STREAM POWER AND GEOMORPHIC CHANGES ON THE BLANCO RIVER POST 2015 MEMORIAL DAY FLOOD OF RECORD IN WIMBERLEY, TEXAS, USA

by

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DEDICATION

For my family. My parents Todd and Cindy, my stepparents Vanessa and John, and my siblings Lindsey and Matt. Thank you for being there for me as tried to figure out (and continue to figure out) what I want to do with my life. I still don't quite know what that might entail, but I know that I will be met with support and encouragement from all of you no matter what.

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LIST OF ABBREVIATIONS

Abbreviation	Description
USGS	United States Geological Survey
USACE	United States Army Corps of Engineers
FEMA	Federal Emergency Management Agency
TNRIS	Texas Natural Resource Information System
NAIP	National Agricultural Imagery Program
StratMap	Strategic Mapping Program
DEM	Digital Elevation Model

ABSTRACT

Stream power is an indicator of a river's ability to trigger geomorphic changes within their channel and surrounding landscape. In May of 2015, the Blanco River watershed experienced a flood of record, the 2015 Memorial Day flood, which initiated multiple geomorphic disturbances. In this study, I aim to determine (1) whether unit stream power had a direct influence on the amount and severity of initial geomorphic disturbance that occurred within a 12,000-meter reach of the Blanco River near Wimberley, Texas, and (2) what types of in-stream and channel changes/adjustments have occurred in the reaches since the Memorial Day flood that could be attributed to annual peak flows. I also examined geomorphic changes proximal to three tributary confluences. My research uses a combination of observation-based aerial imagery analysis, nonparametric statistics, and flood frequency analysis. Results of this study show that unit stream power has weak correlations with the types of geomorphic disturbances, and while the 2015 Memorial Day flood produced substantial changes, no major changes to the study area's width have occurred since 2015. This study contributes to the literature on bedrock rivers, how they respond to catastrophic floods, and whether geomorphic changes can be attributed to high magnitude, low frequency floods or low(er) magnitude, high frequency floods.

1. INTRODUCTION

River processes and forms produce some of the most dynamic landscapes. They are extremely responsive and unpredictable; a single disturbance – whether anthropogenic or natural – can cause changes that persist for varied lengths of time, while in other situations the river may quickly adjust back to its previous form. In general, more studies have focused on the higher frequency, low magnitude processes within these systems such as bankfull and mean annual flows that mobilize bed materials and affect bedforms. However, a distinct gap in research exists in our ability to predict how rivers adjust in response to high magnitude flood events (Borga et al. 2014, NOAA n.d.). To that degree, there is even much less known regarding how high magnitude flood events influence the geomorphic processes on karst bedrock rivers of the Texas Hill Country (Heitmuller 2011). This region experienced two high magnitude floods in 2015, which caused significant flooding on the Blanco River. Global climate change is fueling unpredictable and uncharacteristic extreme weather patterns that are exacerbating the frequency of these extreme events (Ribas, Olcina, and Sauri 2020). Understanding how rivers and streams react, respond, and adjust to high magnitude flood events is critical to interpreting how river-floodplain landscapes develop and change over time. Additionally, researching these powerful natural disturbances can contribute to the ever-growing dialogue on how to manage and protect our water resources as well as our ability to provide technical expertise in future decision-making regarding floodplain management.

Research over the immediate geomorphic and riparian disturbances of the historic 2015 Memorial Day flood (referred to hereon as the Memorial Day flood) occurred in recent years (Meitzen et al. 2018, Manning and Meitzen 2019, Phillips 2017), yet there is still much to be studied. This research will analyze the recent post-flood morphology and hydrology to understand spatial and temporal persistence and/or recovery of geomorphic changes on the Blanco River that stemmed from the Memorial Day flood. Specifically, this research will address the following two questions using the associated methods:

1) How does stream power relate to initial geomorphic disturbances?

It is expected that reaches that experienced higher stream powers during the 2015 Memorial Day Flood will be characterized by more initial geomorphic disturbances, while reaches that experienced lower stream powers will exhibit less geomorphic changes. This question will be answered by calculating the stream power of the peak flow of the Memorial Day Flood along twelve reaches within the study area and displaying the calculated total of each reach as a line feature along the stream centerline to easily differentiate between high and low stream powers. From there, the geomorphic disturbance layers originally created by Meitzen et al. (2018) and Phillips (2017) were layered over the study area to view the initial geomorphic disturbances ranging from no disturbance to major disturbance. The total areas of each category of disturbance will be calculated within each reach to quantify if reaches with higher stream power include more geomorphic change (moderate and major disturbance) and reaches with a lower total disturbed area indicate less geomorphic disturbance (minor disturbance and no disturbance). Further, a Pearson's R and Spearman's Rho tests were utilized to determine if any correlation exists between the types of disturbances that occurred within each reach and the stream power of the Memorial Day Flood, as well as changes in width at the channel and 100-year floodplain scales. This question also explored whether changes in high stream power reaches are confined within that reach, or if there are effects extended or translated to reaches downstream.

2) What types of geomorphic changes have occurred in the study area in the years following the 2015 Memorial Day Flood?

The twelve reaches in question were analyzed individually for continued geomorphic changes in three years, 2016, 2018, and 2021, since the Memorial Day flood using aerial imagery. Geomorphic changes were identified as new deposition of sediment (along the channel margin), deposition of sediment (in-stream – as bars or islands), erosion (of channel margin), erosion (in-stream scour), and changes in channel width (narrowing or widening). These types of features were mapped in ArcGIS Pro using points to simply quantify the total amount of changes identified within each reach, as well as the total amount of each type of geomorphic change. This allowed me to examine if the reaches that experienced high stream power from the Memorial Day Floods have experienced additional geomorphic changes in the years since 2015, and vice versa. To determine the geomorphic effect of flows that have occurred since the 2015 Memorial Day Flood, a flood frequency analysis was performed using the period of record data available from the USGS gage. As tributaries are sources of additional sediment and discharge, this might impact the adjustments of reaches directly downstream of the major tributaries in the study area (Cypress Creek and Lone Man Creek), thus I examined if areas in close proximity to tributaries experienced a greater amount of geomorphic changes since 2015. This will be done by combining all methods described below in section 4.

2. GEOGRAPHY OF THE TEXAS HILL COUNTRY AND THE BLANCO RIVER

The Blanco River originates from a series of Edwards Plateau Limestone -Trinity Aquifer springs in Kendall County, Texas and then flows eastward before meeting the San Marcos River near San Marcos, draining a total area of 440 square miles (Guadalupe-Blanco River Authority 2013) (Figure 1).

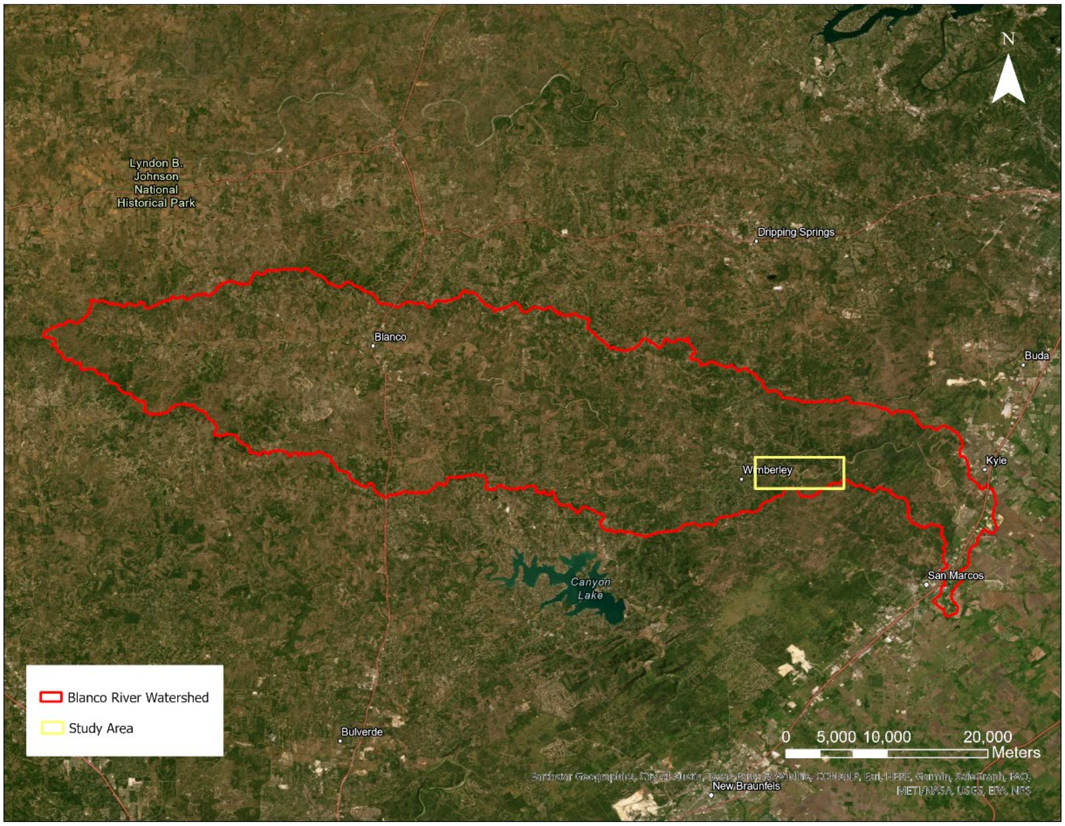

Figure 1: The Blanco River Watershed and Study Area

The Blanco River flows through the city of Wimberley, located approximately 15 miles northwest of San Marcos and 38 miles southwest of Austin. Wimberley has a total population of just over 3,000 permanent residents (U.S. Census) and its economy is largely driven by ecotourism, with popular swimming holes such as Jacob's Well and Blue Hole attracting visitors during the summer months. The United States Geologic Survey (USGS) Blanco River at Wimberley gage (08171000) is located southeast of the downtown area near a bridge and has a discharge record from 1924 to the present. The study area of this project is 12,384 meters long and begins just past the Blanco River's confluence with Cypress Creek and ends at its confluence with Lone Man Creek (Figure 2).

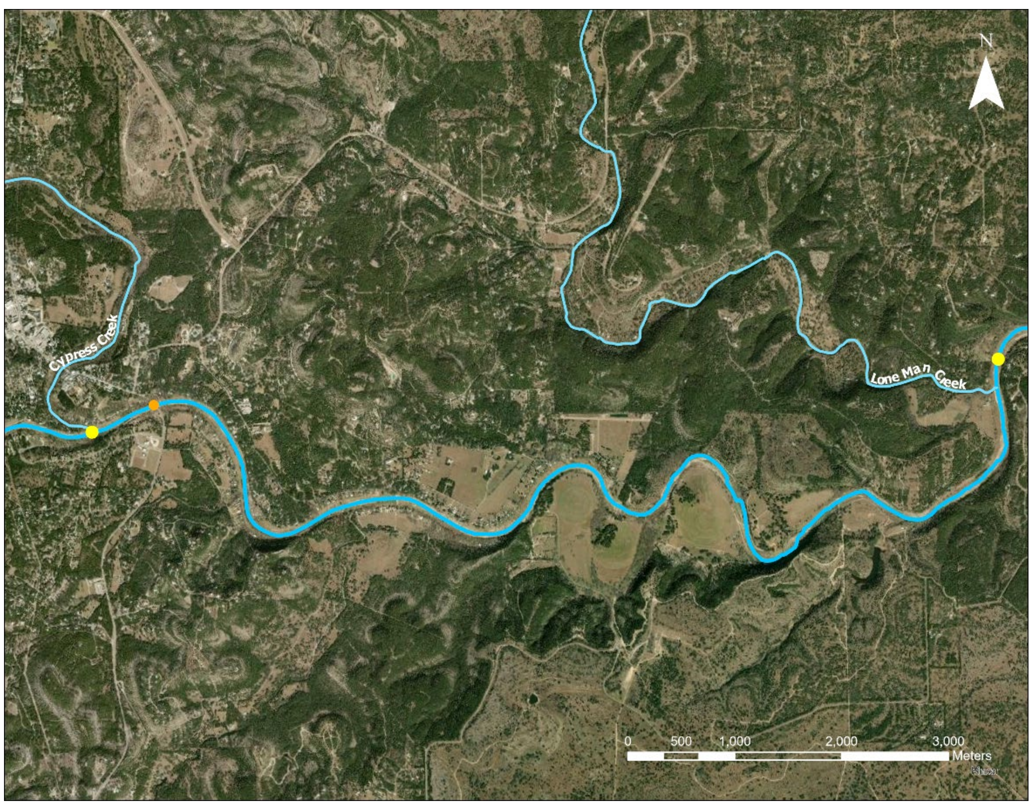

Figure 2: the study area designated with beginning and end points in yellow. The orange point shows the location of the USGS gage.

This region of the Blanco River valley is largely influenced by the Balcones Escarpment, which acts as the divide between the Edwards Plateau and Blackland Prairie ecoregions (Collins 2004). Meteorological and geographic characteristics of the region create conditions that lead to flash flooding. The escarpment's steep rolling limestone outcrops create a slight orographic effect over the region, causing storm systems to stall over the Escarpment. The climate can be classified as humid sub-tropical, characterized by hot and dry summers, mild winters, and two rainy seasons in early spring and late summer. Cycles of wet and dry years in the area are also influenced by cycles of El Nino and La Nina, known together as the Southern Oscillation. Precipitation amounts during El Nino's in the Texas Hill Country are significantly greater for 9 out of 12 months of the calendar year than La Nina's, which correspondingly leads to greater mean stream discharges as well (Slade and Chow 2011). A cycle of El Nino began in March 2015 and was later recorded as one of the strongest El Nino's in recorded history (Lindsey 2016).

The most recent and costly (both in physical damage and lives) floods in the past thirty years were the 1998 October flood and the 2015 Memorial Day and Halloween Floods. This research will be focusing on the stream power of the 2015 Memorial Day flood, and subsequent changes to bank forms and sediment erosion and deposition between 2015 and 2021. The Memorial Day floods occurred in response to eight inches of precipitation that fell on already saturated soils over the course of 15 hours (Furl et al. 2017). The river's stage increased by 36 feet in less than six hours (NWS 2015). The USGS Gage (no. 08171000) recorded a streamflow of 4,955.4 m^3s^{-1} greatly exceeding the calculated one percent chance flood calculated through a flood-frequency analysis using the United States Army Corps of Engineers (USACE) HEC-SSP software. The flood not only caused extensive damage to the community, but also caused extensive damage to the riparian corridor which acts as an important mitigation factor during floods (Meitzen et al. 2018). This research will encompass a comparative analysis over the geomorphic responses on the Blanco River immediately following the 2015 Memorial Day flood, and the subsequent channel adjustments in the years following at different reaches of the Blanco River. Studying the geomorphic impacts of the floods can provide information to support the management of dynamic river – riparian – floodplain areas and help us understand the roles of these environments as natural flood mitigation features.

3. LITERATURE REVIEW

3.2 Rivers and floods

A recurring debate within the field of fluvial geomorphology is the dichotomy of whether frequent, small magnitude events or less frequent, high magnitude events are each more or less responsible for geomorphic changes within rivers and streams. While it has been established that frequent, moderate flows in rivers have the capability to produce geomorphic changes in rivers over time (Wolman and Miller 1960), Costa and O'Connor (1995) suggested that flood magnitude is not the main driving factor in a flood's geomorphic effectiveness. Instead, they posit that the duration of the flood itself, in conjunction with magnitude, is a better indicator of geomorphic effectiveness. Wolman and Miller (1960) also noted that even though high magnitude, low frequency floods have the capability of causing erosion and transporting large amounts of sediment downstream, their impacts to overall morphology are small in comparison to floods that are of a lower magnitude, but more frequently occurring floods. The duration of precipitation and the resulting floods also widely impact the cohesiveness of riverbanks and can eventually cause bank failure if the bank becomes oversaturated (Magilligan, Buraas, and Renshaw 2015). The amount and strength of riparian vegetation adjacent to a river also have a significant impact on its susceptibility to erosion. It has been observed that an increase in riparian vegetation coincidingly leads to more narrow channels due to sediment being more easily trapped and stored, and in turn stabilizing banks (Friedman et al. 1993). In fact, restoring damaged riparian zones is now a commonly used best management practice for stream restoration projects (Simon et al. 2004). The sheer magnitude of the 2015 Memorial Day Flood was powerful enough to all but destroy the riparian corridor of the Blanco River, including the loss of thousands of old-growth bald cypress trees

(Meitzen et al. 2018, Manning and Meitzen 2019). Meitzen et al. 2018 reported some riparian and geomorphic disturbances occurred outside of the FEMA 500-year floodplain, and the most intense disturbance occurred in the channel and lateral riparian areas immediately adjacent to the channel.

As high magnitude floods are becoming more common, geomorphologists are questioning how one can predict continuous river change. Fryirs (2017) implies that revisiting river sensitivity – a relatively underutilized area studied by fluvial geomorphologists that questions the chance of a landscape or system might change due to a single disturbance, what type of changes may occur and the ability to recover from said disturbance – may hold the key to answering those questions. Several case studies have occurred implementing methodologies to examine the geomorphic impacts of historic flooding within river basins both in Texas and the northeastern United States using field measurements, aerial imagery and remote sensing as well as hydraulic modeling to display and quantify the changes rivers experienced after flooding with great success (Dean and Schmidt 2013, Magilligan et al. 2015, and Meitzen et al. 2018). Studies have shown that the width of rivers is likely to be the most obvious change in response to floods (Magilligan, Buraas, and Renshaw 2015, Wolman and Eiler 1958), but the width can both expand and contract frequently depending on the climatic conditions at the time of observation (Friedman et al. 1996, Dean and Schmidt 2013). Stream power can be an indicator to a flood event's geomorphic effectiveness (Marchi et al. 2015), however it is only one factor out of many that can also be used in evaluating a flood's geomorphic effectiveness (Costa and Connor 1995). The results of the Marchi et al. (2015) study found that even after experiencing high stream powers that greatly exceed the threshold that would lead to erosion in bedrock rivers, they displayed minor observances of erosion.

3.2 Limestone Rivers

The geologic makeup of Central Texas rivers in respect as to how they respond to periods of drought and extreme floods has consistently intrigued fluvial geomorphologists. Research over Central Texas rivers that were published in the mid-20th century began to show that bed material is an important factor in how they respond to environmental and climatic stressors such as floods (Baker 1977, Tinkler 1971). These pieces of literature are still cited frequently in publications emerging today. Further research by Tinkler and Wohl (1998) contributed important insight on processes influencing bedrock river morphology and sediment transport. These early contributions have been widely cited, yet there is still much to be learned about how limestone rivers respond to large floods. More recent findings found that the distribution of bedrock channel reaches in rivers can be attributed to several different local environmental factors (Keen-Zebert and Curran 2009). The varied distribution of bedrock reaches can make estimating channel roughness and resistance difficult, which in turn can lead to unprecise floodplain maps – something that could be detrimental in areas of frequent flooding such as the Hill Country (Conyers and Fonstad 2005). Baker (1977) challenged the well-established and accepted theory that most geomorphic change in rivers occurred during multiple moderate precipitation events, not in frequent high magnitude flooding events within Central Texas rivers. He supported his contentions by noting the potential influence of the Balcones Escarpment on creating an orographic effect which triggered large precipitation events and high magnitude floods, and their impact on bedrock river responses to flood events. Limestone beds often create challenges in accurately quantifying essential characteristics of rivers such as a roughness coefficient, which helps fluvial geomorphologists understand channel resistance, as described in Conyers and Fonstad (2005). Bedrock rivers often require tremendously high stream powers to initiate geomorphic changes compared to alluvial channels, and in that would also require a longer duration of flows that exceed the threshold to produce significant changes (Costa and Connor 1995). Characteristics and patterns of bedrock rivers are best understood at a local scale level (Jerin 2021). Jerin's study on bedrock rivers in Kentucky found that local factors such as riparian vegetation, slope, sediment, and bankfull width differed greatly across multiple reaches, contrasting the notion that downstream morphology is determined from upstream contributions as is typical in widely studied alluvial rivers. Heitmuller et al. (2014) conducted an extensive study over the Llano River watershed – another Hill Country river with similar lithology to that of the Blanco River – and found that prominent adjustments to the channel pattern occurred with changes in the lithology of the region, and morphology of the Llano mainstem was formed through occasional high magnitude flows, rather than frequent moderate flows. Further, he concluded that valley confinement in cooperation with resistance in bedrock rivers have major influence over features such as longitudinal profile, and channel geometry. This study will provide insight into how the karst lithology of the Hill Country influences channel morphology.

3.3 Flood Response and Mitigation in Hays County

Over 5,000 properties are at risk of being inundated during a 1% flood in Hays County and increases to over 6,000 during a 0.2% flood (Hays County, Texas n.d.). The suddenness of flash floods that the county so often receives leads to residents and businesses unprepared and little time to evacuate or protect their property. Hays County also has a great number of low-water crossings, adding to the dangerous conditions and lag in real-time emergency notifications to residents who may not be actively checking their devices. A statewide survey conducted by the Texas Water Development Board (TWDB) in 2019 with the goal to gain a better understanding of flooding and mitigation throughout the entire state showed an unorganized, outdated, and discombobulated system that left citizens at greater risk due to their lack of understanding of their risks and what type of resources and assistance they might be able to receive to help build their resilience in the wake of a potentially catastrophic flood (Lake 2021). Lake (2021) also goes on to explain the TWDB's targeted plan to improve the current state of flood mitigation through updating floodplain maps, achieving more coordinated planning efforts throughout the state, and providing financial assistance for mitigation projects. More recently in 2021, the Texas Water Development Board announced the Flood Infrastructure Fund, which dedicated over $50 million dollars for grants to improve flood mitigation and warning systems (Texas Water Development Board, 2021). Hays County in particular, appears to have a lack of built flood mitigation infrastructure, aside from small-medium sized dams. Hays County also has a great number of low-water crossings, which creates dangerous conditions for residents. The city of Wimberley, situated on the Blanco River, relied mainly on small, private dams scattered throughout the mainstem of the Blanco as well as its many tributaries. Aside from these dams, a significant line of defense against flooding has been the reliance on riparian vegetation. Riparian vegetation and buffers provide spaces in floodplains to capture and slow down floodwaters (Meitzen et al 2018). Riparian vegetation also plays an important role in riverine ecosystems by filtering out pollutants, creating habitat, and trapping sediments that provide key nutrients for both aquatic and vegetative species (Rowiński et al. 2018).

4. METHODS

All GIS methods were performed in ArcGIS Pro. Calculations and statistics were performed in Microsoft Excel or JMP Pro 15. The flood-frequency analysis was performed in USACE HEC-SSP software.

4.1 Flow Hydraulics of the Memorial Day flood

In order to identify the correlation between unit stream power, initial geomorphic disturbances, and the subsequent adjustments since the Memorial Day flood, I digitized the channel's stream center-line in ArcGIS Pro and then divided it into twelve reaches based loosely on sinuosity of the study area; I acquired the discharge data for the Memorial Day flood for use in the stream power equation ($\Omega = \rho \times g \times Q \times S$), where ρ equals the density of water, g equals the acceleration due to gravity, Q equals a given discharge, and S equals the slope of the water surface, from USGS gage #08171000 located at the Ranch Road 12 bridge leading into Wimberley. To estimate the slope of the water surface of the Memorial Day flood, I obtained A Digital Elevation Model distributed by the USGS via TNRIS. The DEM is from the year 2013, and has a spatial resolution of 10 m. To estimate the slope of the water level at the time of the 100-year flood, I overlayed the FEMA floodplain layers and isolated the 100-year floodplain polygon. To calculate the change in elevation throughout the study area, I placed a cross-section line, beginning and ending on two points of the same elevation, one on each and left banks of the 100-year floodplain, which required some manual adjustments to ensure that both points on each bank were the same elevation value (Figure 3).

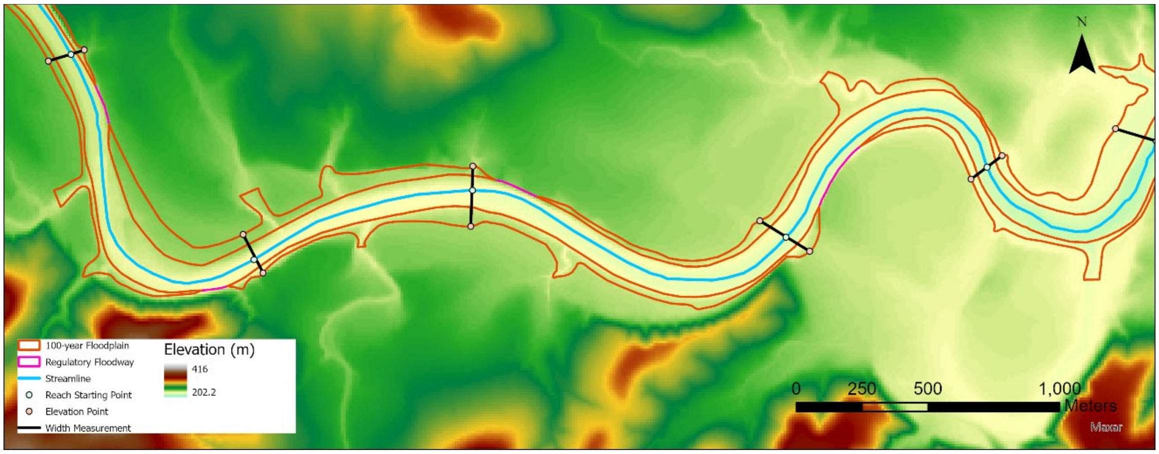

Figure 3: Example of methodology to calculate slope in ArcGIS Pro

I used the Extract Multi Values to Point tool to assign each point an elevation value, and was then able to calculate the slope as the change in water surface elevation divided by the distance from one point to the next using the simple slope equation ($m = \frac{y_2-y_1}{x_2-x_1}$). I calculated the reach slopes and stream powers using Microsoft Excel. After calculating the total stream powers, I standardized the stream power values by the width of the beginning of each reach of the reach to obtain the unit stream powers ($\omega = \Omega \div w$). I attributed the calculated unit stream powers for each reach to their corresponding line segments in the attributes table and then displayed the range of unit stream powers using a color ramp for a better visualization of which reaches experienced higher and lower stream powers.

4.2 Calculating Geomorphic Disturbances

I overlayed the total unit stream power calculations and the geomorphic disturbance layers previously completed by Meitzen et al. (2018) and Phillips (2017) (Table 1) to calculate the total area of disturbance, and the percentages of each type of disturbance for all 12 reaches.

Table 1: Geomorphic disturbance categories, adapted from Meitzen et al. (2018)

Category	Description
Category 0	No disturbance
Category 1	Minor disturbance – Signs of minor scour and deposition of fine sediment.
Category 2	Moderate disturbance – Signs of channel alteration such as changes in width, moderate deposition or scour.
Category 3	Major disturbance – Signs of significant channel alteration such as creation of new channel islands, erosion of previously existing channel features, and channel widening.

I created polygons to separate each reach and clipped the disturbance layers of the reaches to isolate the disturbances that occurred within each reach. The Calculate Geometry tool produced the total area of each disturbance type within each specific reach. As the lengths of the reaches were not uniform, I standardized the disturbance areas of the reaches by reach length. The breakdown of types of disturbance per reach was calculated and displayed in percentages to easily visualize which type of disturbance was the most prominent within the individual reaches.

4.3 Statistics

I ran a bivariate correlation test using the statistical software package JMP Pro 15 between the following pairs:

- Geomorphic disturbance categories (area) and reach stream power (ω)
- Geomorphic disturbance categories (area) and average reach width (channel)

- Geomorphic disturbance categories (area) and average reach width (100-year floodplain)

Results from the correlation test were used to derive Pearson's r and Spearman's Rho values.

I chose to use both the channel and 100-year floodplain to correlate to reach stream power as the Memorial Day flood exceeded the floodplain, but none of the peak flows that occurred since the Memorial Day flood have exceeded the 100-year floodplain. To calculate the average reach width at both the channel and 100-year floodplain, I generated points along the stream centerline at every 100 meters and used the line tool to create measurements of the width. The official FEMA floodplain layers were used to measure the width at the 100-year floodplain levels.

4.4 Analysis of Aerial Imagery

I obtained aerial images from the years 2016 – 2021 from the Texas Natural Resources Information System (TNRIS). The 2016 imagery was captured as part of the National Agricultural Imagery Program (NAIP) run by the United States Department of Agriculture. The NAIP imagery has a 1-meter pixel resolution and is available in RGB bands (natural color). I used imagery for the years 2018 and 2021 from the Strategic Mapping Program (StratMap), a program executed by TNRIS which collects aerial imagery of various regions in the state of Texas in January of every year and is available for free download and use through the TNRIS DataHub. The StratMap imagery is also available in RGB bands and have a pixel resolution of 0.15-meters (2018) and 0.3-meters (2021).

The differences in resolution between the years were cumbersome to work through but did not create major limitations. The biggest challenge was that the NAIP imagery was captured during leaf on conditions (which is necessary for its agricultural purposes), while the StratMap imagery was captured during leaf off conditions, making the latter easier to see the ground surface and stream banks. Despite these differences in the quality of images and seasonality, I still chose to use the different sources of aerial imagery as there was no StratMap imagery available for the year 2016. I wanted to ensure that the imagery used for the years 2018 and 2021 displayed the ideal conditions for the aerial analysis. I stitched together the individual imagery quads using ERDAS Imagine software and ensured they were all in the same coordinate and projection system (NAD 1983 and NAD 1983 UTM Zone 14N) and displayed the same units of measurement. I then brought the stitched imagery into my project where I used the Create Feature Class tool to create points for the different types of geomorphic change (Table 2) I would be identifying. Rather than identifying incremental changes from between the years 2016 to 2018 and 2018 to 2021, I identified total change from 2016 to 2021. I used the 2018 imagery to look for consistent changes, for example, if a very prominent deposition of sediment that was identified in 2021 imagery, was also evident in 2018 as well. I mainly wanted to use the Memorial Day flood as a starting point to my analysis as it was a very rare flood to have occurred, and was interested in seeing if changes could possibly be attributed to its peak stream flow.

Table 2: Categories of geomorphic changes

Category	Description
Category A	**Deposition of Sediment along channel margin** - Observations of new deposits of fine or course sediment, or aggradation of previously existing deposits, along the channel margin, possibly forming new point bars.
Category B	**Deposition of Sediment within channel -** Observations of new deposits of fine or course sediment, or aggradation of previously existing deposits, within the channel. Possibly creating new formations such as bedrock bars and islands.
Category C	**Erosion along the channel margin** - Observations of previously existing formations or areas of deposition along the channel margin that have eroded since 2015.
Category D	**Erosion within the channel** - Observations of previously existing in-channel formations or areas of deposition within the channel that have eroded since 2015.
Category E	**Change in channel width -** widening or narrowing of an area of the channel

I identified these changes by scanning through the layers of imagery and focusing on one reach at a time to identify any observable changes from the five categories. I indicated the type of change with a point, and a measurement for any width changes. I calculated the total amount of changes that occurred within the individual reaches and plotted each category of change on a scatter plot with number of disturbances on the x-axis, and stream power displayed as a line, to observe any patterns of the amount of disturbances in relation to the fluctuating stream power.

4.5 Flood-frequency analysis

I obtained the period of record of flow data from USGS gage #08171000 to perform a Bulletin 17 flood-frequency analysis and calculated the return periods of different flow magnitudes (Table 3, Figure 4). The flood-frequency analysis was based off 94 flood events beginning in 1925 and 1926, however there is a gap in data until 1929. The data becomes continuous after 1929.

Table 3: Computed flows and their corresponding percent chance exceedance from flood-frequency analysis

Computed Flow ()	**Percent Chance Exceedance**
6,766.21	0.2
5,318.55	0.5
4,281.95	1.0
3,313.65	2.0
2,166.18	5.0
1,423.03	10.0
808.65	20.0
227.67	50.0
48.41	80.0
18.63	90.0
7.46	95.0

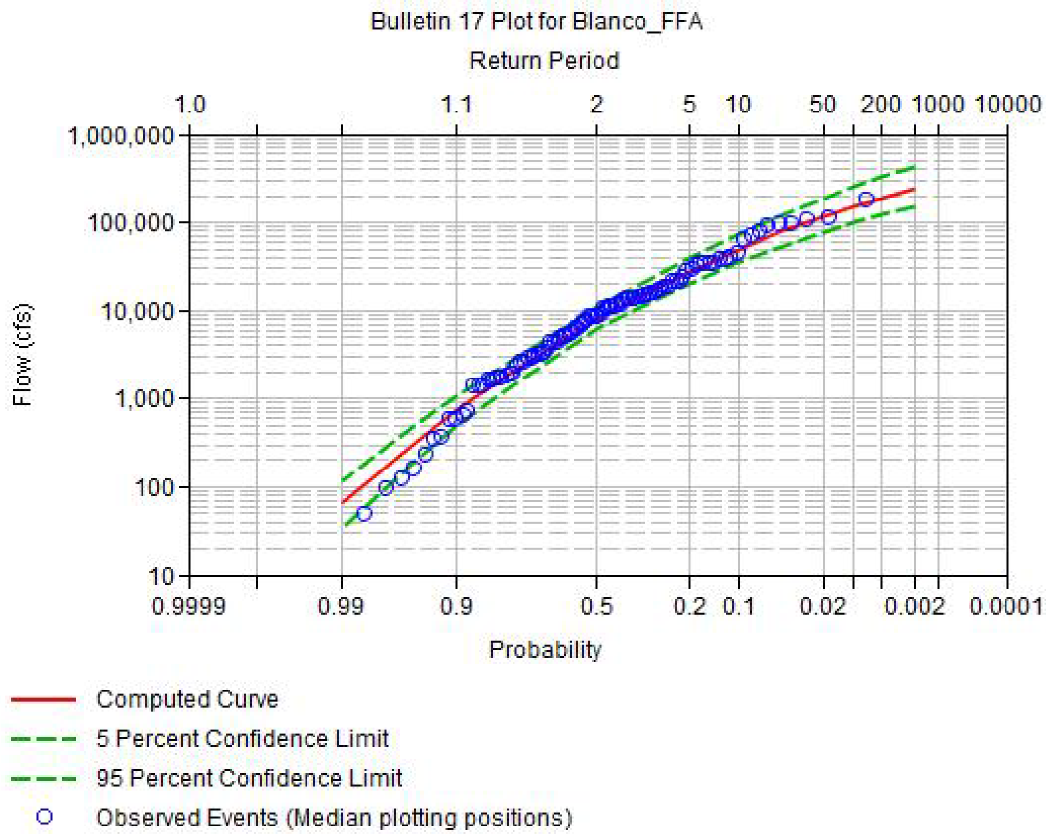

Figure 4: Flood-frequency analysis computed curve from HEC-SSP software

Using the computed report from the flood-frequency analysis, I then found the peak flows for the years 2016 – 2021, their rank amongst all annual peak flows and their annual percent chance probability of recurrence.

5. RESULTS

5.1 Stream Power Calculations

The three reaches that experienced the highest unit stream powers were reaches 10 (1139.7 watts/meter), 6 (972.6 watts/meter), and 11 (9223 watts/meter) (Table 4 and Figure 5). The three reaches that experienced the lowest unit stream powers were reaches 3 (302.5 watts/meter), 8 (307.1 watts/meter), and 12 (327.4 watts/meter).

Table 4: Computed reach stream powers

Reach #	Reach Stream Power (watts/meter)
1	371.5
2	852.8
3	302.5
4	352.6
5	688.6
6	972.6
7	522.1
8	307.1
9	502.3
10	1139.7
11	922.3
12	327.4

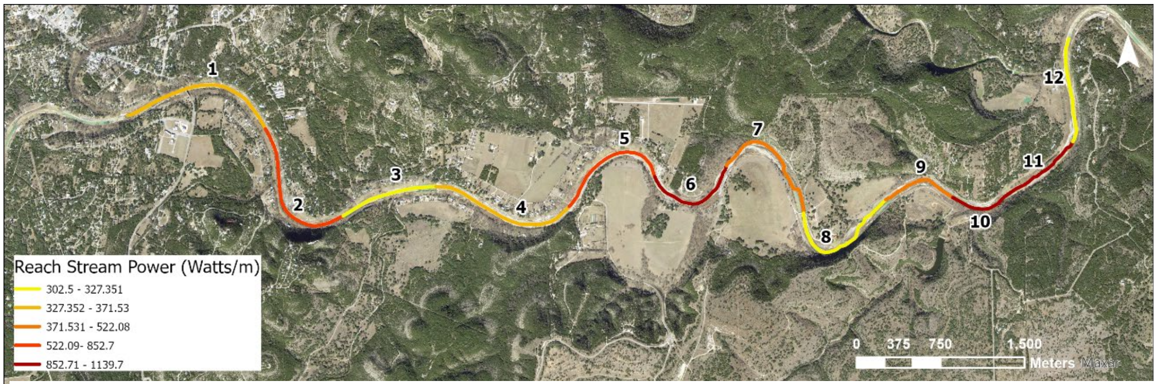

Figure 5: Map of reach stream powers using colors for scale

5.2 Geomorphic Disturbances

There was substantial variability among stream power and disturbance totals (Table 5, Figure 6). The reaches that experienced the most severe geomorphic disturbances (category 3) relative to the total disturbance area were reaches 7, 8, and 9. These reaches follow immediately after the reach that experienced the second highest stream power. As evident in Figure 5 below, there appears to be a pattern emerging of clusters of greater amounts of geomorphic disturbances in their entirety in reaches in close proximity to high stream powers rather than the direct reaches themselves. The reaches that experienced the lowest amount of category 3 disturbances were reaches 2, 3, and 11. Category 1 disturbance was the majority type in four reaches, categories 2 and 3 were the majority in three reaches, and finally category 0 was the majority type for two reaches.

Table 5: Breakdown of disturbance areas by category with corresponding reach steam power

Reach #	Cat 0 (m^2)	Cat 1 (m^2)	Cat 2 (m^2)	Cat 3 (m^2)	Reach Stream Power (watts/meter)
1	59.8	39.7	29.9	32.7	371.53
2	51.4	69.7	52.1	22.1	852.77
3	64.5	67.3	40.5	24.4	302.50
4	60.8	29.9	55.7	29.9	352.60
5	58.4	7.3	82.5	110.0	688.62
6	51.4	48.1	109.3	47.2	972.59
7	36.8	80.8	52.7	104.7	522.08
8	38.8	16.4	49.3	53.3	307.12
9	50.2	50.2	12.5	67.4	502.31
10	71.5	75.8	12.6	24.7	1139.70
11	33.7	64.4	72.6	18.2	922.34
12	40.7	62.5	59.2	23.3	327.35

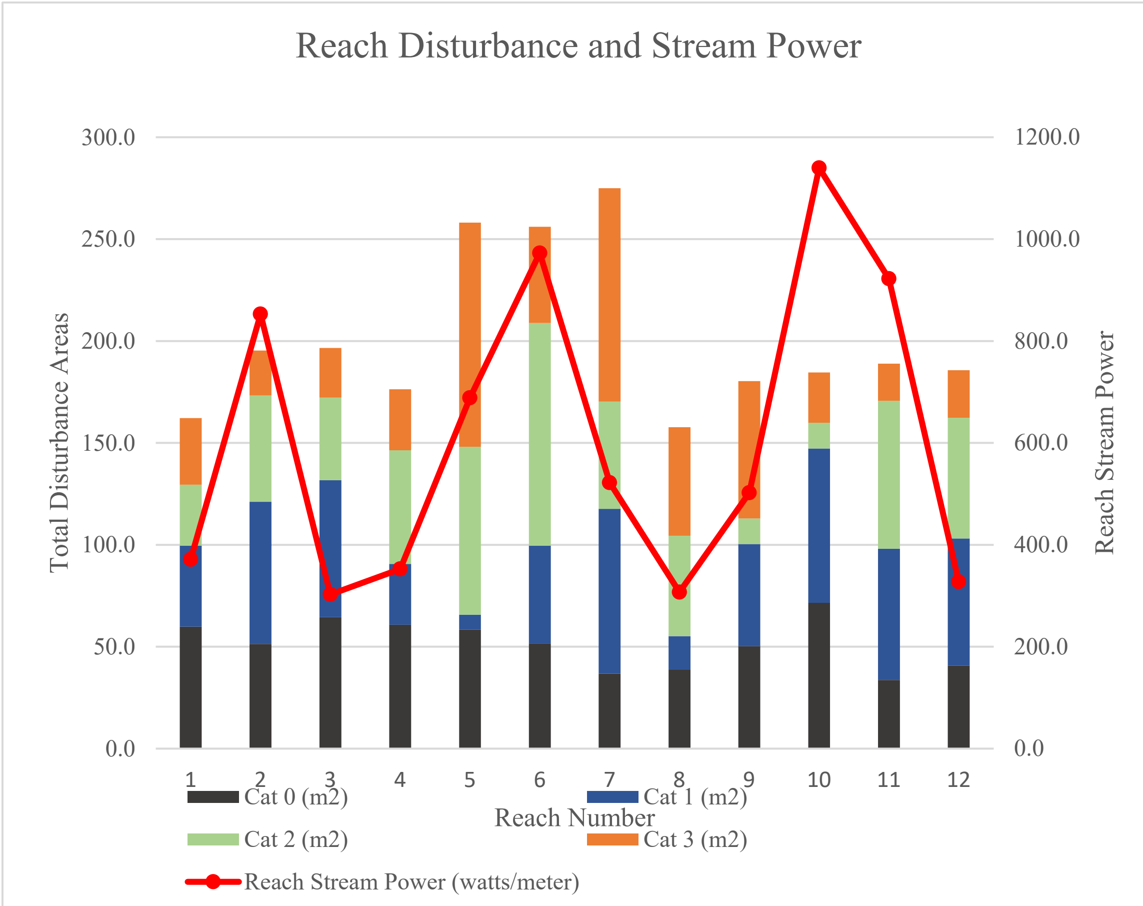

Figure 6: Graphical display of disturbance areas per reach and their corresponding stream powers

5.3 Statistics

The Spearman's Rho (ρ) and Pearson's R (r) tests were utilized to look for potential correlation between several pairs (Table 6).

Table 6: Results from Pearson's and Spearman's tests with their corresponding p-values. Asterisk denotes the most significant statistical relationship.

Disturbance Category		Reach Stream Power	Average Reach Width (channel)	Average Channel Width (100-year floodplain)
Pearson's R				
Category 0	r value	0.1387	0.1612	-0.1634
	p value	0.6671	0.6166	0.6118
Category 1	r value	0.3247	-0.5701	0.2639
	p value	0.3031	0.0529*	0.4072
Category 2	r value	0.2153	0.1848	0.3421
	p value	0.5015	0.5652	0.2763
Category 3	r value	-0.0910	0.2229	-0.3776
	p value	0.7785	0.4863	0.2263
Spearman's ρ				
Category 0	ρ value	-0.0070	0.4799	-0.0911
	p value	0.9828	0.1144	0.7783
Category 1	ρ value	0.3077	-0.3636	0.1748
	p value	0.3306	0.2453	0.5868
Category 2	ρ value	0.2378	0.0559	0.3147
	p value	0.4568	0.8629	0.3191
Category 3	ρ value	-0.0559	0.2238	-0.3916
	p value	0.8629	0.4845	0.2081

Though there are some moderate correlations between the sets of data, all but one show no statistical significance. Reach stream power and category 0 disturbance (no disturbance) have no correlation (ρ = -0.0070) but have a weak positive linear relationship (r = 0.1387). Reach stream power and occurrence of category 1 and 2 disturbance both showed a weak positive correlation, with ρ values of 0.3077 and 0.2378 respectively. They also have weak positive linear relationships ($r = 0.3247$ and $r = 0.2153$). Additionally, a very weak negative correlation exists between reach stream power and category 3 disturbances with no statistical significance ($\rho = -0.0559$ and $r = -0.0910$).

Average reach width (channel) and occurrence of geomorphic disturbance type all had a tangible relationship. Average reach width (channel) and category 0 have a positive correlation ($\rho = 0.4799$ and $r = 0.1612$). Average reach width (channel) and category 1 disturbance have a negative correlation ($\rho = -0.3636$ and $r = -0.5701$). Average reach width (channel) and category 1 also had the greatest statistical significance ($p = 0.0529$). Average reach width (channel) and categories 2 have weak positive correlations ($\rho = 0.0559$ and $r = 0.1855$). And finally, average reach width (channel) and category 3 have weak positive correlations ($\rho = 0.2229$ and $r = 0.2234$).

Average reach width (100-year floodplain) and occurrence of category 0 have a very weak negative correlation ($\rho = -0.0911$ and $r = -0.1634$). Average reach width (100-year floodplain) and category 1 have a weak positive correlation ($\rho = 0.1748$ and $r = 0.2639$). Average reach width (100-year floodplain) and category 2 have a slightly positive correlation ($\rho = 0.3147$ and $r = 0.3421$). While on the other hand, average reach width (100-year floodplain) and category 3 disturbance have a slightly negative correlation ($\rho = -0.3916$ and $r = -0.3776$).

5.4 Analyses of Aerial Imagery

From an aerial view, the changes that were easily observable included Categories A and B (deposition of sediment along the channel margin, and deposition of sediment within the channel). Table 7 shows a breakdown of the total amount of observations made for each category.

Table 7: Number of observations per geomorphic change category. A further breakdown of subcategories for category E below.

Category	# Of Observations
A	40
B	52
C	13
D	4
E	30
Total	139
Category	**# Of Observations**
E (widening)	20
E (narrowing)	10

In total, there were 40 observations of deposition along the channel margin, and 52 observations of deposition within the channel. The largest cluster of deposition along the channel margin occurred within reach 12, with 8 observations in total. Reaches 7 had the most observations of deposition within channel, 15 in total. Observations of categories C and D (erosion along the channel margin and within the channel) were more difficult to observe, with only 13 observations along the channel margin and 4 within the channel. Width was easy to observe in conjunction with some instances of deposition and erosion, widening where erosion has occurred and narrowing at sites of deposition.

5.5 Flood-frequency analysis

The flood-frequency analysis was included to determine if the peak flows that occurred since the 2015 Memorial Day flood were effective for triggering geomorphic changes. The greatest peak flow that has occurred since the 2015 Memorial Day flood occurred in the water year 2016 (calendar year 2015, aka the 2015 Halloween Floods) where the gage captured a peak flow of 2,010 m^3s^{-1} and is currently ranked the 8th highest stream flow captured by the gage. This flow falls at the 8% chance exceedance flood and is significantly less severe than the magnitude of the 2015 Memorial Day flood. The remaining annual peak flows all fall within the types of flows that have a 30 – 80% chance of exceedance (Table 8).

Table 8: Annual peak flows since 2016, their ranks, and specific recurrence intervals

Year	**Annual Peak Flow (m^3s^{-1})**	**Ranked Flood**	**Percent Probability of Recurrence**
2016	2,010	8	7.9
2017	106	65	67.12
2018	73	73	75.41
2019	450	29	29.77
2020	124	62	64.0
2021	20	85	87.86

6. DISCUSSION

The goal of this study was to determine if stream power can be related to the severity and number of geomorphic disturbances that occur after a flood event. Stream power indicates a particular flow's ability to transport water and sediment, and thus a flood of record, such as the Memorial Day flood, has the potential to produce observable geomorphic changes that may persist for years after the event. In particular, I was interested in exploring the debate surrounding the geomorphic effectiveness of high magnitude, low frequency floods as compared to higher frequency, low magnitude flows. I wanted to take a local scale approach to answer my research questions, as Jerin (2021) suggested that bedrock rivers are best understood at smaller scale.

6.1 Initial Geomorphic Disturbances and Stream Power

There is no obvious or statistical pattern showing that reaches that experienced a higher stream power also experienced more severe geomorphic disturbances. For example, reach 10 experienced the greatest stream power out of all of the study reaches, and yet the majority disturbance types that initially occurred within the reach itself was no disturbance and minor disturbance (Figure 7).

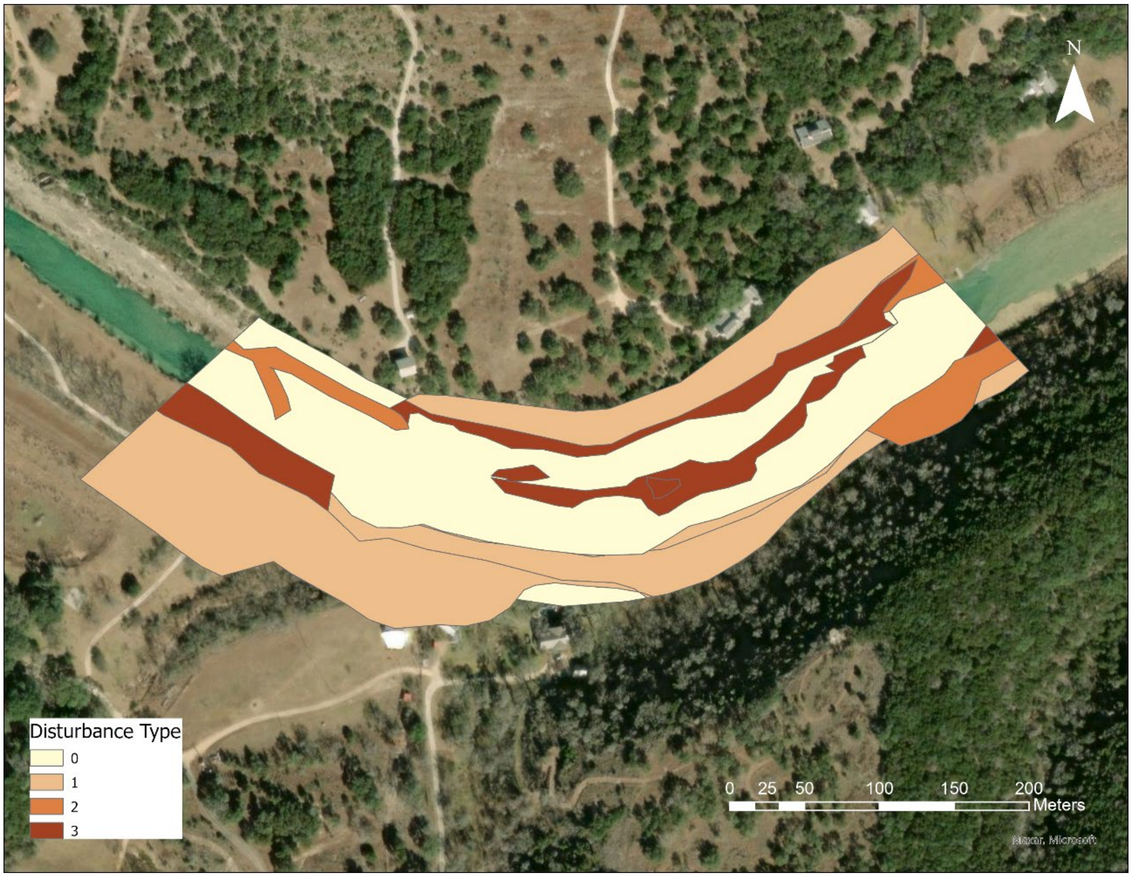

Figure 7: Initial geomorphic disturbance of reach 10

A relationship between stream power and disturbance was very difficult to detect for reaches that experienced lower stream powers. Reach 3 experienced the lowest stream power out of all of the reaches and the majority of disturbance types to have initially occurred were no disturbance and minor disturbance. The reach that experienced the second lowest stream power was reach 8, and the greatest disturbance type was category 3 (figure 8), or major initial geomorphic disturbances.

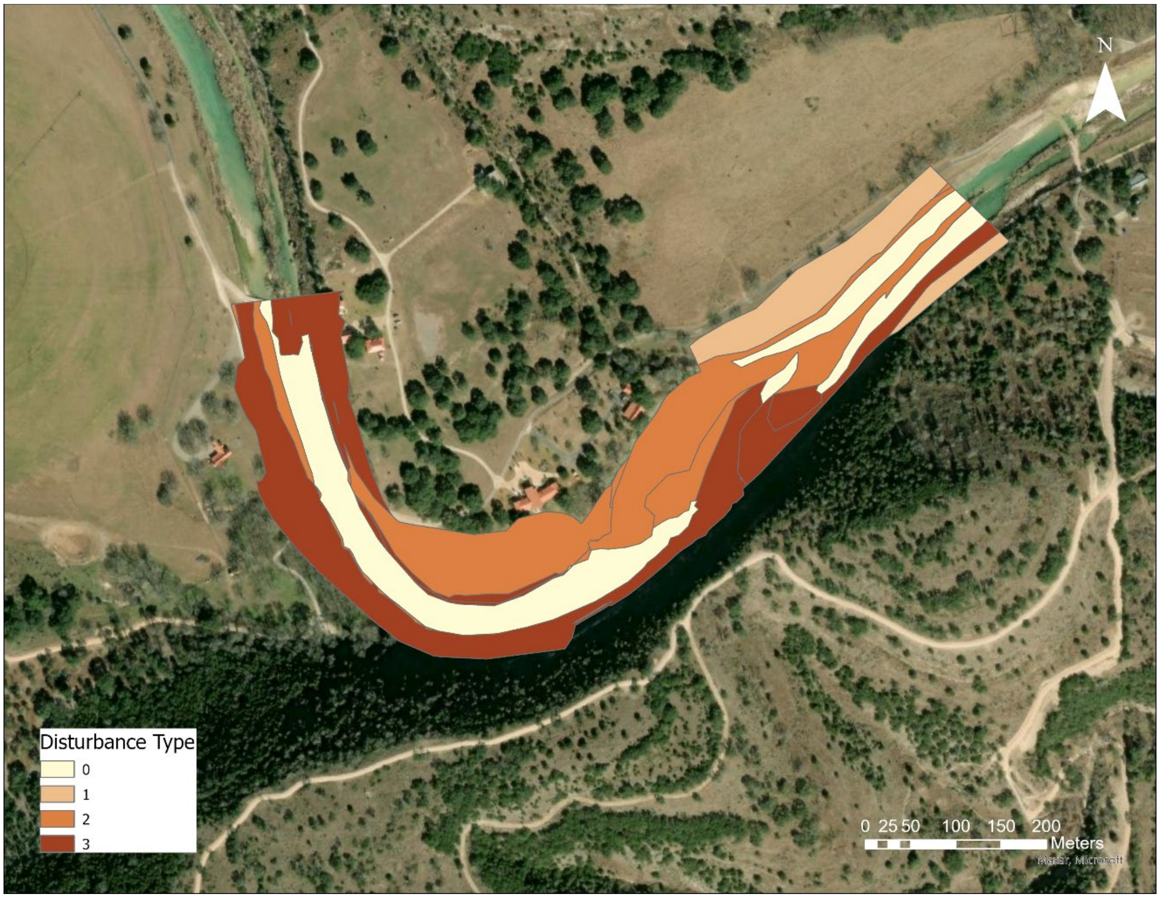

Figure 8: Initial geomorphic disturbance of reach 8

Other reaches confirming that stream power has some influence over the type and amount of geomorphic disturbances that occur within the reaches themselves are reach 5 (moderately-high stream power and greater initial amount of major disturbance), and reach 1 (low stream power and greater initial amount of no to minor disturbances) (figures 9 and 10, respectively).

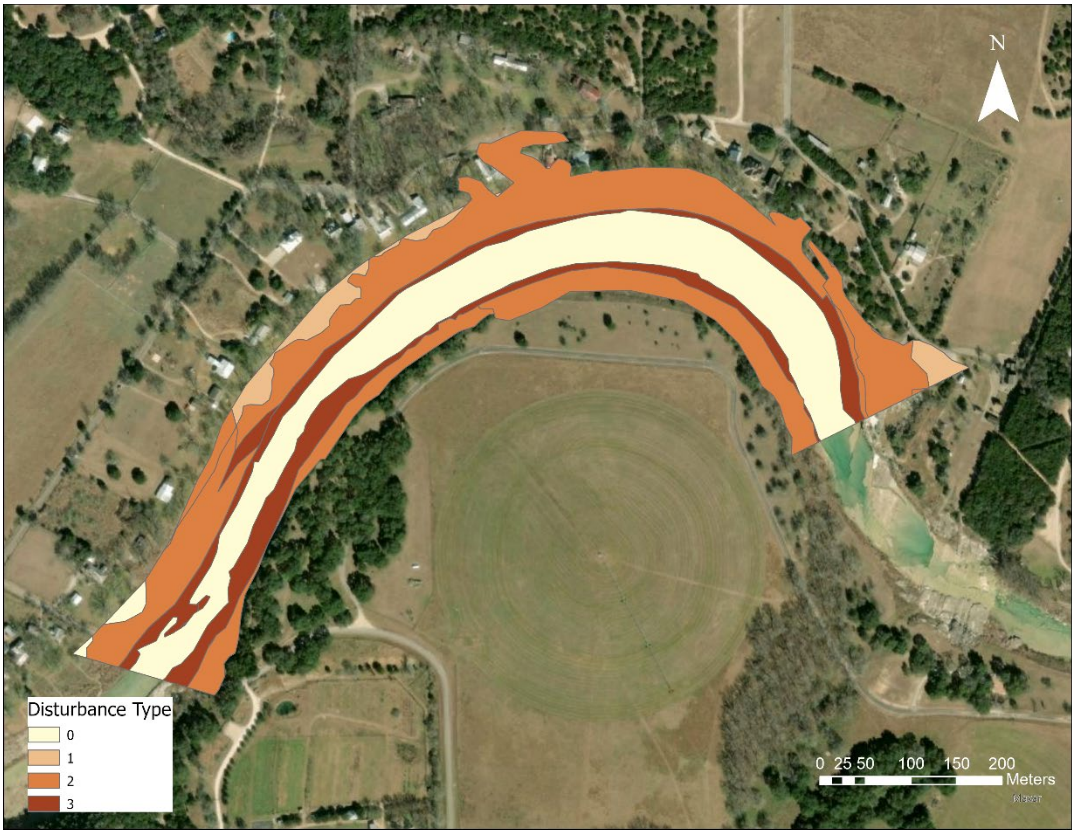

Figure 9: Initial geomorphic disturbance of reach 5

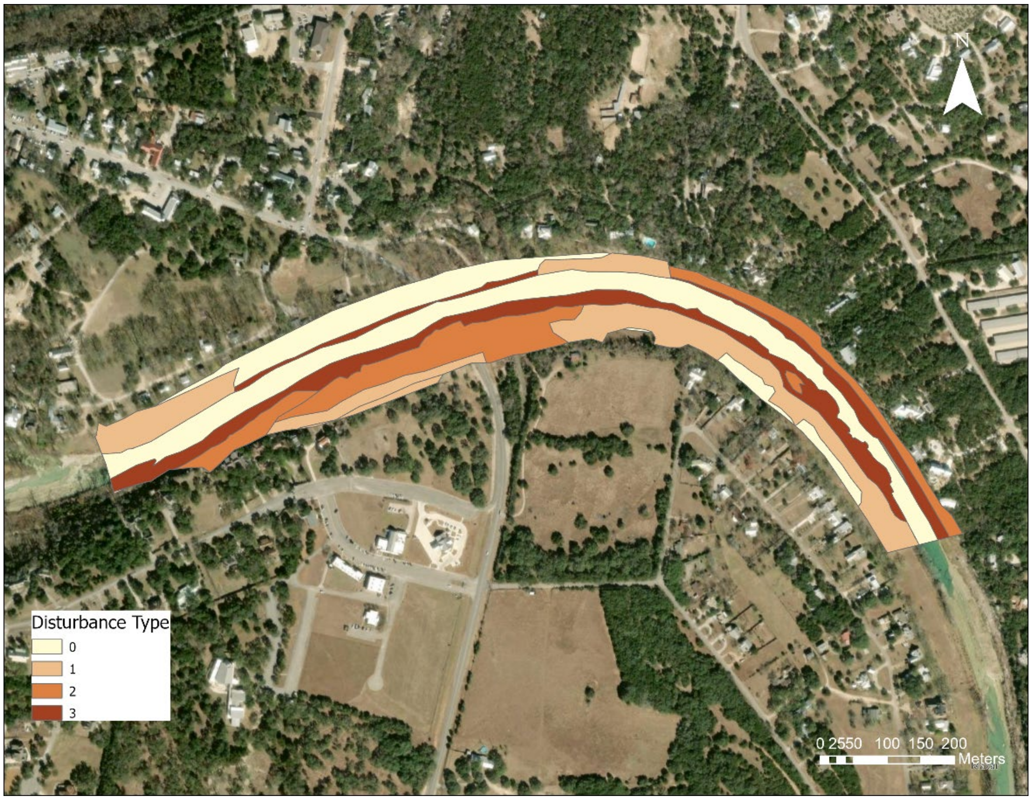

Figure 10: Initial geomorphic disturbance of reach 1

Even though there was no distinct pattern of higher stream powers leading to greater amounts of major disturbance, there are several instances where the combined amounts of mild and moderate disturbances made up the majority of disturbance areas within the reaches. In reaches 2, 6, and 11, the combined totals of mild and moderate disturbances make up more than 50% of the total disturbance areas, which to a degree can confirm my hypothesis that some reaches that experienced a greater stream power also experienced a greater total amount of geomorphic disturbances (Table 9).

Table 9: Breakdown of initial geomorphic disturbance areas per reach, by percentage. The asterisk denotes the majority disturbance category per reach.

Reach #	% Cat 0	% Cat 1	% Cat 2	% Cat 3
1	37%*	25%	18%	20%
2	26%	36%*	27%	11%
3	33%	34%*	21%	12%
4	34%*	17%	32%	17%
5	33%	4%	47%*	16%
6	20%	19%	43%*	18%
7	13%	29%	19%	38%*
8	25%	10%	31%*	34%
9	28%	28%	7%	37%*
10	39%	41%*	7%	13%
11	18%	34%	38%*	10%
12	22%	34%*	32%	13%

Several factors could have contributed to the lack of clear patterns between reach stream power and initial geomorphic disturbance. For one, the reach lengths were not the same and were created with subjectivity, however I attempted to mitigate the potential impacts of this by standardizing the total areas by the individual reach lengths. I chose the natural meanders as the reach starting and end points as they were easily identifiable in my analysis and could possibly provide insight on how sinuosity of a river can also impact stream power and geomorphic disturbances. Had I chosen different starting and end point of the reaches, they could have produced vastly different results. An interesting aspect that could be studied in future research would be the differences in stream power and geomorphic disturbances in reaches with higher and lower sinuosity.

There appears to be somewhat of a pattern of intensification of geomorphic disturbances downstream of reaches that experienced the highest unit stream powers (reaches 2, 6, 10, and 11), rather than impacting the reaches experiencing that amount of energy directly. This suggests that the impacts of higher stream powers are not specifically confined within the reaches themselves, and also creates change within reaches downstream.

6.2 Correlation between pairs

I expected to find positive correlations between reach stream power and disturbance types, however the Spearman's Rho and Pearson's R tests showed weak correlations. Of all the stream power and disturbance type pairings, the one that showed the greatest relationships was reach stream power and category 1 disturbance ($r = 0.3247$, $\rho = 0.3077$), meaning that as stream power increases as does the occurrence of category 1 disturbance (Figure 11). However, there is no statistical significance in the correlation.

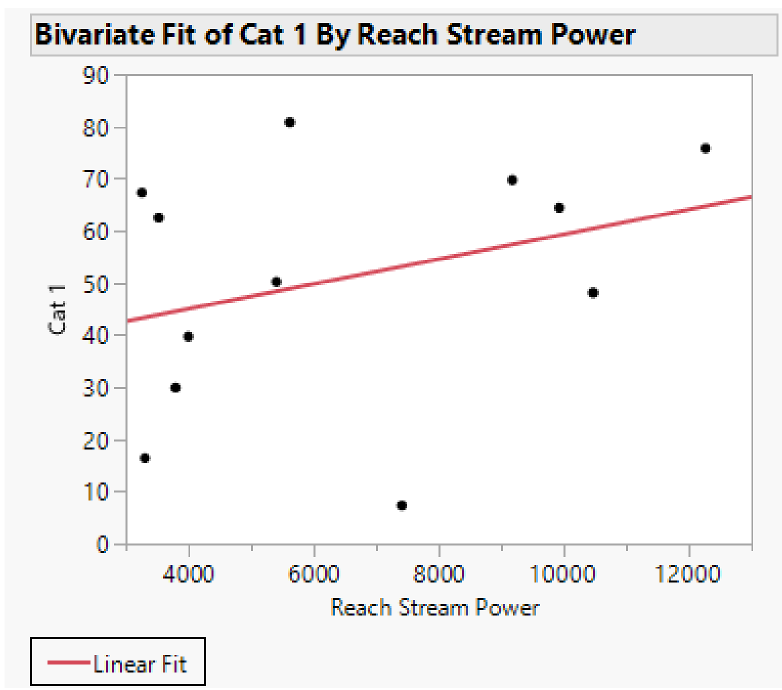

Figure 11: Scatterplot and fit line from correlation of Category 1 disturbance to Reach Stream Power

This might be the case as category 1 is the most minor type of disturbance and did not create any significant changes to the landscape, and minor scour and deposition does not require a large amount of energy to initiate. The relationship between stream power and category 2 disturbances was also a weakly positive relationship. Another intriguing result came from the reach stream power and category 3 disturbance pairing ($r = -0.0910$, $\rho = -0.0559$). The pair had a very weak negative correlation, meaning there is practically no relationship between a reach's unit stream power and the amount of major geomorphic disturbance it experienced due to the Memorial Day flood. I had initially expected this relationship to possibly have a stronger positive correlation with the idea that greater stream power has a greater capacity for initiating sediment transport throughout the river.

As unit stream power is standardized by width of a specific point along a river and allows for comparison between reaches within the same river, I expected to find statistically significant relationships between average reach channel width and geomorphic disturbances. Unit stream power decreases as the width input increases, meaning the amount of energy expended by a certain flow is spread out across a greater area. With that, I assumed that category 1 disturbance would be correlated to average reach width as the types of disturbances that occurred within category 1 did not require a significant amount of energy to initiate compared to the categories 2 and 3. Indeed, average reach width (channel) and disturbance category 1 had the most statistically significant relationship out of all pairs in total. However, it was a moderately strong negative linear relationship ($r = -0.5701$), meaning that as channel width increases, the amount of type 1 disturbance should likely decrease in tandem (Figure 12). This is the strongest correlation of any of the pairs that were tested, and also showed the greatest statistical significance. I assumed that the correlation would be positive and would see that as average channel width increased, the total amount of type 1 disturbance would as well. Average width (channel) and category 0 showed the greatest relationship of all of the Spearman's tests (ρ = 0.4799).

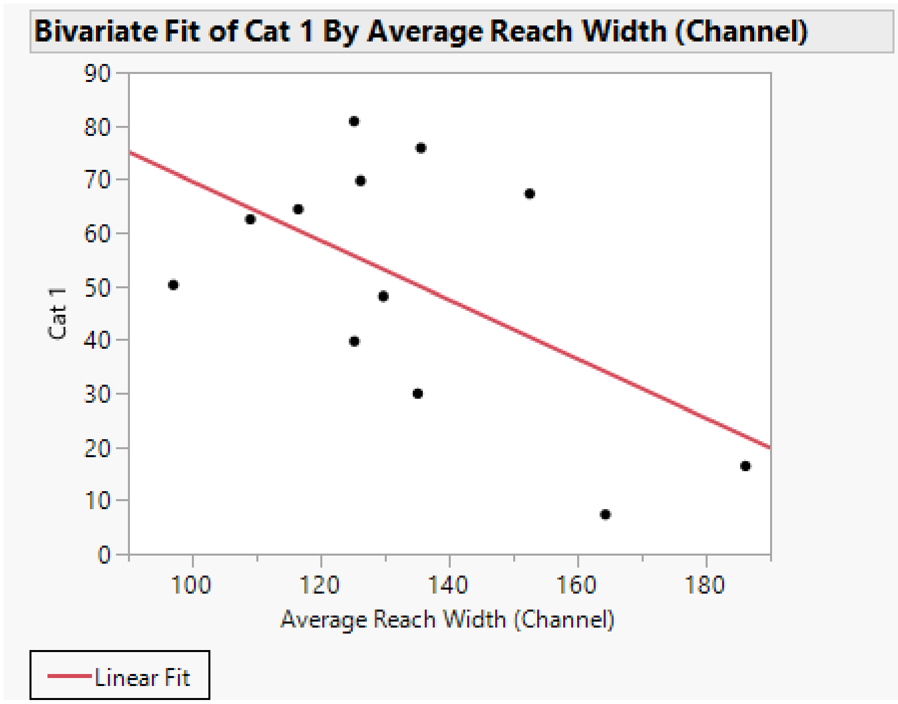

Figure 12: Scatterplot and fit line from correlation of Category 1 disturbance to Average Reach Width (channel)

The initial geomorphic disturbance caused by the Memorial Day flood also extended out into the 100-year floodplain. Because of this, I also expected there to be relationships between average 100-year floodplain width and the different types of disturbances. Specifically, I expected there to be correlation with category 1 disturbance and average width (100-year floodplain). This did not turn out to hold true, as the tests produced weak positive results. However, there was also a weak positive relationship between average 100-year floodplain width and category 2 disturbance, and a weak negative relationship between average floodplain width and category 3 disturbance.

None of these results however, proved strong enough to allow me to confidently say that the correlations between any of the pairs are truly indicative of one another. As there was no indication of a strong relationship, further confirmed by the large probability statistics, between any of the tested pairs, this enhances the findings from section 6.1, that there are no obvious patterns of geomorphic disturbance in relation to reach stream power or channel and 100-year floodplain width. This stays consistent with studies in bedrock rivers and how they are difficult to estimate their dynamics and how they might respond to floods as discussed in Conyers and Fonstad (2005), Baker (1977) and Tinkler (1971). One shortcoming of this method, involved the very small number of reaches, this could be further refined by creating more reaches extending further downstream and upstream.

6.3 Geomorphic Changes Since 2015

The types of geomorphic changes that have occurred within the study area's channel were mapped by hand, and only using visible observations. This introduced human error, as I only mapped changes that were obvious. Because of this, the main types of changes that were observable were depositions of sediment within the channel and along the channel. These observations mainly included the creation of new point bars, and in-channel islands that were consistent with the findings from the initial study of the Blanco River conducted by Phillips (2017) and Meitzen et al. (2018). An example of this occurred in an area where there was deposition of sediment along and within the channel in reach 7 which persisted through 2016, but became a bedrock channel by 2021 (Figure 13), indicating flows of lower magnitude since 2015 and 2016 are important for sediment flushing. Reach 7 experienced a moderate unit stream power but is directly downstream of reach 6 (the second highest unit stream power).

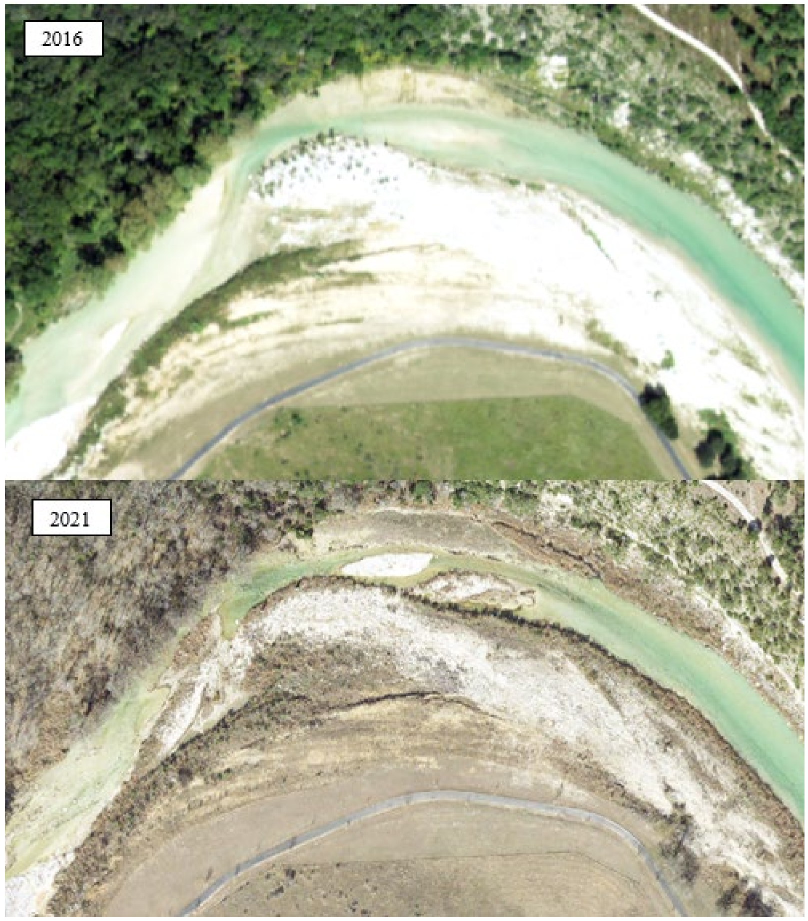

Figure 13: Example of deposition of sediment in reach 7

As the Memorial Day flood also impacted both of the 100 and 500-year floodplains through stripping (Meitzen et al. 2018, Phillips 2017), it can be inferred that there may have been an influx of sediment from these floodplains that washed into the river during the event.

While the StratMap imagery was higher resolution than the NAIP imagery, it was still difficult to discern whether the depositions were composed of fine sediment or more coarse rocks and gravel. Instances of erosion were farther and few between. The area between Reach 4 (upstream of the road) and reach 3 (downstream of the road) contains active erosion on the right bank upstream of the low water crossing that has continued to erode as evidence by the 2021 imagery (Figure 14). This instance also offers an interesting insight on the impacts of anthropogenic features such as roads and dams have on sediment. After the low water crossing was re-built, there is noticeable channel narrowing and aggradation upstream of the road on river left in reach 3.

Figure 14: Example of erosion and channel narrowing in reaches 3 and 4, reach 3 is to the left of the low water crossing (upstream) and reach 4 to the right (downstream)

The lack of observations of erosion can be contributed to the quality of the aerial imagery or could lend to the fact that bedrock rivers are not as susceptible to major erosion after flood events like an alluvial river might. This falls in line with Costa and Connor (1995).

The majority of observations of deposition of sediment did not occur within in reaches that experienced high stream powers, rather they occurred in reaches downstream of those reaches (table 10). Reach 10, only contained 1 observation of geomorphic changes in total, whereas the subsequent reaches contained several more observations. Figures 15 - 19 show a breakdown of the number of observations per category, per reach, in relation to the reach's unit stream power.

Table 10: Observations of geomorphic disturbances per reach

Reach #	Cat A	Cat B	Cat C	Cat D	Cat E (narrowing)	Cat E (widening)	Total # of Observations
1	6	3	2	0	2	2	15
2	3	0	0	0	2	0	5
3	0	0	4	0	0	4	8
4	5	4	1	0	6	0	16
5	2	5	1	0	0	0	8
6	1	2	1	1	0	1	6
7	4	15	0	1	3	1	24
8	2	8	2	0	2	0	14
9	5	1	0	0	2	0	8
10	1	0	0	0	0	0	1
11	3	3	0	2	0	0	8
12	8	11	2	0	3	2	26
TOTAL	40	52	13	4	20	10	

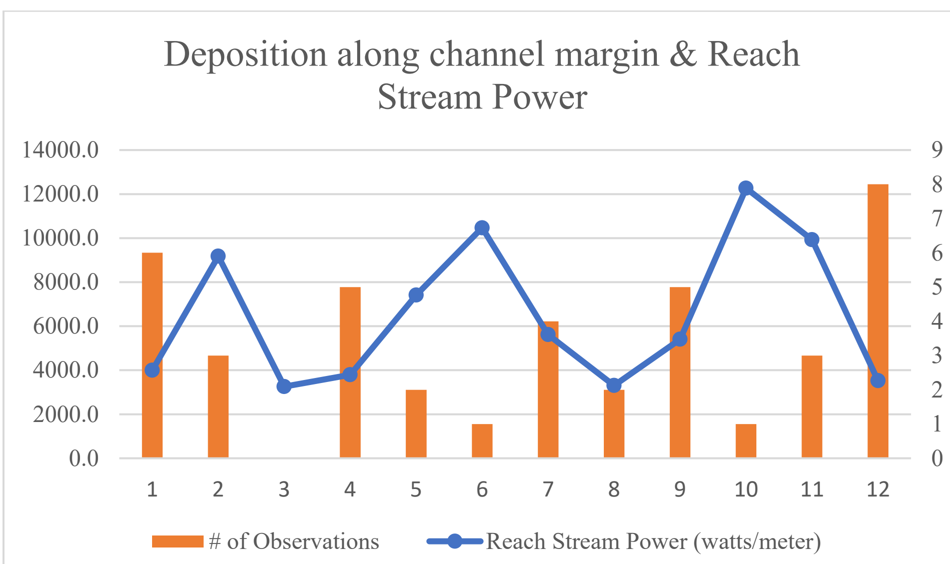

Figure 15: # of observations of deposition along the channel margin per reach with corresponding reach stream power

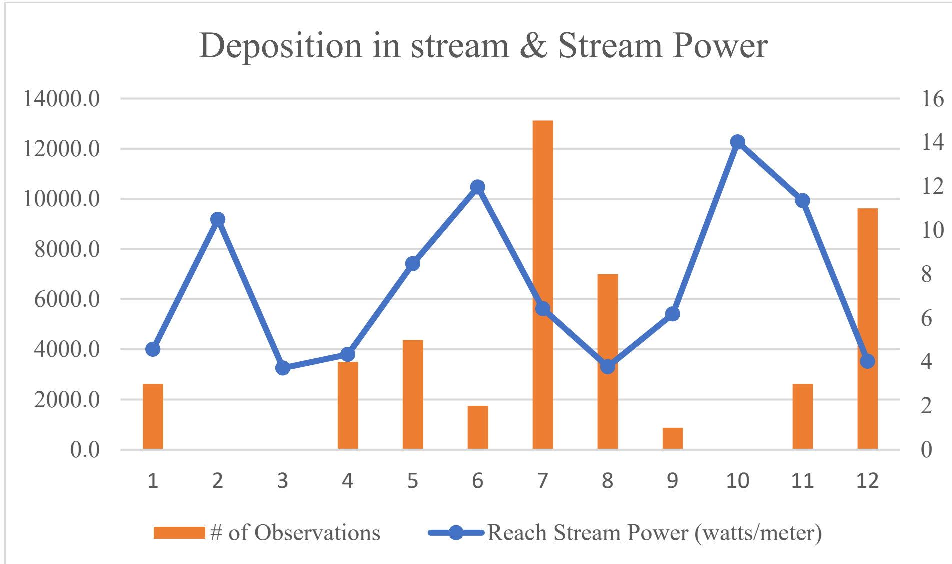

Figure 16: # of observations of deposition within the channel per reach with corresponding reach stream power

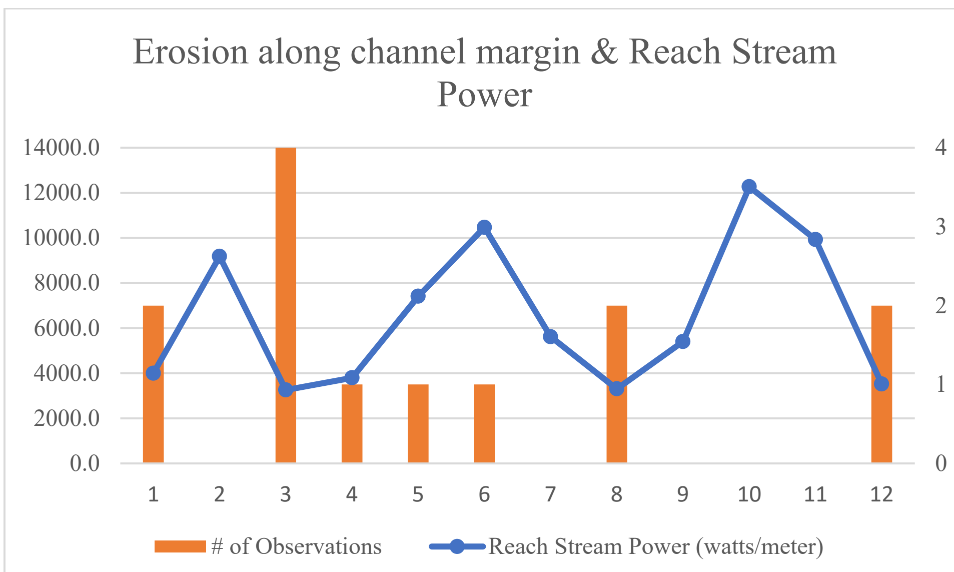

Figure 17: # of observations of erosion along the channel margin per reach with corresponding reach stream power

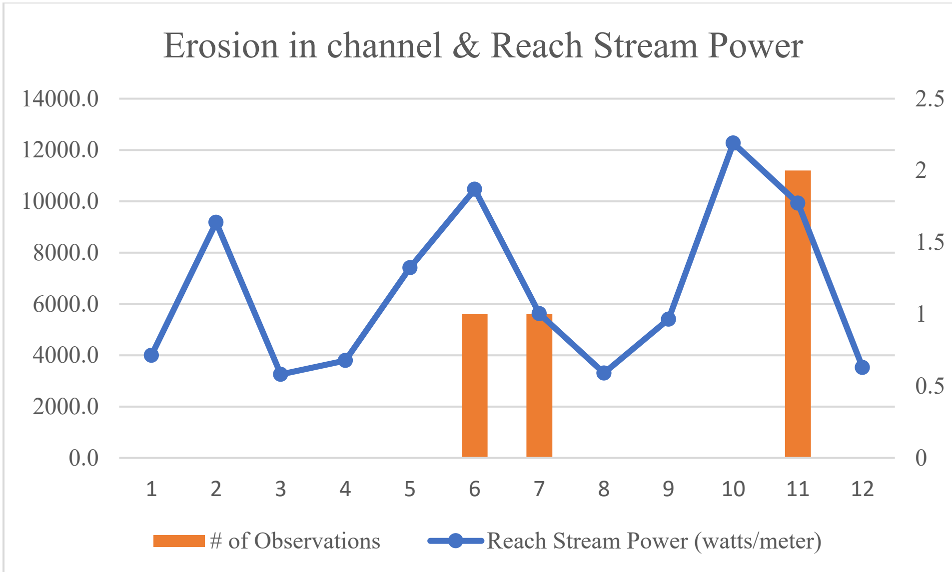

Figure 18: # of observations of erosion within the channel per with corresponding reach stream power

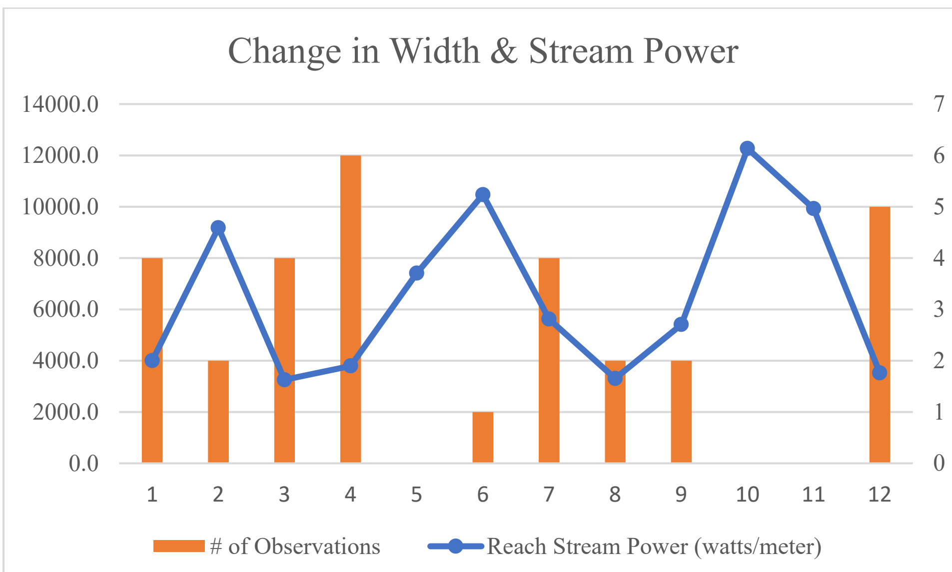

Figure 19: # of observations of change in width per reach with corresponding reach stream power

The amount of observed sediment deposition was expected as it can be expected that the sediment deposited in the downstream reaches was transported from upstream reaches that experienced greater stream power.

Most, if not all, observations of changes in width were in conjunction with erosion and deposition along the channel margin. However, I did not take a width measurement at every instance of deposition and erosion. Some of the deposition observations that I marked existed in both the 2016 and 2021 imagery, as the depositions were observed to become more established and did not necessarily reflect a change in the width between the years.

This portion proved to be the most limiting of all the analysis, but still produced tangible and meaningful results. These methods could be improved by purchasing higher quality aerial imagery all from the same source, and then also conducting a field reconnaissance portion to take width and slope measurements, sediment samples, and site visits to confirm observations from the aerial imagery would greatly benefit this study. This portion could also be improved by taking a comparative approach to identify changes, specifically changes in the years 2016-2018, and then 2018-2021. As a high magnitude flood occurred soon after the Memorial Day flood, this would possibly capture the changes that could have occurred due to two major flood events in one year and then the subsequent years that experienced more "typical" flows.

6.4 Peak flows since 2015 and their ability to initiate geomorphic change

The goal of conducting a flood frequency analysis in this context was to determine if the peak flows that have occurred in the years following 2015 may be attributed to the observable geomorphic changes rather than the peak flow of the Memorial Day flood. As a majority of geomorphic changes observed in section 6.3 above were new depositions of sediment, this looks to be case.

Just 5 months after the Memorial Day flood devastated the Wimberley Valley, the Halloween Flood occurred. The peak stream flow recorded by the USGS gage during the Halloween flood event was 2,010 m^3s^{-1} (an 8% exceedance according to the flood-frequency analysis above). While this flood can be categorized as an infrequent flow experienced by the Blanco River, its magnitude was less than half than that recorded for the Memorial Day flood. The combination of these two high magnitude floods in relatively short succession of one another might lead to assumption that the study area should have experienced some degree of erosive activities, i.e., channel widening, removal of in-channel formations. The erosion that did occur was not apparent enough to be observed through aerial imagery alone. However, the amount of observable sediment depositions and lack of major erosive and channel altering changes that have been observed in the aerial imagery align with the Magilligan et al. (2014) and Marchi et al. (2015) studies that suggest that infrequent, high magnitude flows are capable of transporting sediment rather than initiating erosion.

Other than the Halloween flood, the peak flows that have been recorded since 2015 all fall between 30 – 88% chance of occurring within any given year. As these flows are much less severe in magnitude, it can be inferred that an influx of sediment was deposited into the Blanco River during the two 2015 events and carried downstream, which then settled into the new formations along the channel margin and within the stream throughout the years since 2015 due to lower flows. Future studies could benefit from analyzing the land-use and land-cover over a greater area upstream of the study site.

6.5 Tributaries and their contributions to changes

Tributaries act as an extra source of both water and sediment to the main bodies of water they flow into. I was interested in examining the potential impact that tributaries might impose on the mainstem of the Blanco River by examining the two major tributaries within the study area: Cypress Creek and Lone Man Creek.

Cypress Creek is the jewel of Wimberley, with popular tourist spots such as Jacob's Well and Blue Hole bringing in thousands of visitors each year. It comes to a confluence with the Blanco River just upstream of Ranch Road 12. The first reach in the study area, reach 1, is located just below its confluence with the Blanco River. Reach 1 experienced a moderately low stream power during the 2015 Memorial Day flood in comparison to the rest of the reaches (371.5 watts/meter). However, this is the stream power recorded by the USGS gage and does not take into the consideration the stream power that also came through from Cypress Creek itself. In total, there are 16 observations of geomorphic disturbances that occurred within the reach. 9 of the observations were deposition (6 along the channel margin and 3 within the channel). There are 5 observations of changes in channel width (2 widening, 3 narrowing), and two observations of erosion along the channel margin. Reach 2, only contained 4 total observations of geomorphic changes, but also experienced one of the more severe unit stream powers. Due to this, it can be assumed that the influx of sediment that may have come from Cypress Creek did not have a chance to settle within that reach before being picked up again by a greater amount of energy.

Lone Man Creek is a smaller tributary located in a more remote area of Wimberley. One small dam is located upstream of its confluence with the Blanco River, as well as a low water crossing. Meitzen et al. (2018) pointed out its uniqueness in their study by noting that it experienced a significant amount of sediment deposition post-Memorial Day flood despite being dammed, which should have confined some of the sediment from the tributary. Its confluence with the Blanco River is contained within Reach 12, the last reach of the study area. Reach 12, similar to reach 1, experienced a low stream power in comparison to the rest of the study are (327.4 watts/meter). However, it is located downstream of the reach that had the highest stream power (reach 10). Reach 12 in comparison to reach 1 had far more observations of geomorphic changes, 26 in total. It also had the most observations of any of the reaches in the study area. 19 of the observations were instances of deposition (8 along the channel margin, and 11 in the channel). There are only two observations of erosion along the channel margin, and 6 changes in width (1 instance of widening, and 5 narrowing). Reach 12, however, is located downstream of reach 10 (the highest recorded unit stream power). As the unit stream power of reach 12 was relatively low in comparison to the rest of the study area, this decrease in velocity and energy could have led to the large amounts of sediment that settled within the reach.

This portion of the study could be further refined by expanding the study area to include reaches upstream of reach 1 and downstream of reach 12, and also completing the same methods to determine stream power along the tributaries themselves to ascertain their stream powers. Specifically, knowing the unit stream powers of the reaches upstream of reach 1, and downstream of reach 12 would also contain important clues to the types of geomorphic changes that occurred in these reaches.

7. CONCLUSION

From this study, I was able to determine that weak correlations exist between the initial types of geomorphic disturbance after Memorial Day flood, and individual reach stream power, and are not strong enough to be indicative that one causes another and vice-versa. It may be indicative of the total amount of geomorphic disturbance that occurred within each reach. I also found that reaches that experienced a greater initial stream power did not necessarily experience more severe geomorphic disturbances, and rather the reaches downstream bared the brunt of the forces that came from upstream. I did find, however, that there is a moderately strong correlation of types of geomorphic disturbance to a reach's average width. I identified several observations of geomorphic along the channel margin and within the channel. A majority of these observations were new depositions of sediment, which could possibly be attributed to the more "average" flows that the particular study area has experienced in the years since 2015. The limited study area and data was used to determine that the tributaries along the mainstem of the Blanco Rivers did not impact the reaches that they directly come to a confluence with, but rather the reaches that are downstream of confluences.

This study contributes to the growing body of literature surrounding bedrock rivers and how to better predict how they might respond and change after catastrophic floods. It also reiterates that bedrock rivers are much less predictable than alluvial rivers; there is evidence that the geomorphic changes that have occurred in the study area since the 2015 floods can most likely be attributed to the peak flows since the event, particularly in their abilities to transport and deposit sediment. This study does show however, that inferences can be made to answer that question using simple methodology and readily available pre-existing data. Future studies can build upon this research by examining a larger study area (both in portion of the watershed and adding a land-use analyzation as well), creating smaller and more uniform reaches within the study area itself, and using higher quality aerial imagery.

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