Regional Regression Equations Based on Channel-Width Characteristics to Estimate Peak-Flow Frequencies at Ungaged Sites in Montana Using Data through Water Year 2011

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A proposal prepared for the Montana Department of Transportation

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November 28, 2016

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Problem statement

The Montana Department of Transporation (MDT) uses peak-flow frequency data (i.e. 100-year flood) to design highway infrastructure, secure floodplain permits, and perform stream restoration activities. The USGS in cooperation with MDT proposes to develop regression equations which use channel-width as a predictor to provide peak-flow frequency estimates (hereinafter referred to as "frequency") to MDT.

Peak-flow data has been collected by the USGS in cooperation with MDT since 1955 and is used by many federal, state, and local agencies to increase the understanding of how extreme weather events and climate change can affect flood events in Montana. The proposed research will develop channel-width based regression equations that could increase accuracy and reduce uncertainty when determining flood magnitudes and frequencies for MDT.

Channel-width measurements, which are necessary for using the proposed regression equations, are commonly obtained through on-site surveys. This research proposes to develop and evaluate the use of aerial photography and other remote measurement methods to quickly estimate channel widths to reduce the need for on-site surveys.

Background summary

The U.S. Geological Survey (USGS) publishes peak-flow frequency estimates and methods for estimating frequencies at ungaged sites that are used for economical design of water conveyance and storage structures such as culverts, bridges, storm sewers, dams, and levees. Reliable frequency information also is crucial for effective planning and management of water resources and floodplains, to protect lives and property in flood-prone areas, and for determination of actuarial flood-insurance rates. For several applications, including Federal Emergency Management Agency (FEMA) 100-year floodplain delineation and U.S. Department of Transportation Federal Highway Administration bridge and culvert design, USGS frequency estimates and methods generally are required.

The USGS in cooperation with MDT and Montana Department of Natural Resources and Conservation compiled peak-flow data and peak-flow frequency estimates at 725 gaging stations in Montana based on data through Water Year 2011 (Sando, S.K and others, 2016). Approximately 540 of these gaging stations were used to develop regional regression equations to estimate frequencies at ungaged sites using GIS-based basin characteristics (Sando, Roy and others, 2016). In addition to regression equations developed using basin characteristics; previous studies in Montana (Parrett and Johnson, 2004) also developed regional regression equations based on channel-width characteristics. Channel-width characteristics, particularly bankfull- and active-channel widths, are formed by the flood regimen of a stream. Regression equations based on channel-width characteristics can be used on-site to quickly estimate frequencies and, when weighted with regression equations based on basin characteristics, can be used to reduce uncertainty in frequency estimates.

The purpose of this research is to develop regional regression equations for the eight hydrologic regions of Montana using channel-width characteristics. Additionally, this research will develop and evaluate the use of aerial photography to estimate channel widths. Channel-width characteristics can be used on-site to quickly estimate frequencies and when weighted with regression equations based on basin characteristics, can be used to reduce uncertainty in frequency estimates. Parrett and Johnson (2004) previously developed regional regression equations using data through 1998 and channel-width data that had been collected and maintained by the USGS through previous hydrologic and hydraulic studies.

Frequency estimates have been developed for 725 gaging stations in and near Montana (Sando, S.K. and others, 2016), of which approximately 540 gaging stations were used to develop regional regression equations based on basin characteristics (Sando, Roy and others, 2016). Of these 540 gaging stations, nearly 100 do not have associated channel-width measurements. Channel-width characteristics, such as bankfull- and active-channel widths, are measured at a site of interest using appropriate field methodologies. Research activities in the proposed project will focus on measuring channel widths for gaging stations used in the regional regression equations and developing equations based on channel-width data. Additionally the USGS will evaluate the station basin and frequency characteristics to provide administrative guidance for managing the existing crest-stage gage network cooperatively operated by USGS and MDT.

Benefits

Regional regression equations to estimate frequencies based on channel-width characteristics will allow for field estimation of frequencies and can reduce uncertainty when weighted with regression equations based on basin characteristics. These regression equations will also meet critical needs for numerous structure-design and floodplain-management issues in Montana, especially for MDT. Further, the proposed research will evaluate the use of aerial photography to determine channel widths for use in the developed regression equations.

The final report of this study will provide detailed documentation of methods, which will be of substantial value to MDT and other users in defending design flows and performing auxiliary analyses. This work also will update the channel-width characteristics database and might substantially streamline the process of measuring channel widths, which also might lower the cost of future database updates and facilitate the use of channel-width regression equations.

1. Specific benefits to MDT and the taxpayer include:
    a. <u>Economical hydraulic design.</u> Updating and publishing the channel-width regression equations will allow MDT to use the most current hydrologic methodology based on recent data and will:
        i. Assist designers in accurately selecting proper culvert sizes and bridge openings, and reduce the risk of over- or under-sizing.
        ii. Reduce construction costs that result from oversized culverts and bridge openings based on outdated hydrologic data.
    b. <u>Establishment of road grades and low beam elevations.</u> Setting road grades is predicated upon establishment of accurate flood-elevation data. Updated channel-width regression equations will allow MDT staff to more confidently provide the appropriate level of service

to the road user, and evaluate risks to the road facility and upstream properties during flood events.

c. Defending against lawsuits. It is important to be able to technically justify the specific frequency estimates used in various design applications. Design flows based on up-to-date data and methods are defensible and reduce the risk of costly litigation.

d. Securing floodplain permits. Permitting MDT facilities in floodplains is becoming increasingly common. The authorization of construction in floodplains is scrutinized by local floodplain authorities, FEMA and DNRC engineers. Up-to-date data and hydrologic methods are required for the permitting process.

e. Stream restoration and fish passage. MDT projects sometimes require stream relocation and/or mitigation to reduce environmental impacts and allow fish passage. The design and implementation of mitigation activities requires up-to-date data and hydrologic methods that can withstand review by other agencies.

f. Preliminary engineering and planning process. Up-to-date data and hydrologic methods will allow MDT to make good planning-level decisions and preliminary engineering cost estimates for system facility upgrades or reconstruction efforts.

2. Potential consequences of not updating the channel-width regression equations include:

a. Under-design, resulting in either flood or road damage, or

b. Over-design, resulting in unnecessary capital expenditures based on outdated analysis.

c. Inability to defend against damage claims and lawsuits resulting from flood damage with potential substantial cost of fixing an existing problem or paying damage claims.

d. Falling further behind in analyzing hydrologic data that is being collected annually by USGS in cooperation with MDT.

Objectives

The primary objectives of the proposed project include:

1. Perform site visits for approximately 73 active gaging stations to measure active-channel (Osterkamp and Hedman, 1977) and bankfull-channel widths (Riggs, 1974). Of the 73 gaging stations, the channel-width measurements for 41 gaging stations will be newly collected data, and the measurements for 32 gaging stations will be used to compare with previously collected data (Parrett and Johnson, 2004).
2. Measure channel widths using aerial photography for gaging stations used in the most recent regional regression equations (Sando, Roy and others, 2016).
3. Develop regional regression equations to estimate frequencies at ungaged sites using channel-width data.
4. Provide methods for weighting frequency estimates based on channel widths with frequency estimates based on basin characteristics.
5. Evaluate gaging station basin and frequency characteristics to provide administrative guidance for managing the existing crest-stage gage network cooperatively operated by USGS and MDT.

Research Plan

The research plan for the proposed project includes the following major tasks:

Task 1: Perform site visits at 73 active gaging stations and measure the active channel and bankfull-channel widths.

Channel widths will be measured for 73 active gaging stations across Montana using field methods previously applied in Montana (Parrett and Johnson; 2004). The active-channel width has been described by Osterkamp and Hedman (1977) as the channel width formed by prevailing discharges. It is a short-term geomorphic feature whose upper limit is defined by a break in the relatively steep bank of the active channel to a more gently sloping surface beyond the channel edge. The break in slope normally coincides with the lower limit of permanent vegetation. The bankfull-channel width has been described by Riggs (1974) as the horizontal distance between the tops of the banks of the main channel. The top of the banks is defined as the place where the flood plain and the channel intersect and is usually distinguished by an abrupt change in slope from near-vertical to horizontal. This is commonly the stage at which overbank flooding occurs. Measuring channel widths (at gaging stations that lack channel-width measurements) using field methods consistent with Parrett and Johnson is imperative to maintaining consistency with other sites in the USGS database which have previously been measured. In addition to using the Parrett and Johnson (2004) methods, a literature review will be conducted to evaluate whether other methods for determining channel width indicators may be less subjective. If less subjective methods are indicated, additional measurements will be conducted during the site surveys such that methods can be analyzed.

Site visits will be performed at 73 active gaging stations in Montana. For 41 of the 73 gaging stations, channel-width characteristics have not been previously measured; thus the measurements made in this study will be newly collected data. For 32 of the 73 gaging stations, channel-width characteristics have been previously measured and the data collected in this study will be used to evaluate changes in channel widths. Selection of the 32 gaging stations with previously measured channel widths will be made such that 4 gaging stations fall within each of the eight hydrologic regions.

Active-channel and bankfull-channel widths will be measured at 2-3 cross sections near each gaging station, separated by at least one channel width. The measurements will be averaged to yield single values of active-channel width and bankfull-channel width for each gaging station. Parrett and Johnson (2004) reported that on perennial streams the active-channel width commonly was an easier feature to define than bankfull-channel width. Conversely, on many ephemeral stream channels, the bankfull-channel width was easier to define than active-channel width. Also, on some streams neither active-channel width nor bankfull-channel width could be clearly identified.

The methods used for performing at-site channel width measuremens will be defined and documented in the final report. The locations of the width measurements will also be recorded and documented. The descriptions of the methods used and site measurement locations can be used for others as a guiding document on how to measure channel widths.

Task 2: Develop remote sensing methods for measuring channel width and compare with field measured channel width.

Remote sensing methods for measuring channel width will be developed and evaluated. Channel widths will be measured remotely for gaging stations (approximately 540) that were used to develop the most recent regional regression equations based on basin characteristics (Sando, Roy and others, 2016). The primary data source for the imagery required to develop these methods will be the most recently recorded 1-meter aerial photography published through the National Agricultural Imagery Program (NAIP; USDA, 2015), which is freely available for Montana. The widths determined using remote sensing methods will be saved as digital lines in a geodatabase for future use and reference.

A feasibility analysis was performed for 40 gaging stations in Montana using aerial photography similar to NAIP imagery to measure channel widths (figure 1, table 1). In the feasibility analysis, channel width was determined by the distance between permanent vegetation on the opposing banks, which might be expected to correspond to the active-channel width (Osterkamp and Hedman, 1977). Channel widths could not be measured for 7 gaging stations, all of which were located on ephemeral streams and had drainage areas less than 15 square miles; 5 of the 7 gaging stations had drainage areas less than 3 square miles. The correlation between the previously measured active-channel widths and the remotely measured channel widths was 0.96 and indicated that further investigation into the development of remote sensing methods for estimating channel width is warranted.

The advantage of using aerial photography is that the user can quickly scan large reaches to find more suitable and representative locations to measure, which might result in more consistent measurements at each site. Additionally, the user potentially could estimate channel width without having to visit the actual site saving time, resources, and logistical requirements.

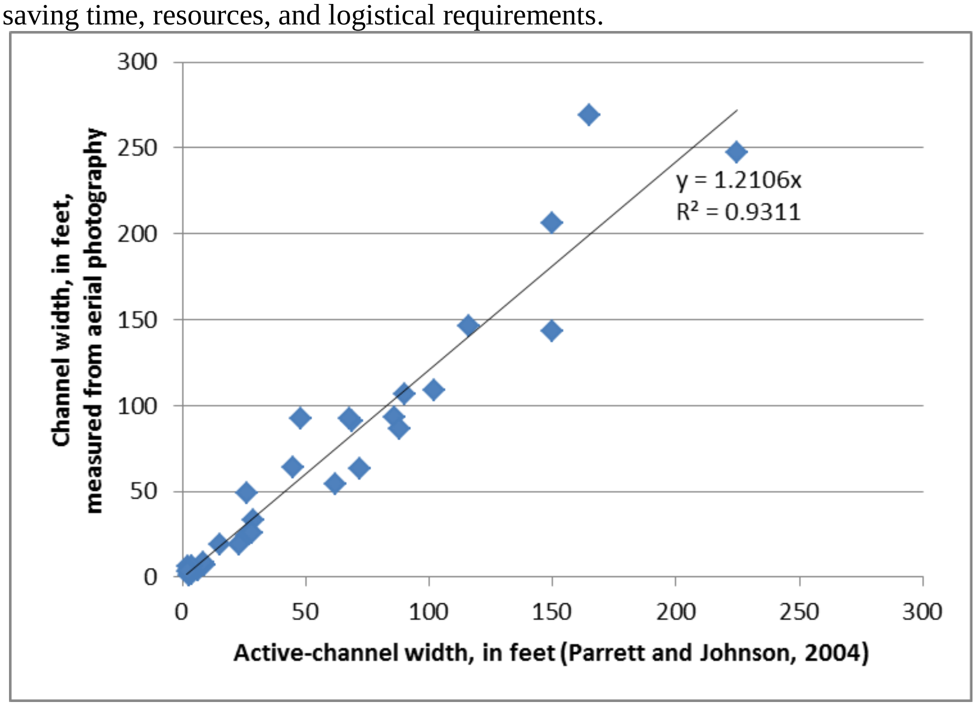

Figure 1. Channel width measured from aerial photography compared to active-channel width from Parrett and Johnson (2004)

Task 3: Develop regional regression equations to estimate frequencies based on channel-width data and provide methods for weighting the frequencies with estimates from the basin characteristic based regression equations.

Regression equations will be developed for each of the 8 hydrologic regions in Montana to estimate frequencies using channel-width data. Specifically, regression equations will be developed using field-measured active- and bankfull-channel widths. If aerial photography is deemed a reliable and accurate method for obtaining channel-width data, the data obtained with these techniques will also be included in the regression equations. The regression equations for each hydrologic region will provide estimates for 10 peak-flow annual exceedance probabilities (the 66.7-, 50-, 42.9-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities [AEPs]; these AEPs correspond to 1.5-, 2-, 2.33-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals). Methods will be provided for weighting the channel width based equations with the basin characteristic based equations. Guidance on the use and limitations of the regression equations will also be outlined and documented in the final report.

Task 4: Evaluate the peak flow data and gaging-station characteristics to provide administrative guidance for managing the existing crest-stage network cooperatively operated by USGS and MDT

The USGS in cooperation with MDT has been operating a crest-stage gage (CSG) program in Montana to collect peak flow data since 1955. Currently there are 88 CSGs being operated in Montana that range in drainage areas from 0.08 to 110 square miles. The CSG program is vital to collecting peak-flow data on small basins that would not typically be gaged without this cooperative program. For

Table 1. Remotely measured channel widths compared to at-site measurements.

Station number	Station name	Drainage area	Active channel width (Parrett and Johnson, 2004)	Remotely measured channel widths with rating and comments		
				Width	Rating	Comments
06308200	Basin Creek Tributary near Volborg MT	0.13	1.8	--	--	could not be measured, no clear channel
06123200	Sadie Cr tributary nr Harlowton MT	0.39	2	--	--	could not be measured, no clear channel
06131300	Mcguire Creek trib near Van Norman MT	0.77	3	1.4	poor	measurement capabilities are too coarse
06130940	Spring Creek trib near Van Norman MT	1.4	4	--	--	could not be measured, no clear channel
06177700	Cow Creek Tributary near Vida MT	1.45	3	--	--	could not be measured, no clear channel
06130610	Bair Coulee near Mosby MT	1.76	3	4.3	poor	no clear channel
06294985	East Fork Armells Cr trib nr Colstrip MT	1.89	3.8	1.9	poor	measurement capabilities are too coarse
06155600	Murphy Coulee Tributary nr Hogeland MT	2.46	7.3	--	--	could not be measured, no clear channel
06326940	Spring Creek trib near Fallon MT	4.05	2.3	3.6	poor	no clear channel
06114550	Wolf Creek trib near Coffee Creek MT	5.05	2.3	6.5	poor	no water, small channel
06073600	Black Rock Creek near Augusta MT	5.63	4	6.2	poor	no water, small channel
06324995	Badger Creek at Biddle MT	6.12	4.5	--	--	could not be measured, no clear channel
06307700	Cow Cr nr Fort Howes Ranger Stat nr Otter MT	8.57	3.5	3.0	poor	measurement capabilities are too coarse
06216200	West Wets Creek nr Billings MT	8.82	4	6.5	poor	channel difficult to see
06156100	Lush Coulee near Whitewater MT	8.9	8.5	8.4	poor	no clear channel
06100300	Lone Man Coulee near Valier MT	13.9	6.5	4.0	poor	no water, small channel
06025100	Quartz Hill Gulch near Wise River MT	14.3	1.8	--	--	could not be measured, no clear channel
06015430	Clark Canyon near Dillon MT	17.3	9	7.4	good	
06031950	Cataract Creek near Basin MT	30.5	29	33.3	poor	trees partially blocking view
06133500	N F Milk River ab St. Mary canal nr Browning MT	60.8	23	18.8	fair	
06035000	Willow Creek near Harrison MT	85.9	26	24.4	good	
06093200	Badger Cr bl Four Horns Canal nr Browning MT	153	90	106.6	good	
06154400	Peoples Creek near Hays MT	227	28	26.1	fair	recent flood activity
06078500	North Fork Sun River near Augusta MT	259	86	93.4	good	
06073500	Dearborn River near Craig MT	322	69	90.7	good	
06169500	Rock Creek bl Horse Creek nr int'l boundary	322	26	48.6	fair	pool riffle system, wide pools, narrow riffles
06090500	Belt Creek near Monarch MT	355	62	54.1	fair	
06033000	Boulder River near Boulder MT	381	45	64.3	fair	recent flood activity
06071300	Little Prickly Pear Cr at Wolf Cr MT	391	--	36.5	fair	entrained
12301300	Tobacco River near Eureka MT	419	48	92.0	good	
06177500	Redwater River at Circle MT	551	15	18.9	fair	pool riffle system
12389500	Thompson River near Thompson Falls MT	638	68	92.4	fair	
12370000	Swan River near Bigfork, MT	672	165	269.0	good	
06043500	Gallatin River near Gallatin Gateway MT	819	102	108.8	good	
12334510	Rock Creek near Clinton MT	889	116	146.6	good	
06099000	Cut Bank Creek at Cut Bank MT	1032	88	86.7	fair	
06108000	Teton River near Dutton MT	1238	72	62.8	fair	
12355500	N F Flathead River nr Columbia Falls MT	1556	225	247.3	good	
06052500	Gallatin River at Logan MT	1789	150	143.2	good	
12340000	Blackfoot River near Bonner MT	2287	150	206.3	fair	entrained

example, in eastern Montana (Northeast Plains, East–Central Plains, and Southeast Plains hydrologic regions) there are currently 59 active continuous gaging stations being operated in cooperation with other state and federal agencies. Of these 59 continuous gaging stations, only 2 are being operated on basins with less than 100 square miles. Additionally, within these 3 hydrologic regions, there are 58 CSGs, of which 2 are being operated on drainages greater than 40 square miles.

Peak-flow data from the CSG program are essential to developing regional regression equations in Montana. Without the CSG program, the regional regression equations would not be valid for drainage areas less than approximately 100 square miles. However, MDT designs culverts and bridges for a large range of drainages areas and needs reliable and accurate frequencies applicable to all drainage areas.

The cooperative CSG program between USGS and MDT has fluctuated in size since its inception in 1955. The initial CSG network consisted of 45 CSGs but increased to 152 in 1959, and then to about 300 in the 1970s. Since the 1970s the CSG program decreased to the currently operated 88 CSGs. The primary reason for the decline in CSGs is due to budgetary constraints. For the past 10 years the funding level for the program has remained at a constant level while operational costs have slowly been increasing. Consequently, each year a few CSGs are discontinued. The selection of CSGs that are discontinued typically is based on the ability to accurately gage a particular site. Those sites which are most difficult to accurately gage are typically discontinued first when the size of the CSG network needs to be reduced.

The USGS proposes to evaluate the CSG program to meet the needs of MDT. Previously, Omang (1992) performed a statistical network analysis of Montana gaging stations to assess the effect of adding or deleting gaging stations. This analysis was based on developing hypothetical future networks and assessing the effect of these hypothetical networks on the regression equations. Active and hypothetical gaging stations were then ranked in order of importance based on their ability to provide regional peak-flow information. While this analysis provided a statistical approach to evaluating the gaging-station network, it might not account for several potentially important factors, including: (1) the need for operating long-term gaging stations for other purposes, such as evaluating climate change or the need to use long-term sites to compare with short term records; and (2) the spatial distribution of gaging stations in the hydrologic regions. The proposed network evaluation will perform the following tasks for the CSG program:

- Compile and statistically summarize gaging stations within each hydrologic region, with respect to drainage areas and periods of record, and evaluate how well active CSGs address potential data gaps.
- Identify long-term CSGs in each region that could be used for other streamflow modeling or climate effects studies as well as provide baseline information on how peak flows might be changing in Montana.
- Explore the feasibility of using aerial photography to identify dams, stock ponds, and diversions from the channel within the drainage basins of active CSGs.
- Query the field personnel responsible for operating the CSGs and provide feedback on sites that are difficult to accurately gage.

- Determine the statistical leverage and influence for each CSG based on the most recent regional regression analysis (Sando, Roy and others, 2016). Leverage measures how similar a CSG's basin characteristics are to the basin characteristics of the other gaging stations in the hydrologic region. Influence measures how strongly a CSG affects the overall regression results. A CSG with low leverage indicates that its basin characteristics are well represented by other gaging stations within the hydrologic region and thus that CSG might be a candidate for discontinuation. Crest-stage gages with high leverage and high influence might indicate gaging stations with poor representation, which might not be candidates for discontinuation. Basin characteristics for gaging stations with poor representation might also provide information for selecting ungaged basins for future inclusion in the CSG program.

The CSG network evaluation is necessary to guide future administrative decisions between the USGS and MDT on how to manage the CSG program. The network evaluation results will be tabled and documented as an appendix to the Scientific Investigations Report.

MDT Involvement

All of the proposed work will be conducted by USGS. MDT involvement primarily will include review of the draft report for technical content. Periodic consultation with MDT will be conducted.

Products

The proposed study will produce the following:

- Quarterly progress reports
- Presentation of results from objectives 1 and 2 upon completion (to the MDT technical panel in place of task reports)
- Draft report for review prior to publication
- USGS Scientific Investigations Report and a MDT Project Summary Report upon completion of the study.
- Various conference presentations and final presentation to MDT

As work progresses on the proposed study, preliminary results will be made available to MDT for review on a provisional basis to allow timely application of study results. The USGS also will prepare and present resuts from objectives 1 and 2 to the MDT technical panel. This presentation will replace the MDT task report requirements for this research proposal.

The final report will be a USGS Scientific Investigations Report available on-line. Data presented will include the measured channel width data and final regression equations for the 8 hydrologic regions of Montana. The report also will document the results of using remote sensing techniques, such as aerial photography, to measure channel widths and, if applicable the resulting regressions based on the remotely-measured channel widths. The methods used to measure channel widths and a discussion on the use and limitations of the resulting regression equations will be included in the report. The channel-width data and regression equations will also be available in StreamStats. StreamStats is a Web-based

Geographic Information Systems application that was developed through a cooperative effort of the USGS and ESRI, Inc. StreamStats provides streamflow statistics for gaged sites and allows users to quickly estimate streamflow statistics at ungaged sites using previously developed regression equations and basin characteristics deployed in StreamStats. The StreamStats home page can be found here: *http://water.usgs.gov/osw/streamstats/index.html*

In addition to the USGS Sicentific Investigations Report, the USGS will concurrently prepare a MDT Project Summary Report to meet MDT requirements for the research. The Project Summary Report will be concurrently written and reviewed with the USGS report to maintain consistency and reduce associated costs.

The final report will include an appendix which includes the analysis and results of the CSG network evaluation. The tables and information presented in the appendix will provide information for making administrative decisions regarding future changes to the ongoing CSG program that has been cooperatively operated by USGS and MDT since 1955.

Implementation

The results of the proposed project will be available to MDT and other users to aid in determining flood characteristics critical to structure design. Updating peak-flow regression equations for Montana will ensure that frequency information is current and based on up-to-date methods.

Project Schedule

Table 2. Project schedule

Work Tasks	Milestone dates	SFY 2017									SFY 2018												SFY 2019												SFY2020		
		FFY 2017												FFY 2018												FFY 2019											
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Project Commencement	1/1/2017				X																																
1. Conduct at-site channel measurements for 73 sites						X	X	X	X	X	X	X	X	X	X	X																					
1a. Literature review of channel width measurement methods						X	X	X																													
1b. Site reconnaissance								X	X	X																											
1c. Perform field work											X	X	X	X																							
1d. Tabulate data														X	X	X																					
2. Develop and use remote methods to measure channel widths					X	X	X	X	X	X	X	X	X	X	X	X	X																				
2a. Research and develop methodologies for remotely measuring channel widths					X	X																															
2b. Remotely measure channel widths							X	X																													
2c. Analyze applicability of using remotely measured channel widths									X	X	X				X	X	X																				
3. Develop regional regression equations																X	X	X	X	X	X																
3a. Develop regional regression equations based on measured active and bankfull channel widths																X	X	X	X	X																	
3b. If applicable, develop regional regression equations using remotely measured channel widths																			X	X	X																
4. Perform evaluation of peak flow data for administrative purposes related to crest-stage gage program																				X	X	X	X	X	X												
5. Quarterly progress reports							X			X			X			X			X			X			X			X			X			X			X
6. Report preparation																				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
6a. Prepare draft tables and figures																				X	X	X															
6b. Prepared draft text and submit draft report	10/1/2018																					X	X	X	X												
6c. Review and address comments; prepare for publication.																										X	X	X	X	X	X	X	X	X			
6d. Submit final report.	7/1/2019																																		X		

Budget

This project is being supported by funding from the USGS Cooperative Water Program ($90,000) (*http://water.usgs.gov/coop/*) and matched by $135,000 in MDT funding (table 3). The budget summary with breakdown by major cost category is shown in table 4.

Table 3. Budget summary by State and Federal fiscal year.

State fiscal year	USGS	MDT	Total
2017	$ 33,000	$ 49,500	$ 82,500
2018	$ 34,250	$ 51,375	$ 85,625
2019	$ 19,000	$ 28,500	$ 47,500
2020	$ 3,750	$ 5,625	$ 9,375
Total	$ 90,000	$ 135,000	$ 225,000
Federal fiscal year	**USGS**	**MDT**	**Total**
2017	$ 44,000	$ 66,000	$ 110,000
2018	$ 31,000	$ 46,500	$ 77,500
2019	$ 15,000	$ 22,500	$ 37,500
Total	$ 90,000	$ 135,000	$ 225,000

Table 4. Budget summary by major cost category by State and Federal fiscal year.

State fiscal year	Salaries	Benefits and overhead	Travel and vehicles	Report publishing	Total
2017	$ 41,250	$ 32,250	$ 9,000	$ -	$ 82,500
2018	$ 52,300	$ 27,400	$ 5,925	$ -	$ 85,625
2019	$ 29,200	$ 12,375	$ 975	$ 4,950	$ 47,500
2020	$ 5,450	$ 2,275	$ -	$ 1,650	$ 9,375
Total	$ 128,200	$ 74,300	$ 15,900	$ 6,600	$ 225,000
Federal fiscal year	**Salaries**	**Benefits and overhead**	**Travel and vehicles**	**Report publishing**	**Total**
2017	$ 55,000	$ 43,000	$ 12,000	$ -	$ 110,000
2018	$ 51,400	$ 22,200	$ 3,900	$ -	$ 77,500
2019	$ 21,800	$ 9,100	$ -	$ 6,600	$ 37,500
Total	$ 128,200	$ 74,300	$ 15,900	$ 6,600	$ 225,000

Staffing

Peter McCarthy will serve as the project chief and co-principal investigator. Peter has been a Hydrologist with USGS for 14 years, and has worked on various hydraulic and hydrologic studies, including managing the data-collection activities of the crest-stage gaging station network, developing Montana StreamStats, and conducting time-of-travel and geomorphologic studies. Peter will conduct most of the analyses for the proposed project and will serve as the primary author and point of contact with MDT.

Roy Sando will serve as a co-principal investigator. Roy has been a Physical Scientist with USGS for 5 years and specializes in remote sensing GIS analyses. Roy was the lead author of the flood frequency regression equations (Sando, Roy and others 2016) for Montana StreamStats. For this study, Roy will develop the methodologies for measuring channel widths using aerial photography, develop the regional regression equations based on channel widths, and coauthor the final report.

Steve Sando will serve as co-principal investigator. Steve has been a Hydrologist with USGS for over 27 years and has worked on various hydrologic studies, including Montana StreamStats and several flood-frequency and streamflow characteristics studies in both Montana and South Dakota. Steve will serve primarily in an oversight role and provide guidance for the proposed project. Steve will also be a coauthor for the final report.

Field personnel will be identified and trained to perform field work to measure the active- and bankfull-channel widths.

Table 5. Summary of hours

Name or title	Role in study	Task					
		1	2	3	4	5	6
Peter McCarthy	Project chief	155	133	0	313	53	155
Roy Sando	Co-principal investigator	0	100	200	187	0	125
Steve Sando	Co-principal investigator	0	0	51	51	0	52
Hydrologist	Data collection	390	0	0	0	0	0
Hydrologic technician	Data collection	390	0	0	0	0	0
Support staff	Report figures and editing	0	0	0	0	0	58

Facilities

All facilities, equipment, and workspace necessary for completing the project tasks will be provided by the USGS.

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