve represent the candidate threshold for these metrics. Across metrics, TN thresholds varied by no more than 0.032 mg/L.

Altogether, single metric logistic models in the Mountains meet all quality criteria and represent statistically viable and ecologically interpretable thresholds of eutrophication influences on macroinvertebrate condition. Since Becks3 was a top model in the Mountains and it is also the top model in the Low Valleys and Transitional (see *Section 4.2.2*), Becks3 was selected as the representative metric and model for the Mountains (Figure 6).

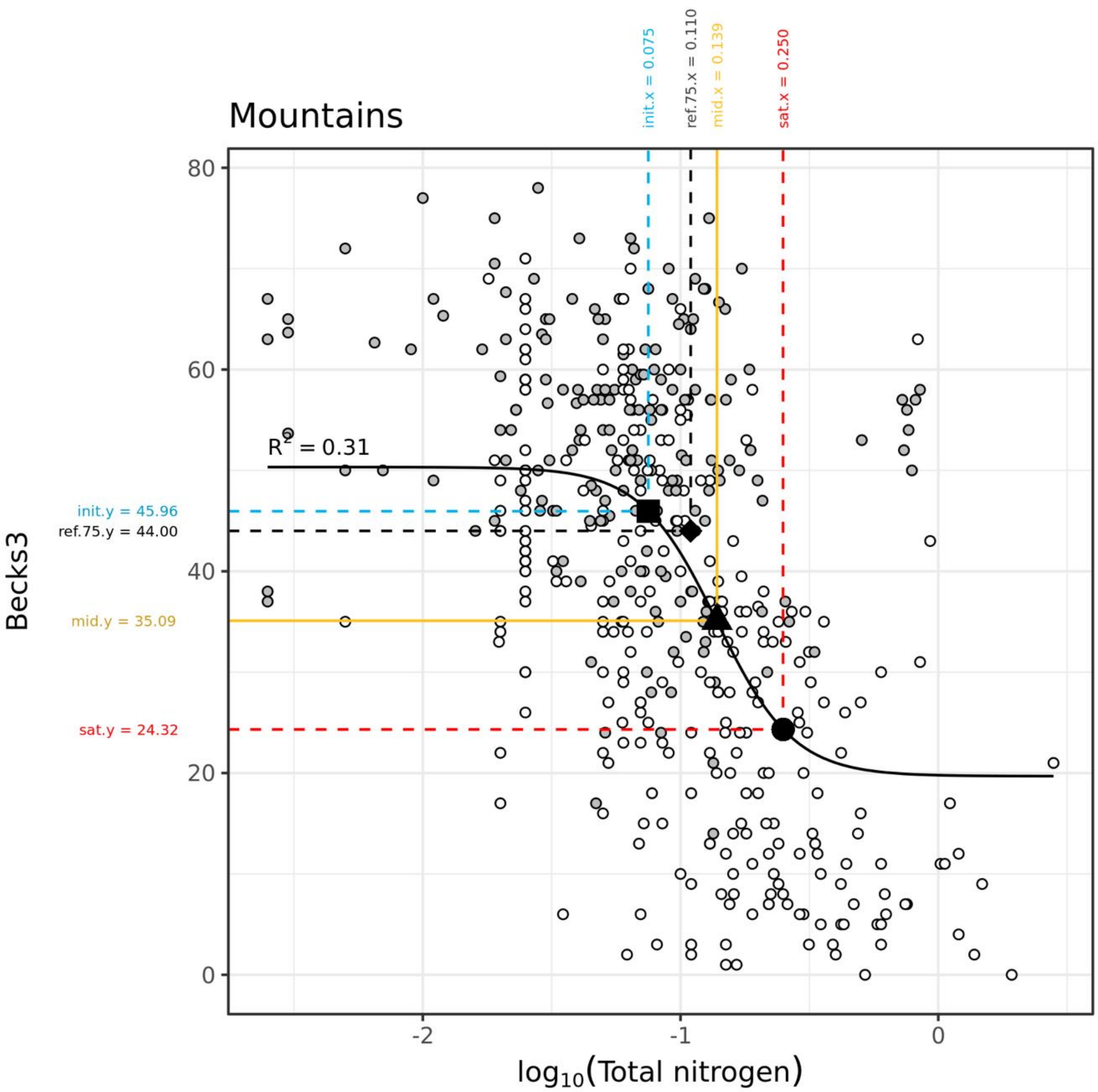

Figure 6. Biplot of reference (gray) and test (white) site values and logistic model curve for the representative single metric model for the Mountains: Becks3. init = initialization point, mid = midpoint, sat = saturation point, and ref.75 = 75th percentile of reference site values.

4.2.2 Low Valleys and Transitional

In the Low Valleys and Transitional, six single metric models passed model selection and quality filtering. The 95th percentile of GAM R^2 values was 0.19, and logistic R^2 values ranged from 0.21 - 0.26. The maximum logistic R^2 was for the Becks3 metric (0.26) and was greater than the linear R^2 (0.24) and comparable to the GAM R^2 (0.26). Following the removal of redundant metrics, three metrics remained - each of which decreased with increasing TN (Table 5).

For the top two models (Becks3 and nt_tv_intol), the midpoint of the curve represented the candidate threshold. For pt_Insect, the TN initialization value was the same as the 75th reference percentile of TN, thus making it unclear whether to select the initialization point or midpoint as the candidate threshold. To be conservative, the midpoint was selected as the candidate threshold for pt_Insect.

Table 5. Top metrics and corresponding thresholds for the Low Valleys and Transitional, arranged by logistic model R^2. Representative metric is bolded.

Metric	Description	Logistic R^2	Linear R^2	GAM R^2	TN threshold (mg/L)	Metric threshold
Becks3	**Beck's Biotic Index v3**	**0.26**	**0.24**	**0.25**	**0.199**	**18.68**
pt_Insect	Percent of insect taxa	0.21	0.18	0.22	0.300	84.22
nt_tv_intol4_EPT	Number of intolerant EPT taxa	0.21	0.19	0.22	0.238	10.64

Since Becks3 was the top model in the Low Valleys and Transitional and also a top model in the Mountains, Becks3 was selected as the representative metric and model for the Low Valleys and Transitional (Figure 7).

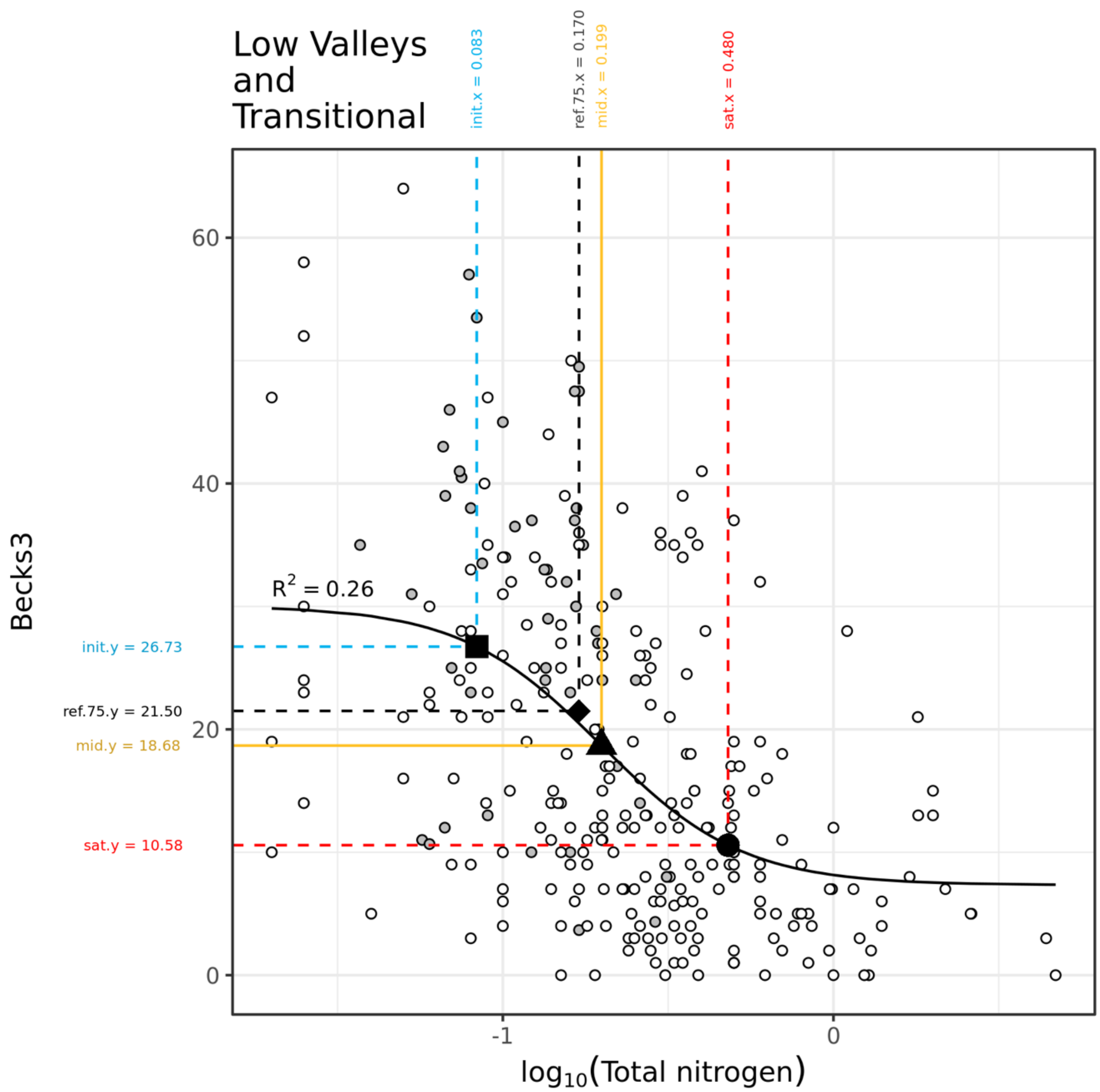

Figure 7. Biplot of reference (gray) and test (white) site values and logistic model curve for the representative single metric logistic model for the Mountains: Becks3.

4.2.3 Plains

In the Plains, no single metric models passed model selection and quality filtering because of at least one of the following: the 75th reference percentile of TN (1.47 mg/L) exceeded all candidate thresholds (initialization, midpoint, and saturation), the 25th or 75th percentile of the metric was above or below the logistic curve, and/or the logistic R^2 was less than the 95th percentile of GAM R^2 values (0.39) (Table 6). However, GAM R^2 values were inflated by a small number of metrics with very high R^2 caused by little variation in the metrics. Therefore, the better measure of model performance is likely the difference between logistic and GAM R^2 for a single model, and all but the top model met the previously defined criteria of the logistic R^2 being no more than 0.05 less than the GAM R^2. The distribution of reference sites, meanwhile, suggests that reference sites in the Plains represent site condition that is controlled by variables other than nutrients: more than 25% of reference sites had TN values greater than the midpoint of logistic curves, and reference sites with high TN had metric values indicative of poor condition. As seen in the boxplots of TN distributions in Figure 2, there was no difference in eutrophication indicators between reference and test sites in the Plains.

Table 6. Top metrics and corresponding thresholds for the Plains, arranged by logistic model R^2. Representative metric is bolded. Unlike the Mountains and Low Valleys and Transitional, both the midpoint and saturation point values are presented because the distribution of reference sites in the Plains exceeds even the saturation point in all models except nt_EPT, which is also why nt_EPT is selected as the representative metric.

Metric	Description	Logistic R^2	Linear R^2	GAM R^2	TN midpoint (mg/L)	TN saturation point (mg/L)	Metric midpoint	Metric saturation point
nt_ECT	Number of ECT taxa	0.34	0.27	0.39	0.885	1.300	8.45	5.48
nt_EPT	**Number of EPT taxa**	**0.32**	**0.28**	**0.37**	**0.937**	**1.490**	**6.29**	**3.18**
pi_tv_toler	Percent of tolerant individuals	0.31	0.28	0.33	0.835	1.240	43.27	58.01
pi_tv_stol	Percent of semi-tolerant individuals	0.30	0.27	0.33	0.791	1.100	39.99	52.44

In the most readily interpretable logistic model for the region (nt_EPT), the 25th percentile of nt_EPT values in reference sites was nt_EPT = 1, despite these sites ranging in TN from 0.58 mg/L to nearly 3.5 mg/L (Figure 8). If model performance alone is considered, nt_EPT, pi_tv_toler, and pi_tv_stol each had strong logistic relationships with TN, and candidate thresholds might be considered based on changepoints in the logistic curve without regard to reference site distributions. Given its common use in macroinvertebrate biomonitoring nationwide and straightforward interpretation, nt_EPT is presented as the representative model for the Plains. nt_EPT was also the only metric for which the saturation point of TN (1.49 mg/L) was slightly greater than the 75th percentile of reference TN (1.46 mg/L). While this value still invalidates the metric based on initial reference site criteria (i.e., the 75th percentile of reference TN must be below the midpoint TN, 0.94 mg/L), nt_EPT represents the top model for a threshold relationship between a macroinvertebrate metric and a eutrophication indicator in the Plains independent of reference site distributions.

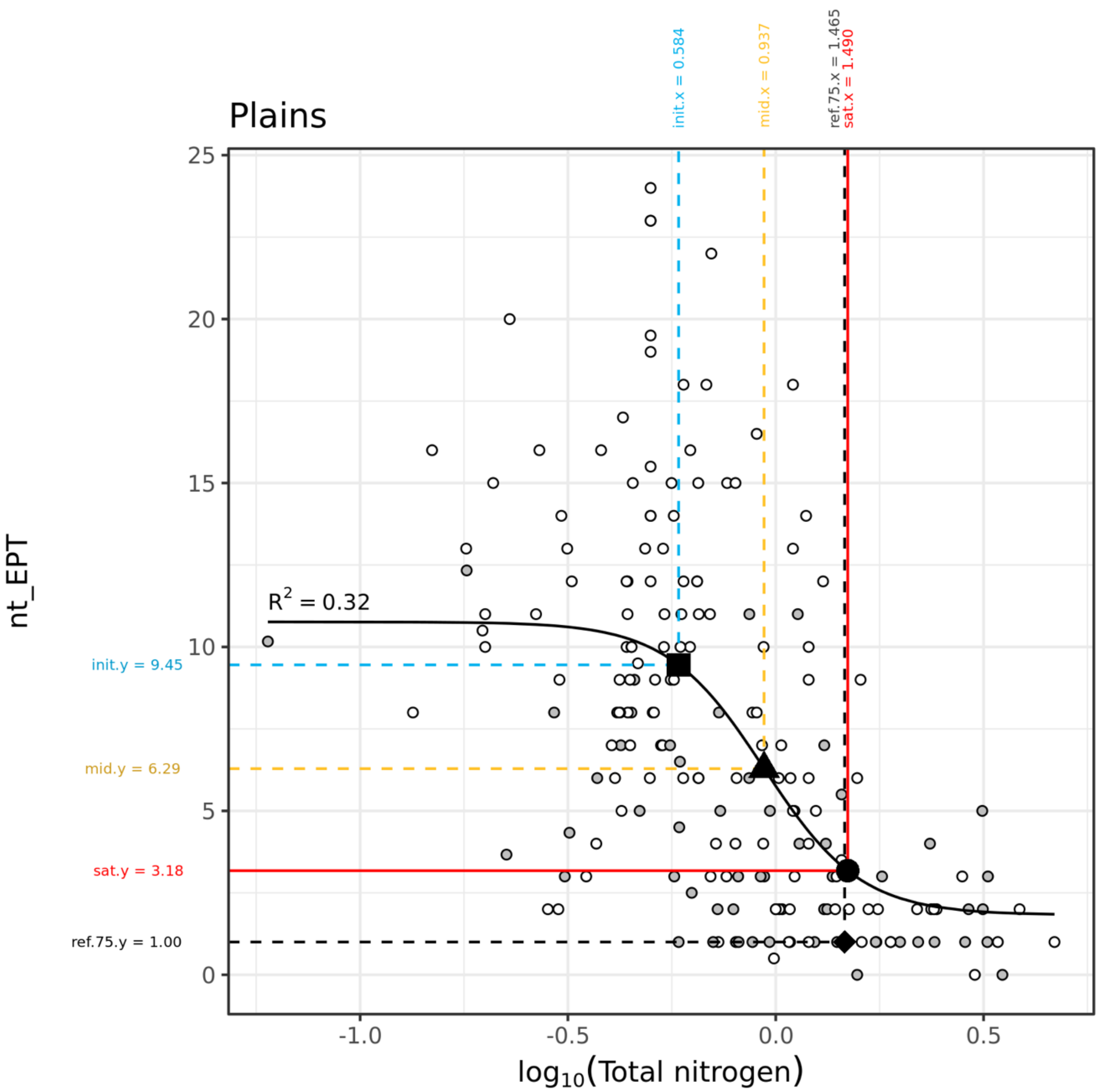

Figure 8. Biplot and curve for the representative single metric logistic model for the Plains: nt_EPT.

4.2.4 Residual influence of covariates

Since macroinvertebrate metrics might be sensitive to other variables beyond the influence of TN, the independent effects of other eutrophication indicators and water quality variables on each of the top metrics were examined. For the top single metric-TN logistic models for each region, the residuals of the metric were calculated. These residuals were then used as the response variable in individual GAMs in which the explanatory variable was each of the remaining eutrophication indicators and water quality variables.

In the Mountains, no covariates explained more than 20% of residual variation (Table 7). In both the Low Valleys and Transitional and Plains, residuals decreased with increasing specific conductance (R^2 = 0.26 and 0.25, respectively). Samples with specific conductance less than

Table 7. R^2 values for generalized additive models (GAMs) with the residuals of representative metric-by-log(TN) logistic models as the response and the water quality variable as the explanatory variable. For each variable, the approximate shape of the relationship is given as residuals decreasing with the variable (\), increasing (/), ∩-shaped, or no change (-).

Variable	Mountains (Becks3)	Low Valleys and Transitional (Becks3)	Plains (nt_EPT)
log(Total phosphorus)	0.12 \	0.00 \	0.07 ∩
log(Chlorophyll *a*)	0.08 /	0.02 ∩	0.15 \
log(Ash-free dry weight)	0.19 \	0.09 /	0.05 -
Temperature	0.12 \	0.04 \	0.05 \
log(Flow)	0.14 /	0.08 \	0.40 /
pH	0.18 ∩	0.08 \	0.02 \
log(Specific conductance)	0.17 \	0.27 \	0.25 \
log(Total suspended solids)	0.19 \	0.02 \	0.01 /

~200 µS/cm in the Low Valleys and Transitional and ~1500 µS/cm in the Plains had higher than expected Becks3 and nt_EPT values, respectively, than the threshold might indicate (Figure 9). Therefore, streams with higher specific conductance will likely have lower-than-expected metric values. For the Plains, residual nt_EPT was greater in streams with high flow, TN being equal (R^2 = 0.40). Therefore, samples from streams with higher flow are likely to have higher than expected nt_EPT values. From correlation analyses, specific conductance and flow were negatively correlated in the Plains (ρ = -0.61), indicating that sites with low specific conductance and high flow often co-occur.

Importantly, a weak relationship between residuals and covariates does not indicate no relationship between the metric and a given covariate, but rather no additional relationship to that between the metric and TN. For example, in each region, TN and TP were moderately correlated, and TP did not explain additional residual variation in metric scores. Therefore, when interpreting metric scores, TN and TP may both have causal effects. That is, metric scores may be influenced by changes in TN, TP, or a combination. This appears to be the case in each region, where logistic models between the representative metric and TP yielded similar patterns and metric thresholds as those with TN, despite weaker relationships with TP than those with TN (Figure 10).

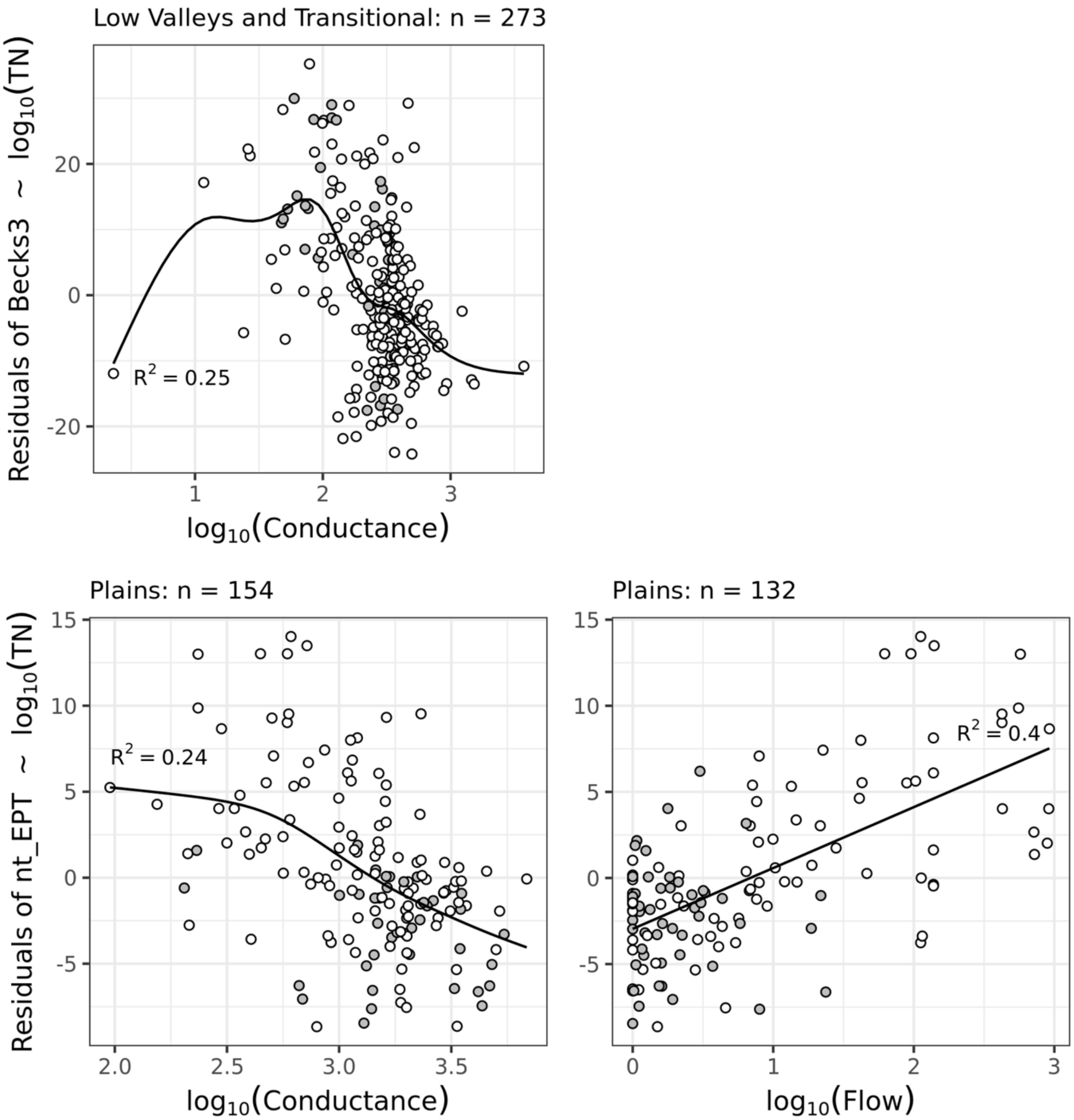

Figure 9. Biplots of residuals and covariates with GAM R^2 > 0.2 for each region.

A detailed table of residual model performance is provided in Table S6, GAM biplots between each pair of water quality variables in Figure S5, and biplots of water quality variables and residuals for all top metrics in Figure S6.

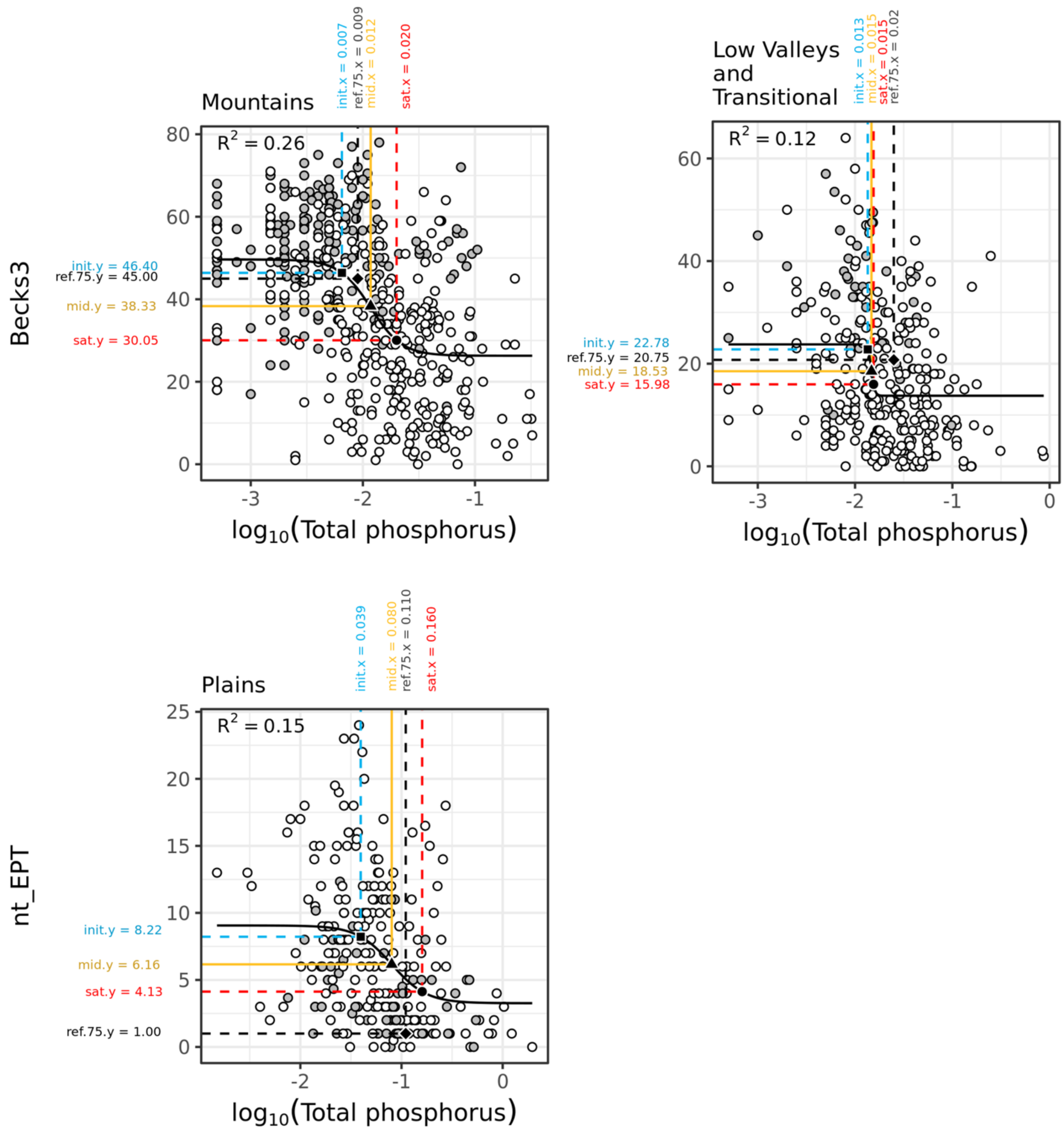

Figure 10. Biplots and curves for the logistic models of the representative metric for each region and total phosphorus.

4.2.5 Multimetric indices

Comparing the explanatory power of MMIs over representative single metrics, logistic model R^2 values in the Low Valleys and Transitional and Plains were 0.13 and 0.16 greater for the best MMIs, respectively (Table 8). Meanwhile, the best MMIs only marginally increased the R^2 by 0.05 in the Mountains over Becks3 alone. Since single metrics and MMIs that contain the single top metric of a region act as distinct metrics, even re-scaled thresholds in the single metrics cannot be directly compared to those of MMIs. Therefore, differences in TN thresholds are the best approximation of whether any increased explanatory power of MMI models affects candidate eutrophication thresholds. In each region the TN thresholds were similar between single metric and MMI models: single metric TN thresholds were 7% lower in the Mountains, 13% higher in the Low Valleys and Transitional, and 7% lower in the Plains.

Table 8. Comparison of top MMI logistic models to representative single metric models. MMIs were not selected for interpretability, though alternative metric combinations were similarly high performing. ^Threshold is initialization point. ⁺Threshold is saturation point.

Region	Single metric	Single metric R^2	Single metric TN threshold (mg/L)	MMI	MMI R^2	MMI TN threshold (mg/L)
Mountains	Becks3	0.31	0.139	Becks3 + nt_tv_toler + nt_volt_uni + pi_SimBtri	0.36	0.148
Low Valleys and Transitional	Becks3	0.26	0.199	Becks3 + li_total + pi_habit_cling_ PlecoNoCling + pi_tv_stol	0.39	0.175^
Plains	nt_EPT	0.32	1.490^+	nt_EPT + nt_habit_sprawl + pi_ffg_pred + pi_tv_stol	0.48	1.600^+

The present analysis shows that MMIs can have a higher percent of variation explained by logistic models than do single metrics, but modeled TN thresholds are not substantially altered. It can be noted that MMIs are arguably more difficult to interpret, as the complementary nature of each component metric is difficult to assess and may not necessarily explain more variation than would be expected by random chance.

A detailed table of MMI model performance for the top 10% of MMIs for each region is provided in Table S7.

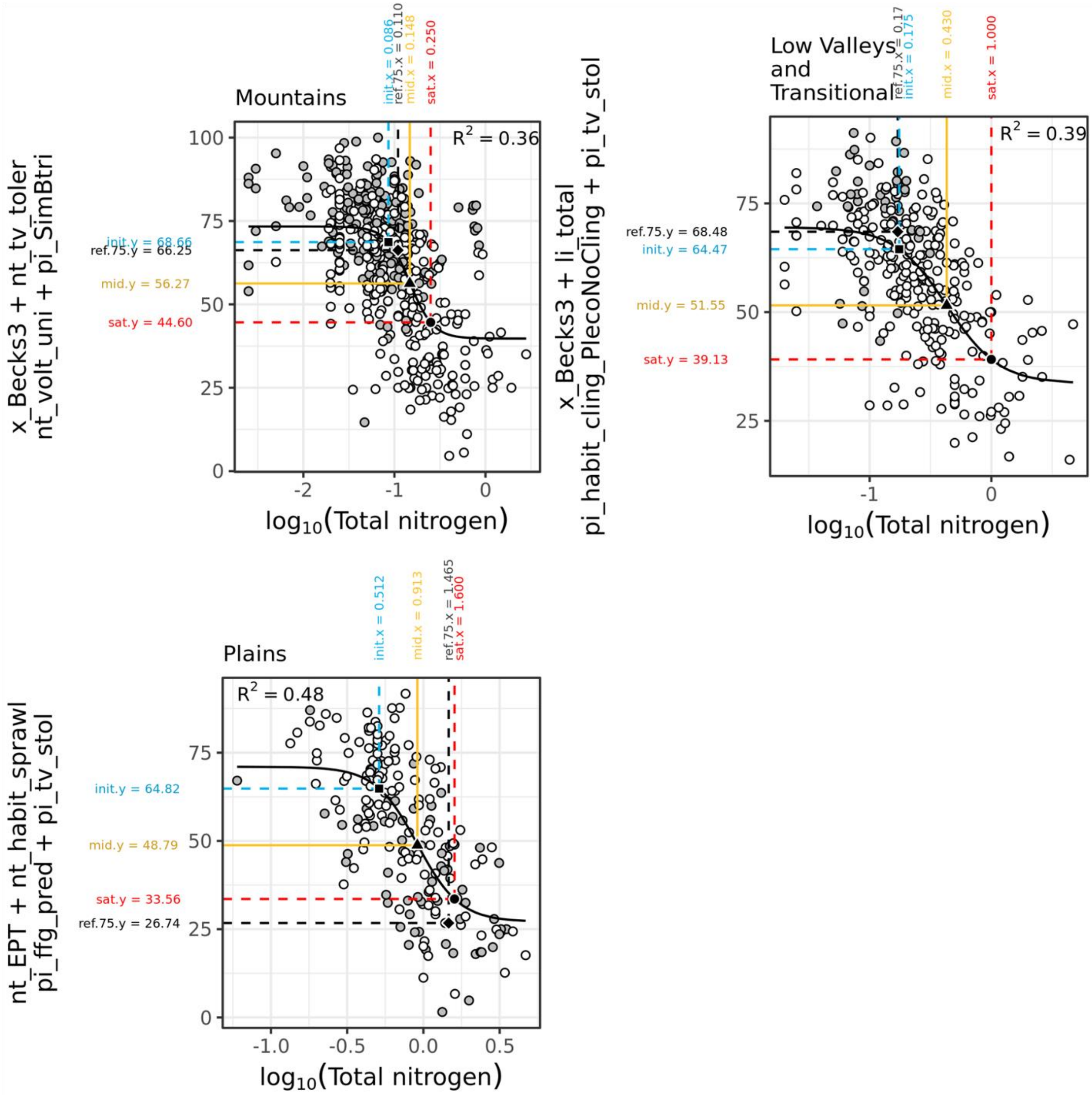

Figure 11. Biplots and curves for the logistic models of the top MMI for each region and total nitrogen.

5.0 Summary

Across three macroinvertebrate regions in the state of Montana, 1410 samples had macroinvertebrate metric data from 2005 to 2021, 1291 of which were associated with at least one water quality measurement. The present analysis revealed strong associations between metrics commonly linked to human disturbance and the eutrophication indicators of total nitrogen (TN), total phosphorus (TP), benthic algal chlorophyll *a*, and benthic algal ash-free dry weight (AFDW). Specifically, EPT taxa, intolerant taxa, Beck's Biotic Index, and diversity indices exhibited negative correlations, while tolerant taxa, dominant taxa, and HBI were positively correlated with these eutrophication indicators. In each region, metrics were more strongly associated with TN than with other eutrophication indicators.

To identify candidate thresholds of change in metrics relative to increasing TN, logistic nonlinear regressions were used to identify regions of change in each sigmoid, or S-shaped, metric-TN relationship. Representative metrics were selected from each region based on the model's explanatory power (R^2) as examples of candidate threshold selection. Becks3 – Beck's Biotic Index version 3, a weighted count of taxon-specific tolerance values whose values generally decrease with disturbance – was selected for the Mountains and Low Valleys and Transitional. The nt_EPT metric – the number of Ephemeroptera/Plecoptera/Trichoptera taxa, whose values generally decrease with disturbance – was selected in the Plains. In the Mountains, a Becks3 value of 35.09 corresponded to the point of maximum change at TN of 0.139 mg/L, which was greater than TN concentrations observed in 75% of Mountains reference sites. In the Low Valleys and Transitional, the point of maximum change in Becks3 was 18.68 at TN of 0.199 mg/L, which was also greater than that in 75% of the region's corresponding reference sites. In the Plains, a large number of reference sites had high TN and low nt_EPT. Ignoring the distribution of reference sites along the gradient of TN, a potential threshold of nt_EPT = 3.18 at TN of 1.490 mg/L could be identified in the sigmoidal relationship for the region.

In each region, neither TP, benthic chlorophyll *a*, nor benthic AFDW explained substantial variation in the observed metric values after accounting for TN. Nevertheless, while the thresholds herein were based on metric relationships with TN, TN and TP were moderately to strongly correlated to each other in each region, and logistic models between representative metrics and TP yielded similar patterns and thresholds to those between metrics and TN. Therefore, metric thresholds may reflect condition relative to TP as well as to TN, representing a general eutrophication effect. Additionally, in both the Low Valleys and Transitional and Plains, sites with increasing specific conductance exhibited lower than expected metric values suggesting an influence of conductance independent of TN on macroinvertebrate communities.

Finally, multiple metrics were combined into a single response variable, or multimetric index (MMI) for each region. Although some MMIs had greater explanatory power than single metrics in logistic regression models in the Low Valleys and Transitional and Plains, relationships between MMIs and TN did not strongly influence change points in TN over those identified by relationships with single metrics.

6.0 References

Bahls, L. L., Bukantis, B., & Tralles, S. 1992. Benchmark biology of Montana reference streams. Montana Department of Health and Environmental Science, Helena. December 1992.

Bowman, M. F., Chambers, P. A., & Schindler, D. W. 2007. Constraints on benthic algal response to nutrient addition in oligotrophic mountain rivers. *River Research and Applications*, *23*, 858-876.

Chambers, P. A., Meissner, R., Wrona, F. J., Rupp, H., Guhr, H., Seeger, J., ... & Brua, R. B. 2006. Changes in nutrient loading in an agricultural watershed and its effects on water quality and stream biota. *Hydrobiologia*, *556*, 399-415.

DEQ (Montana Department of Environmental Quality). 2021. Sample Collection and Laboratory Analysis of Chlorophyll-a Standard Operation Procedure WQPBWQM-011, Version 8.0. February 18, 2021.

EPA (U.S. Environmental Protection Agency). 2000. Nutrient criteria technical guidance manual: rivers and streams. United States Environmental Protection Agency, Office of Water and Office of Science and Technology, EPA 822-B-00-002.

Heiskary, S. A., & Bouchard Jr, R. W. 2015. Development of eutrophication criteria for Minnesota streams and rivers using multiple lines of evidence. *Freshwater Science*, *34*, 574-592.

Jessup, B., Hawkins, C., & Stribling, J. 2006. *Biological Indicators of Stream Condition in Montana using Benthic Macroinvertebrates*. Helena, MT: Montana Department of Environmental Quality. Oct 4, 2006.

Leppo, E.W., J. Stamp, & van Sickle, J. 2021. BioMonTools: Tools for Biomonitoring and Bioassessment. R package version 0.5.0.9039. https://github.com/leppott/BioMonTools.

Mazor, R. D., Sutula, M., Theroux, S., Beck, M., & Ode, P. R. 2022. Eutrophication thresholds associated with protection of biological integrity in California wadeable streams. *Ecological Indicators*, *142*, 109180.

Muggeo, V. M. 2003. Estimating regression models with unknown break-points. *Statistics in Medicine*, *22*, 3055-3071.

Poikane, S., Várbíró, G., Kelly, M. G., Birk, S., & Phillips, G. 2021. Estimating river nutrient concentrations consistent with good ecological condition: More stringent nutrient thresholds needed. *Ecological Indicators*, *121*, 107017.

R Core Team, A., & R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2012.

Teply, M., & Bahls, L. 2007. Statistical evaluation of periphyton samples from Montana reference streams. Larix Systems Inc. and Hannaea. Helena, MT: Montana Department of Environmental Quality.

van Sickle, J. 2010. Correlated metrics yield multimetric indices with inferior performance. *Transactions of the American Fisheries Society*, *139*(6), 1802-1817.

Woods, A. J., Omernik, J. M., Nesser, J. A., Shelden, J., Comstock, J. A., & Azevedo, S. H. 2002. Ecoregions of Montana, 2nd edition (color poster with map, descriptive text, summary tables, and photographs).

Wood, S. N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, *73*, 3-36.

7.0 Appendix

Supplementary tables and figures are available as separate files. Below are the descriptions of each. All tables are in the file “supplementaryTables.xlsx”.

Table S1. Complete dataset of DEQ metadata, macroinvertebrate metric values, and water quality measurements.

Table S2. Spearman rank correlations among water quality variables, long format.

Table S3. Spearman rank correlations among macroinvertebrate metrics, long format.

Table S4. Spearman rank correlations between water quality variables and macroinvertebrate metrics, long format.

Table S5. Threshold analysis model results for all metrics-by-eutrophication indicators for each region.

Table S6. Residual analysis model results for top metrics and all non-TN water quality variables for each region.

Table S7. Multimetric index (MMI) analysis model results for all MMIs with logistic regression R2 within 10% of the top model for each region.

Figure S1. Histograms of untransformed and log10-transformed eutrophication indicators and water quality variables for each region. Available at “figS1_histograms.png”.

Figure S2. Heatmaps of macroinvertebrate metric Spearman correlations for each region. Available as 3 separate files in the folder “figS2_invertCorrelations”.

Figure S3. Heatmaps of macroinvertebrate metric-water quality variable Spearman correlations for each region. Available as 3 separate files in the folder “figS3_wqInvertCorrelations”.

Figure S4. Biplots with logistic regression curves between each of the top metrics and total nitrogen for each region. Available as multiple files in the folder “figS4_logisticPlots”.

Figure S5. Scatter plots with generalized additive model (GAM) curves between each water quality covariate and total nitrogen for each region. Available as multiple files in the folder “figS5_wqBiplots”.

Figure S6. Biplots with generalized additive model (GAM) curves between each water quality covariate and the residuals of all top metrics (from logistic models with total nitrogen) for each region. Available as multiple files in the folder “figS6_residualPlots”.