HOW TO PERFORM A NONDEGRADATION ANALYSIS FOR SUBSURFACE WASTEWATER TREATMENT SYSTEMS (SWTS) UNDER THE SUBDIVISION REVIEW PROCESS

Montana Department of Environmental Quality
Public Water and Subdivisions Bureau

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PREAMBLE

THIS DOCUMENT IS INTENDED FOR USE AS A GUIDANCE DOCUMENT TO ASSISST APPLICANTS AND THEIR AGENTS TO PREPARE AND SUBMIT NON-SIGNIFICANCE APPLICATIONS TO THE REVIEWING AUTHORITY. THIS DOCUMENT DOES NOT HAVE THE FORCE OR EFFECT OF A DESIGN CIRCULAR, RULE OR STATUTE; IT IS STRICTLY TO BE USED FOR INFORMATIONAL AND GUIDANCE PURPOSES. IF THERE IS A CONTRADICTION BETWEEN THIS DOCUMENT AND CIRCULAR, RULE OR STATUTE, THEN THE CIRCULAR, RULE OR STATUTE PREVAILS. THE PROCEDURES IN THIS DOCUMENT ARE VALID ONLY FOR SITES REVIEWED UNDER THE SUBDIVISION LAWS AND RULES.

THIS GUIDANCE DOES NOT LIMIT THE REVIEWING AUTHORITY'S ABILITY TO REQUIRE INFORMATION NOT DISCUSSED IN THIS GUIDANCE IF THE REVIEWING AUTHORITY BELIEVES THE INFORMATION IS NECESSARY AND IS WITHIN THE REVIEWING AUTHORITY'S POWER UNDER THE APPLICABLE RULES AND STATUTES.

WEB-SITE ADDRESSES ARE INCLUDED IN THIS DOCUMENT TO AID THE READER IN FINDING INFORMATION. HOWEVER, AS WEB-SITES ARE FREQUENTLY UPDATED, THE ADDRESSES MAY CHANGE OVER TIME. THEREFORE, THE ADDRESSES IN THIS DOCUMENT MAY BECOME OUTDATED. CONTACT THE DEPARTMENT IF YOU CANNOT ACCESS INFORMATION REFERENCED WITHIN THIS DOCUMENT.

THE INFORMATION PRESENTED IS A REVISION OF BOTH THE REVISED MARCH 2005 AND FEBRUARY 2009 EDITIONS OF THIS DOCUMENT.

1.0 GENERAL INFORMATION

1.1 Introduction

The purpose of the nondegradation rule is to protect high quality state ground and surface waters. Numerical nondegradation limits are defined using several methods, and are described in the nondegradation rules [Administrative Rules of Montana (ARM) 17.30.715(1)]. Whenever a person conducts an activity that may impact water quality they must comply with the nondegradation requirements, ARM 17.30.706(1) (this applies whether the activity is or is not regulated by the Department). If the activity is permitted, approved, licensed or otherwise authorized by the Department, the Department will ensure compliance with the nondegradation requirements prior to issuing its permit, license or other authorizations [ARM 17.30.706(2)]. If the activity is not permitted, approved, licensed or otherwise authorized by the Department, the person proposing the activity may determine for themselves that the activity will not cause significant degradation or they may submit an application for the Department to make the determination [ARM 17.30.706(1)].

Throughout this document the term “Department” is used to refer to the Montana Department of Environmental Quality. The document also uses the term “reviewing authority”, which refers to the state, or local regulatory authorities that review subsurface wastewater treatment systems (SWTSs) as an agent of the state or as a separate entity pursuant to local regulations and statutes.

The term “subdivision” is also used regularly in this document. While the term is defined in 76-4-102(16), Montana Code Annotated (MCA), it is not necessarily used in this document under that strict definition. Local governments are required to comply with the nondegradation rules for SWTSs that are not part of subdivisions as defined in the referenced statute. These guidelines are intended for use for all SWTSs that are in defined subdivisions and for those non-subdivision sites reviewed under local statutes.

Because this guidance does not have the force of a design circular or rule, the requirements listed within the document may be varied from based on site-specific conditions or constraints. However, any changes from the requirements must be based on defensible reasons and agreed to by the reviewing authority. The terms “shall” and “should” are used throughout the document to distinguish between requirements that are more definite (shall) and those that might be varied from more commonly (should) under appropriate circumstances.

1.2 High Quality State Waters

High quality state ground waters are defined in 75-5-103(13) Montana Code Annotated (MCA): *“High Quality Waters” means all state waters except: (a) ground water classified as of January 1, 1995 within the III or IV classifications established by the boards classification rules”*. Class III and IV ground waters are defined in ARM 17.30.1006 as ground waters with: a natural specific conductance greater than or equal to 2,500 and less than or equal to 15,000 microSiemens/cm at 25^{o}C, and a natural specific conductance greater than 15,000 microSiemens/cm at 25^{o}C, respectively (note that 1 microSiemen/cm is equal to 1 umhos/cm). Therefore, ground water with a natural specific conductance less than 2,500 microSiemens/cm at 25^{o}C is considered a high quality state water and is subject to the nondegradation requirements and limits. Ground water with a natural specific conductance of 2,500 microSiemens/cm, at 25^{o}C or higher is not high quality and is not subject to the nondegradation requirements, but is subject to the water quality standards as described in the ground water rules (ARM 17.30 sub-chapter 10) and in Department Circular DEQ-7. The DEQ-7 ground water quality standard for nitrate (as N) is 10 mg/L.

In addition, ARM 17.30.1006 includes modifications of the nitrate ground water quality standard when the ground water quality is very poor (specific conductance over 7,000 µmhos/cm or µS/cm), or when Class III or IV ground water has low hydraulic conductivity (less than 0.1 feet/day). Refer to ARM 17.30.1006(3), (4) and (5) for complete details.

The information needed to classify the shallowest ground water for a SWTS will be determined on a case-by-case basis. This information will in most cases require multiple (2 or more) ground-water analyses for specific conductance. Alternatively, a report published by or for a state or federal agency (or similar report) that determines the specific conductance of shallow water in and around the proposed SWTS may be considered in classifying the local ground-water quality

For surface waters, high quality is defined in 75-5-103(13), MCA as: *"High quality waters means all state waters, except: ... (b) surface waters that: (i) are not capable of supporting any one of the designated uses for their classification [see ARM 17.30 sub-chapter 6]; or (ii) have zero flow or surface expression for more than 270 days during most years"*.

1.3 New or Increased Source

A nondegradation determination must be completed on a new or increased source. A "new or increased source" is defined in ARM 17.30.702(17) as *"... an activity resulting in a change of existing water quality occurring on or after April 29, 1993. The term does not include the following: (a) sources from which discharges to state waters have commenced or increased on or after April 29, 1993, provided the discharge is in compliance with the conditions of, and does not exceed the limits established under or determined from, a permit or approval issued by the department prior to April 29, 1993; (b) nonpoint sources discharging prior to April 29, 1993; (c) withdrawals of water pursuant to a valid water right existing prior to April 29, 1993; and (d) activities or categories of activities causing nonsignificant changes in existing water quality pursuant to ARM 17.30.715, 17.30.716, or 75-5-301(5)(c), MCA."*

The term "new" in the rule is interpreted as either a new source or a new location of an existing source. If an existing source is relocated (for example, a replacement drainfield that was not part of the plat approval) the determination regarding whether it is a new source would be site-specific. That determination would be based on how the new drainfield location would impact sensitive receptors (e.g., surface water, nearby wells, etc.) as compared to the existing source location (note that a replacement drainfield that was reviewed in the initial nonsignificance determination is not a new or increased source). Factors used in that determination include distance to receptors or potential receptors, amount of pollutant load, hydrogeologic conditions (particularly as related to time of travel from source to receptor), and any other relevant factors. An exception to this is that for single-family home replacement drainfields that were not previously approved will typically not be considered new sources.

The applicability of the term "new or increased source" in ARM 17.30.702(17) for older subdivision lots is discussed here. In 1961, the Sanitation in Subdivision Act was enacted. This statute gave the state the authority to review new subdivisions. Prior to that year, the state did not review subdivisions. Between approximately 1961 and 1973 subdivided lots could be created with "sanitary restrictions", which meant the lot could be platted and sold, but that the lot was not approved for a water or wastewater system. The Department has determined that a SWTS on any lot created prior to the Sanitation in Subdivision Act is subject to the nondegradation requirements because the state did not have the authority to review any subdivision lots created before then (the definition of "new or increased source" requires a Department permit or approval which could not have occurred prior to 1961). However, if a lot created prior to 1961 had an operational wastewater disposal system prior to April 29, 1993, then the nondegradation requirements do not apply (assuming the wastewater disposal system use did not change since April 29, 1993) because non-point sources that discharged prior to April 29, 1993 are not considered new or increased sources. If a subdivision lot was created after 1961 without state review (which includes lots with sanitary restrictions and other lots), a SWTS on that lot is also required to meet the nondegradation requirements unless an operational wastewater disposal system existed prior to April 29, 1993.

If a wastewater disposal system was discharging with or without the proper approvals or permits prior to April 29, 1993, it is not subject to the nondegradation regulations as long as the use of the site is unchanged (e.g., a single-family home with four bedrooms has remained a single-family home with four bedrooms).

A new or increased source refers to the load of pollutants, not the wastewater flow rate. For wastewater systems, load is typically expressed in units of pounds/day. For example, a source of wastewater that produces 200 gallons per day (gpd) with a nitrogen concentration of 50 mg/L is the same load as a source that produces 400 gpd with a nitrogen concentration of 25 mg/L. Therefore, an existing source that doubles its flow rate, but halves its nitrogen concentration is not considered an increased source of nitrogen. In this example, if the phosphorus concentration is not reduced by half the phosphorus load would be considered an increased source, and would require a nondegradation review.

1.4 Lot Layout Requirements

Mixing zones shall be shown on the lot layout for both the primary and replacement drainfields [see section 2.11 (Mixing Zones) for standard mixing zone parameters]. The location of all wells and their zones of influence shall be shown on the lot layout, including nearby, off-site wells. Maps shall include a scale and north arrow.

1.5 Consideration of Nearby Developments for Cumulative Effects

ARM 17.30.715(2) (a) states that the Department [or other reviewing authority in this case] may determine there is a significant change in water quality resulting from cumulative impacts.

The nitrate sensitivity and phosphorus breakthrough calculations are conducted for each proposed SWTS and shall account for cumulative effects of consecutive SWTSs (in the direction of ground-water flow) on the proposed subdivision. Off-site SWTSs located nearby (upgradient and downgradient) shall also be included in the cumulative effects analysis.

1.6 Data Requirements

It is the applicant's responsibility to collect the data needed to conduct the nondegradation analysis and submit that information to the reviewing authority. However, if the reviewing authority is aware of additional information that was not submitted by the applicant, the reviewing authority may use that information as part of the review process. Such information may change the results of the nondegradation analysis submitted by the applicant.

All of the hydrogeologic information submitted shall be related to the shallowest ground water beneath the site because the shallowest ground water is the water that will be impacted by the SWTS effluent. All high quality state water is required to be protected from degradation. This is not limited to water that is being used locally for consumption. In many areas, the aquifer of choice for potable water is not the shallowest ground water beneath the site. Hydrogeologic information from a ground-water source that is deeper than the shallow ground water is not applicable for the nondegradation analysis.

The reviewing authority will use the most relevant, applicable and accurate data that are available at the time of the nondegradation review. For example, if the applicant submits a hydraulic gradient estimate based on one-third of the topographic slope, but there is a reliable ground water flow map of the shallowest ground water that includes the site, the reviewing authority will use the ground water map to determine the hydraulic gradient. As based on site-specific conditions and environmental/health concerns, the reviewing authority may request collection of more accurate data for use in the nondegradation analysis. Such data may include, but are not limited to aquifer pumping tests, long-term ground water level monitoring, long-term nitrate monitoring, and construction and testing of monitoring wells.

The reviewing authority may require additional data collection beyond what is typically sufficient for a subdivision if the area being developed is environmentally sensitive or there are other compelling reasons to use more accurate data to complete the nonsignificance analysis.

1.7 Non-degradation and Mixing Zone Checklists

Non-degradation Completeness Checklist (Appendix A)

- This is a useful checklist for determining if the non-degradation determination application is complete. This is a list for a typical subsurface wastewater treatment system (SWTS), some sites may require additional information not specifically included in the checklist.

Non-degradation Significance Determination Checklist (Appendix B)

- This checklist is filled out by the reviewing authority when a proposed SWTS has been determined to have a non-significant impact on state waters. The column labeled "Notes/Basis for Decision" should include site-specific information for at least the mixing zone information in item #5, nitrate sensitivity parameters (hydraulic conductivity, hydraulic gradient, background nitrate level, etc.) in item #11, and the phosphorus breakthrough parameters (distance to surface water, name of surface water) in item #12. With regards to item #5 on the form, a SWTS will always need a ground water mixing zone except when: the shallowest ground water is confined; the SWTS treats the wastewater to concentrations lower than the applicable standard prior to discharge; or the SWTS nondegradation review was approved in accordance with ARM 17.30.716. This form should not be filled out by the applicant.

Ground-Water Mixing Zone Checklist (Appendix C)

- This checklist is used by the reviewing authority to document any ground-water mixing zones that are granted. This form is not required as part of a subdivision application. This form should not be filled out by the applicant.

Surface-Water Mixing Zone Checklist (Appendix D)

- This checklist is used by the reviewing authority to document any surface-water mixing zones that are granted. This form is not required as part of a subdivision application. This form should not be filled out by the applicant.

2.0 NITRATE SENSITIVITY ANALYSIS

2.1 Hydrogeologic Parameters

Hydrogeologic parameters shall be based on the nearest and best information sources for the shallowest ground water beneath the site. Depending on site-specific circumstances, that may include on-site data or data from sources that are miles from the site. As necessary, the reviewing authority may require collection of additional on-site or near-site data such as well construction and aquifer testing, ground water elevations, or other information.

2.2 Nitrogen Information

Total nitrogen is comprised of 4 parameters: nitrate, nitrite, ammonia, and organic nitrogen (total kjeldahl nitrogen, also known as TKN, is the sum of the ammonia and organic nitrogen components). The nitrogen in raw wastewater is comprised primarily of ammonia. Through treatment in the septic tank and drainfield the ammonia is converted to nitrite and ultimately nitrate. In some cases the conversion from ammonia to nitrate occurs in sand filters, trickling filters or aerobic treatment units prior to disposal in the drainfield. The organic nitrogen in the raw wastewater can also be converted to nitrate in the treatment process and below the drainfield. Therefore, all of the nitrogen in the raw wastewater can be transformed into nitrate. The nitrate dilution model discussed in the following section assumes that all the forms of nitrogen in the raw wastewater are eventually transformed to nitrate, and bases the mixing zone calculations on that assumption (Morgan et. al., 2007).

2.3 Nitrate Dilution Model (also known as the Bauman Schafer Model)

The model typically used to calculate the concentration of nitrate at the end of the mixing zone is the nitrate dilution model (Bauman and Schafer, 1984), see Appendices E and F. The standard ground-water mixing zone rules [ARM 17.30.517(1) (d) (v)] do not allow for decay (i.e., reduction in quantity) of nitrate in a standard ground-water mixing zone as it moves through the unsaturated zone. A source specific mixing zone (ARM 17.30.518) can be requested if the applicant wishes to deviate from the standard mixing zone restrictions, which includes accounting for decay of nitrate between the discharge point and the end of the mixing zone. The most likely natural method of nitrate decay is denitrification. Denitrification is the reduction of nitrate (NO_3^-) to nitrogen gas (N_2), which is facilitated by naturally occurring bacteria in the soil.

The nitrate dilution model accounts for the variables discussed in ARM 17.30.517(1) (d) and for the mixing zone dimensions. The Department recommends the use of the nitrate dilution model (see Appendix E) in nonsignificance determinations due to the simplicity of the model. As its name describes, the model only calculates the change in nitrate concentration due to dilution. Dilution comes from two sources, the ground water beneath the site and a fraction of the precipitation (typically 20%) that falls within the mixing zone boundary. Because only dilution is used to reduce the nitrate concentration, the total mass of nitrogen remains constant in the calculations (i.e., the combined load of nitrate from the effluent, precipitation and background in ground water is the same load of nitrate that is calculated at the end of the mixing zone). Therefore, the model treats nitrate as a "conservative" contaminant, which means it assumes that nitrate is not converted to any other form of nitrogen.

If a more complex model were used to predict the nitrate concentration at the end of the mixing zone without any denitrification, the results should be nearly identical to the nitrate dilution model if the same mixing zone size is used. A more complex model could produce higher or lower concentrations than the nitrate dilution model depending on the parameters that are chosen to describe the hydrodynamic dispersion that will occur in the ground water. Hydrodynamic dispersion is the parameter that controls how much the contaminant plume spreads out in the aquifer (i.e., dispersion controls how big the actual mixing zone will be). The dimensions of the standard mixing zone (15 feet deep plus the 5 degree increase in width downgradient of the source) are designed to simulate hydrodynamic dispersion in a typical ground water setting. If the hydrodynamic dispersion in the complex model causes the contaminant plume to "spread out" less than that assumed by the standard nitrate dilution model, the nitrate concentration at the end of the mixing zone will be greater than that predicted by the standard nitrate dilution model. The opposite will occur if the complex model predicts that the plume will "spread out" greater than that assumed by the standard mixing zone. Theoretically, a more complex model could be used to define a more accurate site-specific mixing zone dimension. However, hydrodynamic dispersion is not a simple parameter to quantify, and it is often determined via calibration to known field data. Calibration to field data means that the model is used to determine the hydrodynamic dispersion value rather than the user specifying a known value. Some computer models do provide guidelines for estimating dispersion that could be used to estimate the dimensions of a source specific mixing zone.

The standard mixing depth (15 feet) estimated by the Department is supported by at least two field studies. The first study (Shaw et.al., 1993) measured mixing depths between 11.1 and 25.2 feet at the downgradient end of two subdivisions with multiple septic systems – the lengths from the upgradient to downgradient end of the subdivisions was 360 and 850 feet, respectively. The second study (Woessner et. al., 1996) studied a single drainfield and measured a mixing depth between 7 and 10 feet within 200 feet of the drainfield.

Another factor that can effect the final nitrate concentration at the end of the mixing zone is denitrification. Denitrification is known to occur under specific conditions in the ground, but the occurrence and rate of denitrification is difficult to predict on a site-specific basis. For this reason existing nitrate migration/fate models typically assume nitrate is a conservative parameter.

Despite the difficulties associated with modeling nitrate reduction, the Department allows the use of modeling to demonstrate nitrate reductions beyond those predicted by the nitrate dilution model. However, any parameters used to simulate nitrate reduction or decay must be supported by adequate site-specific data.

2.4 Other Ground Water and Solute Transport Models

There are many ground water and solute transport computer models available from public and private institutions. The Department does not have the resources to evaluate the applicability and accuracy of computer model codes submitted for potential use in evaluating the fate and migration of nitrogen in the environment. Therefore, the Department encourages the use of models that are listed in the USEPA's Center for Subsurface Modeling Support (CSMoS) The Department will accept and review results from models that are on the USEPA or USGS lists. Many of the models used by the USEPA and USGS are included as bundled programs in commercial pre- and post-processor programs that make data entry easier and simplify the presentation of results. Other models that have achieved general acceptance in the scientific community will also be accepted for use. Any model determined to be untested or obscure by the Department will not be accepted for use in the nondegradation analysis. If you are unsure about the applicability of a specific model, please contact the Department

If a model other than the nitrate dilution model is used, the user should tailor the model to the site complexity and the amount of available data. The results from any model are only as good as the quality of the input data. If there are limited data for a particular site, it does not make sense to use a complex model with numerous variables that cannot be accurately determined for the site. And conversely, there are some simplistic models available that are not adequate for the concentration specific results that are needed for the nitrate mixing zone analysis.

Some useful sources of information regarding computer models are included below:

Anderson, M.P. and W.W. Woessner, 1992. Applied Ground Water Modeling: Simulation of Flow and Advective Transport.

ASTM, Subsurface Fluid Flow (ground-water and vadose zone) Modeling. 1996

IGWMC, Systematic Evaluation and Testing of Ground Water Modeling Codes. 1996. GWMI 96-04

IGWMC, Compilation of Saturated and Unsaturated Zone Modeling Software. 1994. GWMI 94-08

International Ground Water Modeling Center (IGWMC), Overview of Chemical Modeling in Ground Water and Listing of Available Geochemical Models. 1996. GWMI 96-01.

Reilly, Thomas, E. and Arlen W. Harbaugh. 2004. Guidelines for Evaluating Ground-Water Flow Models. USGS Scientific Investigations Report 2004-5038.

USEPA, Access EPA, 1995/96 Edition, EPA/220-B95-004.

USEPA, Ground-Water Modeling Compendium 2nd Edition, 1994, EPA/500/B-94/004.

Witten, Jon, Scott Horsley, Sanjay Jeer, and Erin K. Flanagan, A Guide to Wellhead Protection. 1995. American Planning Association, Planning Advisory Service.

2.5 Nitrogen Cycle and Treatment Summary

For additional information on the nitrogen cycle and details about nitrogen treatment, two sources of information are provided below.

The USEPA Nitrogen Control Manual (USEPA, 1993) can be found and ordered at http://yosemite.epa.gov/water/owrccatalog.nsf/0/3963bd6aa3747efa85256b0600723f0d?OpenDocument .

2.6 Shallowest Ground Water

The presence or absence of shallow ground water at a certain subsurface horizon may be disputed for some sites. Therefore, a test well may be required to determine the location and hydraulic properties of the shallowest ground water. If a test well(s) is required, it should be constructed and monitored according to the following procedures.

- The well should be drilled, if possible, without drilling fluids. Drilling fluids interfere with the ability to recognize water-bearing materials;
- an engineer, geologist, or other qualified individual should be on site to observe drilling and to collect and classify drill cuttings by a standardized method such as ASTM or USDA soil classification systems;
- the well shall be drilled into the upper 15 to 25 feet (approximately) of the shallowest water-bearing unit (or less if the water-bearing unit is less than 15 feet thick), or down to a maximum depth as determined by the reviewing authority;
- the well shall be completed with approximately 15 to 25 feet of perforated pipe, well screen, or open hole construction into the geologic material most likely to be water-bearing;
- if water is not immediately evident in the well, the well shall be covered to prevent surface water from entering the borehole and the presence of ground water shall be re-checked at least 24 hours after the well construction was completed; and
- if ground water has entered the well after the 24-hour period, the nondegradation analysis will be based on the ground water intercepted by the test well. If ground water does not enter the well, the analysis will be based on hydrogeologic information from a deeper water-bearing unit.

2.7 Hydraulic Conductivity

Hydraulic conductivity is a measure of the geologic media's ability to transmit water; its units are length/time. The combination of hydraulic conductivity and hydraulic gradient control the amount of ground water that is available for dilution.

Although there may be other methods of determining hydraulic conductivity, a list of the methods typically used is presented below. Assuming equal quality of data collection, the list is in the order of the most accurate to the least accurate method. Therefore, data collected using a method higher on the list will generally be used over data collected via a lower method. On-site data are typically more applicable than off-site data. Therefore, on-site data using a less accurate method may in some cases be more applicable than data collected via a more accurate method from a distant off-site source.

1. Long term (typically 24 hours) on-site or near-site aquifer pumping test with observation wells

1a. Long term (typically 24 hours) on-site or near-site aquifer pumping test without observation wells

2. Slug tests
3. Published reports with estimated or extrapolated hydraulic conductivity values from distant aquifer tests
4. Well log tests / Drawdown Tests

Each of these methods is discussed below.

2.7.1 Aquifer Pumping Tests

Pumping tests can be conducted on existing wells completed in the shallowest ground water or on a new well completed in the shallowest ground water to determine the hydraulic conductivity. However, if the test is being conducted solely for the purpose of demonstrating an adequate water supply the well being tested shall be completed in the aquifer proposed for the water supply.

Each well used for a pumping test must have a complete well log to be acceptable. A complete well log is typically the official state well log that the licensed driller is required to complete. However, it may also be a log prepared by a qualified individual that includes all the necessary well construction and lithologic information that is needed to properly analyze the pumping test results.

A pumping test can be conducted with a single well or with additional well(s) for use as observation wells (observation wells must be completed in the same water-bearing unit as the pumping well). Use of an observation well during the test typically provides higher estimates of hydraulic conductivity. An observation well can also be used to determine aquifer storativity. The storativity can be used for analytical or numerical analysis of impacts to the aquifer from proposed ground water withdrawals. Storativity can also be used in the determination of whether an aquifer is confined, semi-confined or unconfined.

The number of pumping tests required for a subdivision will depend on the size of the subdivision (both number of lots and acreage covered by the subdivision). In addition, the potential for variable aquifer properties across the subdivision can create the need for tests in multiple locations to adequately characterize the variation across the subdivision.

The following procedures shall be followed when conducting a pumping test [a good reference for conducting pumping tests is Groundwater and Wells, 2^{nd} ed. (Driscoll, 1986)].

- The test shall be conducted at a constant pumping rate (removing water from the well using forced air or a bailer are not recommended and typically will not provide useful results). Stepping the test to higher rates or allowing the pumping rate to increase or decrease significantly during a test will likely invalidate the results (although there is no industry standard, a flow rate variation of less than 10% during the test is generally acceptable). It is often a good idea to conduct a pre-test to determine an acceptable pumping rate that will stress the aquifer, but not draw the well dry. If the pumping well goes dry after the test has been running for a significant amount of time, it might be beneficial to collect recovery data at that point rather than run a second test at a lower pumping rate. The results can then be discussed with the reviewing authority to determine if they are acceptable even if the minimum test length was not achieved.

- The test shall be conducted at a pumping rate that will sufficiently stress the aquifer, but not draw the well dry, to create an adequate drawdown curve that can be analyzed via the Cooper-Jacob straight-line method, the Theis curve-matching method, or other accepted and appropriate methods. The pumping rate should be measured at least several times in the first hours of the test and at least every 6 hours thereafter (or more frequently if the pumping rate is expected to fluctuate significantly and needs to be adjusted).

- The test duration is typically required to be at least 24 hours.

- Recovery data shall be collected immediately after the pump has been turned off. The length of time that recovery data are recorded depends on the pumping test duration and the rate at which recovery occurs. As a rule-of-thumb, recovery data should be collected for at least the same length of time that drawdown occurred unless recovery is complete before that time. Recovery data are often more important than the drawdown data in determining water supply dependability and in determining hydraulic conductivity.

- During both the drawdown and recovery phases, the water level data shall be measured to the nearest 0.01 foot, and the water level should be measured at intervals to provide at least 10 evenly-spaced data points per log cycle of time (in minutes). For example, collect one data point every six seconds for the first minute of the test, collect one data point every minute between one and ten minutes, etc. The sampling interval should be more frequent if water level drawdown/recovery is rapid.

- Static water levels shall be measured prior to the test. If possible, water levels in the pumping and observations wells should be monitored for 24 to 72 hours prior to and after the test to determine if natural or anthropogenic water level fluctuations could influence the test results.

- Pumped water shall be diverted sufficiently far downgradient from the pumping well and monitoring wells so as to not recharge the well(s) during the test. The pumped water shall not be discharged into state surface waters. If water is discharged into a state surface water, a nondegradation analysis may need to be conducted [ARM 17.30.706(1) and 75-5-317(2) (f), MCA], and a discharge permit may be required from the Department pursuant to 75-5-401(1), MCA.

- The aquifer thickness (b) used to calculate hydraulic conductivity depends on site-specific conditions. Existing published literature indicates that the aquifer thickness used in analyzing a long-term pumping test can typically be set equal to the distance from the bottom of the well to the static water level for an unconfined or semi-confined aquifer. One study suggests that the aquifer thickness should be set at 1.5 times that value (Weight, et. al., 2003). Use of the screen length instead of the aquifer thickness tends to overestimate the hydraulic conductivity (K.J. Halford et al., 2006)

- All long-term pumping tests submitted to the Department must be submitted on a standardized format for the Department to be able to comply with Title 85, Chapter 2, Part 522, MCA, which requires the DEQ to submit pumping test results to the Montana Bureau of Mines and Geology (MBMG). To provide consistency across state agencies, the DEQ will use the same form (currently referred to as form 633) as is required by the Montana Department of Natural Resources and Conservation (DNRC). This form may be modified in the future to be more compatible with MBMGs database system, keep checking the website every time you submit a new aquifer test to make sure you're using the most current form. The results of each pumping test shall be submitted to the DEQ in both hard copy and in electronic format. If the form is filled out incorrectly or an incorrect form is submitted, the DEQ will request that the correct the information/form be submitted. Applicants should not submit the data to the MBMG, the DEQ will be responsible for transferring the data to that agency.

2.7.2 Slug Tests

Slug tests are an acceptable method for determining hydraulic conductivity, but they typically provide lower hydraulic conductivity values than pumping tests. Slug tests are only acceptable on wells completed in the shallowest aquifer. Slug tests only affect a small area of the aquifer immediately surrounding the well (unlike pumping tests which stress large portions of the aquifer), and provide a hydraulic conductivity value for a limited aquifer area. Depending on the size of the proposed subdivision and site hydrogeology, slug tests on multiple wells may be required to accurately determine the hydraulic conductivity.

To accurately analyze the data, any well used for a slug test should have at least a one-foot screened, perforated, or open-hole interval. Wells completed as open bottom (also known as open casing) are assumed to have a one-foot open-hole interval for use in the equations (the difference between an open-bottom and an open-hole well is that an open-bottom well is completed with solid casing to the bottom of the borehole, whereas in an open-hole well the borehole extends below the bottom of the casing). Each well used for a slug test must have a complete well log to be acceptable. A complete well log is typically the official state well log that the licensed driller is required to complete. However, it may also be a log prepared by a qualified individual that includes all the necessary well construction and lithologic information that is needed to properly analyze the slug test results. The following procedures shall be followed when conducting a slug test [a good reference for conducting slug tests is Groundwater and Wells, 2nd ed. (Driscoll, 1986)].

- A rising head (slug out) or falling head (slug in) test may be conducted on wells where the static water level is above the screened, perforated, or open-hole section of the well.

- A falling head test shall not be conducted in cases where the static water level is below the top of the screened, perforated, or open-hole interval. A falling head test in those conditions tests the geologic media above the water table which may not be applicable to the aquifer properties below the water table.

- High hydraulic conductivity aquifers may not provide useful slug test results because water levels may equilibrate before sufficient data points can be collected. In such cases, electronic data-logging devices may be useful in recording sufficient data points for the slug test analysis.

- Water level data shall be measured to the nearest 0.01 foot. Water levels should be measured at intervals to provide at least 10 evenly-spaced data points per log cycle of time (in minutes). For example, collect one data point every six seconds for the first minute of the test, collect one data point every minute between one and ten minutes, etc. The sampling interval should be more frequent if water level recovery is rapid.

- The amount of initial water level change required to conduct an adequate slug test depends on the aquifer's hydraulic conductivity. One foot may be sufficient for low conductivity aquifers. High conductivity aquifers may require several feet of initial water level change to allow time for sufficient data point collection before water levels equilibrate to static conditions.

- Static water levels shall be measured prior to the test.

- The recommended analysis methods are the Bouwer-Rice method (Bouwer and Rice, 1976; Bouwer, 1989) and the Hvorslev method (Hvorslev, 1951). The Hvorslev equation is not designed to be used when the water level drops below the top of the screened, perforated, or open-hole interval of the well.

2.7.3 Published Data

Published hydrogeologic data are available for select areas in the state; typically the major alluvial valleys have at least one comprehensive hydrogeologic report. Published data are acceptable if it provides adequate information on the test procedures and data reduction. Calibrated computer simulations may also be used to determine hydrogeologic parameters. Sources of published data are usually from a government agency such as USEPA, USGS, or MBMG. Data from non-government agencies (educational institutions, for example) may also be acceptable.

2.7.4 Well Log Tests / Drawdown Tests

Well logs and a map of their locations are available from the MBMG Ground-Water Information Center (GWIC) on the internet at: *http://mbmggwic.mtech.edu*. Although not every well drilled in the state is on the list or map, most wells are included in the GWIC database. Because the well tests conducted for most wells drilled in the state only include pumping rate and a maximum drawdown value, the more advanced methods of analyzing the data (see Aquifer Pumping Test section) are not applicable to these tests. One study (Morgan et. al., 2007) showed that the hydraulic conductivity calculated from specific capacity data was similar to the hydraulic conductivity calculated from slug tests. Therefore, the Department allows the use of two equations that are based on the wells specific capacity (specific capacity is the wells pumping rate divided by the total drawdown). The two methods are the modified Cooper-Jacob's Equation (Driscoll, 1986) and Razack and Huntley equation (Fetter, 1994) (see Appendix G). However, the Razack and Huntley equation was based on data only from unconsolidated materials (Fetter, 1994), not in bedrock units. Therefore, the Razack and Huntley equation cannot be used in bedrock water-bearing units. These two equations are only applicable to well log yield tests or drawdown tests; proper aquifer pumping tests should be analyzed by an appropriate method such as the Cooper-Jacob straight-line method or the Theis curve-matching method.

Due to the higher degree of error in well log tests as compared to a properly conducted aquifer pumping test, it is better to average as many applicable well logs as possible to provide a better approximation of the hydraulic conductivity. Normally, a minimum of three well logs are required to determine an average hydraulic conductivity. However, remote sites may have fewer well logs available and can be based on fewer than three well logs. Conversely, the reviewing authority may request more than three well logs for complex sites or sites with numerous nearby well logs. In some areas with consistent geology over a large area, it can be useful to average a large number of well logs to get a more accurate statistical value; in some cases all the well logs within a specific section (1 square mile), or a quarter section, have been used to determine an average hydraulic conductivity.

Many existing domestic wells are not completed in the shallowest ground water; therefore locating adequate well logs is not always possible. When existing data are not available, the reviewing authority may require the construction of an on-site test well(s). If existing wells are completed below the upper 15 feet of the shallow water-bearing unit, the reviewing authority may accept them for use in the nitrate analysis if the reviewing authority determines the wells are completed in the same water-bearing unit and in similar hydrogeologic materials that exist in the upper 15 feet of the water-bearing unit.

Typically, well log tests are conducted via one of three methods: pump, bailer or air (air testing is the preferred method of testing by drillers because it typically provides better development of the well as compared to pumping or bailing). Of these three methods, air is the least reliable method because in most cases the driller cannot actually measure the water level during the test due to turbulence caused by the air injection. Therefore, for the purposes of determining drawdown, it is assumed that the water level drops to the bottom of the air line (this assumption provides a minimum value for hydraulic conductivity). The other methods (pump and bailer) allow measurement of the water level during pumping, and may be more accurate methods. Of those two methods, the pump method is likely more accurate because the water removal rate is more consistent than with a bailer. However, in some areas of the state the above assessment may not be accurate. According to Dixon (2002), the hydraulic conductivity results from bailer tests were statistically different from pump and air tests in the same hydrogeologic units in over 1,000 well logs that were analyzed in the Gallatin Valley. Dixon (2002) concluded that the pump and air tests were valid test methods to accurately characterize hydraulic conductivity in the unconsolidated aquifers in the Gallatin Valley, but that bailer tests were not valid. Although the information from Dixon (2002) partially conflicts with the previous discussion, the common conclusion is that tests using a pump provide a reasonably accurate estimate of hydraulic conductivity. Whether bailer or air tests provide equally accurate results is not as clear. Therefore, when an adequate number of applicable tests using pumps are available they can be used preferentially over air and bailer tests.

If a drawdown test is conducted on a well where just the static water level and maximum drawdown level are measured, then this information shall be used in the Modified Cooper-Jacob’s equation (Driscoll, 1986) or Razack and Huntley equation

(Fetter, 1994) to determine hydraulic conductivity (see Appendix G). As mentioned previously in this section, the Razack and Huntley equation should not be used in bedrock water-bearing units. This hydraulic conductivity should be averaged with all other applicable and similarly derived hydraulic conductivity values to get the average value for use in the nitrate dilution model.

Some well log tests will indicate no drawdown during the test (the pumping water level will equal the static water level). In these cases, because the large majority of well logs only report water levels to the nearest foot, the drawdown should be assumed at one foot for use in the Modified Cooper-Jacob or the Razack and Huntley equations.

Many of the requirements of an aquifer pumping test also apply to drawdown tests. For example, the well should be pumped at a constant rate for the length of the pumping test, the drawdown shall be measured after it has stabilized, and the discharge water shall be disposed in a location that will not recharge the shallow ground water during the test.

Well logs are also used for determining adequate water supply as part of the subdivision review process. The pumping length and recovery time can be used in this assessment. A recovery time that is longer than the pumping time can be an indication of dependability problems with the aquifer.

2.7.5 Unacceptable Methods

Hydraulic conductivity values based on tables from books (e.g., Freeze and Cherry, 1979; Table 2.2) or lithologic descriptions are not acceptable due to the wide range of possible values for the same type of geologic material. Laboratory methods for determining hydraulic conductivity, such as grain size analysis or permeameter tests, are typically not acceptable because it is very difficult to collect an undisturbed sample that accurately represents the aquifer properties.

2.8 Hydraulic Gradient and Ground Water Flow Direction

Hydraulic gradient is a measure of the slope of the water table in the direction that yields the maximum slope. It is usually expressed as a dimensionless value or “ft/ft” along with a compass direction. Along with the hydraulic conductivity, the hydraulic gradient controls the amount of ground water that is available for dilution.

The slope and direction of the ground water hydraulic gradient can vary seasonally and in response to anthropogenic effects, such as pumping from wells. In most cases, the variations are minimal and can be ignored. However, in some cases the variation may be significant and may require seasonal monitoring to determine the fluctuations. When the variations in direction are significant it may be appropriate to utilize a source specific mixing zone that is wider than a standard mixing zone. The reviewing authority may use any relevant data to determine that seasonal fluctuations may exist and require seasonal monitoring.

Although there may be other methods of determining hydraulic gradient, a list of the methods typically used is presented below. Assuming equal quality of data collection, the list is in the order of the most accurate to the least accurate method. Therefore, data collected using a method higher on the list will generally be used over data collected via a lower method. On-site data are typically more applicable than off-site data. Therefore, on-site data using a less accurate method may in some cases be more applicable than data collected via a more accurate method from a distant off-site source.

1. Static water elevations measured in on-site/near-site wells
2. Published potentiometric maps of the shallowest aquifer
3. One-third of regional topographic slope

Each of these methods is discussed below.

2.8.1 Measured Water Elevations

The most accurate method to determine the hydraulic gradient is to measure the static water elevation in a minimum of three wells to define the plane of the ground-water table. The following procedures shall be followed when measuring the hydraulic gradient with this method.

- Three or more wells that define a plane (i.e., are not oriented in a straight line in map view) should be used;

- Each well shall be completed in the same water-bearing unit (i.e., the shallowest ground water beneath the proposed subdivision) and a well log shall be submitted for each well (the wells do not have to be located on-site);

- The elevation of the measuring point of each well (usually the top of casing) shall be surveyed to the nearest 0.01 foot. Note that gradient can be determined without determining the elevation of each well relative to sea level – the well elevations can be measured against a single arbitrary reference point;

- Static (non-pumping influenced) water levels shall be measured to the nearest 0.01 foot. Static water levels from well logs usually do not meet the accuracy or time requirements in this section and therefore should not be used to determine hydraulic gradient;

- All water levels should be measured on the same date to minimize weather, irrigation, and other external factors from disturbing the relative water elevations (in some cases, water levels collected a few days apart will also be acceptable); and

- The wells shall be located on a USGS topographic map (or other suitable and scaled site map) in order to construct a hydraulic gradient map using the measured ground water elevations. A worksheet for calculating hydraulic gradient is included in Appendix H. The well locations should be surveyed, unless they can be accurately located on the map via other methods. Typically, the location information on well logs is not adequate to determine accurate well locations.

2.8.2 Published Data

Published hydrogeologic data are available for select areas in the state; typically the major alluvial valleys have at least one comprehensive hydrogeologic report. Published data are acceptable if it provides adequate information on how the hydraulic gradient/potentiometric map was determined. Calibrated computer simulations may also be used to determine hydrogeologic parameters. Sources of published data are usually from a government agency such as USEPA, USGS, or Montana Bureau of Mines and Geology (MBMG). Data from non-government agencies (educational institutions, for example) may also be acceptable.

2.8.3 One-Third Regional Topographic Slope

A simple method to estimate the ground-water hydraulic gradient is based on the principle that the hydraulic gradient is a subdued expression of the topographic slope (Haitjema and Mitchell-Bruker, 2005). Using this assumption, the ground-water gradient can be conservatively estimated as one-third of the regional topographic slope. The regional topographic slope can be determined from a USGS topographic map in most cases (topographic maps of the state are available electronically through the state library NRIS system at http://maps2.nris.mt.gov/scripts/esrimap.dll?name=LocMap&Cmd=Map). Minor topographic fluctuations, which typically are not reflected in the ground-water table, shall not be used to determine the hydraulic gradient (an example is shown in Appendix I). In Appendix I, a site location is shown with two potential ways to measure hydraulic gradient, using one-third of the steep topographic slope between A' and A, or one-third the flatter slope between B' and B. In this situation, it is very likely that the regional ground water flow does not "see" or follow the locally steep bank between A' and A. It is more likely that the effluent from the site will follow the regional topography, which is northerly in the direction of B' and B.

Actual hydraulic gradients typically range from one-third to equal to the regional topographic slope. Therefore, assuming hydraulic gradient is one-third of the topographic slope provides a conservative estimate for use in the nitrate analysis. Using this method, the maximum hydraulic gradient accepted is 0.05 ft/ft. When no better data are available and the site is in a topographically flat area, the minimum hydraulic gradient to be used in the nitrate calculations is 0.001 ft/ft.

In certain cases, when a site is near a lake or river, using the conservative value of one-third the regional topographic slope can be shown to be unrealistically shallow. If the ground water depth at the site is known and the assumed hydraulic gradient would cause the ground water level to rise above land surface before the lake or river (and there is no indication of ground water seeps and springs between the site and the lake or river), then the gradient can be based on the gradient between the known on-site ground water elevation and the elevation of water in the lake or river.

2.9 Background Nitrate Concentration

The background nitrate concentration is used to determine the initial quality of the ground water that will be impacted by the SWTS.

The well(s) used for the background nitrate sample shall be completed in the shallowest ground water. In some areas of high development or environmentally sensitive areas, the reviewing authority may require that the nitrate sample be collected from a well that is only screened in the upper 15 to 25 feet of the shallowest ground water. Existing wells completed below the upper 15 feet of the shallow water-bearing unit may be used in the nitrate analysis if the reviewing authority determines the wells are completed in the same water-bearing unit and are likely to have similar nitrate concentrations as wells completed in the upper 15 feet.

As nitrate enters the water table from surface sources (drainfields, for example), it tends to remain near the top of the water table. If a nitrate sample is collected from a well that is completed at depth in the aquifer, it may not account for the higher nitrate concentrations near the water table, and therefore, the impacts to the ground water would be underestimated. Ground-water samples collected from the upper several feet of the aquifer (from shallow ground-water monitoring points, for example) are usually not acceptable because nitrate concentrations in the upper several feet of the ground water may be depressed due to dilution from precipitation or irrigation. If the shallow water bearing unit is thinner than the standard mixing zone thickness (15 feet), then the ground water sample shall be collected from a well penetrating that reduced thickness.

If there is evidence of locally elevated nitrate concentrations or an area is susceptible to nitrate contamination (for example, an area where the local geology and/or soil conditions do not allow adequate treatment or dilution of wastewater) it may be necessary to conduct long-term monitoring of the ground water nitrate concentrations in multiple wells over time. This information may be useful in determining if the elevated concentrations are temporary (possibly due to historic land uses) or are permanent. If the reviewing authority is satisfied that the long-term data show a statistically significant reduction in nitrate concentrations, the more recent and lower nitrate concentrations can be used to re-analyze the impacts of additional subdivision lots (conversely, if nitrate concentrations show a statistically significant increase, those recent higher concentrations would be used in the nitrate analysis).

ARM 17.30.715(1) (d) (iv), allows for the nitrate concentration at the end of the mixing zone to increase up to 7.5 mg/L using a conventional wastewater treatment system if the background nitrate is greater than 5 mg/L (but less than 7.5 mg/L), and the elevated background nitrate concentration is primarily due to sources other than human waste (see Appendix J for a summary of this rule).

2.9.1 Ground Water Sampling Procedures

At least three well volumes should be purged prior to collecting the ground-water sample. The sample should be collected in a laboratory-provided, unused, sample container. If the well draws dry during purging, purging is complete and the sample can be collected when sufficient water is available. The well volume (in gallons) can be calculated using the following equation:

$$volume = (pi)\,(r^2)\,(l)\,(7.48)$$

where:

pi = 3.14

r = radius of well (ft)

l = depth of static water column in the well (ft)

7.48 = conversion factor from ft^3 to gallons

An alternative method to determine when purging is complete is to measure the water temperature at five minute intervals. When three consecutive readings are within 0.5°C (12.2°, 12.5° and 12.0°C, for example), the well purging is considered complete.

Sample collection shall be conducted prior to any water treatment system (treatment systems include but are not limited to reverse osmosis, disinfection, water softeners, and distillers). The sample shall be preserved according to the procedures required by the laboratory, and transported and analyzed within the proper holding times. Concentrations shall be reported as nitrate (as N) or as nitrate+nitrite (as N). The laboratory method detection limit shall be less than or equal to 0.1 mg/L.

The ground-water sample(s) should have been collected within twelve months of the date the non-significance application is initially received by the reviewing authority. If local land uses have not changed recently and the reviewing authority doesn't expect any significant change in the ground water nitrate concentration and it is logistically or economically impracticable to collect a new sample, a sample older than twelve months may be used. A well log from the well used to collect the nitrate sample should be included (or other information to determine the production interval of the well). The well location shall be marked on a USGS topographical map and/or lot layout. The well log, well location map, narrative descriptions, and laboratory results should use the same well identifier to insure that the reviewing authority can identify the source and location of the laboratory results.

The MBMG GWIC database (*http://mbmggwic.mtech.edu*) contains results of ground-water nitrate analyses that may be useful.

In general, the optimum well locations for a background nitrate sample in order of decreasing desirability are listed below.

a) on-site;
b) directly upgradient and adjacent to the proposed subdivision;
c) directly downgradient and adjacent to the proposed subdivision;
d) upgradient but not adjacent to the proposed subdivision;
e) directly cross-gradient and adjacent to the proposed subdivision;
f) downgradient but not adjacent to the proposed subdivision; and
g) cross-gradient but not adjacent to the proposed subdivision

Typically, water samples from springs are not acceptable, but in some situations they may be acceptable sampling locations if the spring water is representative of the shallow ground-water quality beneath the site.

In most cases, a single background nitrate sample will be sufficient. However, the reviewing authority may require additional samples if the reviewing authority has reason to believe that there is temporal or spatial variation in the ground water nitrate concentrations. When multiple analyses are required, the average or median of the results may be used unless the concentrations between wells vary significantly and the average or median would not be protective of state water. Examples of situations where additional nitrate samples may be required include but are not limited to: the initial nitrate (as N) background sample is above 2.0 mg/L; the reviewing authority has information indicating that nearby well(s) have nitrate (as N) concentrations above 2.0 mg/L; the area around the proposed subdivision is experiencing high development rates; the proposed subdivision is in an environmentally sensitive area such as near a stream, lake, or wetland; the potential for contamination of wells is high due to shallow water conditions; or poor geologic conditions exist for wastewater treatment. In areas of elevated nitrate concentrations, the reviewing authority may require analysis of other constituents in the ground water (e.g., chloride, bromide, nitrogen/oxygen isotopes, etc.) to determine the origin of the nitrate.

The nitrate ground water concentration often varies from season to season and from well to well. In most cases, the fluctuations are minimal and can be ignored. However, in some cases the variation may be significant and may require seasonal long-term monitoring to determine the extent and possible cause of the fluctuations.

To protect high quality state waters the reviewing authority can use the highest local nitrate concentrations where appropriate for use in the nitrate dilution calculation. The reviewing authority may use any relevant data to determine that temporal fluctuations may exist and require long-term monitoring.

2.10 Other Parameters

2.10.1 Nitrate (as N) Concentration in Precipitation

A default nitrate (as N) concentration of 1 mg/L is used for the nitrate concentration in precipitation variable. This value is based on a study (Stanford et. al., 1983) that measured total kjeldahl nitrogen (TKN) (as N) 37 times and nitrate (as N) 55 times between 1979 and 1982 at different locations near Flathead Lake. The study found an average of TKN plus nitrate (as N) was 0.76 mg/L. This value has been rounded up to 1.0 mg/L for use in the dilution equation.

A site-specific value can be substituted by measuring nitrate concentration of local precipitation. A substitute value should consist of the average of quarterly precipitation samples collected over a one-year period to account for seasonal variation. Precipitation samples shall be analyzed for total nitrogen [the sum of nitrate, nitrite, and TKN (as N)].

2.10.2 Recharge Percentage

Recharge percentage is the percentage of total precipitation that actually enters the ground-water system. It is a fraction of the total precipitation that lands on the ground. Determining a default value for this parameter is difficult because it is highly dependent on soil type, vegetation type and intensity of rainfall. Based on several references (Stephens, 1995; and Stephens and Knowlton, 1986), 20% recharge percentage appears to be an appropriate average number for Montana’s semi-arid climate.

A default value of 20% (or 0.2) is assumed in the model.

Site specific data to alter the default value may be submitted for reviewing authority review.

2.10.3 Nitrogen Concentration in SWTS Effluent

The default value for effluent total nitrogen concentration from a septic tank and drainfield system is 50 mg/L**.** The default concentration, 50 mg/L, is based on average raw wastewater strength of 60 mg/L and a 10 mg/L reduction to account for treatment in the septic tank and drainfield. The septic tank is assumed to remove 10% of the total nitrogen, which is within the range of published values, 5-30% (Seabloom, 2004; Gold and Sims, 2000; Pell and Nyberg, 1989; and Laak, 1981). The drainfield is assumed to remove an additional 7%, which is similar to other published values: less than 10% (Costa et. al., 2002); and 12 % (Rosen et. al., 2006 and Lowe et. al., 2007). The 60 mg/L influent concentration is consistent with the range of total nitrogen concentrations in raw residential wastewater (EPA, 2002).

The default value for effluent total nitrogen concentration from a nutrient reducing SWTS is 24 mg/L for a Level 2 system, 30 mg/L for a Level 1a system, and 40 mg/L for a Level 1b system. The definitions of these three types of systems are in ARM 17.30.702(11) (9) and (10), respectively. The information necessary to classify a SWTS as nutrient reducing (Level 1a, 1b, or 2) is in ARM 17.30.718.

Although commercial waste effluent strength may vary depending on the commercial use, the domestic effluent average of 50 mg/L is maintained due to difficulty in calculating true waste strength prior to actual SWTS operation. In addition, the property use for a commercial SWTS may change several times over the SWTSs life, and the average concentration (50 mg/L) is likely a good approximation over time. 50 mg/L at 200 gallons per day is equivalent to an annual load of 31.5 pounds, which is a similar load to that reported by Valiela, et.al. (1997).

The concentration of nitrogen in the effluent can be decreased by using nitrogen reducing treatment systems. A list of various alternative systems accepted by the Department and the corresponding nitrate effluent concentrations is included on the Department's website at http://deq.state.mt.us/wqinfo/Nondeg/Index.asp (see the "List of Systems" on that web page). This list may be modified as new technologies demonstrate enhanced nitrogen removal (see the Department's web-site for the most recent version of this list at: http://www.deq.mt.gov/wqinfo/Nondeg/Index.asp). Systems classified as Level 2 systems use a nitrate (as N) effluent concentration of 24 mg/L. Some level 2 SWTSs are approved to treat total nitrogen to concentrations less than 24 mg/L (one system as low as 7.5 mg/L). The list of nitrogen reducing systems and specific requirements for each system are on the Department's web-site at: http://www.deq.mt.gov/wqinfo/Nondeg/Index.asp .

Pursuant to ARM 17.30.715(1) (d) (iii), septic systems that treat domestic effluent using a Level 2 system can increase the nitrate (as N) concentration up to 7.5 mg/L at the end of the ground-water mixing zone. Other treatment systems (including Level 1a and Level 1b SWTSs) must maintain nitrate (as N) below 5 mg/L at the end of the mixing zone, except for situations when existing ground water nitrate (as N) concentrations are elevated between 5 and 7.5 mg/L due to sources other than human waste. In that situation, SWTSs that are not considered Level 2 must maintain nitrate (as N) below 7.5 mg/L at the end of the ground-water mixing zone [ARM 17.30.715(1)(d)(iv)].

Denitrification in the soils beneath the drainfield does occur, but the amount of denitrification depends on several soil properties and is site specific. Appropriate site-specific data shall be submitted for review if an application includes denitrification factors in the nitrate analysis.

The conditions necessary for denitrification to occur are the presence of the correct bacteria, anaerobic conditions, and an appropriate energy source (which is typically carbon). The conditions necessary for denitrification are not ubiquitous in the environment, which creates wide variations of natural denitrification rates. A couple of references on denitrification and past studies are Parkin (1991) and Korom, (1992).

Although there is no universal consensus, the parameter that appears to limit natural denitrification rates is the energy source for the bacteria that facilitates denitrification (the energy source is typically carbon, but the bacteria can also use sulfur or iron). Some studies suggest the carbon source is limited and its availability is based on hydrogeologic factors (Starr and Gillham, 1993; and Trudell et al., 1986). However, other studies indicate that carbon may be in a near infinite supply in some aquifers (Aravena and Robertson, 1998). Riparian areas often contain the proper conditions necessary for denitrification (Rosenblatt, et. al., 2001). Although the denitrification potential in riparian areas is heterogeneous (Hill, 1996) as it is in other environments, riparian areas offer some of the best natural environments for rapid denitrification of nitrate in ground water (Gilliam, 1994; Hinkle et. al., 2007).

The Department's mixing zone rules assume that as nitrate (and other contaminants) moves through the unsaturated zone it is not attenuated. Because anaerobic conditions are necessary for denitrification, and the vadose zone (particularly at relatively shallow depths) is typically under aerobic conditions, this is a valid assumption and is supported by at least one site-specific study (Smith and Duff, 1988). Therefore, most denitrification is assumed to occur beneath the ground water table where anaerobic conditions are more likely to occur. However, in areas where the water table is deep, anoxic conditions may exist in the deeper areas of the vadose zone where oxygen is unable to penetrate (Long et al., 1997). Barriers to oxygen migration in the vadose zone may be caused by geologic materials or through attenuation by biologic respiration.

Variation of natural denitrification rates is well documented by USGS studies and other researchers. Studies have shown that when the conditions for denitrification exist, it can occur completely and rapidly over short distances, or it may occur over longer distances and longer time frames due to larger inputs of nitrogen than the aquifer can denitrify (Woessner et al., 1996; Umari et al., 1995; Smith and Duff, 1988; Aravena and Robertson, 1998; Trudell et al., 1986; Harman et al., 1996; and Nolan, 1999). Other studies have compared similar sites to demonstrate the variation of denitrification rates (Robertson et al., 1991; and Starr and Gillham, 1993); those studies compared separate sites showing relatively rapid denitrification at one site and little or no denitrification at another similar site. Shaw and Turyk (1994) demonstrated less than 10% denitrification beneath 14 drainfields by comparing chloride/nitrogen ratios entering the drainfield to the chloride/nitrogen ratios in the ground water downgradient of the SWTSs.

Additional information regarding SWTS and issues regarding nitrogen removal in different types of SWTSs can be found in Siegrist et.al. 2000, and Gold and Sims, 2000).

2.10.4 Quantity of Effluent

The average single-family home produces approximately 200 gallons per day (gpd) of wastewater. In comparison, the maximum day design flow for a 3-bedroom single-family home wastewater treatment system is 300 gpd (Department Circular DEQ-4). The 200 gpd value is based on a long-term average of typical domestic flows and is applied equally to average-sized single-family homes with between two and five bedrooms. The 200 gpd is consistent with the range of average effluent rates for single-family homes (EPA, 2002). However, for homes with six or more bedrooms, the 200 gpd value used in the nondegradation calculations will be increased by 80 gpd per extra bedroom over five. 80 gpd is the average per capita use based on 1998 housing population data (2.5 persons per home in Montana). In addition, because Department Circular DEQ-4 has a design flow rate for a one bedroom residential dwelling unit of 150 gpd, the allowed wastewater flow rate for the nonsignificance analyses is also 150 gpd.

Typical flows for commercial establishments can be estimated from information in Department Circular DEQ-4. The effluent rate used for the nondegradation analysis of a commercial SWTS can be divided by 200 gpd to get the single-family home equivalents. Most commercial applications will be required to base the nonsignificance calculations (for nitrogen and phosphorus) on the wastewater systems design flow, rather than on average flow. In contrast to single-family sites that use an average flow for nondegradation calculations, most commercial sites are required to use their design flow in the nondegradation calculations because of their potential to operate near their design capacity more frequently and for extended periods of time.

Wastewater systems that have widely fluctuating seasonal effluent rates such as tourist-based businesses (e.g., campgrounds, ski areas, etc.) require additional analysis to determine the appropriate flow rate for use in the nitrate dilution calculation. Seasonal variation should not affect the phosphorus analysis; the annual flow can be adjusted to account for seasonal use to determine the yearly phosphorus load. For the nitrate analysis, the issue is whether to use the annual average flow or to use the flows during the months of high use. The answer depends on several factors: the amount of effluent generated, the mixing zone length, and the local hydrogeology (e.g., depth to ground water, soil types, and ground water velocity).

The reviewer must evaluate whether the geologic materials in the unsaturated and ground water zones will dissipate the effluent released during the high-use period over the course of the year, or whether the effluent discharged during high use will travel relatively rapidly to the end of the mixing zone as a discreet slug of effluent. This analysis attempts to determine the effluent travel time from the drainfield through the unsaturated zone and through the ground water to the end of the mixing zone. If the travel time is relatively long (on the order of years), it is more likely that the effluent discharged during the high-use period will be naturally dispersed and will not travel to the end of the mixing zone as a discreet slug. In that case, an annual flow average or some value less than the flow during the high-use months can be used in the nitrate dilution calculation. If the travel time is relatively short, the effluent discharged during high use is more likely to migrate to the end of the mixing zone as a discreet slug and the high-use effluent rate should be used in the dilution calculation. If the reviewer is uncertain of the travel time, the conservative solution is to use the flow during the high-use months. Alternatively, a numerical computer ground water and solute transport model could be used to simulate the migration of contamination to determine if a flow rate less than the high-use flow could be used to accurately predict concentrations at the end of the mixing zone.

2.11 Mixing Zones

(See Appendix K, Mixing Zone Drawing)

Mixing zones are defined in 75-5-103(21), MCA as *"…an area established in a permit or final decision on nondegradation issued by the department where water quality standards may be exceeded…"* Mixing zones are granted to allow for complete mixing of the effluent with the receiving water, so that at the end of the mixing zone the contaminant concentration is evenly distributed across the mixing zone. SWTS discharges are automatically given standard mixing zone lengths pursuant to ARM 17.30.517(1) (d) (viii). The requirements for source specific mixing zones (SSMZ) are in ARM 17.30.518, and discussed further in section 2.11.2 (Mixing Zone Length).

Mixing zones are required for both primary and replacement drainfields.

2.11.1 Mixing Zone Thickness

The standard mixing zone thickness is 15 feet [ARM 17.30.517(1) (d) (iii) (A)] because this is the theoretical thickness that the effluent plume will mix in the vertical direction below the water table. It is not the actual thickness of the shallowest aquifer. This value is applicable for most circumstances since most ground-water bearing zones are greater than 15 feet thick. However, when evidence exists that the shallow ground-water zone is less than 15 feet thick (for example, a gravel aquifer that is underlain by low permeability clay at 5 feet below the water table); the mixing zone thickness shall equal the saturated ground-water thickness above the lower permeability unit (5 feet in this example).

2.11.2 Mixing Zone Length

Standard mixing zones are defined in ARM 17.30.502(11) as "*… a mixing zone that meets the requirements of ARM 17.30.516 and 17.30.517 and involves less data collection and demonstration than required for a source specific mixing zone.* Standard ground-water mixing zone lengths are prescribed in ARM 17.30.517(1) (d) (viii) and are summarized below (Table 1). The information requirements listed in ARM 17.30.518 apply primarily when a longer than standard mixing zone is requested. For shorter than standard mixing zones some or all of the additional information listed in ARM 17.30.518 may also be required by the reviewing authority.

Table 1: Standard Ground Water Mixing Zone Summary Table (see ARM 17.30.517(1) (d) (viii) for complete rule requirements)

Type of System	Lot Size (acres)	Subdivision Size (acres)	Standard Mixing Zone Length (feet)
Single-family	< 2	NA	100
Single-family	≥ 2	5 to 10	200
Single-family	≥ 2	< 5.0 or > 10.0	500
Commercial	NA	NA	500
Public	NA	NA	500
Duplex	NA	NA	500
Multi-user	NA	NA	500

If the parameters used to define a standard mixing zone (ARM 17.30.517 and 17.30.516 for ground water and surface water mixing zones, respectively) are not applicable or desired by the applicant, a Source Specific Mixing Zone (SSMZ) may be requested [ARM 17.30.518(5)].

The most common request for a SSMZ is to shorten the standard mixing zone length, Requests for SSMZ less than 100 feet for a single-family drainfield or less than 500 feet for a commercial, public, duplex/shared or multiple user drainfield or where standard mixing zones would intersect drinking water wells will require additional information demonstrating protection of surrounding water resources and water uses. A mixing zone establishes an area where the water quality exceeds standards and an area where pathogens from wastewater may be present. When evaluating the request for a SSMZ, the following minimum design standards and site information must be submitted for review:

1. The subsurface wastewater treatment system (SWTS) being proposed must be pressure dosed according to applicable Chapters in DEQ 4.

2. Only proximal data applicable to the site will be allowed in determining the Hydraulic Conductivity and Hydraulic Gradient values used on the Nitrate

Sensitivity Analysis. Hydraulic conductivity may still be determined from well logs but hydraulic gradient must be triangulated from wells or determined from published hydrogeologic data as specified in this manual. All other requirements of the Nitrate Sensitivity Analysis apply.

3. The ‘depth of aquifer’ or ‘mixing zone thickness’ value for lengths shorter than 100 feet, in the Nitrate Sensitivity Analysis must be adjusted by means of a linear ratio dependent on length of SSMZ being proposed. For example, the standard depth of aquifer for a 100-500 foot mixing zone is 15 feet, a SSMZ length of 50 feet requires an analysis with a depth of aquifer value of 7.5 feet and a requested SSMZ length of 25 feet requires the analysis with a depth of aquifer value of 3.75 feet.

4. Quality of the effluent reaching the infiltrative surface must be of residential strength.

5. An assessment of impacts to down-gradient drinking water supplies, including impacts from pathogens, should show 4-log microbial inactivation or the removal of 99.99% of viruses. 4-log microbial attenuation typically occurs within 200 days.

   A single analysis or combination of methodologies can be used to demonstrate viral removal/inactivation. . When evaluating viral inactivation, both horizontal and vertical transport times can be assessed to calculate travel time as shown in Appendix U. Inputs for each model are site specific with many of the parameters described in this document. Specific questions regarding the use of these tools should be directed to the Department.

   Additionally, the United States Environmental Protection Agency has developed a Virus Fate and Transport (Virulo) Model describing pathogen sorption in the vadose zone that can be downloaded at http://www2.epa.gov/water-research/virus-fate-and-transport-virulo-model. This program can be used either alone or in conjunction with time of travel calculations to determine 4- log inactivation.

Using the requirements herein, the approvable SSMZ length or setback envelope if no formal mixing zone is required to be assigned, is that which passes the Nitrate Sensitivity Analysis but that a length of 10 feet is the minimum approvable distance. All set-backs as established in ARM 17.36 sub-chapter 3 and 9 (as applicable) apply.

The second most common request is to lengthen the standard mixing zone to meet the nondegradation nitrate standard. If an applicant requests a longer than standard mixing zone (a source-specific mixing zone), they must demonstrate that the additional length is needed to achieve complete mixing. A mixing zone cannot be lengthened beyond the standard length just for the purpose of getting more dilution.

One method to demonstrate that a longer mixing zone is necessary is to prepare a computer model simulating the proposed mixing zone.

Other than length, SSMZ requests that include modification of the parameters defined for a standard mixing zone in ARM 17.30.517(1) (d) require the following information:

- Install three on-site monitoring wells to be completed in the shallowest ground water beneath the site.

- The three wells should be used to determine the hydraulic gradient beneath the site. The wells should be surveyed and the static water elevations measured (to the nearest 0.01 foot) on two separate dates at least two weeks apart.

- A long term pumping test (at least 24 hours long, with corresponding recovery data) shall be conducted on one of the three monitoring wells to determine the hydraulic conductivity of the shallow ground water beneath the site (observation wells may be used, and in many cases may provide a higher and more accurate hydraulic conductivity value than the pumping well). The test(s) shall be conducted in accordance with the requirements in section 2.7.1 (Aquifer Pumping Tests).

- Ground water from each well should be collected and analyzed for nitrate (as N) concentration for use in determining the background nitrate concentration.

- Long-term compliance monitoring may be required.

- A contingency plan may be necessary if pollutants migrate beyond the mixing zone at concentrations above the allowed limit.

- A specific explanation as to why the proposed mixing zone is the smallest practicable size and why it will have a minimum practicable effect on water users.

The reviewing authority cannot require additional treatment for a SSMZ (pursuant to 75-5-305(1), MCA). However, in some cases (as determined on a site-by-site basis), the reviewing authority may remove some or all of the above requirements if the applicant proposes additional treatment, such as Level 2 treatment for nitrogen.

If a state surface water lies within the ground-water mixing zone, the ground water mixing zone ends at the edge of the mean high-water level of the surface water. If the applicable nitrate concentrations cannot be met within the shortened ground-water mixing zone, the sewage treatment system should be moved, revised, or a surface water mixing zone should be applied for pursuant to ARM 17.30.516 or 17.30.518. Standard mixing zones in lakes or wetlands for new or increased sources are not permitted per ARM 17.30.516(2), however SSMZ are allowed for those water bodies

[ARM 17.30.518(3)]. Standard surface water mixing zones are allowed for streams and rivers.

For situations where the ground water mixing zone does not extend to a surface water, but is adjacent to a surface water, additional analyses may be required. See section 5.0 (Adjacent to Surface Waters) for additional information.

The accurate dimensions of each mixing zone (primary and replacement) shall be shown on a map with any nearby wells as discussed in Lot Layout Requirements.

2.11.3 Mixing Zone Width

The mixing zone width is determined by the total width of the primary drainfield (or replacement drainfield) as measured perpendicular to the ground-water flow direction. The width increases downgradient from the drainfield according to the equation listed in ARM 17.30.517(1)(d)(iii)(B) which states, *"...equal to the width of the source plus the distance determined by the tangent of 5° times the length of the mixing zone on both sides of the source."*

The width of the drainfield as measured perpendicular to ground water flow directly effects the amount of dilution available in the nitrate dilution calculation. A wider drainfield provides more dilution and decreases the nitrate concentration at the end of the mixing zone.

For elevated sand mounds (ESM), the dimensions of the discharge area can be based on the basal area of the sand mound for laterals that are raised no more than 2 feet above the natural ground surface and a mound slope of no less than 3:1. The calculations to determine dimensions should assume that the natural ground surface has no slope.

2.11.4 Wells and Ground Water Mixing Zones

By definition, a mixing zone is an area where water quality standards may be exceeded [75-5-103(18), MCA]. ARM 17.36.323 requires all mixing zones be a minimum of 100 feet from existing or proposed drinking water supply wells. If an onsite test well is drilled for the purposes of meeting subdivision rule or nondegradation/mixing zone rule requirements only, the well can be considered as a test well and not a drinking water supply well. If the test well is to be used later as a drinking water supply well for the proposed subdivision, the mixing zone must be a minimum of 100 feet from the well.

The setback restrictions are typically applied to the horizontal location of drinking water supply wells. However, the restrictions also apply to the vertical placement of a well. Therefore, under appropriate hydrogeological circumstances where a well is located in water-bearing unit that is not hydraulically connected to the water bearing unit that the mixing zone is in (e.g., a confined aquifer beneath a mixing zone) and appropriate well construction techniques are used (e.g., sealing casing throughout a shallow aquifer), installation of a drinking water supply well may be allowed below a mixing zone. Contact the Department on a case-by-case basis to determine if a well can be installed beneath a particular mixing zone.

2.11.5 Applicability of Mixing Zones

In some instances, the Department may not be able to approve a mixing zone in accordance with ARM 17.30.506(2)(g), which states that: *"Aquifer characteristics: when currently available data indicate that the movement of ground water or pollutants within the subsurface cannot be accurately predicted, such as the movement of ground water through fractures, and also indicate that this unpredictability might result in adverse impacts due to a particular concentration of a parameter in the mixing zone, it may be appropriate to deny the mixing zone for the parameter of concern".* The most likely situation where this rule would apply is in fractured bedrock that does not behave like a porous media (e.g., the fractures cause unpredictable movement of the wastewater) and the nitrate dilution equation cannot be used to provide a conservative estimate of the nitrate concentration at the end of a mixing zone.

When mixing zones cannot be approved pursuant to the above referenced rule, some of the available remedies include but are not limited to: re-locate the wastewater discharge to where a mixing zone can be granted; treat the effluent to 7.5 mg/l or less before discharge (e.g. to below the nondegradation water quality limit for level 2 systems); use a non-discharging wastewater system such as an evapotranspiration bed; or connect to another wastewater system.

2.12 Cumulative Effects

The reviewing authority is required to assess the cumulative effects of multiple new sources in an application as well as cumulative effects with surrounding sources of pollution [ARM 17.30.506(2)(f)].

In many instances, multiple drainfields will be aligned in the direction of ground-water flow. This will create a cumulative nitrate impact on the shallow ground water. Cumulative impacts between two or more SWTSs in the same subdivision must be accounted for. In addition, cumulative impacts between proposed SWTSs and previously approved and/or existing surrounding SWTSs (both upgradient and downgradient) must be accounted for if the background ground water nitrate sample(s) do not adequately account for the surrounding development. There are no set criteria to determine when the background nitrate sample accounts for all upgradient development. The decision is related to the age of the upgradient approved uses and the travel time in the unsaturated and vadose zones. It is more likely that the background nitrate sample does account for the upgradient development as the age of the upgradient development increases and as ground water velocities increase.

To determine if cumulative effects with surrounding development are an issue, extensive land ownership information, including names of surrounding subdivisions, property owners name, type of approved water/wastewater system (on-site, or community/public), development status of land, etc. can be determined through the Montana Cadastral Mapping Project: (http://svc.mt.gov/msl/mtcadastral/). The county clerk office may also be a useful source of information.

If any parts of two or more drainfields overlap, as measured in the direction of ground-water flow, cumulative impacts must be assessed (note that the 5° dispersion widening is not accounted for when determining overlap of drainfields). The 5° widening of the mixing zone is not accounted for in the cumulative effects analysis because while the 5° widening of the effluent plume may be reasonable over short distances of single mixing zones, it likely does not approximate real world conditions over longer distances.

The nitrate dilution model can be used to account for cumulative effects according to the procedures outlined in Appendix L.

If cumulative effects of the proposed subdivision cause existing or approved downgradient SWTSs on an unrelated subdivision to exceed 10 mg/L at the end of their mixing zones, the effects on the ground water are significant degradation of state waters. Also, impacts from proposed SWTSs cannot cause a drinking water supply well to exceed 10 mg/L of nitrate (as N). If the nitrate (as N) concentration in an existing downgradient well is already above 10 mg/L, then a proposed SWTS cannot cause the nitrate concentration in that well to increase.

If a subdivision with previously approved mixing zones is re-subdivided, the nitrate concentrations at the end of all the mixing zones in that subdivision must remain below the nondegradation limits of 5 or 7.5 mg/L depending on the type of SWTS used.

In Appendix L the results do not depend on the length of overlap between two drainfields, whether that overlap is 2 feet or the entire drainfield width. Typically, it is easiest to use the full width of each drainfield in the calculations as measured perpendicular to ground water flow.

There may be other methods that can be used to determine cumulative effects. The Department will review and comment on other methods submitted with an application.

In most circumstances it is not necessary to submit the mixing zone calculations for every possible instance of cumulative effects (particularly for larger subdivisions). It is usually adequate to submit some of the worst-case scenarios to demonstrate compliance.

2.13 Confined Ground Water

If the shallowest ground water is confined, then nitrate cannot affect that ground water. Therefore, the impact of nitrate on the ground water is nonsignificant. However, the horizontal migration of the wastewater must still be evaluated with respect to impacts to surface waters or adjacent ground waters that are not confined. The phosphorus breakthrough calculations must still be completed to demonstrate nonsignificant impacts. In addition, if a surface water body is nearby, the nitrate impacts to that surface water may need to be evaluated [see section 5.0 (Adjacent to Surface Waters) for further details]. If the effluent will not impact ground water a mixing zone will not be granted for the SWTS, and the setbacks to drinking water supply wells required in ARM 17.30.508(2) are not applicable.

The amount of evidence needed to demonstrate confined conditions depends on site-specific characteristics. Typically, the reviewing authority requires consistency among local well logs that all show a confining layer, such as a thick continuous layer of clay, in the region of the proposed subdivision. The applicant may be required or may desire in some cases to conduct a pumping test with an observation well to determine aquifer storativity. In conjunction with supporting lithologic data, storativity values between 0.001 and 0.00001 are acceptable for determining confined conditions, depending on the aquifer properties. Values lower than 0.00001 are unrealistic values and indicate problems with the pumping test. Values greater than 0.001 indicate leaky-confined or unconfined conditions. Alternatively, other information demonstrating confined conditions may be submitted.

Another source of information regarding confined aquifers can be published reports. Sources of published data are usually from a government agency such as USEPA, USGS, or Montana Bureau of Mines and Geology (MBMG). Data from non-government agencies (educational institutions, for example) may also be acceptable.

Evidence of barometric-related fluctuations in a well is not necessarily a definitive indicator of confined conditions. Under certain circumstances (such as wells below a low conductivity aquifer, or a thick vadose zone) barometric fluctuations can occur in unconfined aquifers (Hubbell, et. al., 2004; Hare and Morse, 1997).

When the static water level is higher than the reported depth of ground water in well logs it is often used as evidence of confined conditions. This assumption is incorrect and should not be used as evidence for confined conditions. This assumption is incorrect for several reasons: 1) well logs often do not report low-yielding pockets of water that are not feasible for production; 2) well drilling methods (such as using drilling fluids or driving casing behind the drill bit) are not conducive to recognizing low-yielding water bearing units and therefore often go unreported on well logs; 3) local and laterally discontinuous low-permeability units can create ground water under pressure which mimics confined conditions but are not true confined conditions that protect ground water wells from surface contaminants; and 4) fractured bedrock aquifers can also mimic confined conditions due to the orientation of fractures, but despite the pressure head in the well are not truly confined aquifers. See Appendix M for additional detailed description of this topic.

3.0 PHOSPHORUS BREAKTHROUGH ANALYSIS

The phosphorus breakthrough analysis requires sufficient soil adsorption capacity of 50 years (see Appendix N) prior to discharge to surface water [pursuant to ARM 17.30.715(1) (e)]

3.1 Phosphorus Chemistry and Wastewater Systems

A good reference regarding phosphorus chemistry and how it reacts in an SWTS is provided by Lombardo Associates, 2006.

3.2 Dispersion angle in phosphorus plume

The dispersion angle of 5° that is used in the nitrate sensitivity analysis is also appropriate for use in the calculation of phosphorus breakthrough. This dispersion angle is included in the phosphorus breakthrough calculation sheet (see Appendix N).

3.3 Distance to surface water (*D*)

A high-quality surface water and a state surface water are defined in the Water Quality Act [75-5-103(13) and (34), MCA], respectively. If a surface water does not meet the definition of a "state water" or "high quality state water," the phosphorus analysis does not apply to phosphorus discharge for that particular water. In such cases, the phosphorus analysis will have to be calculated for the next downgradient receiving surface water that is classified as a high quality surface water, unless all of the wastewater will be captured by that first non high quality state water.

Distance to the high-quality surface water is based on the map distance between the phosphorus source and the location of the mean high-water level of the surface water.

If site-specific data are not presented to determine the ground-water flow direction (for example, when the ground-water flow direction is assumed from the regional land topography), the wastewater effluent is assumed to move along the shortest distance between the drainfield and the surface water body. Otherwise, the distance to the nearest high quality surface water is based on the measured ground-water flow direction.

3.4 Depth to Limiting Layer (*B*) and Mixing Depth (*T*)

The amount of soil directly beneath the drainfield that is available for absorption of phosphorus is dependent upon the depth to a limiting layer. A limiting layer can be seasonal ground water, an impervious layer such as clay, or bedrock which has no absorption capacity for phosphorus.

The most common method to determine the depth to the limiting layer is to use the on-site test pit information. If ground-water monitoring through the high water period or the soil descriptions in the test pit indicates a limiting layer exists, the depth to that layer (minus the final burial depth of the drainfield laterals) is used in the calculation. If there is no evidence of a limiting layer, then the limiting layer is assumed to be directly beneath the bottom of the test pit.

Static water levels in well logs are not typically acceptable to determine depth to the limiting layer because well logs do not typically note the first water and water levels measured after drilling may not indicate true static water levels, particularly in lower permeability materials. However, if an on-site or near-site well is located in a shallow, unconfined, aquifer that does not have restrictive layers and static water level data are available during the local high water table period, that information may be used to determine the limiting layer depth. The high ground water period is usually during spring or summer depending if the ground-water levels are affected more by spring runoff or summer irrigation.

The imported sand that is beneath the laterals in a sand mound system (up to a maximum depth of 2 feet) can be used in calculating the depth to limiting layer.

The mixing depth for an evapotranspiration absorption (ETA) system is 1.0 foot. This is based on the fine grained nature of the natural material below the ETA bed.

If the ground water cannot physically enter the surface water, that surface water cannot be affected by the phosphorus and a breakthrough calculation to that surface water does not need to be conducted. For example, if the elevation of the bottom of an irrigation ditch is higher than the drainfield laterals, the phosphorus cannot enter the ditch at that point. However, at some point downgradient of the site, the ditch elevation may be below the drainfield laterals and the phosphorus calculations may be required to that point if the effluent can enter the ditch. Another example is a natural stream that is losing water to the ground water all-year long, in this case there is no impact to the stream and the phosphorus calculation can be conducted to the next downgradient receiving high-quality surface water.

Man-made surface water bodies are given the same classification as the basin they are located in (see ARM 17.30 sub-chapter 6 for basin-by-basin classifications). Such water bodies are high-quality state waters unless they do not meet the definitions of “state water” or “high quality state water” as included in 75-5-103(34) and (13), MCA, respectively. Examples of man-made water bodies that are not considered high-quality state waters are: ponds in active gravel pits (however, once the gravel pit is inactive, the water body becomes a high-quality state water); sewage lagoons; and ponds used exclusively for fire protection water reserves. Also, if a man-made water body is constructed and lined with an impermeable liner, which does not allow the effluent to enter the pond, then the nondegradation analysis does not have to assess impacts to the water body (this interpretation does not apply to setback requirements in other rules or statutes).

The phosphorus mixing depth in ground water is defined as either 0.5 foot for coarse-textured soils or 1.0 foot for fine-textured soils. Fine-textured soils are defined in this guidance as any soil that can be described as loam (e.g. gravelly loam, sandy loam, etc.) or finer according to the USDA soil texture classification system. The soil types should be determined by test pits. Typically, sieve analyses do not have to be conducted to determine the soil classification. The soil texture used to define the mixing depth is the soil type immediately above the limiting layer, or where the limiting layer is assumed to be (e.g., the bottom of a test pit with no limiting layer).

3.5 Drainfield Length as Measured Perpendicular to Ground Water Flow (*Lg*)

The length of the drainfield measured perpendicular to ground-water flow is used to determine the width of the soil available to adsorb phosphorus from the drainfield to the surface water. In many cases, the length is equal to the long axis of the drainfield. However, there are cases where the drainfield may be skewed in relation to ground-water flow or the long axis may be parallel to ground-water flow. The calculations can be completed for any drainfield orientation, but the 50-year breakthrough limit is easier to satisfy when the long axis of the drainfield is perpendicular or nearly perpendicular to the ground-water flow direction. Within the restrictions set in Department Circular DEQ-4, drainfields can be made wider by rearranging laterals to maximize the width.

3.6 Drainfield Length (*L*) and Width (*W*)

The length and width of the drainfield are used to determine the area of soil directly beneath the drainfield (up to the top of the limiting layer) that is available to adsorb phosphorus.

For drainfields that are not rectangular or square it does not matter if the values for length and width used in the calculation are equal to any of the actual dimensions of the drainfield as long as the product of the length and width used equals the total footprint area of the drainfield. The individual values do not matter because the calculation sheet only uses the product of these two values (the drainfield area) in the calculations.

For purposes of calculating the drainfield area, the maximum allowed distance between drainfield laterals is 10 feet. For example, if there are 2 laterals spaced on 14-foot centers, only 10 feet of that separation can be used in calculating the amount of soil available for phosphorus absorption beneath the drainfield.

An additional 2 feet can be added to each of the outside laterals to account for lateral dispersion of the effluent when calculating the drainfield width. For example, if the drainfield consists of 3 laterals on 7-foot centers, the width in the calculations is equal to: 2’ + 7' + 7' + 2' = 18 feet.

For elevated sand mounds (ESM), the dimensions of the discharge area can be based on the basal area of the sand mound for laterals that are raised no more than 2 feet above the natural ground surface and a mound slope of no less than 3:1. The calculations to determine dimensions should assume that the natural ground surface has no slope.

3.7 Phosphorus Concentration / Load (*#l* and *Pl*)

The default value for effluent phosphorus concentration from a SWTS is 10.6 mg/L, which is within the range of values reported by the USEPA (2002), Lombardo (2006) and Lowe et. al. (2007). 10.6 mg/L is equivalent to 6.44 lbs/year (lbs/year are the units used in the phosphorus calculation sheet) for a single-family home that produces 200 gallons per day on average. This concentration is used as an average value for domestic and commercial effluent. For one-bedroom units, with an average flow of 150 gpd, the phosphorus load can be reduced by 25% to 4.83 lbs/year. Based on recent census data, the average Montana household has 2.5 persons; therefore the phosphorus load per person is 2.58 lb/year (6.44 / 2.5). Consequently, for each bedroom over 5, an additional load of 2.58 lb/year is added to the calculations. For example, the phosphorus load for an 8 bedroom home would be 14.18 lb/year (6.44 + 2.58 + 2.58 +2.58).

For nonresidential uses, the total phosphorus load to use in the calculation sheets can be calculated using the following equation:

[Nondeg effluent rate (gpd)] / [200 gpd] x [6.44 lbs/year]

If this equation is used, the calculated load should be inserted as the value for "Pl" on the calculation sheet, and the value for "#l" should be set at one.

Although commercial waste effluent strength may vary depending on the commercial use, the average of 10.6 mg/L (or 6.44 lb/yr per 200 gpd) is maintained due to the difficulty in calculating true waste strength prior to actual SWTS operation. In addition, the property use for a commercial lot may change several times over the life of a SWTS, and the average concentration (10.6 mg/L) is likely a fair approximation over time.

If the proposed site has a unique use that is not likely to change over time (e.g., a state river access site, ski area, etc.), the applicant may submit data from a similar site showing what the phosphorus concentration is anticipated to be for use in the phosphorus calculations. Depending on the use and the sampling location, more than one sample over a period of time may be required to get a representative value of the phosphorus concentration. If a concentration other than 10.6 mg/L is used, the phosphorus load (*Pl*) can be calculated using the following equation:

[Phos. concentration (mg/L)] x [Nondeg effluent rate (gpd)] x [0.00305] = Load (lbs/year)

Where, 0.00305 is a unit conversion factor.

3.8 Soil Phosphorus Adsorption Capacity (*Pa*)

The default value for the soil's ability to adsorb phosphorus is 200 ppm. The actual adsorption capacity of a soil can be measured via laboratory methods. The value of 200 ppm should be used unless adequate information is submitted regarding the site-specific adsorption capacity of the soils beneath the SWTS.

Typically, non-calcareous finer grained sediments (clay, silt) contain more adsorption capacity than calcareous sands (Lombardo, 2006). To measure soil adsorption capacity, laboratory preparation of the sample includes removal of all gravel or larger sized particles from the sample before conducting the test. Removing the gravel and larger fragment affects the bulk adsorption capacity of any soil which contains gravel or larger sized grains. Therefore, the laboratory adsorption value calculations shall be adjusted to account for the percentage of gravel and larger materials that were removed. For example, if the laboratory removes 25% of the sample and conducts the adsorption tests on the remaining 75%, the soil adsorption capacity reported by the lab (which is based only on the 75% of material submitted) shall be decreased by 25% to account for the bulk absorption capacity of all of the native soil material. Typically, the graph produced by the laboratory is read by matching the adsorption value that corresponds to when the graph crosses the phosphorus concentration of 10.6 mg/L. .

The location and number of samples that should be collected to determine a phosphorus absorption value are site-specific depending on the local variability of soils, the type and size of treatment system, and other site variables. Contact the reviewing authority to determine the appropriate quantity and location of samples for a particular site or for information regarding laboratories that can perform this analysis.

3.9 Cumulative Effects

In many instances, multiple SWTSs will be aligned in the direction of ground-water flow, which will create a cumulative phosphorus impact on the surface water. Cumulative impacts between two or more SWTSs on the same subdivision must be accounted for. In addition, cumulative impacts between the proposed subdivision and previously approved and/or existing surrounding subdivisions must be accounted for.

If any part of two SWTS overlaps, as measured in the direction of ground-water flow, cumulative impacts must be assessed. To determine the cumulative effects for two SWTSs the phosphorus equation should be completed using the distance from the upgradient SWTS to the second downgradient SWTS as the “distance from SWTS to surface water” in the equation. If the breakthrough is greater than 50 years, then there is no cumulative effect and the phosphorus equation should be run as usual on the downgradient SWTS. However, if the breakthrough from the first to second SWTS is less than 50 years, the calculations for the downgradient SWTS should account for the cumulative effects. For example, if the breakthrough from the upgradient to downgradient SWTS is 35 years (15 years less than the required time), then the breakthrough for the downgradient SWTS must account for the additional 15 years. Therefore, the breakthrough for the downgradient SWTS must be at least 65 years (50 years plus 15 years) to the surface water to be nonsignificant degradation of state waters. See Appendix O for a detailed explanation of cumulative effects calculation for phosphorus breakthrough. This method applies to SWTSs with the same effluent rates. If the SWTSs have different effluent rates, contact the Department to determine how to conduct the cumulative effects analysis.

4.0 CATEGORICAL EXEMPTIONS

The nondegradation rules include a section exempting certain sewage treatment systems from meeting the numeric nitrate and phosphorus criteria (ARM 17.30.716). The exemptions only apply to sewage treatment systems that serve one or two single-family homes, or a non-residential, non-industrial unit with a design flow of 700 gpd or less. The exemptions include general criteria that must be met and five different categories, one of which must be met, to qualify for a categorical exemption. The reviewing authority will use the most relevant, applicable and accurate data that are available at the time of the review. This section provides additional detail on the data that are acceptable to demonstrate compliance with this rule. Appendix P is a summary table for simplified reading of this rule (note that Appendix P is an unofficial summary of the rule; see the rule for specific requirements).

Note that the term "exemption" used here does not imply that the SWTS is exempt from the nondegradation rules, but rather it is exempt from demonstrating compliance with the numeric criteria for significance determination in ARM 17.30.715(1)(d) and 17.30.715(1)(e) for impacts by nitrogen and phosphorus to state ground and surface water. A site that qualifies for a categorical exemption does not require further analyses for impacts to ground water (nitrate sensitivity analysis) or surface water (phosphorus breakthrough, trigger value or numerical analysis).

4.1 Section (2) (a) (i) – Distance to High Quality State Surface Waters

This section describes the minimum distance to surface water from the SWTS. This distance is only applicable to high quality state waters [see section 1.2 (High Quality State Waters)]. The distance is also only applicable to downgradient surface waters that may be impacted by the effluent. If, for example, the nearest downgradient high quality surface water is an irrigation ditch that loses water to the ground all year, then it will likely not be impacted by the sewage effluent (unless there is an impermeable soil layer beneath the SWTS that directs effluent towards the water body). If the surface water will not be impacted then the distance to the next nearest high quality surface water that will be impacted can be used to determine compliance with this part of the rule.

4.2 Sections (2)(a)(ii)(A), (2)(b)(i)(B), (2)(b)(ii)(C), and (2)(b)(iii)(E) – Percolation Tests

These sections include a requirement for percolation test results, "…if a percolation test has been conducted for the SWTS…" The option of requiring a percolation test is to be consistent with requirements in Department Circular DEQ-4 where percolation tests may not be required for some lots. A percolation test value for the lot in question is only required for an exemption if a percolation test has been required separately to meet the requirements of Department Circular DEQ-4. Therefore, if a percolation test is not required under Department Circular DEQ-4 and a test is not conducted, then it is not required for this rule.

"Slower" percolation rates correspond to larger percolation rate values. For example, a percolation rate of 10 minutes per inch is slower than a percolation rate of 6 minutes per inch.

4.3 Sections (2)(a)(ii)(B), (2)(b)(i)(C), (2)(b)(ii)(D), and (2)(b)(iii)(F) – Soil Type

These sections include a minimum of 6 feet of soil type requirement. The six feet of the specific soil type(s) may be anywhere within the soil profile (no matter how deep the test pit is). In addition, the required soil type does not have to be continuous. For example, if six feet of sandy loam is required, that sandy loam can occur in more than one horizon, such as from 2 to 5 feet below ground surface (bgs) and from 8 to 11 feet bgs. Test pit and soil descriptions shall be in accordance with requirements of Department Circular DEQ-4.

4.4 Section (2) (a) (vii) - Ground Water Nitrate Concentration

See section 2.9 (Background Nitrate Concentration) regarding background nitrate (as N) samples.

4.5 Sections (2) (b) (i) (D) and (2) (b) (ii) (E) – Depth to Bedrock and Seasonal High Ground Water

These sections include a minimum depth to bedrock and seasonal high ground water of 8 and 12 feet, respectively. These depths shall be determined from an on-site test pit and ground water monitoring point(s). Ground water monitoring points will be used only if ground water monitoring is required as part of Department Circular DEQ-4. If ground water monitoring is not required to meet the requirements in Department Circular DEQ-4, then compliance with this requirement will be based only on test pit data. The definition of bedrock is listed in section 1.9 of Department Circular DEQ-4.

4.6 Section (2) (b) (iii) (G) – Depth to Bedrock and Ground Water

This section includes a minimum depth to bedrock and ground water of 100 feet. Note that unlike the shallow ground water requirements in sections (2) (b) (i) (D) and (2) (b) (ii) (E), this section does not require the ground water depth be a seasonal high. The depth to bedrock and ground water can be shown by a minimum of three on-site or nearby well logs that indicate there are no bedrock units or water bearing units above 100 feet, or by other adequate information such as published reports. The reviewing authority may require additional local well logs, geologic reports, or other information to verify the absence of bedrock or ground water above 100 feet.

4.7 Section (2) (b) (IV) (A) – Recent Subdivision Lots

This section states the total number of subdivision lots that were reviewed pursuant to 76-4-101 et seq., MCA, and were created in a county during the previous 10 state fiscal years is fewer than 150. The number of subdivision lots that were created will be determined by the Department on an annual basis. A subdivision is defined in 76-4-

102(16), MCA. The fiscal year runs from July 1 to June 30. Contact the Department or visit the Department's web-site for an updated list of counties that meet this requirement (http://www.deq.mt.gov/wqinfo/Nondeg/Index.asp). A list of counties that meet the requirement for fiscal year 2015 are included in Appendix P.

4.8 Section (2) (b) (iv) (B) – Town Population

The Montana Department of Commerce includes a list of town populations in Montana based on the most recent census.

4.9 Section (2) (b) (v) (D) – Depth to Limiting Layer

A limiting layer is typically ground water, an impervious clay/silt layer, or bedrock.

4.10 Section (3) – Provisional Mixing Zone

A provisional mixing zone is designated in the rule to maintain the same distance setback from wells as would be granted for a SWTS that does not qualify for an exemption. This provisional mixing zone should be shown on the lot layout to make sure wells maintain the proper setbacks. The lot layout should indicate that mixing zones were not granted but are only shown for the purposes of proper setbacks from wells.

5.0 ADJACENT TO SURFACE WATERS

Subdivisions located adjacent to state surface waters will require an analysis of the effects of the proposed sewage treatment system(s) on the quality of the nearest downgradient high quality state surface water in accordance with ARM 17.36.312. If the receiving surface water is not high quality, but only a state water, the nondegradation requirements do not apply but the water quality standards still apply. If the nitrate or phosphorus nondegradation limits cannot be met in the ground water prior to the effluent encountering a state surface water, a surface water mixing zone will be required [ARM 17.30.506(2)(h)]. However, if the nitrate nondegradation limit can be met in the ground water prior to encountering a state surface water, an analysis of the nitrogen impacts to the surface water may still be required (as discussed below), but a surface water mixing zone will not necessarily be required. If the phosphorus 50-year breakthrough criteria is satisfied additional analysis of phosphorus impacts to the surface water will not be required.

Determining whether a specific subdivision is considered adjacent to surface waters and is in direct hydrologic connection to the surface water is site specific and depends upon the geology, hydrogeology, size of the wastewater system, sensitivity of the surface water, and other site properties.

If a surface water is not hydraulically connected to ground water, then it does not need to be assessed for impacts from the wastewater systems. Hydraulic connection can be demonstrated using ground water and surface water elevations. In most cases, if the ground water is not hydraulically connected to the surface water during the high water period (spring runoff or during irrigation season), then it is also not hydraulically connected the remainder of the year.

Nitrogen impacts from SWTS to high quality state surface water are dependent on both the distance of the project to the surface water feature and soil type. If the distance between the SWTS and the high quality state surface water is less than ¼ mile, you must run the adjacent to state waters analysis for impacts from nitrogen. If the distance between the SWTS and the high quality state surface water is greater than ½ mile then you do not need to run the adjacent to state waters analysis for impacts from nitrogen. But if the SWTS is greater than ¼ mile and less than ½ mile, has a limiting layer less than 8 feet below the natural ground surface and the soil application rate as defined in Department Circular DEQ-4 Chapter 2 is 0.4 gpd/ft or more restrictive then the adjacent to state surface water analysis for nitrogen must be evaluated. See Appendix T. If you have questions whether a specific subdivision would be considered adjacent to surface waters, contact the Department.

If the proposed discharge(s) does not meet the 50-year phosphorus breakthrough limit then the project must be evaluated for impacts by phosphorus to state surface water.

The trigger value is the allowable increase in nutrients (for both nitrogen and phosphorus) above existing background concentration in the receiving surface water. The first test of whether impacts to surface waters are significant is to determine if the trigger value is exceeded [ARM 17.30.715(1)(c)]. The trigger value listed in DEQ-7, for nitrate (as N) is 0.01 mg/L and for phosphorus (as P) is 0.001 mg/l. The trigger value calculations use dilution to determine the increased concentration as a result of the SWTS(s) (see Appendix Q). This equation requires a known flow rate of the water body. This can be determined from a stream gauge, using a ratio for determining estimated flows, calculating flow through a lake using Darcy's Law or other means acceptable to the Department. If the source does not have an MPDES or MGWPCS permit and the source causes an exceedance of the trigger value, the applicant has the option to demonstrate compliance with the standard for nitrogen and/or phosphorus in ARM 17.30.715(1)(g). The impact to surface water is not significant if the changes outside of a mixing zone are less than 10% of the applicable standard as defined in DEQ-7 and the existing surface water quality level is less than 40% of the standard. Standards for regions in Montana are established in DEQ12-A. It may be necessary to collect seasonal water samples to determine the nutrient status of the stream. Contact the Department to determine specific data requirements and methods of analysis

For surface water impact calculations, the reviewing authority assumes that 100 percent of the effluent load discharged from the SWTS will reach the surface water body unless adequate information is submitted to support a lower loading percentage. Therefore, for a single-family home with between 2 and 5 bedrooms using a septic tank/drainfield SWTS, the nitrate load that is assumed to reach the surface water is based on 200 gpd at 50 mg/L (30.5 lb/year); the phosphorus load is 6.44 lb/year [see section 2.10.4 (Quantity of Effluent) for discussion of pollutant loads for homes with bedrooms outside of that range].

The trigger value determinations are for each individual activity and are not intended to apply to cumulative effects of multiple activities, such as multiple, unrelated subdivisions. However, multiple phases of a single development are considered a single project. Therefore the number of SWTS included in the trigger value calculations shall include all sources in the current and future phases of the subdivision development.

5.1 Lakes and Ponds

The dilution value for nitrate trigger levels (0.01 mg/L) and phosphorus trigger levels (0.001mg/L) in lakes and ponds is calculated using a dilution equation (see Appendix Q). This equation requires a known flow rate into or out of the water body. This can be determined from a stream gauge on a stream flowing into or out of the lake. Alternatively, lake flow can be determined by ground water flow or a combination of the 2 methods. Appendix R demonstrates how to use Darcy's Law to determine the ground-water flow rate into or out of a lake.

In certain parts of the state there are numerous pot hole lakes. Typically, these lakes are an expression of the ground water table and have no discernable surface water inflow or outflow. Therefore, the movement of water through these lakes is very slow. The water quality in these lakes can be quite variable, some are eutrophic. However, almost all of these waters are still considered as high quality state waters and must be protected. Impacts to lakes from nutrient loading is difficult to predict – some lakes can accept significant loadings without any discernable negative effects while other lakes can experience dramatic changes with only minor changes in existing nutrient loading.

5.2 Streams and Rivers

The dilution equation (Appendix Q) is used to calculate trigger values for streams and rivers. The stream flow rate used for the dilution equation is the14Q5. The 14Q5 flow is the 14-day, 5-year low flow for the impacted section of stream. The United States Geological Survey (USGS) calculates 14Q5 values for many streams across the state. That information is available on the USGS website at:
http://pubs.usgs.gov/sir/2004/5266/ with ungauged stream information at
http://water.usgs.gov/osw/streamstats/montana.html

If a proposed subdivision is adjacent to a stream that doesn't have 14Q5 data, the 14Q5 value can be estimated via an extrapolation calculation. Using a simple ratio of drainage basin area to 14Q5, the 14Q5 for an ungauged stream can be estimated from the nearest downgradient (or upgradient) gauge on the same stream or from a downgradient stream in the same drainage basin. An example of this calculation is shown in Appendix S. Drainage basin areas can be estimated using USGS topographic maps. Drainage basin areas can also be calculated electronically, one internet site that facilitates this calculation is www.acme.com/planimeter .

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