WHITE PAPER:
A WATERSHED STRATIFICATION APPROACH FOR TMDL SEDIMENT AND HABITAT INVESTIGATION

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Montana Department of Environmental Quality
1520 East Sixth Avenue
Helena, MT 59620
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Table of Contents

1. INTRODUCTION

1.1. Purpose

This document describes the rationale behind the methodology used by the Montana Department of Environmental Quality to characterize and/or stratify waterbodies to address sediment and habitat condition as it relates to aquatic life and fisheries beneficial uses for use in the TMDL process. In line with this purpose, a primary objective of this approach is to better characterize water body segments within the context of their individual landscape settings by describing the constituent stream reaches in terms of reach-scale reference conditions (observed versus expected values of sediment and habitat parameters). A second purpose of this approach is to establish a general framework for the achievement of data quality objectives (respresentativeness, comparability, and completeness) within sampling designs during TMDL related sediment and habitat investigations in western Montana.

Water body segments are generally delineated by a water use class designated by the State of Montana, e.g. A-1, B-3, C-3 (Administrative Rules of Montana Title 17 Chapter 30, Sub-Chapter 6). Although a water body segment is the smallest unit for which an impairment determination is made, the stratification approach described in this document initially stratifies individual water body segments into discrete assessment reaches that are delineated by distinct variability in landscape controls such as Strahler stream order, valley slope, and valley confinement. The reason for this is that the inherent differences in landscape controls between stream reaches often prevents a direct comparison from being made between the geomorphic attributes of one stream reach to another.

According to Rosgen (1996), "Based on landform and valley type analyses, one can then proceed to develop interpretations as to the stream types present, and their morphological character." In this regard, the underlying assumption of this approach is that inherent landscape characteristics (e.g. stream order, valley slope, etc) are causal factors in determining the form and function of stream reaches. Additionally, because these characteristics are generally beyond anthropogenic control, they serve as a logical context for designing sediment and habitat data collections from streams reaches that display inherently different morphology. For example, it is expected that a 4th order stream of certain landscape characteristics may have inherent differences when compared to a 2nd order stream where all other landscape characteristics are the same. Conversely, it can also be expected that there would be comparability between reaches that share the same landscape characteristics.

By initially stratifying water body segments into stream reaches having similar geomorphic landscape controls, it is feasible to make comparisons between similar reaches in regards to observed versus expected channel morphology. Likewise, when land use is used as an additional stratification (e.g. grazed vs. non-grazed sub-reaches), sediment and habitat parameters for impaired stream reaches can be more readily compared to reference reaches that meet the same geomorphic stratification criteria. This comparability is useful for predicting expected conditions in non-sampled reaches, and developed target values for parameters measured in sampled reaches.

1.2. Scope

The specific water body stratification approach described here is designed to be applied within TMDL Planning Areas of western Montana. This approach is not intended for the assessment of impairments beyond sediment and habitat related issues. In addition it is not applicable to watersheds with origins in Plains Ecoregions as defined by Woods, Alan J. et al. 2002.

This approach is designed for the assessment of intermittent and perennial water body segments composed of 2^{nd} through 5^{th} Strahler stream order extents with bankfull widths less than 60 feet. Stream segments or reaches that do not meet these stream order and bankfull width criteria will be evaluated on an individual basis.

The watershed stratification process is not intended as a substitute for a detailed pollutant source quantification. Nevertheless, this procedure does provide the appropriate time to collect data on riparian zone characteristics and perform bank erosion inventories because this data is prerequisite for subsequent sediment source assessments. This stratification approach is appropriate for use at the watershed scale for both 303(d) listed and non-listed water body segments.

Concurrent with the water body stratification approach, a flexible procedure of field methodology that is composed of a suite of "longitudinal" field methods has been compiled by MT DEQ and is described within a separate document.

Information collected through this design and the related field methods has multiple uses that include sediment and habitat condition analysis, sediment load quantification from bank erosion, reference reach identification, target values development, as well as applications for nutrient source quantification and loading through modeling based on riparian condition estimation.

2. REACH SEGMENTING METHODOLOGY

This section details the reach segmenting approach as it applies to TMDL sediment and habitat condition analysis. The foundation of the approach is the concept that *state variables* of channel morphology {channel slope, sinuosity, roughness, width, depth, discharge, sediment size and sediment load} are intrinsically determined by geographic *driver variables* {e.g. time, geology, climate, topography, soils}. The framework of the approach has been modeled after watershed sampling designs developed by the Timber, Fish, and Wildlife Program in Washington State as well as from scientific research that has shown the need for considering watersheds in a form and function based context. (Montgomery, D. and Buffington, J.1997; Pleus, A. and D. Schuett-Hames, 1998; Montgomery, D. and MacDonald, L, 2002; Rosgen, D.L. 1994). In this manner, the main objective for analyzing stream reach morphology within the context of their inherent or “potential” form and function is to reduce sampling bias, increase accuracy and precision in watershed assessments and increase the ability to achieve representativeness, comparability, and completeness both within and among sediment/habitat investigations.

DEQ uses a spatial hierarchy of **watershed, water body segment, stream reach, sub-reach, survey site, and survey cell** to describe differing scales of watershed analysis used in this assessment approach. Refer to the document *GIS/Aerial Survey and Stream Reach Segmenting Guidance for TMDL Sediment and Habitat Investigations (MT DEQ, 2006)* for the definitions for each of these terms. The term “study area” as used in this document refers to the specified area of investigation, and is synonymous with the term “watershed”.

This approach utilizes a series of scalar stratifications in order to arrive at the geographic scale for which the combined influence of the aforementioned driver variables is essentially homogenous. The scale at which this occurs is defined as the stream reach extent. It is at the stream reach scale that the analysis of sediment and habitat parameters will occur, although as noted previously in this document, the water body segment (composed of one or more stream reaches) is smallest unit for which sediment and habitat impairment determinations are ultimately made.

The DEQ project manager may request a GIS exercise that is concurrent to the water body stratification approach that aids in the preliminarily delineation of channel types by stream morphological variables such as channel slope and sinuosity. **It is important to note that except for stream order (which is more of a landscape measure of relative stream size) stream morphology itself is not the basis for the water body stratification process. Although this process stratifies the water body into reaches, stream reaches are not to be delineated based on parameters of stream morphology because stream morphology is the subject of the assessment. Instead, the water body is stratified into reaches by landscape morphology, because it is the spatial attributes of the landscape that determine the potential morphology of the stream channel itself.**

Through the stratification process, a data management tool must be created wherein the study area, the waterbody segments, stream reaches and their associated geographic and geomorphic attributes that are involved in the investigation are documented and tracked. Although the stratification process can be completed without the use of GIS technology, GIS-based analysis, and associated electronic analysis and data management is strongly preferred. The resulting spatial data management tool is where the geographic attributes such as ecoregion, stream order, valley confinement, valley slope, land use, riparian vegetation characteristics, etc. are associated with the individual stream reaches that compose the water body segments being assessed in the investigation. The database serves as the primary means for documenting and tracking the stratification process and resultant information; the GIS component allows for a visual display of the stratification and provides a means for further spatial analysis.

Stratification of water body segments is an interdisciplinary process and will likely require the integration of work from two or more analysts. However, performing the reach breaks requires knowledge of geomorphology, hydrology, vegetation, local land use, land use impacts, and experience with topographic map and aerial imagery interpretation. Because reach segmentation requires knowledge and analysis beyond GIS software, it is not a simple step by step exercise suitable for someone whose sole expertise is in performing GIS software applications. Likewise, the GIS applications used in the stratification process (e.g. creating and editing shapefiles) need to be performed by analysts with intermediate to advanced GIS experience as the specific applications (e.g. how to edit a shapefile or route the final layer onto NHD shapefile) are not explained in this document. It will be verified that the analysts have the necessary credentials before a watershed analysis is undertaken.

2.1. Preliminary Stratification: Ecoregion and Water Body Segment

EPA ecoregions[2] are landscape level attributes whose spatial delineation represents unique combinations of driver variables that result in the characteristic geography of a particular watershed. Hence, ecoregions were identified as an efficient way for stratifying watersheds into areas where differences in geography will assist in the characterization and analysis of reach scale stream morphology. As defined by the US EPA[2]:

> "Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. By recognizing the spatial differences in the capacities and potentials of ecosystems, ecoregions stratify the environment by its probable response to disturbance. These general purpose regions are critical for structuring and implementing ecosystem management strategies across federal agencies, state agencies, and non-government organizations that are responsible for different types of resources within the same geographical areas…These phenomena include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology."

In this regard, ecoregional delineation of the study area serves as the initial mechanism for stratification. The study area is first stratified by Level 3 ecoregions (e.g. Northern Rockies, Northwestern Glaciated Plains) and second by Level 4 ecoregions (e.g. Bitterroot-Frenchtown Valley, Eastern Batholith).

It should be noted that the mapped borders of ecoregions are not necessarily precise, but rather, they likely indicate a zone of gradation between ecoregions. The transition may be abrupt as in the case where a fault zone exposes an obvious transition to a different type of bedrock geology, or more likely, they are gradual transitions, such as the general change from prairie communities to forest vegetation to alpine zones with elevation. Likewise, as a stream passes from one ecoregion into another, there will be a transition in the influence from one ecoregion to another. The magnitude of the transition is likely to vary according to the size of the contributing watershed upstream of any point along the stream and the percentage of the watershed existing in any particular ecoregion upstream of that point. This transitional sequencing is also tracked through the stratification process.

[2]Source: Woods, Alan J., Omernik, James, M., Nesser, John A., Shelden, J., Comstock, J.A., Azevedo, Sandra H., 2002, Ecoregions of Montana, 2nd edition (color poster with map, descriptive text, summary tables, and photographs). Map scale 1:1,500,000.

2.2. Primary Stratification: Stratification Of Water Body Segments Into Reaches

Stream order, valley confinement, and valley gradient were identified as attributes whose variability accounts for significant inherent differences in the morphology of stream reaches (e.g. meandering versus non-meandering reaches) that compose a particular water body segment. These factors are generally beyond the influence of human activity, which qualifies them as important "non-study" variables that influence the measurement of sediment and habitat parameters. A non-study variable is one whose influence affects the outcome of a measurement, but whose measurement is not the focus of the analysis.

The stream order, valley confinement, and valley gradient criteria are not intended to account for the entire range of natural variability in stream reach morphology; however, because they are major factors in the control of stream reach morphology that can be readily identified using coarse geographic analysis, they facilitate the stratification of stream reaches into groups of stream reaches having similar morphology. In the long run, the ability to understand sediment and habitat parameters in the context of different types of stream reaches will greatly enhance the effectiveness of water quality impairment investigations as well as restoration prescriptions for those water bodies not meeting water quality standards.

The following sub-sections describe the justification behind the application of stream order, valley confinement, and valley gradient stratification.

2.2.1. Strahler Stream Order

Stratifying by Strahler stream order is a simple and efficient means to preliminarily characterize the relative size of a stream within a watershed. Within a watershed, stream order is used as a surrogate for stream discharge. Stream discharge is important because the product of the discharge and gradient of a reach is equivalent to stream power; stream power is proportional to the product of the sediment size and sediment load of a stream reach, thus stream power is a measure of the capacity of a reach to transport sediment. Although the stream order classification system is relative to geography, e.g. second order streams may be significantly larger in one region than in another, the application of the system is universal in that a second order stream always indicates a stream formed by the confluence of two first order tributaries. Drainage area has been used in some cases as the surrogate for stream discharge; however, categories of drainage area may not have the same meaning between regions that have significant differences in hydrology. Also, Strahler stream order is used because it can be derived in a simple and efficient manner either manually or through GIS, whereas calculating drainage area can only be calculated effectively using GIS analysis. Due to these reasons, drainage area was not chosen to represent stream discharge. Likewise, stream discharge itself was not chosen as a stratifying attribute because it can be significantly altered by irrigation activities, dams and reservoirs, whereas stream order will remain the same, except under rare circumstances. Where stream reaches have a significant proportion of their base flow contributed by points of groundwater discharge (springs), the stream order may not change, but stream power will. In this case, the hydrological influence of the springs must be documented and considered in terms of their effects upon sediment and habitat characteristics.

***Strahler stream order Reach Break Delineation*:**

In the Strahler stream order system, all streams having no tributaries are 1st order streams; where two streams of order "n" come together, the resulting stream order is "n +1". Strahler stream order classification is performed on the entire network of streams within the study area. Reach breaks are denoted at any change in order. In addition Reach breaks that do not result from direct stream order changes, but from the confluence of smaller tributaries (e.g. order = n-1) as described above need to be tracked in the stream reach database. Because map scales affect the outcome of Strahler stream ordering, a standard map scale of 1:100,000 is used when deriving stream order classification.

These "n-1" reach breaks provide a means of tracking changes in stream power over long extents where the stream retains the same order. The significance of this measure and its influence on sampling design may differ from water body to water body.

2.2.2. Valley Confinement

Valley confinement is an attribute that corresponds to the potential for a stream reach to develop lateral extensions in its channel pattern (meandering). Valley confinement is distinguished from channel confinement in that valley walls are a landscape attribute that is generally resilient to human alterations, while confinement of the stream channel itself may be altered within a valley by human activity, such as channelization. A primary objective of the reach stratification approach is to recognize the influence of inherent landscape attributes upon stream reaches, therefore, valley confinement was chosen instead of channel confinement to represent the potential for a stream to meander within its valley.

Recognizing the degree of valley confinement for individual stream reaches is essential for understanding the sediment and habitat dynamics of a stream reach because of its influence upon stream reach morphology. As mentioned previously, the product of the sediment size and sediment load of a given stream reach is proportional to the discharge and gradient of the reach. Valley confinement is tied to stream gradient in that stream gradient is largely determined by variation in valley gradient and valley (or channel) confinement. In this regard, it is important to consider valley confinement, in addition to valley gradient and discharge (e.g. stream order) when conducting sediment investigations. Furthermore, the degree of valley confinement relative to the degree of lateral channel confinement and vertical channel entrenchment may be used to characterize anthropogenic channel alterations that may impact sediment and habitat dynamics and thus cause negative impacts to aquatic life habitat.

***Valley Confinement Reach Break Delineation*:**

Valley confinement is designated for all reaches of interest in the watershed. Since the width of the bankfull channel cannot be identified from aerial imagery, the valley confinement is estimated as the width of the valley relative to the width of the active channel.

The primary *indicators* of valley confinement are denoted following the criteria below. The criteria apply to 1:24,000 scale maps with either 20 or 40 foot contour intervals.

(C) Confined Valley: Valley Width < 300 feet

(U) Unconfined Valleys: Valley Width > 300 feet

Reach breaks are placed between measured changes vally confinement as the water body is assessed in the downstream direction.

2.2.3 Valley Gradient

Valley gradient is another important surrogate for the capacity of a stream reach to transport sediment because as previously mentioned, the product of the sediment size and sediment load of a given stream reach is proportional to the discharge and gradient of the reach. Valley gradient has a major influence upon stream gradient; the gradient of the valley for any given stream reach, divided by the channel sinuosity equals the gradient of a stream reach. Since valley gradient serves as a geomorphic control of reach scale gradient, it is a necessary consideration when assessing sediment transport within a reach. Stream channel gradient was not chosen as a stratifying attribute because the slope of a stream channel can be altered by human activity. Although the estimation of valley gradient from maps is not highly accurate, it is sufficient to capture significant changes in the valley slope which will result in changes in reach-scale stream morphology.

***Valley Gradient Reach Break Delineation*:**

Estimation of valley gradient is performed for all reaches of interest within the study area**.** For this process valley gradient is defined as the valley length divided by change in valley elevation. It is important to note that the stream valley rather than the stream itself is used for this measurement.

For this process valley gradient is lumped into four categories:

Category 1: <2%
Category 2: 2% to <4%
Category 3: >4% to 10%
Category 4: 10%

These categories relate to varying degrees of sediment deposition and transport; Category 1 relates to depositional reaches, category 2 relates to transitional reaches and categories 3 and 4 represent sediment transport reaches. Reach breaks are denoted at any categorical change in gradient as the water body is evaluated.

2.2.3. Finalize the Primary Stratification

This procedure integrates the ecoregion, stream order, channel gradient and channel confinement breaks into individual reaches that will be identified by their unique combination of these features. Reaches that have the same stratification attributes are part of a reach category.

Reaches are alike when they fit the same ecoregion, stream order, valley confinement, and valley gradient categories. Each set of similar reaches within a reach category constitutes a group. A group may consist of one or more reaches and may be unique to a water body or may be formed of similar reaches from multiple water bodies.

The purpose of grouping similar reaches is two-fold. It facilitates the sampling design in that it will permit extrapolation in the sampling design, such that the design may opt to sample a designated portion of the reaches in order to represent a reach category. The other reason is that reaches within a group may be directly compared and contrasted during data analysis because they are inherently similar.

In some cases there may be no similar reaches that can be grouped into a reach category. In other cases there will be a multitude of reach categories consisting of one or more reaches. This simply reflects the natural variability of the study area and does not indicate that the stratification process did not work. In fact, it did work because the goal is to recognize inherent dissimilarity in the stream reaches of the study area.

2.3. Secondary Stratification

2.3.1. Incorporate Reach breaks for changes in water body segment IDs

Every water body segment within DEQ's assessment database must be individually assessed in terms of their beneficial uses; therefore, at this point in the stratification procedure, reach breaks are made at the endpoints of every water body segment having a water body segment ID (e,g. MT76005H_100). This stratification is especially important when a single stream is divided into two or more water body segment IDs in that it restricts having a single reach or sub-reach spanning two water body segments.

2.3.2. Land use / land cover and riparian zone characterization

Land use and riparian zone attributes are used as an additional stratification in that they facilitate testing hypotheses that land use activities are having a significant and measurable affect upon the sediment and habitat dynamics of a stream reach.

Land use and riparian characterization is performed for all reaches of interest within the study area. The characterization of land use and riparian areas is most efficiently performed through GIS from an analysis of high resolution aerial imagery and land use layers. Land use characterization includes a summary of the major and minor types of apparent land uses, the intensity of activities, and notes upon the apparent management techniques that are being practiced. Significant irrigation withdrawals or returns justify a division into sub-reaches. Riparian characterization may include, but is not limited to: distinctions in the type of riparian vegetation communities, changes in the apparent density or vigor of riparian community types, and changes in the width of the riparian zone.

***Delineation of reaches into sub-reaches based on land use and riparian characterization*:**

Once the land use and riparian characterization is complete, reaches may be divided into sub-reaches based on apparent changes in land-use or riparian character that may have an effect on channel form and function. Further dividing a reach into sub-reaches is a subjective process that requires an ability to interpret aerial imagery and understand potential differences in stream habitat and morphology response amongst varied landscape conditions. A sub-reach delineation may be based upon apparent natural or anthropogenic variability in riparian character. A long section of channelized stream in an otherwise unchannelized reach would qualify as an appropriate sub-reach. Because a sub-reach has the same potential morphology as its parent reach, but its actual condition varies due to varying land use treatments, it remains associated with its parent reach.

2.4. Buffer Zones

Buffer zones are areas surrounding anthropogenic influences which are not optimal sampling sites when the study design goal is to sample “whole channel” characteristics. In general, their delineation indicates areas that need to be avoided during the placement of survey sites. In certain cases, buffer zones may be sampled as targeted sites in order to determine conditions within the zone(s); however, these data should be distinguished from data that characterizes the whole reach. Since buffer zones are within-reach features, and hence their formations mimic that of a land-use and/or riparian sub-reach delineation, these buffer zone type sub-reaches are generated, flagged and noted as buffers. For instance, a sub-reach may be delineated which extends 100 feet above and below a road crossing to exclude any of the site specific impacts to sediment and morphology character that would not be representative of that reach as a whole. However, if the goal of the investigation was to compare the impacts of road crossings to the general in-stream condition, then these types of buffer sub-reaches could be targeted

3. ADDITIONAL DATA COMPONENTS

Once the reach and sub-reach components have been generated and the waterbodies of interest have been delineated an additional aerial evaluation is undertaken to qualify and quantify near stream impacts, estimate the health of the vegetated riparian buffer, and identify potential bank erosion influences. This data is appended to the reach and sub-reach database.

3.1. Near Stream Impacts and Riparian Health Classification

An aerial assessment of each reach and sub-reach delineation is performed to qualify near stream impacts. The information collected includes: Predominant Vegetation Type, Adjacent Land Use, and Presence of Anthropogenic Activity. Vegetation and land use data is generated following a standard list of vegetation and land use classifications. The presence of anthropogenic activity within the near stream riparian area is simply qualified by a yes / no category.

The qualification of these impacts allows for further investigation into the potential differences in stream response within a reach category. In so doing, it allows for an assessment of the cause and effect land uses and anthropogenic influences have on a reach that would otherwise be inherently similar. Also, it may be used to identify potential reference reach conditions, refine predictions of non-sampled reaches and sub-reaches, better extrapolate sediment loads, and assist with refining landscape scale watershed models (riparian buffer reduction capacities, etc).

Categories for the various riparian vegetation types, predominant land use types, and the presence of anthropogenic activity are described in the table below. A riparian health condition classification is then derived depending on the combination of these attributes and best professional judgment.

Riparian Vegetation Types:	**Predominant Land Use Types:**	**Anthropogenic Activity:**
Bare	Range	Yes
Grass	Wetland	No
Shrubs	Forest	
Mature Deciduous	Urban	
Mature Coniferous	Agriculture (row crops)	
	Road	
	Hay/Pasture	
	Harvest/Fire	
	Rural Res./Hobby Farm	

3.2. Bank Erosion Source Assessment

Concurrent with the tasks in section 3.1. additional data is collected at the sub-reach scale to assist with defining potential sources of bank erosion. Again, the aerial imagery is evaluated and percent influences for potential sources of bank erosion are estimated for the following categories: Transportation, Riparian Grazing, Cropland, Mining, Silviculture, Irrigation, Natural Sources and Other. Identifying the degree to which the land use categories may influence bank erosion is compatible with the field procedures which also apply a percent of influence to each studied eroding bank. While the aerial assessment of bank erosion influence is at an extremely course scale, it allows for continuity and data from sampled eroding banks to be extrapolated to non-sampled reaches. This process thereby facilitates the development of specific source allocations within the TMDL.

4. USE OF STRATIFICATION RESULTS

The stratification process outlined in this document is one of the primary steps in investing sediment related impairments on 303d listed streams. The results of the stratification process and data collected through field efforts subsequent to the stratification process are used throughout TMDL development. Data is reviewed and summarized to identify “reference conditions”, develop target values for parameters related to sediment and habitat, derive sediment loads, and supplement information for watershed scale modeling (riparian condition and buffering capacity). Additionally, the power of the stratification is increased when all appropriate available data is compared to the stratification results, thereby increasing the sample size for the various reach categories and providing a more comprehensive representation throughout the watershed.

In completing the stratification, the resultant reaches and reach categories allow for a more complete characterization of a watershed and its variability, aids in selecting appropriate locations for investigations, and ultimately allows for a more defensible product when developing TMDLs and management plans in western Montana watersheds.

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