Lightner Creek Sediment Monitoring Initiative Report - Phase II

Christopher D. Peltz, MS
Mountain Studies Institute

Koren Nydick, PhD
Mountain Studies Institute

Carolyn Livensperger
Mountain Studies Institute

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Acknowledgements

Protecting the natural environment, especially water quality and stream habitat requires a collective effort. So too did this monitoring effort on Lightner Creek require a collective effort. There are many partners who provided the financial support for the project, especially Trout Unlimited, Colorado Water Conservation Board, San Juan Public Lands Center, Animas RIVERKEEPER, Animas Watershed Partnership, BUGS Consulting, the City of Durango, La Plata County, and the Southwestern Water Conservation District. In addition to the broad organizational support, a range of individuals also provided time, oversight, as well as technical direction and support to the monitoring effort, these people include Chester Anderson, James Forester, Kinsey Holton, Barb Horn, Pamela Leschak, Jan Mayer-Gawlik, Mark Oliver, Ann Oliver, Jack Rogers, Victoria Schmitt, Paul Sheppard, Buck Skillen, Mark Torres, Sal Valdez, Chuck Wanner, Wally White, and Kay Zillich. Special thanks also go out to some current and former Mountain Studies Institute interns and employees, without which this project would not have been possible. These folks include Michael Costello, Aaron Kimple, and Melissa Boley who went out in all conditions to retrieve samples and process them. We also want to especially thank Meghan Maloney from the San Juan Citizens Alliance for her steady support. We appreciate the work that Basin Hydrology and Mark Oliver conducted on the Phase 1 assessment, which greatly helped focus our sampling effort and our understanding of the system.

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Executive Summary

Sediment inputs to the Animas River from Lightner Creek during the summer and fall have been a persistent source of water quality degradation. The problem of excess sediment discharging from Lightner Creek is particularly acute during the low-flow and monsoon seasons, and is of great concern to a range of stakeholder groups and others interested in the ecological health and aesthetic value of the Animas River. A number of hypotheses have been proposed regarding the source and mechanism for the excess sediment in Lightner Creek. Some of these hypotheses include: changes in land uses, changes in vegetation cover, and changes in patterns of disturbance within the highly erodible Mancos Shale drainages that feed into Lightner Creek. Or, that a significant portion of the shale sediments entering the system is a naturally occurring process and that the sedimentation rate in Lightner Creek is within the historical range of variation.

Mountain Studies Institute (MSI), Basin Hydrology, and other collaborators monitored sediment fluxes and other physical characteristics in Lightner Creek from March to December of 2010. The study design collected samples from six sites along Lightner Creek and one site along the Animas River (above the confluence with Lightner Creek). The results of this monitoring suggest that there is a significant difference between the upper Lightner Creek watershed and lower watershed below Perins Canyon in terms of the amount of sediment delivered to Animas River.

We observed that above Perins Canyon total suspended sediment (TSS) values were strongly correlated with TSS values observed in the Animas River. For the lower watershed below Perins Canyon, the TSS values were more influenced by individual storm events, and were much larger in magnitude than the upper Lightner Creek watershed and the Animas. From these results, we conclude that a large proportion (>70%) of the sediment delivered to the Animas River from Lightner Creek during the summer low-flow periods and late summer monsoon has its origin in Perins Canyon. The monitoring indicates that this sediment is mobilized during intense summer precipitation events which create flow conditions that transport sediment downslope to its confluence with Lightner Creek, but that flows are not large enough to maintain entrainment of particles when the material reaches Lightner Creek. This sediment, now deposited in Lightner Creek below the Perins Canyon culvert, is then mobilized downstream to the Animas over successive precipitation events which increase flows in Lightner Creek.

Project Description/Background

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." The goal of reducing sediment inputs from Lightner Creek was developed by the Lightner Creek Group (San Juan Citizens Alliance, Trout Unlimited, City of Durango, and MSI) in 2009. MSI has been involved with the Lightner Creek Group since its inception in 2009, and has taken the lead on the Phase 2 portion with its sampling and analysis effort with support from Basin Hydrology. Phase 1 was completed by Basin Hydrology in March of 2010.

Lightner Creek Watershed

The Phase 1 assessment of the Lightner Creek watershed, conducted by Basin Hydrology in 2009 (Oliver, 2010), details 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 area 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 (Oliver 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.

Sampling Sites

Six sites along Lightner Creek and one site in the Animas River mainstem were sampled (Figure 1, Table 1). The sites on Lightner Creek constitute areas that encompass the range of geomorphic conditions found in the lower Lightner Creek watershed, and were selected based on the findings of Basin Hydrology 2010 study, which focused on the lower watershed. The sites listed in Table 1 are arranged from downstream to upstream, with the Animas River site located just upstream from the confluence with Lightner Creek. Dog Park Bridge is the most downstream site on Lightner Creek and is where the staff gage was placed by Basin Hydrology. Upstream from Dog Park Bridge are Rosemary Lane and the Perins culvert sites. These three sites collectively constitute the lower sites, or sites that would be directly influenced by Perins Canyon. The remaining three sites (upstream of Perins Canyon, Lower Twin Buttes, and Upper Twin Buttes) are sites that, for this analysis are considered the upper sites.

The climate of the Southern San Juan Mountains are strongly affected by monsoon weather patterns, which contribute to heavy, localized precipitation events occurring in the late summer and early fall (Figure 3 and Figure 4). These events contribute a significant amount of precipitation and may initiate the detachment and transport of erodible material from side drainages feeding Lightner Creek at a time of year when turbidity in the Animas River is low.

Table 1. Lightner Creek Sampling Sites

Site	Position	Location (NAD 83, 13N)	Distance from Animas River (kilometers)	Number of times sampled
Animas at Albertsons	Animas	244099.17, 4128927.76	0	19
Dog Park	Lower	243973.98, 4128542.23	0.18	33
Rosemary Lane	Lower	243275.94, 4128817.13	1.2	33
Perins culvert	Lower	242852.25, 4128786.16	1.58	34
Upstream of Perins Canyon	Upper	242839.53, 4128784.50	1.59	34
Lower Twin Buttes	Upper	241254.84, 4128494.11	3.4	32
Upper Twin Buttes	Upper	240649.17, 4128674.98	4.2	32

Methods

Field sampling began in March of 2010, and continued through November 2010. Sampling was conducted thirty-four times over this period, roughly corresponding to once a week. Samples were collected at six points along Lightner Creek and at one point on the Animas just upstream from the confluence with Lightner Creek (Table 1, Figure 1, and Figure 2). During each sampling trip, dissolved oxygen (DO) (mg/L), temperature (°C), specific conductivity (μS/cm^{-1}), and turbidity (Secchi depth[1], cm) were measured and reference photos taken at each site. At the Dog Park Bridge site, stage height (in) was recorded. At Perins Culvert, the flow rate (liters/$second^{-1}$) of water coming out of the culvert was approximated using a stopwatch and one-liter bottle. Additionally, one-liter grab-samples of water were collected at each site for laboratory analysis of total suspended sediment (TSS).

DO, temperature, and specific conductivity were measured using a YSI 85 multi-meter (http://www.ysi.com/). Turbidity was measured with a one-meter Secchi tube[1] (EPA, 1979). 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 rinsed with 100 mL of distilled water and dried to a constant weight.
2. One-liter water samples are remixed by vigorous shaking vigorously for 30 seconds.
3. Mixed samples are filtered through the rinsed filters, using a suction flask, filter holder and funnel.
4. Filters and residue are placed on an aluminum weighing dish and oven dried at 110°C until a constant weight.
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*

(1) Fill the tube with the sample water and allow the water to drain to the zero mark on the centimeter tape measure. (Slowly lower the disk while viewing from the open end of the tube. (2) Record the depth at which the disk disappears, in centimeters. Simply pinch the line against the tube and then hold the tube up so you can sight across the point at which the disk and tape measure intersect. (If the disk does not disappear because the sample water is clear there is no reading to record). (3) Slowly raise the disk and record its depth of reappearance. Again pinch the line against the tube and then hold the tube up so you can sight across the point at which the disk and tape measure intersect. The secchi depth is the average of the depth of disappearance and reappearance.

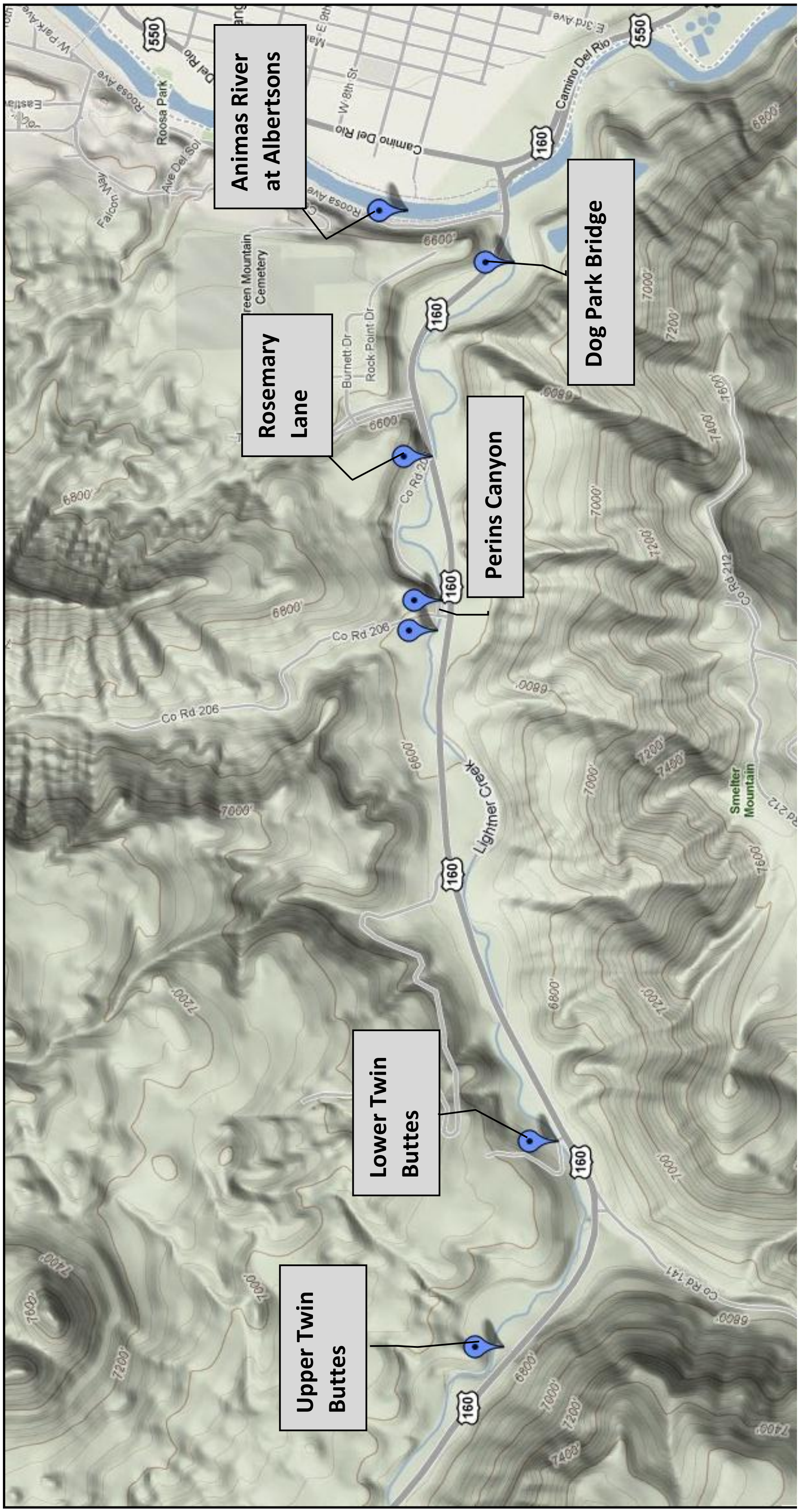

Figure 1. Location of sediment sites along Lightner Creek. During each sampling trip, 1-liter water samples (TSS), Dissolved Oxygen (DO), Turbidity (Secchi Depth), Conductivity (µS), Temperature, and Stage (at Dog Park) were measured.

Figure 2. Sampling sites along Lightner Creek with Perins Canyon outlined in red.

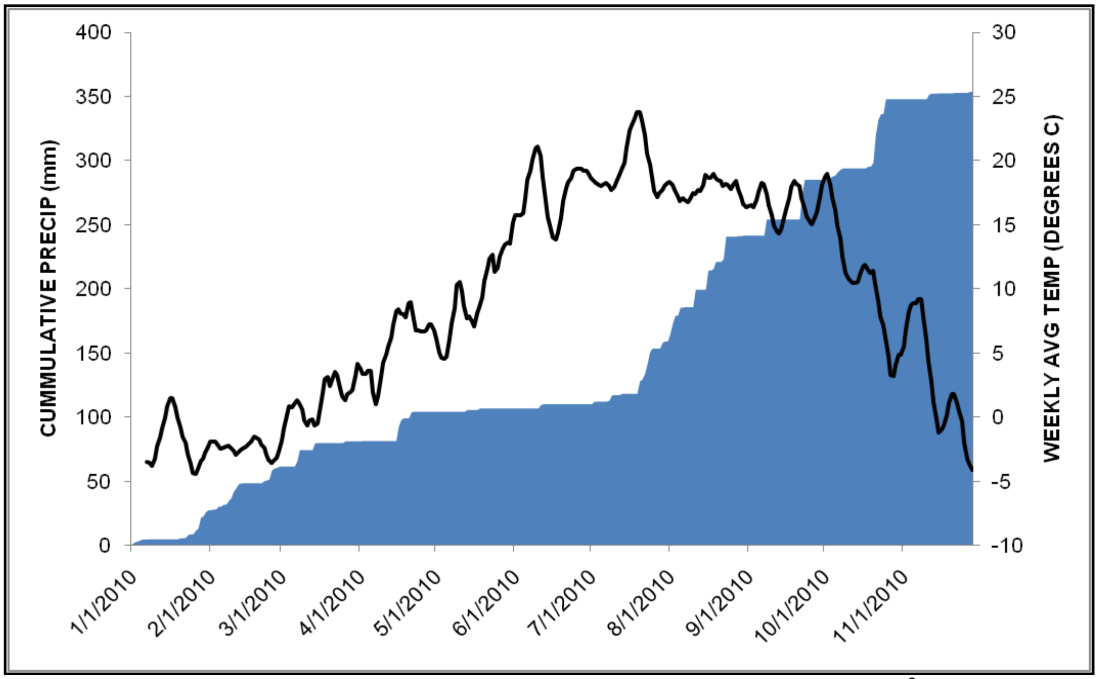

Figure 3. Cumulative precipitation (mm) – blue, and weekly average temperature (^{0}C) - black line, for Log Chute RAWS weather station (Durango, CO) 2010. The monsoon period beginning in August of 2010, is evident in both increases in cumulative precipitation and a marked decline in average weekly temperature; data courtesy of Western Regional Climate Center - Desert Research Institute Reno, NV.

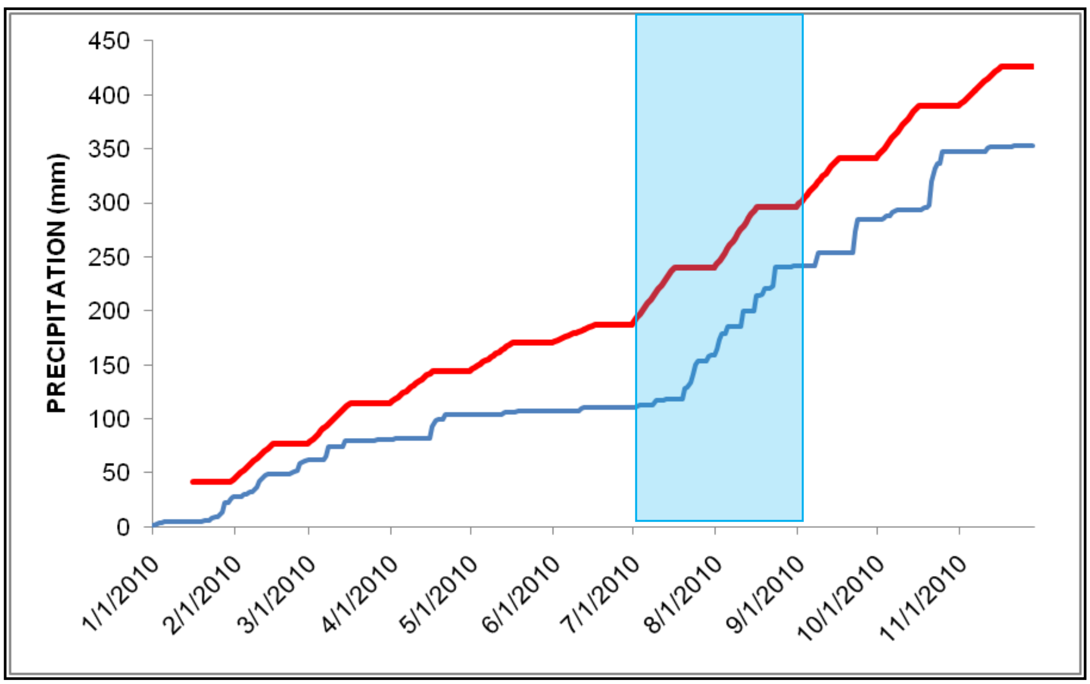

Figure 4. Cumulative precipitation (mm) for Log Chute (2010, blue) and cumulative average monthly precipitation for Durango Fort Lewis College COOP Station (period of record: 1/1/1915 - 7/31/2010, red). Data from this station indicates a drier than average year in 2010, with cumulative total monthly precipitation generally between 20% to 80% percent below the period of record average. Blue shaded area depicts the historic monsoon period.

Results

The following results present data collected from March of 2010 through November, 2010 and that are organized by each water quality parameter measured. The results from our sampling effort indicate that during the snowmelt runoff period (March-May) levels of suspended sediment at the Upper Twin Buttes site and Dog Park Bridge are strongly correlated (Figure 10). Additionally, values of DO, temperature, and specific conductance were generally consistent and are well correlated between all sampling locations during the March – May period (Figure 5, Figure 6, and Figure 7). This is contrasted during the summer monsoon period (July – August), when the relationship between the upper and lower sites for water quality parameters, especially TSS, which is much weaker. We found that that there is a strong relationship between specific storm events and associated sediment transport from Perins Canyon Gulch.

Turbidity

Turbidity is a measure of the presence of suspended and dissolved matter e.g., clay, silts, fine organic matter, plankton and other microscopic organisms, organic acids, and dyes (Clescerl et al., 1999). Currently, there are no Environmental Protection Agency (EPA) maximum contaminant level goals (MCLG) for turbidity. However, for fisheries, and especially rainbow (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*), higher turbidity levels in streams are associated with increased physiological stress, lower reproductive success, lower body weights and reduced predation success (Barret et al., 1992; Redding et al., 1987; Sweka and Hartman, 2001). Optimal water quality for trout consists of turbidity values below 35 ppm (Hickman and Raleigh 1982).

In Lightner Creek, turbidity generally increased in a downstream pattern, with large increases in turbidity below Perins Canyon (Table 2). For any single sampling trip, the largest turbidity values were generally found near the Animas confluence, at the Dog Park Bridge site. The lowest turbidity values were usually recorded at the Upper Twin Buttes site. Values for turbidity on the Animas were generally low with a mean Secchi tube distance of greater than 90 cm.

Table 2. Turbidity results for Lightner Creek. Larger numbers depict the distance (cm) through the Secchi tube that the Secchi disk is visible, thus larger numbers suggest less turbidity with lower values indicating higher levels of suspended sediment.

	Turbidity (cm) (centimeters of Secchi depth)						
	Dog Park Bridge	Rosemary Lane	Perins culvert	U/S Perins culvert	Lower Twin Buttes	Upper Twin Buttes	Animas at Albertsons
Average	46	52	71	72	82	82	92
Median	19.4	28.4	100	100	100	100	100
Minimum	0	0	0	0	9	5.6	35
Maximum	100	100	100	100	100	100	100

Dissolved Oxygen and Temperature

Measurements of DO and temperature in surface and ground waters are essential for documenting changes in environmental water conditions resulting from natural fluxes and human activities. Dissolved oxygen is necessary in aquatic systems for the survival and growth of many aquatic organisms and is an indicator of the overall health of surface water systems. For rainbow trout, and especially juveniles, the lethal level of dissolved oxygen is approximately 3 mg l^{-1} or less, depending on environmental conditions (e.g. temperature) (Raleigh *et al.*, 1984; Mathews and Berg, 1997).

Along with dissolved oxygen, temperature is an important metric of the synoptic environmental conditions of a stream, as it can directly influence the metabolic rate, physiology, and life-history stages of aquatic organisms through effects on behavior and physiology (Quigley and Arbelbide, 1997). Additionally, changes in thermal regime, particularly increases, can negatively affect stream communities by limiting the area of suitable habitat and altering nutrient cycling processes (Allen, 1995; Poole and Berman, 2001). Rainbow trout, in particular are sensitive to increases in temperature, and usually do not occur where temperatures exceed 25 ^{0}C (Hokanson *et al.*, 1977). The expected range for dissolved oxygen in Colorado streams, is between 4.0 to 12.0 mg l^{-1} (Colorado River Watch Network, 2010), with 6 mg l^{-1} the standard for cold water fisheries (USDA, 2005).

For Lightner Creek, measurements of DO and temperature were collected during the summer low-flow (May - July) and monsoon season (August - October) periods (Table 3 and Table 4). DO values ranged from greater than 14 to less than 1 mg l^{-1} and temperature varied from a low of 4.1^{0}C (November 11th) to a high of 20^{0}C (August 17th) (Figure 5**)**. Generally, stream temperature did not fluctuate greatly over the course of the study period; however, there was a significant trend of decreasing temperatures during the onset of the monsoon period (Figure 6).

Table 3. Dissolved oxygen results

	Dissolved Oxygen (mg l^{-1})					
	Dog Park Bridge	Rosemary Lane	U/S Perins culvert	Lower Twin Buttes	Upper Twin Buttes	Albertsons
Average	8	7	7	7	7	7
Median	8.1	8.185	7.9	7.69	7.23	7.95
Minimum	0.1	0.13	0.17	0.15	0.12	0.06
Maximum	14.7	9.38	9.31	9.25	8.92	13.1

Table 4. Temperature results

	Temperature (°C)					
	Dog Park Bridge	Rosemary Lane	U/S Perins Culvert	Lower Twin Buttes	Upper Twin Buttes	Animas at Albertsons
Average	13	13	13	14	14	15
Median	13.8	13.5	14.2	13.95	14.25	16.5
Minimum	4.1	4.1	4.1	5.4	5.8	6.4
Maximum	18.9	18.8	18.3	19.8	20	19.7

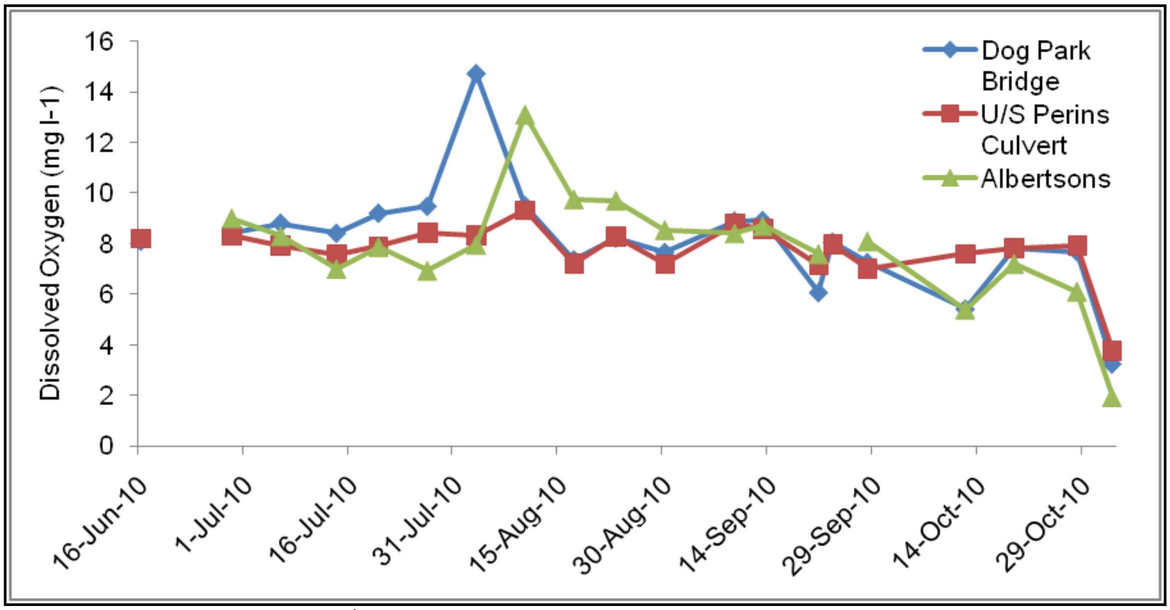

Figure 5. Dissolved oxygen (mg l^{-1}) in Lightner Creek for Dog Park Bridge, Upstream of Perins Culvert and the Animas River above the confluence with Lightner Creek from June, 2010 to October, 2010.

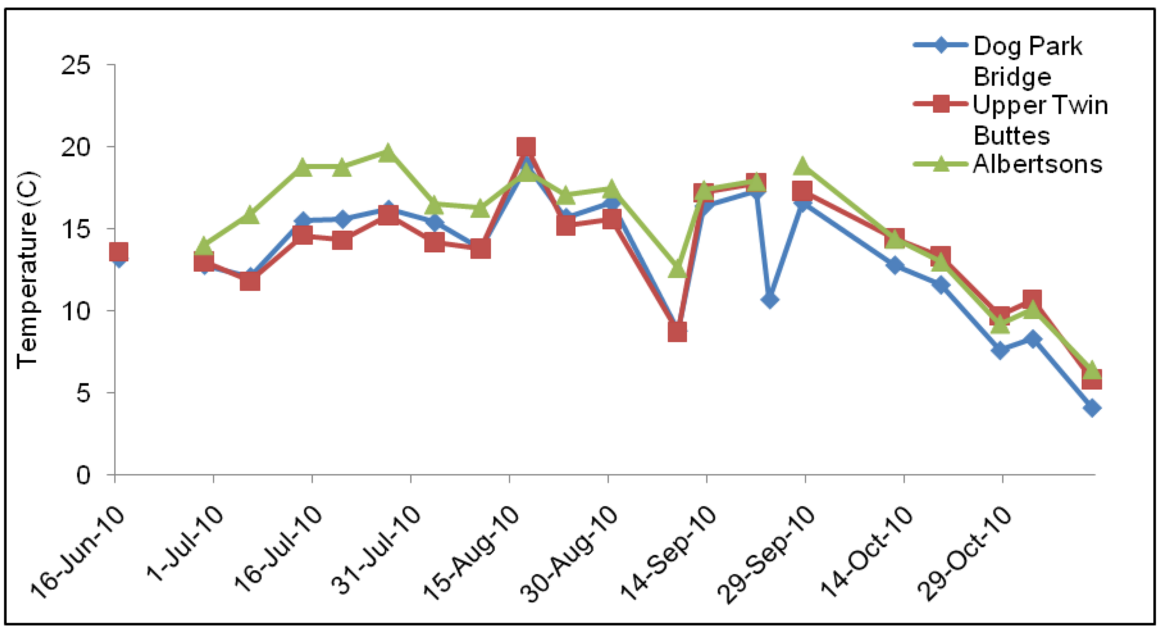

Figure 6. Stream temperatures (^{0}C) in Lightner Creek for Dog Park Bridge, Upper Twin Buttes, and the Animas River above the confluence with Lightner Creek from June, 2010 to October, 2010.

Specific Conductivity

Specific conductance (SC) is measured in micro-Siemens per centimeter (µs/cm^{-1}), and is a measure of the ability of water to conduct an electrical current. It is highly dependent on the amount of dissolved solids (such as salt) in water. High specific conductance indicates high dissolved-solids concentration which can affect the suitability of water for domestic, industrial, and agricultural uses.

Specific conductivity (SC) was measured during the late summer low flow periods from July through November. The lowest values for SC were recorded at Upper Twin Buttes on August 23rd, with the highest value recorded at Dog Park Bridge on September 23rd (Table 5). Generally, SC did not vary greatly during the sampling period (Figure 7) and stayed within the expected levels for the Colorado River Basin of 300 to 700 µs/cm, (Colorado River Watch Network, 2010).

Table 5. Specific Conductivity results

	Specific Conductivity (µS/cm^{-1})					
	Dog Park Bridge	Rosemary Lane	U/S Perins culvert	Lower Twin Buttes	Upper Twin Buttes	Animas at Albertsons
Average	575	561	541	494	489	488
Median	582	563.5	540	495.8	498.05	505.6
Minimum	439	512	491	459	369	336
Maximum	683	622	600	536	523	653

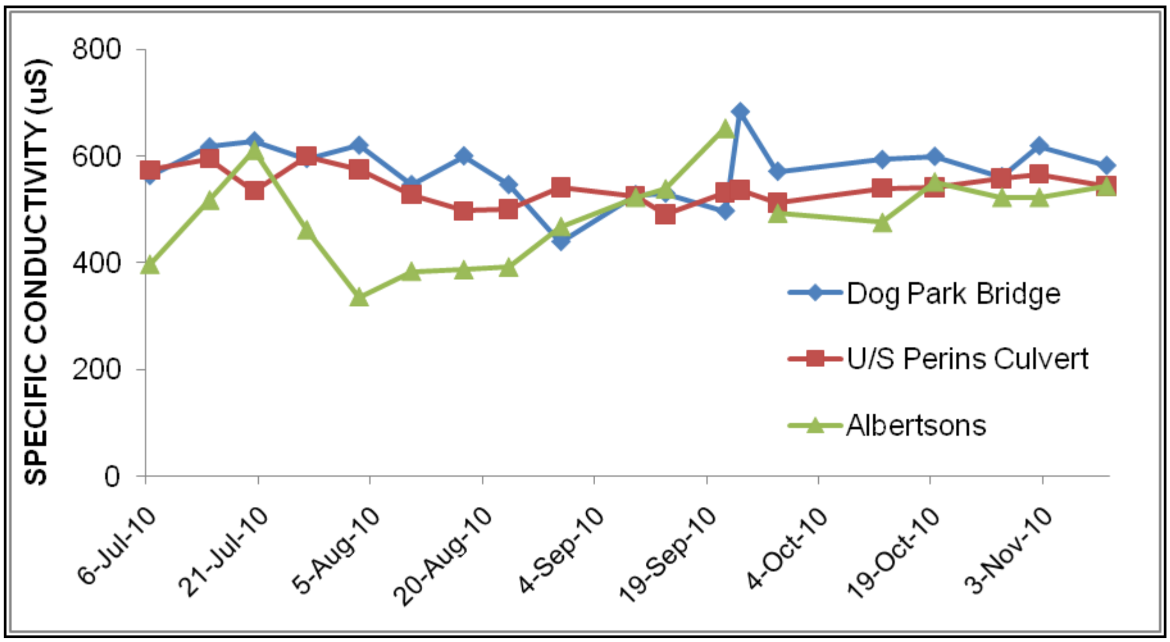

Figure 7. Specific conductivity (µS) measured at Dog Park Bridge, Upstream of Perins Culvert, and on the Animas near Albertsons. Measurements were taken weekly from July 6th through November 11th.

Total Suspended Solids

Total suspended solids (TSS) is a measure of the wash load within a fluvial system. TSS usually is comprised of material smaller than 2 mm in diameter. 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) has recognized 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).

TSS was measured during each sampling trip by collecting one liter grab samples of stream water and processing those samples for dry mass TSS at Fort Lewis College. The results showed a strong downstream trend, with large increases in both mean and maximum TSS below Perins Canyon (Figure 8). TSS values for sites located above Perins Culvert generally fell between ~20 – 260 mg l^{-1} with maximum values close to an order of magnitude greater than mean values (Table 6). This is contrasted with sites below Perins Culvert, where mean values were 128 -262 mg $l^{-1}$and maximum values of 1304 and 2435 mg l^{-1} were recorded at Rosemary Lane and Dog Park Bridge, respectively. The largest values of TSS were recorded from samples taken directly from Perins Culvert, where mean TSS, was 354 mg $l^{-1}$and maximum was 6600 mg l^{-1}.

Table 6. Total Suspended Solids (TSS)

	Total Suspended Solids (mg l^{-1})						
	Dog Park Bridge	Rosemary Lane	Perins culvert	U/S Perins culvert	Lower Twin Buttes	Upper Twin Buttes	Animas at Albertsons
Average	262	128	354	27	20	24	6
Median	40	22	12	7	4	5	3
Minimum	2	2	2	1	0	1	0
Maximum	2435	1304	6600	235	158	259	37

TSS in Lightner Creek showed a strong seasonal and event-based signal, with the largest values coming during the spring runoff period (March – May) and during specific events in August (Figure 9). The values of high TSS during the spring runoff period coincide with high TSS values in the Animas; however, the large values apparent during the monsoon season are directly contrasted with the low TSS values in the Animas during the same period. The relationship during the spring runoff period between TSS in Lightner Creek below Perins Canyon and above Perins Canyon is strong $R^2 = 0.97$, $p < 0.01$(Figure 10), however this relationship is much weaker during the monsoon runoff season $R^2 = 0.17$, $p > 0.01$ (Figure 11). This is most likely because the high TSS levels were in both the upper and lower watershed during the spring runoff, whereas TSS levels were low from the upper watershed and very high from the lower watershed during the monsoon runoff season $R^2 = 0.19$, $p > 0.01$ (Figure 11**)**. Additionally, the magnitude difference between TSS values for the above Perins Canyon sites and below Perins Canyon during the low flow periods are large, with the range of values for the above section going from 2 – 13 mg/l^{-1} and the below Perins Canyon TSS values ranging from 1 – 842 mg/l^{-1}.

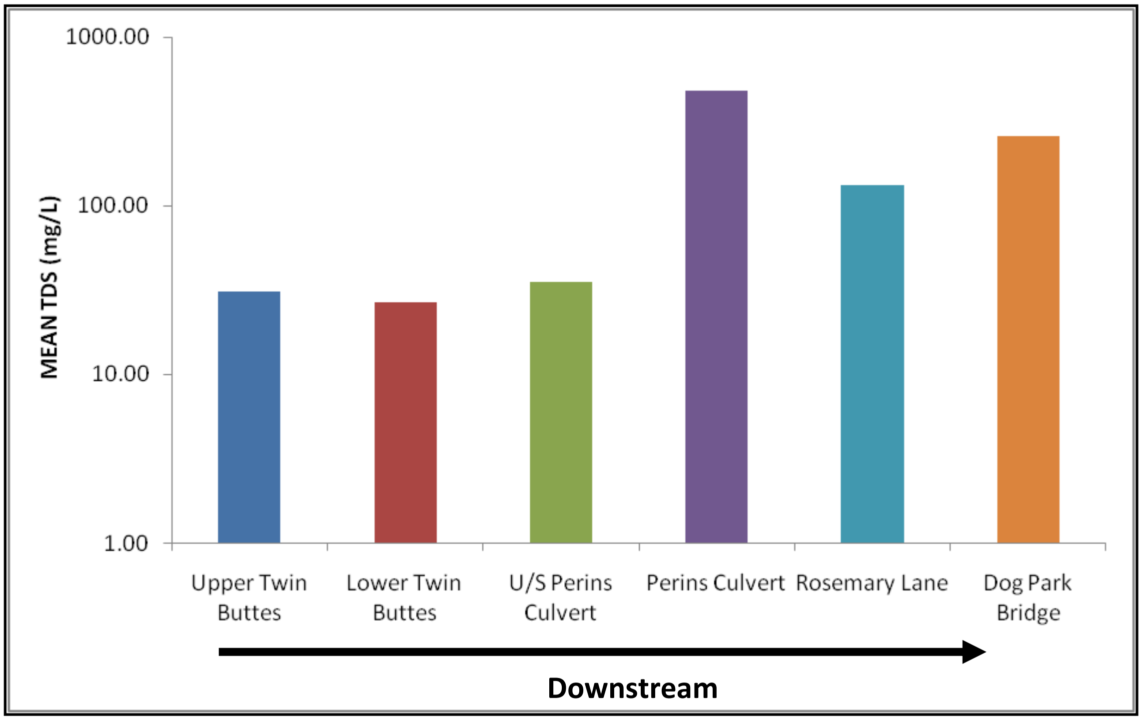

Figure 8. Log scaled average total suspended sediment (mg l^{-1}) at sample sites along Lightner Creek. Bars are arrayed from upstream to downstream with Dog Park Bridge near the confluence with the Animas River mainstem.

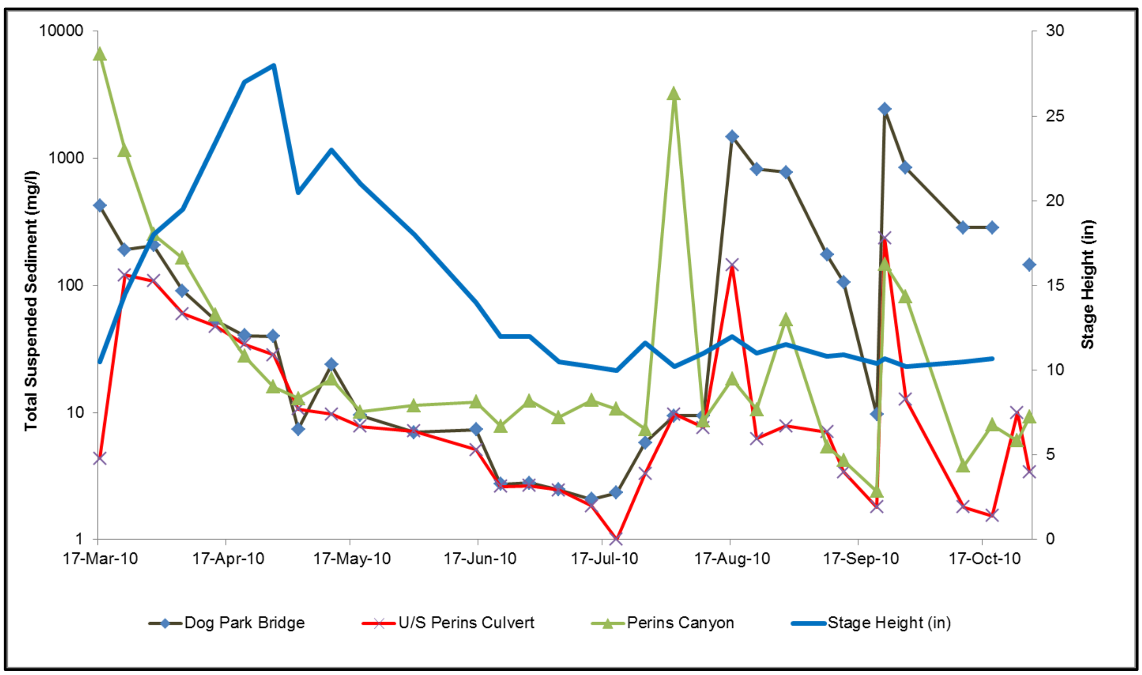

Figure 9. Total suspended sediment (mg l^{-1}) and stage (inches, Dog Park Bridge) measured during 24 sampling trips between March 17 and October 23, 2010. Left axis is log scale mg l^{-1} of suspended sediment. Right axis is stage in inches.

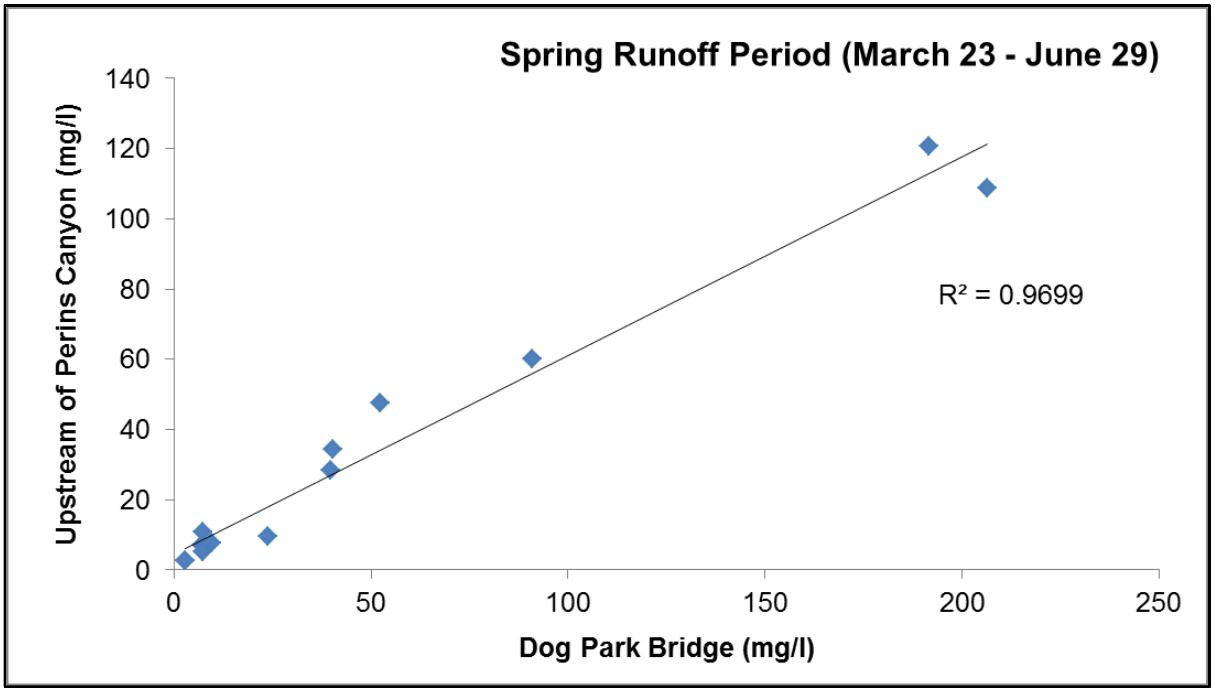

Figure 10. Suspended sediment (mg l^{-1}) relationship for Dog Park Bridge (near confluence with Animas River mainstem) and upstream of Perins Culvert during low flow conditions (March 23 - June 29, 2010).

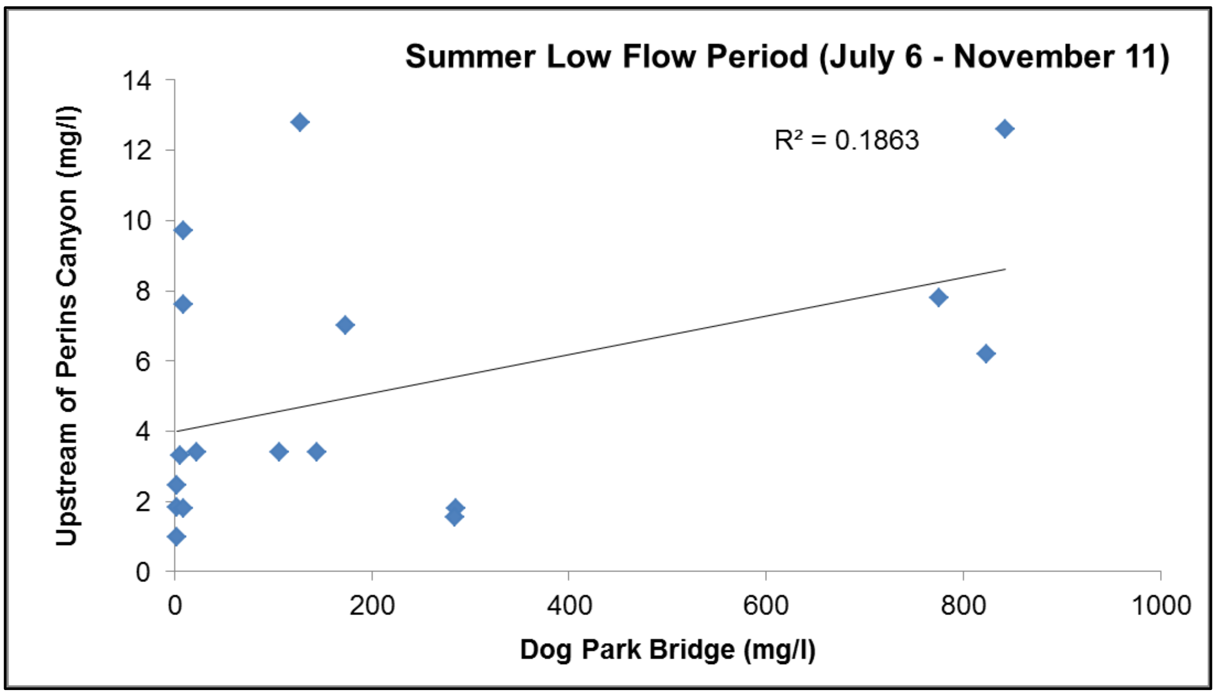

Figure 11. Suspended sediment (mg l^{-1}) relationship for Dog Park Bridge (near confluence with Animas River mainstem) and upstream of Perins Culvert during low flow conditions (July 6 - November 11, 2010).

Hydraulic Modeling

A staff gage was installed by Basin Hydrology at the Dog Park Bridge sampling site and stream stage was recorded in inches during each sampling trip. Based on hydraulic modeling conducted by Basin Hydrology (Oliver, 2010) a stage discharge relationship was modeled for Lightner Creek (Figure 12). The relationship was developed from field data collected in 2009 and was applied to stage measurements observed at Dog Park Bridge to estimate stream volume in cubic feet per second (cfs) (Figure 13).

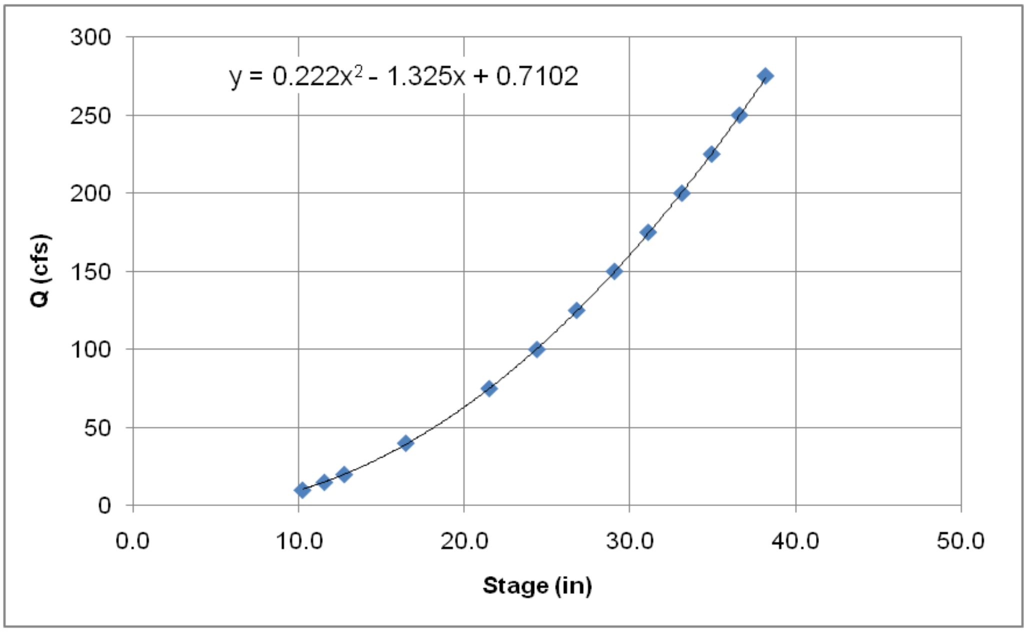

Figure 12. Modeled stage discharge relationship for Lightner Creek as measured near Dog Park Bridge. Stage-Discharge Rating Curve developed by Basin Hydrology (Oliver, 2010) yields a second order polynomial regression equation. This was used to estimate discharge for subsequent sampling trips.

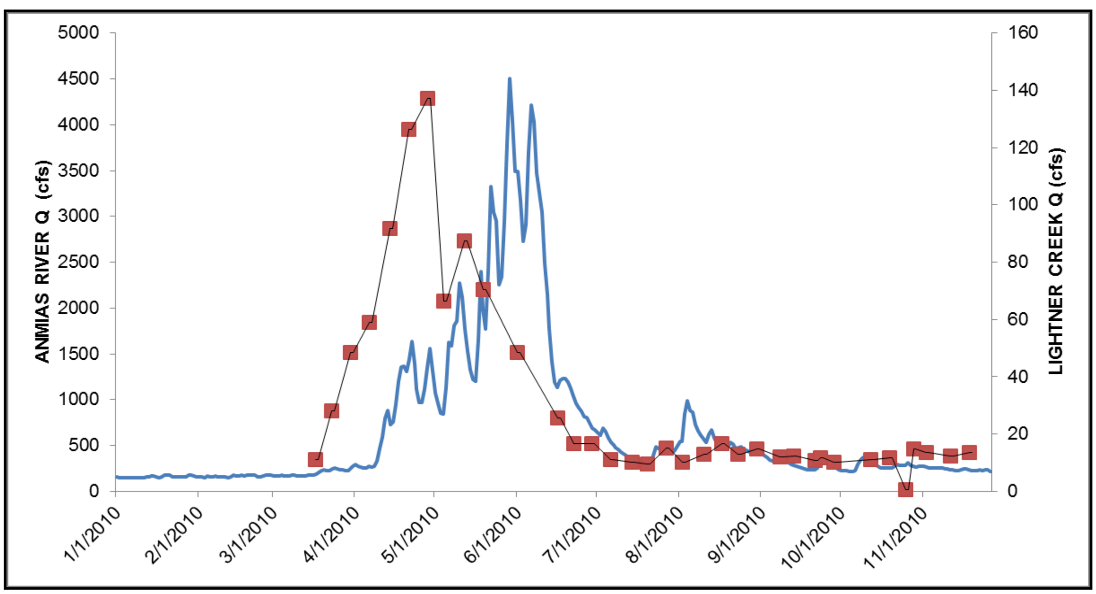

Figure 13. Stream flow (cfs) in the Animas River at Durango (blue line) and estimated streamflow (cfs) (black line red squares) in Lightner Creek at Dog Park Bridge for each sampling trip.

Sediment Transport

To estimate sediment transport of different particle classes present at the mouth of Lightner Creek, a channel cross section and longitudinal profile were surveyed approximately 50 meters upstream of the Dog Park Bridge; from these a stage/discharge and stage/moveable particle size relationship was developed. The site was selected due to its location near the Animas confluence and because this location was considered to be representative of the lower Lightner Creek's channel morphology (Oliver, 2010).

Estimates of sediment yield focused primarily on the dissolved load[2] and wash load[3], as bed material was not sampled and because the impairment found in the Animas River is mainly due to turbidity (i.e., particles < 1.0 mm).

Using data from the hydraulic model developed by Basin Hydrology (Oliver, 2010) and estimates of suspended sediment concentration measured during each of the sampling trips, methods outlined in Richardson, Simons and Lagasse (2001) were used to estimate total suspended load (tons day^{-1-day}) for different flow magnitudes and durations, which gives the equation:

$$Q_s = K_u Q_w C$$

Where: $K_u = 0.086$ (SI)
$K_u = 0.0027$ (English)

Q_s = Suspended sediment discharge, metric or English tons per day
Q_w = Water discharge, m^3/s or cfs
C = Velocity-weighted mean concentration of sediment, mg/l
K_u = Coefficient to convert to metric or English tons per day

The measurement of suspended-sediment discharge is described in detail in *Techniques of Water-Resources Investigations of the United States Geological Survey* [available at http://pubs.usgs.gov/twri/] The general procedure is as follows:

1. Record a time dependent measurement of the water discharge (discharge hydrograph).
2. Measure the velocity weighted mean suspended-sediment concentration of the flow.
3. Develop a time suspended-sediment concentration graph similar to the stage hydrograph at a gaging station (suspended sediment hydrograph).
4. Determine the daily suspended-sediment discharge in English or metric tons per day.

A major caveat to our estimates of suspended sediment is that sediment discharge of a stream requires a time dependent measurement of the water discharge (discharge hydrograph) and a velocity weighted measurement of the concentration of sediment particles moving past the cross-section. Our sampling regime was limited to one sample per day once a week, i.e. instantaneous. Therefore our estimates could not reliably be used to accurately estimate time weighted yield. Given the limitations of our sampling interval, our estimates assume a constant flow rate for 24 hours. We recognize that a constant

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[2] Dissolved load is characterized by material transported in solution.
[3] Wash load is comprised of particles generally finer than those found in bed material and are readily transported in suspension at the same speed as the flow (Walling, 1987).

flow rate for 24 hours in Lightner Creek is most likely not a valid assumption; however, we are confident that the provided estimates give a good approximation of the gross pattern of suspended sediment dynamics occurring at the mouth of Lighter Creek. We estimate that suspended sediment transport out of Lightner Creek ranges from <0.5 to >77 tons^{-day} with most of the production occurring during the late summer and fall periods.

Given the limitations of our sampling regime, we estimate that suspended sediment production during the spring (March – April) runoff period, has a mean of 15.7 tons^{-day} (~10 m^3) and closely follows the spring flood flows in magnitude. The summer low flow period (June – August 10th) has much less suspended sediment production (mean of 0.3 tons^{-day}, 0.2 m^3). The monsoon and early fall periods had the highest average suspended sediment load (18 tons^{-day}, 11.4 m^3) as well as the highest single recorded value of 77 tons^{-day} (48 m^3)recorded on September 23rd. The overall pattern (Figure 14) suggests that the suspended sediment production generally follows flow magnitude for most of the year, with the exception during the late summer and monsoon periods where there are large spikes of sediment load occurring in the channel, most likely due to relatively large runoff events originating from within the lower watershed.

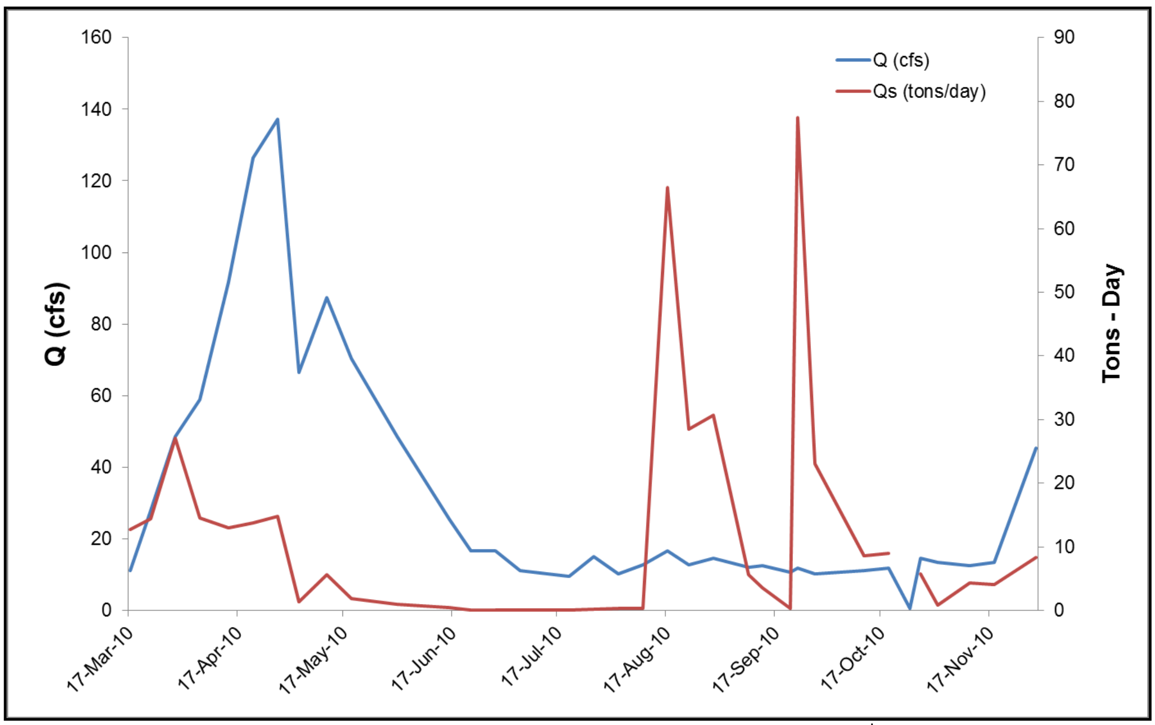

Figure 14. Flow magnitude (cfs) as blue line and sediment production (tons^{-day}) as red line, for Lightner Creek, measured at weekly intervals at the Dog Park Bridge sample site.

Conclusions

Beginning in March 2010 and continuing through November 2010, we measured several water quality parameters associated with turbidity and water quality condition at five points along Lightner Creek. During our weekly sampling efforts we observed changes in both the water quality parameters as well as the size of the depositional sediment bar which occurs at the mouth of Perins Canyon.

The water quality parameters measured (e.g., TSS, Turbidity, DO, Temp, and SC) changed significantly, both collectively and individually during the sampling period. We observed that during the spring runoff period (March – April) and during summer low flow (June – July), conditions in Lightner Creek were relatively consistent across all sampling sites with values typically being within 10% -20% and TSS in Lightner Creek above Perins Canyon similar in magnitude to values observed in the Animas at Albertsons (0-37 mg/L). The strong relationship of water quality parameters, especially TSS between sampling sites above and below Perins Canyon, becomes much weaker during the onset of late summer, monsoon precipitation events. These events mobilize a significant portion of sediment from the lower Lightner Creek watershed with the result being TSS values that are 10 – 15 times larger (1-1.5 orders of magnitude) than background levels found in the upper watershed and in the Animas River mainstem (Figure 15).

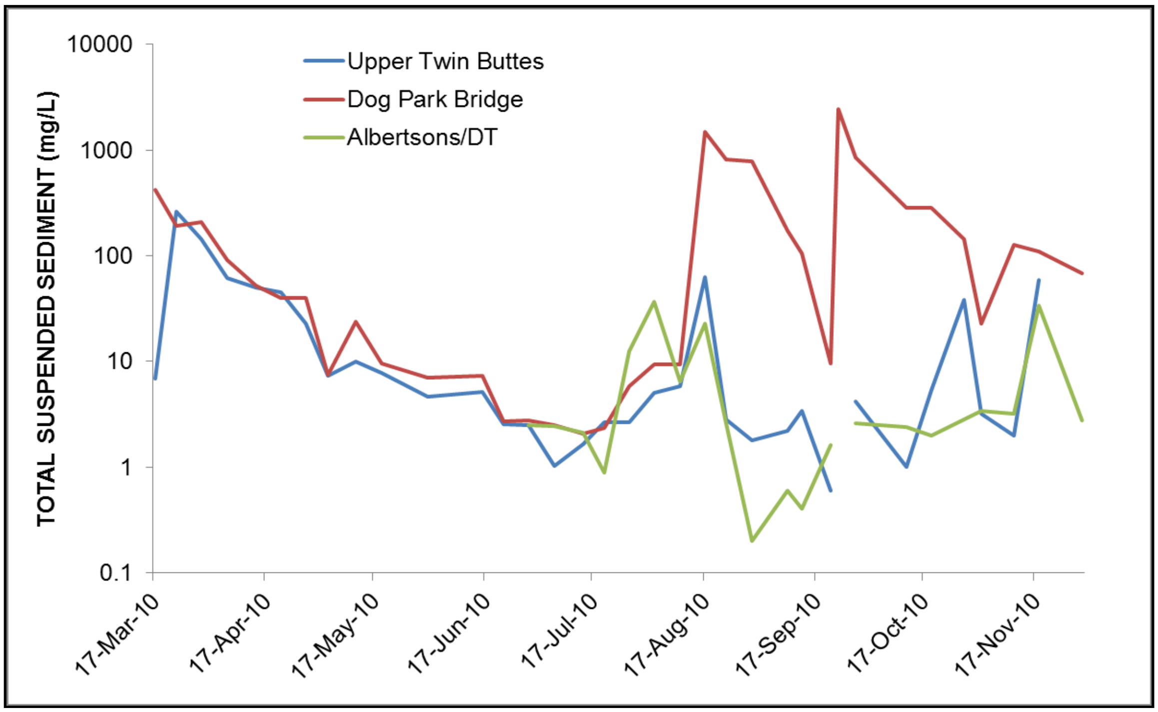

Figure 15. Log scale total suspended sediment (TSS) for Upper Twin Buttes (upper watershed), Dog Park Bridge (lower watershed), and the Animas River mainstem. Note that values for the upper and lower watershed generally track during the spring and summer periods. Values diverge during the onset of late summer precipitation events with values increasing by 10-15 times at Dog Park Bridge relative to both the upper watershed and background values of TSS recorded in the Animas.

Based on our sampling efforts and the analysis of total suspended sediment, we conclude that the higher TSS values found in the sections of Lightner Creek below Perins Canyon are primarily due to sediment inputs from Perins Canyon. We propose a model (Figure 16) for describing the mechanism for this sediment to be transported out of Perins Canyon, into Lightner Creek, and eventually to the Animas

River. The initiating event for the excess sediment derives from late summer (monsoonal) precipitation events (1) which wash sediment out of Perins Canyon (2). Some of this sediment is deposited below the culvert at the base of Perins Canyon in the Lightner Creek channel (3), some is deposited in the Lightner Creek channel, and some remains in suspension and is transported to the Animas River. The in-channel deposited sediments create large alluvial bars, which over subsequent storm events become washed downstream to the confluence with the Animas (4).

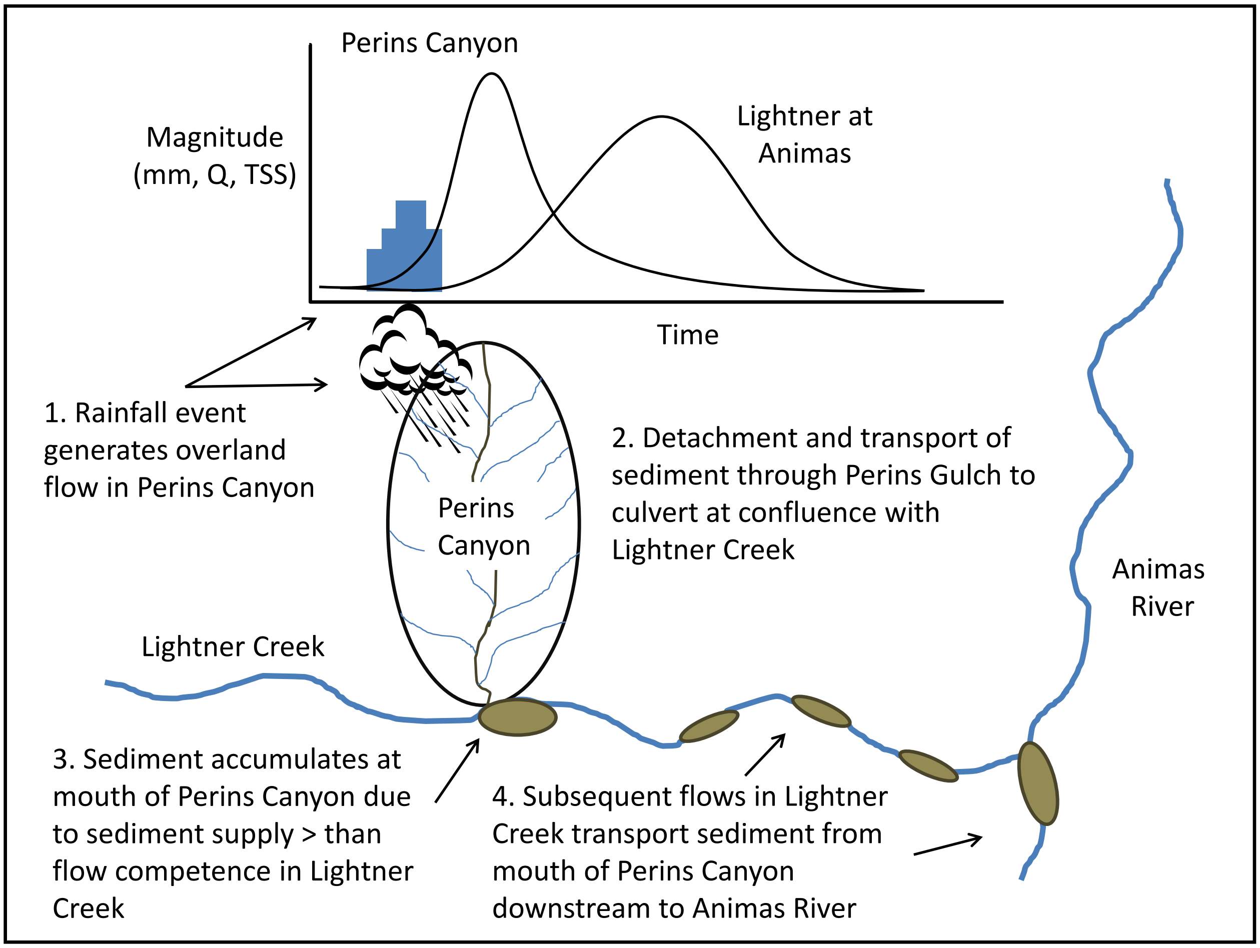

Figure 16. Sediment dynamics model for Perins Canyon and Lightner Creek during summer low flow periods and during/following monsoon precipitation events large enough to detach and mobilize sediment in Perins Canyon downslope to its confluence with Lightner Creek and eventually to the Animas River.

Recommendations

Based on our conclusions, a series of actions are proposed that may reduce the excess sediment reaching Lightner Creek and being transported to the Animas mainstem during the summer low-flow and late summer periods:

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.
4. Continue to monitor sediment supply and transport in Lightner Creek.

The scope of the proposed work includes characterizing the nature of the erosion and transport of sediment in Perins Canyon, applying different BMP's, and assessing the efficacy and cost effectiveness of each. The BMP's proposed may include straw waddles, silt fences, excelsior logs, and vegetation management.

The work would be conducted in a phased manner, with the initial phase implemented in the early spring of 2011 (February). During this phase, sites would be selected for the installation of BMP's, the channel will be surveyed, and cross-section monitoring transects will be installed where we will measure aggradation, scour, and post-flood channel changes in Perins Canyon.

Selection of sites for BMP installation will be guided by a GIS analysis of Perins Canyon using a high-resolution digital elevation model with less than 2-feet contour intervals to identify discrete process zones and/or other homogeneous source areas. Based on the GIS analysis and existing field investigation, 4-7 sampling spots will be located for monitoring of sediment flux from side-slopes to the channel and along the channel. Sediment flux will be monitored using a variety of techniques including sediment fences and mass balance techniques that measure sediment collected during each producing storm event. During this phase, we will also establish passive monitoring of sediment transport, utilizing automatic cameras and bed channel elevation monitoring.

We will follow methods outlined in Rough (2007), Robichaud and Brown (2002) and utilizing equations adapted from Gardner (1986) which generally follows as:

1. Sediment fences placed in small swales and side drainages with each fence constructed from 1.2-m wide geotextile fabric attached to rebar that has been pounded into the ground (Robichaud and Brown, 2002).
2. Following each sediment-producing storm, all material washed into the fence will be collected and weighed. Two sub-samples will be collected and placed in airtight plastic bags for transport to a laboratory where samples would be weighed, dried for 24 hours at 105°C, and weighed again to determine water content following an equation adapted from Gardner (1986):

$$Wc = [(Ww-\tau)-(Wd-\tau)]/(Ww-\tau)$$

where Wc is the water content of the collected sample, Ww is the wet weight of the sample, Wd is the weight of the sample after drying, and τ is the tare weight of the container. The water content is used to convert the field-measured wet weights to a dry mass by:

$$Wd = Ww - (Wc * Ww)$$

where Ww is the wet weight of the sediment collected from the sediment fence and Wd is the calculated dry weight. Unit area sediment yields will be calculated as the dry weight divided by the contributing area. After drying, the samples will be sieved to determine the percentages of gravel or coarse material (>2.0 mm) coarse to very coarse sand (0.50 to 2.0 mm), medium sand (0.25 to 0.50 mm), very fine to fine sand (0.063 to 0.25 mm), and clay/silt (<0.053 mm).

The final phase will evaluate the BMPs to determine which configuration might best reduce the maximum amount of sediment transported through Perins Gulch. The results will be presented to the neighborhood of Perins Gulch, Lightner Creek Sediment Initiative, and the City of Durango in order to assist them with decisions regarding sedimentation and water quality in Lightner Creek.

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Appendix A: Photo Documentation

March (Early runoff period, hydrograph rising limb, **Q = 28 cfs**)

Dog Park Bridge, 3/23/10

Rosemary Lane, 3/23/10

Perins Culvert, 3/23/10

Upper Twin Buttes, 3/23/10

	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons (Animas)**	**Dog park Bridge**
3-23-10	191	175	1153	121	158	259	XX	14.5 (28)

April (Runoff period – hydrograph peaking, **Q = 92 cfs**, hydrograph will peak at **137 cfs on 4-28-10**.

Dog Park Bridge, 4/14/10

Rosemary Lane, 4/14/10

Perins Culvert, 4/14/10

Upper Twin Buttes, 4/14/10

	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons (Animas)**	**Dog park Bridge**
4-14-10	52	50	58	47	52	50	XX	23.5 (92)

May (Hydrograph falling limb, **Q = 70 cfs**)

Dog Park Bridge, 5/19/10

Rosemary Lane, 5/19/10

Perins Culvert, 5/19/10

	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons (Animas)**	**Dog park Bridge**
5-19-10	10	7	10	8	5	8	XX	21 (70)

June (Summer low flow conditions, **Q = 17 cfs**)

Dog Park Bridge, 6/22/10

Rosemary Lane, 6/22/10

Perins Culvert, 6/22/10

Upper Twin Buttes, 6/22/10

	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons (Animas)**	**Dog park Bridge**
6-22-10	3	3	8	3	3	3	XX	12 (17)

July (summer low flow conditions, **Q = 10 cfs**)

Dog Park Bridge, 7/14/10

Rosemary Lane, 7/14/10

Perins Culvert, 7/20/10

Upper Twin Buttes, 7/20/10

	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons**	**Dog Park Bridge**
7-14-10	2	5	13	2	2	2	2	10.2 (10)
7-20-10	2	2	11	1	2	3	1	10 (9)

August (Summer, precipitation driven event, **Q = 17 cfs**, between Aug 8th and Aug 16th 28 mm of precipitation fell in the Durango area, see also **Figure 4**)

Dog Park Bridge, 8/17/10

Rosemary Lane, 8/17/10

Perins Culvert, 8/17/10

Upper Twin Buttes, 8/17/10

	Total Suspended Solids (mg/L)							Stage Height(in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons**	**Dog Park Bridge**
8-17-10	1483	1304	18	145	55	63	23	12 (17)

September (Late summer, monsoon flow, **Q = 12 cfs**, notice large difference in turbidity between Upper Twin Buttes and Dog Park Bridge)

Dog Park Bridge, 9/23/10

Layers of sediment deposition from Perins Culvert outflow

Perins Culvert, 9/23/10

Upper Twin Buttes, 9/23/10

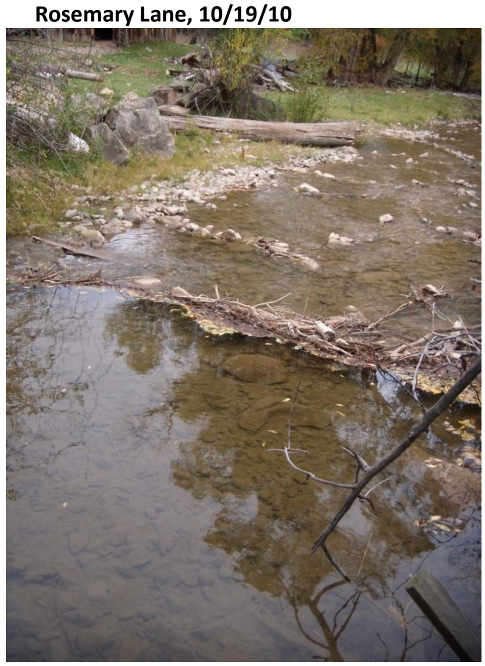
	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons (Animas)**	**Dog Park Bridge**
9-23-10	2435	XX	148	235	XX	XX	XX	10.7 (12)

October

Dog Park Bridge, 10/19/10

Rosemary Lane, 10/19/10

Perins Culvert, 10/19/10



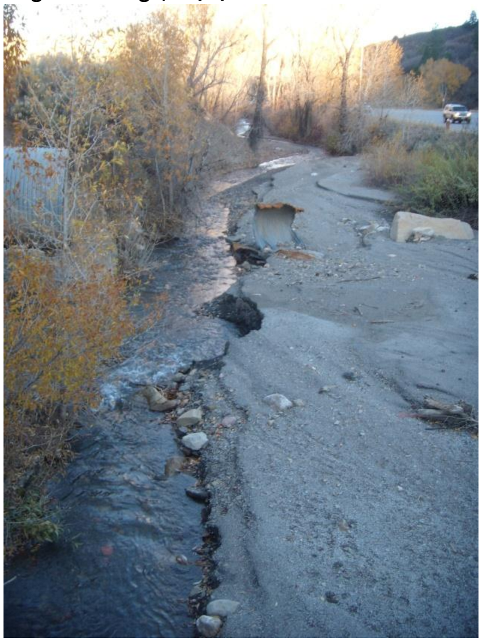
Upper Twin Buttes, 10/19/10

	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons (Animas)**	**Dog Park Bridge**
10-19-10	284	16	8	2	1	5	2	10.7 (12)

November (fall low-flow period, **Q = 14 cfs**)

Dog Park Bridge, 11/2/10

Rosemary Lane, 11/2/10



Perins Culvert, 11/2/10

Upper Twin Buttes, 11/2/10

	Total Suspended Solids (mg/L)							Stage Height (in) (cfs)
Date	**Dog Park Bridge**	**Rosemary Lane**	**Perins Culvert**	**U/S Perins Culvert**	**Lower Twin Buttes**	**Upper Twin Buttes**	**Albertsons (Animas)**	**Dog Park Bridge**
11-2-10	23	30	4	3	5	3	3	11.2 (14)