Lightner Creek Sediment Monitoring & Rating Curve - Phase III

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Table of Contents

Executive Summary

The Animas Watershed Partnership (AWP) received funding from the Colorado Water Conservation Board (CWCB) Watershed Restoration Grant Program to sample sediment loads in Lightner Creek during spring and monsoon storm surges and to develop a sediment rating curve. Developing a sediment curve will allow the AWP to prepare for and assess changes to the Lightner Creek drainage. Sediment rating curves are often used to estimate suspended sediment loads where the sampling program is insufficient to define the continuous record of sediment concentration (D.E. Walling 1977) and to identify threshold flows above which sediment is actively mobilized in the water column.

Regional observers have recognized Lightner Creek as a persistent source of water quality degradation in the Animas River because it appears to contribute a large amount of sediment to the river. Sediment loading is a concern because it can influence water temperature, dissolved oxygen, macro invertebrate populations, nutrient availability, and spawning habitat. A group of stakeholders initiated a series of studies to understand the sources and patterns of sediment loading from Lightner Creek into the Animas River. This report is the third phase of an effort to understand the dynamics of seasonal sediment loading as total suspended solids (TSS) by Lightner Creek in the early snowmelt runoff period and during monsoon storms in order to develop a sediment curve.

Two previous studies examined sediment sources; characterized channel conditions to identify potential contributing sub-basins; and quantified the timing and amount of sediment loading into the Animas River (Basin Hydrology 2010, Peltz et al. 2011). Phase II determined that Perins Canyon and the lower reach of Lightner Creek contribute the highest proportion of sediment to the system. Phase II developed a conceptual model of the sediment dynamics for Perins Canyon and Lightner Creek. The conceptual model suggests monsoons and large precipitation events mobilize sediments downslope of Perins Canyon to the confluence with Lightner Creek, where it is stored and transported over time through a series of smaller events to the Animas River (Peltz et al. 2011, pg. 22).

Phase III combined automated sampling to collect suspended sediment and cross-channel measurements to calculate discharge. The sampling site was chosen on Lightner Creek above the confluence with the Animas and below the contributing sub-basins to capture total suspended solids in the system. An automated sampling device (ISCO 1672) was installed and programmed to collect a water sample daily from March through August of 2013. Water samples were filtered in the laboratory and the sediment was weighed (wet and dry). After late July, storm surges proved problematic for the equipment, and for this reason the sampling effort was ultimately discontinued for the remainder of the monsoon season.

The wide range of suspended sediment load across a broad spectrum of low to high flows did not provide a clear relationship that could be translated into a sediment curve. Sampling in 2013 supported Peltz et al. conceptual model (2011). The cycle of sediment loading into Lightner Creek may be described as a heavy sediment load being contributed to Lightner Creek during late summer storms. While some of the load is carried to the Animas River during storm events, a considerable amount of sediment appears to be stored in the low gradient section of Lightner Creek (within 500 meters of the confluence with the Animas River). Stored sediment is then carried into the Animas River during spring runoff and during early summer flow events until the stored sediment is cleared out, by early summer.

Recommendations for further sediment study on Lightner include the need for a permanent, flood-proof monitoring location, the monitoring of sediment movement on the bed of the stream, and GIS assessment of where potential fixes could be implemented within the watershed.

Introduction

Lightner Creek is of concern to the region because of its proximity to designated Gold Medal Trout Waters of the Animas River. The AWP has worked with Mountain Studies Institute (MSI), Basin Hydrology, City of Durango, San Juan National Forest, Bureau of Land Management Tres Rios Field Office, La Plata County, and the Five Rivers Chapters of Trout Unlimited to further understand sediment loading from Lightner Creek. Initial studies examined sediment deposition and identified top sources of sediment in six sub-basins. In response to these studies, the City of Durango developed a catchment basin at the base of Perins Canyon to help mitigate loading from the canyon.

The goal of the Lightner Creek Project is to "reduce the sediment load contributed from Lightner Creek to the Animas River, and improve aquatic habitat and fishing conditions while reducing infilling of water infrastructure." (Basin Hydrology 2010, Peltz et al. 2011). The Lightner Creek Group (San Juan Citizens Alliance, Five Rivers Chapter of Trout Unlimited, City of Durango, and MSI) developed an initiative to better understand the source of sediment in Lightner Creek in 2009. Phase I of the effort located top source areas for contributing sediment and characterized sources of sediment contributions from seven tributary basins (Basin Hydrology 2010). Phase II established that of the six tributaries the lower segment of Lightner Creek below Perins Canyon was more influenced by individual storm events, with intense summer storm events mobilizing the majority of the sediment for the system (Peltz et al. 2011). The objective of this effort, Phase III, was to monitor sediment and stream flows and to develop a sediment rating curve for Lightner Creek above the confluence with the Animas River. Concurrent with these study efforts, the City of Durango installed a sediment basin at the bottom of Perins Canyon in an effort to settle sediment out of the water column before entering Lightner Creek.

Lightner Creek Watershed Context and Assessments

The Phase I assessment of the Lightner Creek watershed, conducted by Basin Hydrology in 2009 (Basin Hydrology, 2010), detailed the geographic extent and soil conditions of the drainages contributing to Lightner Creek. This report describes the Lightner Creek watershed, which encompasses 63.7 square miles, with the highest elevations located on the east slope of the La Plata Mountains at an elevation of approximately 11,500 feet. The watershed discharges to the Animas River in Durango, Colorado just south of Colorado State Highway 160, at an elevation of approximately 6,500 feet.

Soils within the Lightner Creek watershed are comprised of a mix of residuum, alluvium, and alluvial fans derived from inter-bedded sandstone and shale. Badland and Zyme clay loam soils, which contain high percentages of shale, lie within the lower Lightner Creek watershed. The high percentages of fines and the erodibility of the Badland and Zyme soils are notable, as these soils contribute significantly to the sediment found in Lightner Creek (Basin Hydrology 2010). Components of the Archuleta – Sanchez Complex soil also contain soils of similar character as the Zyme clay loam hence this map unit has high potential for high percentages of fines and high erodibility.

Studies conducted by Basin Hydrology and MSI identified likely sediment source locations (Basin Hydrology 2010) and timing of loading (Peltz et al. 2011). In 2010 MSI collected data from six locations along Lightner Creek and at one point on the Animas River just upstream from the confluence with Lightner Creek. Each sampling trip gathered information on dissolved oxygen (DO) (mg/L), temperature (°C), specific conductivity (µS/cm-1), and turbidity (Secchi depth1, cm). The findings of the study suggested (1) that a relationship existed between the snowmelt runoff period (March-May) and the levels of suspended sediment; and (2) that that there is a strong relationship between specific storm events and associated sediment transport from Perins Canyon (Peltz et al. 2011).

Objectives

The Animas Watershed Partnership (AWP) received funding from the Colorado Water Conservation Board (CWCB) Watershed Restoration Grant Program to sample sediment loads in Lightner Creek and develop a sediment rating curve. Developing a sediment curve will allow the AWP to prepare for and assess changes to the Lightner Creek drainage. Specifically, the objective was to understand the dynamics of sediment transport in the early snowmelt runoff period (March- May) and the dynamics of sediment transport during monsoon storms (late July- early September).

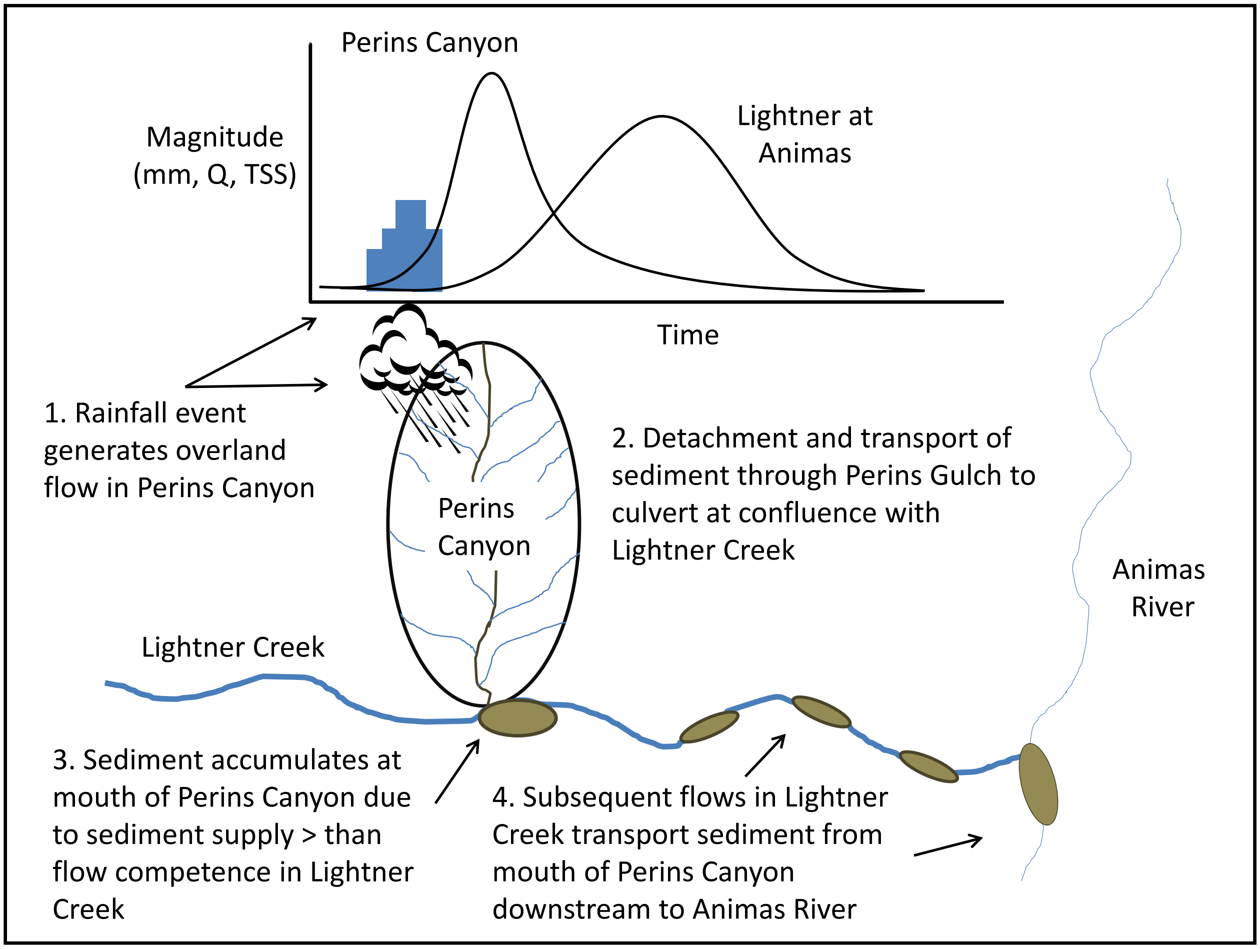
Total Suspended Solids (TSS) is a measure of the wash load within a fluvial system. TSS usually is comprised of material smaller than 2-millimeters (mm) in diameter (Clescerl et al., 1999; EPA, 1971). TSS is an important measure of water quality and landscape condition, as it integrates the amount of erosion and sediment transport within a watershed. The Colorado Department of Public Health and Environment Water Quality Control Commission (WQCC) recognize that excessive salinity and suspended solids can be detrimental to different beneficial water use classifications. In 1993, WQCC established salinity standards for the Colorado River Basin ("Water Quality Standards for Salinity including Numeric Criteria and Plan of Implementation of Salinity Control," Commission Regulation No. 39), but has not yet established standards for suspended solids.

The effect of TSS on aquatic environments and biota are more widely understood (Caux et al., 1997; Wilber and Clarke, 2001) and are similar to turbidity in that excess suspended sediment can have deleterious effects on biota by altering light regimes, thus directly impacting primary productivity, species distribution, behavior, feeding, reproduction, and survival of aquatic biota (Berry et al., 2003).

Sediment rating curves are often used to estimate suspended sediment loads where the sampling program is insufficient to define the continuous record of sediment concentration (D.E. Walling 1977). A rating curve is a graph of discharge versus stage for a given point on a stream, usually at gauging stations, where stream discharge is measured across the stream channel with a flow meter (Herschy, et al 1999). The curve is designed to assess the minimum flows at which sediment becomes actively incorporated into the water column (threshold flow) and at what flows the water column is saturated with sediment. To build the curve multiple measurements of stream discharge are made over a range of stream levels. The process involves 1) measuring the stream characteristics and flow regimes, 2) calculating the amount of sediment that is being carried at given flows, and 3) correlating flows to suspended sediment (sediment in the water column).

In Phase II, Peltz et al. (2011) developed the conceptual model that there is likely a cycle of sediment loading into Lightner Creek. Further the study proposed that the cycle includes a heavy sediment load contributed to Lightner Creek during late summer storms and that deposits sediment on the bed of Lightner Creek and the Animas River at the confluence that can be activated during low flow or spring runoff events until the load is cleared out in early summer (Figure 1). These previous studies determined that Perins Canyon is the largest sediment contributor to Lightner Creek.

The Phase III sampling plan was designed to measure sediment transport, monitor flows, and develop a sediment curve for TSS. This study did not attempt to quantify the potential sediment bedload, i.e. what is creeping downhill along the stream floor that is not suspended in the water column. While it is recognized that bedload also contributes sediment into Animas River, it was beyond the means of this grant to address this component at this time. The sampling equipment was designed for daily collection of samples from the water column and does not offer the ability to sample the movement of the heavier

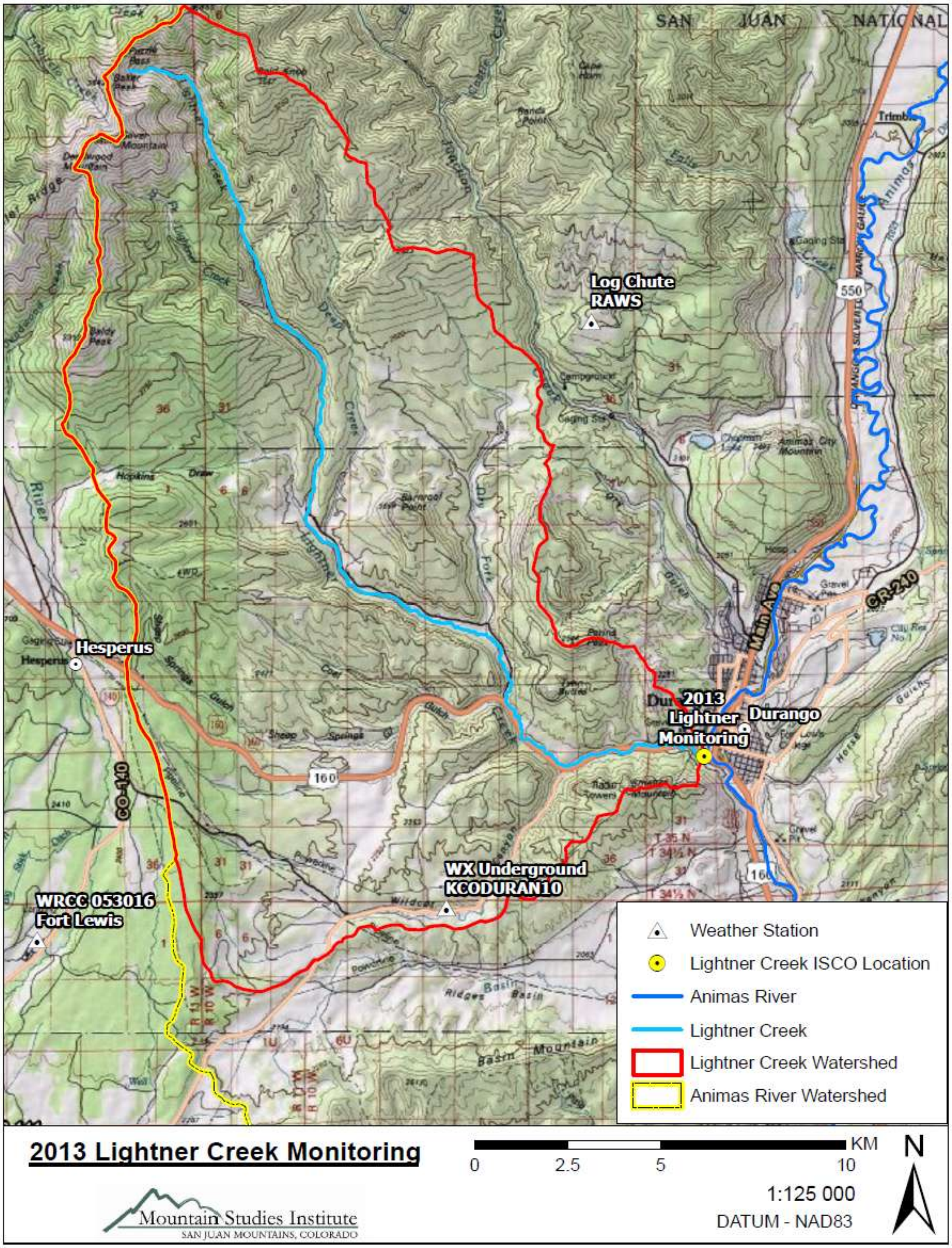


sediment (>2mm) entrained in the creek.

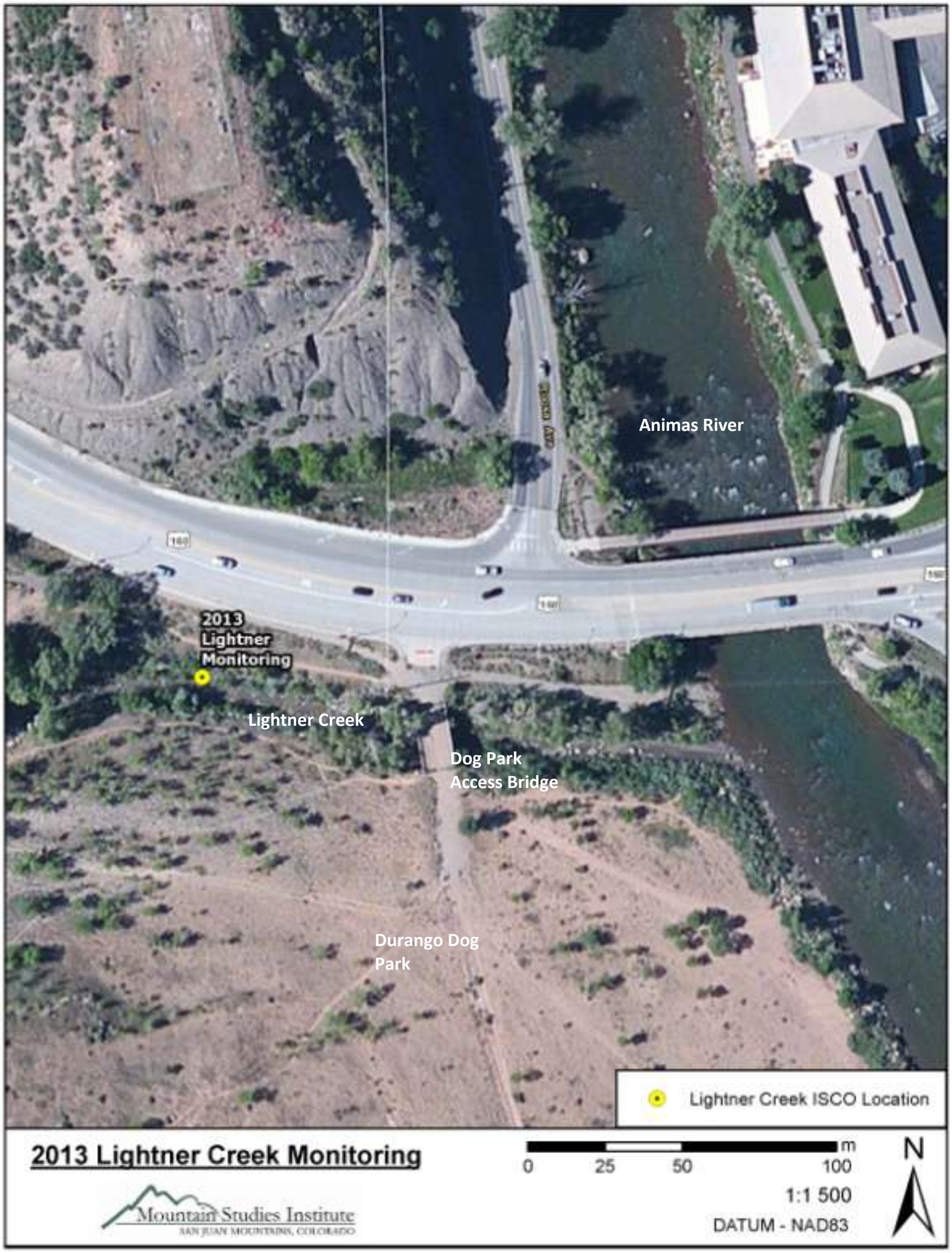
Figure 1: Conceptual Diagram of Sediment Loading. From Peltz et al. (2011). Sediment dynamics model for Perins Canyon and Lightner Creek during summer low flow periods and during/following monsoon precipitation events large enough to detach and mobilize sediment in Perins Canyon downslope to its confluence with Lightner Creek.

Sampling Site

The ideal sampling site was characterized as a location that allowed for the measurement of TSS being contributed to the Animas River from Lightner Creek. Results from previous sampling efforts indicated that the sediment contributions come from sub-drainages to Lightner Creek that have confluences above the Durango Dog Park (Basin Hydrology 2010, Peltz et al. 2011). The sample site for the equipment was chosen on Lightner Creek to be below all major tributaries, including Perins Canyon (Map 1, approximately 100 meters above the confluence with the Animas River). The site was located approximately 20 meters upstream of the bridge that accesses the dog park (very close to the 2011 sampling site). The location was selected because of its uniform channel to moderate flows and stream bottom, bank contours, public access, and proximity to the Animas River. A site further up-stream had been selected for a sampling attempt in 2012 but high flows swept the equipment away from the stream channel. The site location selected in 2013 was intended to offer a more stable location for equipment. Perins Canyon was explored as a complimentary monitoring site; however, field reconnaissance determined that 1) there was not adequate public access to the drainage near the confluence with Lightner Creek and 2) the drainage lacks continuous flow, which would not have worked with the available sampling equipment. The selected Lightner Creek location allowed for the measurement of all sediment contributions to the creek, and thus to the river (Map 2).



Map 1: Lightner Creek Watershed. The Lightner Creek sampling location, and location of weather monitoring stations: Log Chute RAWS from http://www.wunderground.com, Wildcat Canyon Station, and WRCC 053016 Fort Lewis from Western Regional Climate Center.



Map 2: Lightner Creek Sampling Site. Map showing the location of the Lightner Creek sampling location in relation to the confluence of the Animas River and the Dog Park Access Bridge.

Methods

Sediment rating curves are developed by collecting water samples, filtering the sediment, and measuring the dry weight of the sediment in relation to the sample size. These findings are then correlated with a hydrograph developed by measuring stream flow at various stages (very low to very high). The rating curve should demonstrate a “threshold” flow, the flow at which the stream begins to pick up sediment and incorporate it into the water column. The curve then increases until the water column meets maximum capacity, at which point the curve flattens out. The curve is developed by plotting suspended sediment against flow and calculating the curve of fit (D.E. Walling 1977).

MSI installed an ISCO sampler into Lightner Creek approximately 20 meters upstream of the bridge to the Dog Park in Durango, CO. The sampling installation consisted of a stilling well, made from a perforated 5-gallon bucket, secured to a t-post in the center of the stream channel. The large stilling well was designed to minimize turbulent flows around the staff gauge and provide a uniform water column from which to draw the suspended sediment sample. A staff gauge and a sample collection tube for water collection with suspended sediment were also attached to the t-post to secure the equipment mid-channel. The sample collection tube extended to the ISCO, which was secured to vegetation on the northern stream bank. The staff gauge was used to record stream depth when manual discharge measurements were taken. The ISCO collected a 1-liter sample each day, drawing water through the collection tube and depositing it into one of 24 bottles located within the storage area of the ISCO. The ISCO would then automatically pivot the collection tube over the next collection bottle in the rotation. Sample bottles were removed from the ISCO approximately every 2 weeks and the water was filtered in a laboratory. The sediment filtered from the samples was weighed, dried, and weighed again. The weight of sediment was used to calculate TSS (Clescerl et al., 1999; EPA, 1971).

Precipitation and Temperature

Precipitation data was gathered from three established regional weather stations accessible on http://www.wunderground.com/: Log Chute RAWS, Fort Lewis, and Wildcat Station. Data from Log Chute RAWS MTS761 weather station in Junction Creek was used to provide information on daily and monthly weather events in the proximity of Lightner Creek. This station was selected because it is located on the west side of the Animas Drainage in the shadow of the La Plata Mountains (Map 1). Precipitation data was also gathered from the Wildcat Station (weather underground station KCODuran10), located in the Lightner Creek watershed. Historical comparative data was collected from the FORT LEWIS, COLORADO (053016) station from the Western Regional Climate Center - Desert Research Institute Reno, NV page (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?co3016). This station is located at the old Fort Lewis College Campus in Hesperus Colorado and represents the region west of the Animas River.

The Log Chutes Station and the Fort Lewis stations were selected, in part, because they were used as reference stations for the MSI report of 2011 (Peltz et al. 2011). Selecting these stations offered consistency in comparative analysis of weather conditions for Lightner Creek. The Wildcat Station was added because it is located within the southwestern portion of the Lightner Creek Watershed.

Channel Characterization and Flow Measurement

In order to characterize the channel shape and measure flows at the site, MSI established a cross section in Lightner Creek adjacent to the sediment sampling location (Map 2). The cross section was divided into

1-foot segments. Depth (feet) and velocity (feet per second) were recorded in each segment and summed to calculate a mean discharge (cubic feet per second, or cfs).

Sediment Measurement

Once samples were collected from the ISCO, they were filtered in a laboratory using a hand-powered vacuum pump. Filters were weighed before filtration and after. Filters were then dried and were re-weighed to get dry weight. In some cases multiple filters were required because of the volume of sediment. In these cases the weight of sediment found in each filter were combined. Laboratory analysis of TSS was conducted at Fort Lewis College, using a dry mass method (Clescerl et al., 1999; EPA, 1971) and is summarized as follows:

1. Prior to filtration, a 47mm Whatman© glass fiber filter is weighed.
2. One-liter water samples are remixed by vigorous shaking vigorously for 30 seconds.
3. Mixed samples are filtered through filters, using a suction flask, filter holder and funnel.
4. Filters and residue are placed on an aluminum weighing dish and dried.
5. The equation for determining TSS is:

$$\text{Total Suspended Solid (TSS), mg } l^{-1} = (A\text{-}B) \times 1{,}000/C$$

Where: A = weight of filter and dish + residue in mg
B = weight of filter and dish in mg
C = volume of sample filtered in mL

Results

MSI collected data daily from March through July 2013. The data represents TSS during spring runoff and the early part of the monsoons (Figure 2). Following July, high flows repeatedly interrupted the sampling equipment and prevented data collection during the monsoon season (August and September). Late monsoon data were lost in part because of the complication of keeping equipment in Lightner Creek during high flows (see discussion). The sediment data was used in an attempt to develop a sediment curve associated with the spring runoff. The data offers a range of sediment values for flows that can occur within Lightner, though no clear relationship between flows and suspended sediment was identified.

Precipitation and Temperature

Precipitation and temperature data was gathered for historical averages and compared with 2013 data. When compared with historical data from Western Regional Climate Center Fort Lewis Station (1915 - 2013), data from Log Chute RAWS MTS761 shows that precipitation totals for the months of March, April, May, and June were below average in 2013. July and August were above average in 2013 (Figure 3). Daily precipitation totals from the Log Chute RAWS MTS761 show that there were isolated precipitation events in the spring of 2013. Precipitation events typical of monsoon season began in July and continued through August (Figure 3).

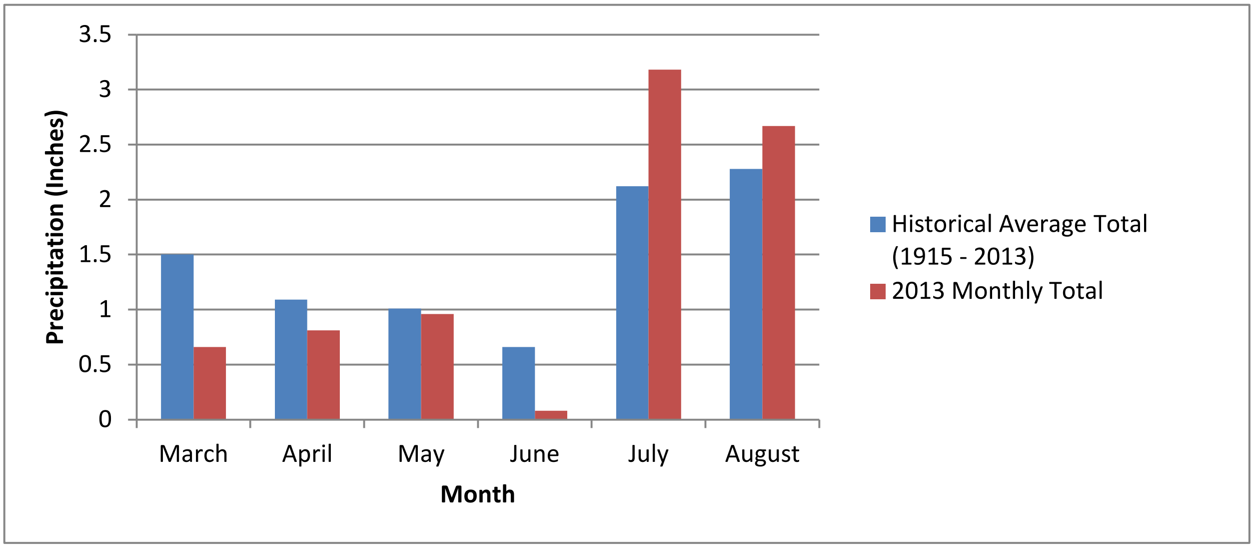


Figure 2: Precipitation: Average Historical Monthly Totals vs. 2013 Compares the average monthly precipitation totals from 1915 to 2013 to the monthly precipitation totals for 2013.

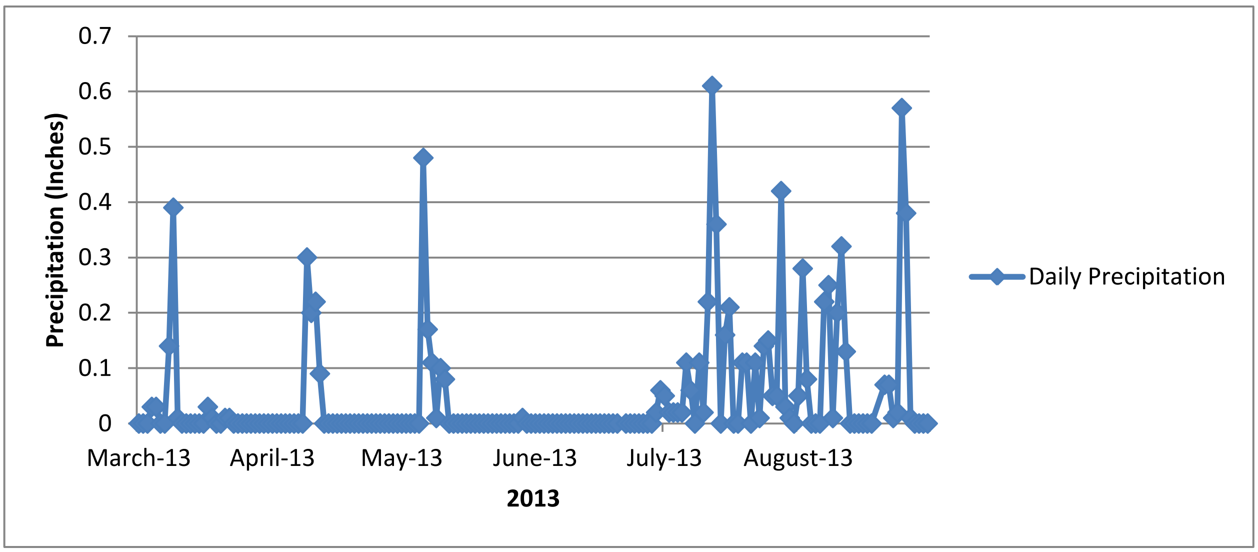


Figure 3: Daily Precipitation Totals: March 1 to August 31 of 2013 (inches).

Channel Characterization and Flow Measurement

The manual stream flow measurements were collected nine times between March 9 and June 20, 2013. The last three measurements collected in June were excluded because the data was suspect after the flow gauge could not be calibrated. The March to June measurements captured a range of discharges between 3 and 12 cfs. Manual stream flow measurements were correlated to stream stage height measurements taken from a staff gage established in the creek at the collection point. The measurements were used to establish a relationship between the stream flow and stream gage. The relationship is expressed through the equation $y = 2.6309x^{0.712}$ with an $R^2 = 0.98736$.

Table 1. Channel Measurements, Width, and Flow

DATE	TIME	WIDTH (Ft)	CFS	Stream gage (In)
3-20-2013	16:25	8	3.0745	6
4-03-2013	9:30	9	5.3407	8.5
4-11-2013	12:00	11.5	8.4183	11.5
4-29-2013	13:30	11.5	11.96125	16
5-03-2013	14:00	11.1	8.9131	13
5-10-2013	11:30	10	8.41175	11.25

Flow measurements were compared to stream gage heights. A strong relationship ($R^2 = 0.98736$) was shown between the two variables. This relationship allows for flows to be calculated from gage heights by using the equation generated by the relationship ($y = 2.6309x^{0.712}$, Figure 5).

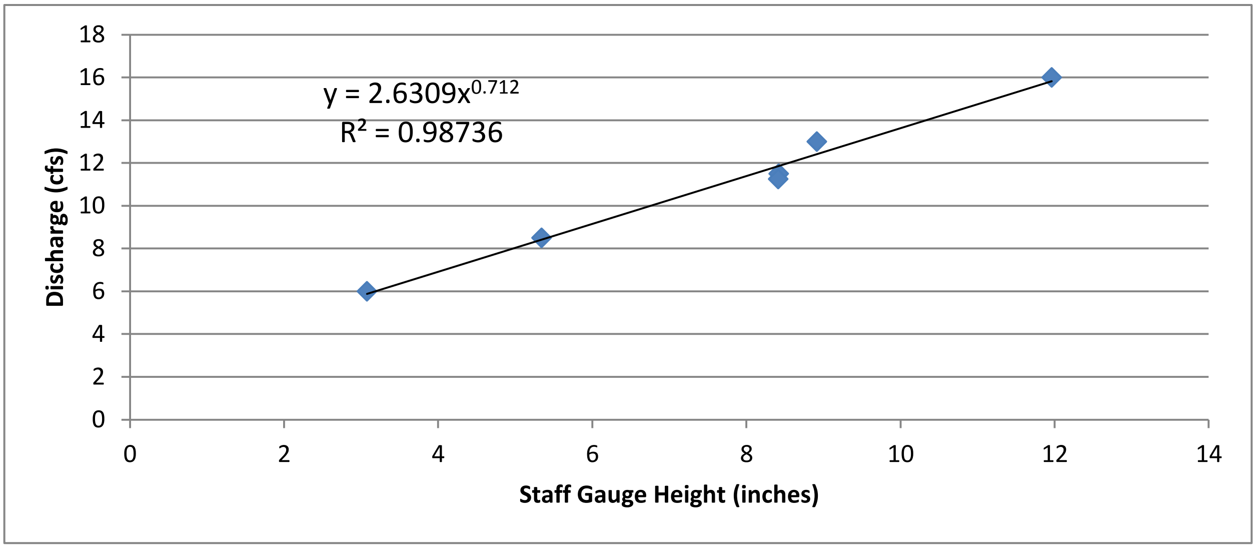


Figure 4: Measured Discharge vs. Staff Gauge Measurements. Stream gage heights plotted against stream discharge in cubic feet per second (cfs).

Sediment Measurement

The ISCO sampler collected a 1-liter sample from Lightner Creek once daily, at 1600 hours from March 21 to August 15, 2013. A total of 118 samples were collected, dried and weighed. There were two periods when data was lost due to issues with the sampling equipment (May 26-30; June 13-14) and one due to high flows dislodging the equipment and carrying it down stream (July 21-August 10). The station was re-established on August 13, however the ISCO was removed from Lightner Creek following August 15 because high flows continued to threaten the equipment.

When TSS is plotted against the daily total precipitation for spring runoff (March to June) no relationship was revealed (R^2 value of less than 0.5). The inability to correlate precipitation events recorded at the monitoring stations in the Lightner Creek watershed with TSS suggests that the pulses of sediment loading are related to snow melt and/ or very localized storms occurring in tributaries that do not have established precipitation monitoring stations. TSS was not determined to be associated with precipitation.

Table 2. Total Suspended Sediment Sample Statistics

Total Number of Samples	118	**Monitoring Period:**	March 21-August 15, 2013
Average (g)	0.620	**Dates of Samples Analyzed:**	3/21-5/26; 5/30-6/12; 6/15-7/21; 8/13-8/15
Minimum (g)	0.006	**Maximum (g)**	15.856
1st Quartile (g)	0.09	**2nd Quartile**	0.142
3rd Quartile (g)	0.50	**4th Quartile**	15.865

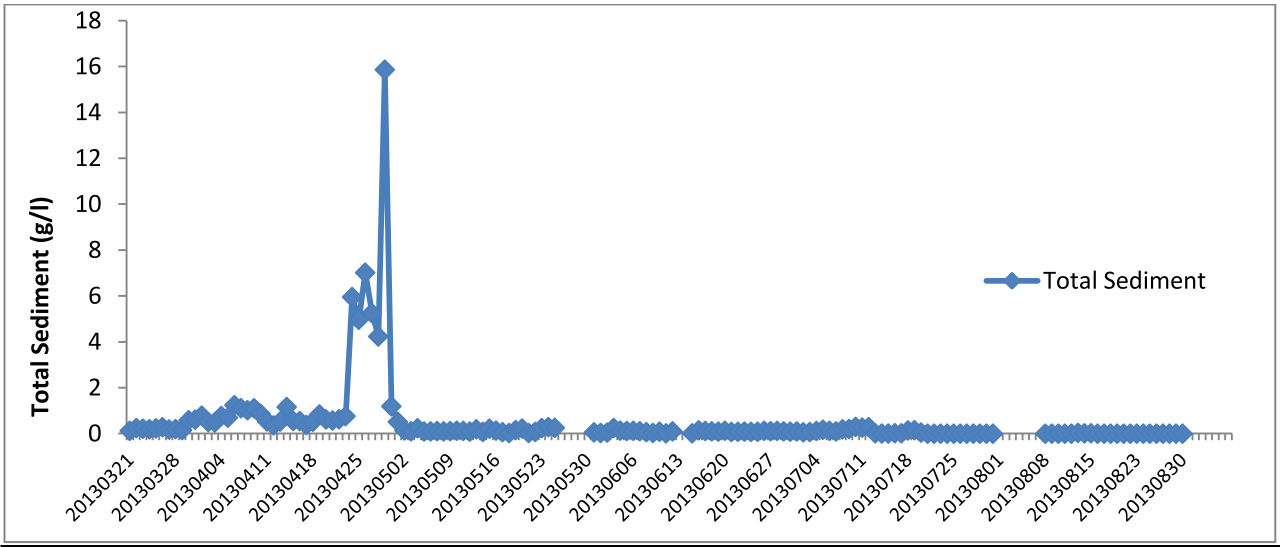


Figure 5: Total Sediment March 2013- August 29. Sediment data plotted over time. The graph shows the extent of data collected, data holes, and sediment load over time.

Sediment Transport

Channel measurements and flow measurements were used to calculate stream flow (cfs) on six days from March 20 to June 20. These data were used to correlate flows to recorded stream gage heights (from the yard stick on the t-post) taken during those sampling periods. A strong correlation (R^2 = 0.98736) was identified between the stream gage heights and stream flow calculations (Figure 4). The resulting equation ($y = 2.6309x^{0.712}$) was used to calculate stream flow from gage height measurements expanding the number of data points incorporated in the calculation of the hydrograph.

From the correlation and additional stream gage measurements, a hydrograph was constructed for the period of time between March and June of 2013 (Figure 7). The hydrograph was plotted against total daily precipitation records for the same period of time. The small sample size for flow does not allow for correlations to be drawn but no relationship was found between cfs from March to June and precipitation events. This suggests flows are most closely associated with snow melt and runoff and/or that the available precipitation gauges are not representing precipitation events occurring in the Lightner Creek watershed.

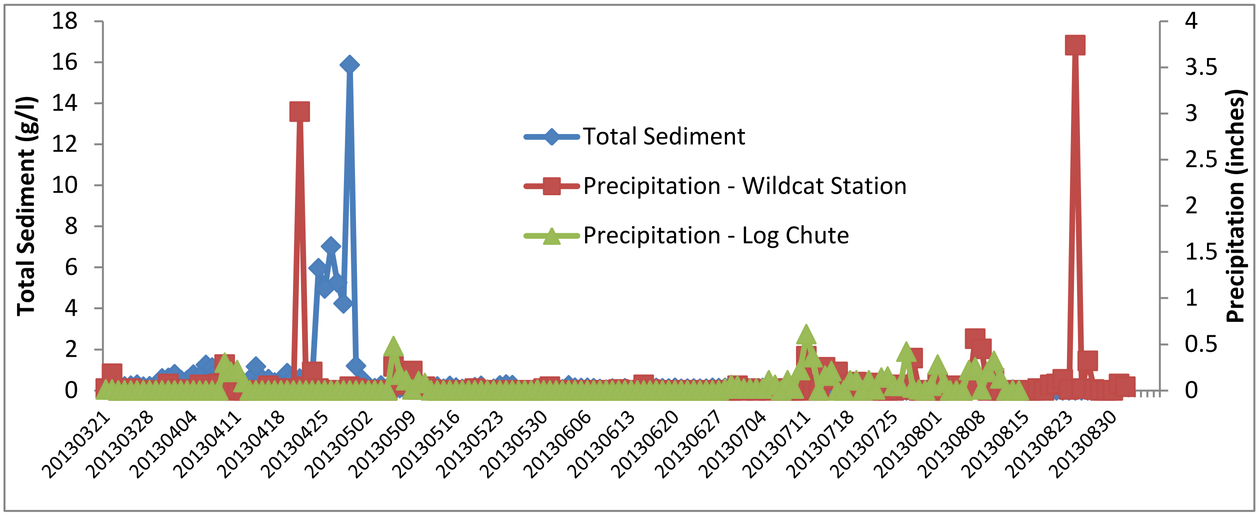


Figure 6: Total Suspended Solids vs. Total Daily Precipitation.

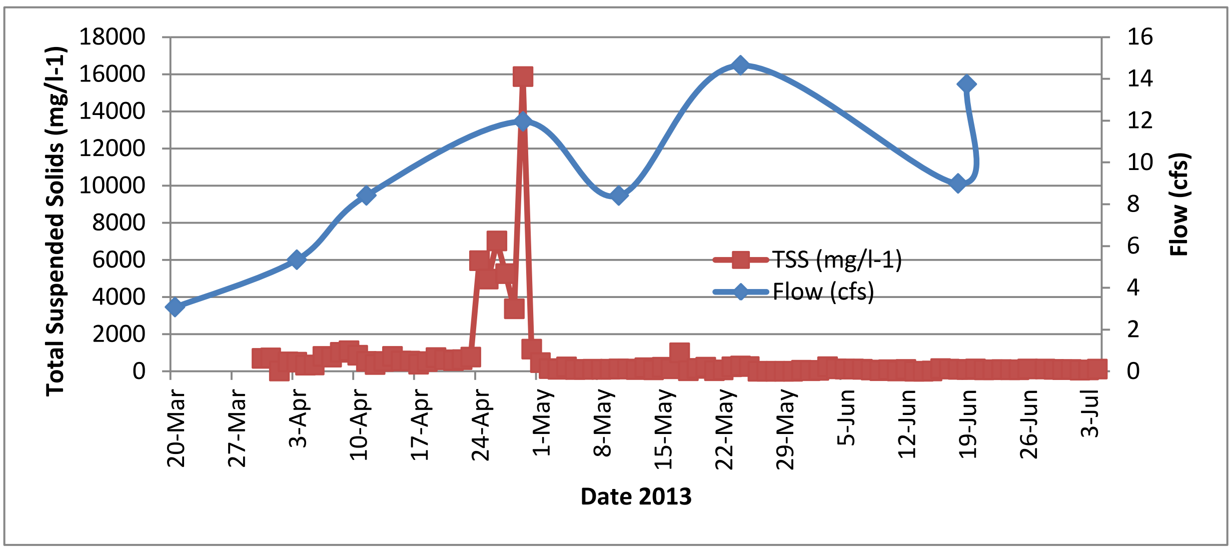


Figure 7: Total Suspended Solids vs. Hydrograph for Lightner Creek, March to June of 2013. Plotting flow (cfs) vs. time. The hydrograph was developed from measurements taken from a manual gage installed at the Lightner Creek sample site. Suspended sediment (mg l^{-1}) during spring flow conditions.

When the hydrograph for the March to June period is plotted with the TSS measurements the results show an initial flush of sediment associated with early snowmelt in the hydrograph (Figure 7). Sediment load is reduced following this flush despite increasing flows (following May 1). Sediment loads for the spring were highest in April of 2013 with a couple of smaller loading events in May. Sediment data is limited to sampling that occurred during spring runoff and pre-monsoon events. The extreme nature of runoff that occurred during the monsoon period made it difficult to maintain equipment required to measure sediment loading.

When plotted, the data shows a wide range of sediment loads (between 1,000 and 12,000 kg/l) for flows in Lightner Creek (Figure 8). Other creeks in the southwest have been shown to have a great degree of variability in sediment load (Ryan et al. 2005). The data gathered was largely collected during periods of high sediment loading. A sediment curve could not be established for Lightner Creek that had a significant statistical relationship. The curve does not suggest a straight forward mathematical relationship between TSS and flow (cfs). It demonstrates that a wide range of sediment loading is possible at a broad spectrum of high and low flows.

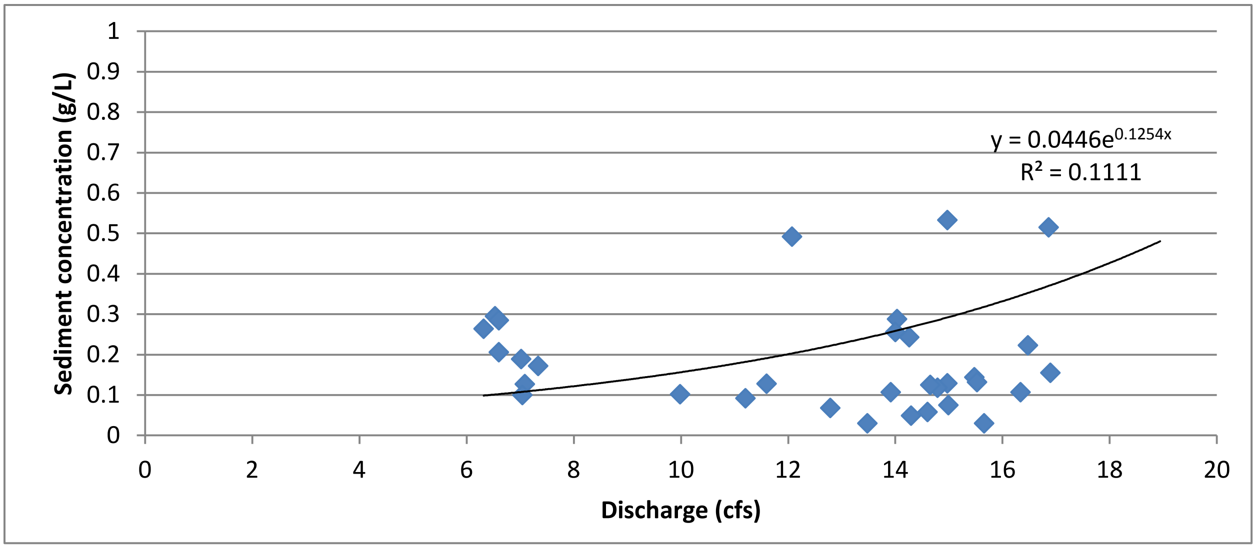


Figure 8: Discharge vs. Sediment concentration - Exponential relationship for discharge plotted against Sediment (R^2=0.1111).

Conclusions & Discussion

Sampling

The automated sampling device (ISCO) was installed within Lightner Creek on March 9 and stayed within the creek until August 24. Other data collection designed to facilitate the study of sediment in Lightner, with an ultimate goal of establishing a sediment rating curve, occurred within that sampling period. Stream channel measurements and flow were taken nine times from March through June of 2013, however three of those measurements were suspect and removed from the study. Stream gage measurement notations occurred up until June 21 of 2013. Because stream gage measurements weren't collected past June, a hydrograph could not be developed for the July to August time frame and the rating curve did not include the monsoonal months.

Precipitation and Temperature

The findings of the study suggest that the spring of 2013 had below average (1915 to 2013) precipitation, while precipitation for the fall was above average. Precipitation measures used in this study included one station within the Lightner Creek watershed and two that were outside of the watershed, in the next drainage to the north, Junction Creek and to the west, old Fort Lewis. Historical averages were provided by the Fort Lewis Station (Map 2). The stations used were selected because of previous reference to these stations (Peltz et al. 2011) and their relative proximity to Lightner Creek.

The data from this study supports the findings of Phase II that suggested that the first flush of the spring runoff carries a large amount of sediment. Eventually sediment is cleared out and TSS was reduced, generally by early summer. Data did not demonstrate a direct correlation between precipitation events during the spring and sediment in Lightner Creek. Ideally, environmental measurements would be taken from within Lightner Creek watershed, specifically in sub drainages identified as major contributors to sediment in Lightner. Storm events can be spotty, effecting small portions of the watershed. Specifically focused precipitation sampling would help to correlate sediment loading with precipitation events in a geographic context.

Channel Characterization and Flow Measurement

On nine occasions between March 9 and June 21, 2013 MSI measured stream cross sections at the established site location, approximately 20 m up-stream of the Dog Park Bridge. Each time stream width, depth and flow was measured, and a reading was taken from an established gage in the stream channel. Of these nine occasions, data from three of the sampling times were removed because the data was suspect. The equipment used to measure flow was found to be giving erratic measurements and could not be calibrated. Statistical significance and correlations increase with the number of stream characterization measurements taken, with a preferred minimum of 10 (Walling 1977). Sampling was spread out so that it included measurements from periods of high and low flows. Depth, width, and flow measurements were used to calculate stream flow in cfs. The lowest flow recorded was 3 cfs and the highest was 12 cfs. A slightly broader spectrum of flows would have given a more thorough picture of the hydrograph in Lightner Creek.

The discharge measurements were correlated with the stream gage measurements so that a quick reading could be taken off the gage that would correlate with cfs. The data gathered was used to develop a hydrograph that could only extend through the period that data associated with flow was collected, that is through June 21. The hydrograph could not be extended any further because no stream gage measurements were taken past that date.

The hydrograph demonstrates the flows in Lightner for the spring runoff. The hydrograph suggests that runoff is composed primarily of snow melt or isolated storm events rather than precipitation events throughout the Lightner Creek drainage.

Sediment Measurement

The ISCO collected a 1 liter sample from Lightner Creek once daily, at 1600 hours. These samples were filtered, the sediment content weighed, and used to calculate Total Suspended Solids (mg/l^{-1}). Despite the programming, there may be some variation in the amount of water that the ISCO collected. The ISCO may not have collected 1 liter every time or water may have been lost in transport (the lids were not secure), and some water may have been lost transitioning between the bottles and the filtering process. This variation was not accounted for in the calculations. Future sediment monitoring should include a measure of the water that was run through the filter.

Sediment Transport

The goal of this study was to develop a sediment rating curve for Lightner Creek. The sediment rating curve for Lightner Creek was restricted to the spring runoff period. This was a result of the difficulties presented by sampling during monsoonal events. Lightner Creek is prone to flash floods. Initial monitoring efforts during 2012 ended when the ISCO sampler was swept from its location by a flash flood. The timing of the event prevented equipment being re-installed until 2013. The delay imposed restrictions on time and money for the research to continue.

During 2013 sampling, MSI did not find a relationship between flows and sediment load and, as a result, were not able to develop a sediment rating curve for Lightner Creek. Data collected during the spring run-off time period (March to June 2013) offered a wide range of sediment load within the stream at a spectrum of flows. The variation in suspended sediment appears to be dependent on the timing of the flow and the amount of sediment that had been deposited on the bed of Lightner during previous high flows. The variations in sediment load observed in Lightner appear to be consistent with findings presented by Ryan et al. (2005) during an assessment of creeks and rivers in Colorado and Wyoming, including the San Juan and Florida Rivers.

High flows made it difficult to adequately secure equipment in Lightner Creek. As a result, a sediment curve was not developed for the monsoon period. In 2012, a high flow event removed the ISCO from Lightner on August 7. High flows on August 10, 2013 again removed the ISCO despite a new location and better securing methods. The ISCO was removed from the stream channel immediately before storm events at the end of August in 2013 that brought flows higher than those that removed the ISCO the first time.

The findings of this study do support the idea that there is a cycle associated with suspended sediment in Lightner Creek. That cycle includes a heavy sediment load contributed to Lightner Creek during late summer storms that may be stored in the bed of Lightner Creek and carried to the Animas River during low flow events (Peltz et al. 2011). This sediment is stored in the lower portions of the creek and in the form of a fluvial fan at the confluence with the Animas River. This study also suggests that spring runoff will carry sediment load at lower flows from Lightner Creek until the stored load is cleared out, usually by early summer. Previous studies determined that Perins Canyon is the largest sediment contributor to Lightner (Basin Hydrology 2010 and Peltz 2011).

In late 2011, the City of Durango installed a catchment basin at the base of Perins Gulch. In August of 2012 a flash flood overwhelmed the catchment basin and large amounts of sediment were deposited in Lightner. This is the same event that washed the ISCO installed in Lightner Creek out of the channel. The results of the sediment event included the development of a large fluvial fan into the Animas. It may be that sediment collected during spring runoff of 2013 was associated with the flash flood that occurred in the fall of 2012.

Accurate sediment curves can be difficult to develop. They have been shown to underestimate sediment load (R.I. Ferguson 1987). Errors of ± 50 percent or more may be associated with many rating curve estimates of sediment load (D.E. Walling 1977). Many variables (rainfall, moisture content of soil, land use pattern, slope factor, soil characteristics etc.) affect sediment load (Özgür Kişi 2007). This is further complicated by the fact that seasonal variations in sediment flux have been shown to be associated with specific conditions at individual sites (Ryan et al. 2005). All this suggests that where and when rain falls within the Lightner Creek watershed, for what duration and at what velocity, as well as the overall condition of soils and vegetation, for a given period of time, will influence a sediment curve.

The correlations between discharge and sediment could be strengthened with increased resources. More modern automated sampling units would allow for sampling to occur with increased flows. It would also provide the opportunity to directly correlate sample collection with flow at sample time. Additionally, the installation of a true "permanent", concreted into the stream channel, stream gaging station would allow for repeatable measurements that can be correlated over a series of years.

Sediment rating curves do miss a component of sediment loading that should be included in future research. Samples collected and analyzed were built around water carried in suspension in the water column. The opening for the collection hose from the ISCO was located as close to the bed of Lightner

Creek as possible (approximately 12.7 mm) while preventing it from sucking up any of the bedload sediment. Heavier sediments will move directly along the bottom of the creek and may not have been included in the development of the sediment rating curve.

Recommendations

The findings of this study suggest that sediment is deposited in Lightner Creek during late summer events and is carried into the Animas River with spring runoff. Addressing the late summer contributions would help to reduce what is carried to the Animas River main stem during the summer low-flow and late summer periods. Both Basin Hydrology (2010) and Peltz et al. (2011) identified Perins Gulch as a primary contributor to sediment in Lightner. Peltz et al. made the following recommendations:

1. Determine the mechanism of sediment transport and expected background level of erosion in tons/year in Perins Canyon.
2. Install sediment reduction technologies, including: biological controls, engineered structures, soil stabilizers, and other erosion control techniques in Perins Gulch.
3. Evaluate the effectiveness of those BMP's for reducing sediment from Perins Gulch to Lightner Creek and the Animas River, including include straw waddles, silt fences, excelsior logs, and vegetation management.
4. Continue to monitor sediment supply and transport in Lightner Creek.

The City of Durango has already installed a catchment basin at the base of Perins. This basin was overwhelmed during a flash flood in August of 2012. Any infrastructure installed should be prepared for large influxes of water and sediment that may occur during dramatic events. Installation of these BMP's and catchments face constraints associated with natural topography and established infrastructure. It is recommended that planning for future development and construction include plans for mitigation measures of appropriate size during initial planning proposals. Other potential sources of sediment can be identified and addressed following the implementation of effective mitigation measure for loads from Perins Gulch.

In order to monitor the effectiveness of mitigation measures, a permanent, concreted or similarly secured, gaging station and monitoring location should be installed within Lightner Creek. Monitoring above the Dog Park Bridge, as the past studies have done, offers an assessment of what is being carried in Lightner with a likelihood of reaching the Animas River. This location could serve as a permanent monitoring station.

The end goal of the project is to reduce sediment influx into the Animas River from Lightner Creek. Three studies have been conducted on where the sediment in Lightner Creek is coming from. The previous studies offer us a reasonable idea of sources. Addressing the problem also requires exploring potential fixes given constraints with property ownership and geography. A GIS assessment that incorporates land ownership and land use within the sub-basins of Lightner could be used to launch development of feasible mitigation measures. Mitigation measures should include creative, new storm water technologies that allow for incorporation of previously unutilized areas (i.e. parking lots) for settling and mitigating silt deposition.

References

Allen, J.D. 1995. Stream ecology: Structure and function of running waters. Chapman & Hall, New York, 388 pp.

Barret, J.C., Grossman, G.D., Rosenfeld, J. 1992.Turbidity induced changes in reactive distance of rainbow trout. *Transactions of the American Fisheries Society* 121:437–443.

Berry, W., Rubinstein, N., Melzian, B., Hill, B. 2003. The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review. (Internal Report) U.S. Environmental Protection Agency. [available at http://water.epa.gov/scitech/swguidance/waterquality/standards/criteria/aqlife/pollutants/sediment/index.cfmhttp://water.epa.gov/scitech/swguidance/waterquality/standards/criteria/aqlife/pollutants/sediment/index.cfm]

Caux, P.Y., Moore, D.R.J., MacDonald, D. 1997. Ambient water quality guidelines (criteria) for turbidity, suspended and benthic sediments. Technical Appendix. Prepared for British Columbia Ministry of Environment, Land and Parks. April, 1997.

Clescerl, L.S., Greenberg A.E., Eaton A.D. 1999. Standard Methods for Examination of Water and Wastewater. American Public Health Association, USA.

Colorado Department of Public Health and Environment Water Quality Control Commission. 1993. Regulation No. 30 Colorado River Salinity Standards, pursuant to section 25-8-101 et seq. C.R.S., as amended, and in particular, sections 25-8-202(2), 25-8-204; and 25-8-207(1)(c), [available at www.cdphe.state.co.us/regulations/wqccregs/100239salinity.pdf.]

Colorado River Watch Network, 2010. Water quality indicators: Key measures provide a snapshot of conditions. http://www.lcra.org/water/quality/crwn/indicators.html *Accessed 11/29/2010.*

Ferguson, R.I. 1987. Accuracy and precision of methods for estimating river loads. Earth Surface Processes and Landforms: Volume 12, Issue 1, pages 95–104, January/February.

Gardner, W.H. 1986. Water content. In Methods of Soil Analysis: Part 1. American Society of Agronomy, Madison, WI, p. 493-507.

Hickman, T. and R. F. Raleigh. 1982. Habitat suitability index models: cutthroat trout. U.S.D.I. Fish and Wildlife Service. FWS/OBS-82/10.5. 38 pp.

Hokanson, K.E.F., Kleiner, C.F., Thorslund, T.W. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout (*Salmo gairdneri*). *Journal of the Fisheries Research Board of Canada* **34,** 639–648.

Kişi, Özgür. 2007. Development of streamflow-suspended sediment rating curve using a range dependent neural network. International Journal of Science & Technology. Volume 2, No 1, 49-61.

Matthews, K.R., Berg, N.H. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. *Journal of Fish Biology* 50:50-67.

Basin Hydrology. 2010. Lightner Creek Watershed Evaluation Report: prepared for the Lightner Creek Watershed Group, La Plata County, Colorado by Basin Hydrology Inc.

Peltz, C.D., K. Nydick, and C. Livensperger. 2011. Lightner Creek Sediment Monitoring Initiative Report - Phase 2: prepared for the Lightner Creek Watershed Group, La Plata County, Colorado by Mountain Studies Institute.

Poole, G.C., Berman, C.H. 2001. An Ecological Perspective on In-Stream Temperature: Natural Heat Dynamics and Mechanisms of Human-Caused Thermal Degradation, *Environmental Management* 27(6) 787-802.

Quigley, T.M., and S.J. Arbelbide. 1997. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great basins. USDA Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR-405, Vol. 3.

Raleigh, R.F., Hickman, T., Soloman, R.C., Nelson, P. C. 1984. Habitat suitability information: Rainbow trout (*Oncorhynchus mykiss*). *U.S. Fish and Wildlife Service FWS/OBS-82/10.60*. 64 pp.

Redding, J. M., C.B. Schreck, and G. H. Everest. 1987. Physiological effects on coho salmon and steelheads of exposure to suspended solids. *Transactions of the American Fisheries Society* 116:737–744.

Richardson, E.V., Simons, D.B., Lagasse, P.F. 2001. River Engineering for Highway Encroachments: Highways in the River Environment, Hydraulic Design Series #6. U.S. Department of Transportation Federal Highway Administration.

Robichaud, P.R., and Brown, R.E. 2002. Silt fences: an economical technique for measuring hillslope soil erosion. U.S.D.A. Forest Service, General Technical Report RMRS-GTR-94. Fort Collins, Colorado, 24 p.

Rough, D. 2007. Effectiveness of Rehabilitation Treatments in Reducing Post-Fire Erosion after the Hayman and Schoonover Fires, Colorado Front Range, unpublished Master's Thesis, Colorado State University, Fort Collins, CO. [available at http://warnercnr.colostate.edu/~leemac/Dissertations/D_Rough_Thesis.pdf]

Ryan SE, Porth LS, Troendle CA. 2002. Defining phases of bedload transport using piecewise regression. Earth Surface Processes and Landforms 27: 971–990.

Sweka, J.A., Hartman, K.J. 2001. Influence of Turbidity on Brook Trout Reactive Distance and Foraging Success. Transactions of the American Fisheries Society 130:138-146

U.S. Department of Agriculture 2005. Colorado Coldwater Fish Stream Habitat. http://efotg.sc.egov.usda.gov//references/public/CO/coldwaterfish.pdf

U.S. Environmental Protection Agency (EPA) Method 160.1. 1971. [available at http://www.umass.edu/tei/mwwp/acrobat/epa160_1filtres.pdf]

_____1979. Methods for the Chemical Analysis of Water and Waste, EPA 600/4-79-020, p. 160.2.

Walling, D.E. 1977. Assessing the accuracy of suspended sediment rating curves for a small basin. Water Resources Research. Volume 13, Issue 3, pages 531–538.

Walling, D.E. and Webb, B.W. 1987. Suspended load in gravel-bed rivers: UK experience. In Thorne, C.R., Bathurst, J.C., and Hey, R.D. (eds), Sediment transport in gravel-bed rivers. Chichester: Wiley, 251-723.
White, Jim. 2009. Animas River, Durango: fish survey and management information. Colorado Division of Wildlife. http://wildlife.state.co.us/SiteCollectionDocuments/DOW/Fishing/FisheryWaterSummaries/Summaries/Southwest/AnimasRiverDurango.pdf .

Weather Underground.

Wilber, D.H. and D.G. Clarke. 2001. Biological effects of suspended sediments: a review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. North American Journal of Fisheries Management. l21:855-875.

Ryan, S.E., L.S. Porth, and C.A. Troendle. 2005. Coarse sediment transport in mountain streams in Colorado and Wyoming, USA. Earth Surface Processes and Landforms 30, 269–288.

R.W.Herschy (Ed.) (1999). Hydrometry—Principles and Practices. John Wiley & Sons, Chichester. pp. VI+376. ISBN 0-471-97350-5.