INTEGRATION OF SEDIMENT FINGERPRINTING TECHNIQUES AND SAMPLING APPROACHES WITHIN A PRAIRIE WATERSHED IN SOUTHERN ALBERTA

BY

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ABSTRACT

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Soil erosion can cause sedimentation and eutrophication of waterbodies, which can decrease the quality of water. Water quality is important for human consumption as well as for agricultural use. This study took place in southern Alberta within the Lower Little Bow River (LLBR) watershed, which has been a source of water quality studies as a part of the Oldman River Basin Water Quality Initiative. The objectives of this study were, firstly, to identify and apportion sources of suspended sediment using a sediment fingerprinting technique and the mixing model, MixSIAR, within a small 6-km reach of the LLBR, secondly, to build a better understanding of colour properties as tracers, and thirdly, to explore the effect of reach sampling within using the MixSIAR model. The first objective was accomplished through the sampling of multiple watershed sources including Agricultural Land, Coulee Walls, Stream Banks, an Irrigation Return-Flow channel and Upstream sediment. Suspended sediment was collected within the reach itself and un-mixed to determine source proportions contributed by each of the five potential sediment sources. The second objective was accomplished by taking three approaches in order to determine the appropriate environmental tracer combination to apportion sources accurately and how these affect choosing appropriate environmental tracers for sediment fingerprinting. The third objective of this thesis was accomplished by determining the composition and incorporation of upstream inflowing sediment into a watershed reach when conducting a sediment fingerprinting study. The mixing model, MixSIAR, was used as a tool to manipulate the watershed in order to determine how to

improve the efficiency of the sediment fingerprinting process regarding tracer selection and sampling approaches. The MixSIAR model is used as a tool to determine how to design an approach to a reach within a watershed and the significance of upstream inflowing sediment inclusion as a sediment source.

FOREWORD

Previous work on the Lower Little Bow River watershed has been conducted by Agriculture and Agri-Food Canada and the University of Manitoba's Department of Soil Science. I assisted in this research, including co-authoring a paper by Kui Liu, that focussed on the use of colour coefficients of soil and sediment as viable colour tracers in sediment fingerprinting within the Lower Little Bow River. This paper was titled "Determining sources of fine-grained sediment for a reach of the Lower Little Bow River, Alberta, using a colour-based sediment fingerprinting approach", and was published in the Canadian Journal of Soil Science. My part in this research was to expand upon the previous study and to continue to explore how to approach sampling and sediment fingerprinting within a watershed reach, as well as how this can affect tracer selection and sampling. My part in this research was also to continue to explore the use of mixing model programs as exploratory and management tools to lead to better understanding of watershed processes and to help implement land and sediment erosion control practices.

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1. INTRODUCTION

1.1 Background

The research goal of this thesis is to identify and apportion sediment sources for the Lower Little Bow River (LLBR) located in southern Alberta, in the Oldman River basin. The LLBR watershed has intensive irrigated and non-irrigated agricultural land consisting of cereals and oilseeds, as well as intensive pasture operations including cow-calf. A need for water quality assessment started up the Oldman River Basin Water Quality Initiative to monitor flow and quality in the Oldman River and its tributaries (Koning et al., 2006). One tributary that became a focus of study was the LLBR due to its decline in water quality before joining the Oldman River (Koning et al., 2006). A small reach of the LLBR has been used as a focus for studies of beneficial management practices (BMP's) by Agriculture and Agri-Food Canada (AAFC) through the program called the Watershed Evaluation of Beneficial Management Practices (WEB's). One of the main concerns that arises when discussing water quality in a heavily agricultural area is that agricultural activities are the main cause of water quality decline; whether this is regarding surface run-off, wind erosion, irrigation practices or livestock management. Lethbridge Northern Irrigation District (LNID) is one of the closest district that interacts with the LLBR. This district began in 1919 and has been supplying water to agricultural land around the city of Lethbridge from the Oldman River as well as the Lower Little Bow River (LNID Annual Report, 2015). Irrigated agricultural land in the LNID was approximately 71,629 hectares (177,000 acres) as of 2010 and has been developing to increase the total number of acres irrigated even more (LNID Annual Report, 2015). Due to the arid climate, precipitation in the LLBR watershed is around 365 to 385 mm annually in the LLBR (Liu et al., 2017; AAFC, 2013; Jedrych et al. 2006). About one third of the precipitation annually is snowfall and thus is marginally available for crop water use. Irrigation is a requirement to maintain crop production in this watershed, the question is to what extent has it changed the landscape and has it effected local water sources like the LLBR.

In a report by the Technology and Innovation Branch of Alberta report on Irrigation in Alberta, they state that the soils in southern Alberta are suitable for irrigation due to the glacial tills that are medium to fine-textured (Irrigation in Alberta, 2015). The report states that these soils have good water-holding capacities, but there are some coarse textured soils with high water percolation rates and low water retention that are more of a challenge to manage (Irrigation in Alberta, 2015). This becomes a challenge in areas such as the LLBR where there is a significant amount of coarse textured soils that make up the coulee river valley formations. With low water retention and high percolation rates, this means that any water being added to the soil can potentially move through soil quickly and in an irrigated field, excess water will be redirected to a return flow channel. Little et al. (2003) calculated that two irrigation return-flow channels entering the LLBR were found to have higher total phosphorus levels than the mainstream of the river and peak flow rates of $0.8m^3/s$ and $2.8m^3/s$. These peak flow rates can carry significant sediment loads to the mainstream of the LLBR, which raises concern for management of irrigation return-flow channels (Liu et al., 2017).

Not only is the effect of the potential run off from irrigation an issue within this area, so is the impact of irrigation return-flow channels and the initial and continuing construction of irrigation networks within southern Alberta. Irrigation return-flows, pipelines and pumping equipment within just the LNID alone stretches 650km (Irrigation in Alberta, 2015). In an annual report by LNID in 2015 they announced the expansion of irrigated acres for 2016 to add an additional 2,528 acres (1039.2 ha) and applications for

653 acres (264.3 ha) will potentially be added in 2017. Every addition of irrigation acres requires the construction of pipeline to the field, and increases the area of potential run off from fields receiving irrigation, including irrigation return-flow channels. Within southern Alberta approximately 7,500 kilometers of pipelines and canals provide water to irrigation systems; although these systems are maintained by irrigation districts, there is also a number of privately licensed irrigation systems irrigating more than 112,000 hectares of land (Irrigation in Alberta, 2015). Privately licensed irrigation groups are operated under Alberta Irrigation Projects Association. The irrigation network within southeastern Alberta is extensive and is necessary for cropping systems within this region. Within the LLBR watershed, majority of irrigation is from private licenses (Irrigation in Alberta, 2015). Although some soils are deemed more suitable for irrigation practices, there may be soils that are affected by irrigation activities, including pipelines and irrigation return-flow channels in southeastern Alberta, that are not suitable. Management of how irrigation return-flow channels and the effect that the expansion of irrigated acres has on water systems should be assessed.

Sediment fingerprinting has become a useful tool in applying beneficial management practices to landscapes and watersheds. In the case of the LLBR, sedimentation has become an issue (Liu et al., 2017). Heavy sedimentation in a river body can lead to excessive nutrient transfer by sediment acting as a vector for transport, as well as it could lead to detrimental impacts on aquatic biota through processes of eutrophication (Barthod et al., 2016; Koiter et al., 2013a). Sedimentation can also create issues for irrigation, it makes it harder on irrigation equipment to pump water out of the river (Liu et al., 2017). In order to manage suspended sediment within the LLBR, an understanding of where sediment inputs are coming from can be determined through sediment fingerprinting techniques. As sediment fingerprinting is a growing tool for landscape management, there are still areas that lack understanding or validation of the technique of apportioning sources. Two areas that remain a challenge are the validity of using colour properties as conservative sediment fingerprinting tracers, as well as appropriate sampling within catchments to capture all possible sources of suspended sediment. To appropriately apportion sources of suspended sediment in the LLBR, these were taken into consideration in this thesis.

1.2 Literature review

1.2.1 Catchment size and sampling

Sediment fingerprinting and tracking is a relatively new and rapidly evolving area of research. A variety of sample collection methods have been used for sediment fingerprinting and tracking studies. Understandably, this has led to discussions regarding the accuracy and precision of these methods and the need for consistency in sampling methods to ensure comparability amongst watersheds. When sampling within a catchment for sediment fingerprinting and tracking, the geometry of the catchment, climate, hydrology, geology, pedology, vegetation, and land use and management must all be considered, as well as the practical considerations of accessibility and previous knowledge. Given the variability that exists in conditions that affect the production, transport and fate of sediment within and between catchments, it is reasonable to expect that one sampling method will not be effective in all applications (Brosinsky et al., 2014). Landscape variability is one of the biggest challenges to consider and address in sediment fingerprinting studies. Landscape variability poses an issue when selecting tracers to use in sediment fingerprinting modelling. For example, when considering colour tracers, some catchments may have very uniform source soil colour throughout the study area compared to others which may have various coloured bedrock material creating various coloured source soils. In the uniform coloured source catchment it may not be as effective to use colour properties to distinguish sources compared to the various coloured source catchment. Wilkinson et al. (2015) conducted a study on the validity of some sediment fingerprinting properties being able to apportion sources correctly by looking at the differences between properties identifying sources in a known landscape as well as adjusting fingerprint properties by weighting certain sources from observed knowledge. Wilkinson et al. (2015) was able to use the processes that were occurring naturally, including areas of high and low erosion, to properly weight environmental tracers for certain sources. The ability to adjust a model for a local watershed area is significant as well as understanding that sediment fingerprinting also has an observation and previous knowledge component to it.

In sediment fingerprinting, one of the most widely used methods of sample collection is the random spatial sampling design, which does not take into account active erosion or land variation, but requires a large number of samples (Du and Walling, 2016). An extension of this random design was the addition of transects along a sampling point to get a more representative idea of the surrounding area; or simply only sampling directly from areas of active erosion or areas that are more likely to be a source of erosion (Du and Walling, 2016; Koiter et al., 2013a). Each sediment fingerprinting study is unique depending on the size of catchment, which can range from a few hectares to thousands of hectares, and depending on the technique used to apportion sources or trace sediments. Different approaches have provided standards for sampling and justifying the accuracy of techniques. These studies have displayed some unique statistics on sample number recommendations and discrimination of sources. Du and Walling (2016) conducted a study on a 7-hectare field examining the variation within the field amongst 53 different fingerprint properties including Cesium-137 (Cs-137), inorganic and organic minerals as well as geochemical components. Although the data they proposed was statistically sound, the study size is relatively unique compared to catchments studied in Australia, Canada and the United States. Sediment fingerprinting is usually conducted in medium- to large-sized catchments; which can be hundreds of kilometers in length. Du and Walling (2016) conducted an analysis on spatial variation in sample collection within the 7-hectare field and produced a sampling number recommendation depending on the fingerprint properties used and their variation when collected in a random spatial format. The study done by Du and Walling (2016) is also unique within the sediment fingerprinting field since it involves comparing sampling between eroded and depositional areas rather than distinguishing sources and sampling at an outlet. When conducting a sediment fingerprinting study and determining source material it may seem that there is potential for a source to have been missed in the sampling process. Du and Walling (2016) describe that there is no significant difference in the 7-ha catchment between depositional and eroded areas for most fingerprinting properties other than the fallout radionuclide Cs-137, which is directly correlated with soil redistribution. With this information, it could be concluded that if this field were to be sampled as a source for a sediment fingerprinting study, it would not matter where within the field samples were taken, as long as it is understood which fingerprinting properties to use. This selective approach of fingerprinting properties seems to then overcome the large factor of landscape variability since it implies that there will be no missed source sampling if there is not a significant difference between certain sampling areas for a source. Although, the extrapolation of suggested techniques in Du and Walling (2016) is difficult to adjust for larger catchment sizes. The increase in catchment size can increase the amount of landscape variability, introducing new uncertainties that are not seen in the 7-ha field. This then creates an issue of selecting appropriate fingerprinting properties as the number of unknowns increases. The suggestion by Du and Walling (2016) was that for fingerprinting properties with a coefficient of variation (CV) of +/- 5% approximately 25 samples should be collected, and that with a coefficient of variation of +/- 10% approximately 100 samples should be taken. When extrapolating these values to a watershed that is hundreds of hectares, this exponentially increases the number of samples required. Although these suggestions are supported within the specific study, it is not relevant to studies larger than 7-ha. If this data was extrapolated to a catchment that was only 140-hectares, one would need to sample 500 samples for +/- 5% CV or up to 2,000 samples for +/- 10% CV, depending on the fingerprinting property being used. An area of 140-hectares is still, for most sediment fingerprinting studies, a very small study area for a catchment. Any ability to limit or reduce the need of excessive amounts of sampling should be considered when conducting a sediment fingerprinting study in order to remain efficient.

With large numbers of samples usually required, the size of the watershed cannot be ignored when determining how many and where to take samples for sediment fingerprinting. The larger the watershed, the more difficult it will be to capture all potential sources entering the watershed and the more time-consuming sample collection and analyses will be, which can become quite costly (Brosinsky et al., 2014). When attempting to determine sources to sample within a catchment, although the random spatial design is appealing and refrains from bias, it may not accurately represent a catchment area. As Du and Walling (2016) have shown that the random spatial design should work within a small area, this does not adequately inform what to do in a much larger area. Boudreault (2016) discussed building a spatial framework to appropriately sample and subset a watershed to apportion sources accurately by accounting for potential changes in sediment composition throughout a watershed and applied the transect method. By breaking up a watershed into subsets, it allows more accuracy of local source apportionments within each subset. This relates to catchment and watershed size sampling, in that sampling should be assessed on the size of catchment and also the similarity of sources throughout the catchment area. Boudreault (2016) touches upon this with the Black Brook Watershed, where there are seven different soil associations within the study area that change dominance as sediment moves downstream. This means that there is potential for sources to be switching due to the change in soil associations, similar to studies done by Koiter et al. (2013b) and Barthod et al. (2015) in the South Tobacco Creek Watershed. Watersheds and catchment areas like the Black Brook Watershed and South Tobacco Creek Watershed have been broken up into certain boundary lines in order to sample appropriately and to learn about potential management processes in local areas. This means that when sampling for a watershed area, local sources are sampled, and any inflowing sediment into the boundary area can be sampled as a source as well. Understanding how to sample and incorporate upstream inflowing sediment is still not consistent within sediment fingerprinting studies, as well as how can a decision be made about where boundaries begin and end for a management area when there are not distinct soil associations or barriers.

1.2.2 Sediment fingerprinting: environmental tracers

As sediment fingerprinting grows as a tool for landscape management, the validity of sediment fingerprinting properties being able to apportion sources correctly can be assessed. Martinez-Carreras et al. (2010) discusses the opportunity to use colour properties from diffuse reflectance spectrometry as a form of sediment fingerprints. It is noted that when using the colour properties to correctly identify and distinguish sediment sources, not one colour property independently could correctly classify all sediment sources (Liu et al., 2017; Martinez-Carreras et al., 2010). Concluding that when using colour tracers, a composite of colour tracers must be used to correctly identify one hundred percent of the sources. Liu et al. (2017), Boudreault (2016) and Barthod et al. (2015) make use of this technique by statistically identifying the most suitable colour properties to use for sediment source discrimination by using the Shapiro-Wilk test, biplot analysis, Kruskal-Wallis test and stepwise discriminant function analysis. Through these statistical tests, the best composite suite of colour properties can be identified to correctly identify and apportion sources in a mixing model, such as MixSIAR, for each unique watershed. By combining the use of colour tracers and classical fingerprinting tracers, another type of composite fingerprint can be made and this may address the question of accuracy in using solely colour tracers. This composite fingerprint would allow for avoidance of potential redundancy that may be associated with the use of multiple colour tracers.

Haddadchi et al. (2013) and Martinez-Carreras et al. (2010) discuss three necessary components for sediment fingerprinting tracer properties, these are:

1. Be capable of differentiating between potential sources
2. Exhibit conservative behavior during erosion and transport
3. Be linearly additive.

In the study of Attert River an assessment of colour properties as sediment fingerprint tracers was conducted to see how well sources could be determined (Martinez-Carreras et al., 2010). As mentioned, a combination of colour tracers could be used to determine sources efficiently, but what remains a question still is the conservativeness of colour properties as tracers. Sediment colour has the potential to change during storage and transport through a stream network. The potential for sediment that has been stored or blocked has potential to change due to residence time and potential for chemical reactions with water (Surridge et al., 2007; Fryirs et al., 2007). These reactions that cause exchange of oxygen and elements such as phosphorus, can cause a change of colour through processes such as redox reactions (Surridge et al., 2007). This means there is potential for sediment to go through a colour change between the moment of entry to the stream from a source to the moment it reaches the outlet of sediment capture. In mixing models, if colour is not conservative and changes as it is stored and transported, this creates a lack of credibility in the mixing model apportionments. There needs to be further study conducted on the conservativeness of colour as a sediment tracer and how it can affect source discrimination and apportionment.

1.3 Thesis objectives

There are two main objectives for this thesis to determine the sources of sediment in the Little Bow River. The first objective is to assess how to choose environmental tracers using three different approaches to accurately identify the sources of suspended sediment within a micro-watershed reach of the Lower Little Bow River using Cs-137, colour properties, and geochemical elements. The second objective of this thesis is to assess source sampling accuracy within sediment fingerprinting using the mixing model, MixSIAR.

1.4 Organization of thesis

This thesis is composed of four chapters, the first chapter providing a general introduction and the fourth chapter providing a synthesis of the research. The second chapter focuses on the integration of sediment fingerprinting properties, Cs-137, colour properties, and geochemical elements, to apportion sources of suspended sediment within a micro-watershed reach of the Lower Little Bow River. The second chapter assesses how to choose appropriate environmental tracers to apportion sediment sources given three approaches and how this will affect source apportionment.

The third chapter assesses the conservativeness of colour properties as fingerprints and explores inflowing sediment in a reach of LLBR. Upstream inflowing sediment is explored through the comparison of inflowing and outflowing sediment source apportionment in MixSIAR with colour properties and Cs-137. The third chapter of this thesis focuses on sampling for sediment fingerprinting within the LLBR with the addition of larger watershed sources and the effect this will have on inflowing and outflowing sediment.

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2. INTEGRATION OF COLOUR, GEOCHEMICAL AND FALLOUT RADIONUCLIDE TRACERS IN A SEDIMENT FINGERPRINTING STUDY FOR A PRAIRIE WATERSHED REACH IN SOUTHERN ALBERTA USING THE MIXING MODEL, MIXSIAR

ABSTRACT

Sedimentation and eutrophication of watersheds reduces the quality and productivity of water bodies not only ecologically, but economically as well. Sediment fingerprinting provides a means of assessing the origin and proportion of sediment sources within a watershed using environmental tracers. Environmental tracers that can withstand biological and chemical processes through transport and storage in a watershed are ideal, but in order to improve efficiency and reduce costs, other environmental tracers such as colour are being utilised.

The objectives of this study were, firstly, to apportion sediment sources within the micro-watershed reach of the Lower Little Bow River (LLBR) located in southern Alberta using colour tracers, the fallout radionuclide, Cesium-137 (Cs-137) and geochemical elements. Secondly, in order to build sediment fingerprinting as a management technique, three different approaches are taken to assess how best to choose environmental tracers to apportion sediment sources accurately.

Suspended sediment was collected using time-integrated sediment samplers at four different locations within the 2,565 ha micro-watershed reach. Two suspended sediment samples were collected outside of the reach including one inflowing suspended sediment sample, and one irrigation return-flow sediment sample, both located upstream of the micro-watershed reach. Soil samples were collected as sediment sources including the grouped agricultural and pasture land, coulee walls and stream banks. Spectral,

gamma and ICP-OES analysis were done on all sediment and soil samples for colour tracers, Cs-137 and geochemical tracers, respectively.

The total number of sources used in the apportionment of suspended sediment was five including, Upstream, Agricultural Land, Coulee Walls, Irrigation Return-Flow and Stream Banks. The first scheme containing the best statistical tracers only had means of 67.8 %, 8.2 %, 8.0 %, 8.0 % and 8.0 %, respectively. The second scheme of solely geochemical tracers had means of 29.2 %, 18.1 %, 17.7 %, 17.7 % and 17.3 %, respectively. The third scheme of statistically significant tracers and chosen based on tracer behaviour had means of 68.4 %, 9.0 %, 8.2 %, 7.8 % and 6.5 %, respectively.

To properly characterise the composition of suspended sediment within a reach of a watershed multiple approaches can be taken when using composite fingerprints. Future research should be focused on using composite fingerprints that contain a number of different environmental tracers that can identify and distinguish different characteristics within soil and sediment samples.

2.1 Introduction

Sediment fingerprinting has proven to be an effective method to inform the management of soil erosion in agricultural landscapes and watersheds affected by sedimentation and pollution (Brosinsky et al., 2014; Mukundan et al., 2012). Sediment fingerprinting is the technique of using environmental tracers to link sources of sediment from within a watershed to outflowing suspended sediment (Boudreault, 2017; Davis and Fox, 2009). With the rising global population and increased demand for food, land management has become a key part in maintaining agricultural output as well as maintaining sustainability to provide food over the long term (Mukundan et al. 2012, Montgomery, 2007). Erosion processes degrade soils, making it difficult to sustain crop growth, and they can negatively affect areas beyond agricultural field through siltation and contamination. Nutrients lost from agricultural land through erosion can lead to eutrophication of surface waters, and other contaminants, such as E. Coli bacteria, originating from agricultural land can also pollute surface waters through erosion processes (Barthod, 2015; Chambers et al., 2008). A thorough understanding of soil erosion and sedimentation processes within agricultural watersheds are essential for the development of effective methods of land management to ensure more sustainable systems for plant growth and to protect surface waters (Brosinsky et al., 2014).

Sediment fingerprinting studies have demonstrated the use of many different tracers to discriminate and apportion sources of suspended sediment. Such tracers include, but are not limited to, fallout radionuclides, Cesium-137 (Cs-137), Lead-210 in excess ($^{210}Pb_{ex}$) and Beryllium-7 (^{7}Be), as well as a suite of geochemical elements (Haddadchi et al., 2013; Koiter et al., 2013a; Collins et al., 2004). Martinez-Carreras et al. (2010) discussed three requirements for sediment fingerprinting tracer properties, these included: conservative behaviour during transport and deposition, the ability to be linearly additive and the ability to differentiate between potential sources. With these criteria, sediment fingerprinting tracers are chosen and can be used to identify and apportion sediment sources within a watershed. Cesium-137 (Cs-137) has been used as an environmental tracer in many soil erosion and sediment fingerprinting studies. Cs-137 is a fallout radionuclide from nuclear bomb testing in the 1950's and 1960's (Koiter et al., 2013b). It strongly adsorbs to sheet silicate particles and has a low solubility, which causes the radionuclide to remain concentrated in the top 10-15 cm of a soil (Koiter et al., 2013a; Ritchie and McHenry, 1990). This creates an ability to distinguish between surface and subsurface soil as potential sediment sources by the presence or absence of Cs-137 activity (Koiter et al., 2013a; Owens et al., 2012; Wallbrink et al., 1998). However, ^{137}Cs has its limitations and drawbacks; in particular, samples can take anywhere from 12 to 48 hours to analyze, making it a lengthy and costly process to analyze a large number of samples (Boudreault, 2016; Caron et al., 2016). Recently, colour properties have been used as tracers to identify sources (Liu et al., 2017; Boudreault, 2016; Barthod et al., 2015; Brosinsky et al., 2014; Martinez-Carreras et al., 2010). The use of colour can identify and discriminate potential sediment sources when multiple colour properties are used in combination. One colour property alone as a tracer cannot successfully identify sources, but a suite of colour properties may be able to (Liu et al., 2017; Boudreault 2016; Barthod et al., 2015; Martinez-Carreras et al., 2010). With this knowledge, coupled with the fact that this analysis is relatively quick and inexpensive, the use of colour properties as tracers has become of interest. Geochemical elements have also been used as tracers for sediment fingerprinting in numerous studies. Geochemical tracers are appealing since they represent the mineralogical composition of soil and sediment (Koiter et al., 2013a) as well as chemicals that are artificially applied to the sources. This is beneficial for identifying and distinguishing sources since it provides distinction between parent material that may not be represented by other tracers. There are also a number of elements that will be conservative through transport and deposition.

There are many tracers to choose from and multiple factors must be considered in making the selection. Two of the most important factors are time and cost of analysis. Using tracers such as colour properties that reduce analytical time and cost is appealing, but understanding how they behave during sediment transport may be challenging. How do we systematically approach choosing appropriate tracers for each individual watershed, when behaviours of watersheds can be drastically different between each one? Understanding how colour tracers behave compared to conservative tracers such as Cs-137 and geochemical elements can help broaden our ability to choose tracers. The use of statistical analyses, previous knowledge of watershed areas and an understanding of tracer behaviour can also lead to an understanding of whether our own influence on tracer selection effects results.

Agriculture and Agri-Food Canada (AAFC) established a long-term study area within the Lower Little Bow River (LLBR) watershed to conduct studies on beneficial management practices through a program called the Watershed Evaluation of Beneficial Management Practices (WEBs). WEBs was a part of Canada-wide research initiative carried out in selected agricultural watersheds to understand and control processes such as soil erosion, sedimentation, erosion, nutrient transport and eutrophication (AAFC, 2013). Lake Winnipeg is a major focus of such research in the Prairie Region, understanding the decline of Lake Winnipeg's health, particularly the causes of the increase in eutrophication and algae blooms (Barthod et al., 2015; Koiter et al., 2013b). In the

LLBR, a small 6 km reach was selected for WEBs research by AAFC (Liu et al., 2017; Miller et al., 2011). Stations previously used for water quality monitoring by Alberta Agriculture, Food and Rural Development were used as points of collection for sediment and flow rates (Little et al., 2003). Liu et al. (2017) apportioned sediment sources in the LLBR micro-watershed reach using only four colour properties as tracers. Due to the unique study area of the micro-watershed reach, Liu et al. (2017) took an approach to apportioning sediment sources that treated inflowing sediment into the micro-watershed reach as a source in the mixing model. This approach was taken for two reasons: 1) the study area was located in the middle of watershed, and 2) the start of the study area was not the mouth of a tributary; therefore, inflowing sediment would be from the larger watershed and it could be considered a sediment source into the smaller reach. Liu et al. (2017) determined the inflowing suspended sediment to be different than any other sources collected within the micro-watershed. With the inclusion of inflowing sediment, referred to as Upstream, as a potential sediment source, Liu et al. (2017) calculated the sources of sediment to be 37.4 %, 25.6 %, 14.5 %, 13.4 % and 9.2 %, for Upstream, Irrigation Return-Flow, Stream Banks, Coulee Walls and Agricultural Land sources, respectively. Liu et al. (2017) demonstrated that the majority of the suspended sediment within the LLBR micro-watershed reach was contributed by the Upstream source and the Irrigation Return-Flow source. It is not clear what the inflowing suspended sediment, the Upstream source, is composed of. The Upstream sediment source is different from all other locally collected sources, and yet it demonstrates that the majority of the suspended sediment within the LLBR micro-watershed is from elsewhere upstream of the reach. In order to explore whether using colour properties alone as tracers results in any redundancy, and to assess the accuracy of sediment source apportionment within the

LLBR watershed, a model was run in this study with the addition of the conservative and well-established tracer, Cs-137 and a suite of geochemical tracers.

The objectives of this study were: 1) to apportion suspended sediment in the LLBR AAFC WEB's micro-watershed using colour tracers, Cs-137 and geochemical elements, and 2) to assess the viability of choosing appropriate environmental tracers using statistical analyses and previous knowledge.

2.2 Materials and Methods

2.2.1 Study Area

The focus area for this study was the LLBR watershed, located within the Oldman River basin of southern Alberta, Canada (Figure 2.1). The study area is approximately 40 km north of Lethbridge, Alberta, located at 50°00'00"N, 112°37'30"W. This study was conducted in a micro-watershed reach of 2,545 ha within the 55,664-ha watershed of the LLBR. Glacial processes formed the landscape of the LLBR; there are flat floodplains alongside steep slopes of the coulees throughout the watershed. The watershed is a mixed grass sub-region in the Grassland Ecoregion (AAFC, 2013; Natural Regions and Subregions of Alberta, 2006). Temperatures range from the daily average of 17.6 °C in the summer months (July) to -10.2 °C in the winter months (January). Precipitation is normally 365 to 385 mm annually in the LLBR, with one third as snowfall, and is affected by strong, drying Chinook winds (Liu et al., 2017; AAFC, 2013; Jedrych et al. 2006). Surficial material is dominated mainly by undulating glacial plains of eolian sediments and glacial till, with thicker till deposits on upland slopes (Natural Regions and Subregions of Alberta, 2006). The geology of the LLBR bedrock consists of Upper Cretaceous non-marine sandstones and siltstones and marine shales (Natural Regions and

Subregions of Alberta, 2006). Soils found within this region are dominated by Dark Brown Chernozems (Typic Haploboroll) (Liu et al., 2017). Topographic relief can range from 159 m (from 799 m to 958 m) upstream of the LLBR micro-watershed to 86 m (787 m to 873 m) within the study area (Liu et al., 2017). Agricultural uses within this watershed include intensive irrigated cropping and non-irrigated cropping of cereals, forage and oilseeds (Natural Regions and Subregions of Alberta, 2006). Land use in the LLBR also consists of intensive livestock production including pasture and cow-calf operations. The Travers Reservoir, annual precipitation, and irrigation return-flow channels are major sources affecting the flow rate within the LLBR. The Travers Reservoir maintains a steady flow rate in the summer and winter months, at 0.57 m^3/s and 0.85 m^3/s, respectively (Little et al., 2003), while irrigation return-flow channels are not regulated.

Figure 2.1 Map of the Lower Little Bow AAFC WEB's micro-watershed including the four suspended sediment sampling locations, LBW1, LB4-14, LBW4 and LB4 (Caron et al., 2016).

In the study area of the LLBR, and in the larger watershed, irrigation is commonly used by growers. In the LLBR, sedimentation can create an issue with irrigation systems as the sediment can be damaging to pumping equipment. There is a question of what is causing such sedimentation in the LLBR, whether it is from natural levels of land surface and stream channel erosion or accelerated levels from anthropogenic activities. Uncontrolled irrigation return-flow channels in the LLBR have the potential to cause erosion of soil and transport sediment to the river stream (Liu et al., 2017). In the LLBR watershed, there is potential for erosion from agricultural land surface run off, from coulee walls and from stream erosion of stream bank material that could be depositing sediment into the river. In order to properly mitigate the amount of sediment entering the LLBR through beneficial management practices, an understanding of the major contributing sources of sediment needs to be assessed.

2.2.2 Sediment and soil collection

Through AAFC's WEBs program, soil and sediment samples were collected throughout the LLBR micro-watershed reach. Collection was done over the period of 2009-2013. Soil samples were collected from multiple sources that showed evidence of active erosion or were in potential flow paths to the river. Samples were taken in irrigated and non-irrigated agricultural fields and pasture fields along transects; sampling from upper, middle and lower slope landscape positions. Coulee wall samples and streambank samples were taken in vertical incremental measurements, sampling every 10 cm, up to a depth of 60 cm. In total 104 soil, six coulee wall and 45 streambank samples were taken.

In-stream sediment samples were collected in the LLBR at four different monitoring stations used by Liu et al. (2017); LBW1, LB4, LB4-14 and LBW4 (Figure 2.1). These were previously established by Alberta Agriculture, Food and Rural Development for water quality monitoring. Sediment samples were collected from the four monitoring stations as well as two upstream locations, over the period of 2009-2013 (Figure 2.1). One upstream location previously used by Alberta Agriculture, Food and Rural Development, S2, was used to collect sediments, this is referred to in the study by Liu et al. (2017) and in this study as the Irrigation Return-Flow channel (Figure 2.1). The second upstream site is referred to by Liu et al. (2017) and in this study as Upstream. At each sampling location, one time-integrated sediment sampler was used to collect sediment. Each sediment sampler was deployed in April of each year. Sediment from the time-integrated samplers was collected two to three times throughout the season from

July to November (Liu et al., 2017). Each sediment sampler was based on the design of Roddan (2008) with these dimensions:

- body length (pipe) = 60 cm
- inside diameter of body = 15.5 cm
- end caps (slip cap with inside diameter) = 17 cm
- inlet (male threaded coupling cut on a 45-degree angle, minimum inside diameter) = 2.5 cm
- outlet (male threaded 90-degree slip elbow with minimum inside diameter) = 2.5 cm

The upstream suspended sediment samples were taken at two locations upstream of the LLBR AAFC WEBs micro-watershed reach. The first was at an irrigation return-flow channel mouth flowing into the LLBR and the second was at a location upstream of the irrigation return-flow channel to represent inflowing sediments into the study area (Figure 2.1). Both were sampled as potential sources of suspended sediment in the study area; in total five upstream samples and eight irrigation return-flow samples were collected.

2.2.3 Analytical techniques

2.2.3.1 Gamma spectrometry. Following source material and sediment collection, all samples were sieved to < 2 mm and shipped to the University of Manitoba, Environmental Radioactivity Laboratory in the Department of Soil Science for further processing and analysis. The < 2 mm samples received at the University of Manitoba, were further processed for radiochemical analysis by using gamma spectrometry (Canberra BEGe30). Dried source material and sediment samples were placed into 120 mL containers; samples were analyzed from 24 to 48 hours depending on the strength of emissions. Before analysis, the weight, height and geometry of each sample was input into the software program (Boudreault, 2016). The identification or absence of Cs-137 was detected by the germanium. The germanium can receive emitted gamma photons from samples at a level of 662 keV (Boudreault, 2016). Cs-137 activity was measured across the gamma spectrum at the 662 keV peak as the number of nuclear disintegrations per second. This was recorded in Becquerel's per kilogram (Bq/kg). Each measurement of Cs-137 was corrected back to the time that samples were initially collected in the first year, in this case January 1st, 2009. Caron et al. (2016) describes the equation used to determine the activity of Cs-137 as:

$$\text{Cs activity} = \Sigma\text{Cs} / 0.85 \times \text{Eff-137} \times 1/e{-}\lambda t \quad [1]$$

Where: Cs activity is the activity of Cs-137 at the time of sampling (dps); ΣCs is the counts per second (cps) of 662 kiloelectron volt (keV) photo peak; Eff-137 is the counting efficiency for Cs-137 at 662 keV for the sample geometry used (container); 0.85 is the percent of the 662 keV peak of Ba-137M; λ is the decay constant for Cs-137 (years); and t is elapsed time (years) between sampling and counting.

2.2.3.2 Diffuse reflectance spectrometry. A subsample of the < 2 mm portion of soil and sediment samples were sieved down to < 63 μm for analysis by diffuse reflectance spectrometry in the Centre for Earth Observation Science at the University of Manitoba. Diffuse reflectance spectrometry was conducted using a spectroradiometer (ASD FieldSpec4) with RS3 software to measure the colour of a sample across the visible – near-infrared spectrum (350-2500 nm). The colour properties determined from this analysis were R (red), G (green), B (blue) as well as colour properties defined by the Commission Internationale d l'Eclairage (CIE). CIE defined colour properties include; x, y, z, L, a, b, u and v. Each property represents a component of colour. Hue and saturation are defined by x, y and z, where x and z are virtual components of the primary spectra, y represents brightness and x and y both define differences for colour from blue to red and blue to green (Barthod et al., 2015; CIE, 1932). The remaining colour properties represent chromaticity from red-green and blue-yellow scales, including a, b, u and v, where L represents light intensity (Barthod et al., 2015; Rossel et al., 2006; CIE, 1932). Soil and sediment samples were placed in a 10-cm diameter clear Petri dish and smoothed with a straight-edge tool to make sure there would be no interruption to reflectance values. A fibre optic cable at a 45-degree angle captured the reflectance of the soil or sediment sample (Boudreault, 2016; Barthod et al., 2015). Prior to each run, a Spectralon standard was used to optimize the calibration of the equipment. This is referred to as a white reference. A 1000 W quartz halogen lamp (12 VDC, 20 Watt) was mounted 10 cm above the sample to light the sample and the Spectralon standard (Boudreault, 2016; Barthod et al., 2015). Ten absolute reflectance spectra were collected for each sample and an average was converted into graph and text form using the software, ViewSpecPro. The data from ViewSpecPro was exported as a text file in a table form of points and subsets for wavelength and reflectance values. These values for wavelength and reflectance were computed into MatLab to determine all colour properties from relation to X, Y and Z. The following equations were used to compute these colour properties as determined by Barthod et al. (2015):

$$X = K \sum_{360\,nm}^{830\,nm} R(\lambda) \cdot S\,(\lambda) \cdot \bar{x}(\lambda) \qquad [2]$$

$$Y = K \sum_{360\,nm}^{830\,nm} R(\lambda) \cdot S\,(\lambda) \cdot \bar{y}(\lambda) \qquad [3]$$

$$Z = K \sum_{360\,nm}^{830\,nm} R(\lambda) \cdot S\,(\lambda) \cdot \bar{z}(\lambda) \qquad [4]$$

The four colour tracers selected by Liu et al. (2017) to be used in this study included: G (green), Y (brightness), X (virtual component x) and L (light intensity).

2.2.3.3 Geochemical analysis. Geochemical analysis was conducted on all soil and sediment samples using the UESPA method 3050B with Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) in Quebec City, Quebec by AAFC's Quebec Research and Development Centre Water Quality Laboratory. This method, as shown in Figure 2.2, involves acid digestion of samples allowing elements to become "environmentally available" (U.S. EPA, 1996). This allows for the measurement of the concentration of elements present in each sample. Samples were sieved to 2 mm and analyzed in batches of 45. Samples were digested using nitric acid, hydrogen peroxide and hydrochloric acid. After samples have been sieved to < 2mm for uniformity, digestion begins with repeated additions of nitric acid and hydrogen peroxide to either wet or dry form samples in either 1 gram or 1-2 grams, respectively (U.S. EPA, 1996). Hydrochloric acid is added to the digestate and refluxed by adding 2 mL of water and 3 mL of 30% hydrochloric acid (U.S. EPA, 1996). Samples were either filtered, centrifuged or settled to remove particulates (U.S. EPA, 1996). If the elemental activity was measured as a bad value, samples were diluted and re-digested to accurately measure for a second time. In total, 15 elements were analyzed for activity in all the samples including, Aluminum (Al), Beryllium (Be), Calcium (Ca), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Potassium (K), Magnesium (Mg), Manganese (M), Nickel (Ni), Phosphorus (P), Lead (Pb) and Zinc (Zn).

Figure 2.2 Flow diagram describing the steps for geochemical analysis using the ICP-OES, ICP-AES Method 3050B Acid Digestion of Sediments, Sludges and Soils (U.S. EPA, 1996).

2.2.4 Data analysis

2.2.4.1 Canonical Discriminant Analysis. In a previous study of the LLBR micro-watershed, by Liu et al. (2017), source groupings were determined using a Canonical Discrimination Analysis (CDA). In addition to colour tracers used by Liu et al. (2017), a suite of geochemical tracers and Cs-137 were used to run a CDA to determine source groupings for this study. Using the open source program, R (R Package, 2012), all samples were recorded into comma separated value format for all 15 colour values and Cs-137 values. Through the process of elimination certain source groups were combined because of overlap from the CDA according to the first and second discriminant values. In sediment fingerprinting, to have an appropriate number of tracers relative to sources in a study, the general rule of thumb is for *n* sources there must be at least *n-1* tracers (Liu et al., 2017; Philips et al., 2014; Walling 2013).

2.2.4.2 Shapiro – Wilk test. The Shapiro-Wilk test assesses the normality of each tracer; if a tracer does not follow normal distribution, it is removed from the dataset. In order to run an efficient MixSIAR model, the data must follow a normal distribution. The Shapiro-Wilk test was conducted using SAS software, using the PROC UNIVARIATE procedure (SAS institute, 2008). Normality was tested using the Shapiro Wilk result, W; if $W > 0.9$ then the distribution is normal, if $W < 0.9$, the data do not follow normal distribution.

2.2.4.3 Biplot analysis. Biplot analysis allows a test of conservativeness and redundancy of tracers (Boudreault, 2016; Barthod et al., 2015; Smith and Blake, 2014). Biplot analysis was run using the program, MixSIAR, in the open-source R statistical program (R Package, 2012). This was conducted for the tracers that passed the Shapiro-Wilk test in section 2.2.4.2. The tracer means and standard deviations for the sources were plotted against the values for the suspended sediment mixtures, in this case from the four monitoring stations of sediment collection; LBW1, LB4, LB4-14 and LBW4. Tracer means were plotted with ± 1 standard deviation represented as error bars, the length of the error bars represents the uncertainty and variability within the tracer (Boudreault, 2016). If suspended sediment data fell within the range of the source data and error bars this would represent that all sources have been included and that the tracers behave conservatively (Barthod et al., 2015). If the biplot, or isospace plot, revealed suspended sediment samples outside the range of the sources, this would represent that the tracers used were non-conservative and should be removed from analysis (Boudreault, 2016).

2.2.4.4 Kruskal – Wallis test. The Kruskal-Wallis test was conducted in order to look at the tracers that had passed the Shapiro-Wilk test and biplot analysis. This was done in the open source program R (R package, 2012). The Kruskal-Wallis tests the uniqueness of sediment sources by the ability of a tracer to distinguish between source types (Collins et al. 1998). This nonparametric procedure provides a means of determining whether the tracers can provide distinction between the different source groups (Boudreault, 2016; Collins and Walling, 2002; Walling et al., 1999). In order to test whether the source distinction by each individual tracer is significant, the p-value was set to < 0.01. If a tracer was significant and passed the Kruskal-Wallis test, it could then be used within the discriminant function analysis to provide the best combination of properties (Collins et al., 1998).

2.2.4.5 Stepwise discriminant function analysis. Of the tracers that passed the Kruskal-Wallis test and can significantly distinguish between source groups, these tracers are used in a stepwise discriminant function analysis to determine the best combination of the colour properties, Cs-137 and geochemical tracers to provide the best discrimination between sediment source groups. This was done in the open source program R (R package, 2012). This analysis provides the ability to use more than one tracer to distinguish source groups for source apportionment within the mixing model, MixSIAR. An optimal combination of tracers can be determined that will provide the greatest amount of discrimination between source groups by the minimization of the Wilk's lambda (Boudreault 2016; Collins and Walling, 2002). As the Wilk's lambda is reduced closer to zero, from adding and removing tracers in combination, the greater the discrimination between source groups becomes and there is a decrease in variability within source groups. (Collins et al., 2002). The tracers that provided the best combination to reduce Wilk's lambda were used for source apportionment in MixSIAR.

2.2.4.6 MixSIAR. The mixing model, MixSIAR, was used as a tool to analyze the source and suspended sediment samples. The model MixSIAR, was originally developed for ecology studies of food webs and animal diets (Stock and Semmens, 2016). MixSIAR can use isotopes or environmental tracers as a basic multivariate mixing model, to model processes for environmental studies outside of trophic interactions, assuming that linear mixing is always met (Stock and Semmens, 2016). MixSIAR can interpret source contributions by the use of probability distributions (Boudreault, 2016; Nosarti et al., 2014; Stock and Semmens, 2013) as MixSIAR is a Bayesian isotopic mixing model. In the case of sediment fingerprinting, the source or "prey" values are any source sampled, such as agricultural land, stream banks or channels; the "diet" values are the suspended sediment or outlet values. Using a mixing model, like MixSIAR, provides a medium to input values and assign proportions of sources to suspended sediment. By using the mixing model, MixSIAR, as a tool, an assessment of how landscape processes and tracer selection can affect the outcome in source apportionment can be made.

An assumption that is made for the MixSIAR model is that it will account for 100% of the sources; whatever the number of sources inputted into the program, it will assign a proportion to a source that is included in the model, it will try to best fit proportions, but will not include any proportions as an unknown. Three files are used to run the mixing model in the open source program, R. The first file is a mixture file, which contains all the values for the outflowing suspended sediment. The mixture file is the data that will be used to determine the sources contributing to it. The second file contains the sources themselves; this file contains the means and standard deviations for all tracers for each individual source. This file also contains the number of samples taken for each source. The final file is the discrimination file which is used to weight or discriminate any differences in sources and tracers due to factors such as trophic enrichment as in the case of the original model use (Stock and Semmens, 2016). This file has assigned a zero for each tracer mean and standard deviation since there is no weighting towards any sources in this study. Each MixSIAR model scheme was run for the length of 'Long', meaning that the length of the MCMC (Markov Chain Monte Carlo) was 300,000 iterations with a burn-in of 200,000 (Liu et al., 2017; Stock and Semmens, 2016).

2.2.5 MixSIAR Schemes

Three schemes were run with the mixing model, MixSIAR. Five sediment source groups were included in the first scheme including; Agricultural Land, Coulee Wall, Stream Bank, Irrigation Return-Flow and Upstream. This MixSIAR model scheme was run for the length of 'Long', against the suspended sediment collected at the four monitoring stations; LBW1, LB4, LB4-14 and LBW4 (Figure 2.3). Scheme 1 was run using tracers chosen with the best statistical mixing percentages based on stepwise discriminant function analysis. These four tracers are the colour tracers G, Y and X and the geochemical tracer Co.

The second MixSIAR scheme was also designed as shown in Figure 2.3. Using the suspended sediment from the four monitoring stations and the five sediment source groups of Agricultural Land, Stream Banks, Irrigation Return-Flow channel, Coulee Walls and Upstream. This MixSIAR scheme differs from Scheme 1 in that a different suite of tracers were used to determine the source proportions of the LLBR suspended sediment. The tracers used in Scheme 2 are geochemical tracers only, including, Mn, Co, Fe and Al. Scheme 2 was designed with only geochemical elements to understand if there are any differences when colour properties are used as tracers alone, as in the scheme conducted by Liu et al. (2017), compared to geochemical elements alone.

The third MixSIAR model scheme is designed as the combination of the best statistically chosen tracers between colour, geochemical and radionuclide tracers analyzed, as well as the addition of prior knowledge of tracers and judgement on the watershed itself. To understand if there is a need for a certain level of understanding of a watershed before assumptions based on sediment fingerprinting results can be made for implementation of soil and sediment management practices or policies. For this scheme, the same five source groups are used, including, Agricultural Land, Stream Banks, Irrigation Return-Flow channel, Coulee Walls and Upstream. The tracers used for this scheme are the colour tracers, G, X and Y, along with the fallout radionuclide tracer, Cs-137, and the geochemical element, Co.

Figure 2.3 MixSIAR scheme diagram demonstrating the MixSIAR model design and inputs including; sediment mixture, direction of flow for scheme organization and sediment sources.

2.3 Results

2.3.1 Canonical Discriminant Analysis

The CDA was conducted using all geochemical, fallout radionuclide and colour tracers. Five source groups were determined to have the best source discrimination and were grouped based on the original source grouping of Liu et al. (2017). These groups are Agricultural Land, Stream Banks, Upstream, Irrigation Return-Flow channel and Coulee Walls. Without source grouping, the percentage of sediment source variability is determined as 98.5% for the first discriminant and 0.7% for the second discriminant, giving a total of 99.2% with 16 groupings. When the sediment sources are grouped into the five sediment source groups similar to Liu et al. (2017), the first discriminant function is 58.8% and the second discriminant function is 33.5%, giving a total of 92.3%.

Figure 2.4 CDA of original soil and sediment samples within the LLBR watershed, first and second discriminant functions.

Figure 2.5 CDA of regrouped soil and sediment samples within the LLBR watershed, first and second discriminant functions.

2.3.2 Shapiro-Wilk test

The Shapiro Wilk test was conducted for the tracer, Cs-137. Cs-137 did not follow a normal distribution since $W < 0.9$. The values for Cs-137 were transformed using Log_{10} and thus reached a normal distribution with $W > 0.9$. The remaining tracers that passed the Shapiro Wilk test were the colour tracers; R, G, B, X, Y, Z, x, y, L, u, v, a, b, and c, and the geochemical tracers; Al, Co, Fe, K and Mn.

2.3.3 Bi-Plot Analysis

Each tracer mean and standard deviation was calculated and input to the biplot analysis. In total, 20 tracers were used including the colour tracers; R, G, B, X, Y, Z, x, y, L, u, v, a, b, and c, and the geochemical tracers; Al, Co, Fe, K and Mn, and the fallout radionuclide, Cs-137. The most conservative of all tracers from visual analysis of the biplot or ispospace plots produced in MixSIAR were R, G, X, Y, Z, L, Cs-137, Al, Co, Fe, K and Mn (Figure 2.6). The largest amount of uncertainty in source groups was in the Agricultural Land source group, as well as the Coulee Wall source group.

Figure 2.6 Isospace plots for X, Y, Cs-137, Co and G, demonstrating amount of uncertainty in suspended sediment sources: 1) Agricultural Land, 2) Upstream, 3) Stream Bank, 4) Irrigation Return-Flow, and 5) Coulee Wall.

2.3.4 Kruskal-Wallis Test

Of the tracers chosen from the biplot analysis, R, G, X, Y, Z, L, Cs-137, Al, Co, Fe, K and Mn, all had p-values < 0.01, for the 99% confidence interval, demonstrating that each tracer had the ability to distinguish between sources groups (Table 2.1).

2.3.5 Stepwise Discriminant Function Analysis

From the tracers that passed the Kruskal-Wallis test, a stepwise discriminant function analysis was conducted in order to determine which tracers would provide correct classification of sources on their own (Table 2.1) and when in combination (Table 2.2). The Upstream source and Irrigation Return-Flow sources were both not correctly classified by any fingerprint property on its own as shown in Table 2.1. The best combination of fingerprint tracers was Co, X, Y and G, correctly classifying 93.81% of the total source groups (Table 2.2).

Table 2.1 Kruskal-Wallis test results and percentage of sources correctly classified by the tracers, Cs-137, Co, X, Y and G.

Table 2.2 Stepwise discriminant function analysis results demonstrating optimal combinations of tracers, Co, X, Y and G for the largest percentage of correctly classified sediment sources.

2.3.6 Scheme 1

The tracers chosen for this scheme were based on purely statistical analyses for the tracers that could distinguish between sediment sources. The tracers used in the MixSIAR model for Scheme 1 were the colour tracers G, X and Y, and the geochemical tracer, Co. In Scheme 1, Upstream suspended sediment contributed a mean of 67.8 % of the downstream suspended sediment mixture (Figure 2.7, Table 2.3). The remaining sources contributed means of 8.2 %, 8.0 %, 8.0 % and 8.0 % for Coulee Walls, Agricultural Land, Stream Banks and the Irrigation Return-Flow channel, respectively (Table 2.3).

2.3.7 Scheme 2

Scheme 2 was conducted using solely geochemical elements as tracers in order to understand if the findings changes for sediment source apportionments compared to using colour tracers alone. The geochemical tracers used were chosen from the remaining geochemical elements that passed the Kruskal-Wallis test. The geochemical tracers used in the Scheme 2 MixSIAR model were Al, Co, Fe and Mn (Figure 2.8). In this scheme, similar to Scheme 1, the Upstream source contributes the largest proportion to the downstream suspended sediment load, with a mean of 29.2 % (Table 2.3). The second largest contributing source is Stream Banks, followed by Agricultural Land, Irrigation Return-Flow channel and Coulee Walls, contributing means of 18.1 %, 17.7 %, 17.7 % and 17.3 %, respectively (Table 2.3). The variability is large within sediment sources (and illustrated by the values of SD, Table 2.3), but there is not a large amount of variability between the different sediment sources.

2.3.8 Scheme 3

The tracers used in Scheme 3 were chosen using a combination of previous knowledge of tracer behaviour, the watershed area and past studies as well as statistical analyses. From the results of Caron et al. (2016), which had shown that Cs-137 could distinguish well between surface and subsurface material in the LLBR, Cs-137 was included in this scheme. Colour tracers had been proven to be sufficient tracers when a purely statistical approach was taken, as in Scheme 1, and so colour tracers that were statistically strong were also chosen for this scheme. In order to help reduce redundancy and create a broader composite fingerprint, a strong statistical geochemical element was also added to the suite of tracers. The tracers that were chosen for the Scheme 3 MixSIAR model were the colour tracers, G, X and Y, the fallout radionuclide Cs-137 and the geochemical element, Co. The results for Scheme 3 are very similar to Scheme 1 (Figure 2.9). The largest contributing sediment source is the Upstream source, which contributed a mean of 68.4 % (Table 2.3). The remaining sources contributed means of 9.0 %, 8.2 %, 7.8 % and 6.5 %, for Agricultural Land, Coulee Walls, Irrigation Return-Flow channel and Stream Banks, respectively (Table 2.3). This scheme had slight differences between the smaller sediment source groups compared to Scheme 1, and had less variability within source groups compared to Scheme 2 (Table 2.3).

2.3.9 Liu et al. (2017) Scheme

The MixSIAR scheme conducted by Liu et al. (2017) used the colour tracers; G, L, X and Y. The largest sediment source in this scheme was the Upstream source, contributing a mean of 37.4 %. The remaining sources contributed means of 25.6 %, 14.5 %, 13.4 %

and 9.2 %, for Irrigation Return-Flow, Stream Banks, Coulee Walls and Agricultural Land sources, respectively.

Figure 2.7 Scheme 1 95 % confidence interval source proportions of suspended sediment in the LLBR.

Figure 2.8 Scheme 2 95 % confidence interval source proportions of suspended sediment in the LLBR.

Figure 2.9 Scheme 3 95 % confidence interval source proportions of suspended sediment in the LLBR.

Figure 2.10 Liu et al. (2017) MixSIAR scheme using the colour tracers; G, L, X and Y (Liu et al., 2017).

Table 2.3 Source proportion means and standard deviations as percentage of suspended sediment in the LLBR.

2.4 Discussion

Moving forward in sediment fingerprinting studies, one of the main focuses should be understanding applications of mixing model results. Through the study of sediment fingerprinting mixing models and their real-world applications, sampling strategies can become more efficient and effective and so can the selection of tracers. Sediment fingerprinting mixing models can provide information on sediment source proportions that could be directly applicable to sediment loading and soil erosion management practices. Understanding all the tools available and the appropriate use of such tools is important for interpreting results of sediment fingerprinting studies.

The three schemes in this study each look at using a different approach to apportion sediment sources in the LLBR watershed through tracer selection. The first approach in Scheme 1 uses a purely statistical method to choose tracers. Scheme 1 represents the strategy used by multiple sediment fingerprinting studies, as a base to compare other approaches. Scheme 2 was run using solely geochemical elements in order to compare whether there is much difference in the sediment source proportions compared to using colour properties by themselves or in a composite fingerprint with other tracers. Scheme 3 incorporated the ability to use knowledge about the behaviour of the properties of sediment and sediment source materials used as environmental tracers that may not be represented solely through statistical analyses. These include the potential for transformation of tracers through transport and deposition from processes such as redox reactions, preferential transport and enrichment. Fryirs et al. (2007) discusses the implications of the fate of sediment through water bodies as a means of potential blockages, transformations and interruptions that can occur as sediment moves. To incorporate the knowledge of some of these potential dynamics within a watershed, some level of understanding how this can affect what the outcome of sediment source proportions can be used in the selection of appropriate tracers. Scheme 3 demonstrates the ability to find and determine from a large group of 12 tracers, that there are some statistically strong tracers, as well as tracers that can provide certain distinctions about sediment behaviour that may not be provided through a process such as the stepwise discrimination analysis. For example, Cs-137 throughout literature has proven to be an effective tracer in distinguishing between surface and subsurface material in watershed landscapes (Caron et al., 2016; Koiter et al., 2013a). Caron et al. (2016) demonstrated that specifically within the LLBR itself, Cs-137 can distinguish between the five different sediment sources used in this study. The ability to distinguish between a characteristic such as subsurface or surface material can be beneficial when adding it to a suite of tracers that distinguish other characteristics about sediment. This can be demonstrated in both Scheme 1 and Scheme 3, where multiple types of tracers are used that identify different characteristics of soil and sediment. Liu et al. (2017) used solely colour tracers and determined that source proportions of sediment to be 37.4 %, 25.6 %, 14.5 %, 13.4 % and 9.2 %, for Upstream, Irrigation Return-Flow, Stream Banks, Coulee Walls and Agricultural Land sources, respectively (Figure 2.10). A question that is posed with using solely colour properties is whether or not the sediment source proportions may be skewed if there is redundancy among the tracers since they could all be distinguishing for similar or related characteristics and attributes of soil and sediment. When a statistical approach is taken to choose tracers in Scheme 1, there are a number of colour tracers that are high performing compared to geochemical elements and Cs-137. The addition of Co to a suite of three colour tracers creates a different story of sediment source proportions within the LLBR micro-watershed reach from Liu et al. (2017) results. Source proportions are higher for the Upstream source, which is 67.8 % in Scheme 1, compared with Liu et al. (2017) which was 37.4 %. This difference of 30.4 % is a statistically large. A difference such as 30.4% can create issues when the results of a mixing model such as these are applied to policies and measurement and implementation of management practices to reduce soil and sediment movement. If source proportions are inaccurate, management could be applied in the wrong proportion to the wrong area and sediment source. The cumulative variance in Table 2.3 addresses the variability within each scheme and can be a direct assessment of the MixSIAR model. The lower the cumulative variance, the more precise a scheme will be. The lowest cumulative variances were in both Scheme 1 and Scheme 3, with cumulative variances of 0.287 and 0.295, respectively. These cumulative variances are much lower than Scheme 2, which was 0.812, demonstrating that Scheme 1 and Scheme 3 are more precise models than Scheme 3.

The differences between Scheme 1 and the results from Liu et al. (2017), demonstrate that the addition of another tracer outside of colour tracers alone can have an effect on the sediment source proportions. Scheme 2 demonstrates the sediment source proportions in the LLBR when a composite of geochemical elements alone were used as tracers. This was done in order to assess whether the sediment source proportions change or stay the same compared to using colour tracers alone or in combination with one or two other environmental tracers. The results of Scheme 2 show high amounts of variability within each source group, demonstrating that there is no clear distinction of which sediment sources contributed sediment to the suspended sediment load (Figure 2.5). Similar to Scheme 1, the largest amount of sediment is contributed by the Upstream source. Between the remaining four sediment sources in Scheme 2, there is no real distinction between how much each source is contributing, similar also to Scheme 1, although Scheme 1 has less variability within each of the source groups. The use of geochemical tracers alone does not give a clear picture of the exact sediment source proportions within the LLBR, the model shows less confidence around each sediment source proportion since there is large variability compared to Scheme 1 and Liu et al. (2017) models (Figure 2.5). Scheme 3 demonstrates the ability to combine approaches and use the best available tools and knowledge to apportion sediment sources. A well-rounded composite of environmental tracers can be provided when using the combination of geochemical elements, colour properties and the fallout radionuclide Cs-137. Scheme 3 was run with three colour tracers, one geochemical tracer, and one fallout radionuclide. The results of this scheme gave similar results to the sediment source proportions in Scheme 1 (Figure 2.4 and Figure 2.6). There is a small percentage of difference between Scheme 1 and Scheme 3, showing that the addition of Cs-137 did not drastically change the difference in source proportions within the sediment fingerprinting model. Although the addition of Cs-137 may not have changed the overall sediment source proportions, it may be a safe assumption to help determine whether a model prediction accurately reflects real events. For example, since Cs-137 is a confident tracer from previous sediment fingerprinting studies, it could perhaps be a check for other tracer composites. With the addition of Cs-137 in Scheme 3, there is no real difference or deviation from the results in Scheme 1. This could mean that either the addition of Cs-137 or the suite of tracers used in Scheme 3, confirm that Scheme 1 is also an accurate use of tracers to predict source proportions in the LLBR watershed. The addition of Cs-137 having no effect could also mean the opposite, that overloading three different types of environmental tracers eventually does not change the results of the sediment source proportions, when the threshold of having enough tracers to distinguish the characteristics of the soil and sediment samples is reached. Either response on the model from the addition of Cs-137 comes to the same conclusion that it helped to confirm that Scheme 1 and Scheme 3 are realistic accurate models of the LLBR watershed.

2.5 Conclusions

To apportion sediment sources accurately within a watershed, understanding the behaviour of environmental tracers and how to choose them is important. Based on the findings of this study, the best two models that can represent a watershed are either purely statistical with a suite of different environmental tracers, not just multiple tracers of the same category, for example, using colour tracers only or geochemical tracers only. The ability to choose tracers based on knowledge of their behaviour and knowledge of the watershed also helps to confirm accurate predictions of sediment source proportions, as well as it can be a check for other composite tracer combinations accuracy. Moving forward with the study of sediments in LLBR, these approaches should be taken at the larger watershed scale and be used to explore the reason for the large amount of sediment that is being contributed by the Upstream sediment source in all three schemes.

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2.7 Chapter 2 Figures and Tables

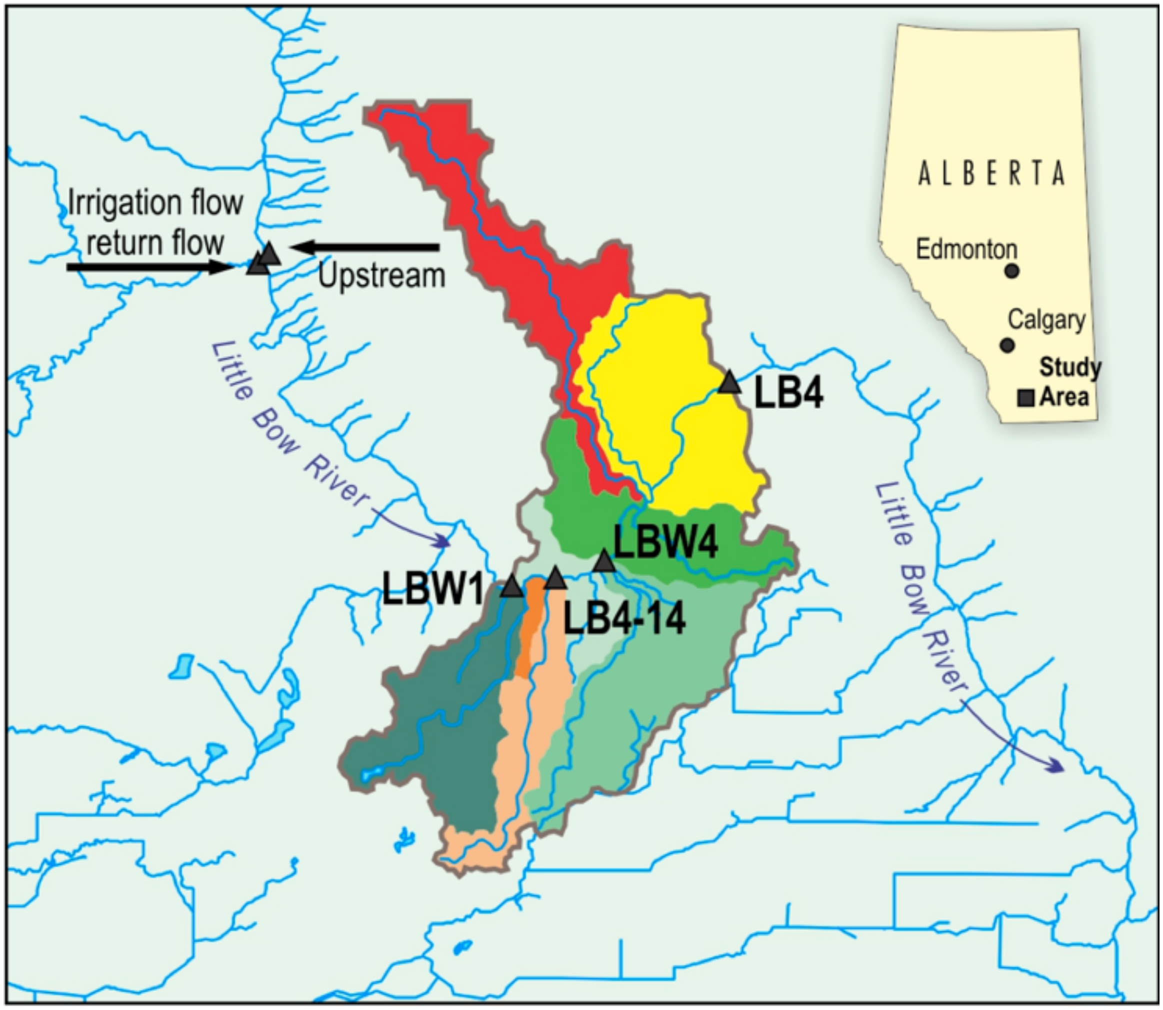

Figure 2.1 Map of the Lower Little Bow AAFC WEB's micro-watershed including the four suspended sediment sampling locations, LBW1, LB4-14, LBW4 and LB4 (Caron et al., 2016).

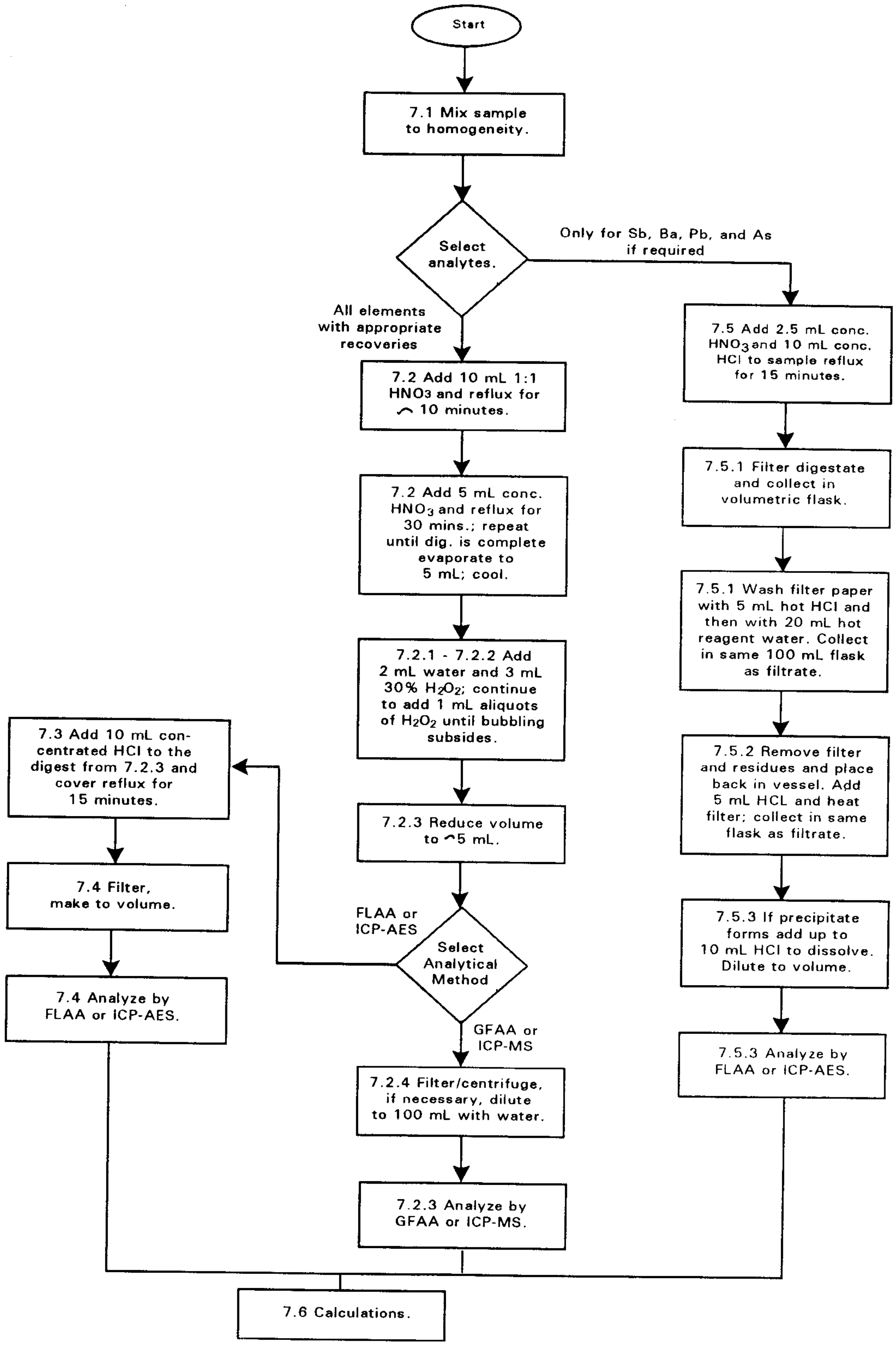
Start
7.1 Mix sample to homogeneity.
Select analytes.
Only for Sb, Ba, Pb, and As if required
All elements with appropriate recoveries
7.2 Add 10 mL 1:1 HNO3 and reflux for ~ 10 minutes.
7.2 Add 5 mL conc. HNO3 and reflux for 30 mins.; repeat until dig. is complete evaporate to 5 mL; cool.
7.2.1 - 7.2.2 Add 2 mL water and 3 mL 30% H2O2; continue to add 1 mL aliquots of H2O2 until bubbling subsides.
7.2.3 Reduce volume to ~5 mL.
Select Analytical Method
FLAA or ICP-AES
GFAA or ICP-MS
7.2.4 Filter/centrifuge, if necessary, dilute to 100 mL with water.
7.2.3 Analyze by GFAA or ICP-MS.
7.3 Add 10 mL concentrated HCl to the digest from 7.2.3 and cover reflux for 15 minutes.
7.4 Filter, make to volume.
7.4 Analyze by FLAA or ICP-AES.
7.5 Add 2.5 mL conc. HNO3 and 10 mL conc. HCl to sample reflux for 15 minutes.
7.5.1 Filter digestate and collect in volumetric flask.
7.5.1 Wash filter paper with 5 mL hot HCl and then with 20 mL hot reagent water. Collect in same 100 mL flask as filtrate.
7.5.2 Remove filter and residues and place back in vessel. Add 5 mL HCL and heat filter; collect in same flask as filtrate.
7.5.3 If precipitate forms add up to 10 mL HCl to dissolve. Dilute to volume.
7.5.3 Analyze by FLAA or ICP-AES.
7.6 Calculations.

Figure 2.2 Flow diagram describing the steps for geochemical analysis using the ICP-OES, ICP-AES Method 3050B Acid Digestion of Sediments, Sludges and Soils (U.S. EPA, 1996).

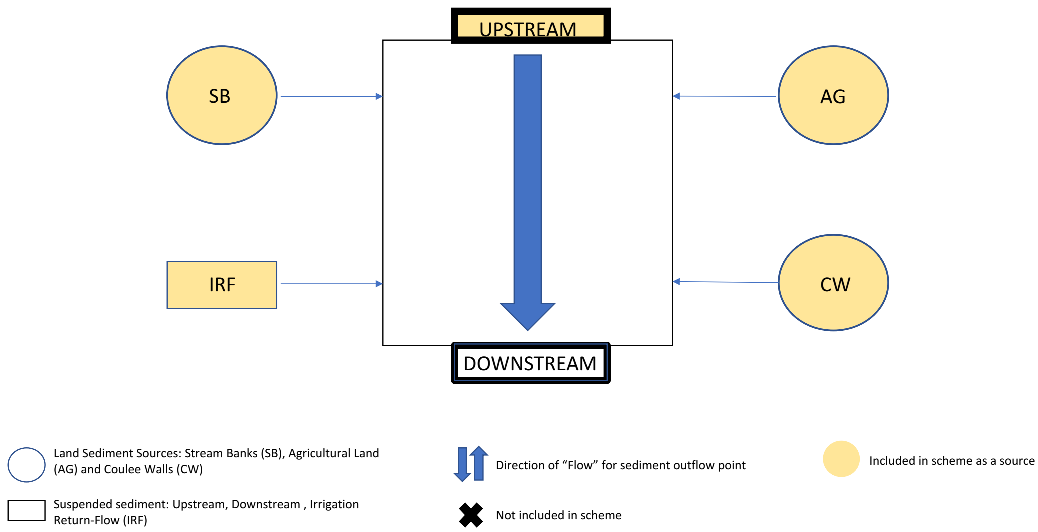

Figure 2.3 MixSIAR scheme diagram demonstrating the MixSIAR model design and inputs including; sediment mixture, direction of flow for scheme organization and sediment sources.

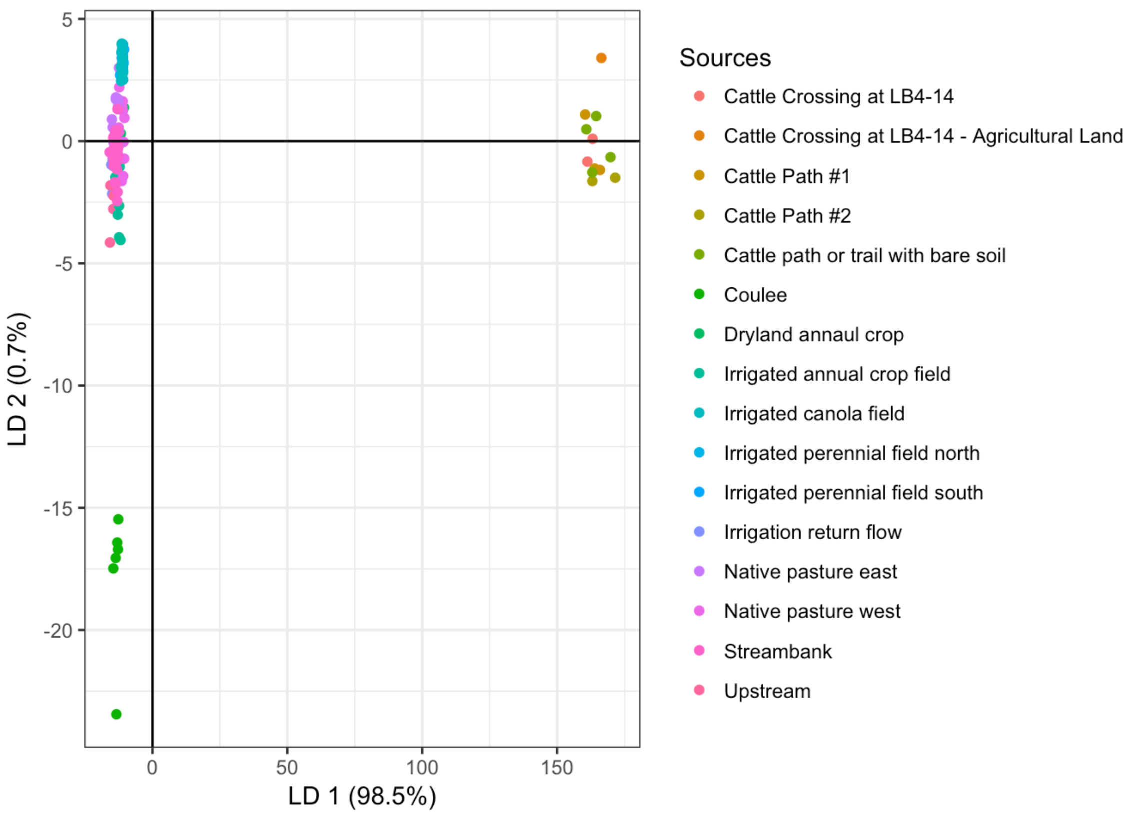

Figure 2.4 CDA of original soil and sediment samples within the LLBR watershed, first and second discriminant functions.

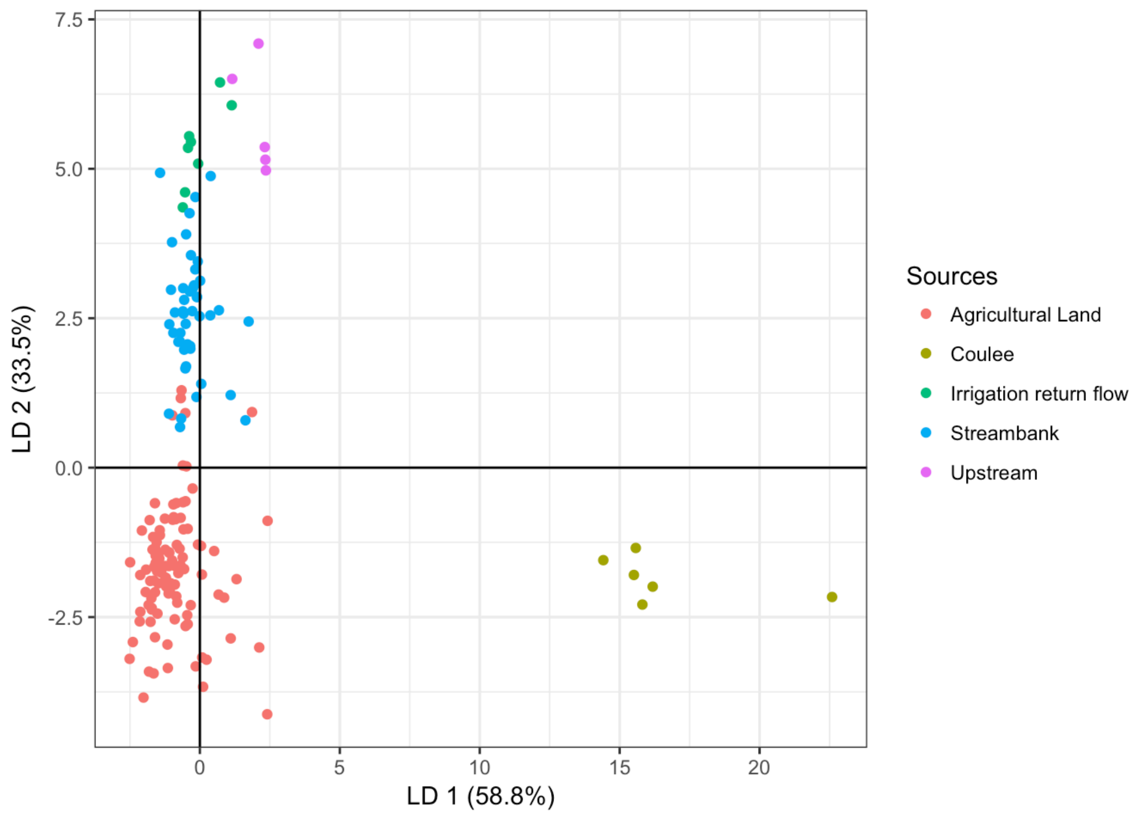

Figure 2.5 CDA of regrouped soil and sediment samples within the LLBR watershed, first and second discriminant functions.

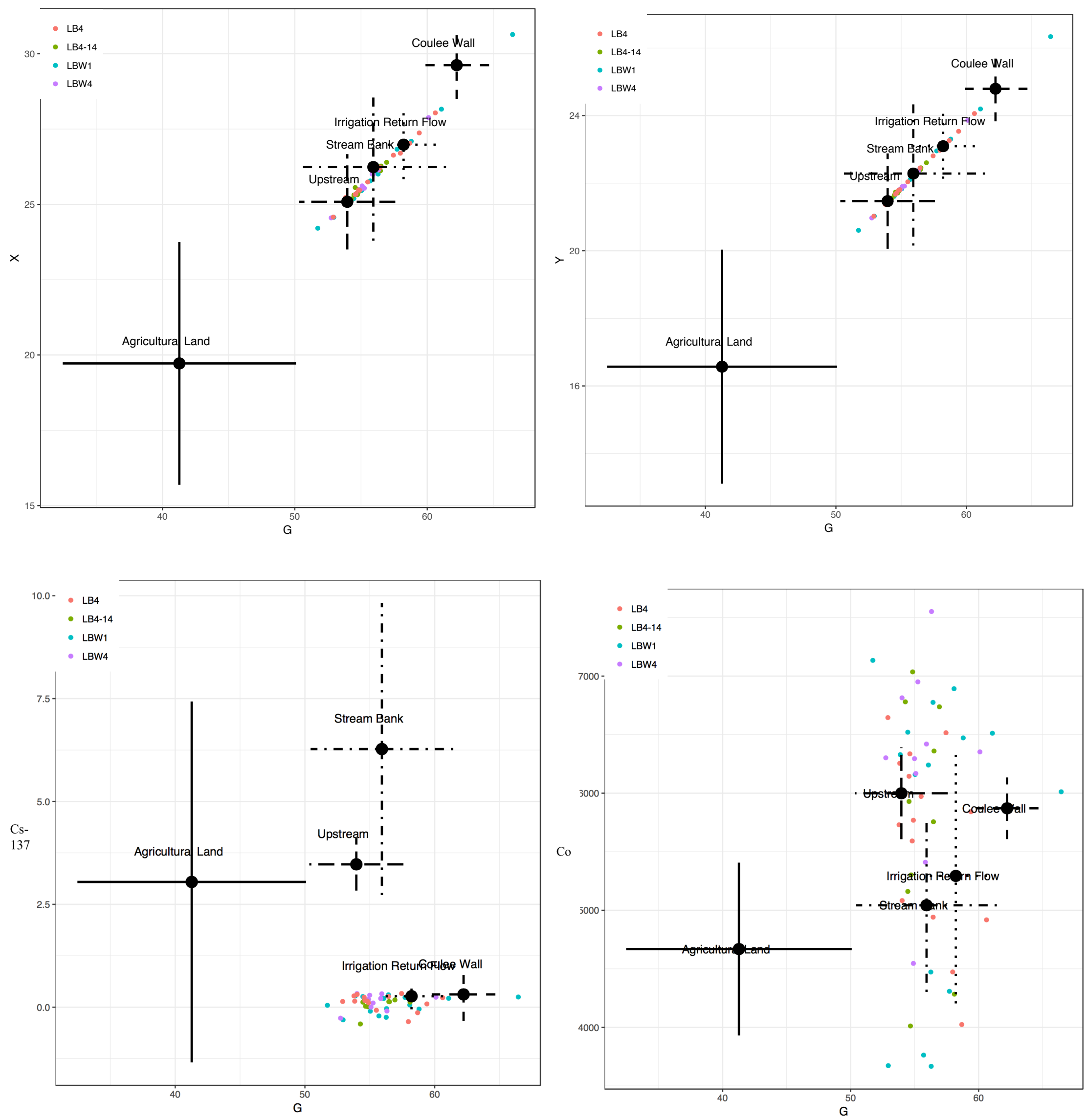

Figure 2.6 Isospace plots for X, Y, G, Cs-137 and Co demonstrating amount of uncertainty in suspended sediment sources: 1) Agricultural Land, 2) Upstream, 3) Stream Bank, 4) Irrigation Return-Flow, and 5) Coulee Wall.

Table 2.1 Kruskal-Wallis test results and percentage of sources correctly classified by the tracers, Cs-137, Co, X, Y and G.

		Percentage of sources correctly classified					
Fingerprint Property	**Kruskal-Wallis**	**Total (%)**	**Agricultural Land (%)**	**Irrigation Return-Flow (%)**	**Upstream (%)**	**Coulee Wall (%)**	**Stream Bank (%)**
Cs-137	<0.01	48.08	28.85	66.67	80.00	83.33	80.43
Co	<0.01	64.31	86.54	0.00	40.00	100.00	0.00
X	<0.01	67.26	75.00	37.50	60.00	100.00	0.00
Y	<0.01	67.55	75.96	37.50	60.00	60.00	0.00
G	<0.01	75.36	88.41	0.00	0.00	11.11	78.26

Table 2.2 Stepwise discriminant function analysis results demonstrating optimal combinations of tracers, Co, X, Y and G for the largest percentage of correctly classified sediment sources.

		Percentage of sources correctly classified					
Fingerprint Property	**Composite Fingerprint**	**Total (%)**	**Agricultural Land (%)**	**Irrigation Return-Flow (%)**	**Upstream (%)**	**Coulee Wall (%)**	**Stream Bank (%)**
X	**G**	67.26	75.00	37.50	60.00	100.00	0.00
Y	**X+Y**	84.37	89.42	100.00	37.50	73.33	80.00
G	**X+Y+G**	93.51	85.58	100.00	100.00	84.44	100.00
Co	**X+Y+G+Co**	93.81	85.58	100.00	100.00	86.67	100.00

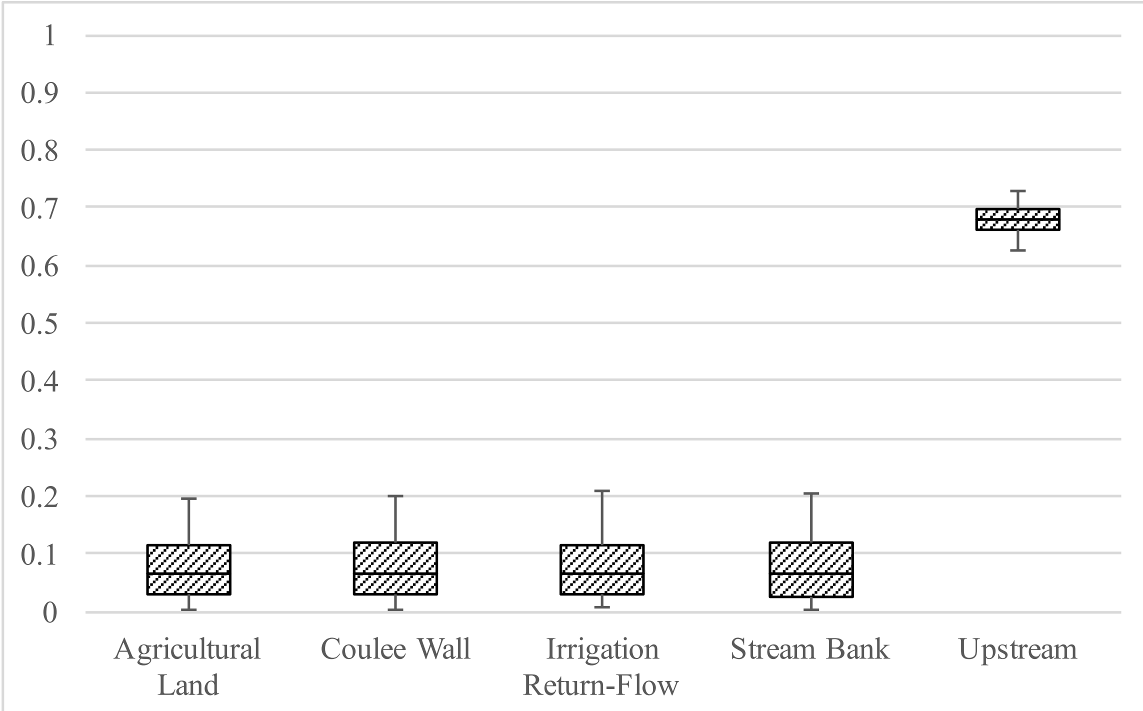

Figure 2.7 Scheme 1 95% confidence interval source proportions of suspended sediment in the LLBR.

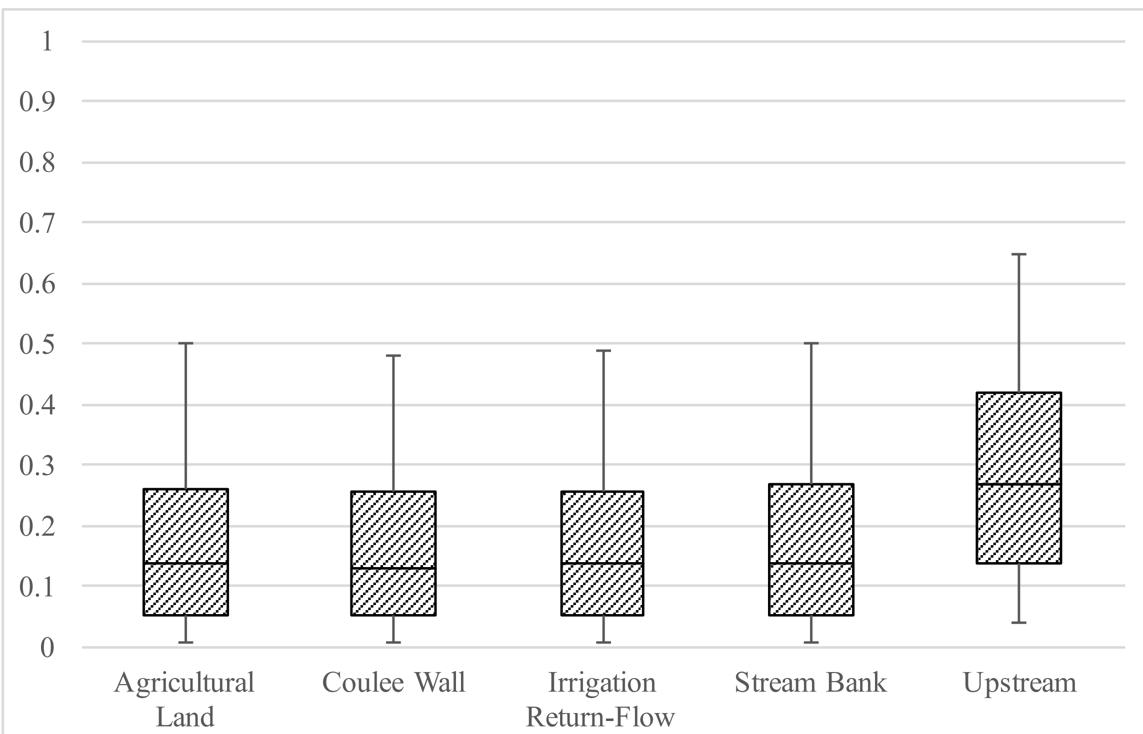

Figure 2.8 Scheme 2 95% confidence interval source proportions of suspended sediment in the LLBR.

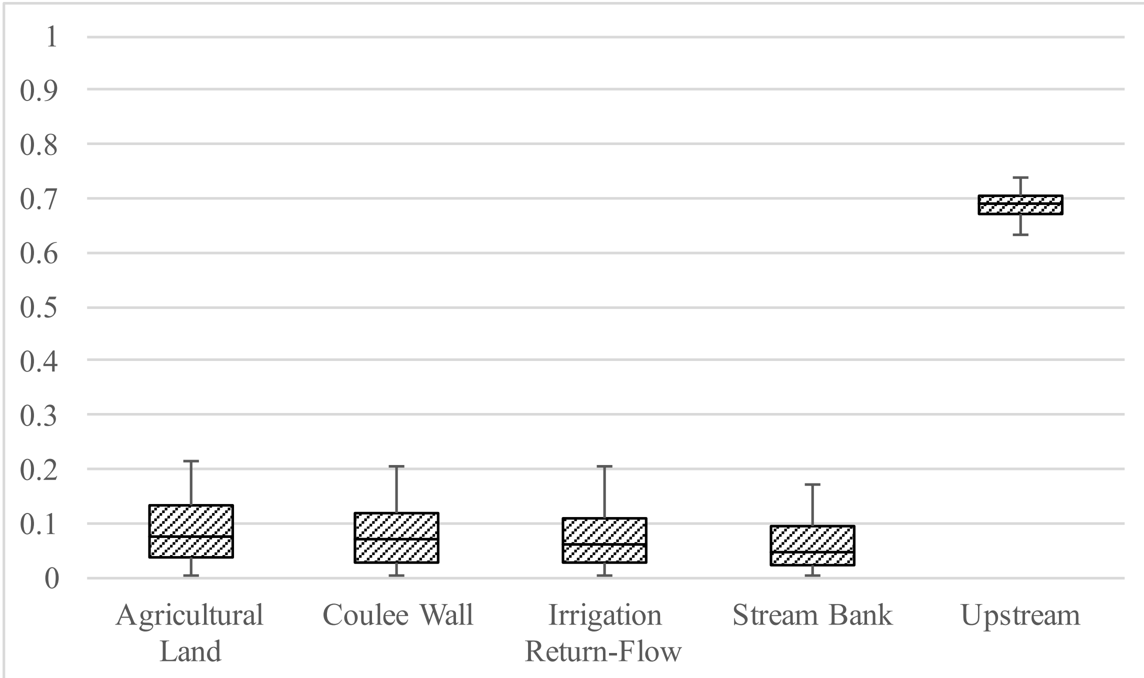

Figure 2.9 Scheme 3 95% confidence interval source proportions of suspended sediment in the LLBR.

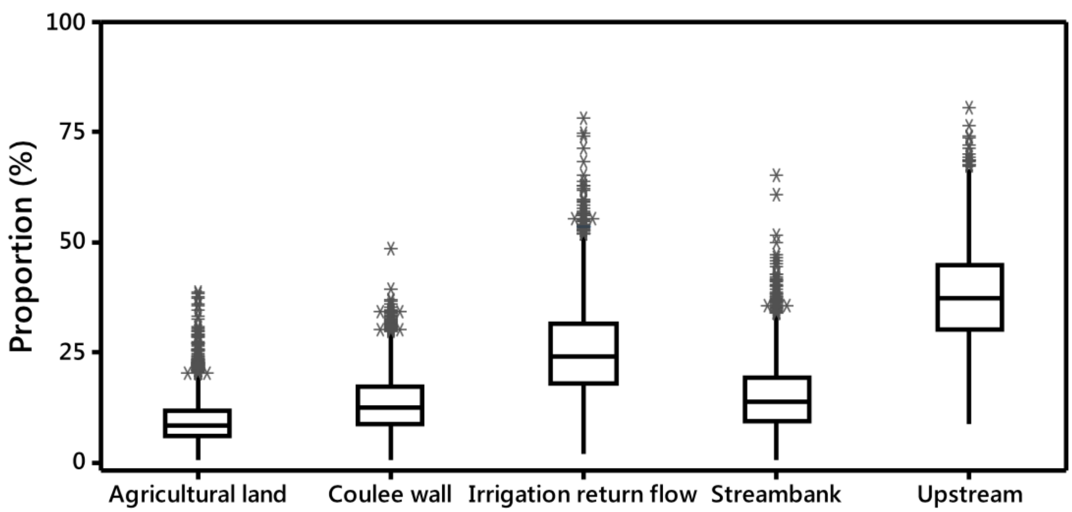

Figure 2.10 Liu et al. (2017) MixSIAR scheme using the colour tracers; G, L, X and Y (Liu et al., 2017).

Table 2.3 Source proportion means and standard deviations as percentage of suspended sediment in the LLBR.

Scheme	Source	Mean	SD
1	Agricultural Land	0.08	0.062
	Coulee Wall	0.082	0.063
	Irrigation Return-Flow	0.08	0.064
	Stream Bank	0.08	0.064
	Upstream	0.678	0.034
	Cumulative[1]	*1.00*	*0.287*
2	Agricultural Land	0.177	0.154
	Coulee Wall	0.173	0.153
	Irrigation Return-Flow	0.177	0.155
	Stream Bank	0.181	0.16
	Upstream	0.292	0.19
	Cumulative[1]	*1.00*	*0.812*
3	Agricultural Land	0.09	0.067
	Coulee Wall	0.082	0.064
	Irrigation Return-Flow	0.078	0.064
	Stream Bank	0.065	0.056
	Upstream	0.684	0.044
	Cumulative[1]	*1.00*	*0.295*

[1]Cumulative mean and standard deviation for all five sediment sources.

3. COLOUR TRACERS AND THE EFFECT OF UPSTREAM SOURCE SAMPLING ON INFLOWING SUSPENDED SEDIMENT OF A STREAM REACH IN A PRAIRIE WATERSHED IN SOUTHERN ALBERTA

ABSTRACT

Sediment fingerprinting has the potential to be used as tool to improve and implement beneficial management practices. In order to maximize the use of sediment fingerprinting as a tool for watershed management, techniques need to be refined to maintain consistency and efficiency in various watersheds, as well as an understanding the most efficient sampling and model designs.

The objectives of this study are to firstly, identify and distinguish inflowing and outflowing suspended sediment within the LLBR micro-watershed using a combination of colour tracers and Cs-137, and secondly to assess the origin of the upstream inflowing sediment into the sub-catchment of the LLBR with the addition of upstream watershed sediment sources.

Sediment and soil samples were collected within the Lower Little Bow River micro-watershed, including any potential sediment source material such as agricultural and pasture land, stream banks, coulee walls and inflowing sediment. Sediment samples were collected at four locations along the micro-watershed reach. Soil samples were collected as sediment source material upstream of the micro-watershed reach in 2016 in order to determine if there were any different sources outside of the micro-watershed reach that could be contributing to the suspended sediment load. Five different mixing model schemes were run in order to determine whether upstream inflowing sediment into the watershed is composed of the same sediment sources as found within the LLBR micro-watershed reach, whether there is a missing source not sampled locally or whether

the inflowing suspended sediment has been transformed through transport and storage time.

The sediment source proportions were determined using samples from the LLBR micro-watershed and additional samples from the large Little Bow watershed. These sources were; Upstream, Agricultural Land, Coulee Walls, Irrigation Return-Flow and Stream Banks, each contributing a mean of 74.3 %, 6.6 %, 6.3 %, 6.3 % and 6.4 %, respectively. The inclusion of inflowing sediment as a source can help to distinguish whether sediment has changed through transport and deposition and whether this can affect how management practices for soil and sediment erosion are applied locally or at the watershed scale. Future research should continue to explore whether this change during transport and residency is due to particle size changes, sediment enrichment or chemical reactions throughout the watershed.

3.1 Introduction

As studies of sediment fingerprinting have grown and techniques have been refined, the viability of using sediment fingerprinting as a tool for landscape management can be assessed. The variability within each landscape affects the potential for the use of sediment fingerprinting as a tool. The more variability within a catchment area increases the complexity, inaccuracy or potential change of sediment sources throughout a catchment (Wallbrink et al., 1998). The processes from when sediment is deposited to when it is collected are not well accounted for in sediment fingerprinting studies and could be especially important when considering the use of environmental tracers. The 'black box approach' as described by Koiter et al. (2013a) measures inputs and outputs solely as they are at the time of collection for sediment fingerprinting and ignores the processes that occur during transport and deposition. This creates concern regarding uncertainties and errors within mixing models and therefore, the application of sediment fingerprinting as a management tool. Sources are identified by the potential for material to enter the depositional area, and are sampled based on this knowledge. The sampled sources are then related to the collected suspended sediment, assuming there is no change in the composition of the source through transport and deposition (Koiter et al., 2013a). This poses an issue among the tracers being chosen to identify and tag sources, as well as how large and diverse the catchment is that is being sampled. The more opportunities for sediment to be stored for long periods of time before reaching an outlet means there is a chance for sediment change during transport (Fryirs et al., 2006). Large catchments can take longer for a source to reach an outlet, as well as stoppages within catchments like reservoirs, dams and bridges can cause longer transport and storage time (Fryirs et al., 2006). This comes into consideration for choosing efficient and reliable environmental tracers in sediment fingerprinting studies that will not be affected by transport and deposition. This also should be taken into account when setting up a sampling strategy and in the analysis of a watershed. In every catchment and watershed, there is a starting point of a study area where there is inflowing water and sediment and an end point of a study area where there is outflowing water and sediment. In order to sample properly and to assess the sediment fate and transport within each watershed, understanding how to set boundaries and interpret inflowing sediment is pertinent to properly fingerprinting outflowing sediment. Philips et al. (2014) describes the steps to take when using mixing models in order to appropriately assess a study, and one of the main factors is that a mixing model will be useful and accurate based on the data acquired and how it is acquired. In other words, if good research is conducted, then a model should represent good results, but if bad data is used then the model results will be inaccurate. As George E. P. Box wrote, "All models are wrong, but some are useful.", taking this into account during the exploration of using sediment fingerprinting models as tools for landscape management is important and mandatory to consider when moving forward with current and future sediment fingerprinting studies. Appropriate sampling design, previous and informative knowledge as well as concise research questions are all qualities that Philips et al. (2014) describes as necessary to appropriately use mixing models. With this in mind, mixing models can be used as an assessment for sample design and questions about gaps in research areas.

Boudreault et al. (2016) used the mixing model, MixSIAR, to assess boundaries and sampling requirements for sediment fingerprinting studies looking at sampling watershed areas as one reach, or sectioning a watershed into smaller sub-reaches. Boudreault et al. (2016) demonstrated that a change in proportions of sources can be seen when a stepwise approach is used to fingerprint sediment sources in the Black Brook watershed, rather than a single watershed reach approach. Two studies conducted in the South Tobacco Creek watershed by Koiter et al. (2013b) and Barthod et al. (2015) both used an approach to break up a watershed into smaller reaches for sediment fingerprinting. By sectioning the study area into smaller reaches, the ability to assess local sediment source contribution becomes more accurate; both Koiter et al. (2013b) and Barthod et al. (2015) demonstrated a change in suspended sediment sources throughout the South Tobacco Creek by using this strategy. Liu et al. (2017) continued the use of this "reach" approach, by assessing a micro-watershed reach in southern Alberta, a part of the Lower Little Bow River. Liu et al. (2017) used MixSIAR to assess the composition of the outflowing suspended sediment in a 6 km reach of the Lower Little Bow River watershed. Liu et al. (2017) used colour tracers to demonstrate the ability to assign proportions of suspended sediments to sources within a local watershed reach by including inflowing sediment as a source. This inflowing sediment source contributed majority of the suspended sediment load, as was the case for two of three schemes in Chapter 2. For watershed reaches, if the inflowing sediment is composed of similar sources as sampled locally within a reach, this means that the composition of sediment is not changing throughout the watershed. If inflowing sediment within a reach is composed of sources not found within the local reach area, this means that the composition of sediment may be changing throughout the watershed. By comparing whether inflowing sediment is similar to outflowing sediment, it can be assessed whether the Upstream source within the LLBR micro-watershed is composed of similar sources found locally or not. This is important to determine when including inflowing suspended sediment as a source within a reach. The reason this becomes important is that the inflowing sediment will be a proportion of the outflowing sediment in a reach, so if it is not similar to the outflowing sediment then the local sources used in the mixing model may not be appropriately assigning proportions for solely the outflowing sediment from just within that reach only. Figure 3.1 demonstrates the general mixing model for sediment fingerprinting; if source A is white and source B is red, then the mixture will be a combination of the two and make a pink colour, C. There is an issue that lies with this theory and understanding when it comes to a watershed like LLBR. If a sediment mixture (i.e. a mixture similar to C) is included in the model as a source, how will it be interpreted as contributing some proportion to the pink mixture, C itself? Understanding how sediment mixtures behave within sediment fingerprinting models is crucial for the appropriate interpretation of sediment source proportions.

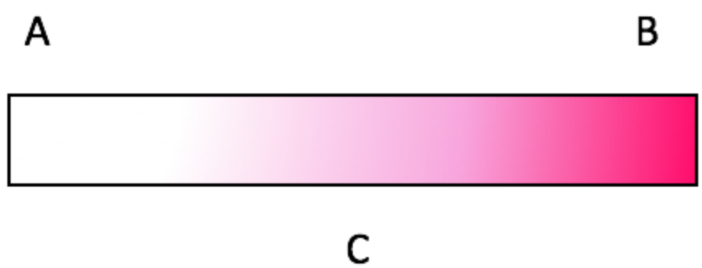

Figure 3.1 The general mixing pattern for sediment fingerprinting mixing models including; C = Sediment Mixture, B = Sediment Source and A = Sediment Source.

The use of colour properties as tracers has become an efficient and unique technique for identifying sediment and soil (Brosinsky et al., 2014). The use of colour identification in soil science has been associated with distinguishing between different mineralogical properties of soil and sediment, both chemical and physical (Brosinsky et al., 2014). These properties include iron oxides, clay minerals and organics. During sediment transport and deposition there is potential for sediment sources to become altered from the time they enter the watershed to the point where they exit or are collected as the outflowing suspended sediment due to processes such as chemical reactions. An iron rich topsoil may have a black colour when sampled in a field due to high organic matter content; when this topsoil is deposited in-stream and transported there is potential for redox reactions to occur which may cause the sediment to become a more purple-grey colour and once dried exhibit a red colour. Surridge et al. (2007) describes a relationship between sediment bound phosphorus and iron within inundated sediment; there is potential due to the quality of water that sediment has entered, to have phosphorus release occur from sediment due to redox reactions in the top layer of sediment. This process described by Surridge et al. (2007) focuses on the relationship and potential of phosphorus release, but it demonstrates the potential for redox reactions to occur with sediment in water, that varies with depth of sediment. Due to the 'black box theory' stated by Koiter et al. (2013a), an issue of tracer conservativeness becomes an underlying variable within sediment fingerprinting studies. Any unknown that is introduced into a mixing model, such as MixSIAR, can add variation that will undermine results. The mixing model, MixSIAR, will always assign a proportion for a sediment source included in the mixing model, but will not assign any proportions as just unknown. This means that the larger the amount of variation associated with a source proportion can show that there is less direct matching of the proportion to the actual mixture or in the case of sediment fingerprinting, the suspended sediment. Due to the processes of deposition and transport that occur in between the point of entry and the point of collection of a catchment area if there is any chance for source material to change during transport, there is currently no way to pinpoint or determine when or whether the source has changed. One way to demonstrate this is by sampling upstream of the LLBR micro-watershed to assess the origin of the inflowing suspended sediment. As Chapter 2 demonstrated, the Upstream source is identified as either a unique mixture, due to missing sources upstream of the reach that are different than locally sampled sediment sources or that the sediment itself has been transformed through transportation and residence time. By sampling a larger watershed area of potential sources that are not found locally will provide an assessment on whether the Upstream source is identified as unique due to a missing source or perhaps due to transport and storage time of the sediment.

The objectives of this study were: 1) to discriminate inflowing and outflowing suspended sediment within the LLBR micro-watershed using a combination of colour tracers and Cs-137; and 2) to assess the origin of the upstream inflowing sediment into the sub-catchment of the LLBR with the addition of upstream sources.

3.2 Materials and Methods

3.2.1 Study Area

This study took place in the Lower Little Bow River (LLBR) watershed located in southeastern Alberta, Canada, expanding upon sediment fingerprinting studies done in the Agriculture and Agri-Food Canada (AAFC) Watershed Evaluation of Beneficial Management Practices (WEB's) micro-watershed reach of the LLBR. The Little Bow River consists of two main river sections. The first is referred to as the Upper Little Bow, extending from the town of High River and flowing into the Travers Reservoir (Alberta Lakes, 2017). The second section is the Lower Little Bow, which was the focus of Liu et al. (2017) and Chapter 2 studies; this section begins at the mouth of Travers Reservoir and flows into the Oldman River (refer to Chapter 2, Section 2.2.1). The LLBR is a tributary to the Oldman River, the LLBR joins the Oldman River northeast of Lethbridge, Alberta. Previous studies were conducted in a micro-watershed area of 2,565 ha located at 50°00'00"N, 112°37'30"W. This study will include the micro-watershed area as well as the larger 55,664 ha area of LLBR watershed (Figure 3.2 and Figure 3.4) and upstream of the Travers Reservoir and Lake McGregor (Figure 3.3). The Upper Little Bow River contributes 10 % of the capacity of the Travers Reservoir, while the remaining 90 % inflows from McGregor Lake just north of Travers Reservoir (Alberta Lakes, 2017). Throughout this larger watershed, the landscape does not differ from the micro-watershed described in Chapter 2, Section 2.2.1. The Travers Reservoir and McGregor Lake both have hummocky terrain to the west, and with flat plains on the eastern side, with the most dominant soil type being Orthic Dark Brown Chernozemic (Alberta Lakes, 2016; Greenlee 1974; Wyatt and Newton, 1925). Coulee wall formations are still a dominant landscape feature alongside water bodies, similar to the LLBR micro-watershed. Only about 3 % of the outflow from Travers Reservoir flows into the LLBR, with 97 % being diverted to the Little Bow (Alberta Lakes, 2017).

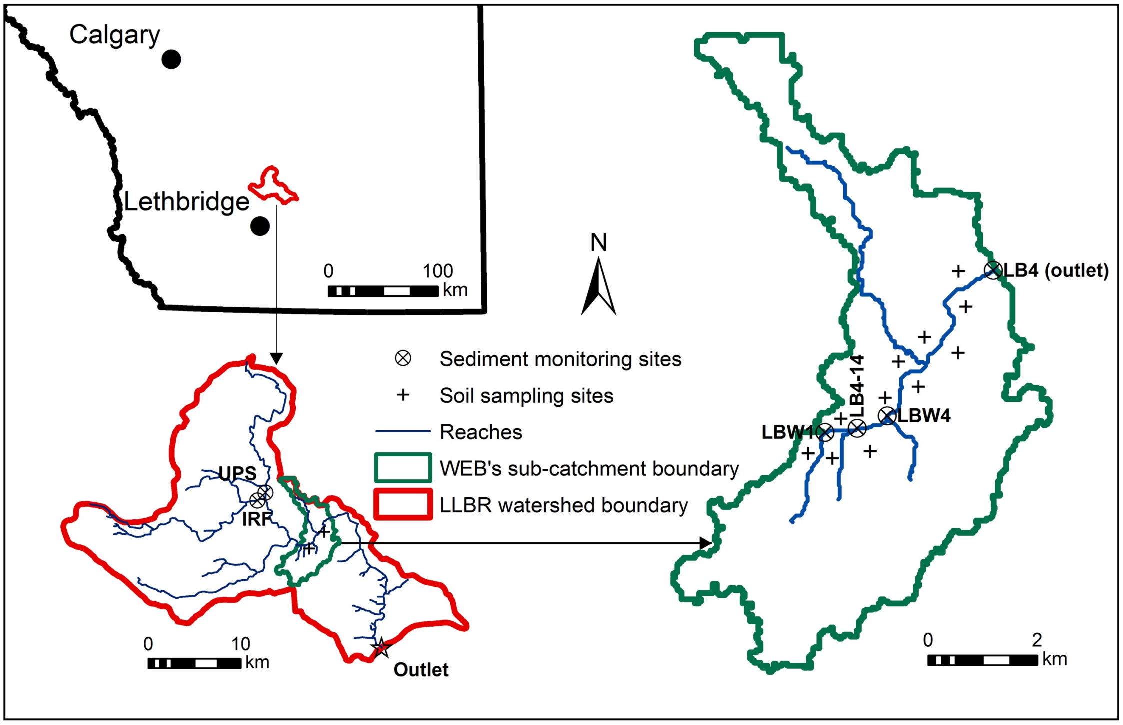

Figure 3.2 LLBR study area represented by the larger 55,664 ha watershed and the WEB's 2,565 ha micro-watershed including sites of sediment collection; LBW1, LB4-14, LBW4 and LB4 as well as the upstream inflowing sediment (UPS) and irrigation return-flow sediment (IRF) collection points (Liu et al., 2017).

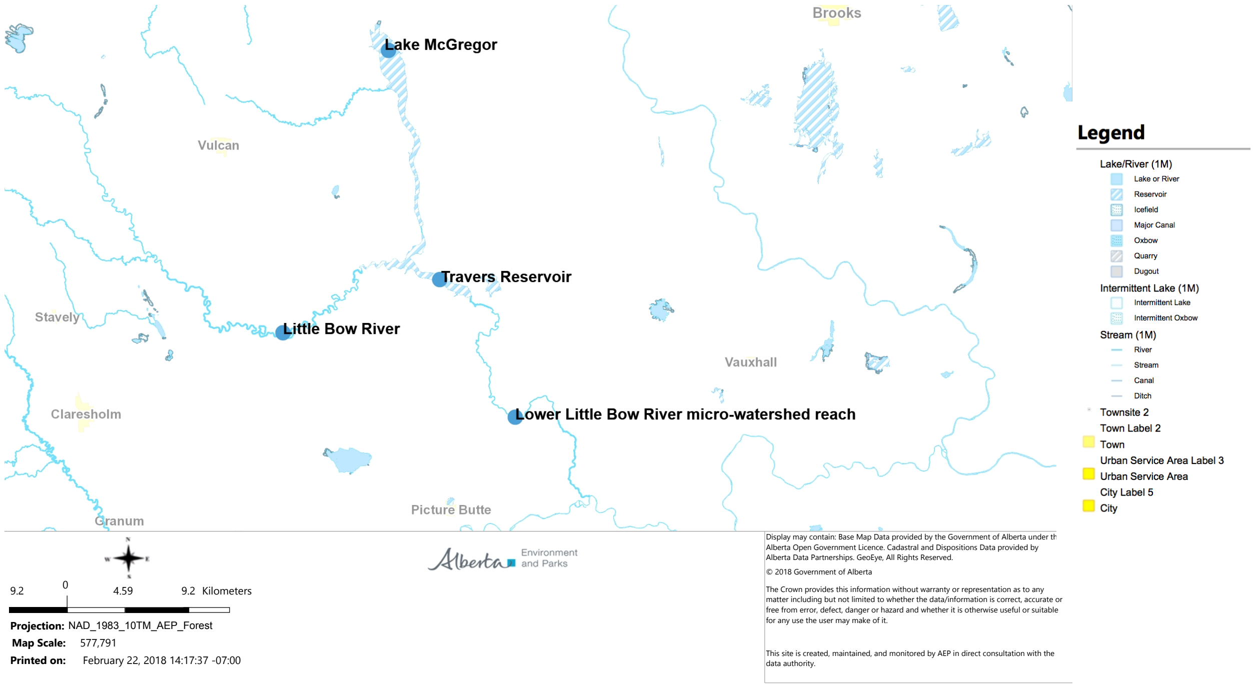

Figure 3.3 Upstream water bodies of the LLBR micro-watershed reach including; Travers Reservoir, Lake McGregor and the upper and middle Little Bow River.

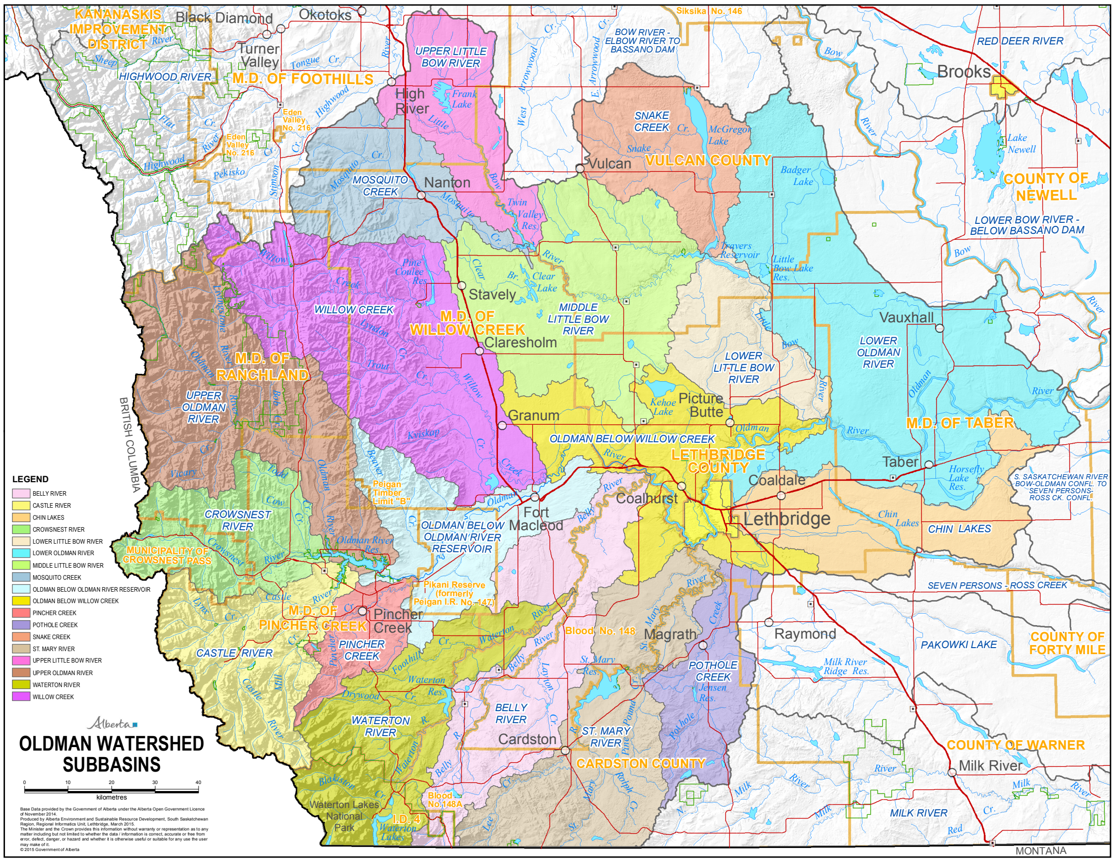

Figure 3.4 Map of the Oldman Watershed Subbasins in southern Alberta produced by Alberta Environment and Sustainable Resource Development, South Saskatchewan Region, Regional Informatics Unit, Lethbridge, March 2015.

3.2.2 Selection of sampling sites and method of sediment and soil collection

Samples from the previous study, Chapter 2, Section 2.2.2, were used along with the addition of samples outside of the AAFC WEB's micro-watershed reach. Sampling was done in transect form as well as point samples throughout the larger LLBR watershed, the Upper and Middle Little Bow River watershed as well as surrounding the Travers Reservoir and McGregor Lake (Figure 3.3). Decisions on where to sample were made using the Alberta Soil Viewer (2016) to determine different soil types and boundaries throughout the larger watersheds from the 2,565 ha micro-watershed reach. Specifically, soil types were targeted that were different from the micro-watershed soils of Chapter 2, in order to capture any potential new source. Coulee walls, streambanks and agricultural and pasture land were all sampled with a JMC Back-saver probe. The JMC Back-saver probe was used with a one inch in diameter sampling tube. In total, an additional 50 samples from soil depths of 0-15 cm were collected throughout May and October of 2016, including; 7 agricultural land, 39 pasture land, 1 stream bank and 3 coulee wall samples.

Sampling outside of the LLBR micro-watershed reach was done in 2016 and was based on a few factors. These included the decision making of where to sample for representative material upstream and outside of the LLBR micro-watershed reach. The first goal, was to capture any source that was significantly different or stood out as unique compared to the source materials found in the LLBR micro-watershed reach. From analyzing soil maps with Alberta Soil Viewer (2016) and ground truthing, there were no unique outstanding sources that could be found. A few similar sources were sampled in order to test whether they did change from the LLBR micro-watershed to further upstream, including coulee walls, agricultural fields and pasture land. Multiple samples were taken near the irrigation return-flow channel pasture in order to see if this source was being affected by different compositions of soil, but it was found that majority of the soil in this area was similar to agricultural land that was surrounding it.

3.2.3 Analytical techniques

3.2.4.1 Gamma spectrometry. Source samples collected in 2016 were analyzed for Cs-137 following the same procedure described in Chapter 2, Section 2.2.3.1. Samples were air dried and sieved down to 2 mm. The 2 mm sieved samples were analyzed for Cs-137 activity by a germanium gamma spectrometer in the Environmental Radioactivity Laboratory in the Department of Soil Science at the University of Manitoba.

3.2.4.2 Diffuse reflectance spectrometry. The source samples collected in 2016 were analyzed by diffuse reflectance spectrometry for colour, following the same procedure as in Chapter 2, Section 2.2.3.2. After the sample analysis for Cs-137 was completed, the 2-mm sample was sieved down to 63 μm for colour analysis. Diffuse reflectance spectrometry of the 2016 samples was conducted in the Center for Earth Observation Science at the University of Manitoba.

3.2.4 Data Analysis

3.2.4.1 Canonical Discriminant Analysis: Grouping upstream and downstream sources. A Canonical Discriminant Analysis (CDA) was run for the comparison and combination of the additional 2016 larger watershed samples and the original samples used in the previous study in Chapter 2 and by Liu et al. (2017). Using the open sourced program, R (R Package, 2012), all samples were recorded into comma separated value format for all 15 colour values and Cs-137 values following the same procedure as Chapter 2, Section 2.2.4.1. The additional 2016 samples were labelled as general descriptors to their sample location.

3.2.4.2 Shapiro – Wilk test. The Shapiro-Wilk test was conducted using SAS software, using the PROC UNIVARIATE procedure (SAS institute, 2008) as described in Chapter 2, Section 2.2.4.2. Normality was tested using the Shapiro Wilk result, W, if $W > 0.9$ then distribution is normal, if $W < 0.9$ then the data does not follow normal distribution. The Shapiro-Wilk test was conducted for the regrouped sources determined by the CDA in section 3.4.1.

3.2.4.3 Biplot analysis. Biplot analysis was conducted following the same procedure as in Chapter 2, Section 2.2.4.3. This was conducted for the tracers that passed the Shapiro-Wilk test in section 3.2.5.2. The tracer means and standard deviations were plotted against the values for the suspended sediment mixtures, in this case from the four monitoring stations of sediment collection; LBW1, LB4, LB4-14 and LBW4. Tracers that were found to be non-conservative were removed from further analysis.

3.2.4.4 Kruskal – Wallis test. The Kruskal-Wallis test was conducted following Chapter 2, Section 2.2.4.4 procedure with the p-value set to < 0.01. If a tracer was significant and passed the Kruskal-Wallis test, it was then carried on to the stepwise discriminant function analysis.

3.2.4.5 Stepwise discriminant function analysis. Of the tracers that passed the Kruskal-Wallis test and can significantly distinguish between source groups, these colour properties are used in a stepwise discriminant function analysis to determine the best combination of the colour properties to provide the best discrimination between sediment source groups. The stepwise discriminant function analysis was conducted using the same procedure as Chapter 2, Section 2.2.4.5. The tracers that provided the best combination to reduce Wilks' lambda were used for source apportionment in MixSIAR.

3.2.5 MixSIAR model schemes

The mixing model program, MixSIAR, was used as a tool to determine source proportions of suspended sediment in exploration of the Upstream source as well as in the larger watershed of the LLBR. The mixing model, MixSIAR, was used to run five different schemes to view how the upstream suspended sediment can be interpreted within the LLBR micro-watershed reach, and to gain further understanding of the need for upstream sampling. For Schemes 1, 2, 3 and 4, tracers G, L, X, Y and Cs-137 were used the same as in Chapter 2, determined by Liu et al. (2017). For Scheme 5, the procedure of choosing statistically significant tracers was done due to the addition of new sample data from the 2016 samples and regrouped source groups. MixSIAR was run using the following procedure from Chapter 2, Section 2.2.4.6, set for the run length of 'Long' for the five different model variations.

3.2.5.1 Scheme 1. The first MixSIAR model scheme was structured with five source groups including; Agricultural Land, Coulee Wall, Stream Bank, Irrigation Return-Flow and Upstream (Figure 3.5). This MixSIAR model scheme was run using the suspended sediment collected at the four monitoring stations; LBW1, LB4, LB4-14 and LBW4 as the sediment mixture.

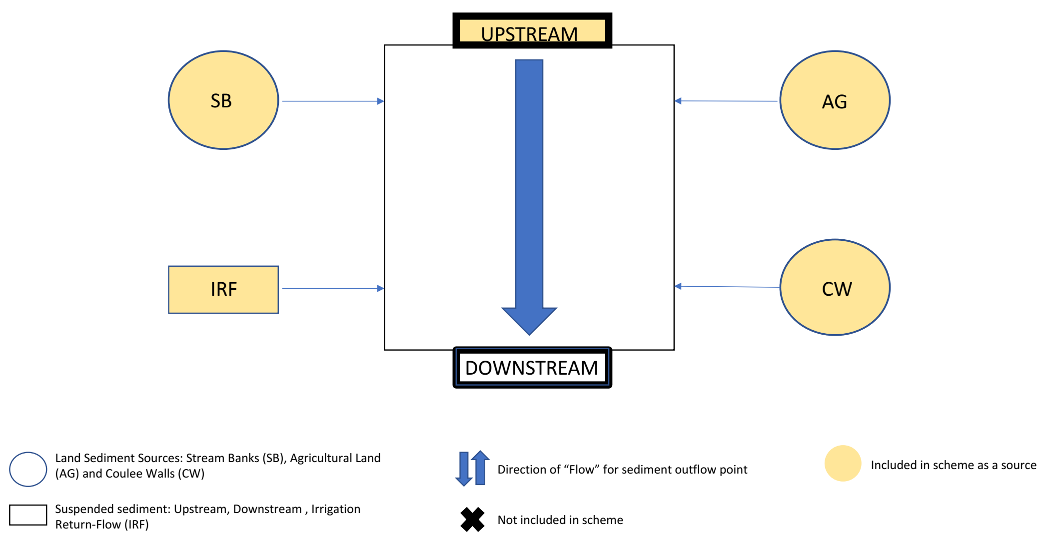

Figure 3.5 Scheme 1 diagram demonstrating the MixSIAR model design and inputs including; sediment mixture, direction of flow for scheme organization and sediment sources.

3.2.5.2 Scheme 2. In this second scheme of the MixSIAR model, the model was run without the upstream inflowing sediment as a source and only with the four source groups

(Figure 3.6). The source groups included; Agricultural Land, Coulee Wall, Stream Bank and Irrigation Return-Flow. The designated sediment mixture for Scheme 2 is the suspended sediment collected at the four different monitoring stations along the LLBR micro-watershed reach, including; LBW1, LB4, LB4-14 and LBW4 (Figure 3.2).

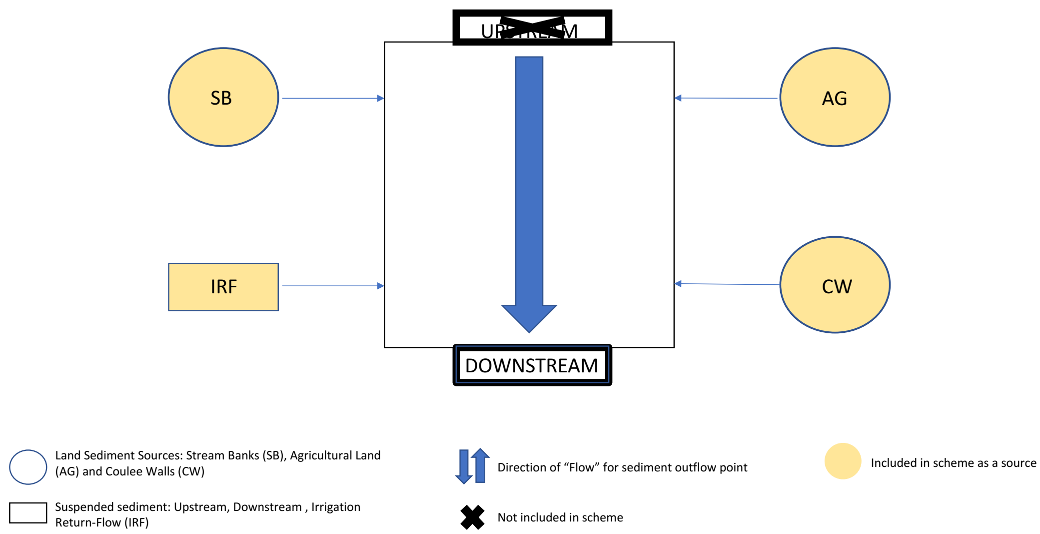

Figure 3.6 Scheme 2 diagram demonstrating the MixSIAR model design and inputs including; sediment mixture, direction of flow for scheme organization and sediment sources.

3.2.5.3 Scheme 3. The third scheme as shown in Figure 3.7, is structured with the inflowing sediment from the upstream sample point as the suspended sediment mixture that will be unmixed into sediment source proportions. The remaining sources are included as in Scheme 2; Agricultural Land, Coulee Walls, Stream Banks and the Irrigation Return-Flow. The downstream, outflowing suspended sediment composed from the four monitoring stations, LBW1, LB4, LB4-14 and LBW4, is completely removed from the MixSIAR model (Figure 3.2).

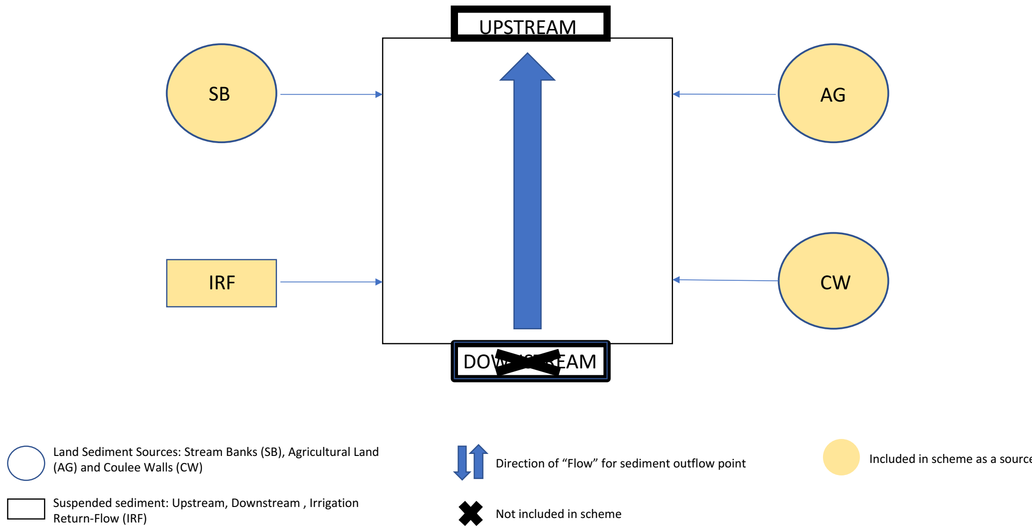

Figure 3.7 Scheme 3 diagram demonstrating the MixSIAR model design and inputs including; sediment mixture, direction of flow for scheme organization and sediment sources.

3.2.5.4 Scheme 4. The fourth scheme is structured as shown in Figure 3.8. The suspended sediment mixture that will be unmixed into source proportions is the combination of suspended sediment collected from the four monitoring stations, LBW1, LB4, LB4-14 and LBW4 (Figure 3.2). This scheme uses the additional samples from 2016 plus the LLBR micro-watershed reach samples. The micro-watershed reach samples are found to be no different than any material upstream and outside of the reach and therefore with the 2016 collected samples, they will be able to be used in combination for determining the Upstream source composition. With the addition of source samples to the inventory used in the previous study in Chapter 2 and Liu et al. (2017), the fourth scheme was run with the regrouped source groups (Figure 3.8). The sediment sources included in Scheme 5 are Agricultural Land, Coulee Walls, Upstream, Stream Banks and Irrigation Return-Flow.

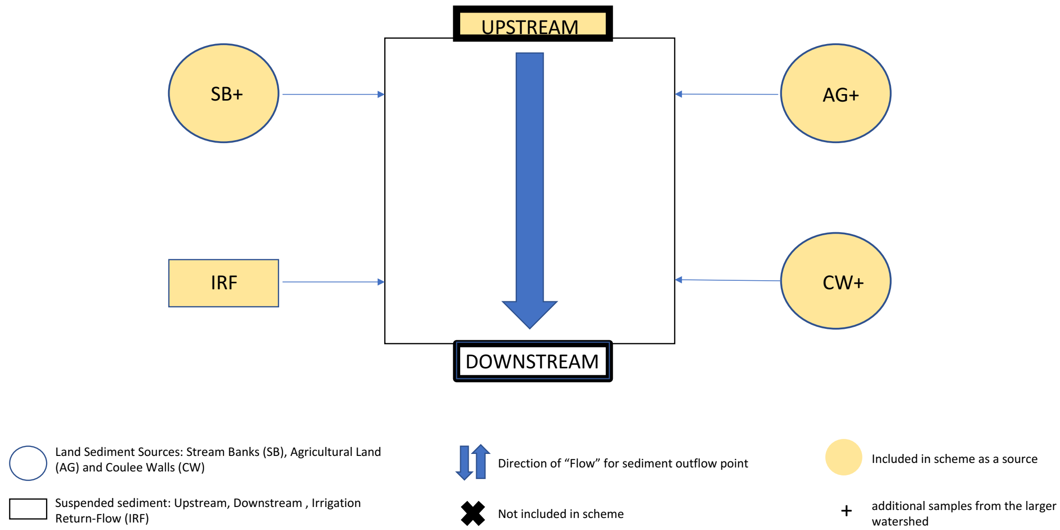

Figure 3.8 Scheme 4 diagram demonstrating the MixSIAR model design and inputs including; sediment mixture, direction of flow for scheme organization and sediment sources.

3.2.5.5 Scheme 5. The fifth scheme is structured as shown in Figure 3.9. Scheme 5 includes inflowing suspended sediment as the mixture in the MixSIAR model, similar to section 3.2.5.4. The remaining sediment sources include Agricultural Land, Stream Banks, Coulee Walls and Irrigation Return-Flow (Figure 3.7). The source groups are a combination of sediment sources collected in 2009-2013 and the 2016 samples, similar to Scheme 4.

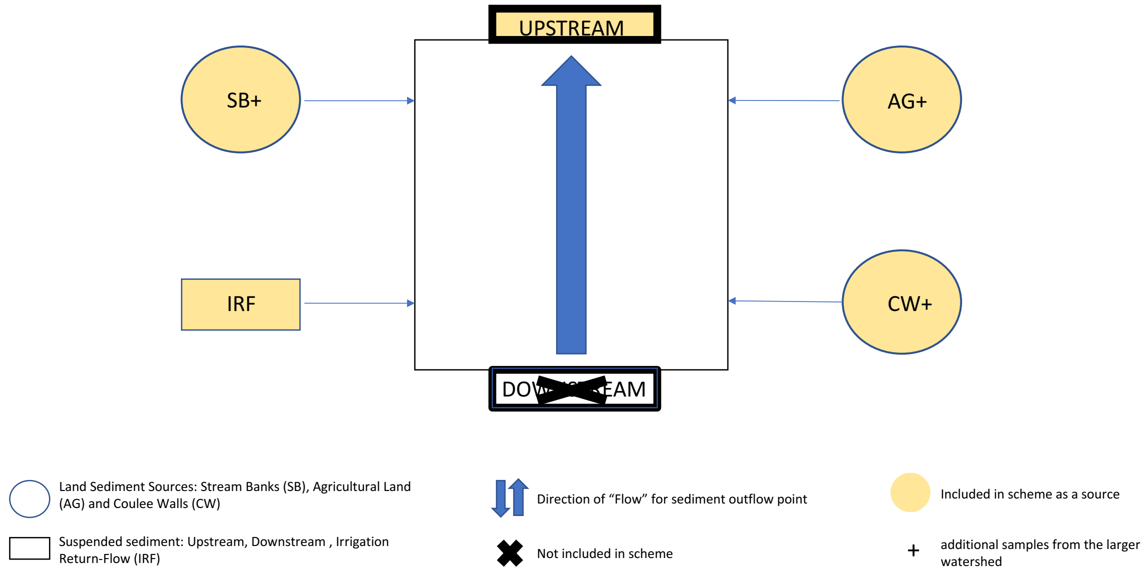

Figure 3.9 Scheme 5 diagram demonstrating the MixSIAR model design and inputs including; sediment mixture, direction of flow for scheme organization and sediment sources.

Table 3.1 Research question, comparison and potential outcome for all five MixSIAR model schemes.

SCHEME	RESEARCH QUESTION	COMPARISON	OUTCOME
1	Scheme based on Liu et al. (2017): what are the sediment source proportions in the LLBR, when upstream inflowing sediment is included as a sediment source?	Base scheme for comparisons to other schemes.	Source proportions within LLBR micro-watershed reach that represent sediment source proportions when upstream inflowing sediment is included as a sediment source within the MixSIAR model scheme.
2	Classic sediment fingerprinting scheme. With no inclusion of upstream inflowing sediment as a source: what are the sediment source proportions locally?	**Scheme 2 vs Scheme 1:** If upstream inflowing sediment is not included in the modelling scheme, how different is it from including the upstream inflowing sediment as a source?	1) If the sediment source proportions are different, this would mean that the upstream suspended sediment either is a sediment mixture that contains sources not found locally, or the mixture itself is identified as a unique independent source different than the local sediment sources, even though it is some combination of sources itself. Or; 2) If the sediment source proportions are similar, then we can conclude that the upstream source is most

			likely composed of a mixture of sources similar to those sampled locally, and the inclusion or exclusion of the source does not change how the MixSIAR model un-mixes the sediment into source proportions.
3	Can the local sediment sources be used as sediment sources to determine the composition of the upstream inflowing sediment?	**Scheme 3 vs Scheme 2:** When the local sediment sources are used to determine the composition of the upstream inflowing sediment, are the sediment source proportions similar to the composition of downstream suspended sediment source proportions?	1) If the sediment source proportions are similar for both the upstream suspended sediment mixture and downstream suspended mixture using only local sources, then both suspended sediment mixtures would be composed of the same mixture of sources. Or; 2) If the sediment source proportions are different, this would mean that the upstream and downstream suspended sediment mixtures are composed of either a combination of different sources or different proportions of local sources.
4	If sediment sources from upstream of the LLBR micro-watershed are included in the model scheme, does this change the sediment source proportions contributed from each source?	**Scheme 4 vs Scheme 1:** Do the source proportions differ from the proportions in Scheme 1? If there is a missing source upstream of the LLBR that was not included in Scheme 1, would the inclusion of this source change the outcome of sediment source proportions and the behaviour of the Upstream source?	1) The upstream sediment sources are the same as the local sediment sources and the model does not change. Or; 2) The upstream sediment sources are different from the local sediment sources and the behaviour of the Upstream sediment source is better explained by the incorporation of a missing source.
5	If sediment sources from upstream of the LLBR micro-watershed are included in the model scheme, does this explain the Upstream sediment composition better than just local sources alone?	**Scheme 5 vs Scheme 3:** Do the source proportions differ from Scheme 3 when local sources and additional upstream sources are used in combination in the mixing model?	1) The sediment source proportions are the same when using just local sources and when using local sources plus additional 2016 upstream samples. Or; 2) The sediment source proportions are different when the upstream samples are added and the proportion of the Upstream sediment is defined by different source groups than when local sediment sources are used alone.

3.4 Results

3.4.1 Canonical Discriminant Analysis: Grouping upstream and downstream sources

The addition of the original source samples from Chapter 2 and Liu et al. (2017) with the 2016 collected samples was tested in order to determine if there was a need for new source groupings. The first CDA was completed without renaming any source groups to test the hetero- and homogeneity of all source groups (Figure 3.10). With this CDA, 78.5 % of the variation between sources can be explained by the first and second discriminant function. By regrouping sources that were overlapping and similar into five source groups, the first and second discriminant function could explain 89.2 % of the variation between the source groupings (Figure 3.11). The regrouping and joining of the newly collected upstream sources with the original micro-watershed sources proved to create better distinction between the groups of sources. The five new source groupings were Agricultural Land, Upstream, Coulee Walls, Stream Banks and Irrigation Return-Flow.

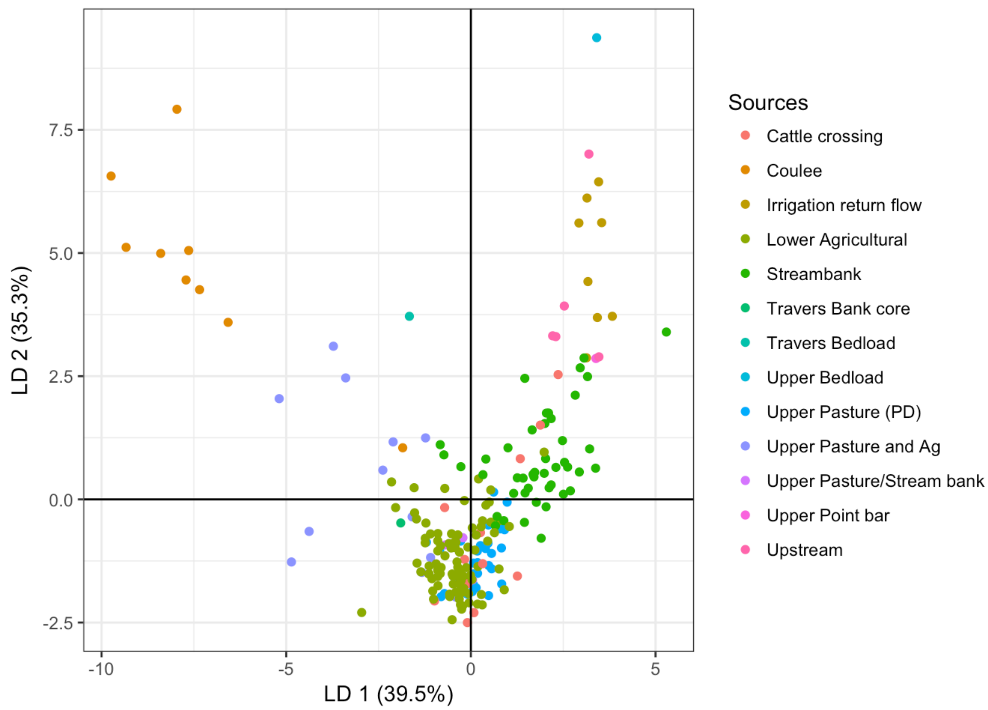

Figure 3.10 CDA of original sources and newly collected 2016 source samples, first and second discriminant functions.

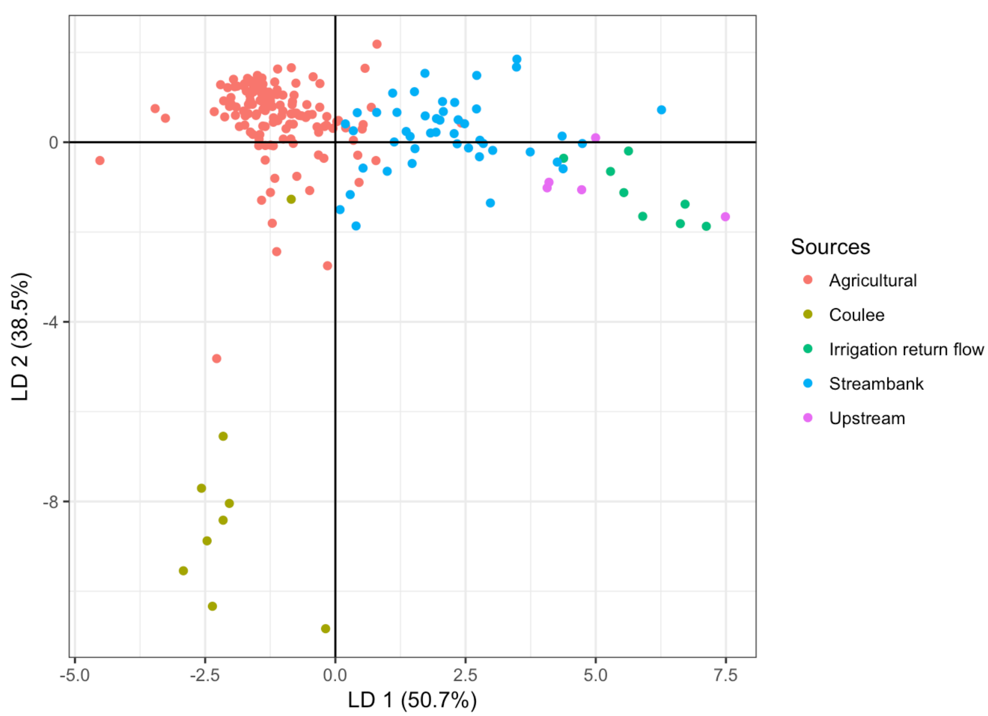

Figure 3.11 CDA of regrouped sources from original source groupings and 2016 samples, first and second discriminant functions.

3.4.2 Shapiro – Wilk test

All 15 colour tracers R, G, B, X, Y, Z, x, y, L, u, v, a, b, h passed the Shapiro Wilk test with $W > 0.9$. Cs-137 did not pass this test and was logarithmically transformed using Log_{10}, which then passed with a normal distribution, $W > 0.9$.

3.4.3 Biplot analysis

Each tracer mean and standard deviation was calculated and input to the biplot analysis, in total 16 tracers were used including; R, G, B, X, Y, Z, x, y, L, u, v, a, b, h, and Cs-137. The most conservative of all tracers from visual analysis of the biplot or ispospace plots produced in MixSIAR were G, L, Cs-137, X and Y (Figure 3.12). Certain tracers were removed based on previous knowledge of potential to change during transport and residence due to redox reactions, including R, a and u which all relate to the redness, or red-green scales (chromaticity) (CIE, 1932). The largest amount of uncertainty in source groups was in the Agricultural Land source group, as well as the Coulee Wall source group, having the largest error bars of all five sources.

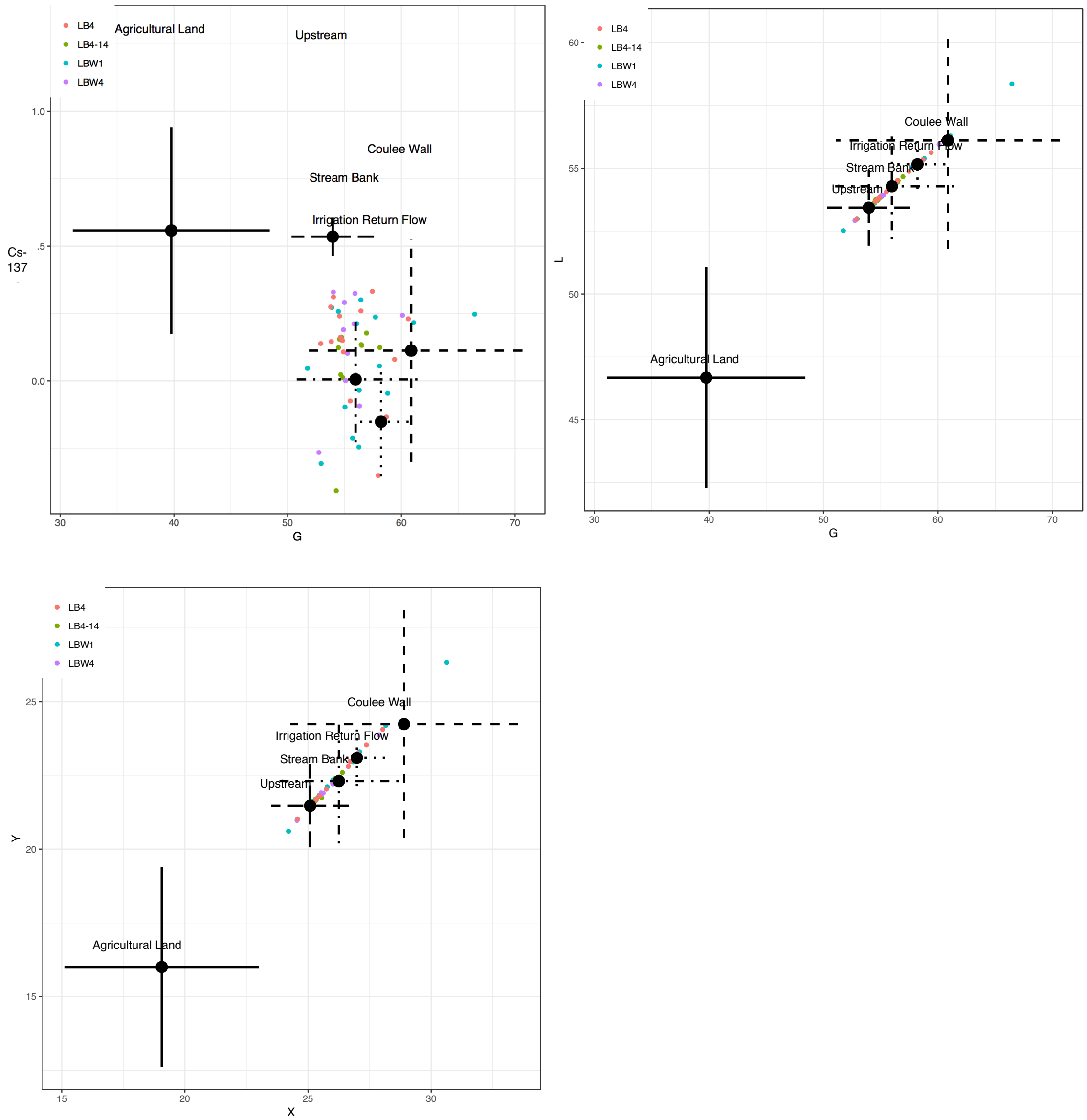

Figure 3.12 Isospace plots for tracers X, Y, L, G and Cs-137, demonstrating amount of uncertainty in suspended sediment sources: 1) Agricultural Land, 2) Upstream, 3) Stream Bank, 4) Irrigation Return-Flow, and 5) Coulee Wall.

3.4.4 Kruskal – Wallis test

Of the colour tracers chosen from the biplot analysis, G, L, X, Y and Cs-137, all five had p-values < 0.01, for the 99% confidence interval, demonstrating that each tracer had the ability to distinguish between sources groups (Table 3.2).

3.4.5 Stepwise discriminant function analysis

From the tracers that passed the Kruskal-Wallis test, a stepwise discriminant function analysis was conducted in order to determine which tracers would provide correct classification of sources on their own (Table 3.2) and when in combination (Table 3.3). Both the Upstream source and Irrigation Return-Flow sources were not correctly classified by any fingerprint property on its own as shown in Table 3.2. The best combination of fingerprints was found to correctly classify 85.71% of the total source groups, with tracers G, Cs-137, X, Y and L (Table 3.3).

Table 3.2 Kruskal-Wallis test results and percentage of sources correctly classified by the tracers, G, Cs-137, X, Y and L.

		Percentage of sources correctly classified					
Fingerprint Property	**Kruskal-Wallis**	**Total (%)**	**Agricultural Land (%)**	**Irrigation Return-Flow (%)**	**Upstream (%)**	**Coulee Wall (%)**	**Stream Bank (%)**
G	<0.01	75.36	88.41	0	0	11.11	78.26
Cs-137	<0.01	69.67	79.71	0	0	0	80.43
X	<0.01	75.36	87	0	0	22.22	80.43
Y	<0.01	74.88	87	0	0	11.11	80.43
L	<0.01	74.41	84.78	0	0	11.11	84.78

Table 3.3 Stepwise discriminant function analysis results demonstrating optimal combinations of tracers G, Cs-137, X, Y and L for the largest percentage of correctly classified sediment sources.

		Percentage of sources correctly classified					
Fingerprint Property	**Composite Fingerprint**	**Total (%)**	**Agricultural Land (%)**	**Irrigation Return-Flow (%)**	**Upstream (%)**	**Coulee Wall (%)**	**Stream Bank (%)**
G	**G**	75.36	88.41	0	0	11.11	78.26
Cs-137	**G+Cs-137**	78.2	86.23	0	100	0	78.26
X	**G+Cs-137+X**	83.89	84.06	75	100	55.56	87
Y	**G+Cs-137+X+Y**	85.71	83.94	62.5	100	55.56	97.82
L	**G+Cs-137+X+Y+**	85.71	83.94	62.5	100	55.56	97.82

3.4.6 MixSIAR model schemes

3.4.6.1 Scheme 1. In this scheme, the Upstream source contributes the largest proportion to the downstream suspended sediment compared to Agricultural Land, Stream Banks, Coulee Walls and the Irrigation Return-Flow channel (Figure 3.13). The Upstream suspended sediment contributed a mean of 57.2 % of the downstream suspended sediment mixture (Table 3.4). The remaining sources contributed means of 14.2 %, 10.8 %, 10.5 % and 7.3 % for Agricultural Land, Coulee Walls, Stream Banks and the Irrigation Return-Flow channel, respectively (Table 3.4).

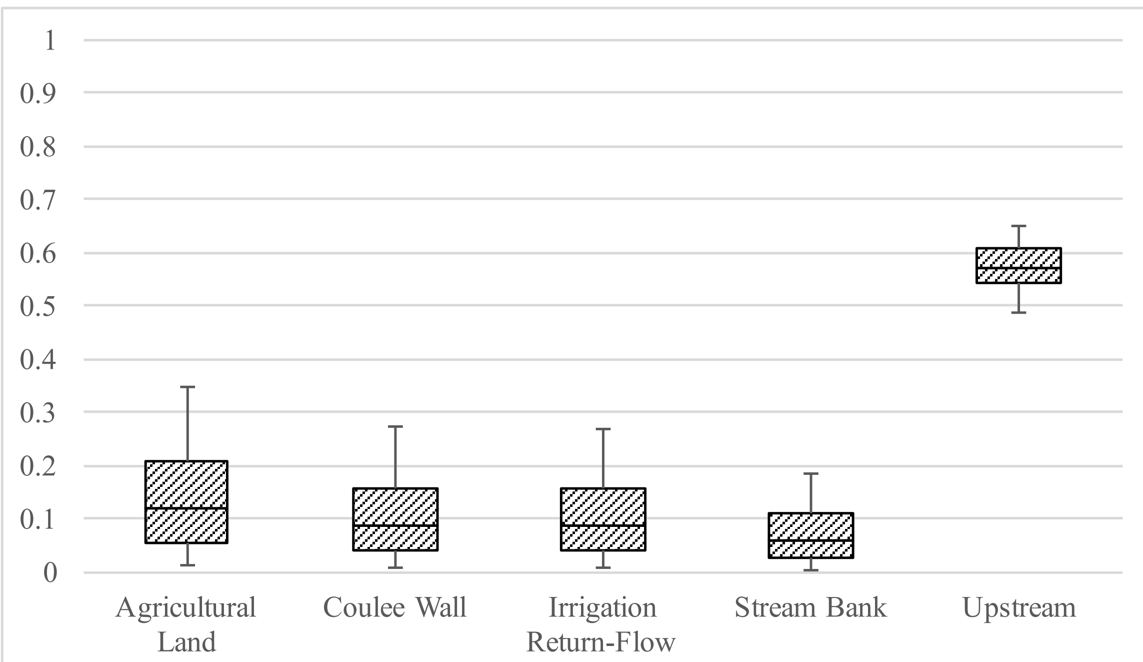

Figure 3.13 95% confidence interval source proportions of suspended sediment in the LLBR for Scheme 1.

3.4.6.2 Scheme 2. For the second scheme, the Upstream source was removed from the mixing model and the downstream suspended sediment was used as the mixture. The largest contributing source was from the Agricultural Land source, contributing a mean of 34.2 % of the downstream suspended sediment (Table 3.4). The remaining sources contributed 22.4 %, 22.1 % and 21.4 % for Irrigation Return-Flow channel, Coulee Walls and Stream Banks, respectively (Table 3.4). There is a larger amount of variation within the remaining sources when the Upstream source is removed from the scheme compared to Chapter 2, section 2.3.2. (Figure 3.14).

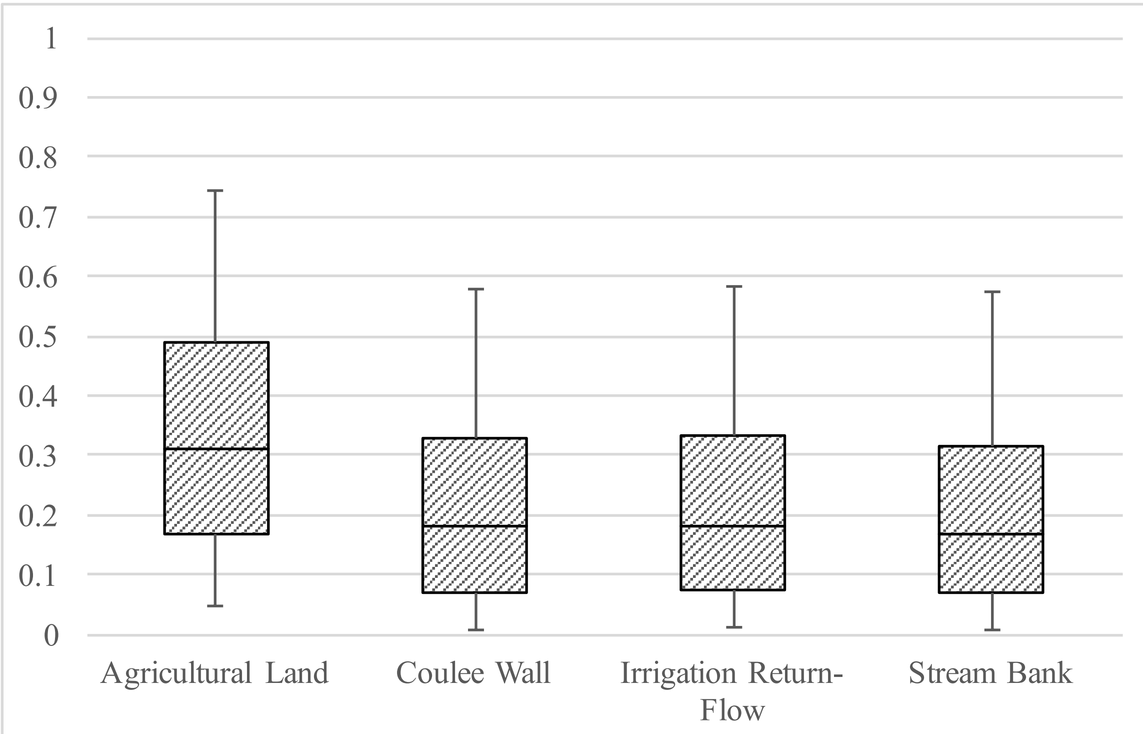

Figure 3.14 95% confidence interval source proportions of suspended sediment in the LLBR for Scheme 2.

3.4.6.3 Scheme 3. In the third scheme, Upstream suspended sediment was used as the mixture and, replaced the downstream suspended sediment which was removed from the model entirely. From this model, the largest contributing source to the suspended sediment was Agricultural Land, with a mean of 28.7 % (Table 3.4). The remaining sources contributed 24.1 %, 23.8 % and 23.4 % for Coulee Walls, Irrigation Return-Flow channel, and Stream Banks, respectively (Table 3.4). When the Upstream source is used as the mixture, it is quite similar to Scheme 2, showing very little difference across the source proportions and large variation within all source groups (Figure 3.15).

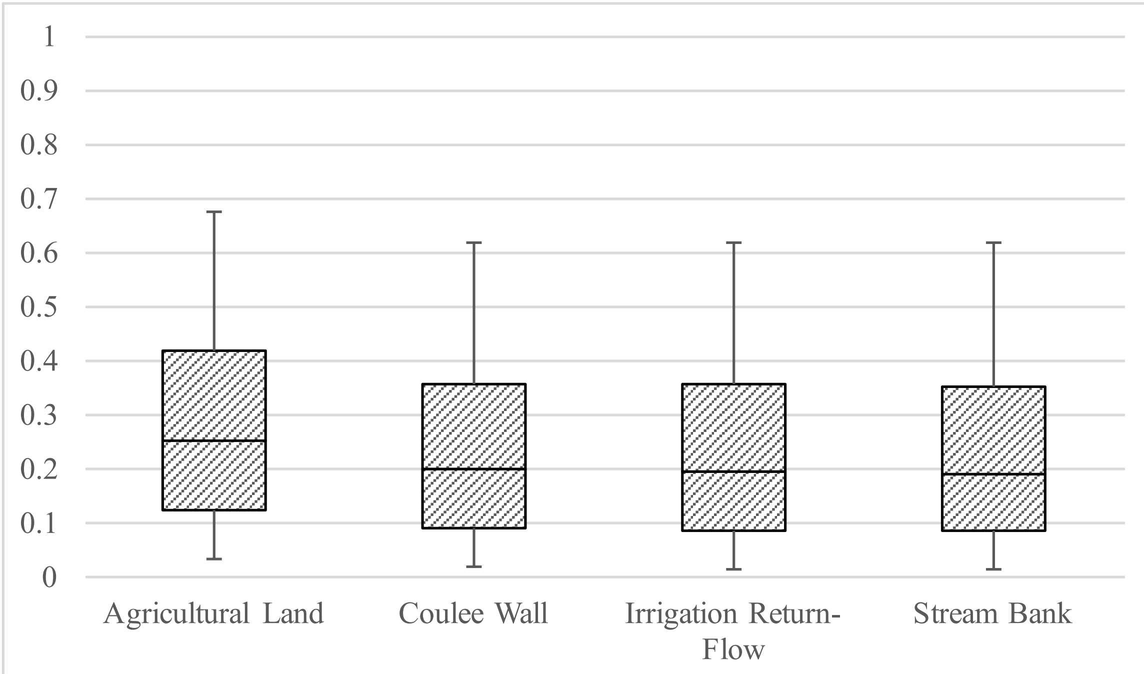

Figure 3.15 95% confidence interval source proportions of suspended sediment in the LLBR for Scheme 3.

3.4.6.4 Scheme 4. With the five new regrouped sediment sources, a mixing model scheme to determine proportions of the outflowing suspended sediment for the larger watershed of the LLBR was conducted. Figure 3.16 demonstrates the source proportions for all five sediment source groups. The largest contributing source to the outflowing suspended sediment is the Upstream inflowing sediment source. Upstream suspended sediment contributed a mean of 74.3 to the outflowing suspended sediment load (Table 3.4). Of the remaining four sources, there is no real distinction of large contributing sources, each source contributes similar proportions (Figure 3.16). The remaining four sources contributed 6.6 %, 6.4 %, 6.3 % and 6.3 % for Agricultural Land, Stream Banks, Irrigation Return-Flow and Coulee Walls, respectively (Table 3.4).

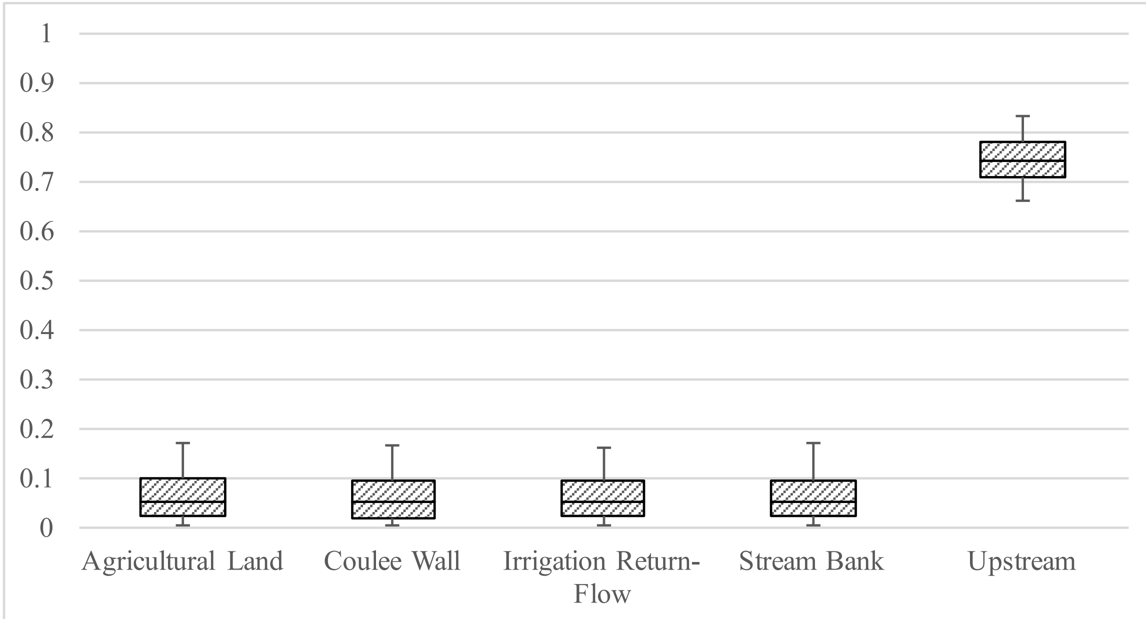

Figure 3.16 95% confidence interval source proportions of suspended sediment in the LLBR for Scheme 4.

3.4.6.5 Scheme 5. In this fifth scheme, Upstream suspended sediment was used again as the mixture similar to Scheme 3, but with the addition of upstream samples. The largest sediment source in this model is Stream Banks with a mean of 25.4 % (Table 3.4). The remaining sediment sources contributed means of 24.9 %, 24.9 % and 24.8 % for Coulee Walls, Irrigation Return-Flow channel and Agricultural Land, respectively. Scheme 5 has a large amount of variability within each sediment source and almost no difference or variability between sources (Figure 3.17). This is similar to the results in Scheme 3.

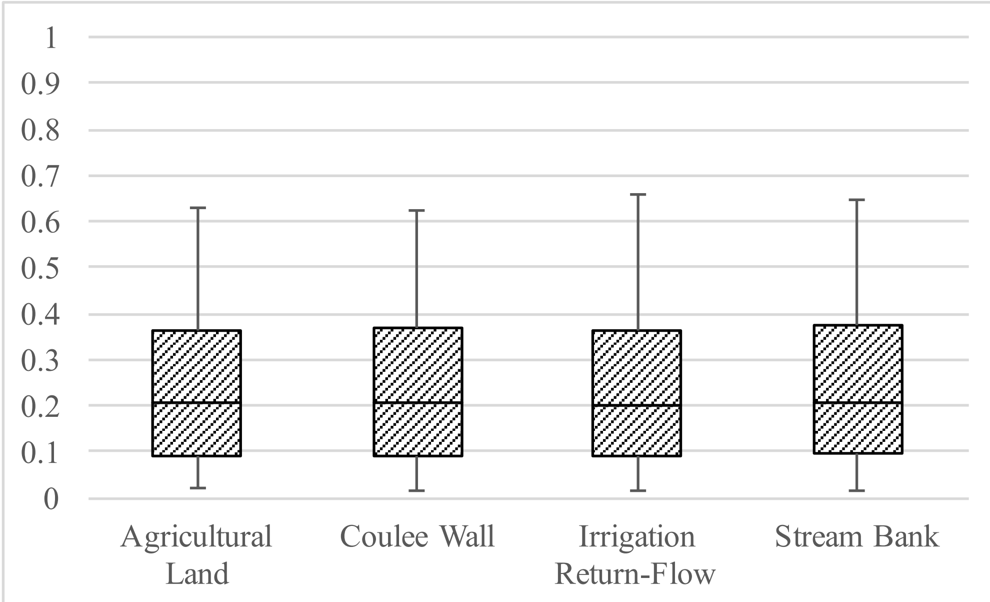

Figure 3.17 95% confidence interval source proportions of suspended sediment in the LLBR for Scheme 5.

Table 3.4 Source proportion means and standard deviations as percentage of suspended sediment in the LLBR for Schemes 1, 2, 3, 4 and 5.

Scheme	Source	Mean	SD
1	Agricultural Land	0.142	0.106
	Coulee Wall	0.108	0.085
	Irrigation Return-Flow	0.105	0.082
	Stream Bank	0.073	0.058
	Upstream	0.572	0.050
	Cumulative[1]	*1.00*	*0.381*
2	Agricultural Land	0.342	0.215
	Coulee Wall	0.221	0.180
	Irrigation Return-Flow	0.224	0.184
	Stream Bank	0.214	0.180
	Cumulative[1]	*1.00*	*0.759*
3	Agricultural Land	0.287	0.200
	Coulee Wall	0.241	0.190
	Irrigation Return-Flow	0.238	0.188
	Stream Bank	0.234	0.188
	Cumulative[1]	*1.00*	*0.766*
4	Agricultural Land	0.066	0.053
	Coulee Wall	0.063	0.053
	Irrigation Return-Flow	0.063	0.051
	Stream Bank	0.064	0.052
	Upstream	0.743	0.053

	Cumulative[1]	*1.00*	*0.262*
5	Agricultural Land	0.248	0.191
	Coulee Wall	0.249	0.192
	Irrigation Return-Flow	0.249	0.197
	Stream Bank	0.254	0.195
	Cumulative[1]	*1.00*	*0.775*

[1]Cumulative mean and standard deviation for all five sediment sources.

3.4 Discussion

Any method that allows fewer sample locations or sample numbers or less time analyzing samples will reduce the time requirements and costs associated with sediment fingerprinting, as well as lead to potentially more rapid transfer of the knowledge gained (Brosinsky et al., 2014). In catchments that are very large, size poses significant challenges in source sampling. By targeting certain areas that are of interest to manage, the area that needs to be sampled can be reduced. In this case, the micro-watershed reach of the LLBR is a good example. When targeting an area like the LLBR reach in this study, determining the local sources to sample small area of only 2,545 ha is relatively easy, but understanding what this selective data means is important. Five MixSIAR model schemes were run in order to explore and understand the composition of the inflowing sediment in the reach of the LLBR micro-watershed reach. Table 3.5 refers to the comparisons between and outcomes of the MixSIAR model schemes. The LLBR micro-watershed Upstream sediment source is not only a source, but is a mixture of sediment sources itself. Within the MixSIAR model, if it is a mixture composed of sources similar or the same as the local sources, it would be expected to look like an average or similar sized source proportion to the sediment sources it is composed of. The Upstream source is represented within MixSIAR as a dominant sediment source as demonstrated in Scheme 1 (Figure 3.13). The question remains whether there is a source upstream of the LLBR reach that is significantly different than locally sampled sources that causes the Upstream source to have a different signature than the local sources, or that the MixSIAR model itself tags sediment mixtures as unique signatures within the model when used as sediment sources. If it was just a mixture of sources similar or the same as local sources, then it would be possible to use the local sources as sources for the upstream inflowing sediment. It would also be possible to remove the upstream inflowing sediment source, as the local sources alone would be sufficient to represent the whole composition of the outflowing suspended sediment since there are no different sources missing from upstream of the LLBR reach. These results are demonstrated in Scheme 2 and Scheme 3 (Table 3.5). Scheme 2 demonstrates the Upstream source being removed, resulting in large amounts of variation. For the confidence range of 95% in Scheme 2, all sources would be contributing anywhere from the lowest of 0.4% to the highest of 74.5% of the outflowing suspended sediment (Figure 3.14). This is a large amount of variation that cannot conclude any real contributing sources. The same results occur in Scheme 3, when the Upstream source is used as the outflowing suspended sediment and the local sources are used as the only sources, there is a large amount of variation within the source proportions. According to this scheme, the local sources would be contributing anywhere from 0.6% to 67.2% of the outflowing suspended sediment (Figure 3.15). Although Figures 3.13 and 3.14 are similar, there can be no conclusion about whether they are the exact same since the variabilities are so large. From these comparisons among the different schemes, it can be noted that the Upstream source needs to be included in the mixing model when determining the composition of the outflowing suspended sediment in the LLBR. These schemes have also shown that the Upstream source or inflowing suspended sediment is an unknown. It may be composed of similar sources as the local sources sampled within the LLBR reach, but the variation in Scheme 2 and Scheme 3 are too large to assume that. Schemes 2 and 4 have demonstrated that the Upstream source is a mixture that is identified as a separate and distinct source in MixSIAR, either from sediment transformation or a from a missing source not sampled within the LLBR micro-watershed reach (Table 3.5).

Table 3.5 Research question, comparison and outcome for all five MixSIAR model schemes.

SCHEME	RESEARCH QUESTION	COMPARISON	OUTCOME
1	Scheme based off of Liu et al. (2017), what are the sediment source proportions in the LLBR, when upstream inflowing sediment is included as a sediment source?	Base scheme for following schemes to compare.	Source proportions within LLBR micro-watershed reach that represent sediment source proportions when upstream inflowing sediment is included as a sediment source within the MixSIAR model scheme.
2	Classic sediment fingerprinting scheme. With no inclusion of upstream inflowing sediment as a source, what are the sediment source proportions locally?	**Scheme 2 vs Scheme 1:** If upstream inflowing sediment is not included in the modelling scheme, how different is it from including the upstream inflowing sediment as a source?	The upstream suspended sediment is either a sediment mixture that contains sources not found locally, or the mixture itself is identified as a unique independent source different than the local sediment sources, even though it is some combination of sources itself.
3	Can the local sediment sources be used as sediment sources to determine the composition of the upstream inflowing sediment?	**Scheme 3 vs Scheme 2:** When the local sediment sources are used to determine the composition of the upstream inflowing sediment, are the sediment source proportions similar to the composition of downstream suspended sediment source proportions?	The sediment source proportions are similar for both the upstream suspended sediment mixture and downstream suspended mixture using only local sources, then both suspended sediment mixtures would be composed of the same mixture of sources.
4	If sediment sources from upstream of the LLBR micro-watershed are included in the model scheme, does this change the sediment source proportions contributed from each source?	**Scheme 4 vs Scheme 1:** Do the source proportions differ from the proportions in Scheme 1? If there is a missing source upstream of the LLBR that was not included in Scheme 1, would the inclusion of this source change the outcome of sediment source proportions and the behaviour of the	The upstream sediment sources are the same as the local sediment sources and the model does not change.

		Upstream source?	
5	If sediment sources from upstream of the LLBR micro-watershed are included in the model scheme, does this explain the Upstream sediment composition better than just local sources alone?	**Scheme 5 vs Scheme 3:** Do the source proportions differ from Scheme 3 when local sources and additional upstream sources are used in combination in the mixing model?	The sediment source proportions are the same when using just local sources and when using local sources plus additional 2016 upstream samples.

The use of colour properties as fingerprinting tracers, provides the ability to quickly advance study results through the quick and efficient analysis process (Brosinsky et al., 2014). Throughout the studies done by Liu et al. (2017), Boudreault (2016), Barthod et al. (2015) and Martinez-Carreras et al. (2010), colour has proven itself to provide relevant results regarding identifying and apportioning sources within multiple watersheds. Barthod et al. (2015) is especially notable in that it was able to conclude similar results with the use of colour tracers to that of Koiter et al. (2013b). Both studies were looking at apportioning suspended sediment sources in the South Tobacco Creek using a stepwise process; both studies identified sources of suspended sediment within smaller sub-watersheds throughout the creek length. This gave the ability to demonstrate a switch in sources throughout the watershed, both demonstrated by colour tracers and Cs-137 in combination with geochemical tracers. These two studies did not include inflowing sediment as a source in the downstream reach, and this becomes an issue when looking at whether local sources sampled are sufficient enough. Through the CDA of the LLBR source samples, it was demonstrated that of all the sources collected upstream of the LLBR micro-watershed reach, there were no significantly new or different sources to be found (Figure 3.10 and Figure 3.11). This is important in the consideration of the large amount of the suspended sediment load contributed by the Upstream source in Scheme 4 (Figure 3.16). The Upstream source is considered a separate source within

MixSIAR and contributes over 74.3% to the suspended sediment load. This distinction as a separate and unique source demonstrated by Schemes 1, 2, 3 and 4, creates two scenarios. The first scenario is that MixSIAR will identify a mixture of sediment sources as a unique source on its own, regardless of its composition. This can be demonstrated by other sediment sources that are mixtures such as the Irrigation Return-Flow channel. The Irrigation Return-Flow source in Scheme 4 is most likely a mixture of some run-off agricultural land sediment, coulee wall material and stream bank erosion (Liu et al., 2017). The difference between the Irrigation Return-Flow source and the Upstream source, is that the Irrigation Return-Flow, although also represented as a separate source on its own, is actually similar in proportions to the sources it is most likely a combination of. The Upstream source represents such a high contribution to the suspended sediment load in this small reach, most likely due to the fact that the sediment has undergone change through transport. Through the change in transport, it has been tagged as a unique source, different from the mixture of Irrigation Return-Flow channel, which will contribute local sources as a mixture, but will have less residence time in its transport of material. The large contribution of sediment by the Upstream sediment source could also be the result of MixSIAR matching the most similar sediment source to the suspended sediment, which may not make the proportion it is contributing realistic. For example, if the Upstream source is exactly the same as the downstream suspended sediment mixture, as shown in Schemes 2 and 3, then the high proportion of sediment contributed by the Upstream sediment source may be due to matching exactly the same sediment mixtures. There is also potential for the Upstream sediment to have changed from storage and transport time through Travers Reservoir and Lake McGregor. The next step, would be to determine whether there is a change in transport due to the sediment itself changing from residency time or processes of enrichment or if the proportion of Upstream sediment can be determined as significant due to being similar sediment mixtures. This could be explored by looking at particle size within the LLBR micro-watershed and the larger watershed area that may explain physically what the sources are when they are being transported and whether the size of the sediment is staying conservatively the same or is changing.

The cumulative variance in Table 3.4 addresses the variability within each scheme and can be a direct assessment of the MixSIAR model. The lowest cumulative variances were in both Scheme 1 and Scheme 4, with cumulative variances of 0.381 and 0.262, respectively. These cumulative variances are much lower than Scheme 2, Scheme 3 and Scheme 5, which had 0.759, 0.766 and 0.775, respectively, demonstrating that Scheme 1 and Scheme 4 are more precise models than Scheme 2, Scheme 3 and Scheme 5. In the study conducted by Barthod et al. (2015) in the South Tobacco Creek watershed, inflowing sediment was not included as a source for downstream reaches. By including the upstream inflowing sediment as sediment sources into each reach in the South Tobacco Creek watershed, such as Scheme 1 and Scheme 4, this may have represented how much sediment from local sources is actually being contributed in each reach, and whether it is a significant amount or not depending on transport time. This study demonstrates that sediment fingerprinting can be useful as a soil erosion and landscape management tool, if the inputs and outputs of the mixing model are well understood and explored. Background information and previous knowledge of a study area will help improve upon this, as well as what type of management measurements are being made based on results. In order to properly fingerprint watersheds for sediment management, a better understanding of what processes are occurring in the “black box” for each variable watershed will be an improvement to the field of study as an applicable management tool.

3.5 Conclusions

The Upstream source within the LLBR micro-watershed reach is distinguished as a unique sediment mixture within MixSIAR. Schemes 1, 2, 3 and 4 demonstrated that although it is a different sediment mixture within MixSIAR, it is not necessarily composed of locally sampled sources or sources similar to these. Upstream of the LLBR micro-watershed, potential source samples were found to be the same or similar to the locally sampled sources; Scheme 4 and Scheme 5 show that this does not change the composition and contribution of the Upstream source within the LLBR micro-watershed reach, demonstrating there is likely no missing sediment source upstream of the LLBR micro-watershed that could not be sampled locally. This brings the conclusion that the Upstream source contributes such a large proportion of sediment to the outflowing suspended sediment load due to potential change in the sediment through transport and residence time within Travers Reservoir and McGregor Lake. The inclusion of inflowing sediment as a source can help to distinguish whether transport and deposition has changed sources between sampling and collection and how to use this information when applying management practices locally or at the watershed scale. Future research should continue to explore whether there is a change in sediment during transport and residence time, or due to particle size changes or enrichment of sediment throughout the watershed or whether MixSIAR will skew proportions to the most similarly composed sediment source.

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4. CONCLUSIONS AND FUTURE SEDIMENT FINGERPRINTING RESEARCH

This thesis focused on the use of sediment fingerprinting to apportion sources within the Lower Little Bow River, in southern Alberta from the time periods of 2009-2013 and 2016. Through the use of colour properties as tracers, geochemical elements and the fallout radionuclide, Cs-137, an assessment of how to interpret and approach inflowing sediment in a watershed reach was conducted, as well as an assessment on how this can improve sampling and interpretation for sediment management. These studies aimed to improve the efficiency of the process when conducting sediment fingerprinting studies through tracer use, sampling and source treatment in a reach in an effort to improve the sediment fingerprinting technique for watershed and land management.

The first study conducted in this thesis, Chapter 2, focused on building a better understanding on how different methods of tracer selection can affect a sediment fingerprinting model. Chapter 2 also focused on how colour tracers apportioned sediment sources compared to Cs-137 and geochemical elements by conducting three different tracer schemes of the MixSIAR model. This study was conducted in the 2,565 ha micro-watershed reach within the LLBR using the source groups Agricultural Land, Stream Banks and Coulee Walls, as well as two upstream inflowing sediment sources from an Irrigation Return-Flow channel and an Upstream source. It was determined that the colour tracers G, X and Y combined with Cs-137, the proportion of sources that contribute to the suspended sediment load in the LLBR micro-watershed were 57.2 %, 14.2 %, 10.8 %, 10.5 % and 7.3 % for Upstream, Agricultural Land, Coulee Walls, Stream Banks and Irrigation Return-Flow channel, respectively. In conclusion, Chapter 2 demonstrated that in order to apportion sediment sources using the mixing model, MixSIAR, the best method is to use statistically significant tracers and choose significant tracers that will provide distinction of different sediment characteristics. This study also demonstrated that in MixSIAR, the Upstream source mixture was identified as a unique and separate source within the study area.

The second study conducted in this thesis, Chapter 3, was focused on exploring the composition of the inflowing sediment into the LLBR reach as a means of determining how much sampling is required. The Upstream source, inflowing sediment, was found to be a unique mixture that was entering the LLBR reach. Therefore, the Upstream source, inflowing sediment, had to either be composed largely of a missing upstream source or that the mixing model, MixSIAR identified the mixture as a unique source due to transport and residence time of the sediment. Through the analysis of five different MixSIAR schemes, it was found that the Upstream source was composed of the same or similar sources that were sampled locally. Additional samples were added from the larger watershed area and concluded to be the same as the locally sampled sources in the LLBR reach from a Canonical Discriminant Analysis. When the mixing model was run with the additional upstream samples, source proportions for the suspended sediment were found to be 74.3%, 6.6%, 6.4%, 6.3% and 6.3%, for Upstream, Agricultural Land, Stream Banks, Irrigation Return-Flow and Coulee Walls, respectively.

Both of these studies contributed to the understanding of how to treat inflowing sediment within reaches of watershed catchments when conducting sediment fingerprinting studies. Both studies also looked at better understanding the use of colour properties as tracers. The second chapter demonstrated that if sediment fingerprinting source proportions are to be applied for implementation of management practices, such as sediment production values, that in a watershed reach scenario, upstream inflowing sediment should always be included as a source. The second chapter's identification of the Upstream source as a uniquely identified mixture within the mixing model, MixSIAR, lead into the third chapter's explorations. An understanding of what exactly composed the inflowing sediment would provide answers to understand whether it actually is a unique mixture source that is different from outflowing sediment either from a missing upstream source that wasn't sampled locally, or that the sediment itself had somehow changed through transport. The third chapter used MixSIAR as a tool to explore the upstream source, and determined that it was different from the downstream outflowing sediment, and more sampling upstream of the LLBR reach should be explored to determine if there was a new source to be added to the mix. The third chapter determined that there was uniform source material upstream of the LLBR reach within the LLBR watershed, as well as around the upstream water bodies, Travers Reservoir and McGregor Lake. The explorations within Chapter 2 and 3 concluded that the Upstream source of inflowing sediment is being identified by colour tracers, Cs-137 and geochemical tracers as a unique source within MixSIAR. The sediment fingerprinting model for the LLBR reach using colour properties and Cs-137, has provided identification of a source that represents sediment within the "Black Box", as described by Koiter et al. (2013), allowing us insight into processes occurring within this "Black Box" that may be caused by model structure or by sediment enrichment.

4.1 Implications for application of sediment fingerprinting and management practices

The studies conducted within the LLBR micro-watershed in this thesis assess a critical aspect of sediment fingerprinting research, which is the ability to use sediment fingerprinting models for land and watershed management. With the addition of Cs-137 to a suite of colour tracers, any expected change in proportions of sources, would be representative of the difference between surface and subsurface material (Koiter et al., 2013). Any addition of conservative tracers to the suite of tracers used in analysis is beneficial in source apportionment (Collins, 2002). Chapter 3 clearly demonstrates the difference in sediment source proportions when the Upstream source is included or excluded. This difference in sediment proportions is large enough to be a concern when the sediment proportions are used as statistics to measure management impacts for soil erosion. Although this may seem obvious, it is not always the case with sediment fingerprinting studies or land management applications. Stressing the point of understanding watershed characteristics, and using a model like MixSIAR as a tool to explore proper management techniques is crucial to gaining a better understanding in how processes occur. Miller et al. (2010) discusses implementing cattle fencing within the Lower Little Bow River micro-watershed as an evaluation of a Beneficial Management Practice (BMP). To apply sediment fingerprinting as a form of measurement for BMPs, for example, when a sediment budget is used with sediment source proportions there needs to be assurance that the model is accurately representing true results that represent the management area. For example, Miller et al. (2010) measured the impact of cattle fencing on water quality within a small portion of the LLBR reach. Sediment fingerprinting provides a means to test not only water quality, but the effect of such a practice as cattle fencing on sedimentation in a watershed through methods other than tools such as erosion pins. This is important for how closely related sediment transport is related to nutrient transport (Barthod et al., 2015; Koiter et al., 2013). The ability to properly harness the tool of sediment fingerprinting to help manage and understand water systems affected by eutrophication and sedimentation is important. Both of these studies have added to this in a manner that exploits the use of the mixing model tool itself to better understand watershed processes as well as the effect of tracer selection.

In light of the two studies conducted in this thesis, the management of sedimentation within the LLBR can be better understood. Including the Upstream inflowing sediment as a source into the reach provides understanding of the actual amount of local source contributions. If the Upstream source was not included, this would be more representative of the watershed scale of source proportions, and management efforts would not necessarily be measureable or noticeable within the LLBR reach itself. It creates the ability to measure the success or failure of BMP's within local sources for the LLBR micro-watershed reach. Moving forward, management within the LLBR may not necessarily take place with management of local sources, but an exploration of upstream inflowing sediment. Since it was determined that the inflowing sediment is most likely composed of similar sources found downstream in the LLBR reach, but most likely are represented differently from transport, residence time or sediment enrichment. An exploration into whether this means that sediment hungry water is being released from Travers Reservoir and scouring the channel at the beginning of the Lower Little Bow so that large amounts of sediment are being carried from the mouth of Travers Reservoir to the inflowing point of the LLBR reach and causing a change in sediment. As well as an exploration into sediment leaving the Travers Reservoir would also be a management option, exploring if the residence time within the reservoir itself is having an effect on the composition of sediment. Both of these scenarios could have an effect on what is occurring downstream within the LLBR and any management efforts to reduce sedimentation within the LLBR and improve water quality will involve understanding and exploring the nature of the Upstream source further.

4.2 Future research

There are implications for sediment fingerprinting from the studies conducted in this thesis regarding future research on the use of colour properties as tracers, and the ability to include upstream inflowing sediment as a source. There are also some implications of strategic methods to approaching target areas within watersheds regarding time management and sampling. Studies conducted by Boudreault (2016), Barthod (2015), Martinez-Carreras (2010) and Brosinsky et al. (2014), that have demonstrated the opportunity to use colour properties as tracers within sediment fingerprinting, this thesis has shown that there are some opportunities to use colour tracers in combination with conservative tracers in order to confirm the story of sediment source proportions. In both studies conducted, colour tracers demonstrated that upstream inflowing sediment within the LLBR micro-watershed reach, was designated as a significant source of sediment within the reach. There needs to be further exploration of how the MixSIAR model itself identifies and apportions sediment mixtures as sources when the composition of the sediment mixture, such as the Upstream, is a composition of all the sources found locally. Moving forward in the exploration of sediment fingerprinting models, an understanding of how source proportions are assigned within the model. This will benefit studies in building an understanding of how manipulation of watersheds can be done regarding sampling and model structures. Further exploration of the inclusion of inflowing sediment as a source may also benefit the area of study by building upon the idea that sediment may become enriched as it moves downstream. This enrichment may affect tracer relation within sources and sediment within sediment models. The behaviour of sediment mixtures within mixing models should be explored more.

The second implication of the use of colour properties in combination with sampling and source inclusion of upstream inflowing sediment is the ability to reduce sampling time. The target area of the LLBR micro-watershed reach was a small area of a larger watershed that was being studied, initially, when just looking at this small reach, upstream inflowing sediment should be included as a source in order to appropriately assess how much of the processes of sedimentation locally are actually from local source erosion and input. Colour tracers with the combination of Cs-137, gave the ability to identify upstream inflowing sediment as a unique source. By identifying this inflowing sediment as a unique source, proportions of local sources can be observed as either impactful or minimal sources for local sedimentation issues. If the case is that the inflowing sediment is making up majority of the outflowing suspended sediment, then the study can be expanded for further sampling as was done in Chapter 3. This can create more control over how much sampling needs to be conducted based on how the reach of a watershed and larger watershed behaves. This ties into the ability of using other tracers as a confirmation of what is happening at the watershed scale, while colour tracers can predict what is happening at the local watershed scale. Moving forward in future research, the use of colour properties as tracers can still be beneficial in sediment fingerprinting practices by reducing sample analysis time. Further exploration into how the effect of sediment stored in water affects colour properties needs to be conducted, as well as further research into the conservativeness of colour properties as tracers for sediment fingerprinting.

4.3 References

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APPENDICES

Appendix A: MixSIAR spreadsheets for Chapter 2, Scheme 1

Table A.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers G, X, Y and Co

	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanCO	SDCO
Agricultural Land	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0
Upstream	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0

Table A.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers G, X, Y and Co grouped by site

	Site	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanCO	SDCO	n
Agricultural Land	1	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	4668.92423	738.038406	104
Agricultural Land	2	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	4668.92423	738.038406	104
Agricultural Land	3	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	4668.92423	738.038406	104
Agricultural Land	4	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	4668.92423	738.038406	104
Irrigation Return-Flow	1	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	5293.5	1089.15196	8
Irrigation Return-Flow	2	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	5293.5	1089.15196	8
Irrigation Return-Flow	3	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	5293.5	1089.15196	8
Irrigation Return-Flow	4	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	5293.5	1089.15196	8
Upstream	1	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	5999.2	392.654046	5
Upstream	2	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	5999.2	392.654046	5
Upstream	3	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	5999.2	392.654046	5
Upstream	4	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	5999.2	392.654046	5
Coulee Wall	1	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	5871	263.388686	6
Coulee Wall	2	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	5871	263.388686	6
Coulee Wall	3	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	5871	263.388686	6
Coulee Wall	4	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	5871	263.388686	6
Stream Bank	1	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	5042.56444	740.00496	45
Stream Bank	2	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	5042.56444	740.00496	45
Stream Bank	3	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	5042.56444	740.00496	45
Stream Bank	4	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	5042.56444	740.00496	45

Table A.3 MixSIAR sediment mixture spreadsheet for the Upstream sediment collection site and the tracers G, X, Y and Co

G	X	Y	CO	Site
55.701	25.778	22.112	3763.02187	LBW1
56.264	26.06	22.332	4472.44095	LBW1
53.877	25.004	21.412	6328.65732	LBW1
55.038	25.459	21.834	6159.36255	LBW1
54.463	25.195	21.612	6520.87475	LBW1
52.939	24.569	21.026	3673.12253	LBW1
51.732	24.209	20.607	7134.26854	LBW1
56.077	26.09	22.287	6240.48096	LBW1
56.435	26.249	22.428	6775.34791	LBW1
58.078	26.909	23.06	6891.94499	LBW1
61.074	28.161	24.198	6512	LBW1
58.794	27.095	23.306	6472	LBW1
56.292	26.007	22.339	3667.45562	LBW1
66.447	30.639	26.338	6011.88119	LBW1
57.717	26.83	22.957	4308	LBW1
54.842	25.429	21.778	7035.71429	LB4-14
54.465	25.31	21.644	5160.64257	LB4-14
54.273	25.179	21.554	6780.19802	LB4-14
54.73	25.32	21.711	5301.77515	LB4-14
54.671	25.362	21.709	4011.97605	LB4-14
56.933	26.397	22.605	6737.47495	LB4-14
54.562	25.559	21.738	5929.27308	LB4-14
56.512	26.272	22.456	6360	LB4-14
58.104	26.987	23.079	4283.46457	LB4-14
56.468	26.116	22.399	5755.51102	LB4-14
60.099	27.879	23.864	6352.70541	LBW4
54.901	25.499	21.816	4546.18474	LBW4
54.988	25.509	21.841	6294.82072	LBW4
55.251	25.537	21.915	6950.69034	LBW4
56.318	26.14	22.37	7551.1022	LBW4
54.015	25.076	21.459	6814.22925	LBW4
52.745	24.553	20.973	6302.18688	LBW4
55.838	26.01	22.204	5410.35857	LBW4
55.922	25.997	22.227	6419.80198	LBW4
55.089	25.613	21.905	6168.33667	LBW4
57.447	26.633	22.81	6515.87302	LB4
54.901	25.471	21.808	5768.9243	LB4
54.625	25.353	21.702	6335.96838	LB4
52.909	24.579	21.024	6645.29058	LB4
54.563	25.329	21.677	6144.28858	LB4
55.504	25.743	22.041	5972.22222	LB4
53.835	25.226	21.451	6254.98008	LB4
54.024	25.12	21.471	5082.82828	LB4
53.782	24.998	21.376	5730.15873	LB4
54.809	25.48	21.796	5591.91919	LB4
59.399	27.372	23.536	5841.89723	LB4
58.683	27.031	23.263	4024.0481	LB4
57.97	26.699	22.974	4473.16103	LB4
60.613	28.037	24.062	4918.16367	LB4
56.445	26.226	22.452	4941.41414	LB4

Appendix B: MixSIAR spreadsheets for Chapter 2, Scheme 2

Table B.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers Al, Co, Fe and Mn

	MeanAL	SDAL	MeanCO	SDCO	MeanFE	SDFE	MeanMN	SDMN
Agricultural Land	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0
Upstream	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0

Table B.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers Al, Co, Fe and Mn grouped by site

	Site	MeanAL	SDAL	MeanCO	SDCO	MeanFE	SDFE	MeanMN	SDMN	n
Agricultural Land	1	9500.11233	1944.54027	4668.92423	738.038406	11488.0848	1677.62783	293.991634	57.4400651	104
Agricultural Land	2	9500.11233	1944.54027	4668.92423	738.038406	11488.0848	1677.62783	293.991634	57.4400651	104
Agricultural Land	3	9500.11233	1944.54027	4668.92423	738.038406	11488.0848	1677.62783	293.991634	57.4400651	104
Agricultural Land	4	9500.11233	1944.54027	4668.92423	738.038406	11488.0848	1677.62783	293.991634	57.4400651	104
Irrigation Return-Flow	1	6929.375	2251.62747	5293.5	1089.15196	10104.375	2150.97738	253.875	56.4963652	8
Irrigation Return-Flow	2	6929.375	2251.62747	5293.5	1089.15196	10104.375	2150.97738	253.875	56.4963652	8
Irrigation Return-Flow	3	6929.375	2251.62747	5293.5	1089.15196	10104.375	2150.97738	253.875	56.4963652	8
Irrigation Return-Flow	4	6929.375	2251.62747	5293.5	1089.15196	10104.375	2150.97738	253.875	56.4963652	8
Upstream	1	9532	586.542411	5999.2	392.654046	12645	703.140811	242.4	40.7835751	5
Upstream	2	9532	586.542411	5999.2	392.654046	12645	703.140811	242.4	40.7835751	5
Upstream	3	9532	586.542411	5999.2	392.654046	12645	703.140811	242.4	40.7835751	5
Upstream	4	9532	586.542411	5999.2	392.654046	12645	703.140811	242.4	40.7835751	5
Coulee Wall	1	10256.3333	912.356655	5871	263.388686	13822.8333	579.5372	282.5	20.1866292	6
Coulee Wall	2	10256.3333	912.356655	5871	263.388686	13822.8333	579.5372	282.5	20.1866292	6
Coulee Wall	3	10256.3333	912.356655	5871	263.388686	13822.8333	579.5372	282.5	20.1866292	6
Coulee Wall	4	10256.3333	912.356655	5871	263.388686	13822.8333	579.5372	282.5	20.1866292	6
Stream Bank	1	8283.34222	2158.88252	5042.56444	740.00496	10964.46	1555.59585	249.988889	37.7701555	45
Stream Bank	2	8283.34222	2158.88252	5042.56444	740.00496	10964.46	1555.59585	249.988889	37.7701555	45
Stream Bank	3	8283.34222	2158.88252	5042.56444	740.00496	10964.46	1555.59585	249.988889	37.7701555	45
Stream Bank	4	8283.34222	2158.88252	5042.56444	740.00496	10964.46	1555.59585	249.988889	37.7701555	45

Table B.3 MixSIAR sediment mixture spreadsheet for the Upstream sediment collection site and the tracers Al, Co, Fe and Mn

AL	CO	FE	MN	Site
3675	3763.02187	7344	183	LBW1
4744	4472.44095	8000	193	LBW1
9098	6328.65732	12401	303	LBW1
8243	6159.36255	11271	294	LBW1
8743	6520.87475	11952	286	LBW1
3462	3673.12253	6494	161	LBW1
12048	7134.26854	15315	427	LBW1
8116	6240.48096	11655	283	LBW1
9936	6775.34791	13229	287	LBW1
11316	6891.94499	14589	399	LBW1
9208	6512	12120	286	LBW1
9216	6472	12340	275	LBW1
3988	3667.45562	6856	192	LBW1
8839	6011.88119	11881	315	LBW1
5032	4308	8016	191	LBW1
9781	7035.71429	13440	353	LB4-14
6269	5160.64257	9639	239	LB4-14
10130	6780.19802	13291	346	LB4-14
6927	5301.77515	10675	296	LB4-14
4051	4011.97605	7820	214	LB4-14
10665	6737.47495	13647	348	LB4-14
8428	5929.27308	11383	285	LB4-14
8952	6360	12004	292	LB4-14
4515	4283.46457	8276	269	LB4-14
7454	5755.51102	11106	275	LB4-14
9635	6352.70541	13054	324	LBW4
5457	4546.18474	8470	201	LBW4
9095	6294.82072	12526	298	LBW4
11076	6950.69034	14229	353	LBW4
11972	7551.1022	15451	366	LBW4
10446	6814.22925	14099	320	LBW4
9379	6302.18688	12755	328	LBW4
7071	5410.35857	10896	287	LBW4
8598	6419.80198	12554	317	LBW4
9050	6168.33667	12537	326	LBW4
10396	6515.87302	13500	334	LB4
7717	5768.9243	11143	262	LB4
9122	6335.96838	12447	297	LB4
10096	6645.29058	13880	356	LB4
7755	6144.28858	11483	272	LB4
7884	5972.22222	11504	301	LB4
8792	6254.98008	12060	319	LB4
7717	5082.82828	10291	257	LB4
10004	5730.15873	13452	238	LB4
9184	5591.91919	12077	197	LB4
10304	5841.89723	13352	210	LB4
6244	4024.0481	9427	201	LB4
6557	4473.16103	9881	230	LB4
7198	4918.16367	10974	270	LB4
7556	4941.41414	10352	255	LB4

Appendix C: MixSIAR spreadsheets for Chapter 2, Scheme 3

Table C.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers G, X, Y, Co and Cs-137

	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanCS	SDCS	MeanCO	SDCO
Agricultural Land	0	0	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0	0	0
Upstream	0	0	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0	0	0

Table C.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers G, X, Y, Co and Cs-137 grouped by site

	Site	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanCS	SDCS	MeanCO	SDCO	n
Agricultural Land	1	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	0.36029385	0.33586725	4668.92423	738.038406	104
Agricultural Land	2	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	0.45914256	0.44386611	4668.92423	738.038406	104
Agricultural Land	3	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	0.4805514	0.44137841	4668.92423	738.038406	104
Agricultural Land	4	41.2763077	8.81071449	19.7203462	4.03007806	16.5708942	3.46371216	0.59289864	0.38419741	4668.92423	738.038406	104
Irrigation Return-Flow	1	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	-0.0655385	0.27477572	5293.5	1089.15196	8
Irrigation Return-Flow	2	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	-0.0655385	0.27477572	5293.5	1089.15196	8
Irrigation Return-Flow	3	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	-0.0655385	0.27477572	5293.5	1089.15196	8
Irrigation Return-Flow	4	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	-0.0655385	0.27477572	5293.5	1089.15196	8
Upstream	1	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	-0.1517527	0.20350303	5999.2	392.654046	5
Upstream	2	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	-0.1517527	0.20350303	5999.2	392.654046	5
Upstream	3	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	-0.1517527	0.20350303	5999.2	392.654046	5
Upstream	4	53.9618	3.62640134	25.0852	1.58276805	21.4712	1.41078266	-0.1517527	0.20350303	5999.2	392.654046	5
Coulee Wall	1	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	0.02117887	0.16221243	5871	263.388686	6
Coulee Wall	2	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	0.02117887	0.16221243	5871	263.388686	6
Coulee Wall	3	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	0.01196103	0.25650028	5871	263.388686	6
Coulee Wall	4	62.2243333	2.45006316	29.622	1.11995571	24.7951667	0.96296031	0.00553498	0.23617967	5871	263.388686	6
Stream Bank	1	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	0.53519098	0.06694461	5042.56444	740.00496	45
Stream Bank	2	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	0.53519098	0.06694461	5042.56444	740.00496	45
Stream Bank	3	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	0.53519098	0.06694461	5042.56444	740.00496	45
Stream Bank	4	55.9295111	5.49367622	26.2387333	2.44513588	22.2868667	2.13195984	0.53519098	0.06694461	5042.56444	740.00496	45

Table C.3 MixSIAR sediment mixture spreadsheet for the Upstream sediment collection site and the tracers G, X, Y, Co and Cs-137

G	X	Y	CS	CO	Site
55.701	25.778	22.112	-0.2132486	3763.02187	LBW1
56.264	26.06	22.332	-0.2456517	4472.44095	LBW1
53.877	25.004	21.412	0.27207379	6328.65732	LBW1
55.038	25.459	21.834	-0.0974532	6159.36255	LBW1
54.463	25.195	21.612	0.25743857	6520.87475	LBW1
52.939	24.569	21.026	-0.3071531	3673.12253	LBW1
51.732	24.209	20.607	0.04610479	7134.26854	LBW1
56.077	26.09	22.287	0.2121876	6240.48096	LBW1
56.435	26.249	22.428	0.30059548	6775.34791	LBW1
58.078	26.909	23.06	0.05499586	6891.94499	LBW1
61.074	28.161	24.198	0.21590181	6512	LBW1
58.794	27.095	23.306	-0.0462403	6472	LBW1
56.292	26.007	22.339	-0.0352691	3667.45562	LBW1
66.447	30.639	26.338	0.24748226	6011.88119	LBW1
57.717	26.83	22.957	0.2367891	4308	LBW1
54.842	25.429	21.778	0.01157044	7035.71429	LB4-14
54.465	25.31	21.644	0.12287092	5160.64257	LB4-14
54.273	25.179	21.554	-0.4078232	6780.19802	LB4-14
54.73	25.32	21.711	0.16226561	5301.77515	LB4-14
54.671	25.362	21.709	0.02284061	4011.97605	LB4-14
56.933	26.397	22.605	0.17724784	6737.47495	LB4-14
54.562	25.559	21.738	0.15472821	5929.27308	LB4-14
56.512	26.272	22.456	0.13161866	6360	LB4-14
58.104	26.987	23.079	0.12352498	4283.46457	LB4-14
56.468	26.116	22.399	0.13449586	5755.51102	LB4-14
60.099	27.879	23.864	0.24328615	6352.70541	LBW4
54.901	25.499	21.816	0.18949031	4546.18474	LBW4
54.988	25.509	21.841	0.29092456	6294.82072	LBW4
55.251	25.537	21.915	0.10209053	6950.69034	LBW4
56.318	26.14	22.37	-0.0931265	7551.1022	LBW4
54.015	25.076	21.459	0.32939788	6814.22925	LBW4
52.745	24.553	20.973	-0.2660007	6302.18688	LBW4
55.838	26.01	22.204	0.21138755	5410.35857	LBW4
55.922	25.997	22.227	0.32428246	6419.80198	LBW4
55.089	25.613	21.905	0.00086772	6168.33667	LBW4
57.447	26.633	22.81	0.33203428	6515.87302	LB4
54.901	25.471	21.808	0.10720997	5768.9243	LB4
54.625	25.353	21.702	0.16106839	6335.96838	LB4
52.909	24.579	21.024	0.1383027	6645.29058	LB4
54.563	25.329	21.677	0.24054925	6144.28858	LB4
55.504	25.743	22.041	-0.0746879	5972.22222	LB4
53.835	25.226	21.451	0.14550717	6254.98008	LB4
54.024	25.12	21.471	0.31154196	5082.82828	LB4
53.782	24.998	21.376	0.27415785	5730.15873	LB4
54.809	25.48	21.796	0.14952701	5591.91919	LB4
59.399	27.372	23.536	0.07954301	5841.89723	LB4
58.683	27.031	23.263	-0.1343039	4024.0481	LB4
57.97	26.699	22.974	-0.35164	4473.16103	LB4
60.613	28.037	24.062	0.23019338	4918.16367	LB4
56.445	26.226	22.452	0.25959388	4941.41414	LB4

Appendix D: MixSIAR spreadsheets for Chapter 3, Scheme 1

Table D.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers G, X, Y, L and Cs-137

	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS
Agricultural Land	0	0	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0	0	0
Upstream	0	0	0	0	0	0	0	0	0	0

Table D.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers G, X, Y, L and Cs-137 grouped by site

	Site	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS	n
Agricultural Land	1	49.91495	5.613299	23.77005	2.519498	19.99925	2.1879883	51.74525	2.5635932	0.36029385	0.33586725	20
Agricultural Land	2	46.39032	7.510847	22.14913	3.392951	18.6045	2.9397049	50.03018	3.626014	0.45914256	0.44386611	38
Agricultural Land	3	46.88242	7.559884	22.29976	3.419809	18.78017	2.9594654	50.2371	3.6214109	0.4805514	0.44137841	59
Agricultural Land	4	41.27631	8.810714	19.72035	4.030078	16.57089	3.4637122	47.41399	4.385527	0.59289864	0.38419741	104
Coulee Wall	1	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	2	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	3	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	4	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Irrigation Return-Flow	1	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	2	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	3	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	4	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Stream Bank	1	54.3668	3.042123	25.58307	1.375191	21.68827	1.1814324	53.6728	1.2734627	0.02117887	0.16221243	15
Stream Bank	2	54.3668	3.042123	25.58307	1.375191	21.68827	1.1814324	53.6728	1.2734627	0.02117887	0.16221243	15
Stream Bank	3	56.0453	5.944948	26.30763	2.639502	22.33327	2.2978847	54.3058	2.2826047	0.01196103	0.25650028	30
Stream Bank	4	55.92951	5.493676	26.23873	2.445136	22.28687	2.1319598	54.26551	2.1357815	0.00553498	0.23617967	45
Upstream	1	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.06694461	5
Upstream	2	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.06694461	5
Upstream	3	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.06694461	5
Upstream	4	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.06694461	5

Table D.3 MixSIAR sediment mixture spreadsheet for the Upstream sediment collection site and the tracers G, X, Y, L and Cs-137

G	X	Y	L	CS	Site
55.701	25.778	22.112	54.145	-0.2132486	LBW1
56.264	26.06	22.332	54.378	-0.2456517	LBW1
53.877	25.004	21.412	53.397	0.27207379	LBW1
55.038	25.459	21.834	53.85	-0.0974532	LBW1
54.463	25.195	21.612	53.613	0.25743857	LBW1
52.939	24.569	21.026	52.978	-0.3071531	LBW1
51.732	24.209	20.607	52.517	0.04610479	LBW1
56.077	26.09	22.287	54.33	0.2121876	LBW1
56.435	26.249	22.428	54.478	0.30059548	LBW1
58.078	26.909	23.06	55.134	0.05499586	LBW1
61.074	28.161	24.198	56.286	0.21590181	LBW1
58.794	27.095	23.306	55.386	-0.0462403	LBW1
56.292	26.007	22.339	54.385	-0.0352691	LBW1
66.447	30.639	26.338	58.356	0.24748226	LBW1
57.717	26.83	22.957	55.028	0.2367891	LBW1
54.842	25.429	21.778	53.791	0.01157044	LB4-14
54.465	25.31	21.644	53.647	0.12287092	LB4-14
54.273	25.179	21.554	53.551	-0.4078232	LB4-14
54.73	25.32	21.711	53.719	0.16226561	LB4-14
54.671	25.362	21.709	53.717	0.02284061	LB4-14
56.933	26.397	22.605	54.663	0.17724784	LB4-14
54.562	25.559	21.738	53.748	0.15472821	LB4-14
56.512	26.272	22.456	54.507	0.13161866	LB4-14
58.104	26.987	23.079	55.154	0.12352498	LB4-14
56.468	26.116	22.399	54.448	0.13449586	LB4-14
60.099	27.879	23.864	55.951	0.24328615	LBW4
54.901	25.499	21.816	53.832	0.18949031	LBW4
54.988	25.509	21.841	53.858	0.29092456	LBW4
55.251	25.537	21.915	53.936	0.10209053	LBW4
56.318	26.14	22.37	54.418	-0.0931265	LBW4
54.015	25.076	21.459	53.448	0.32939788	LBW4
52.745	24.553	20.973	52.92	-0.2660007	LBW4
55.838	26.01	22.204	54.243	0.21138755	LBW4
55.922	25.997	22.227	54.267	0.32428246	LBW4
55.089	25.613	21.905	53.926	0.00086772	LBW4
57.447	26.633	22.81	54.876	0.33203428	LB4
54.901	25.471	21.808	53.822	0.10720997	LB4
54.625	25.353	21.702	53.71	0.16106839	LB4
52.909	24.579	21.024	52.976	0.1383027	LB4
54.563	25.329	21.677	53.683	0.24054925	LB4
55.504	25.743	22.041	54.071	-0.0746879	LB4
53.835	25.226	21.451	53.44	0.14550717	LB4
54.024	25.12	21.471	53.461	0.31154196	LB4
53.782	24.998	21.376	53.358	0.27415785	LB4
54.809	25.48	21.796	53.81	0.14952701	LB4
59.399	27.372	23.536	55.621	0.07954301	LB4
58.683	27.031	23.263	55.342	-0.1343039	LB4
57.97	26.699	22.974	55.046	-0.35164	LB4
60.613	28.037	24.062	56.15	0.23019338	LB4
56.445	26.226	22.452	54.503	0.25959388	LB4

[*] MixSIAR sediment mixture spreadsheet also used for Chapter 3, Scheme 2, and 4

Appendix E: MixSIAR spreadsheets for Chapter 3, Scheme 2

Table E.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers G, X, Y, L and Cs-137

	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS
Agricultural Land	0	0	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0	0	0

Table E.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers G, X, Y, L and Cs-137 grouped by site

	Site	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS	n
Agricultural Land	1	49.91495	5.613299	23.77005	2.519498	19.99925	2.1879883	51.74525	2.5635932	0.36029385	0.33586725	20
Agricultural Land	2	46.39032	7.510847	22.14913	3.392951	18.6045	2.9397049	50.03018	3.626014	0.45914256	0.44386611	38
Agricultural Land	3	46.88242	7.559884	22.29976	3.419809	18.78017	2.9594654	50.2371	3.6214109	0.4805514	0.44137841	59
Agricultural Land	4	41.27631	8.810714	19.72035	4.030078	16.57089	3.4637122	47.41399	4.385527	0.59289864	0.38419741	104
Coulee Wall	1	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	2	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	3	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	4	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Irrigation Return-Flow	1	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	2	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	3	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	4	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Stream Bank	1	54.3668	3.042123	25.58307	1.375191	21.68827	1.1814324	53.6728	1.2734627	0.02117887	0.16221243	15
Stream Bank	2	54.3668	3.042123	25.58307	1.375191	21.68827	1.1814324	53.6728	1.2734627	0.02117887	0.16221243	15
Stream Bank	3	56.0453	5.944948	26.30763	2.639502	22.33327	2.2978847	54.3058	2.2826047	0.01196103	0.25650028	30
Stream Bank	4	55.92951	5.493676	26.23873	2.445136	22.28687	2.1319598	54.26551	2.1357815	0.00553498	0.23617967	45

Appendix F: MixSIAR spreadsheets for Chapter 3, Scheme 3

Table F.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers G, X, Y, L and Cs-137

	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS
Agricultural Land	0	0	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0	0	0

Table F.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers G, X, Y, L and Cs-137 grouped by site

	Site	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS	n
Agricultural Land	1	49.91495	5.613299	23.77005	2.519498	19.99925	2.1879883	51.74525	2.5635932	0.36029385	0.33586725	20
Agricultural Land	2	46.39032	7.510847	22.14913	3.392951	18.6045	2.9397049	50.03018	3.626014	0.45914256	0.44386611	38
Agricultural Land	3	46.88242	7.559884	22.29976	3.419809	18.78017	2.9594654	50.2371	3.6214109	0.4805514	0.44137841	59
Agricultural Land	4	41.27631	8.810714	19.72035	4.030078	16.57089	3.4637122	47.41399	4.385527	0.59289864	0.38419741	104
Coulee Wall	1	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	2	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	3	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Coulee Wall	4	62.22433	2.450063	29.622	1.119956	24.79517	0.9629603	56.86517	0.9433424	-0.0655385	0.27477572	6
Irrigation Return-Flow	1	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	2	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	3	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Irrigation Return-Flow	4	58.21487	2.429078	26.98212	1.144223	23.09562	0.9628596	55.159	0.980756	-0.1517527	0.20350303	8
Stream Bank	1	54.3668	3.042123	25.58307	1.375191	21.68827	1.1814324	53.6728	1.2734627	0.02117887	0.16221243	15
Stream Bank	2	54.3668	3.042123	25.58307	1.375191	21.68827	1.1814324	53.6728	1.2734627	0.02117887	0.16221243	15
Stream Bank	3	56.0453	5.944948	26.30763	2.639502	22.33327	2.2978847	54.3058	2.2826047	0.01196103	0.25650028	30
Stream Bank	4	55.92951	5.493676	26.23873	2.445136	22.28687	2.1319598	54.26551	2.1357815	0.00553498	0.23617967	45

Table F.3 MixSIAR sediment mixture spreadsheet for the Upstream sediment collection site and the tracers G, X, Y, L and Cs-137

G	X	Y	L	CS	Site
52.895	24.611	21.05	53.004	0.50460677	Upstream
50.726	23.672	20.213	52.077	0.49540556	Upstream
50.583	23.615	20.159	52.017	0.4652341	Upstream
57.998	26.75	23.012	55.085	0.55461029	Upstream
57.607	26.778	22.922	54.992	0.6560982	Upstream

*MixSIAR sediment mixture spreadsheet also used for Chapter 3, Scheme 5

Appendix G: MixSIAR spreadsheets for Chapter 3, Scheme 4

Table G.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers G, X, Y, L and Cs-137

	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS
Agricultural Land	0	0	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0	0	0
Upstream	0	0	0	0	0	0	0	0	0	0

Table G.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers G, X, Y, L and Cs-137 grouped by site

	Site	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS	n
Agricultural	1	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Agricultural	2	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Agricultural	3	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Agricultural	4	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Coulee Wall	1	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Coulee Wall	2	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Coulee Wall	3	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Coulee Wall	4	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Stream Bank	1	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Stream Bank	2	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Stream Bank	3	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Stream Bank	4	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Irrigation Return-Flow	1	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8
Irrigation Return-Flow	2	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8
Irrigation Return-Flow	3	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8
Irrigation Return-Flow	4	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8
Upstream	1	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.07056582	5
Upstream	2	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.07056582	5
Upstream	3	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.07056582	5
Upstream	4	53.9618	3.626401	25.0852	1.582768	21.4712	1.4107827	53.435	1.515536	0.53519098	0.07056582	5

Appendix H: MixSIAR spreadsheets for Chapter 3, Scheme 5

Table H.1 MixSIAR discrimination spreadsheet for sediment sources using the colour tracers G, X, Y, L and Cs-137

	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS
Agricultural Land	0	0	0	0	0	0	0	0	0	0
Coulee Wall	0	0	0	0	0	0	0	0	0	0
Irrigation Return-Flow	0	0	0	0	0	0	0	0	0	0
Stream Bank	0	0	0	0	0	0	0	0	0	0

Table H.2 MixSIAR sediment source means and standard deviation spreadsheet for the colour tracers G, X, Y, L and Cs-137 grouped by site

	Site	MeanG	SDG	MeanX	SDX	MeanY	SDY	MeanL	SDL	MeanCS	SDCS	n
Agricultural Land	1	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Agricultural Land	2	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Agricultural Land	3	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Agricultural Land	4	39.7620026	8.66058991	19.0607543	3.95238915	16.0034348	3.38371465	46.6738961	4.38996654	0.55807445	0.38363112	138
Coulee Wall	1	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Coulee Wall	2	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Coulee Wall	3	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Coulee Wall	4	60.8595309	9.79312958	28.899045	4.62530932	24.2419083	3.86287662	56.1078553	4.32752814	0.11216213	0.41299812	9
Stream Bank	1	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Stream Bank	2	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Stream Bank	3	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Stream Bank	4	55.9719465	5.4399114	26.2541646	2.42007921	22.3028693	2.11093035	54.2835653	2.11546415	0.00541466	0.23354214	46
Irrigation Return-Flow	1	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8
Irrigation Return-Flow	2	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8
Irrigation Return-Flow	3	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8
Irrigation Return-Flow	4	58.214875	2.4290781	26.982125	1.14422294	23.095625	0.96285957	55.159	0.98075598	-0.1517527	0.20350303	8

Appendix I: Raw data for Biplot Analysis Chapter 2

	MeanR	SDR	MeanG	SDG	MeanB	SDB	Meanx	SDx	n
Agricultural Land	51.7719139	9.93906958	39.7620003	8.66058991	29.1731769	6.26302445	0.49344732	0.0031587	138
Irrigation Return Flow	68.840875	2.94417616	58.214875	2.4290781	44.552375	1.69352194	0.48525	0.0010351	8
Upstream	64.6442	3.48958759	53.9618	3.626401	42.0392	3.89474415	0.4848	0.00154919	5
Coulee Wall	75.8039308	11.6006864	60.8595309	9.79312958	41.2452895	5.94117097	0.49716994	0.00333938	8
Stream Bank	68.4161559	5.66333625	55.9719465	5.4399114	41.8819049	4.15023463	0.48885731	0.00196433	46
	MeanX	SDX	MeanY	SDY	MeanZ	SDZ	MeanL	SDL	n
Agricultural Land	19.0607543	3.95238915	16.0034348	3.38371465	3.59182595	0.75701891	46.6738961	4.38996654	138
Irrigation Return Flow	26.982125	1.14422294	23.095625	0.96285957	5.521375	0.21311294	55.159	0.98075598	8
Upstream	25.0852	1.582768	21.4712	1.4107827	5.2052	0.37258699	53.435	1.515536	5
Coulee Wall	28.899045	4.62530932	24.2419083	3.86287662	4.95038059	0.68737981	56.1078553	4.32752814	8
Stream Bank	26.2541646	2.42007921	22.3028693	2.11093035	5.15842254	0.52720388	54.2835653	2.11546415	46
	Meanu	SDu	Meanv	SDv	Meana	SDa	Meanb	SDb	n
Agricultural Land	14.4028022	1.37412917	5.76488157	0.79562238	6.35710088	0.51462393	15.1968211	1.71800667	138
Irrigation Return Flow	12.751625	0.55589283	6.275625	0.2069223	5.139625	0.22591904	14.840875	0.51792124	8
Upstream	12.2638	0.40634873	5.8618	0.10957575	5.0294	0.22305316	14.007	0.26749538	5
Coulee Wall	18.0389934	2.1924499	8.21683889	1.12575106	7.32776502	0.76568349	20.5385104	2.63805249	8
Stream Bank	14.2308698	0.77358836	6.50014174	0.36484508	5.87087569	0.34526844	15.8440399	0.83716894	46
	Meanh	SDh	Meanc	SDc	Meany	SDy	MeanCS	SDCS	n
Agricultural Land	67.1948853	1.46466526	16.4781084	1.7446343	0.41392472	0.00115902	0.55807445	0.38363112	138
Irrigation Return Flow	70.9025	0.23106647	15.705875	0.56159987	0.41525	0.00046291	-0.1517527	0.20350303	8
Upstream	70.2562	0.57260978	14.883	0.31535729	0.415	5.85E-17	0.53519098	0.07056582	5
Coulee Wall	70.2797557	1.01446981	21.8090251	2.72462646	0.41713236	0.00126064	0.11216213	0.41299812	8
Stream Bank	69.6620208	0.78879319	16.8983673	0.87482469	0.41507777	0.00065073	0.00541466	0.23354214	46

Appendix J: Raw data for Biplot Analysis Chapter 3

	MeanR	SDR	MeanG	SDG	MeanB	SDB	Meanx	SDx	n
Agricultural Land	53.3588846	9.88936185	41.2763077	8.81071449	30.1976923	6.47595875	0.49325	0.00269393	104
Irrigation Return Flow	68.840875	2.94417616	58.214875	2.4290781	44.552375	1.69352194	0.48525	0.0010351	8
Upstream	64.6442	3.70126657	53.9618	3.62640134	42.0392	3.13488456	0.4848	0.00164317	5
Coulee Wall	77.8931667	2.72657554	62.2243333	2.45006316	41.5816667	1.88535107	0.49883333	0.00116905	6
Stream Bank	68.3923111	5.72499511	55.9295111	5.49367622	41.8306444	4.18237896	0.48891111	0.00195195	45
	Meany	SDy	MeanX	SDX	MeanY	SDY	MeanZ	SDZ	n
Agricultural Land	0.41400962	0.00110159	19.7203462	4.03007806	16.5708942	3.46371216	3.71046154	0.78343015	104
Irrigation Return Flow	0.41525	0.00046291	26.982125	1.14422294	23.095625	0.96285957	5.521375	0.21311294	8
Upstream	0.415	6.21E-17	25.0852	1.58276805	21.4712	1.41078266	5.2052	0.39518818	5
Coulee Wall	0.4175	0.00054772	29.622	1.11995571	24.7951667	0.96296031	4.96733333	0.23979213	6
Stream Bank	0.41506667	0.00065366	26.2387333	2.44513588	22.2868667	2.13195984	5.15242222	0.53157034	45
	MeanL	SDL	Meanu	SDu	Meanv	SDv	Meana	SDa	n
Agricultural Land	47.4139904	4.38552699	14.4730192	1.11450965	5.84403846	0.72880222	6.35553846	0.42314793	104
Irrigation Return Flow	55.159	0.98075598	12.751625	0.55589283	6.275625	0.2069223	5.139625	0.22591904	8
Upstream	53.435	1.51553604	12.2638	0.43099791	5.8618	0.11622263	5.0294	0.2365836	5
Coulee Wall	56.8651667	0.94334244	18.8941667	0.31909398	8.58033333	0.17355191	7.65333333	0.11884388	6
Stream Bank	54.2655111	2.13578152	14.2535778	0.76666861	6.50142222	0.36886321	5.88277778	0.33949253	45
	Meanb	SDb	Meanc	SDc	MeanCS	SDCS	MeanAL	SDAL	n
Agricultural Land	15.3089327	1.45453973	61.4122019	16.1182096	3.043875	4.38623412	9500.11233	1944.54027	104
Irrigation Return Flow	14.840875	0.51792124	70.9025	0.23106647	0.265875	0.31791528	6929.375	2251.62747	8
Upstream	14.007	0.2837217	70.2562	0.60734438	3.472	0.6387476	9532	586.542411	5
Coulee Wall	21.5273333	0.46980663	70.4268333	0.15065247	0.31033333	0.64505524	10256.3333	912.356655	6
Stream Bank	15.8555333	0.84295054	69.6365778	0.77838339	6.27348889	3.54927378	8283.34222	2158.88252	45
	MeanCO	SDCO	MeanFE	SDFE	MeanK	SDK	MeanMN	SDMN	n
Agricultural Land	4668.92423	738.038406	11488.0848	1677.62783	2208.7253	498.642904	293.991634	57.4400651	104
Irrigation Return Flow	5293.5	1089.15196	10104.375	2150.97738	1266.25	389.373765	253.875	56.4963652	8
Upstream	5999.2	392.654046	12645	703.140811	1721	109.377786	242.4	40.7835751	5
Coulee Wall	5871	263.388686	13822.8333	579.5372	1837.83333	136.942932	282.5	20.1866292	6
Stream Bank	5042.56444	740.00496	10964.46	1555.59585	1598.88	350.841398	249.988889	37.7701555	45

Appendix K: Raw data for Stepwise Discriminant Function Analysis Chapter 2

Source	G	B	x	X	Y	Z	L	v	b	h	c	y	CS
Agricultural	19.7269259	15.6929155	0.48605823	9.42666733	7.95850668	2.00893705	33.8963202	3.07733751	9.0256869	62.936402	10.1355038	0.41035687	1.11252187
Agricultural	30.9903704	22.5973099	0.49524307	15.0417595	12.5354613	2.79525764	42.054795	5.07236575	14.1291993	65.3871502	15.5412334	0.41272435	1.08036017
Agricultural	34.5392778	23.1647747	0.50323861	17.0194862	14.0088157	2.79161171	44.2455717	6.36171995	17.9437926	66.4505031	19.5740088	0.41421796	0.53893935
Agricultural	32.9249074	23.5975563	0.49565114	15.9082452	13.2717023	2.91570166	43.1698135	5.40511242	14.8342557	66.3248658	16.1974855	0.41350472	0.94740928
Agricultural	61.5330741	42.5824859	0.49574959	29.1649769	24.5245267	5.14055456	56.6091803	8.01513946	19.8662416	70.2405135	21.1091471	0.41687069	0
Agricultural	23.174463	17.4283521	0.49282716	11.259382	9.39233516	2.19479574	36.7289573	3.96388794	11.6045774	63.4273261	12.9751752	0.41110585	0.71086047
Agricultural	25.6123889	18.7884718	0.49604426	12.5401314	10.4045574	2.33557815	38.5589319	4.49571919	13.0990314	63.8239104	14.5959555	0.41156834	0.86486751
Agricultural	34.3377963	26.1410916	0.49020743	16.4393931	13.8346838	3.26150826	43.9949095	4.82561401	12.938105	65.7554713	14.1896108	0.41253742	0.66223617
Agricultural	27.744	20.9861409	0.49088792	13.329385	11.1891365	2.63510055	39.8972162	4.33895699	12.0834527	64.9935661	13.3333131	0.41206792	0.83248586
Agricultural	60.1752778	46.6312394	0.48519477	28.092402	23.9743928	5.83243161	56.0621466	6.00956643	14.3953505	69.0164485	15.4178092	0.41407104	0.59098256
Agricultural	37.7686482	24.8621409	0.50541637	18.7207747	15.3423938	2.97713265	46.0996327	6.82688866	19.277634	66.3040638	21.0525515	0.41420813	0.42260232
Agricultural	40.4999815	33.5953521	0.47887034	18.8097571	16.1664303	4.30324937	47.1920872	3.89429806	9.69027278	66.6236426	10.5567908	0.4115749	0.7926839
Agricultural	29.2236296	22.0628873	0.49013437	13.947479	11.7484233	2.76053696	40.8134529	4.53401789	12.3463713	66.2179524	13.4920329	0.41285641	0.96769387
Agricultural	32.0591667	24.2415211	0.49080976	15.3409981	12.9077344	3.00777353	42.623894	4.81409332	12.9848257	66.2597703	14.185173	0.41296153	0.75586094
Agricultural	42.6725185	31.8035282	0.49005508	20.1755086	17.0623227	3.93204814	48.3384667	5.73259758	14.6071541	68.3935046	15.7110984	0.41443703	0.21523786
Agricultural	46.984537	34.8495211	0.49021961	22.1874878	18.7681972	4.30461773	50.4148978	6.05260548	15.2363227	68.6705828	16.35668	0.41467237	0
Agricultural	33.6193889	24.9522887	0.49237283	16.0986809	13.5254997	3.07193885	43.5446064	5.20350883	13.9502444	66.9770297	15.1575734	0.41367294	0.6523435
Agricultural	35.7352593	26.2111268	0.49303429	17.1081184	14.360823	3.23071108	44.7460112	5.44654988	14.5188661	67.1197794	15.7587713	0.41386072	0.54328396
Agricultural	48.0970926	35.1328944	0.49194438	22.7937681	19.2299	4.31036676	50.9551002	6.37906181	16.1235314	68.7850689	17.2956669	0.41502753	-0.3883193
Agricultural	39.4551111	28.453331	0.4942355	18.8805613	15.8400555	3.48093149	46.7639435	5.98075177	15.7266444	67.916529	16.97174	0.41464433	0.49893282
Agricultural	42.4899259	30.6459718	0.49395527	20.2956593	17.0418698	3.75052197	48.3127485	6.17993916	16.068475	68.1075347	17.3173075	0.41476462	0
Agricultural	44.0218148	31.4415	0.49446339	20.9866846	17.6279163	3.82875263	49.0416648	6.45570515	16.6705183	68.7025322	17.8924418	0.41532808	0
Agricultural	32.6825	23.5059718	0.49557483	15.7814605	13.1754852	2.88781232	43.0264769	5.42980092	14.8659886	66.625408	16.1951107	0.4137411	0.57345147
Agricultural	35.076037	25.2374578	0.49518929	16.8936574	14.1210843	3.10081298	44.4060824	5.60804835	15.1584674	66.8927365	16.4806838	0.41391924	0
Agricultural	38.3756111	27.5303028	0.49549664	18.4903456	15.4490237	3.37742357	46.2431652	5.88560645	15.7547127	66.9479988	17.1218989	0.41399656	0
Agricultural	29.7679444	21.6383662	0.49548249	14.4433391	12.034642	2.67206821	41.2711251	5.02298279	14.0599188	65.524866	15.4480639	0.41285152	0.83656254
Agricultural	35.6212963	25.3286831	0.49704181	17.2769322	14.3801864	3.10239625	44.7733012	5.77325511	15.7764599	66.4140352	17.2145501	0.41370504	0
Agricultural	46.1011667	33.1992042	0.4941872	22.0381049	18.4947965	4.06174801	50.0908253	6.42242115	16.5808355	68.0300525	17.8792207	0.41473129	0
Agricultural	36.4571296	26.4672042	0.49452371	17.5439838	14.6809086	3.25163469	45.1940177	5.62611088	15.0969504	66.8575211	16.4181097	0.41382034	0.56581734
Agricultural	38.4048889	27.141338	0.49638375	18.4693844	15.4368623	3.30162842	46.2268284	6.16233901	16.4166634	67.885892	17.7202354	0.41488159	0.46360473
Agricultural	44.1486852	31.4343169	0.49473419	21.0547093	17.6800089	3.82290118	49.1056704	6.51625401	16.829533	68.786168	18.0528583	0.41543698	0
Agricultural	42.3967407	31.318669	0.49152	20.1577022	16.9923253	3.86092259	48.2503642	5.83889713	15.0395654	67.9824537	16.2227018	0.4143363	0
Agricultural	45.2162222	32.6529296	0.49332135	21.5286505	18.1078106	4.00375564	49.6266099	6.32602297	16.2460879	68.4201239	17.4706828	0.41493402	0
Agricultural	47.5675741	34.7780493	0.49163755	22.5237973	19.01085	4.27917874	50.6998976	6.29945518	15.9236442	68.7573401	17.0844599	0.41495879	0
Agricultural	37.4774444	27.8133169	0.49205597	17.9279451	15.0699412	3.43688155	45.7298434	5.42286814	14.3355007	66.9489539	15.5794179	0.41361431	0.62678964
Agricultural	39.3339074	28.3710845	0.49442946	18.8385688	15.7962565	3.46680575	46.706041	5.97735261	15.7520874	67.8110183	17.0119364	0.41458216	0
Agricultural	47.5826852	34.6864648	0.49223932	22.5815478	19.0324687	4.26112353	50.7251712	6.34277911	16.1067604	68.5392774	17.3066552	0.41487544	0
Agricultural	27.2	22.5042887	0.49404539	18.2425161	15.2773089	3.40495227	46.011696	5.6665615	15.1075353	66.8229224	16.4338654	0.4137414	0.45030023
Agricultural	37.8265741	26.9772042	0.49623429	18.2352446	15.2340461	3.27795734	45.9531051	6.04167323	16.1624146	67.5320157	17.4900261	0.41456291	0.85270504
Agricultural	47.4872963	34.2913944	0.49352714	22.6060402	19.018146	4.18087368	50.7084293	6.54897842	16.7029274	68.705755	17.9268334	0.41519749	0.3943078
Agricultural	32.7514444	24.3973944	0.49284105	15.7642324	13.2157678	3.00644327	43.0865712	5.08344364	13.7955336	66.2461724	15.0723982	0.41316778	0.5335334
Agricultural	39.8637407	28.6285986	0.49545892	19.1831128	16.0468387	3.48791579	47.0358797	6.08715821	16.1336845	67.5090243	17.4618353	0.41445565	0.36127092
Agricultural	40.5239074	29.3846197	0.49419507	19.4172482	16.2852531	3.58815382	47.3465295	6.01430072	15.7910708	67.7235054	17.0646885	0.41448159	0
Agricultural	43.7151852	31.1807535	0.49530149	20.9395957	17.5479291	3.78893978	48.9431395	6.46480263	16.832713	68.2702042	18.1203415	0.4150756	0.86937616
Agricultural	48.1002407	33.9674366	0.49540371	22.9478235	19.2599723	4.11366494	50.9899842	6.9204181	17.718011	69.08499	18.9677793	0.4157894	0
Agricultural	51.2597222	36.5849578	0.49429213	24.3827836	20.5069776	4.43892927	52.4056344	6.97968971	17.6466958	69.1955944	18.8775423	0.4157211	0
Agricultural	48.974	36.159	0.492	23.314	19.641	4.43	51.428	6.314	16.03	68.099	17.277	0.414	0
Agricultural	53.978	39.563	0.492	25.629	21.605	4.85	53.606	6.669	16.712	68.491	17.963	0.415	0
Agricultural	53.528	38.421	0.494	25.507	21.437	4.676	53.424	6.985	17.646	68.706	18.939	0.415	-0.0783135

Agricultural	52.924	38.802	0.492	25.053	21.154	4.754	53.118	6.634	16.555	68.944	17.74	0.415	0.23979982
Agricultural	52.381	37.744	0.494	24.932	20.971	4.6	52.917	6.859	17.327	68.722	18.595	0.415	0.08600371
Agricultural	56.893	42.025	0.49	26.808	22.703	5.149	54.765	6.78	16.633	69.5	17.758	0.415	-0.0056828
Agricultural	52.441	38.575	0.492	24.889	20.993	4.73	52.942	6.545	16.422	68.511	17.648	0.415	0.13893394
Agricultural	51.607	37.936	0.492	24.529	20.672	4.654	52.589	6.493	16.366	68.296	17.615	0.415	0.52335621
Agricultural	51.612	37.15	0.494	24.588	20.671	4.528	52.587	6.823	17.292	68.627	18.57	0.415	0.11859537
Agricultural	52.881	37.394	0.495	25.16	21.14	4.539	53.103	7.163	18.103	69.214	19.363	0.416	0
Agricultural	56.263	40.53	0.493	26.605	22.451	4.937	54.502	7.116	17.645	69.588	18.827	0.416	0
Agricultural	49.482	36.966	0.49	23.451	19.813	4.561	51.625	6.114	15.391	68.13	16.585	0.414	0.63658818
Agricultural	46.062	33.547	0.494	22.05	18.505	4.112	50.103	6.264	16.201	67.572	17.526	0.414	0.47986311
Agricultural	46.518	34.615	0.492	22.189	18.681	4.271	50.311	5.97	15.32	67.316	16.604	0.414	0.68895346
Agricultural	41.354	30.217	0.495	19.972	16.688	3.726	47.864	5.819	15.505	66.09	16.961	0.413	0.85046243
Agricultural	40.611	28.922	0.497	19.653	16.378	3.535	47.466	6.142	16.459	66.728	17.917	0.414	0.83720953
Agricultural	57.448	41.533	0.492	27.152	22.919	5.092	54.989	7.033	17.405	69.291	18.607	0.415	0.64845759
Agricultural	44.454	32.107	0.494	21.31	17.861	3.929	49.327	6.271	16.334	67.596	17.668	0.414	0.6794279
Agricultural	37.017	26.289	0.497	17.939	14.937	3.211	45.548	5.925	16.084	66.662	17.517	0.414	0.77305469
Agricultural	51.871	37.583	0.493	24.671	20.765	4.609	52.691	6.678	16.873	68.462	18.14	0.415	0.58916739
Agricultural	42.397	30.078	0.496	20.309	17.012	3.662	48.275	6.406	16.756	68.267	18.038	0.415	1.28350476
Agricultural	51.554	37.448	0.492	24.391	20.59	4.578	52.498	6.705	16.768	69.286	17.927	0.415	0.11693965
Agricultural	50.156	35.918	0.493	23.724	20.01	4.377	51.849	6.832	17.155	69.646	18.297	0.416	0.24079877
Agricultural	42.401	30.4	0.495	20.306	17.021	3.718	48.286	6.231	16.294	67.883	17.588	0.415	1.09324653
Agricultural	34.75	25.209	0.494	16.679	13.975	3.087	44.197	5.563	14.93	67.347	16.178	0.414	1.40365233
Agricultural	36.006	25.045	0.499	17.554	14.554	3.046	45.017	6.078	16.741	66.541	18.249	0.414	0.69486833
Agricultural	34.03	24.158	0.498	16.57	13.764	2.955	43.892	5.671	15.688	66.053	17.165	0.413	0.34713478
Agricultural	37.563	26.279	0.499	18.324	15.194	3.193	45.899	6.15	16.859	66.413	18.396	0.414	1.2389489
Agricultural	36.576	26.181	0.496	17.713	14.76	3.211	45.304	5.765	15.662	66.397	17.091	0.414	0.4217684
Agricultural	28.918	21.008	0.497	14.193	11.76	2.578	40.833	4.998	14.306	64.519	15.848	0.412	1.19670111
Agricultural	47.787	33.392	0.496	22.782	19.113	4.029	50.819	7.062	18.098	69.421	19.332	0.416	0.20763437
Agricultural	46	31.679	0.497	21.973	18.399	3.817	49.976	7.106	18.382	69.436	19.633	0.416	0
Agricultural	46.094	33.812	0.492	21.869	18.444	4.155	50.03	6.188	15.741	68.498	16.918	0.415	0
Agricultural	33.692	23.601	0.499	16.465	13.64	2.888	43.712	5.751	16.046	65.889	17.58	0.413	0
Agricultural	57.407	41.456	0.492	27.086	22.886	5.072	54.954	7.091	17.483	69.675	18.643	0.416	0.96118371
Agricultural	45.967	34.197	0.49	21.74	18.384	4.206	49.959	6.027	15.217	68.683	16.334	0.415	0.64008373
Agricultural	55.668	40.899	0.49	26.176	22.18	5.027	54.217	6.734	16.522	69.687	17.618	0.415	1.13136199
Agricultural	51.245	38.911	0.488	24.227	20.508	4.872	52.407	5.779	14.485	67.305	15.701	0.413	0.66492389
Agricultural	52.58	40.066	0.488	24.641	20.977	4.924	52.924	6.168	15.016	69.781	16.002	0.415	0.34713478
Agricultural	39.979	29.769	0.491	18.969	16.015	3.663	46.994	5.635	14.539	68.182	15.661	0.414	0.86923172
Agricultural	46.203	33.362	0.493	21.999	18.503	4.097	50.1	6.364	16.313	68.343	17.552	0.415	0.54195347
Agricultural	49.748	39.051	0.485	23.313	19.881	4.856	51.702	5.46	13.384	68.54	14.381	0.414	0.95741571
Agricultural	32.427	25.852	0.486	15.401	13.054	3.253	42.845	4.141	11.034	65.206	12.154	0.412	1.25777454
Agricultural	41.39	32.217	0.486	19.454	16.549	4.031	47.687	5.019	12.678	67.779	13.695	0.413	1.14674801
Agricultural	50.342	38.037	0.488	23.659	20.094	4.699	51.943	6.049	14.927	69.148	15.973	0.415	0.50987429
Agricultural	58.923	42.034	0.493	27.834	23.489	5.118	55.572	7.395	18.231	69.938	19.409	0.416	0.16196662
Agricultural	47.847	34.956	0.492	22.654	19.124	4.279	50.832	6.405	16.154	69.052	17.298	0.415	0.73591812
Agricultural	37.301	27.109	0.494	17.897	14.999	3.337	45.633	5.66	15.072	67.125	16.358	0.414	0.28103337
Agricultural	35.567	26.143	0.493	17.01	14.289	3.227	44.644	5.403	14.381	67.18	15.602	0.414	0.49526674
Agricultural	35.126	25.928	0.493	16.842	14.133	3.208	44.423	5.29	14.176	66.631	15.443	0.413	0.52465571
Agricultural	38.354	27.79	0.494	18.409	15.423	3.408	46.208	5.806	15.414	67.282	16.71	0.414	0.11527759
Agricultural	33.436	24.386	0.494	16.075	13.461	3.007	43.449	5.321	14.413	66.696	15.694	0.414	0.58534791
Agricultural	35.103	25.869	0.493	16.818	14.117	3.194	44.401	5.334	14.267	66.871	15.514	0.414	0.65040467
Agricultural	40.775	29.528	0.494	19.543	16.386	3.628	47.477	5.96	15.668	67.443	16.965	0.414	0.55254655

Agricultural	35.633	26.257	0.493	17.046	14.319	3.245	44.687	5.364	14.285	67.027	15.516	0.414	0.65001595
Agricultural	34.779	25.743	0.493	16.697	14.003	3.192	44.238	5.202	14.002	66.275	15.294	0.413	0.70372116
Agricultural	33.432	24.297	0.495	16.123	13.478	2.991	43.475	5.368	14.617	66.492	15.94	0.414	0.40671046
Agricultural	35.208	25.532	0.495	16.975	14.19	3.144	44.505	5.512	14.913	66.544	16.256	0.414	0.36229394
Agricultural	30.668	22.227	0.496	14.882	12.398	2.74	41.842	5.141	14.33	65.675	15.726	0.413	0.6734817
Agricultural	34.984	25.416	0.495	16.872	14.105	3.12	44.383	5.518	14.934	66.62	16.27	0.414	0.68178377
Agricultural	41.453	30.188	0.494	19.888	16.673	3.705	47.845	5.955	15.645	67.246	16.966	0.414	0.17376882
Agricultural	30.872	22.364	0.496	14.978	12.479	2.756	41.967	5.166	14.383	65.712	15.78	0.413	0.71172289
Agricultural	33.018	24.593	0.492	15.826	13.291	3.047	43.198	5.04	13.594	66.436	14.83	0.413	0.905148
Agricultural	33.798	24.66	0.495	16.345	13.647	3.046	43.722	5.303	14.508	65.888	15.895	0.413	0.98529172
Agricultural	29.904	22.022	0.495	14.511	12.098	2.735	41.371	4.839	13.568	64.881	14.985	0.412	0.84478772
Agricultural	35.711	26.163	0.494	17.179	14.386	3.227	44.781	5.433	14.614	66.52	15.934	0.413	0.83531
Agricultural	30.912	22.892	0.494	14.944	12.489	2.843	41.983	4.883	13.522	65.287	14.886	0.413	0.88456881
Agricultural	29.832	22.239	0.493	14.398	12.047	2.769	41.291	4.711	13.078	65.17	14.41	0.412	0.99559132
Agricultural	33.675	24.576	0.495	16.279	13.594	3.034	43.645	5.299	14.494	65.937	15.873	0.413	0.92967432
Agricultural	32.643	24.907	0.49	15.578	13.13	3.113	42.959	4.676	12.551	65.993	13.739	0.413	0.85570083
Agricultural	28.625	21.239	0.494	13.869	11.578	2.643	40.538	4.662	13.109	64.83	14.484	0.412	0.84966506
Agricultural	34.69	25.427	0.494	16.708	13.981	3.138	44.206	5.34	14.455	66.289	15.788	0.413	0.89652622
Agricultural	31.192	22.916	0.495	15.127	12.615	2.84	42.177	4.988	13.883	65.142	15.3	0.412	0.88980575
Agricultural	29.087	21.708	0.493	14.069	11.76	2.707	40.831	4.621	12.933	64.784	14.295	0.412	0.92158244
Agricultural	36.621	26.857	0.493	17.575	14.735	3.312	45.269	5.493	14.666	66.802	15.956	0.414	0.84509804
Agricultural	31.551	23.334	0.494	15.253	12.746	2.894	42.378	4.954	13.683	65.362	15.053	0.413	0.76192784
Agricultural	26.171	19.848	0.491	12.608	10.57	2.491	38.847	4.195	11.84	64.571	13.11	0.412	0.88868485
Agricultural	34.528	24.911	0.496	16.744	13.951	3.06	44.163	5.521	15.133	66.029	16.562	0.413	0.87569776
Agricultural	31.744	23.89	0.492	15.272	12.808	2.982	42.472	4.741	12.978	65.277	14.287	0.412	1.08873837
Agricultural	31.695	23.412	0.493	15.251	12.776	2.9	42.424	5.018	13.71	66.128	14.992	0.413	0.85107481
Agricultural	37.781	27.788	0.493	18.143	15.211	3.425	45.922	5.551	14.773	66.723	16.082	0.414	0.71290213
Agricultural	36.02	25.894	0.496	17.443	14.54	3.181	44.998	5.667	15.418	66.266	16.843	0.413	0.70139527
Agricultural	34.153	24.75	0.495	16.497	13.776	3.037	43.91	5.477	14.917	66.456	16.272	0.414	1.10886933
Agricultural	36.79	27.182	0.493	17.617	14.795	3.355	45.352	5.431	14.423	66.928	15.677	0.414	0.74904027
Agricultural	35.849	25.697	0.496	17.327	14.455	3.149	44.879	5.719	15.511	66.656	16.894	0.414	0.58703712
Agricultural	33.8	25.278	0.491	16.172	13.596	3.138	43.648	5.031	13.494	66.457	14.72	0.413	1.06152787
Agricultural	32.467	24.055	0.493	15.619	13.087	2.977	42.895	5.051	13.752	66.094	15.043	0.413	0.77458995
Agricultural	34.801	25.423	0.494	16.799	14.039	3.144	44.289	5.351	14.546	66.016	15.921	0.413	0.76797172
Agricultural	34.156	24.922	0.494	16.452	13.764	3.073	43.892	5.363	14.542	66.442	15.864	0.413	0.75365965
Agricultural	33.15	24.255	0.494	15.949	13.353	2.993	43.29	5.257	14.278	66.493	15.57	0.413	0.90644279
Agricultural	35.753	25.659	0.496	17.239	14.4	3.151	44.801	5.686	15.363	66.841	16.71	0.414	0.75724415
Agricultural	33.865	24.649	0.495	16.382	13.672	3.037	43.758	5.356	14.659	65.969	16.05	0.413	0.75534118
Irrigation ret	57.785	43.994	0.486	26.833	22.938	5.441	55.008	6.35	15.091	70.756	15.984	0.415	-0.537602
Irrigation ret	55.82	42.539	0.486	25.932	22.163	5.264	54.2	6.233	14.876	70.641	15.768	0.415	-0.35164
Irrigation ret	56.016	42.853	0.485	25.97	22.228	5.294	54.269	6.235	14.793	71.046	15.641	0.416	-0.0963675
Irrigation ret	62.039	46.823	0.487	28.856	24.63	5.789	56.713	6.658	15.789	70.627	16.737	0.416	0
Irrigation ret	61.611	47.113	0.485	28.542	24.435	5.85	56.521	6.412	15.074	70.894	15.953	0.415	0
Irrigation ret	58.015	44.762	0.484	26.787	22.986	5.563	55.058	6.13	14.38	71.266	15.184	0.415	-0.2284125
Irrigation ret	58.302	44.788	0.485	26.971	23.115	5.554	55.191	6.232	14.668	71.133	15.501	0.415	0
Irrigation ret	56.131	43.547	0.484	25.966	22.27	5.416	54.312	5.955	14.056	70.857	14.879	0.415	0
Upstream	52.895	41.05	0.485	24.611	21.05	5.082	53.004	5.858	14.051	70.183	14.935	0.415	0.50460677
Upstream	50.726	39.294	0.486	23.672	20.213	4.86	52.077	5.776	14.001	69.762	14.922	0.415	0.49540556
Upstream	50.583	39.152	0.486	23.615	20.159	4.841	52.017	5.785	14.037	69.738	14.963	0.415	0.46523409
Upstream	57.998	45.868	0.482	26.75	23.012	5.696	55.085	5.829	13.575	71.228	14.338	0.415	0.55461029

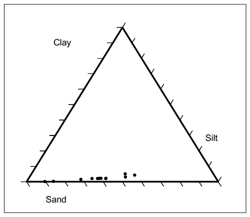
Upstream	57.607	44.832	0.485	26.778	22.922	5.547	54.992	6.061	14.371	70.37	15.257	0.415	0.6560982
Upstream	52.895	41.05	0.485	24.611	21.05	5.082	53.004	5.858	14.051	70.183	14.935	0.415	0.50460677
Upstream	50.726	39.294	0.486	23.672	20.213	4.86	52.077	5.776	14.001	69.762	14.922	0.415	0.49540556
Upstream	50.583	39.152	0.486	23.615	20.159	4.841	52.017	5.785	14.037	69.738	14.963	0.415	0.46523409
Upstream	57.998	45.868	0.482	26.75	23.012	5.696	55.085	5.829	13.575	71.228	14.338	0.415	0.55461029
Upstream	57.607	44.832	0.485	26.778	22.922	5.547	54.992	6.061	14.371	70.37	15.257	0.415	0.6560982
Coulee	58.789	39.324	0.499	28.051	23.456	4.692	55.539	8.371	21.178	70.214	22.507	0.417	0.20709554
Coulee	60.647	40.567	0.499	28.892	24.179	4.842	56.266	8.488	21.356	70.386	22.672	0.418	0
Coulee	65.687	44.309	0.498	31.217	26.168	5.307	58.196	8.642	21.478	70.432	22.794	0.417	0
Coulee	63.929	42.977	0.498	30.403	25.469	5.149	57.53	8.57	21.395	70.358	22.717	0.417	0
Coulee	62.786	42.131	0.498	29.823	24.995	5.049	57.071	8.528	21.293	70.51	22.587	0.418	0
Coulee	61.508	40.182	0.501	29.346	24.504	4.765	56.589	8.883	22.464	70.661	23.807	0.418	-0.6003263
Coulee	70.7499074	48.6249085	0.49453919	33.1345973	28.0279566	5.83839905	59.913987	8.75401756	20.9990034	72.0529732	22.0730374	0.41832176	0.48837429
Coulee	67.0646852	45.6378169	0.49748562	31.9284792	26.7439653	5.50725877	58.7365861	8.47214455	21.0870798	69.7640998	22.4742708	0.41670441	0
Coulee	36.5751852	27.4548803	0.48950466	17.2963286	14.6342528	3.40376746	45.1291242	5.24338786	13.59651	68.1397279	14.6499174	0.41416506	0.9143156
Streambank	57.881537	44.1886268	0.48643636	26.9485707	23.0229853	5.42843659	55.0960056	6.44252005	15.3268348	70.8069575	16.228897	0.41557741	0
Streambank	48.212	36.187	0.489	22.73	19.26	4.479	50.99	5.963	14.906	68.628	16.007	0.414	0.04414762
Streambank	53.131	40.193	0.487	24.838	21.151	4.966	53.114	6.192	15.046	69.864	16.025	0.415	-0.3685562
Streambank	56.106	42.167	0.488	26.347	22.372	5.22	54.419	6.367	15.552	69.17	16.64	0.415	0
Streambank	56.596	42.001	0.49	26.651	22.58	5.169	54.637	6.633	16.273	69.269	17.4	0.415	0
Streambank	50.752	37.85	0.491	24.087	20.334	4.658	52.213	6.234	15.688	68.086	16.909	0.414	0.44591541
Streambank	51.779	39.143	0.489	24.451	20.709	4.861	52.629	6.001	14.949	68.053	16.117	0.414	0
Streambank	54.095	40.757	0.489	25.472	21.6	5.056	53.6	6.19	15.262	68.603	16.392	0.414	0
Streambank	53.206	39.286	0.492	25.272	21.309	4.836	53.286	6.471	16.256	68.108	17.519	0.414	0
Streambank	53.664	40.735	0.487	25.036	21.348	5.028	53.328	6.203	14.983	70.187	15.925	0.415	0.19617619
Streambank	51.646	38.482	0.49	24.335	20.621	4.719	52.532	6.385	15.797	69.326	16.885	0.415	0
Streambank	58.91	44.057	0.488	27.503	23.42	5.42	55.502	6.7	16.083	70.458	17.066	0.416	0
Streambank	58.057	42.794	0.49	27.229	23.109	5.255	55.184	6.846	16.633	70.063	17.694	0.416	0
Streambank	54.84	39.914	0.492	25.867	21.871	4.886	53.89	6.854	16.944	69.584	18.08	0.416	0
Streambank	56.273	40.518	0.493	26.589	22.445	4.946	54.496	7.094	17.568	69.625	18.74	0.416	0
Streambank	58.235	43.089	0.49	27.339	23.195	5.3	55.272	6.773	16.482	69.771	17.565	0.415	0
Streambank	63.941	46.333	0.491	30.015	25.433	5.669	57.495	7.408	17.899	70.33	19.008	0.416	0
Streambank	63.463	46.716	0.489	29.692	25.228	5.741	57.297	7.13	17.102	70.406	18.153	0.416	-0.3605135
Streambank	57.637	41.431	0.493	27.22	22.982	5.066	55.053	7.164	17.693	69.648	18.872	0.416	-0.4111683
Streambank	68.277	50.189	0.488	31.726	27.046	6.182	59.017	7.365	17.338	71.309	18.304	0.416	0
Streambank	78.047	58.835	0.485	35.828	30.787	7.302	62.327	7.355	16.656	72.614	17.453	0.417	0
Streambank	54.564	42.025	0.486	25.46	21.737	5.169	53.747	6.135	14.737	70.225	15.661	0.415	-0.0510982
Streambank	50.922	38.556	0.488	23.901	20.322	4.713	52.199	6.231	15.266	69.873	16.258	0.415	-0.3893398
Streambank	54.337	40.746	0.489	25.575	21.693	5.002	53.7	6.44	15.808	69.341	16.895	0.415	-0.3297541
Streambank	53.061	40.06	0.489	24.981	21.199	4.919	53.166	6.288	15.463	69.2	16.542	0.415	0.07881918
Streambank	53.209	39.671	0.49	25.087	21.254	4.862	53.226	6.469	15.97	69.27	17.076	0.415	0
Streambank	52.558	39.905	0.488	24.596	20.943	4.912	52.887	6.181	15.036	69.889	16.012	0.415	0.51666756
Streambank	50.658	38.51	0.488	23.75	20.205	4.745	52.069	6.045	14.814	69.539	15.812	0.415	0.54629584
Streambank	54.659	40.161	0.491	25.757	21.802	4.925	53.816	6.709	16.547	69.503	17.665	0.415	0
Streambank	53.408	39.367	0.49	25.131	21.293	4.83	53.269	6.605	16.273	69.649	17.357	0.415	-0.1706962
Streambank	57.116	42.785	0.489	26.764	22.75	5.268	54.814	6.561	15.907	69.843	16.944	0.415	0.61193563
Streambank	50.465	36.836	0.492	23.886	20.165	4.507	52.024	6.573	16.48	69.117	17.639	0.415	0.2161659
Streambank	53.842	39.742	0.49	25.377	21.485	4.882	53.476	6.583	16.26	69.333	17.378	0.415	0.36492603
Streambank	59.541	45.457	0.487	27.884	23.732	5.662	55.818	6.231	15.054	68.962	16.129	0.414	0.07445072
Streambank	64.821	49.401	0.486	30.235	25.783	6.145	57.831	6.531	15.519	69.709	16.546	0.415	-0.0788339
Streambank	64.658	49.666	0.486	30.112	25.713	6.19	57.763	6.388	15.127	69.723	16.126	0.415	0
Streambank	55.152	41.743	0.488	25.845	21.983	5.156	54.009	6.282	15.276	69.513	16.307	0.415	-0.3372422
Streambank	52.466	38.681	0.49	24.71	20.927	4.743	52.87	6.557	16.211	69.545	17.302	0.415	0
Streambank	52.639	39.028	0.49	24.847	21.027	4.789	52.979	6.477	16.065	69.103	17.196	0.415	-0.2967086
Streambank	54.039	40.442	0.489	25.35	21.536	4.966	53.531	6.456	15.763	69.836	16.792	0.415	0
Streambank	61.385	47.508	0.485	28.579	24.423	5.919	56.508	6.156	14.622	69.682	15.592	0.414	-0.2580609
Streambank	51.446	38.547	0.489	24.145	20.51	4.733	52.409	6.307	15.484	69.763	16.502	0.415	-0.1290112
Streambank	55.374	42.058	0.487	25.918	22.064	5.199	54.095	6.242	15.133	69.606	16.145	0.415	0.17114115
Streambank	52.578	40.035	0.487	24.583	20.945	4.937	52.889	6.118	14.86	69.868	15.827	0.415	0.19256745
Streambank	53.843	40.636	0.488	25.151	21.427	4.995	53.414	6.347	15.357	70.311	16.311	0.415	-0.015923
Streambank	53.22	40.136	0.488	24.892	21.191	4.932	53.158	6.324	15.357	70.141	16.328	0.415	-0.0132283

Appendix L: Raw data for Stepwise Discriminant Function Analysis Chapter 3

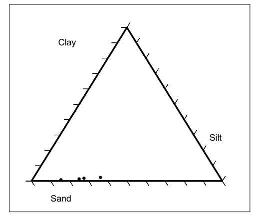
Source	G	X	Y	CS	Co	Fe	Source	G	X	Y	CS	Co	Fe
Irrigation ret	57.785	26.833	22.938	0.29	5972	11504	Agricultural l	35.711	17.179	14.386	2.522	4874.2515	12003.992
Irrigation ret	55.82	25.932	22.163	0.445	6255	12060	Agricultural l	30.912	14.944	12.489	7.312	4561.61616	11171.7172
Irrigation ret	56.016	25.97	22.228	0.801	5083	10291	Agricultural l	29.832	14.398	12.047	0.588	6875	14375
Irrigation ret	62.039	28.856	24.63	0	3763	7344	Agricultural l	33.675	16.279	13.594	0.445	5170.34068	12553.1062
Irrigation ret	61.611	28.542	24.435	0	3673	6494	Agricultural l	32.643	15.578	13.13	4.907	3966	10048
Irrigation ret	58.015	26.787	22.986	0.591	6512	12120	Agricultural l	28.625	13.869	11.578	2.924	3984.30584	9991.95171
Irrigation ret	58.302	26.971	23.115	0	5161	9639	Agricultural l	34.69	16.708	13.981	0.922	4858.28343	12566.8663
Irrigation ret	56.131	25.966	22.27	0	5929	11383	Agricultural l	31.192	15.127	12.615	1.027	4194.05941	11164.3564
Upstream	52.895	24.611	21.05	3.196	5730	13452	Agricultural l	29.087	14.069	11.76	0.605	3631.2	9328
Upstream	50.726	23.672	20.213	3.129	5592	12077	Agricultural l	36.621	17.575	14.735	1.561	5599.20635	13650.7937
Upstream	50.583	23.615	20.159	2.919	5842	13352	Agricultural l	31.551	15.253	12.746	2.502	4250	10987.9032
Upstream	57.998	26.75	23.012	3.586	6472	12340	Agricultural l	26.171	12.608	10.57	6.107	3683.93574	9546.18474
Upstream	57.607	26.778	22.922	4.53	6360	12004	Agricultural l	34.528	16.744	13.951	19.209	4927.41936	12080.6452
Coulee	58.789	28.051	23.456	1.611	6197	14225	Agricultural l	31.744	15.272	12.808	1.309	3919.11469	9167.00201
Coulee	60.647	28.892	24.179	0	5972	13440	Agricultural l	31.695	15.251	12.776	1.741	4015.93626	9669.32271
Coulee	65.687	31.217	26.168	0	5976	13435	Agricultural l	37.781	18.143	15.211	12.395	3609.65795	8720.32193
Coulee	63.929	30.403	25.469	0	5657	14223	Agricultural l	36.02	17.443	14.54	25.331	4908	11980
Coulee	62.786	29.823	24.995	0	5960	14535	Agricultural l	34.153	16.497	13.776	4.953	4272.54509	10456.9138
Coulee	61.508	29.346	24.504	0.251	5464	13079	Agricultural l	36.79	17.617	14.795	2.224	4907.63052	11967.8715
Agricultural l	48.974	23.314	19.641	0	4470	10131	Agricultural l	35.849	17.327	14.455	17.336	4989.89899	11806.0606
Agricultural l	53.978	25.629	21.605	0	4940	14171	Agricultural l	33.8	16.172	13.596	2.641	4751.00402	11417.6707
Agricultural l	53.528	25.507	21.437	0.835	4806	11165	Agricultural l	32.467	15.619	13.087	15.729	3864.67066	9876.24751
Agricultural l	52.924	25.053	21.154	1.737	4863	11133	Agricultural l	34.801	16.799	14.039	1.613	5104.9505	12253.4654
Agricultural l	52.381	24.932	20.971	1.219	5786	13734	Agricultural l	34.156	16.452	13.764	0	4361.82903	10254.4732
Agricultural l	56.893	26.808	22.703	0.987	5042	11535	Agricultural l	33.15	15.949	13.353	0	4883.53414	11690.7631
Agricultural l	52.441	24.889	20.993	1.377	4733	11367	Agricultural l	35.753	17.239	14.4	0	4969.81891	11963.7827
Agricultural l	51.607	24.529	20.672	3.337	4940	12210	Agricultural l	33.865	16.382	13.672	9.145	5142.85714	12297.6191
Agricultural l	51.612	24.588	20.671	1.314	5309	12541	Streambank	48.212	22.73	19.26	4.366	4024	9426.9
Agricultural l	52.881	25.16	21.14	0	5413	13162	Streambank	53.131	24.838	21.151	13.532	4473.2	9880.7
Agricultural l	56.263	26.605	22.451	0	5869	13623	Streambank	56.106	26.347	22.372	4.623	4918.2	10974.1
Agricultural l	49.482	23.451	19.813	4.331	5912	13194	Streambank	56.596	26.651	22.58	2.224	4941.4	10351.5
Agricultural l	46.062	22.05	18.505	3.019	5170	13214	Streambank	50.752	24.087	20.334	7.4	5465.6	12085
Agricultural l	46.518	22.189	18.681	4.886	5320	12668	Streambank	51.779	24.451	20.709	3.483	5044	11572
Agricultural l	41.354	19.972	16.688	7.087	5131	12187	Streambank	54.095	25.472	21.6	9.066	4261.9	10103.2
Agricultural l	40.611	19.653	16.378	6.874	5119.71888	12987.9518	Streambank	53.206	25.272	21.309	18.104	4139.7	10039.9
Agricultural l	57.448	27.152	22.919	4.451	5378.26613	13939.5161	Streambank	53.664	25.036	21.348	14.02	5209.7	11282.3
Agricultural l	44.454	21.31	17.861	4.78	5483.57143	12765.873	Streambank	51.646	24.335	20.621	3.235	4266.9	8661.4
Agricultural l	37.017	17.939	14.937	5.93	5622.68537	14032.0641	Streambank	58.91	27.503	23.42	1.452	4177.4	8915.3
Agricultural l	51.871	24.671	20.765	3.883	4800.23904	11760.9562	Streambank	58.057	27.229	23.109	5.444	5026.2	10929.6
Agricultural l	42.397	20.309	17.012	1.107	4725.4509	11038.0762	Streambank	54.84	25.867	21.871	1.91	5078.8	11074.7
Agricultural l	51.554	24.391	20.59	0.428	4440.47619	11460.3175	Streambank	56.273	26.589	22.445	3.128	5232.6	11355.9
Agricultural l	50.156	23.724	20.01	0	3986.4	9272	Streambank	58.235	27.339	23.195	3.347	4814.4	10686.6
Agricultural l	42.401	20.306	17.021	0	5400	13088	Streambank	63.941	30.015	25.433	1.304	6076.2	14897.8
Agricultural l	34.75	16.679	13.975	2.792	4580.64516	10963.7097	Streambank	63.463	29.692	25.228	3.849	5541.8	13713.1
Agricultural l	36.006	17.554	14.554	0	4784.70825	11279.6781	Streambank	57.637	27.22	22.982	4.471	7718.3	14495
Agricultural l	34.03	16.57	13.764	0	5107.56972	12362.5498	Streambank	68.277	31.726	27.046	3.569	5221.6	11868.3
Agricultural l	37.563	18.324	15.194	0	6476.95391	15659.3186	Streambank	78.047	35.828	30.787	4.467	6294.8	11000
Agricultural l	36.576	17.713	14.76	1.571	6505.9761	14585.6574	Streambank	54.564	25.46	21.737	5.055	3519.1	7852.6
Agricultural l	28.918	14.193	11.76	0	3928	10060	Streambank	50.922	23.901	20.322	2.551	3989.9	9456.7
Agricultural l	47.787	22.782	19.113	0	5478.08765	12322.7092	Streambank	54.337	25.575	21.693	2.303	4019.8	8464.3
Agricultural l	46	21.973	18.399	0	4268.31325	10477.9117	Streambank	53.061	24.981	21.199	4.715	4600.8	9991.9
Agricultural l	46.094	21.869	18.444	0	3686.84	9276	Streambank	53.209	25.087	21.254	4.806	4469.2	8827
Agricultural l	33.692	16.465	13.64	0	3964.48485	9579.79798	Streambank	52.558	24.596	20.943	1.492	5419.5	12008
Agricultural l	57.407	27.086	22.886	0	4425.79477	12197.1831	Streambank	50.658	23.75	20.205	5.149	5340	11871.2
Agricultural l	45.967	21.74	18.384	0	4047.24	9996	Streambank	54.659	25.757	21.802	8.038	6322.6	13572.6
Agricultural l	55.668	26.176	22.18	0.436	4147.83133	10975.9036	Streambank	53.408	25.131	21.293	9.667	5612.1	12101
Agricultural l	51.245	24.227	20.508	0.388	4582.73642	10040.2415	Streambank	57.116	26.764	22.75	6.995	5677.4	13016.1
Agricultural l	52.58	24.641	20.977	0	3860.92742	9463.70968	Streambank	50.465	23.886	20.165	6.844	5244.1	11578.7
Agricultural l	39.979	18.969	16.015	0	4371.52475	10356.4356	Streambank	53.842	25.377	21.485	7.666	5128.2	11471.4
Agricultural l	46.203	21.999	18.503	0.889	3922.3506	9836.65339	Streambank	59.541	27.884	23.732	9.899	4729.8	10608.9
Agricultural l	49.748	23.313	19.881	0.408	3689.50298	9920.47714	Streambank	64.821	30.235	25.783	8.505	4788	10644
Agricultural l	32.427	15.401	13.054	0.468	3501.65323	8705.64516	Streambank	64.658	30.112	25.713	7.173	4178.6	8944.4
Agricultural l	41.39	19.454	16.549	1.199	4655.17103	11050.3018	Streambank	55.152	25.845	21.983	7.074	4880.5	10589.6
Agricultural l	50.342	23.659	20.094	0	4173.50495	10752.4753	Streambank	52.466	24.71	20.927	7.88	5333.3	11670.6
Agricultural l	58.923	27.834	23.489	3.286	3013.92857	7944.44444	Streambank	52.639	24.847	21.027	7.759	4933.3	10917.2
Agricultural l	47.847	22.654	19.124	3.518	4177.0101	10581.8182	Streambank	54.039	25.35	21.536	8.348	5191.1	11227.4
Agricultural l	37.301	17.897	14.999	0	4024.09639	10020.0803	Streambank	61.385	28.579	24.423	7	4778.2	10568.5
Agricultural l	35.567	17.01	14.289	0.675	5428	13596	Streambank	51.446	24.145	20.51	5.78	5460.8	9814.9
Agricultural l	35.126	16.842	14.133	4.092	5132.53012	12742.9719	Streambank	55.374	25.918	22.064	7.739	5662.7	13622.5
Agricultural l	38.354	18.409	15.423	1.645	4168.33667	10192.3848	Streambank	52.578	24.583	20.945	7.511	4958.3	10755.5
Agricultural l	33.436	16.075	13.461	2.317	4963.85542	12309.237	Streambank	53.843	25.151	21.427	12.267	5337.3	10257.9
Agricultural l	35.103	16.818	14.117	1.187	5505.9761	13310.757	Streambank	53.22	24.892	21.191	7.097	5414.1	10254.5
Agricultural l	40.775	19.543	16.386	0.834	4622.22222	11466.6667	Agricultural l	44.858	21.319	18.017	5.163	3560	13848
Agricultural l	35.633	17.046	14.319	0	5258.51703	12985.9719	Agricultural l	48.481	23.049	19.444	5.028	4071	11398
Agricultural l	34.779	16.697	14.003	0.46	5273.09237	13148.5944	Agricultural l	45.863	21.96	18.403	12.849	5291	16056
Agricultural l	33.432	16.123	13.478	0	4095.80838	10155.6886	Agricultural l	58.038	27.211	23.101	5.611	4179	10422
Agricultural l	35.208	16.975	14.19	0.505	3960.24096	10244.9799	Agricultural l	53.987	25.473	21.547	3.864	3693	9570
Agricultural l	30.668	14.882	12.398	0	4829.65932	11923.8477	Agricultural l	37.796	18.218	15.219	11.522	4208	10600
Agricultural l	34.984	16.872	14.105	0.552	3832	9336	Agricultural l	53.914	25.157	21.464	5.951	3976	8934
Agricultural l	41.453	19.888	16.673	0.743	3269.32271	8239.04383	Agricultural l	47.264	22.499	18.936	5.861	6307	14458
Agricultural l	30.872	14.978	12.479	1.483	4415.32258	10451.6129	Agricultural l	35.331	17.071	14.239	5.671	5625	13426
Agricultural l	33.018	15.826	13.291	1.558	4678.64272	11105.7884	Agricultural l	50.634	23.733	20.201	8.062	3538	8277
Agricultural l	33.798	16.345	13.647	0.964	4933.86774	11895.7916	Agricultural l	56.484	26.655	22.535	5.718	5247	13339
Agricultural l	29.904	14.511	12.098	0.97	4580	11964	Agricultural l	37.464	17.935	15.059	5.693	4613	11585

Appendix M: Particle Size Results for 2009-2013 samples

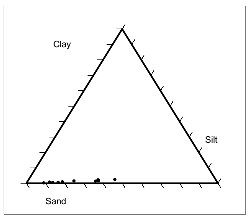
BL09



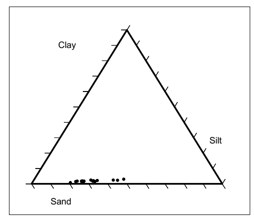
BL11



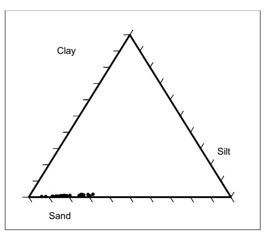
BL10



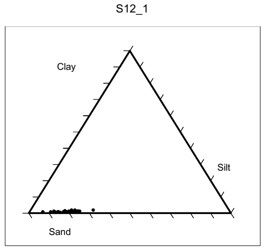
BL12



S12_0



S12_1



Appendix N: Residence time experiment

N. 1 Soil Source Residence Time Protocol

Objective: This experiment will assess the potential for shifts in the VIS colour spectra (350 – 2500 nm wavelength) resulting from a transition from oxidized soil to reduced sediment. If soil has settled for a certain period of time in water, will the colour coefficients, R, G, B, x, y, X, Y, Z, L, u, v, a, b and h change compared to a control soil that has not been exposed to reduction by the addition of water.

Equipment required:

- Deionized water
- Mason jars (1L)
- Filter papers
- Erlenmeyer flask (equipment to filter, suctioning)
- < 63 um sieve

1. Begin with minimum 500 g of 2 mm sieved soil
2. Set up sample groups
    - Time blocks x number of soil source groups
    - ex. For control (0 hours), 48 hours, 4 days, 8 days, 16 days, 2 months
        - 5 time blocks x [2 replicates x 3 soil sources] soil sources = 30 samples
        - control does not need to be placed in mason jar

3. Measure the Eh, pH and temperature of deionized water being used

4. Take 50 g of 2 mm soil sample, place in mason jar

- Rinse mason jars with deionized water 3 times
- Fill all sample jars with 50 g of soil and add 0.5L deionized water
- Stir all jars to mix water and soil with metal stirring rod
    - 10 minutes each
- cover mason jars
- Let sit in a cool, dark, stable environment

5. First time block (ex. 24 hours)

- Decant both mason jar replicates separately using filter paper to catch any sediment in suspension
    - Remove water from jar with least amount of disturbance to settled soil as possible – i.e. Using a syringe to remove water
- Mason jars placed in oven
    - Dry at just above room temperature – i.e. 35 – 38 degrees Celsius
- After 48 hours, remove from oven
    - Empty mason jar into Ziploc bags, shake filter paper into Ziploc bag, close and shake for light mixing

6. Any following time blocks

- Follow procedure in #4

7. After final time block, analyze all samples for colour

- Analyze as they are after drying, using diffuse reflectance spectrometry in CEOS lab

- Ex. 30 residence sample mason jars plus 6 control samples (2 from each source group that had no residence time, from the 2-mm sieved soil)

8. After initial colour analysis, sieve all samples to < 63 um

- After sieving, analyze using diffuse reflectance spectrometry in CEOS lab

N.2 Results

Table N.1

Particle Size	Tracer	Source	Residence time (days)	Mean	Tukey Grouping	
63 um	L	Surface soil	Control	43.2079	A	
			2	42.7741	A	
			4	42.5940	A	
			8	42.7598	A	
			16	42.6291	A	
			60	42.6746	A	
		Coulee	Control	54.4437	A	
			2	53.6552	A	B
			4	52.6876	C	B
			8	52.7701	C	B
			16	51.5766	C	
			60	52.8615	A/C	B
		Subsoil	Control	57.8994	A	
			2	56.6395	A	
			4	56.1657	A	
			8	55.4462	A	
			16	55.6094	A	
			60	55.7979	A	
	X	Surface soil	Control	15.7779	A	
			2	15.3812	A	
			4	15.2138	A	
			8	15.3333	A	
			16	15.2038	A	
			60	15.1985	A	
		Coulee	Control	26.3634	A	
			2	25.4688	A	B
			4	24.4284	C	B
			8	24.4830	C	B
			16	23.1113	C	
			60	24.4310	C	B
		Subsoil	2	30.5730	A	
			4	28.9460	A	
			8	27.5010	A	
			16	27.6520	A	
			60	27.8410	A	
	Y	Surface soil	Control	13.2974	A	
			2	13.0137	A	
			4	12.8892	A	

			8	13.0016	A	
			16	12.9115	A	
			60	12.9427	A	
		Coulee	Control	22.3951		
			2	21.6519	A	
			4	20.7750	A	B
			8	20.8367	C	B
			16	19.7719	C	
			60	20.9197	C	B
		Subsoil	Control	25.8552	A	
			2	24.5745	A	
			4	24.0875	A	
			8	23.3688	A	
			16	23.5276	A	
			60	23.7152	A	
	G	Surface soil	Control	33.0620	A	
			2	32.4110	A	
			4	32.1320	A	
			8	32.4180	A	
			16	32.2150	A	
			60	32.3120	A	
		Coulee	Control	56.3226	A	
			2	54.4373	A	B
			4	52.2447	C	B
			8	52.4066	C	B
			16	49.8291	C	
			60	52.6951	C	B
		Subsoil	Control	64.7450	A	
			2	61.6400	A	
			4	60.4190	A	
			8	58.6560	A	
			16	59.0840	A	
			60	59.5890	A	

Table N.2

Particle Size	Tracer	Source	Residence time (days)	Mean	Tukey Grouping	
2 mm	L	Surface soil	Control	39.5410	A	
			2	41.0650	A	
			4	40.4060	A	
			8	39.8360	A	
			16	41.4640	A	
			60	40.5550	A	
		Coulee	Control	50.2360	A	
			2	52.4064	A	
			4	51.7489	A	
			8	51.9727	A	
			16	50.9606	A	
			60	51.9759	A	
		Subsoil	Control	55.5556	A	
			2	55.4169	A	
			4	55.4777	A	
			8	55.4688	A	
			16	55.2920	A	
			60	54.9622	A	
	X	Surface soil	Control	12.9080	A	
			2	14.0391	A	
			4	13.5207	A	
			8	13.0884	A	
			16	14.2507	A	
			60	12.9080	A	

		Coulee	Control	21.7491	A	
			2	23.9510	A	
			4	23.2906	A	
			8	23.4943	A	
			16	22.4216	A	
			60	23.3773	A	
		Subsoil	Control	27.5899	A	
			2	27.3755	A	
			4	27.4260	A	
			8	27.3651	A	
			16	27.1418	A	
			60	26.7383	A	
	Y	Surface soil	Control	10.9765	A	
			2	11.9282	A	
			4	11.4984	A	
			8	11.1526	A	
			16	12.1569	A	
			60	11.6123	A	
		Coulee	Control	18.6170	A	
			2	20.5100	A	
			4	19.9282	A	
			8	20.1318	A	
			16	19.2356	A	
			60	20.1301	A	
		Subsoil	Control	23.4724	A	
			2	23.3461	A	
			4	23.4011	A	
			8	23.3872	A	
			16	23.2143	A	
			60	22.8945	A	
	G	Surface soil	Control	27.3980	A	
			2	29.7610	A	
			4	28.7070	A	
			8	27.8620	A	
			16	30.3930	A	
			60	29.0480	A	
		Coulee	Control	46.9560	A	
			2	51.7290	A	
			4	50.2470	A	
			8	50.7860	A	
			16	48.5330	A	
			60	50.8380	A	
		Subsoil	Control	58.9330	A	
			2	58.6860	A	
			4	58.8470	A	
			8	58.8510	A	
			16	58.4450	A	
			60	57.6640	A	

Table N.3 Raw data for four replicates of coulee, subsurface and surface material

	id	X	Y	Z	x	y	L	u
1	coulee_0_da	29.4205543	24.5875905	4.82558982	0.50006267	0.41791653	56.6713642	19.287236
2	coulee_0_da	30.360476	25.4343291	5.06366755	0.49887016	0.41792585	57.4961774	18.9840376
3	coulee_0_da	30.7328352	25.7456046	5.11696819	0.49894686	0.41797929	57.7947877	19.1006274
4	coulee_0_da	30.2393192	25.2982864	4.9774332	0.49969925	0.41804958	57.3649046	19.2983776
5	coulee_16_d	25.9629352	21.6539645	4.18147381	0.5012307	0.41804333	53.6579137	18.7494001
6	coulee_16_d	25.7497722	21.4365341	4.07893861	0.50228517	0.41814945	53.4239807	19.1089974
7	coulee_16_d	25.2522771	21.0178644	4.00203882	0.50231116	0.41808142	52.9690405	18.980909
8	coulee_16_d	25.4635214	21.194033	4.03876132	0.50227558	0.41805864	53.1612008	19.04145
9	coulee_4_da	28.717044	23.958415	4.64508384	0.50099044	0.41797258	56.0461344	19.4950088
10	coulee_4_da	29.355047	24.5179562	4.79828294	0.50033072	0.4178868	56.6026953	19.4030619
11	coulee_4_da	29.6747016	24.7836779	4.83155278	0.50050153	0.4180082	56.864039	19.5311145
12	coulee_4_da	29.2429114	24.416889	4.76486064	0.50052342	0.41792094	56.5027978	19.448817
13	coulee_60_d	25.359561	21.1528363	4.10457976	0.501009	0.41790003	53.1163601	18.5087653
14	coulee_60_d	24.8068608	20.6559552	3.96081141	0.50192311	0.41793685	52.5708842	18.7137131
15	coulee_60_d	26.0065587	21.6839689	4.17925175	0.50138171	0.41804629	53.6900722	18.8283263
16	coulee_60_d	26.0442156	21.7406536	4.23333083	0.50067506	0.41794321	53.7507456	18.5629843
17	coulee_8_da	26.2706187	21.8919083	4.20637672	0.50164538	0.41803259	53.9121293	19.0313671
18	coulee_8_da	26.425187	21.9970013	4.17912242	0.50236746	0.41818352	54.0238227	19.3495086
19	coulee_8_da	25.4682398	21.2237473	4.07743221	0.50164528	0.41804196	53.1935073	18.7744732
20	coulee_8_da	25.2742746	21.0113893	3.96979159	0.50291604	0.41809171	52.9619573	19.2465319
21	subsurface_(	27.8847361	23.6443229	5.30596763	0.4906259	0.41601675	55.7299095	15.181788
22	subsurface_(	27.9818824	23.7172836	5.29992513	0.49091804	0.41609933	55.8036142	15.3109967
23	subsurface_(	27.5674285	23.3677358	5.2168161	0.49094312	0.41615159	55.4491172	15.2074328
24	subsurface_(	27.1858154	23.0295278	5.12049874	0.49128764	0.41617742	55.1027395	15.2640746
25	subsurface_1	24.9356392	21.2729818	4.88569167	0.4880316	0.41634735	53.2469706	13.2294458
26	subsurface_1	25.1454728	21.4793778	4.96971482	0.48736669	0.41631086	53.470201	12.9970378
27	subsurface_1	24.4970658	20.9581582	4.88886106	0.48659273	0.41629832	52.9036711	12.518131
28	subsurface_1	24.628725	21.0907519	4.94962908	0.48606986	0.4162448	53.0486741	12.3360779
29	subsurface_4	26.7132821	22.7322182	5.17248426	0.48909315	0.4162039	54.7954361	14.1538123
30	subsurface_4	27.2470461	23.2232285	5.35927267	0.48803989	0.41596663	55.3015309	13.8739704
31	subsurface_4	27.7452735	23.6448485	5.44026823	0.48821191	0.41605994	55.7304411	14.0303392
32	subsurface_4	27.4538866	23.3585458	5.3135459	0.48914758	0.41618064	55.4397495	14.3537195
33	subsurface_6	24.941126	21.1987411	4.78044625	0.489807	0.41631207	53.1663215	14.0178566
34	subsurface_6	25.2097932	21.4918956	4.91105413	0.48844126	0.41640677	53.4836936	13.4534852
35	subsurface_6	25.4798966	21.7108891	4.95414601	0.48863611	0.41635665	53.7188999	13.6176403
36	subsurface_6	24.932192	21.2150714	4.80300911	0.48934364	0.41638779	53.1840776	13.7894513
37	subsurface_8	25.602294	21.7914366	4.96545828	0.48897423	0.41619126	53.8050126	13.8481685
38	subsurface_8	24.9143109	21.2153502	4.8492009	0.48871846	0.41615974	53.1843807	13.5839546
39	subsurface_8	25.1249654	21.4097503	4.899112	0.48849107	0.41625816	53.3950548	13.5027268
40	subsurface_8	25.4856692	21.7359976	4.99210169	0.48810247	0.41628862	53.745766	13.4050209
41	surface_0_da	17.5742645	14.7391092	3.31985496	0.49319877	0.41363384	45.2747763	13.9984993
42	surface_0_da	16.6352644	13.9315671	3.12000108	0.49382097	0.41356121	44.1346304	13.899914
43	surface_0_da	17.0201392	14.2590468	3.19029274	0.4937742	0.41367167	44.6021671	13.9982106
44	surface_0_da	17.2686296	14.4640972	3.24209674	0.49374458	0.4135574	44.8912795	14.1101115
45	surface_16_(	15.1263839	12.7520277	2.91218537	0.49126634	0.41415331	42.387212	12.2709341
46	surface_16_(	15.0204364	12.6478915	2.87347811	0.49179922	0.41411734	42.2278427	12.4253901
47	surface_16_(	14.4589365	12.1801726	2.79130948	0.49129225	0.41386338	41.5010538	12.0991133
48	surface_16_(	14.9203315	12.5717462	2.86880648	0.49143271	0.41407708	42.1107558	12.2705417
49	surface_4_da	17.4738909	14.712575	3.37275238	0.49140256	0.41374855	45.2379841	13.2636228
50	surface_4_da	16.7234472	14.0626197	3.20361409	0.49201542	0.41373203	44.322602	13.2306676
51	surface_4_da	17.2582066	14.5227289	3.31452385	0.49175041	0.41380649	44.9734449	13.3025808
52	surface_4_da	17.4417273	14.6719471	3.32501466	0.49216627	0.41400931	45.1815639	13.4660803
53	surface_60_(	14.7166559	12.4456743	2.9238809	0.48914953	0.41366705	41.9158542	11.5091369
54	surface_60_(	14.387028	12.1480721	2.83710286	0.48981781	0.41359077	41.4504952	11.6362923
55	surface_60_(	15.7301405	13.2997734	3.10293984	0.4895345	0.41389954	43.211501	11.9432054
56	surface_60_(	14.6647941	12.3959559	2.90627228	0.48936441	0.41365324	41.8386299	11.5678488
57	surface_8_da	16.2866049	13.7163417	3.16248636	0.49107168	0.41357342	43.8233534	12.773923
58	surface_8_da	16.7354135	14.1021358	3.2510772	0.49093833	0.41369035	44.3790515	12.8530081
59	surface_8_da	16.5688283	13.9573186	3.20698999	0.49117366	0.41375691	44.1716591	12.8627636
60	surface_8_da	15.5425811	13.0778237	2.96399668	0.49209674	0.41405957	42.8802731	12.7413011

	id	v	a	b	h	c	R	G	B
1	coulee_0_da	8.79195486	7.80072079	22.1699931	1.23246597	23.5023368	154.631868	130.078975	96.6517452
2	coulee_0_da	8.78625185	7.62854876	21.9232854	1.23593506	23.2126086	156.500464	132.333313	99.1086756
3	coulee_0_da	8.85537598	7.66235419	22.071722	1.23665643	23.3639163	157.381084	133.074909	99.5732376
4	coulee_0_da	8.89441087	7.76225696	22.295245	1.23576387	23.60785	156.438151	131.89013	98.1150732
5	coulee_16_d	8.48137264	7.68551824	21.7835417	1.23161763	23.0995645	146.369982	122.485327	89.9986507
6	coulee_16_d	8.58335876	7.84878833	22.1904833	1.23082853	23.5376513	146.088694	121.763878	88.7093007
7	coulee_16_d	8.49589685	7.81916408	22.0227522	1.22963029	23.3696585	144.811789	120.635158	87.9134437
8	coulee_16_d	8.51720719	7.83928149	22.0586141	1.22933303	23.4101856	145.358584	121.105564	88.3153372
9	coulee_4_da	8.81324864	7.91608543	22.3942218	1.23101767	23.75217	153.196127	128.386454	94.7232216
10	coulee_4_da	8.80345508	7.85825643	22.2464875	1.23124172	23.5936093	154.559202	129.857225	96.3509409
11	coulee_4_da	8.89622299	7.89200214	22.4597311	1.2328886	23.8059493	155.347855	130.500904	96.6005746
12	coulee_4_da	8.81873024	7.87984437	22.313794	1.23132887	23.6642631	154.339913	129.584179	95.984531
13	coulee_60_d	8.33618798	7.6156256	21.4562145	1.2297292	22.7676721	144.771931	121.167612	89.2778089
14	coulee_60_d	8.3553559	7.73085467	21.6701302	1.22811938	23.007839	143.560275	119.697708	87.585735
15	coulee_60_d	8.50333277	7.719274	21.8564057	1.23129019	23.1795095	146.523229	122.540333	89.9480239
16	coulee_60_d	8.41109546	7.6063897	21.5388384	1.23132014	22.8424763	146.444205	122.78284	90.6614978
17	coulee_8_da	8.56326194	7.80142105	22.0270552	1.23040744	23.3677841	147.275762	123.039071	90.1857389
18	coulee_8_da	8.69731216	7.92510699	22.4328517	1.2312013	23.7915985	147.841749	123.225389	89.7278261
19	coulee_8_da	8.45147452	7.71892553	21.8051202	1.23056603	23.1310414	145.202695	121.282086	88.8398351
20	coulee_8_da	8.56109471	7.93826157	22.271477	1.22840319	23.6439143	145.030709	120.52339	87.4585822
21	subsurface_(	7.09645061	6.17226582	17.2324765	1.22685609	18.3045107	148.505702	128.938801	103.178884
22	subsurface_(	7.16026474	6.22036276	17.3999739	1.2274622	18.4784199	148.81323	129.090336	103.061638
23	subsurface_(	7.13144946	6.1818508	17.3478604	1.22847876	18.4163932	147.801105	128.213842	102.276487
24	subsurface_(	7.13133819	6.21852512	17.4060792	1.22766701	18.4835507	146.961487	127.300983	101.322407
25	subsurface_1	6.59153617	5.34060992	15.8394951	1.24559634	16.7156131	140.29162	123.252604	99.4800042
26	subsurface_1	6.53952011	5.22824359	15.6341246	1.24807502	16.4851565	140.642112	123.904405	100.383018
27	subsurface_1	6.38614385	5.02859214	15.2252125	1.25179576	16.0341459	138.742941	122.618647	99.7034787
28	subsurface_1	6.33520503	4.94369359	15.0478447	1.25337348	15.8391205	138.940378	123.050241	100.36727
29	subsurface_4	6.86048817	5.72078972	16.521483	1.23745394	17.4839022	145.131309	126.900392	102.103681
30	subsurface_4	6.74554633	5.59625158	16.1386397	1.2370099	17.0813853	146.176462	128.287203	104.031437
31	subsurface_4	6.84183774	5.64336063	16.3428243	1.23830468	17.2897491	147.424574	129.348007	104.726175
32	subsurface_4	6.94093199	5.79033583	16.6815504	1.23669828	17.6579193	146.976319	128.491923	103.411235
33	subsurface_6	6.75924235	5.71051728	16.4494049	1.23665697	17.4124361	140.830621	122.766085	98.2328477
34	subsurface_6	6.67942542	5.42963824	16.0687624	1.24494123	16.9613117	141.105492	123.785739	99.6582761
35	subsurface_6	6.71656462	5.5009754	16.1717796	1.24291536	17.0817794	141.863103	124.328603	100.059227
36	subsurface_6	6.73207727	5.59769952	16.3185355	1.24034692	17.2519228	140.658456	122.897421	98.4964618
37	subsurface_8	6.72055761	5.61901486	16.2411269	1.23771224	17.1856781	142.306497	124.456883	100.162557
38	subsurface_8	6.6080735	5.52374708	15.9900323	1.23818123	16.9172372	140.473613	122.954018	99.0814091
39	subsurface_8	6.63549031	5.46930251	16.0000852	1.24141873	16.9090507	140.930985	123.530174	99.5714097
40	subsurface_8	6.64564382	5.40828096	15.9530962	1.24394428	16.8449037	141.733267	124.467364	100.508198
41	surface_0_da	5.47602368	6.25990703	14.6082841	1.16595001	15.8930299	121.086316	102.638943	82.5734997
42	surface_0_da	5.37721867	6.2705042	14.5072647	1.16281608	15.8044283	118.189108	99.8359326	80.0524564
43	surface_0_da	5.45387142	6.28699408	14.6486581	1.16538573	15.9408117	119.426441	100.968172	80.9127393
44	surface_0_da	5.4617593	6.33636523	14.6634738	1.16291133	15.9739472	120.245965	101.639425	81.5786524
45	surface_16_(	5.07055422	5.52036558	13.5200038	1.18314593	14.6035933	112.376923	96.1395342	77.5454147
46	surface_16_(	5.08882098	5.60543069	13.6330595	1.18070255	14.7404601	112.135641	95.689482	76.9878782
47	surface_16_(	4.90848077	5.50016652	13.2149661	1.17639661	14.31388	110.071789	94.005967	75.9930262
48	surface_16_(	5.03586861	5.53882843	13.4782283	1.18088922	14.571934	111.706512	95.4547145	76.9717397
49	surface_4_da	5.33522608	5.90277029	14.063873	1.17341354	15.2523841	120.307368	102.817983	83.3882205
50	surface_4_da	5.27767994	5.92853965	14.0417811	1.17129367	15.2420209	118.022832	100.553402	81.2595622
51	surface_4_da	5.34771092	5.92811266	14.1375037	1.17374804	15.3300858	119.689516	102.149332	82.6345982
52	surface_4_da	5.45410572	5.98028601	14.4004339	1.17718296	15.5928291	120.34902	102.621621	82.6754125
53	surface_60_(	4.73944031	5.20863079	12.5908104	1.17854839	13.6256501	110.524853	95.2251809	78.0008822
54	surface_60_(	4.72645429	5.29739991	12.6604571	1.1745114	13.7240526	109.519518	94.0327428	76.801775
55	surface_60_(	4.9676076	5.34468411	13.0785026	1.18284527	14.1284422	114.084704	98.2747606	80.2265861
56	surface_60_(	4.74574151	5.24178152	12.6331959	1.17749334	13.6774966	110.393625	95.0135676	77.7511086
57	surface_8_da	5.10242426	5.74442712	13.5676448	1.17028878	14.7336156	116.374764	99.4699211	80.8788482
58	surface_8_da	5.18050896	5.74863799	13.6970035	1.17342303	14.854452	117.809254	100.826288	81.9691128
59	surface_8_da	5.19117689	5.75702283	13.7499454	1.17427882	14.9065191	117.306925	100.312491	81.3867696
60	surface_8_da	5.1808043	5.73261813	13.8563237	1.17851984	14.9953532	114.023098	97.1802383	78.1512952