ASSESSMENT OF EPHEMERAL CHANNEL CROSS-SECTION MORPHOLOGY FOLLOWING PIPELINE CONSTRUCTION IN SOUTHERN ARIZONA

by

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Table of Contents

List of Tables

List of Figures

Assessment of Ephemeral Channel Cross-Section Morphology Following Pipeline Construction in Southern Arizona

Abstract

Morphologic change of ephemeral stream cross-sections is a natural component of fluvial geomorphology but disruptions to natural erosion and deposition by anthropogenic disturbances has the potential for cascading impacts down the channel corridor. The proximal impact of a natural gas pipeline construction on ephemeral stream cross-section geometry in southern Arizona was evaluated from July 2014 (pre-construction) to July 2016 (two years post construction). Cross-sections at three locations (upstream the pipeline Right-Of-Way (ROW)), through the middle of the ROW, and downstream of the ROW) were measured using Light Detection And Ranging (LIDAR) and field methods for 16 ephemeral streams. Results of both the LIDAR and field measurements indicated insignificant difference in cross-sectional area change between upstream, across, and downstream-ROW cross-sections [$(F_{2,64}) = 0.341$, $p = 0.73$; $(F_{2,18}) = 0.980$, $p = 0.395$]. Sediment generated during pipeline construction appeared to have moved beyond the physical confines of the study site, which limited the assessment of larger-scale geomorphic impacts. Furthermore, the 2014-2016 study period experienced only small (high-recurrence frequency) precipitation events, indicating the absence of large flows capable of significant morphologic change. To further explain differences in cross-section area change between LIDAR datasets, a linear regression model was used to assess the predictive value of nine variables: year of measurement, drainage area, drainage density, basin slope, upstream-, across-, downstream-ROW cross-section locations, percent bare soil in basin, percent mesquite in basin, total precipitation, and number of storms with average precipitation above 25 mm/hour. Though the amount of bare soil in the basin and the second study period (February 2015-July 2016) at least partially explained the changes in cross-section area, the model was not a strong predictor of morphologic change during the 2014-2016 study period. The majority of the variability in cross-sectional area change in the study basins remained unexplained.

1. **Introduction**

Ephemeral streams strongly influence the function and structure of dryland landscapes (Levick et al., 2008). These streams are driven by runoff generated from precipitation events, rather than the groundwater flows which support more mesic perennial streams. This ephemeral water flow provides the motive force for sediment and nutrient transport as well as sculpting the channel morphology. The channel morphology and water availability, in turn, control vegetation establishment and abundance (Hupp and Osterkamp, 1996). Vegetation stabilizes channel beds and banks (Groeneveld and Griepentrog, 1985), regulates morphologic response through erosion reduction during flood events (Bevan, 2002), and slows flow velocity (Coulthard, 2005) which increases nutrient and sediment retention (Levick et al., 2008). Though ephemeral channels are dynamic systems, disturbances, both in the uplands as well as to ephemeral channels themselves, can result in changes to hydrology, ecology, and morphology beyond the range of natural variability. In addition to altered landscapes and decreased productivity, these disturbances to also have economic impacts; the response to erosion and flooding events costs the United States more than U.S. $40 billion annually (Telles et al., 2011). Disturbances to ephemeral channels include natural events, such as wildfire or land degradation, and anthropogenic disruptions, such as construction events.

Anthropogenic disturbances to ephemeral stream systems can interfere with upland and riparian ecology, sediment availability, and sediment transport, as well as change the channel morphology and geomorphic response to flow events. Though the U.S. Environmental Protection Agency classifies more than 80% of streams in the U.S. Southwest as ephemeral, the research on changes to ephemeral systems following anthropogenic disturbances is lacking when compared to perennial streams (Tooth, 2000; Sutfin et al., 2013; O'Connor et al., 2014). The research in this study was generated in response to the 2014 construction of a natural gas pipeline between Tucson, Arizona to Sasabe, Arizona, USA. The 98-km buried pipeline crossed 213 ephemeral streams. Initial work was begun by Farrell (2016) and from April 2015-January 2016, ten of these ephemeral channel crossings were chosen for study to assess changes in cross-section morphology (Farrell 2016). Farrell (2016) measured the change in cross-section area at three locations at each pipeline crossing: upstream of the pipeline right-of-way (ROW), across the ROW, and downstream the ROW in the year following pipeline construction and determined a pattern of cross-section area increases (scour) at the across-ROW cross-sections and a decrease in cross-section area at the downstream-ROW cross-sections (infill), which was attributed to unconsolidated sediment across the construction footprint and sediment introduction during the construction process. The follow-on study, presented here, extends the morphology monitoring on the 10 study streams identified by Farrell (2016) and includes the cross-section area change results of an additional 6 study channels identified using LIDAR to determine whether the patterns of scour and infill at the across and downstream-ROW cross-sections are observed over a longer study period. Additionally, this study aims to use a modeling approach to explain variability in cross-section area change using both watershed characteristics (area, drainage density, land-cover, soil type) and precipitation values (average storm intensity and number of storms exceeding a 25 mm/hour intensity threshold).

Similar to the results of Farrell, 2016, the study was hypothesized to show increased scour across the pipeline ROW cross-sections and increased deposition at the downstream-ROW cross-sections when compared to the undisturbed upstream-ROW cross-sections due to unconsolidated soil in the ROW and increased sediment introduced during pipeline construction. Additionally, larger changes in cross-sectional area at the across-ROW and downstream-ROW locations were expected compared to cross-section area changes at the upstream, non-impacted cross-sections also due to a larger proportion of unconsolidated sediment.

2. Literature Review

Transport and deposition of sediment plays a role in the channel dynamics in streams and rivers (Vericat and Batalla, 2010). Water and sediment movement influences the morphology, ecology, and composition of beds, floodplains, and riparian areas (Pitlick and Wilcock, 2001; Levick et al., 2008). Despite its widespread ubiquity, sediment movement typically has a periodic or episodic peak driven by high flow events (Aalto et al., 2003, Poletto et al., 2011; Rosen and Xu, 2014). For ephemeral streams with flashy hydrographs, the infrequent flow gives the resulting sediment movement an even more episodic and pulsed pattern and results in scour and deposition events as sediment is entrained, transported, and deposited. Three main natural factors influence ephemeral channel and bank morphology: stream flow, sediment characteristics, and vegetation along the banks and uplands.

The flow in ephemeral streams is controlled by the amount of precipitation in the catchment area, the precipitation intensity, and infiltration both in uplands and in the channel bed. Runoff provides the motive force for changes in channel morphology (Greer, 1971; Graf, 1988; Bull and Kirkby, 2002). Overland flow into ephemeral streams occurs when surface depression storage is filled and rainfall intensity exceeds infiltration capacity (Tarboton, 2003). High-intensity, short-duration convective summer precipitation in the Sonoran Desert generally results in more runoff events than lower-intensity, long-duration winter rainfall (Houser et al., 2000) and it is these high-intensity events that influence the geomorphic processes (Etheredge et al., 2004). The convective monsoon rainfall is highly spatially variable and small-cell convective storms can distribute rainfall and generate runoff in one watershed while a neighboring drainage basin experiences no precipitation (Adams and Comrie, 1997). Though precipitation is the main driver in runoff, watershed characteristics also play a role in the rainfall-runoff relationship.

Watershed topography and drainage network characteristics influence the amount of runoff and eroded upland sediment transported through ephemeral streams. Slope is positively correlated to runoff generation and sediment yield (Duley, 1932) due to decreased infiltration rates (Nassif and Wilson, 1975). Catchment area and drainage generally have a negative relationship to sediment delivery to streams (Branson et al., 1981, Graf, 1988) while drainage density's relationship is less clearly defined (Dingman, 1978) and may exhibit a positive or negative correlation depending on climate, soil erodibility, and slope (Royden and Perron, 2012; Clubb et al., 2016). In addition to topographic factors, the rainfall-runoff-sediment transport relationship is further influenced by vegetation dynamics.

Plant cover regulates overland flow and sediment transport to ephemeral channels (Renard et al, 1997; Wainwright et al., 2000). Vegetation reduces overland runoff through three primary methods: increasing soil infiltration capacity through the rooting system, reducing total precipitation that reaches the ground through interception, and slowing overland flow (Zhao et al., 2015). In addition to regulating sediment transport through overland runoff reduction, vegetation cover decreases raindrop splash erosion and increases soil-aggregate stability, limiting soil entrainment in flow events (Duran Zuazu and Rodriguez Pleguezuelo, 2008). Though any vegetative cover provides superior resistance to erosion than bare soil, there is variability in runoff and sediment regulation by land-cover classifications. Studies in southeastern Arizona (Pelletier et al., 2016) and arid China (Qichang et al., 2012) indicate grasslands have lower erosion and sediment transport rates than woodlands, due to the lower ratio of bare soil to canopy cover. The encroachment and expansion of woody-plants, including mesquite (*Prosopis* spp.)

into native grasslands in the U.S. Southwest increases sediment transport to and within ephemeral streams and is of concern to land managers (Liu et al., 2013). The high-intensity precipitation and large percentage of bare soil common in drylands and deserts is conducive to runoff generation, but channel bed characteristics limit the duration of flow through ephemeral channels.

Due to the high porosity of channel beds, ephemeral streams have high transmission losses (Renard, 1970) and runoff generally reduces in volume and eventually ceases completely as it moves downstream (Renard 1970, Levick et al., 2008). The distance an individual soil sediment particle travels during a runoff event is a function of its properties and hydrologic characteristics of the flow and the channel (Schumm, 1961; Hassan and Church, 1991; Levick et al., 2008). These effects combine into wavelike pulses of sediment entrained, transported, and deposited during flow. Entrainment and deposition of channel and bank sediment occur during the entire duration of flow (Lee et al., 1981; Powell, 1998) and as a result, ephemeral streams may experience a gradient of aggradation and degradation along a single reach (Zaimes and Emanual, 2006).

Despite being dry between the flow events, ephemeral streams generally support riparian obligate or xeroriparian vegetation along or near their banks. Channel morphology and water availability control vegetation establishment and abundance (Hupp and Osterkamp, 1996). Vegetation establishment can be a self-reinforcing cycle where the vegetation slows sediment transport and increases deposition and infiltration rates, which in turn can increase soil moisture as well as vegetation distribution and density. The reverse is also true where reduction in vegetation makes channel morphology more dynamic and increases erosion and sediment movement (Coutlhard, 2005). Though loss of vegetation can occur naturally, disturbances associated with land use or management often expedite and amplify plant mortality.

Hydrologists and ecologists classify disturbances as discrete “pulse” events (such as dam removal or construction projects) or continuous “press” events, including ecosystem degradation or land-cover changes (Bender et al., 1984; Gran and Czuba, 2017). Both types can modify flood regimes, vegetation dynamics, and landscape productivity due to changes in sediment availability (Levick et al., 2008; O’Connor et al., 2014). For ephemeral networks with drainage outlets in coastal areas, anthropogenic disturbances impact water quality and aquatic-terrestrial dynamics (Bartley et al., 2007; Dougall et al., 2014). Geomorphic responses to dryland disturbances include increased runoff, erosion, and sediment movement through ephemeral channels due to reduced vegetation, soil disruption, and unconsolidated sediment (Levick et al., 2008; Farrell 2016). Increases in sediment deposition 50-200 m downstream immediately following natural gas pipeline construction have been observed in multiple perennial streams, including the Little Miami River, Ohio (Vinikour et al., 1987), Fletcher Creek, Michigan (Crabtree et al., 1978), and Findlay Creek, Ontario (Anderson et al., 1998). In all three studies, the deposited sediment was flushed out of the study site or system within one year following construction (Reid and Anderson, 1999). However, morphologic response to ephemeral channels following pipeline construction has not been well researched; this study assesses the impacts to ephemeral stream cross-sections in the two years following pipeline construction.

3. Methods

3.1 Study Area

The study is located in the Altar Valley in southern Arizona, USA (Figure 1). The ten field-study channels identified by Farrell (2016) were chosen due to their location on public land, lack of additional anthropogenic disturbances, and proximity to one another. An additional 15 ephemeral streams were chosen for study based on lack of upstream anthropogenic disturbances using high-resolution LIDAR-derived digital elevation models (DEMs). The twenty-five study streams lie along a 9-km stretch of the pipeline (approximately 111°30'04.7313" W, 31°47'06.0038"to 111° 34’19.6237”W, 31°35’40.3598” N, Figure 1). Elevation of the study sites varies from 1104 – 1143 m above sea level (asl). The drainage basins range from 1070 -1641 m asl in elevation.

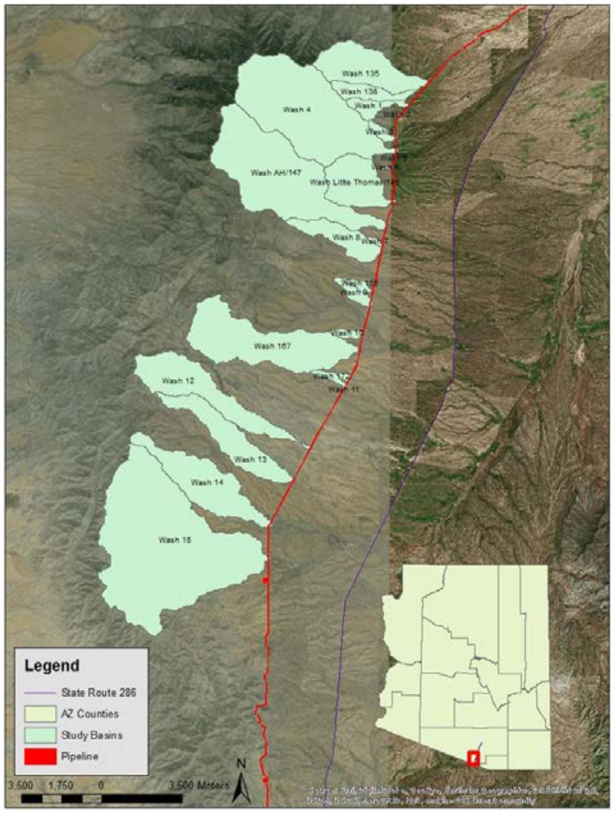


Figure 1: Location of 25 ephemeral study stream drainage basins and pipeline footprint

The Sonoran Desert has a bimodal precipitation regime (approximately half of all precipitation occurs during the high intensity summer monsoon season and half falls as low-intensity winter precipitation (National Park Service, 2016)). Average annual precipitation in the study region ranges from 289-465 mm and average summer temperatures range from 25-28°C (based on 1981-2010 NOAA climate averages from three gauges within the study region: 111° 36' 7.92"W, 31° 36' 12.96"N; 111° 30' 19.8"W, 31° 34' 17.76"N; 111° 22' 58.8"W 31° 58' 44.76" N (NOAA-NCDC, 2016 is this cited). Dominant vegetation classifications include Apacherian-Chihuahuan mesquite upland scrub, Chihuahuan Mixed salt desert scrub, and Apacherian-Chihuahuan Semi-Desert Grassland and Steppe (USGS, National Gap Analysis Program, 2013).

3.2 Pipeline Construction

The 98-km long by 91.4-cm diameter natural gas pipeline was constructed June-September 2014. The construction process occurred along a 22-46 meter right-of-way (ROW) and included mechanical vegetation removal, trench excavation, pipeline burial, and backfill. Subsoil and topsoil were kept separately during excavation and backfill processes. The depth of the pipe ranged from 0.93-3.1 meters below the thalweg depth of the ephemeral stream crossing depending on the maximum scour and lateral erosion calculated from a 100-year flow event. Construction activities (including preliminary surveying and final cleanup) at any given point along the pipeline lasted from 6-10 weeks. To control erosion during and immediately following construction, the pipeline company installed both temporary controls (silt fences and straw bales) and permanent structures (slope breakers and riprap).

3.3 Methods Summary

Cross-section profiles were obtained using field measurements and available LIDAR data. Changes in cross-section morphology between each of the field measurements and LIDAR-derived cross-sections were determined by calculating the percent change in area at each cross-section location (upstream-ROW, across-ROW, and downstream-ROW) for each of the study channels between individual measurement dates using Microsoft Excel (Ver. 14.6.5). The significance of the changes in cross-section area at the three measurement locations was assessed using the statistical package R (Ver. 3.3.2). Watershed and precipitation characteristics (area, drainage density, vegetation cover, soil type, slope, average precipitation, storm intensity) were obtained from remotely sensed data, NOAA RADAR, digital elevation models (DEMs) and publically available land-cover and soil datasets in ESRI ArcMap. A stepwise linear regression model based on the derived watershed characteristics and cross-section area changes was evaluated using the statistical package R. A more detailed explanation of each step is described below.

3.4 Field Methods (April 2015-January 2017)

Between April 2015 and January 2017, three stream cross-sections were measured at each of ten streams: approximately 10-30 m upstream of the pipeline intersection (upstream-ROW), across the center of the pipeline construction footprint (across-ROW), and 10-30 m downstream of the pipeline intersection (downstream-ROW). Each cross-section was measured during three distinct time periods: once between April and June 2015 (Period 1), once between December and January 2016 (Period 2), and three to six times between June 2016 – January 2017 (Period 3, Table 1). Cross-sections were obtained using two methods: (1) depth measurements every 15 cm or 30 cm, depending on channel slope, along a horizontal zero datum (Heitke et al., 2008), and (2) a Trimble R10 GNSS GPS system (Trimble, Westmoor, CO).

Table 1: Field measurement dates for the ten field study streams

Wash	Period 1	Period 2	Period 3					
135	4/3/2015	12/10/2015	7/6/2016	7/20/2016	7/27/2016	8/16/2016	9/9/2016	
138	4/12/2015	12/10/2015	7/6/2016	7/20/2016	7/27/2016	8/9/2016	10/12/2016	1/24/2017
145	4/24/2015	12/10/2015	7/1/2016	7/5/2016	7/13/2016	7/22/2016	10/22/2016	
Little Thomas	5/11/2015	12/10/2015	7/1/2016	7/13/2016	7/22/2016	10/22/2016		
147	5/22/2015	N/A	7/1/2016	7/5/2016	7/13/2016	7/22/2016	10/22/2016	
Arroyo Hondo	06/05/2015	01/05/2016	7/1/2016	7/5/2016	7/13/2016	7/22/2016	1/24/2016	
158	5/22/2015	12/10/2015	7/20/2016	7/27/2016	8/9/2016	8/16/2016	9/9/2016	10/22/2016
167	6/13/2015	12/5/2015	6/20/2016	7/28/2016	10/12/2016			
171	6/15/2015	12/5/2015	7/28/2016	7/28/2016	10/22/2016			
172	6/20/2015	12/4/2015	6/30/2016	7/28/2016	10/12/2016			

3.5 LIDAR Data (July 2014- July 2016)

Airborne LIDAR data was obtained from three flyover dates: July 30, 2014 (pre-construction), February 11, 2015, and July 9-12, 2016 (Pima Association of Governments, 2016; SWCA**,** 2015). Average pulse densities for the three dates were 1.0 pulses/m^2, 2.0-pulses/ m^2, and 1.5 pulses/m^2. The raw data was processed using only the ground return points to create 1-m digital elevation model (DEM) for each dataset. Cross-section profiles at the upstream-ROW, across-ROW, and downstream-ROW location were extracted for each LIDAR dataset at each of the 25 study washes using ESRI ArcMap (*3D Analysis tool*, ESRI Ver. 10.4.1, Redlands, CA). Nine of the twenty-five channels were not used in the final cross-section analysis due to morphological discrepancies attributable to LIDAR coverage gaps in at least one or more datasets. To be eliminated from the dataset, a cross-section had to meet both following criteria: 1) vary in area by a minimum of 30% from the other two cross-sections and 2) show morphological characteristics when graphed indicating data gaps, such as linearity and jagged lines. Figure 2 provides an example of an eliminated cross-section.

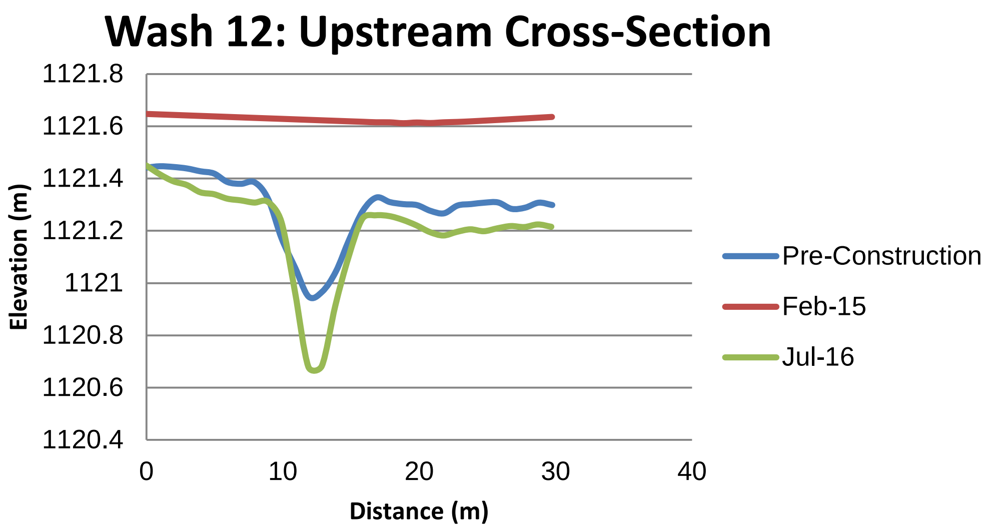


Figure 2: LIDAR-derived cross-sections for Wash 12, which was excluded from the final analysis due to the discrepancies in morphology between the February 2015 data and both the pre-construction and July 2016 data. The 2015 cross-section area varied by 90% and 1298% between the pre-construction and 2016 cross-section.

3.6 Geoprocessing Methods

Watershed characteristics used in the stepwise linear regression were derived in ESRI ArcMap (Ver. 10.4.1, Redlands, California) using LIDAR, publically available digital elevation models (DEMs), and land-cover and soil datasets. The watershed area and stream length were calculated for each study channel using the Automated Geospatial Watershed Assessment (AGWA 3.6.5.1791, USDA-ARS, 2016) modeling plugin. The 1-meter DEM created from the July 2016 LIDAR flyover data was used as the input in ESRI ArcMap (ESRI, Redlands, California) to create a 1-meter flow-direction and flow accumulation raster. The DEM was filled to remove sinks, or areas with undefined drainage outlets (*Fill* tool in Spatial Analysis, ESRI, Redlands, California). The watershed drainage outlet for each of the 16 basins was defined as the lowest point in the downstream-ROW LIDAR cross-section at each study channel. Watersheds were delineated using the flow accumulation and outlets points; the attributes of each delineated watershed were combined into a composite geodataset. Total stream length for each watershed was derived through watershed discretization, using the program-defined contributing source area (CSA) to determine the stream drainage feature class. Average watershed slope (calculated as percent rise) was extracted for each watershed using a 1/3 arc-second DEM and Spatial

Analysis (the *Slope* and *Tabulate Area* tools, ESRI, Redlands, California). Land cover and soil classifications were derived for each watershed from the publically available USGS Southwest Land-Cover data and the SSURGO soil survey (USGS National Map, 2016; USDA Web Soil Survey, 2016) using Spatial Analysis ESRI plugin (the *Zonal Statistics as Table* tool, ESRI, Redlands, California, Table 2).

Table 2: Summary of area, drainage density, average slope of the watershed, percent bare soil in the contributing uplands, and dominant soil type for the study channels.

Study Stream	Area (km^2)	Drainage Density (km/km^2)	Average Slope	% Bare Soil	% Mesquite	Dominant Soil Type
135	8.04	2.69	20.40	0.83	13.17	Pantak-Deloro
138	1.87	17.30	22.07	1.52	10.32	Pantak-Deloro
Little Thomas	5.01	2.83	12.38	16.1	8.04	White House Caralampi
147	5.01	2.83	12.38	16.1	2.59	White House Caralampi
Arroyo Hondo	17.30	1.21	21.65	1.12	2.59	Lampshire-Pantak-Rock
158	0.39	7.47	1.69	0.00	0.00	White House Caralampi
167	12.53	1.89	6.34	2.27	3.02	White House Caralampi
171	0.16	14.60	1.55	0.00	0.00	White House gravelly loam
172	0.44	6.98	1.69	0.00	26.28	White House gravelly loam
1	1.25	5.04	22.94	0.40	16.24	Lampshire-Romero
2	0.027	65.00	6.85	0.00	0.47	White House Caralampi
6	0.063	17.34	6.63	0.00	28.48	White House Caralampi
7	0.14	13.80	1.90	0.00	0.00	White House gravelly loam
8	3.34	2.87	6.72	0.24	9.17	Caralampi gravelly sandy loam
10	0.46	8.19	1.50	0.00	0.00	White House Caralampi
11	1.71	3.53	1.39	0.00	5.59	White House Caralampi

3.7 Precipitation

An ONSET Hobo Precipitation Logger (Onset Computer Corporation, Bourne, MA) installed within the study area (111° 30’49.1” W, 31° 45’09.4” N) and three NOAA precipitation gauges within the region (111° 32' 36.96" W, 31° 28' 58.8" N; 111° 35' 49.92" W, 31° 57' 36" N, 111° 30' 19.8" W, 31° 34' 17.76" N) were used to identify the 35 largest storm events during the July 2014 – October 2016 study period.

Average precipitation and the number of storms exceeding a 25 mm/hour intensity threshold for each storm event was calculated for each drainage basin using NOAA NEXRAD Dual Polarization RADAR data (NOAA NCEI, Asheville, North Carolina), the NOAA Weather and Climate Toolkit (Ansari Ver. 4.0.6) and ESRI ArcMap (ESRI Ver. 10.4.1 Redlands, CA).

Many studies have observed the rainfall-runoff relationship is not linear and precipitation thresholds for runoff generation vary (Graf, 1988; Ye et al., 1997); however, the assumption that runoff events occurred during the study period based on precipitation data was validated by studies linking dryland precipitation thresholds and runoff in Yuma, Arizona (Faulconer et al., 2014) and Murcia, Spain (Cammeraat, 2004 or 2005). Faulconer (2014) found that for watersheds ranging from 0.83-2.2 km^2 with bedrock and alluvium channels and a bimodal, high intensity precipitation regime, runoff was generated for precipitation events that exceeded a 30-minute peak intensity of 20 mm. In a semi-arid rangeland site in southeastern Spain with average annual precipitation (270 mm) just below the lower range limit of average rainfall of the study region, runoff through ephemeral streams was detected for drainage areas ranging from 0.01-1 km^2 at precipitation intensities of approximately 20 mm/hour or greater (Cammeraat, 2004 or 2005). Of the sixteen ephemeral study streams in this study, nine catchment areas fell within the 0.01 – 2.2-km2 range (Table 2) evaluated in the combined Spain and Yuma studies. Furthermore, runoff in the remaining seven streams with drainage basins larger than 2.2 km^2 is probable as corroborated by extensive monitoring of runoff at the Walnut Gulch Experimental Watershed also in the Sonoran Desert near Tombstone, Arizona. Ongoing monitoring of 30 watersheds ranging from 0.0018 – 149 km^2 beginning in mid-1950s indicates an average of nine runoff events per year in ephemeral channels regardless of drainage area (Stone et al., 2008). Based on these studies, the minimum precipitation intensity of 25 mm/hour was used to estimate the number of runoff events.

Digital Storm Total Accumulation (DTA) files were downloaded for each of the 35 previously identified dates. The DTA files detail total accumulated precipitation in six-minute time steps; each DTA file for each of the 35 days was imported and animated in the Weather and Climate Toolkit to identify the individual DTA file where storm accumulation in the study area reached a peak. That DTA file was exported as a shapefile and used in ESRI ArcMap to determine the average precipitation at each watershed. Average precipitation and the number of storms exceeding an approximate 25 mm/hour intensity threshold at each drainage basin were grouped into two study periods based on the LIDAR flyover dates: July 2014-Februrary 2015 (LIDAR Period 1) and February 2015-July 2016 (LIDAR Period 2, Table 3). The largest precipitation event during the study period was 53.3 mm on September 17, 2014, which has an approximate 1-year, 24-hour recurrence interval. The 25-, 50, and 100-year, 24-hour precipitation recurrence intervals for the study region are 103.6 mm, 115.8 mm, and 128.5 mm (NOAA PFDS, 2014).

Table 3: Rainfall distribution and intensities for 2014 – 2016 study period

	LIDAR Period 1 (July 2014-February 2015)		**LIDAR Period 2 (February 2015- July 2016)**	
Study Stream Drainage Basin	Average Precipitation (mm)	Storms Exceeding 25 mm/hour	Average Precipitation (mm)	Storms Exceeding 25 mm/hour
135	17.5	4	13.1	5
138	18.3	4	12.7	6
Little Thomas	23.0	5	11.2	3
147	23.7	6	14.0	7
Arroyo Hondo	23.7	6	14.0	7
158	22.0	5	13.6	6
167	18.6	4	138.8	6
171	20.3	5	17.1	9
172	19.1	4	17.3	10
1	19.4	4	11.6	4
2	17.4	4	10.6	4
6	20.7	5	10.3	3
7	24.0	5	12.2	5
8	21.8	5	12.6	6
10	20.8	5	14.1	9
11	22.2	5	19.8	10

3.8 Statistical Methods

An analysis of variance was used to determine if the pipeline construction significantly altered across-ROW and downstream-ROW channel morphology in terms of cross-sectional area change when compared to the undisturbed upstream-ROW cross-section.

The changes in cross-section area were normalized by calculating the percent change in area (Equation 1). For the LIDAR analysis, the three cross-section measurement dates were July 2014, February 2015, and July 2016. The percent change in area for the June-October 2016 fieldwork data was calculated between the first and last field measurement.

$$\textbf{\textit{Equation 1}}: Percent\ Change\ in\ Area = \frac{CSA_2 - CSA_1}{CSA_1} * 100$$

Where:
CSA_1 = Cross Section Area at date 1
CSA_2 = Cross Section Area at date 2

The changes in cross-section area for the upstream-, across-, and downstream-ROW locations during each study period were log-transformed to meet Shapiro-Wilks normality assumptions (p = 0.1591) and analyzed in a nested Analysis of Variance (ANOVA) to assess impact of the pipeline on channel cross sections.

In addition, a stepwise linear regression model was built to explain differences in cross-section area change based on 9 variables (drainage basin area, drainage density, dominant soil type, upstream-, across-, and downstream-ROW location, slope, bare soil area, Apacherian-Chihuahuan mesquite upland scrub area, total precipitation, and number of storm events that exceeded a 25 mm/hour intensity threshold). Stepwise regression determines the combination of explanatory variables that best explains the response variable by comparing all possible regression models to one another. The criteria used for model quality assessment was the Akaike Information Criterion (AIC). All statistical analysis was completed in R (Ver. 3.3.2 R Core Team, Austria 2013).

4. Results

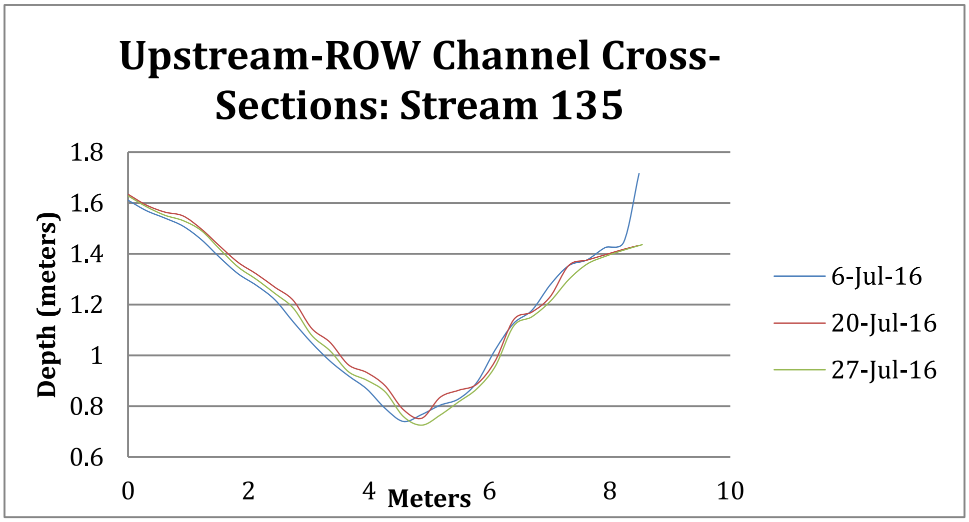
4.1 Field Data (June 2016 – January 2017) Cross-Section Analysis

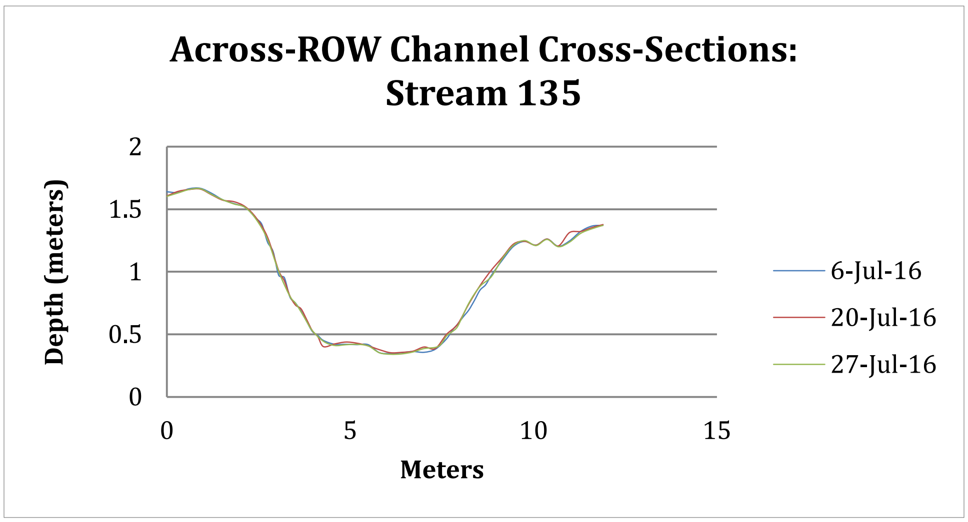
The ANOVA analysis of the log-normalized 2016 monsoon season cross-section data indicated no statistically significant difference in change in cross-section area between the upstream-ROW, across-ROW, and downstream-ROW cross sections for both the actual change (showing scour and deposition) and absolute change (indicating magnitude of scour or deposition event) analyses [($F_{2,18}$)= 0.980, p = 0.395, Figure 3A, ($F_{2,18}$)= 0.198, p = 0.822, Figure 3B).

Upstream cross-sections had an average change in area of 3.20% (1.07 m^2, SD = 9.45%), across-ROWs average change was 1.54% (0.709 $m^{2,}$ SD = 8.90%), and downstream-ROWs had an average area change of -0.91 (0.293 m^2, SD = 7.64%, Figure 4, Table 4). The absolute change in area for upstream-ROWs during the 2016 monsoon season was 1.48% (0.493 m2, SD = 1.68%). Across-ROWs average absolute change was 6.13% (2.76 m^2, SD = 6.20%), and downstream-ROWs had an average absolute area change of 6.14% (1.94 m^2, SD= 4.93%, Figure 4B).

Table 4: Changes in Cross-Section Area for he 2016 fieldwork

Wash	% Change in Cross-Section Area	Location
135	-0.8	Upstream-ROW
138	0	Upstream-ROW
Little Thomas	-3	Upstream-ROW
Arroyo Hondo	-0.4	Upstream-ROW
147	-0.1	Upstream-ROW
158	-0.9	Upstream-ROW
167	5.2	Upstream-ROW
171	0.2	Upstream-ROW
172	2.7	Upstream-ROW
135	1.1	Across-ROW
138	-1	Across-ROW
Little Thomas	-1.8	Across-ROW
Arroyo Hondo	-8.5	Across-ROW
147	3.7	Across-ROW
158	-3.4	Across-ROW
167	17.2	Across-ROW
171	-1.7	Across-ROW
172	16.9	Across-ROW
135	-1.1	Downstream-ROW
138	-6.3	Downstream-ROW
Little Thomas	-16.7	Downstream-ROW
Arroyo Hondo	-6.9	Downstream-ROW
147	0.1	Downstream-ROW
158	10.3	Downstream-ROW
167	4.3	Downstream-ROW
171	1.6	Downstream-ROW
172	8	Downstream-ROW





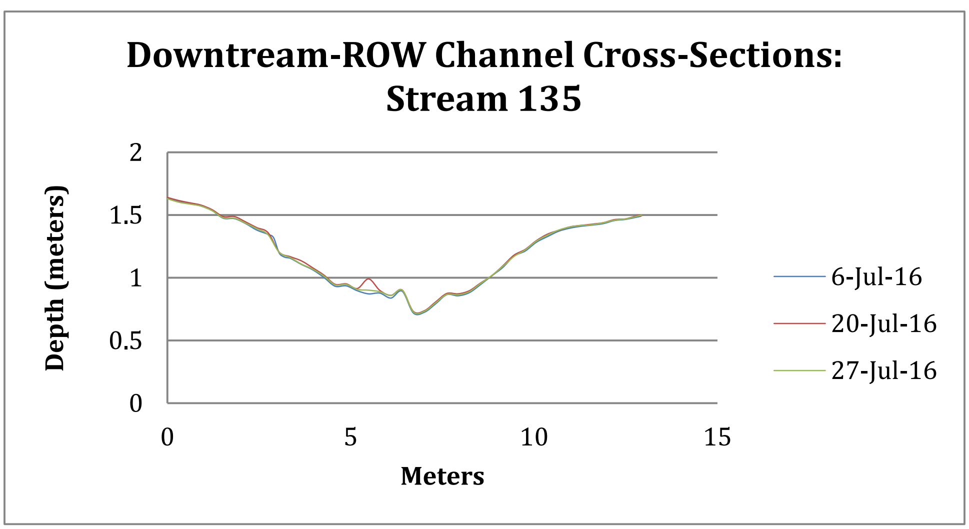
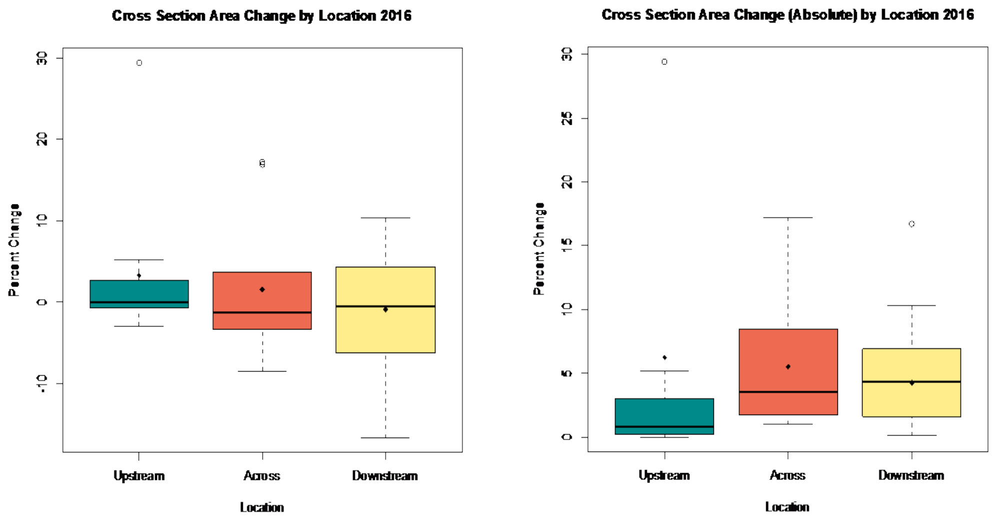


Figure 3: Fieldwork Channel Cross-Section Profiles for Stream 135



A B

Figure 4: A) Boxplot showing mean (black point), 25th and 75th percentile (bottom and top of box), median (solid black line) and range of cross-section area change data for each cross section location for the 2016 monsoon season. Open circles indicate outliers (values greater than 1.5 times the interquartile range). (B) Boxplot showing mean (black line), 25th and 75th percentile (bottom and top of box), median (solid black line) and range of the absolute change in cross-section area for each location for the 2016 monsoon season. Open circles indicate outliers

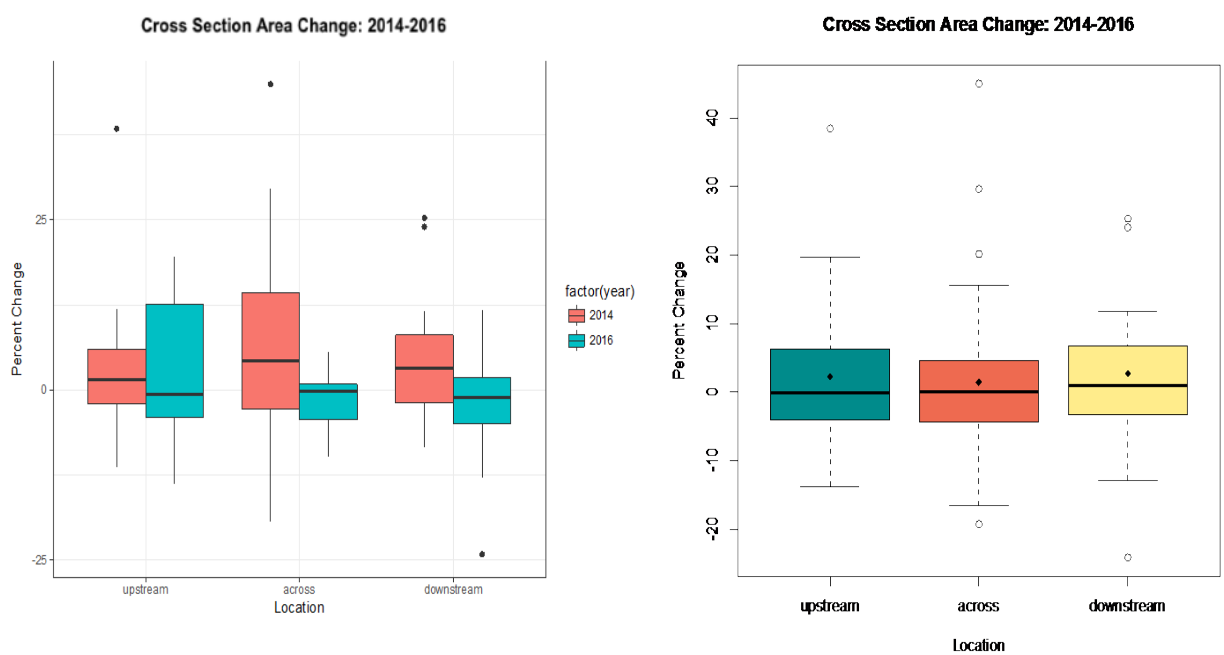
Table 5: ANOVA results of the 2016 cross sections area change for the raw 2016 data (A) and absolute-value data (B)

(A) 2016 Cross Sections: Raw Change					
Factor	Sum of Squares	*df*	Mean Square	*F*	Significance (*p*)
Location	0.178	2	0.089	0.980	0.395
Wash	1.369	9	0.152	1.668	0.170
(B) 2016 Cross Sections: Absolute Change					
Factor	Sum of Squares	*df*	Mean Square	*F*	Significance (*p*)
Location	19.8	2	9.92	0.198	0.822
Wash	449.2	9	49.91	0.966	0.479

4.2 LIDAR Data (July 2014- July 2016) Cross-Section Analysis

Upstream-ROW channel areas changed an average of 2.83% (6.88 m^2 SD = 11.51%) between July 30, 2014 and February 11, 2015 and 2.51% (6.18 m^2, SD = 10.51%) between February 11, 2015 and July 9-12, 2016. Across-ROW channel area changed an average of 5.72% (13.12 m^2, SD= 16.06%) between July 30, 2014 and February 11, 2015 and -1.20% (2.31 m^2, SD=4.10%) between February 11, 2015 and July 9-12, 2016. Downstream-ROW channel area changed an average of 4.87% (9.09 m^2, SD = 9.30%) between pre-construction and February 11, 2015 and -2.01% (3.78 m^2, SD = 8.07%) between February 11, 2015 and July 9-12, 2016 Figure 5A)

Between July 20, 2014 and July 9-12, 2016, upstream-ROW cross-sections changed an average of 2.67% (6.58 m^2, SD = 10.85 %), across-ROW cross-section areas saw an average change of 2.62% (6.10 m^2, SD = 12.06%), and downstream-ROWs had an average cross-sectional area change of 1.43% (2.67 m^2, SD = 9.26%, Figure 5B).



A **B**

Figure 5: A) Boxplot showing mean (black line), 25th and 75th percentile (bottom and top of box), median (solid black line) and range of cross-section area change data for across, downstream, and upstream locations, grouped by year (teal=2014, coral=2016). Open circles indicate outliers (values greater than 1.5 times the interquartile range). (B): Boxplot showing mean (black line), 25th and 75th percentile (bottom and top of box), 50th percentile (solid black

line) and range of cross-section area change data for each cross section location. Open circles indicate outliers.

An analysis of variance of the log normalized LIDAR cross-section data indicate no significant differences in cross-sectional area change between the study periods [period 1 = July 30, 2014 – February 11, 2015; period 2 = February 11, 2015 – July 9-12, 2016; $(F_{1, 16}) = 2.213, p = 0.156$], or between upstream-ROW, across-ROW, downstream-ROW cross-section measurements [$(F_{2,64}) = 0.341, p = 0.713$, Table 6)].

Table 6: ANOVA results of the 2014-2016 LIDAR cross-sections

Factor	Sum of Squares	*df*	Mean Square	*F*	Significance (*p*)
Study Period	0.757	1	0.7567	2.213	0.156
Cross-Section Location	0.136	2	0.06811	0.341	0.713
Study Period *Cross Section Location	0.625	2	0.31242	1.562	0.218

During the 2014 – 2016 study period, there were both minor infill and scour events at the measured cross sections. The largest net scour occurred between July 20, 2014 and February 11, 2015 (44% increase in cross-section area at the across-ROW cross section of Study Stream 7) and the largest net deposition occurred between February 11, 2015 and July 9-12, 2016 (24% reduction in cross-section area at the downstream-ROW cross section of Study Stream 7). The average scour event yielded a 9.4% increase in cross-section area (SD = 9.79%) and the average depositional event resulted in a 5.5% (SD = 8.43%) decrease in cross-section area.

4.3 LIDAR Data (July 2014-July 2016) Stepwise Linear Regression

The stepwise linear regression of nine variables (area, drainage density, percent bare soil, percent, slope, soil type, Apacherian-Chihuahuan mesquite upland scrub area, LIDAR measurement period, total precipitation, and number of events exceeding a 25 mm/hour intensity threshold) indicated that percent bare soil (B) and the LIDAR period of cross-section measurement (Y) were significant in explaining differences in cross-sectional area change (p =

0.0380 and p = 0.0230, Table 8). The results indicate a positive correlation between percent bare soil and change in cross-sectional area (b = 0.4320, standard error = 2.14) and negative correlation between the second LIDAR study period (February 2015-July 2016) and percent area change (b = -4.9474, standard error = 2.1402, Table 7). When the changes in area were evaluated for magnitude of change rather than scour or deposition, the stepwise linear regression indicated that bare soil and the measurement period remained significant (p = 0.00271 and p = 0.0453, Table 8) and maintained their positive (bare soil) and negative (LIDAR study period) correlations to change in cross-sectional area (bare soil: b = 0.4635, standard error = 0.1504; LIDAR period 2: b = -3.1817, standard error = 1.1561).

Table 7: Results of the stepwise linear regression models using the variables Treatment (T), Year (Y), Area (A), drainage density (D), slope (M), percent Bare soil (B), Soil type (S), percent mesquite (V), total Precipitation (P), number of storms exceeding 25 mm/hour intensity (C). AIC stands for Akaike's Information Criteria (AIC), a unit-less value that decreases with improved regression parameterization. R^2 is adj R^2.

Model: Change in Area	**AIC**	R^2	**Significant variables (*p* value <0.05)**
C=T+Y+A+D+M+B+S+V+P+C	465.69	0.0438	Y
C=Y+A+D+M+B+S+V+P+C	462.47	0.0585	Y
C=Y+A+M+B+S+V+P+C	460.55	0.0685	Y, B
C=Y+A+M+B+V+P+C	458.63	0.0783	Y, B
C=Y+M+B+V+P+C	456.79	0.0871	Y, B
C=Y+B+V+P+C	454.93	0.0960	Y, B
C=Y+B+V+P	453.94	0.0963	Y, B
C=Y+B+V	453.88	0.0880	Y
C=Y+B	453.72	0.0803	Y, B
Model: Absolute Change in Area	**AIC**	R^2	**Significant variables (*p* value <0.05)**
C=T+Y+A+D+M+B+S+V+P+C	407.85	0.0617	
C=Y+A+D+M+B+S+V+P+C	404.21	0.0801	
C=Y+A+D+M+B+S+V+C	402.24	0.0904	
C=Y+A+D+M+B+S+V	400.63	0.0971	Y
C=Y+A+D+M+B+S	399.71	0.0971	Y
C=Y+A+M+B+S	398.60	0.0988	Y, B
C=Y+M+B+S	397.38	0.1014	Y, B
C=Y+B+S	395.60	0.1014	Y. B
C=Y+B	394.07	0.1145	Y, B

Table 8: Estimates standard errors, *t*-values, and *p*-values for the explanatory variables: B= Bare Soil (%), Y= Year of measurement for raw change and absolute change.

	Estimate	**SE**	**t-Ratio**	**Prob > |t|**
Raw Change				
Intercept	3.5722	1.5773	2.265	0.025
Y	-4.9474	2.1502	-2.312	0.0230
B	0.4320	0.2025	2.105	0.0380
Absolute Change				
Intercept	7.9644	1.1561	6.889	5.6e-10
Y	-3.1817	1.5686	-2.028	0.0439
B	0.4635	0.1504	3.081	0.00271

5. Discussion

5.1 Cross-Section Change Analysis (Fieldwork and LIDAR)

Results of both the 2016 fieldwork and 2014 – 2016 LIDAR data indicated that the pattern of scour across the pipeline-ROW and deposition downstream of the pipeline-ROW as observed immediately after construction in the Farrell (2016) study were not observed over the longer 2014 – 2016 study period. Sediment introduced to the ephemeral study streams from construction processes was not detected as impacting channel cross-section morphology during the longer study period likely due to the transport of sediment from pipeline construction out of the study extent and the high-recurrence precipitation experienced from 2014-2016. .

Though the mechanisms and transport thresholds that govern sediment transport in perennial streams differs from ephemeral streams, the assumption that sediment was transported further downstream as noted in Farrell (2016) is similar to observations of sediment transport following six runoff events in the Negev and Judean deserts of Israel (Hassan, 1993). Hassan (1993) used tracer particles to track sediment movement in two ephemeral reaches and found the average sediment movement distance ranged from 11.7 – 145.8 meters per runoff event. In this study, distance between the across-ROW and downstream-ROW cross-sections ranged from 30-60 m. The introduced sediment that contributed to the morphologic trend of scour and deposition immediately following construction may have been moved out of the study area limit through a series of flow events. Though individual flow events were not measured during the 2015 season, RADAR derived precipitation intensity data indicated a high likelihood that runoff occurred in each study stream, as indicated by the number of storms in each basin that exceeded 25 mm/hour (Table 3). There were 31 storms where precipitation within the study-region exceeded 25 mm/hour during the 2014 – 2016 study period. Of these large events, 22 occurred during the second year after construction (February 2015 – July 2016).

Analysis of the 2014 – 2016 cross section data showed both minor scour and infill events (Figure 4). The cycle of scour and re-deposition at individual cross sections observed during the 2016 monsoon season has been detected in multiple other ephemeral stream studies, including in the Guadalentin basin of southeastern Spain (Hooke and Mant, 2000) and southeastern Arizona (Powell et al., 2005). Variability in cross-section area at the upstream-, across-, and downstream-ROW locations in this study was attributed to the spatial variability of precipitation in the study reach and the pulse movement of sediment through the drainage system, which is corroborated by variability in cross-section morphology following small flow events in Guadalentin, Spain over a 8 month study period (Hooke and Mant, 2000) and observations of both deposition and erosion events over a 40-year study period at cross-sections along an ephemeral reach of the Colorado River near Yuma, Arizona (Mueller et al., 2015). The average erosion and deposition events (9.4% increase in cross-section area and 5.5% decrease in cross-section area) fall within the range of natural variability in scour and deposition events observed along ephemeral cross-sections at the Walnut Gulch Experimental Watershed in the Sonoran Desert near Tombstone, Arizona (Powell et al., 2005) and in gully monitoring experiments at an ephemeral stream in McPherson, Kansas (Karimov et al., 2015). Hooke and Mant (2000) found that high flow events are responsible for significantly altering the morphology of channels, while small-flow events have smaller impacts to through minor deposition and erosion events. The largest 24-hour precipitation event during the study period here was 53.3 mm, which has approximately a 1-year recurrence interval. This implies that any changes to cross-section morphology in this study were likely minor depositional and erosion events.

In general, pipeline construction projects form discrete, pulse disturbances that contribute unconsolidated sediment into waterways**.** Reid and Anderson (1999**),** in a comprehensive study of 27 natural gas pipeline construction projects between 1974 and 1999, noted that construction activities have the largest impact on sediment related events (deposition, scour) in downstream reaches due to the availability of unconsolidated soil during construction both in the uplands and within the channels. Similarly, Wang et al. (2011) found that construction events can be the primary source of increased sediment in a study in forest haul roads in Virginia, a linear disturbance similar to a pipeline. The Army Corps of Engineers, responsible for many US waterways, recommends minimizing construction processes to reduce sediment in stream systems as a best management practice (BMP, U.S. Army Corps of Engineers, 2015). However, it is important to separate between the sediment created in the channel and the sediment generated in the uplands.

One expected source of sediment in the pipeline construction studied here would be from the upland disturbance and vegetation loss (vegetation was completely removed throughout the ROW). The effects of this sediment were not seen likely both from the limited area impacted (Table 9) and the use of construction BMPs. The maximum reduction in vegetation cover during construction falls within the natural range of plant mortality in the Sonoran Desert (McAuliffe and Hamerlynck, 2010). These authors noted perennial plant mortality as high as 90% following a period of below-average precipitation in 2003. Munson et al. (2012) similarly found up to a 4% reduction in perennial grasses and forbs proceeding low-precipitation years so the total loss of vegetation here simply was likely not high enough to have a detectable effect. The effect was even further reduced because, following the recommended BMP, the pipeline construction company reseeded the pipeline-ROW immediately after the construction was complete.

Table 9: Percent of watershed impacted by pipeline-ROW same

Ephemeral Study Stream	**(%) Watershed within pipeline ROW**
167	0.01
8	0.03
Arroyo Hondo	0.04
Little Thomas	0.04
147	0.04
135	0.15
138	0.24
1	0.32
158	0.72
172	1.13
10	1.15
7	3.13
171	4.57
11	4.66
6	6.31
2	10.62

5.2 LIDAR: Stepwise Linear Regression

The stepwise linear regression analyses indicated that the amount of bare soil in the drainage basin and year when the cross-section measurement took place were the best predictor variables for explaining the observed cross-section area change. Bare soil was positively correlated to magnitude of area change, implying that reduced upland vegetation cover resulted in higher magnitudes of geomorphic change in the ephemeral streams. The positive relationship between percent land-cover, erosion, and sediment transport has been shown in numerous studies in arid-lands (Graf, 1998; Duran Zuazu and Rodriguez Pleguezuelo, 2008; Nunes et al., 2011; Wilkinson et al., 2015). Studies in drylands in Australia have similarly shown a 5-15% increase in land-cover can reduce erosion in channels by 35-60% (Wilkinson et al., 2015). The amount of bare soil in the study washes, based on the USGS Gap Analysis classification codes, varied from 0-16%. However, the amount of bare soil in the drainage basins was likely significantly higher than the reported values due to a high ratio of bare soil to vegetation cover for many of the dryland GAP classification codes. For example, mesquite bosques in the Southwest typically have approximately 20% canopy cover and 15% plant basal cover (Coconino National Forest Plan Revision, 2010); meaning the remaining 65% of the mesquite ecosystem classification is actually bare soil.

The significance of year when the cross-section measurement took place was likely derived from the negative correlation between area change and the February 2015 – July 2016 measurement period agrees with Farrell (2016); soil introduced to the system from the pipeline construction fell within the study confines during the first study period and resulted in larger changes to cross-section morphology. As the pipeline construction soil was pushed beyond the study limits, changes in cross-sectional area became more aligned with morphologic response caused by natural variability.

Watershed slope, drainage density, area, total precipitation, number of days where average intensity exceeded 25 mm/hour, soil type, and upstream-, across-, and downstream-ROW cross sections were not good predictors of cross-section area change. Though each variable has been linked to morphologic response in other ephemeral streams, the results here indicate that these factors did not predict geomorphic change variability between study basins of similar topography and vegetation albeit during a period of exclusively high-recurrence interval, small precipitation events.

Rainfall and precipitation intensity have been positively correlated to erosion in uplands and sediment transport to ephemeral streams in a number of studies (Greer 1971; Graf, 1988; Ziadat and Taimeh, 2013) and have been considered the primary drivers of geomorphic change in ephemeral streams (Greer, 1971; Bull and Kirkby, 2002). Though the average rainfall varied between study washes, none of the precipitation occurred during a large storm event capable of producing significant geomorphic changes. Additionally, there was not a large amount of variability in the number of precipitation events that exceeded 25 mm/hour at each of the drainage basins during the 2015 - 2016 study period (mean= 10.93, SD = 2.59). Larger discrepancies between storm intensities and magnitudes at each of the study watersheds would have potentially yielded more variability in geomorphic response and cross-sectional area change.

Drainage area and density were also not important predictors of cross-sectional area change. This is different from Hadley and Schumm (1961) and Strand (1975) who found that drainage area is negatively correlated to sediment yield per unit area for watersheds ranging from 0.1 – 1000 km^2 in the semiarid Southwest due to greater availability of upland sediment storage. Despite the general trend, Hadley and Schumm (1961) note the influence of hillslope and sub-basin topography on sediment transport and acknowledge variability in observed response depending on climatic, topographic, and vegetative factors. I hypothesized that a higher drainage density would decrease sediment transport to individual channels due to a greater distribution of drainage outlets; however the results of the regression modeling do not indicate a negative correlation.

Slope and dominant soil type were not important predictors of cross-sectional area change. In other areas, the upland slope gradient has been positively correlated to sediment transport (Fu et al., 2011; Lau and Engel, 1999) and was included as a variable in the Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997). Slopes of the study drainage basins here ranged from 1-22%’; larger differences in slope would likely have shown more variability in sediment erosion, similar to a model linking erosion to watershed slope in the Guadalupe Rim, New Mexico where interill erosion on slopes of 50-70% was nearly a magnitude greater than erosion from slopes of 0-20% (Wilcox and Wood, 1989). Soil erodibility, or the long-term resistance of a soil type to the erosiveness of precipitation, was also a variable in RUSLE. Soils with high clay content generally have low soil erodibility indices; silty loams have high-erodibility (Graf 1988). Though there was variability in the dominant soil type for each watershed, soils in the study area are generally well-drained gravelly to sandy loams (USDA Soil Survey, 2016) with similar erosivity indices, and significant differences in sediment yield to the channels due to the soil type would not be expected.

The results of the stepwise linear regression modeling indicated that the selected factors were not good predictors of cross-section area change in ephemeral channels. Though bare soil and the study period were significant variables in explaining the observed differences in cross-sectional area, the low R^2 value indicates poor model fit. The lack of predictability can be attributed to three main factors. First, the ANOVA results of the 2014-2016 found no significant differences in cross-section area; an empirical regression model would likely not be able to explain the minute differences in cross-section area change. Second, the short time period only allows for interpretation of recent flows capable of minor infill and scour events through the study reaches, not large-scale watershed conditions. Changes to cross-section morphology near the watershed outlet are not indicative or representative of watershed impacts. Finally, the explanatory variables described sediment yield, not morphologic change. Though the two are interrelated, small changes in cross-section morphology are not indicative of the magnitude of sediment movement through ephemeral channels. Additionally, the similarities in variables at each study basin, the exclusion of additional factors that influence sediment dynamics (such as micro-topography or antecedent soil conditions), and the inability to include contributions from the channel bed and bank detracted from the model function. If there were more variability in the topography and land-cover characteristics of the study basins, smaller total area, and more low-recurrence, large storm events, the model would likely better explain variability in cross-section area.

6. Conclusion

The 2016 fieldwork and 2014 – 2016 LIDAR data analysis indicate that there have not been significant morphologic impacts in the two years following pipeline construction. The trend noted by Farrell (2016) of increased scour across the pipeline-ROW and increased deposition downstream the pipeline-ROW was not observed over the longer study period. Changes to cross-section area observed during the 2014 – 2016 study period fell within the range of natural channel adjustment through small-scale deposition and erosion events. Though this study found no significant impacts to cross-section area due to pipeline construction, the longer-term and larger-scale geomorphic response cannot be assessed. Further analysis over a longer stretch of the ephemeral network may provide additional insight to morphologic change. This study occurred during precipitation and runoff events of high-recurrence intervals (only small storms). Continued monitoring of changes to cross-section morphology during lower recurrence events may provide insight to morphologic impacts of pipeline construction in large storms. Analysis of cross-section change using nine explanatory variables found bare soil and the measurement dates significant in explaining variability, but the model is not an overall good predictor of morphologic response during periods of high-recurrence interval precipitation. Continued assessment during larger storm events capable of producing significant morphologic changes may result in better model performance but the large area and flashy runoff may ultimately defy prediction other than that the channels have a highly dynamic morphology. Sediment transport is a critical component of dryland dynamics, and an understanding of the long-term, large-scale impacts and trends following a pulse construction event can lead to more effective management strategies and construction BMP protocols to minimize the impact to arid watersheds.

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