Priorities for improving sediment pollution in the South Platte Headwaters Watershed

Results of a Watershed Assessment of River Stability and Sediment Supply (WARSSS) study

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Purpose

Our overarching goal is to improve water quality and ecological condition of the upper South Platte River watershed. Excess sediment and its consequences are thought to be an important source of ecological degradation throughout the watershed[1], and the need for mitigation and restoration, and for water and land protection is well understood. While the problem of sediment pollution and the need for action has been recognized, the extent of the problem and locations of primary concern are not well documented. This study aims to fill this knowledge gap by identifying locations where activities could produce the greatest improvements. The specific goal of this study is to complete a systematic assessment of all the reaches in the watershed to create a priority list to direct future efforts that aim to improve the state of sediment pollution in the watershed. Prioritization is accomplished using a Watershed Assessment of River Stability and Sediment Supply (WARSSS).

Methods

WARSSS methodology

Our methods for assessing the watershed and prioritizing reaches follow directly from WARSSS. WARSSS is a process for assessing sediment impairment developed by the Environmental

[1] The Upper South Platte Watershed located in Park County is recognized by multiple agencies as a priority for identification and protection of its natural resources. The South Platte basin is listed as a priority in 2010 by the Colorado Department of Health and Environment Non-point Source Program (NPS). In addition, the Environmental Protection Agency (EPA) has recognized the watershed as sediment impaired. The Upper South Platte was a FY2008 Priority 1 for Tier 2, 319 base activities funding, with 303(d) listed segments (COSPUS02a – sediment).

Protection Agency (EPA) and Dave Rosgen[2]. It is designed to "reveal significant, adverse influences of land uses on stream channel stability, sediment sources, and sediment yield that may affect the material beneficial uses of rivers and streams." It is intended to be used for watershed planning, TMDL assessments for clean sediment non-point source pollution, and a stability analysis for river restoration.

The WARSSS process consists of 3 phases of assessment and ongoing monitoring:

1. *Phase 1: Reconnaissance Level Assessment (RLA).* This phase is a rapid scan of the watershed to identify locations with land uses that could adversely impact sediment supply or stream stability. In RLA, the watershed is delineated into individual reaches and sub-watersheds and each is assessed independently using specific criteria to evaluate observable impacts to surface erosion, mass erosion, streamflow change, channel processes, and direct channel impacts. Reaches that are determined in RLA to have potential for anthropogenic impacts with sediment or stream stability consequences are assessed in greater detail in phase 2 (RRISSC).

2. *Phase 2: Rapid Resource Inventory for Sediment and Stability Consequences (RRISSC).* This phase of WARSSS is a more detailed qualitative assessment of reaches in the watershed for which anthropogenic impacts to sedimentation or stability are suspected. In RRISSC, each reach is classified by stream type. Then, human impact on 11 specific sediment-related factors (grouped into three types of processes) are assessed for each reach: Hillslope processes (mass erosion, surface erosion, and roads); Hydrologic processes (changes in streamflow); and Channel processes (streambank erosion potential, enlargement, aggregation/ excess sediment, channel evolution, degradation, direct impacts, and in-channel mining). For each factor, observable indicators are used to assess risk according to specific criteria outlined in the method. The result is a risk rating for each of the 11 factors for each reach. Based on these factor ratings, an overall RRISSC rating is also assigned to each reach. RRISSC ratings range from 1 - 5 (very low risk to very high risk). Reaches that receive risk ratings of moderate, high or very high are recommended for quantitative assessment in phase 3 (PLA), or prescribed for specific treatment.

3. *Phase 3: Prediction Level Assessment (PLA).* The PLA phase of WARSSS involves making detailed quantitative studies of specific reaches or groups of reaches with the goal of

[2] *Rosgen, D.L. (2006). Watershed Assessment of River Stability and Sediment Supply (WARSSS). Wildland Hydrology Press. Fort Collins, CO.* A detailed website is also available for information about the WARSSS methodology at http://www.epa.gov/warsss/index.htm.

predicting degrees of channel instability, departure from reference condition, and actual sediment volume yields by source and process. PLA studies are specifically designed to inform management decisions and restoration or mitigation designs by quantifying the potential for improvement by different options.

4. *WARSSS Monitoring*. In addition to the three phases of assessment, the WARSSS process specifies monitoring procedures for validating predictions made in PLA and for evaluating effectiveness of specific management changes, mitigation practices, or restoration activities. The watershed and our knowledge of it are constantly changing and growing. Monitoring provides a means to update and adapt the WARSSS assessment and the recommendations that follow from it based on increasingly precise quantitative information about sediment processes in general and on understanding the effects of various mitigation measures.

For a detailed description of the methodology, consult the reference[2].

In this study we completed the RLA and RRISSC phases of WARSSS for the South Platte Headwaters watershed, and the results are discussed in this report for use in setting priorities. We also have a considerable amount of work completed in PLA on various reaches in addition to 6 years of validation and effectiveness monitoring throughout the watershed under the direction of Park County. The knowledge gained from past and present PLA/monitoring studies was useful for making RRISSC assessments, the detailed results from these studies are beyond the scope of this report. The present study is meant to "take a step back" to do a thorough review of the entire watershed and to reorganize our prediction and monitoring efforts based on the findings in RLA and RRISSC. This report is focused on the results of the RLA and RRISSC analysis.

Interpretation of WARSSS risk ratings for prioritization

The RLA and RRISSC assessments combine to produce a risk rating for each reach in the watershed, and interpretations of the rating are used for prioritization. Ratings are from 1 to 5, and each category is color-coded as described below:

5 Very high risk (red)

4 High risk (orange)

3 Moderate risk (yellow)

1-2 Very low or low risk (green)

Reaches that score 5 (very high risk) are considered "red flags". These are locations where the level of human impact is extreme or there is some reason to believe there is especially acute instability or extremely great sediment production. Red flag reaches are the highest priority for advancement to PLA and the most obvious targets for **restoration or mitigation**. Because problems on these reaches are presumed to be so severe that direct mechanical treatments may be required to mitigate the hazard. Restoring these reaches or mitigating impacts at these locations may have the greatest positive influence on the system as a whole, but may also be the most invasive and expensive.

Reaches in the 4 (high risk) category are flagged orange. According to WARSSS protocol, "orange flag" reaches, like red flags, are also high priority for mitigation or restoration and also recommended for direct advancement to PLA. While secondary to red flag reaches in terms of priority, improvement opportunities on orange flags should be considered. These reaches have a disproportionately high degree of instability or sediment yield. Whereas the problems may not be as severe or acute as on red flag areas, mitigation may be simpler and/or less expensive. This is where quantitative PLA assessment methods may be the most useful in decision-making. By quantifying the amount of sediment pollution that can reasonably be mitigated on these reaches, and by investigating the potential for less intensive restoration options, PLA studies may be used for cost-benefit analyses to compare the merits of competing projects.

There are two groups that comprise the 3 (moderate risk) "yellow flag" category. Some of the reaches in this category are determined to have significant anthropogenic instability or sediment production, but to a less severe degree than high risk reaches. On these reaches, the degree of impairment is either thought to be acceptable or mitigable by simple changes to land management. Where the evaluator is confident in the process or factor that is impaired, specific prescriptions for land use change may be made directly, without further study in PLA. The other group of yellow flag reaches contains those for which the degree or nature of human impact could not be determined with confidence in RRISSC. These reaches are considered a low priority for mitigation or restoration, but further assessment in PLA is recommended to make a judgment about whether a higher prioritization is warranted.

Reaches that score 2 (low risk) or 1 (very low risk) are "green flags". These tend to be the least-impacted or most stable. They are considered functional and therefore not candidates for mitigation, restoration or additional study in PLA. As functional components of the watershed, green reaches are a high priority for **protection**. The rationale is that these areas are in good condition and the best thing we can do is to protect them from future harm. These well-functioning reaches are also valuable as references to help assess departure of impaired reaches and to direct the form of future restoration. Additionally, they can be used as templates for understanding best management practices and applying these techniques across the watershed.

Results

The RLA phase was completed on the South Platte Headwaters in December 2008. During this phase the watershed network was divided into 278 reaches among four primary drainages (Michigan-Jefferson, Tarryall, Middle Fork South Platte, and South Fork South Platte), and each reach was assessed individually. On 103 of the total 278 reaches, RLA assessment yielded a rating of low risk. That is, on 103 reaches, a significant indication of human impact to sediment systems was not detected. These 103 reaches were placed in the low risk category and excluded from further assessment. Where appropriate, the reasons for exclusion were documented.

On 175 reaches, significant land use or human impact factors were identified in the RLA phase. For these reaches, we documented the land use or nature of human impact that was detected as well as the specific sediment-related processes that might be impacted. These reaches were assessed further in RRISSC.

The RRISSC phase was completed in October, 2009. During this phase, we made site visits to the 175 reaches that were tagged for further assessment in the RLA phase. Each reach was assessed for impacts related to the following factors: mass erosion, roads, surface erosion, streamflow change, streambank erosion, in-channel mining, direct channel impacts, channel enlargement, aggradation, channel evolution, and degradation. Then, based on these individual factor scores, an overall RRISSC rating was assigned, and specific recommendations made for each reach.

178 (64% of the 278 total) reaches are green flags that are rated low or very low risk for sediment pollution, 48 (17%) are yellow flags rated moderate, 44 (16%) are orange flags rated high, and 8 (3%) are red flags with a rating of very high. The red flag reaches group into 6 individual zones (one of the zones contains 3 separate reaches).

A summary of how reaches scored for each of the 11 individual factors is seen in Table 1.

Table 1 Summary of RRISSC ratings for various sediment-related processes through the South Platte Headwaters watershed

factor	number of reaches with RRISSC rating				
	very low	low	moderate	high	very high
mass erosion	217 78%	51 18%	7 3%	2 1%	1 0%
roads	265 95%	6 2%	6 2%	0 0%	1 0%
surface erosion	176 63%	59 21%	29 10%	11 4%	3 1%
streamflow change	148 53%	48 17%	50 18%	25 9%	7 3%
streambank erosion	160 58%	55 20%	29 10%	22 8%	12 4%
in-channel mining	265 95%	2 1%	1 0%	3 1%	7 3%
direct channel impacts	155 56%	30 11%	28 10%	37 13%	28 10%
channel enlargement	193 69%	30 11%	31 11%	22 8%	2 1%
aggradation/ excess sediment	160 58%	50 18%	29 10%	24 9%	15 5%
channel evolution/ successional states	196 71%	37 13%	33 12%	11 4%	1 0%
degradation	160 58%	57 21%	40 14%	17 6%	4 1%
overall RRISSC	**87** **31%**	**91** **33%**	**48** **17%**	**44** **16%**	**8** **3%**

Discussion

There are many different ways to analyze the problem of sediment pollution in a watershed. This discussion is divided into two parts, and each part breaks down the problem a different way. The two perspectives give insight into different aspects of the problem. In Part 1, we use our results to look at patterns of human impact to sedimentation factors across the watershed. Under this heading, we explain each of the 11 sediment-related factors were analyzed in RRISSC and use our results to describe the distribution and relative importance that human impacts have on each factor in this watershed. In this discussion, we also explain the specific problem of unstable meadow stream channels which is widespread in this watershed. On meadow streams with impaired riparian vegetation condition, a whole suite of channel factors may be impacted. This process is important to understand since it is very prevalent and recurring in the watershed, and it may be the cause of most systemic sediment yield in many of these drainages.

In Part 2, we use our results to complete the primary goal of the study which is to create a priority list for actions related to improving sediment pollution in the watershed. Under this heading, we group reaches into potential project areas and prioritize them using WARSSS RISSC ratings. We briefly describe each project area and give some general recommendations.

Part 1: Patterns of sediment pollution in the South Platte Headwaters

Sediment-related factors

In this section, we explain each of the 11 sediment-related factors studied as part of the RRISSC assessment and use our results to describe the distribution and relative importance of each factor in the South Platte Headwaters watershed.

Mass Erosion

The process of mass erosion describes large scale events that erode hill slopes such as landslides and debris torrents. Where this occurs near a waterway it is a concern for watershed sediment pollution. Mass erosion is a natural geologic process, but it may be created or exacerbated by activities such as road building, channel relocation, mining, or disturbance to vegetation. The key to evaluating mass erosion in terms of sediment input to a reach for WARSSS is to determine whether the source is natural or anthropogenic. Mass erosion that occurs as a natural geologic process considered normal. But if the cause is anthropogenic, there is high potential for excessive amounts of sediment to be delivered to a system that cannot accommodate it. Anthropogenic mass erosion was only suspected as an influencing factor in sediment impairment for 4% of the reaches in the watershed. There are two general cases where significant mass erosion was noted: 1) at locations where hydraulic mining created large, un-vegetated, loose cobble slopes directly adjacent to a river, and 2) where road and/or dam development artificially forced a river into a confined reach with high, steep, loose slopes.

Roads

Roads can influence the amount and the timing of sediment moving through a system. Excess sediment can be delivered from eroding road fill, cut banks, road surfaces or from road maintenance efforts such as surfacing and traction sand. Additionally, roads that are constructed of impermeable surfaces may increase or concentrate the amount of surface water runoff and consequently carry more sediment to a stream. The potential effect of a roadway is largely dependent on its proximity to a waterway. Where roads are located some distance from a significant drainage, sediment consequences are not readily transmitted to the system. But where roads are adjacent to waterways, increased sediment yield is directly communicated. In these cases, it is important to consider the quality of road construction and maintenance by looking for indicators of increased sedimentation.

In locations where roads cross streams or drainages, several adverse effects may occur. The elevation and size of bridge or culvert crossings are critical. If the elevation is too high or too low it may cause changes to the base elevation of the stream which can have a cascading effect on stream aggradation or degradation both upstream and down. The size of the bridge or culvert also must allow for all ranges of flow to pass in a way that maintains floodplain function and sediment transport.

Roads are fairly common throughout the watershed, and in many locations there are roads adjacent to or crossing drainages. Though common, the effects of roads on sediment pollution here appear to be minimal. The factor was only documented as significant on 3% of reaches in RRISSC. In most cases, increased sediment yield from roads tended to be localized to small areas in upper portions of drainages. For example, many of the tributary drainages of Tarryall Creek such as Indian Mountain have a density of roads that produce large amounts of sediment, but consequences of this increased sediment load appear to be localized and not communicated to the stream. One exception is upper Trout Creek where the stream flows directly on the roadbed for some distance. The result is a burst of fine sediment to downstream reaches every time a vehicle passes. Here, the impact of the road is severe and direct, and this reach is red flagged on account of it.

Surface Erosion

Surface erosion occurs when water (precipitation as rain or snow melt) runs overland carrying sediment with it from uplands to the valley bottom. The rate of surface erosion depends on the slope of the land, vegetation, and geology. Like mass erosion, surface erosion is a natural process that can be impacted by land uses. Activities that increase the percentage of bare ground, increase or dissect slope gradient, or decrease the permeability of soils all increase the potential for surface erosion. Factors that lessen the impacts of anthropogenic surface erosion include the distance from the disturbance to a waterway and the quality of the riparian buffer. Increased surface erosion negatively affects 15% of the reaches in the watershed. Signs of anthropogenic surface erosion include accelerated gully and rill formation, headcutting, and sediment plumes greater than those occurring in neighboring reference reaches.

In the South Platte Headwaters, the most common land use that affects surface erosion is upland grazing. Grazing disrupts root systems and alters species composition, and these factors impact soil stability and surface roughness to cause surface erosion. Grazing is suspected as a factor in increased surface erosion on several tributary drainages in the watershed, particularly those along the north side of Middle Tarryall Creek and in the Upper South Fork drainage where the signs of increased surface erosion are readily observable. Mining is another factor found to influence surface erosion in the watershed especially where mining leaves behind large areas of bare, loose soil such as tailings piles in or near waterways.

Streamflow Change

This factor is concerned with tracking the impacts of flow augmentation, depletion or timing to the waterway. Changes to the hydrograph can have long lasting and far reaching effects in the watershed. The morphology of a stream channel and its ability to transport sediment load are directly related to the amount and timing of its water source. If these levels are changed the stream will tend to adjust to fit the new hydrologic regime, and this processes of adjustment typically involves long periods of instability and high sediment yield. Flow augmentation is often a result of increased runoff from urban areas or roads (impermeable surfaces) or trans-basin diversions. In this watershed, significant flow augmentation is observed at one location only. This is a trans-basin diversion supplying water to the upper Platte Gulch (reach 3001) from the other side of the continental divide. Augmentation effects from this diversion are immediately absorbed by the effects of Montgomery reservoir, however.

Flow depletions, on the other hand, are observed throughout the watershed. An estimated 30% of reaches in the watershed are significantly impacted. The most common causes are agriculture diversions and reservoirs. In some cases bankfull flow is thought to be reduced by 50% or more from of the cumulative effects of multiple diversions. By itself, flow depletion may not have serious consequences, but it is often a cumulative factor on reaches that are otherwise impacted. For example, most unstable meadow streams in this watershed suffer from impaired sediment transport ability and excess deposition due channel morphology and stability factors, and the condition is greatly exacerbated when peak flows are depleted. In an extreme case, the South Fork of the South Platte below Antero is in a highly degraded condition, and depletions due to managed hydrology may be a significant factor.

Streambank Erosion

Streambank erosion is probably the single greatest contributor of sediment to waterways in the South Platte Headwaters. Erosion rates are related to land uses, riparian vegetation, bank height, bank material and erosive potential (a factor of channel morphology). Streams that have low sinuosity or that are confined to canyons with large rock material experience minimal amounts of bank erosion. Bank erosion is most commonly observed on meandering meadow streams where bank material is generally weak (soil, sand, or gravel) and channels are more sinuous. On these stream types, bank strength and resistance to erosion is highly dependent on the quality, density, and depth of root mass from riparian vegetation. The highest bank erosion rates are observed on meadow streams where naturally occurring riparian vegetation has been eliminated to allow for land use development. In these cases, bank erosion is almost always associated with other factors of instability or sediment yield such as direct channel impacts, channel enlargement, aggradation, channel evolution, and degradation (see the discussion below about unstable meadow streams).

Accelerated bank erosion was indicated as a significant factor on 22% of reaches over the whole watershed. It is rarely indicated in headwaters or tributary drainages, but it is an important sediment factor on almost all of the main stem 2nd or 3rd order streams. Rates of sediment production from by bank erosion vary greatly throughout the watershed depending on stream type and degree of impairment, and we are presently conducting studies to quantify these values. Additionally, a great deal of effort has been made towards controlling bank erosion in this watershed by a wide variety of natural and artificial means, and extensive studies are also underway to evaluate results.

In-Channel Mining

The effects of in-channel mining are dramatic. Common historical mining techniques that directly disturb stream channels and sediment yield in the South Platte Headwaters include placer mining, dredging, and hydraulic mining. These activities have had striking impacts to the form and function of miles of streams and their valleys. Sediment consequences from in-channel mining include channel instability and all the associated sedimentation processes that go with it. Mined reaches typically also have an associated high risk for mass and surface erosion rates due to the level of disturbed soils, exposed hillsides and tailings, and the presence of high-risk roads. In some locations where mining has been abandoned for a long time, systems have managed to recover after years of adjustment. Other reaches are so heavily impacted that the there is virtually no potential for unassisted recovery, and the problems will continue until something is done.

This factor is unique as it generally has very intense but often quite localized effects. A low percentage of the watershed (4%) is directly impacted by in-channel mining, but the result for those reaches may be intense. Generally speaking, while the degree of disturbance is striking, the actual consequences of mining for system-wide sediment pollution are largely unknown in this watershed

Direct Channel Impacts

Direct channel impacts incorporate a variety of human impacts that directly affect stream channels, such as: 1) changes in riparian vegetation, 2) channel relocation (particularly straightening), 3) channel or bank hardening, and 4) channel blockage including woody debris and structures. Changes to riparian vegetation is often a very important factor of sediment impairment depending on the type of stream and valley system. In meadow streams, riparian vegetation is a driving factor for stream stability, morphology, and erosion rates, and this process is described in detail later in the report. Part of determining the rating for this factor is observing what percentage of the stream length has had a vegetation shift. If the natural vegetation has been impacted or removed, the reach is considered a high risk for sediment impairment. This is a common theme is this watershed. 33% of reaches receive a high risk rating for direct channel impacts are due to a shift in riparian vegetation. Most of these are reaches of the main stem streams on gentle valleys that have been settled and developed as ranches.

Manipulations to the location, dimension, pattern, or profile of a channel can have important implications to the sediment capabilities of a reach. If stream manipulation results in a change to the gradient or morphology of the channel, the sediment capacity (particle size) and competence (volume) of the reach may be increased or decreased causing excess deposition or scour and instability. There are also often unforeseen consequences from channel hardening and blockage, and ironically sometimes the very treatments made to try to arrest bank erosion and improve sediment pollution (hardened banks, in-stream structures, etc.) end up being sources of instability.

Direct manipulation of stream channels is fairly common in this watershed. Many meadow streams were physically relocated at one time or another to make way for land development or to make the transport of water "more efficient" by channelization. The most extreme example of this is on Fourmile Creek where several miles of the creek was converted to a straight, wide, hardened trapezoidal channel. Hardened channels and in-channel structures are also common. Most of these manipulations were made to accommodate roads, to protect infrastructure, or to serve as diversions. More recently, there has been a great deal of channel hardening and artificial structures installed in the name of "restoration" or habitat improvement, even on meandering meadow streams. Approximately 6% of reaches in the watershed are significantly impacted by artificial manipulation of channels.

Channel Enlargement

The risk of channel enlargement is based on the potential for a stream to incise (lowering of the base level) or widen. It is usually a response to changing meadow conditions (vegetation), sediment load, or streamflow change; but it may also be caused by direct manipulation of the channel or mining. The process of channel enlargement may produce large amounts of sediment either from bed scour or bank erosion. Beyond the obvious impacts to sediment yield, the process may result in diminished floodplain function and changes to sediment transport ability. A significant risk of channel enlargement is indicated on 20% of the reaches in the watershed. All of these reaches are meadow streams that also have high risk ratings for direct channel impacts (vegetation shift) and streambank erosion.

Aggradation/Excess Sediment

The aggradation risk factor is a measure of the potential for excess sediment to accumulate in a reach. This process may occur as a result of increased sediment volume or because the reach is altered such that it is no longer capable of transporting the amount of sediment that normally moves through the system. Sediment deposition can negatively impact a reach by decreasing habitat quality and initiating processes that can drastically change the morphology of the stream and how it functions. Common causes and effects of aggradation include channel widening, enlargement, braiding, and avulsions. Aggradation is a serious instability concern. When a stream becomes wide and flat, its sediment transport capabilities diminish, sediment continues to accumulate and the process continues. Conditions that increase risk of aggradation are decreased streamflow, direct impacts to the channel and banks, and artificial blockages or impoundments. On 24% of reaches, the risk for aggradation was assessed moderate or higher. Again, these reaches tend to be main stem meadow streams with impaired vegetation condition.

Channel Evolution/Successional State

It is natural for streams to change over time and adjust to shifting climatic conditions. Streams will modify their dimension, pattern, and profile to match changing hydrologic and sediment regimes. These natural processes can occur quickly as a result of a major geologic event or be a gradual process as long term trends shift. When streams are disturbed by anthropogenic forces the same processes are put in motion. By understanding these processes it is possible to assess whether a stream is in a stable state or is moving from one form to another in response to changing conditions. Depending on the level and extent of the disturbance, a stream may be able to regain a stable state without a producing large amounts of sediment. On the other hand, some channel evolution processes involve long periods of instability and sediment yield. 16% of reaches received ratings of moderate or higher for sediment risk due to channel evolutionary condition. Nearly all of these are unstable meadow streams on main stem channels.

Degradation

Degradation is the lowering of base elevation of a streambed relative to the surrounding landscape due to excess scour. The result of excess bed scour is down-cutting, and when a channel down-cuts, bank heights are increased and the channel becomes disassociated from its floodplain; that is, the channel becomes incised or entrenched. Incision and entrenchment are true channel instability processes that set a host of sediment-related processes in motion, particularly on meadow streams. As the channel adjusts to a new base level, bank erosion rates may be extreme. Indeed the highest bank erosion rates ever documented on a South Park stream (25 feet in one season) was on a recently incised segment of the Middle Fork. The volumes of sediment produced by an adjusting degraded channel can be astounding.

In the case of degraded channels, the landscape also has to adjust to the new base elevation of the stream and tributaries rejuvenate to match to the new confluence elevation. That is, tributaries also down-cut and become unstable. All of the sediment produced in this string of events moves downstream where it has negative effects on the rest of the watershed. Conditions that increase the risk of degradation are poorly sized or poorly placed culverts or bridge openings, clear water discharge, streamflow augmentation, channel relocation (straightening), decreasing sinuosity, and avulsions. Potential risk of degradation is indicated on 21% of reaches in the watershed.

Unstable meadow streams

Explanation of a recurring theme of sediment pollution in the South Platte Headwaters

A very important pattern of instability and sediment yield in this watershed involves the diminished function and instability of low-gradient meadow stream channels that have impaired riparian vegetation. Because this pattern is so prevalent in the watershed, and because it is such an important source of sediment due to the cascading effects of instability, we describe the pattern in more detail here. Finding creative solutions to improve riparian condition and restore stable channels on reaches with this type of instability could be the greatest challenge to improving the state of sediment pollution in this watershed.

The major streams in the South Platte Headwaters (Jefferson Creek, Michigan Creek, Tarryall, Middle Fork, Fourmile, and South Fork) come out of the mountains into South Park. At this point, they change a great deal in character from their headwaters upstream. Through most of South Park, stream channels are on low-gradient, wide alluvial or lacustrine valleys. The stream types that exist in these locations[3] are **highly** dependent upon riparian vegetation to maintain stability. It is also the case that streams in these areas have been prone to a high degree of direct impact from agriculture through vegetation clearing, beaver removal, and mechanical alteration of stream channels. Most river valleys throughout South Park are managed as ranches that use valley bottoms for livestock pasture, hay meadows, or other agricultural uses. The shift in riparian vegetation that occurred when river valleys were settled for agriculture explains most of the instability and sediment production from these locations.

When vegetation is cleared from riparian areas or shifted from native strong-rooted vegetation to weaker pasture grasses, these channels respond in a fairly predictable way; one that has significant consequences for sediment pollution. Diminished root strength means that impacted streams are far more susceptible to bank erosion. Through a mechanism that is very easy to imagine, rapid bank erosion can easily cause channel enlargement and over-widening (eroding channels become larger). Both of these factors negatively impact sediment transport

[3] Most of the 2nd order low gradient meadow streams in South Park are C4, C3, E4, or E3 channels in the Rosgen classification scheme. Many are Db (beaver dominated systems), and F4 or F5 channels exist where they were directly constructed. Most 3rd order streams are C3, C4, or C5. E4 and E5 channels are also common, and Db systems exist in un-impacted areas. F3, F4 and F5 channels also exist on a few low-gradient meadow locations.

capacity, so the risk for aggradation goes up as well. In what seems like a paradox, these streams also have an increased risk for degradation, for the accelerated channel migration that follows from rapid bank erosion increases the risk for avulsions, cutoff channels, and channel evolutionary scenarios that include degradational states.

By this mechanism, meadow streams that have been directly impacted by altered riparian vegetation commonly show elevated RRISSC ratings in a suite of the 11 factors including direct impact, bank erosion, channel enlargement, aggradation, degradation, and channel evolution. Because so many factors are involved, these reaches have are potential sources for large volumes of sediment. Sediment risk may also be exacerbated, of course, on reaches where this pattern of instability coincides with impacts to other factors such as increased surface erosion, altered hydrology, or roads. Because of the causal chain that links so many factors through vegetation, because impacts to riparian vegetation are common in the watershed, and because the consequences for sediment pollution are severe, this pattern of instability should be viewed as an important problem to be solved for the South Platte Headwaters.

It may seem obvious that treating unstable meadow streams should begin with reversing the cause of instability by restoring native riparian vegetation to these meadows and valley-bottoms. In fact, we believe that in some cases the solution may be no more complicated than that. Thus, there is tremendous potential for improving the condition of sediment pollution in the watershed by identifying areas where stream buffers can be restored with appropriate vegetation to support stability, and this model is only just beginning to be applied and tested in the watershed. However, the problem may be somewhat more complicated than just reversing past vegetation disturbance. There are often complicating factors. A few common ones are listed below:

- In some cases, stream channels have become so altered (e.g. incised or entrenched) that the evolution to a stable form may require a long time of natural adjustment **or** direct manipulation.
- Many unstable meadow reaches are on private lands that are managed for agriculture which can require creative management to promote riparian restoration.
- Riparian vegetation does not always recover on its own. More often than not, restoration of these areas will require extensive revegetation efforts in addition to protection.
- The historical and present mindset for stream restoration is focused on manipulating or hardening channels, rather than treating the factors that affect channels.

To date, most of the stream restoration, enhancement, and restoration efforts in the watershed have been focused on reaches that exhibit this pattern of instability. A wide array of approaches have been tried ranging from pure passive protection to vegetation treatments to artificial channel stabilization to enhancement with structures. The efforts have met with varied success. As a result, there is a great deal of knowledge, experience, and data to draw from in planning solutions to this problem in the future as long as monitoring and PLA efforts continue to assess these trials.

All of the main-stem streams in South Park exhibit this pattern of sediment pollution to some degree. Several reaches on Tarryall Creek which are severe examples of this are pattern are flagged red. The pattern is also responsible for about half of the orange-flag reaches in the watershed on all of the major drainages. Of the remaining meadow reaches that pass through South Park, many are flagged yellow for reasons related to vegetation shift. On yellow flag reaches, impacts are lesser in degree or have less conspicuous consequences.

Priorities for sediment pollution

Priority 1 project sites

8 of the 278 reaches (3 %) in the watershed are flagged red. These are considered the highest priorities for possible mitigation or restoration and advancement to PLA. We grouped these into six potential project sites. From the evidence provided in our WARSSS assessment, we suggest that this list of potential projects merits top priority attention from the perspective of sediment pollution in the watershed.

Middle Tarryall Red Flag Zone

A span of Tarryall Creek through its middle reaches shows up as a red flag. This zone includes 3 reaches of Tarryall Creek with very high risk including the Stagestop reach (2033) and the reaches that span from Old House Gulch down to the SWA (2048 and 2049). It makes sense to define the project area to include the entire section of Tarryall Creek from just upstream of the confluence with Michigan Creek down through the Upper State Wildlife Area (SWA). This project area includes the following reaches, highlighted to show risk rating: 2030, 2033, 2046, 2047, 2048, 2049, 2050, and 2051 which share a similar condition but with varying degrees of severity. The reaches downstream of this on Eagle Rock Ranch and the Lower SWA (2052, 2053, 2054, and 2055) are also similar, so the project area could be extended to include these. On the other hand, most of the Eagle Rock Ranch reaches have artificial stabilization measures in place, so it may be better to consider these projects separate.

As described above, this section of Tarryall Creek is an extreme example of low-gradient meadow channel instability related to vegetation shift. For some reason, the effects of instability on these reaches are especially intense, and there are a number of possible explanations for this. This is quite speculative, but one explanation could be that this location has an especially deep layer of fine soil on top of the base layer of coarse alluvium which creates high, soft banks. This explanation is consistent with the hypothesis that the historically stable system for this valley would have been a beaver complex and that a stable single-thread channel is unlikely. It also could be that sedimentation and instability is exacerbated on these reaches from other sources such as high yield from tributary drainages. Or perhaps the direct channel and vegetation impacts are just more intense here than on other reaches.

Regardless of the reasons why, this zone is a very impaired system and a very important source of sediment to downstream reaches. Ball-park estimates for the volume of sediment produced by bank erosion and channel instability on these red flag reaches may be as much as 100 times greater than on stable reference reaches, and perhaps 10 times greater than on moderately impacted reaches in similar locations. The volume of sediment produced by these reaches negatively impacts the entire system downstream to Tarryall Reservoir. Indeed, signs of impairment are readily observed throughout the reaches downstream of this section. Mitigating this level of damage will likely require considerable effort, but great improvements stand to be gained.

Due to the far reaching negative effects of sediment input from this site, we recommend immediate action with the goal of eventually treating the cause of instability and significantly reducing sedimentation. Action should begin with quantitative evaluation of the reaches in the PLA phase of WARSSS to validate the severity of our assessment, to quantify the amounts of sediment produced here, and to determine what types of mitigation or restoration might be possible. At present we have one detailed PLA study in place to evaluate restoration effectiveness of a project implemented in 2005 on reach 2050 along with a control site on 2051. These studies would serve as a good start for PLA analysis of the Middle Tarryall red flag zone.

Tarryall Creek at Benes Ranch Red Flag Zone

The BNSUP2 reach (2080) is on a meadow immediately downstream of Tarryall Reservoir, and conditions there are very similar to those described for the Middle Tarryall Red Flag Zone. This is another main stem meadow stream system that is heavily impacted by vegetation change and land use. One important difference, though, is that the negative effects of sedimentation downstream of the Benes Ranch do not appear to be nearly as intense as they are downstream of the Middle Tarryall red flag zone. For this reason, a project on the Benes Ranch red flag zone may be a lower priority. On the other hand, due to the location of this impaired reach just downstream of a reservoir, and just upstream of miles of stream that is in relatively good condition and protected status, there may be an argument to mitigate damage on this reach as a means of protecting downstream reaches[4].

The project area could be defined as the reach of Tarryall downstream of the reservoir from the CR 77 bridge down to the lower end of the first meadow. This incorporates reaches 2079 and 2080. Below this, the creek drops into a canyon with no identified sediment concerns, but below that there is a second meadow that has conditions similar to the upper meadow, but perhaps to a less severe degree. It may make sense to include the reaches on the lower meadow of the ranch on the same project. This would define the project area as 2079, 2080, 2082, and 2083, with the one low risk reach (2081) in between.

A good amount of quantitative work in for sedimentation and stability has been completed towards PLA on this project area, and the magnitude of sediment production is fairly well established. An extensive study has been ongoing for 6 years now to evaluate the effectiveness of mitigation efforts that were applied on reach 2079 in 2004. Control reaches have been similarly studied on the lower meadow (reaches 2082 and 2083). With comprehensive data on the effectiveness of past restoration approaches on the project area, and detailed work defining the present condition and potential already in place, valuable information is already available to guide mitigation or restoration of this high-priority area. Apparently a plan for channel stabilization is already designed for reach 2082 and awaiting a permit for construction. This would provide another great opportunity to improve our understanding of the effectiveness of mitigation approaches by monitoring the effects.

Middle Fork at Fairplay Red Flag Zone

The Middle Fork South Platte where it flows by Fairplay (reach 3025) is severely impacted by past mining activity. Basically, the entire valley bottom was disrupted by placer mining and dredge mining, and the channel was completely altered.   Valley side slopes were denuded of vegetation from hydraulic mining and left bare, artificially steep, and highly susceptible to surface erosion and mass wasting. The RRISSC assessment raised a red flag for this reach due to direct channel impacts, in-channel mining, and the potential for mass and surface. While the

[4] This rationale was a primary justification for funding previous restoration work at this location. The argument is that waters coming from the reservoir are essentially clean from sediment (which is true most of the time except for when large slugs are released with flush flows from the bottom of the dam). The reaches on Benes Ranch are therefore viewed as an immediate source of sediment pollution in an otherwise clean system that directly feeds miles of stream below that are otherwise in decent shape.

level of disturbance on this reach is obviously extreme, the consequences of disturbance for sediment contribution and channel instability are not well established. In fact, habitat impairment due to sediment pollution is not immediately apparent on the reach beyond the deltaic deposition and rapid filling of Fairplay Beach Reservoir just downstream. In other words, Fairplay Beach appears to be absorbing most of the negative impact from instability of the reach. Quantitative PLA methods should be employed as a next step on this reach to better understand whether the reach truly warrants the red flag rating from the RRISSC assessment. Channel stabilization and reclamation of mining-impacted valley bottom and side slope areas are mitigation measures that could be pursued if quantitative assessments validate the severity impact from this reach.

South Mosquito Creek Red Flag Zone

The South Mosquito Creek Drainage (reach 3013) is red-flagged due to tremendous direct channel impacts in the area of London Mine. Channelization, in-channel mining, increased surface erosion and mass erosion are all expected to be important sources of sediment pollution here, but there are few details available about the degree of impacts or consequences for sediment pollution from the reach. PLA assessment of this reach and those downstream of it are a necessary next step towards treating concerns on this high-priority reach. Possible solutions, if the RRISSC assessment results are validated, include alterations to mining procedures as they impact the channel, stabilization of the channel and side slopes, and possible restoration if mining activity allows.

Trout Creek at FR 194 Red Flag Zone

Trout Creek crosses Forest Road 194 a few miles downstream of its headwaters below Mount Silverheels at reach 3038. The road crossing is a severe and acute sediment pollution source in an otherwise highly functional system, and the effects are readily apparent downstream with increased turbidity, rapidly filling beaver ponds, and substrate embeddedness. We expect that the volume of sediment produced at the poor road crossing is not particularly great, and that the effects are not felt very far downstream, but the red flag rating is appropriate in light of the fact that this is one of the few reaches designated for sediment impairment on the state 303-d water quality list. Fortunately, a solution may be fairly simple to obtain. Recommended action for this reach begins with considering alternatives to the existing stream-road crossing that do not require vehicles to travel a long distance in the streambed. An appropriately-sized culvert, small bridge, or engineered low-water crossing are possible alternatives.

Fourmile Creek DWB near Beery Ditch Red Flag Zone

Fourmile Creek was channelized and straightened for several miles about 50 years ago, creating an impaired stream system and relatively dry floodplain area. These impacts alone have significant sediment pollution impacts that rate moderate to high. In an attempt to mitigate stream and riparian impairment caused by channelization, about 5 miles of new, sinuous channel were constructed to convey the flows of Fourmile Creek. Much of the newly-constructed channel is functioning well, but some long segments were built in an entrenched, overwide condition with poor vegetation, highly-erodible soils, and managed hydrology. Reach 4046 is red flagged because the rebuilt channel segments are particularly unstable. The function of the newly-constructed channel is compromised because it is unable to conduct all the flows of the Fourmile Creek drainage without producing massive amounts of sediment from active erosion. Therefore flows must be artificially maintained below optimum levels to mitigate sediment input to the system. This high-maintenance solution will continue unless action is taken to change the morphology of the stream so that it can accommodate appropriate flows without eroding severely. PLA efforts have been initiated on this reach and have led to design, implementation and monitoring of one possible solution on a pilot segment which involved lowering the effective floodplain elevation, resizing the channel, and reconstructing more stable banks with native vegetation. Implementing a solution for the rest of the entrenched Fourmile Creek channel should be a high priority.

Priority 2 project sites

A list of priority 2 potential mitigation or restoration projects includes the more prominent orange flag reaches in the watershed. As for priority 1 projects, we recommend advancing these priority 2 sites directly to the PLA phase of WARSSS. For these projects, it is especially important to quantify the degree of impairment and to assess the potential costs and risks of realistic restoration or mitigation options. The list is provided below, in an order that makes it more convenient to describe the sites, not necessarily in order of importance or priority.

Lower Michigan Creek

The Lower Michigan Creek project site runs from the confluence with Jefferson Creek down to the confluence with Tarryall Creek includes 3 reaches flagged orange with one green-flagged reach in between (1035, 1036, 1037, and 1038). Reach 1039 is a tributary drainage called Mud Creek that enters Michigan Creek at the bottom of this site. It is included in the potential project site on account of its orange flag status. Reaches 1035 and 1036 have the typical characteristics of unstable meadow streams. 1038 is similarly impaired, but may potentially be in a less stable aggradational state. 1037 (between the two) is a confined reach with no apparent concerns. Reach 1037 appears to have adequate sediment transport ability and a stable channel despite its location. Headcutting, gully, and rill formation on the tributary reach 1039, in addition to heavy livestock use merit the orange flag.

Middle Michigan Creek

Middle Michigan Creek from Highway 285 through the Portis Ranch includes two impacted orange-flag meadow reaches, a green-flag reach, and a yellow flag reach (1012, 1013, 1014, 1015). Some portions of this site are worthwhile considering for restoration or mitigation. In fact, restoration on reach 1012 has already been designed and funded, and the project is awaiting permits. The project includes some aspects of PLA assessment and a detailed monitoring plan.

Tarryall Creek on Collard/Link Ranches

Tarryall Creek on the Collard and Link Ranches (reaches 2023-2027) appear to have all the factors of the familiar pattern of instability due to vegetation shift and land use, but the degree of impairment in unclear. This site is also heavily impacted by flow depletions from numerous irrigation diversions just upstream.

Other orange-flag meadow reaches on Tarryall

There are several other short main stem meadow reaches on lower portions of Tarryall Creek that are worth considering as high priority for a project. These potential sites include parts of the Lazy River Ranch (2091), Lower Allen Ranch (2098), Spruce Grove subdivision (2101), and Puma Hills Ranch (2107-2110). PLA studies are ongoing at the Lazy River, Allen, and Puma Hills Ranches, and restoration or mitigation work has been done on sections of each of these ranches. Additional opportunities may still exist at all of these locations, though, particularly where mitigation efforts are not fully successful. All of the projects have detailed monitoring to report on effectiveness using methods from WARSSS. The reach at Spruce Grove is highly impacted by land use, particularly on Tarryall River Ranch.

Middle Fork at Buffalo Peaks Ranch

About 1½ miles of the Middle Fork on Buffalo Peaks Ranch (reach 3030) was treated in 2008 to improve fish habitat. Some portions of the reach continue to have very high sediment contribution from bank erosion, but further mitigation measures may have successfully ameliorated the problem. Downstream of the project reach, one long segment is at very high risk for avulsion and potential degradation. This project site is a good candidate for continued study to assess the consequences if avulsion should occur and to develop a strategy for reducing that risk.

South Fork from Antero to Hartsel

Reaches of the South Fork from Antero reservoir to Hartsel (4035 and 4036) appear to be a special case of meadow instability. Here, habitat impairment due to sedimentation appears to be extreme. The problem, though, does not seem to be one of excess sediment supply (the reach is just downstream from a dam) but rather an unusual inability of the channel to deal with what is there. This channel is extremely overwide and shallow for the length of the reach. Aggradation, excess deposition of fine material, and embeddedness are common. We suspect that altered hydrology and diminished flows below Antero Reservoir is an important factor. It is also possible that sedimentation is a minor component to habitat degradation here, compared to factors such as temperature and eutrophication. Nevertheless, so little is known about this unusual degraded stream system, that it is worthy of study to rule out or identify sedimentation factors.

Trout Creek from Highway 285 through Safari Ranch

Trout Creek is highly impacted at highway 285 (reach 3040) and for most of the length of the Safari Ranch (3041). Headcutting and gully formation at the highway 285 crossing appear to be a direct result of the highway bridge. On the Safari ranch, intense livestock use and vegetation impairment are likely causes of instability which is typical of the impacted meadow condition.

Lower Fourmile Creek

Lower Fourmile Creek, downstream of the Mills/Cargill Ranch (reach 4048) is orange flagged due to heavy livestock use, unstable meadow conditions with impoverished vegetation, and several segments where the stream has been channelized. The reach appears to be similar to the Beery reach of Fourmile Creek on DWB property. Information gained by the work on that property will be useful in assessing and solving problems on Lower Fourmile.

Lower High Creek

Downstream of High Creek Fen, lower reaches on High Creek appear to be highly impacted. Sediment consequences, however, are not well known. On reach 4040, the channel is severely altered by channelization. On 4041, impacts from a breached dam need to be assessed. Since this is a very small creek, systemic consequences of sedimentation are probably minor, but local impacts may be significant.

Projects on reaches with mine tailings

We identify four important sites for potential projects related to mining and the presence of mine tailings. Each of these may be considered a separate site, but the conditions of impairment and potential for mitigation or restoration are similar. Any project on these mine tailings areas aimed at reducing sedimentation should begin with detailed PLA assessment since the nature and magnitude of sediment consequences have not been documented. These project sites include **Upper Tarryall Creek** near the Boreas Pass Road (reaches 2013 and 2014), **Montgomery Gulch** (reach 2004), a tributary drainage to Upper Tarryall Creek, the **Middle Fork near Alma** (reach 3011), and **Middle Beaver Creek** (reach 3022).

Sites recommended for management change

Reaches may warrant a yellow flag, or moderate risk rating, for one of two reasons. Either the reach is determined to have a significant but relatively low degree of impact, or some level of impairment is suspected and the reach is tagged for additional study to identify and understand the specifics. Looking at the distribution of yellow flag zones through the watershed, we grouped them into three major categories.

Moderate risk meadow streams

Many yellow flag reaches are along main stem channels in South Park. These are generally meadow streams with the typical pattern of channel impacts related to altered vegetation and agriculture. Unlike similar reaches flagged red or orange, these reaches merit only a moderate risk rating for sediment because detected impacts are lesser in degree or have less conspicuous consequences. These reaches may be low priorities for restoration or mitigation, and sedimentation rates tend to be at acceptable levels. They are possible candidates for implementing riparian protection and passive restoration. We expect that these reaches could have realistic potential for improvement simply by changing in management without the need for mechanical assistance. Riparian protection would ensure that these streams will not be negatively impacted in the future. While the degree of sediment consequences from these reaches is not large, the cost for implementing a change may be very low. The overall benefits from implementing land use change over large areas with moderate impact can be great due to cumulative effects, and these approaches are worth considering as long as the costs for implementing land use change are low.

Impacted upland drainages

In the South Platte Headwaters watershed, we are fortunate to have relatively minor disturbance to upland areas that would impact sediment pollution. This is why most small drainages and headwaters areas score in the low risk category. However, at a few locations we identified reaches (or sub-watersheds) where anthropogenic sedimentation could be significant. The drainages on the north side of the Middle Tarryall Valley from about Stagestop to Tarryall Reservoir (reaches 2044-2045, 2057-2060, and 2073-2076) show a much higher degree of headcutting, gulley formation, and sediment than other drainages in the watershed. The effect seems to be fairly recent, so there is good reason to suspect anthropogenic impact rather than a simple difference in geology. One suspected factor related to this is increased surface erosion due to high intensity grazing in these uplands. Because the volume of sediment from these side drainages is significant and because they empty directly into the main stem of Tarryall Creek, it seems worthwhile to use PLA methods to assess the degree of impact on these upland systems and/or to implement changes to grazing management directly. It is plausible, and even likely, that considerable improvements could be made to sedimentation on these drainages by altering grazing management. Some of the drainages in the Upper South Fork watershed are similar, particularly reach 4011, and a similar prescription for assessing the degree of impact is recommended.

High-traffic headwaters

Platte Gulch (reach 3001) at the headwaters of the Middle Fork is another reach flagged yellow for moderate sediment risk based on suspected human impact that has not been quantified. This drainage sees extensive off-road travel and a network of steep roads with high usage. Further study is recommended on this reach to assess the degree of anthropogenic sedimentation from these sources, and to determine if changes to management may be warranted.

Priorities for protection

Green flag reaches are those that merit low and very low risk sediment ratings. This group comprised 66% of the reaches is the watershed. Green flag reaches either not impacted, or the impacts that affect them do not have significant sediment consequences. Properly functioning green flag reaches are important to the overall function of the watershed as a whole, and are thus a high priority for protection. Many, but not all, green flag reaches are on properties that are already protected. As a first step towards protecting the most functional reaches in the watershed, a map of green flag reaches could be overlaid upon a land conservation map to highlight possible protection opportunities that are still available on relatively unimpacted areas.

Well-functioning reaches are also valuable as a reference to assist in directing the form of future restoration. Additionally, these reaches can be a template for understanding best management practices and applying these techniques across the watershed. This can be an effective way to develop management plans for large areas.