

IMPORTANCE OF WETLAND DRAINAGE IN A HIGH-ELEVATION, SNOWMELT-DOMINATED CATCHMENT, SENATOR BECK BASIN, SAN JUAN MOUNTAINS, SW COLORADO

For my Master's thesis, I am examining the contribution of high-elevation wetlands to baseflow (the groundwater contribution to streamflow) in the Senator Beck Basin (SBB), a small, snowmelt-dominated, headwater watershed in the San Juan Mountains in southwestern Colorado. Within the SBB, there is a group of wetlands of varying sizes and a small stream, all of which are hydraulically connected. Snowmelt is a major contributor to streamflow in high-elevation headwater basins, and post-snowmelt wetland drainage may play a vital role in maintaining baseflow. In the summer of 2020, photographs from a game camera located upstream of the wetlands showed that the stream was dry, yet the stream gauge downstream still recorded streamflow. It appears that the SBB wetlands contribute to baseflow, supplying a crucial component to late season streamflow. My work evaluates a group of wetlands in the SBB to study how the timing and amount of snowmelt influences wetland hydrology and how baseflow is maintained by wetland drainage. To examine potential streamflow input from the wetlands, baseflow discharge was estimated using a baseflow separation technique known as the Conductivity Mass Balance method, which uses specific conductance and streamflow values recorded at the stream gauge to estimate baseflow discharge. The method incorporates two endmembers: a runoff endmember with a relatively low specific conductance and a baseflow endmember with a relatively high specific conductance. I also calculated baseflow indices (BFIs) to determine the proportion of baseflow within streamflow (baseflow discharge / streamflow discharge). In the summer 2021, I made several visits to the field to examine the hydrology of the basin, explore the wetlands, identify groundwater inputs to the stream such as seeps, and look at controls on streamflow. I installed 3 shallow (< 1m) wells in the wetlands along with water level and specific conductance data loggers to estimate water flux in and out of the wetlands. I also placed additional game cameras and stream intermittency loggers in the streambed upstream and downstream of the wetlands to determine when and where the stream goes dry. Another goal of my thesis project is to relate the influence of snowfall variability on baseflow generation. I have been working with the well data collected from the basin along with nearby meteorological and snow hydrological data to examine the timing and amounts of peak snow water equivalent (SWE: amount of water in snowpack), peak streamflow and the timing of when baseflow becomes a substantial proportion of streamflow (the time at which BFI >15%). Recently, I have been evaluating three hydrologically distinct years: a low snow year (2018), a high snow year (2019), and an average snow year (2020). In the SBB, the timing of peak streamflow and BFI >15% varied considerably after peak SWE. In 2018, peak streamflow occurred 21 days after peak SWE; in 2019, peak streamflow occurred 59 days after peak SWE; and in 2020, peak streamflow occurred 41 days after peak SWE. Years 2018 and 2020 both had the same date of peak SWE yet had different dates of peak streamflow, possibly owed to total amount of SWE and to meteorological conditions at that time. In 2018, the timing of BFI >15% occurred 56 days after peak SWE; in 2019, the timing of BFI >15% occurred 86 days after peak SWE; and in 2020, the timing of BFI >15% occurred 74 days after peak SWE. In 2019, the date of BFI >15%

was 37 days later than the date of BFI >15% in 2018, showing the importance of delayed wetland drainage on streamflow. These results indicate that high snow years result in larger and later streamflow peaks, which causes baseflow to become a substantial proportion of streamflow later in the season. Based on results from the SBB, I plan to develop a methodology to quantify wetland drainage in other headwater basins. High-elevation wetland drainage may have cumulative effects on downstream water supply. Since most rivers in the western US start in high-elevation headwater basins, it is becoming increasingly important to understand these relationships in the context of future climate variability which may influence the timing, amount, and form of precipitation, thus modifying the local water budget and subsequent baseflow discharge.

I am currently a second year Master's student at Colorado State University, working on a degree in Geosciences with an emphasis in Hydrogeology. I intend to graduate in summer 2022.

Natural Floodplain Heterogeneity

Research Summary 2022

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Restoring the natural processes that create and maintain floodplain functions is of increasing interest, both in Colorado and nationally. A high degree of spatial heterogeneity is one of the salient characteristics of a floodplain along an unregulated, laterally mobile channel. Spatial heterogeneity, or three-dimensional patchiness within a floodplain, at the scale of an entire floodplain results primarily from lateral channel mobility as water and sediment fluxes interact with the floodplain boundaries as influenced by valley geometry, vegetation, large wood, and substrate erosional resistance. Existing research indicates that floodplain ecosystem functions, including peak flow attenuation, subsurface water storage, denitrification, carbon sequestration, and habitat abundance and diversity, correlate with surface and subsurface spatial heterogeneity. The river science community is rapidly developing numerical models of channel mobility and associated floodplain heterogeneity in response to changes in water and sediment fluxes. Currently, we have limited insight into the key processes that create and maintain the spatial heterogeneity apparent of floodplains. We also know very little about how (or whether) spatial heterogeneity varies in relation to drainage area, channel planform, and flow regime – key geomorphologic components in managing rivers and designing successful river and floodplain restoration projects.

Our primary objective is to examine whether characteristic levels of floodplain spatial heterogeneity exist in relation to the potential control variables of biome, channel planform, flow regime, valley confinement, and hydrologic regime. We will statistically examine floodplain spatial heterogeneity with on-the-ground field data and remote sensing by calculating 10+ heterogeneity metrics from the field landscape ecology and using multivariate linear analysis to determine the best predictor variables of heterogeneity. For the Colorado component of the research, we will be conducting field work at West Bijou Creek, East Plum Creek, and Sheep Creek (where there are active beaver) in order to characterize a variety of Colorado floodplains in varying biomes. While the scope of the project for this proposal only includes Colorado rivers, the scope of the entire project spans the United States. The data collected for Colorado rivers will provide crucial information on the form and function of floodplains in the Intermountain West. This work will also inform Colorado river managers about the natural form and functions of Colorado riverscapes and assist in the design of successful river restoration projects in the state.

Since the funding was awarded, we have developed a robust method for combining the field data and remotely-sensed elevation and multispectral images in ArcGIS Pro to create classified floodplain maps that can then be imported into RStudio for calculating heterogeneity metrics. We have created floodplain maps and calculated heterogeneity metrics for three prairie streams (West Bijou Creek and East Plum Creek in Colorado, and Sand Creek in Oklahoma). We currently have a paper under review in *Earth Surface Processes and Landforms* presenting our methods and results of this analysis.

The Timing of Peak Streamflow in a Small River Versus Snowpack Melt-Out

The timing of peaks in snowmelt streamflow have been correlated to the disappearance of the snowpack. Previous researchers showed that snow-all-gone (SAG) dates in forest and alpine areas matches the timing of streamflow peaks. The studies built on the premise that estimating the SAG date could provide a simple estimate of the timing of peak flow. In our research we examine the correlation between the timing of peak flow and snowpack melt-out or SAG for a smaller river, where there is usually only one main peak streamflow. The specific objectives were as follows: (1) determining the correlation between streamflow and snow water equivalent (SWE), and (2) determining the correlation between the timing of peak streamflow ($t_{Q\text{-peak}}$) and the SAG date. The Michigan River near Cameron Pass Watershed was paired with the Joe Wright snow telemetry (SNOTEL). The watershed has a drainage area of 3.96 km² (1.54 mi²), with a majority of the basin being in the alpine. A 40-year time series of daily streamflow and SWE data were used for water years (1 October through 30 September) from 1981 to 2020. For each year, the amount and date of peak streamflow, the amount and date of peak SWE, and the date of snow-all-gone were determined. The key correlation between the date of peak streamflow and the SAG date, where the difference between the two dates was assessed. A linear regression was fit between the two variables, and further, a new regression was fit once outliers were removed. Three different snow years were highlighted: 2010 was an average snow year, while 2011 was the highest snow year in the 40-year period of record, and 2012 was the lowest on record.

The three snow years had different accumulation, peak SWE, the onset of melt, and streamflow characteristics. Peak SWE occurred more than two months later in 2011 than in 2012. In 2010, peak streamflow was only 22 days after peak SWE; it doubled this in 2011 and doubled again in 2012. Multiple larger streamflow peaks occurred in 2011, likely due to more differential melting across the basin than in other years. For this headwater basin, the SAG date represented the timing of peak streamflow well, within two days of one another for 18 of the 40 years. The mean (median) difference was SAG occurring 1.2 (0.5) days after peak streamflow. The date of peak streamflow and SAG are well correlated ($R^2 = 0.68$). The SNOTEL station represents the forested area, and a majority of this basin is higher than the treeline. Snowpack measurements in the alpine could improve the understanding of melt-out. The three demonstration years illustrated the inter-annual variability in snowpack accumulation, snowmelt, and streamflow characteristics. Forty years of data can represent a vast range of hydro-climatic conditions. Using snowpack meltout to estimate the timing of peak streamflow is a simple approach that does not consider all the complex hydrological processes that occur in a snow-dominated system. However, due to spatial variability, extrapolating meteorological data from a single station for use in a hydrological model would not necessarily improve the estimation of peak streamflow. A simple approach can provide some initial insight into the functioning of a small headwater basin.

I would like to thank the American Water Resources Association – Colorado Section for supporting my master's research at Colorado State University via the Richard Herbert Memorial Scholarship. This scholarship provided funding for additional radiocarbon geochronology, and it allowed me to revisit the study site for my master's research to perform additional ground-penetrating radar (GPR) data collection and a site assessment following the Cameron Peak Fire. These additional data were crucial to understanding the long-term sediment dynamics of the South Fork Cache la Poudre (South Fork) Valley, and post-fire observations provided insights regarding the impacts of modern ecologic disturbances on valley bottom sedimentation in formerly glaciated valleys.

My master's work focused on the sediment dynamics of the South Fork Valley to answer two key questions: i). What are the dominant processes of post-glacial sedimentation in the South Fork Valley? ii). What is the timing of valley bottom and floodplain sedimentation in unconfined valleys following deglaciation? Using surficial geologic mapping, sediment coring, GPR surveys, and radiocarbon geochronology, I found that the dominant processes driving sediment accumulation in the South Fork Valley include bar migration, channel filling, and overbank deposition. Additionally, I documented three distinct periods of sedimentation or erosion following glacial retreat. Shortly after deglaciation over 10 m of sediment was deposited in the South Fork Valley. Sediments from these deposits were dated to 16.8 ka, and sedimentation in this period was driven by fluvial processes associated with lateral accretion. Following the initial period of sedimentation, the South Fork River incised 5–8 m into the post-glacial sediments. Aggradation of sediment in the South Fork Valley resumed in the late Holocene, with 1–2 m of sedimentation occurring since 2.1 ka. Late Holocene sedimentation was primarily driven by fluvial processes associated with vertical accretion, namely overbank deposition on the floodplain.

Findings from this investigation, coupled with observations following the Cameron Peak Fire, suggest that the relict glacial topography of the South Fork Valley promotes the storage of sediment in the valley and influences the behavior of the channel. The wide, low gradient valley geometry makes it an effective sediment storage site, and likely an important site for water storage and surface-subsurface water exchange. Additionally, despite recent fires burning the valley walls, modern sedimentation on the floodplain has been minimal. Recent field observations suggest that little to no hillslope sedimentation has occurred in response to the Cameron Peak Fire, and I did not recognize any extensive deposits of new sediment on the floodplain in summer 2021. The relict glacial topography of the site limits hillslope and tributary connectivity in the valley, and valley bottom topography changes slowly as it is largely buffered against the effects of disturbances.

I presented the results of my work at the Geological Society of America's annual conference in October 2021. Additionally, I used some of the findings summarized here to develop a new geologic map and technical report for the USGS EDMAP student mapping program. I completed my master's thesis in January 2022, and I will graduate from Colorado State University this spring. Support from the American Water Resources Association – Colorado Section helped make this work possible!