Making Post-wildfire Hydrologic Change Assessments Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool

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Applicant
Texas A&M University, Kingsville
700 University Blvd, Kingsville, TX 78363

Project Managers
Adnan Rajib, Ph.D.
Assistant Professor
Department of Environmental Engineering
Texas A&M University, Kingsville
917 W Ave B, Kingsville, TX 78363, USA
adnan.rajib@tamuk.edu
(361) 593 3068

Melanie Vanderhoof, Ph.D. (Technical Coordinator)
Research Geographer
Geoscience and Environmental Change Science Center
U.S. Geological Survey
MS980, DFC, Denver, CO 80225, USA
mvanderhoof@usgs.gov
(303) 236 1411

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1.1 Executive Summary

April 21, 2021

Dr. Adnan Rajib
Texas A&M University, Kingsville
Kleberg county, Texas

The applicant (Category B) is proposing this project in partnership with the City of Missoula (Category A), Missoula Valley Water Quality District, Clark Fork Coalition, and The Nature Conservancy in Montana. US Geological Survey's Geosciences and Environmental Change Science Center at Denver, Colorado is appointed as the technical coordinator. The project also involves task-specific collaborations with the US Army Corps of Engineers-Seattle District and Oak Ridge National Laboratory.

The main objective of this project is to develop an intuitive web-based tool for efficient simulation of post-wildfire hydrologic changes by integrating remotely sensed data in a hydrologic model. Specifically, by using the Clark Fork Basin in the Western United States (draining 49,500 km^2 of Montana) as a testbed, this project will equip watershed managers and stakeholders with a user-friendly semi-automatic workflow that can perform four tasks: (1) download of remotely sensed datasets from NASA satellites and rapid post-processing of fire- and drought-relevant variables (i.e., leaf area index, evapotranspiration, soil wetness), (2) seamless integration of remotely sensed data into a hydrologic model, (3) simulation and analyses of hydrologic flow and sediment transport across a large river network, and (4) visualization of input-output data through a dynamic, interactive map interface. In addition to its web-based semi-automatic functionality, a unique feature of the proposed tool lies in its **reproducible architecture** which will allow users to perform the aforesaid data-model integration tasks at different spatial and temporal scales with minimal effort. **This project will test four cases in the Clark Fork Basin to demonstrate practical applications and broader impacts of the proposed tool**: (1) simulate daily streamflow and sediment load across a large river network, both immediately and over the long-term after a wildfire event, (2) quantify the uncertainty in post-fire streamflow predictions and show how and to what extent the proposed tool can improve model reliability, (3) compare before- and after-fire scenarios, identifying areas that may need management interventions for post-fire streamflow recovery, and (4) simulate and quantify the compound impacts of past/recurring wildfire events, droughts, and future climate projections on surface water storage especially in the headwater subcatchments. **Finally, this project will organize stakeholder training activities aiming towards a sustained and widespread future usage of the proposed tool**. By addressing these critical needs, the proposed project will demonstrate how a stakeholder workforce equipped with next-generation data-driven web-based computational capabilities can enhance water management, outreach, and environmental justice in rural western US communities.

This project fulfills the requirements of two eligible project types as noted in Bureau of Reclamation's Notice of Funding Opportunity – section C.3.1, specifically, **Project Type 1**: to enhance modeling capabilities to improve water supply reliability and increase flexibility in water operations, and **Project Type 3**: to improve access to and use of water resources data or to develop new types of data to inform water management decisions. Majority portion of the proposed work will be conducted at non-federal facilities in Texas and Montana, while some part of data analyses and interpretation will be conducted at the USGS Denver Federal Center in Denver, Colorado. Federal funds are primarily being requested to support personnel for model/tool development tasks and to organize training workshops for stakeholder outreach and project dissemination. Non-federal cost-share contributions are committed by the applicant organization Texas A&M University, Kingsville, with partial in-kind contribution from Clark Fork Coalition, Montana. The work described in this proposal will be conducted over the course of 24 months and completed no later than December 2023.

1.2 Technical Project Description

1.2.1 Problem Statement

Climate-driven megadroughts and very large fires (VLFs) are emerging in North America (Barbero et al., 2015; Williams et al., 2020). The National Interagency Fire Center reported 107,000 wildfire events in the past two years (2019-2020), most of which occurred in the drought-prone western United States. Consequently, understanding the compound hydrologic effects of recurring fire, drought, and climate projections, and their immediate and long-term implications on water management, has become time-sensitive for communities across the western United States. While it is widely acknowledged that wildfires can devastate aquatic ecosystems, quantification of wildfire effects on freshwater supply, especially at large basin-scales, remain challenging (Bladon et al., 2014; Robinne et al., 2020). The following are the three main reasons why a hydrologic modeling framework capable of linking fire and water does not yet exist for western United States basins.

(i) Commonly used hydrologic models lack capabilities to capture land surface disturbances due to wildfires. Existing burned area products like MTBS (Monitoring Trends in Burn Severity: https://www.mtbs.gov/), USGS Landsat Burned Area Product (Hawbaker et al., 2020), BAER (Burn Area Emergency Response: https://fsapps.nwcg.gov/baer/), and NASA-FIRMS (Fire Information for Resource Management System: https://firms.modaps.eosdis.nasa.gov/) have made estimates of burned area extent and burn severity readily available. Converting these disturbance products into soil properties via statistical regressions and using those relationships for localized simulation of erosion, debris flow, and hillslope runoff is doable. Nonetheless, **simulating the immediate and long-term hydrologic effects of wildfires across large river networks by directly integrating burned area extent or burn severity into commonly used hydrologic models is not feasible without significantly changing model source codes.** Needless to say, rural water districts are not well-resourced to conduct such model development activities.

(ii) Initiatives to link observed fire perimeters with watershed drainage area, gage stations etc. are already underway (e.g., Fire-Hydro tool in USGS streamstats: https://test.streamstats.usgs.gov/fire-hydro-demo/). Yet, these are predominantly statistical approaches and may offer limited assistance to stakeholders interested in running what-if scenarios of past/recurring fires, droughts, and future climate projections.

(iii) Employing near real-time remotely sensed estimates of vegetation, evapotranspiration, and soil moisture across areas impacted by wildfire can be effective solutions to the abovesaid limitations. There are numerous scientific studies showing how such estimates can effectively capture impacts of drought and fire disturbances (e.g., Kumar et al., 2020; Sazib et al., 2018), and more importantly, there are proven, widely accepted techniques to integrate these estimates in a variety of hydrologic models (Rajib et al., 2020). However, downloading and processing these spatially distributed and temporally continuous datasets, and subsequently integrating these "big data" with hydrologic models require specialized computational frameworks. Furthermore, translating modeling and remote sensing outputs into actionable results for stakeholder workforce development would require data sharing and visualization frameworks.

1.2.2 Objectives

This project has three objectives.

<u>*Objective 1*</u>: **The main objective of this project is to develop an intuitive web-based tool for efficient simulation of post-wildfire hydrologic changes by integrating remotely sensed data in a hydrologic model (Figure 1).** Specifically, by using the Clark Fork Basin in Montana (see section 1.3) as a testbed, this project aims to equip watershed managers and stakeholders with a user-friendly semi-automatic workflow that can perform four tasks:

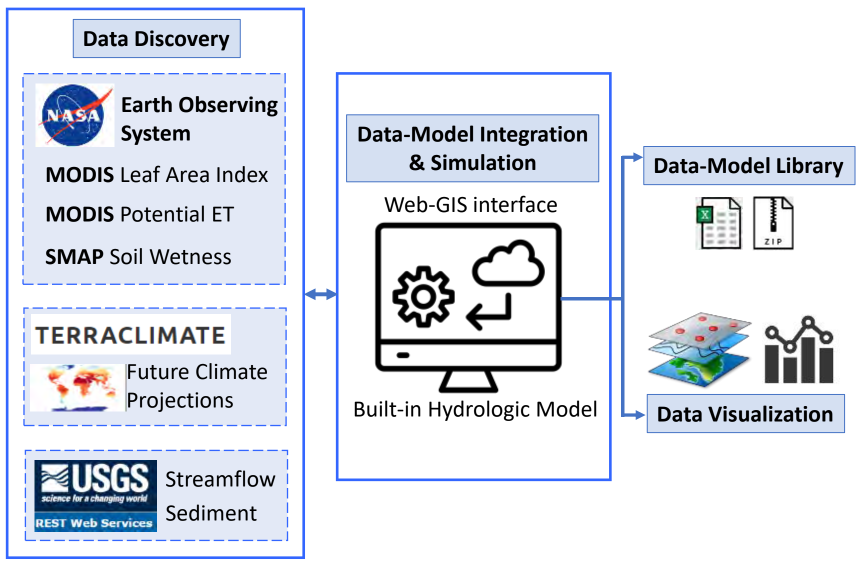


Figure 1. A schematic framework of the proposed tool.

(i) instantaneous download of remotely sensed datasets from NASA satellites and rapid post-processing of four fire- and drought-relevant variables (i.e., leaf area index (LAI), evapotranspiration (ET), soil wetness (SW))

(ii) seamless integration of remotely sensed data into a hydrologic model;

(iii) simulation and analyses of past/recurring fire, near real-time drought, and climate change effects on hydrologic flow and sediment transport across a large river network; and

(iv) visualization of input-output data through a dynamic, interactive map interface.

<u>*Objective 2*</u>: This project will test four cases in the Clark Fork Basin to demonstrate the practical applications and broader impacts of the proposed tool:

(i) simulate daily and seasonal streamflow and sediment load across a large river network, both immediately and over the long-term after a wildfire event,

(ii) quantify the uncertainty in post-fire streamflow predictions and show how and to what extent the proposed tool can improve model reliability,

(iii) compare before- and after-fire scenarios, identifying areas that may need management interventions for post-fire streamflow recovery, and

(iv) simulate and quantify the compound impacts of past/recurring wildfire events, droughts, and future climate projections on surface water storage especially in the headwater subcatchments.

Objective 3: Finally, this project intends to coordinate with local partners, regional offices of federal agencies, and a national laboratory to develop a targeted stakeholder outreach activity aiming towards a sustained and widespread future usage of the proposed tool.

1.2.3 Methodology

1.2.3.1 Development of HydroFlame: As outlined in **Figure 1**, the proposed web-based tool (referred to as HydroFlame for simplicity) will have four loosely coupled structural components: (i) data discovery (DD), (ii) data-model integration and simulation (DMIS), (iii) data-model library (DML), and (iv) data visualization (DV). **Loose coupling allows modification (or addition) of an existing (a new) component without having to develop the entire workflow again. Such a flexible architecture will facilitate future reproducibility of HydroFlame for any western United States basin.**

(i) Data Discovery (DD): The DD component will search, download, and post-process seven specific datasets (**Table 1**). The three remotely sensed datasets, i.e., LAI, ET, and SW, can be obtained within 3-4 days of a wildfire event. This will allow stakeholders to perform near real-time simulation of wildfire hydrologic effects. Importantly, the DD component will retrieve future-year drought severity and corresponding weather variables from a recent, quality-controlled data repository called TerraClimate (Abatzoglou et al., 2018). Such functionality will allow stakeholders to run numerous scenarios and quantify the compound effects of recurring fire/drought and potential climate change. Another unique feature of the DD component is its ability to seamlessly interact with any stream gage station via existing USGS URL, which will facilitate instantaneous model validation in parallel with scenario runs without diverting stakeholders from HydroFlame's interface. The DD component will be developed in Google Earth Engine (GEE)

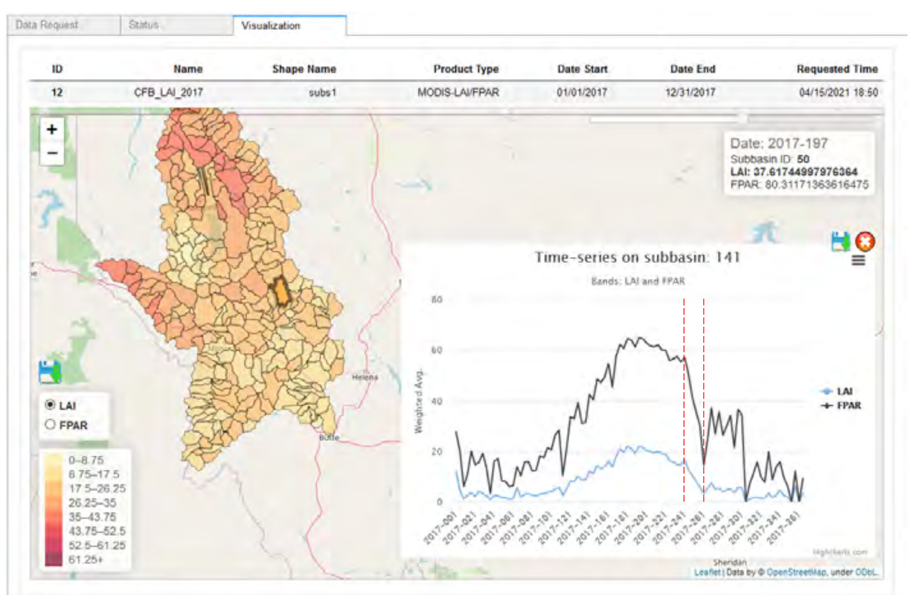


Figure 2. An example Google Earth Engine application developed for instantaneous download and visualization of NASA earth observations at stakeholder-specified watershed scales. The graph shows a **drastic 88% reduction of land surface vegetation within a span of only three weeks during the historic 2017 Rice Ridge wildfire in Clark Fork Basin (study area of this project)**.

using R and python programming. **Figure 2 shows an example Google Earth Engine application for the Clark Fork Basin developed by project manager Rajib** (accessible online at: https://mygeohub.org/tools/hydroglobetool).

(ii) Data-model integration and simulation (DMIS): As the parent component of the HydroFlame tool, DMIS will function as a message passing interface (MPI) across all other components. Briefly, DMIS will allow stakeholders to see a pre-set Clark Fork Basin hydrologic model and insert simple user-commands via an interactive GIS interface. Provided with a start date and end date by a user, DMIS will seamlessly (meaning, without requiring any human intervention) activate DD component, receive post-processed data, integrate that data into the model, and let stakeholders run simulations. DMIS will be initially hosted at the Texas A&M University's High Performance Computing Center for project development and dissemination purposes (TAMUK-HPCC: https://www.tamuk.edu/engineering/institutes-research/hpcc/).

Table 1. Datasets used to develop the HydroFlame tool.

	Data	**Spatial, Temporal Resolution**	**Source**
Remotely sensed fire- and drought-relevant variables			
1	Leaf Area Index (LAI)	500 m, 4 day	NASA MODIS (MCD15A3)
2	Evapotranspiration (ET)	500 m, 8 day	NASA MODIS (MOD16A2)
3	Soil Wetness (SW)	9 km, daily	NASA NSIDC
4	Landsat Burned Area Product	30 m, 8-16 days	USGS
5	MODIS Burned Area Product	500 m, monthly	NASA MODIS (MCD64A1)
SWAT model inputs			
6	DAYMET climate	1 km, daily	NASA ORNL DAAC
7	Digital Elevation Model	30 m, 8-16 days	USGS
8	Land use	30 m	USGS NLCD, USDA cropland layer
9	Soil Texture	1:250,000	STATSGO built in with SWAT database, NRCS
Future-year drought estimates			
10	Precipitation and temperature	4 km, monthly	TerraClimate, University of CA, Merced
11	Palmer Drought Severity Index	4 km, monthly	TerraClimate, University of CA, Merced
Gage information for model evaluation			
12	Streamflow	point data, daily	USGS stream gage data
13	Sediment	Daily, monthly	USGS stream gage data

(iii) Data-model Library (DML): The DML component will store all input data, metadata, and model results for a given simulation, and subsequently allow stakeholders to download these datasets in user-friendly formats (e.g., excel, PDFs). Like DMIS, DML too will be initially hosted at TAMUK-HPCC. After project completion, both DMIS and DML can be moved to any other secured HPCC server suggested by the Bureau of Reclamation. However, as noted before, such relocation will not affect the other two end components (DD and DV) because of HydroFlame's loosely coupled architecture.

(iv) Data Visualization (DV): The DV component will offer GIS mapping and graph plotting functionalities such that stakeholders can browse over a map interface, click on any stream segment, and explore results in a spatially explicit manner. Like DD, the DV component will be

developed in Google Earth Engine. **Figure 3 shows an example Google Earth Engine application developed by project manager Rajib for streamflow visualization across the Clark Fork river network** (accessible online at: https://mygeohub.org/groups/water-hub/swatflow)

1.2.3.2 The Clark Fork Basin SWAT model: This project will use Soil and Water Assessment Tool (SWAT) for hydrologic modeling because it is a process-based semi-distributed model often used for simulating the post-wildfire effects on streamflow and sediment across large river networks (e.g., Loiselle et al., 2020). **Project manager Rajib recently set up a prototype SWAT model for the Clark Fork Basin** (study area of this project). This prototype model was constructed with 30-m resolution topography and land cover datasets. After forcing the model with 1-km DAYMET weather data (Thornton et al., 2018), the project team performed a 5-year (2015-2019) multi-objective calibration using (i) USGS streamflow estimates at gage station #12389000 (Clark Fork near Plains, Montana) and (ii) North American Land Data Assimilation System (Xia et al., 2012) snow water equivalent (SWE) estimates at two headwater subcatchments. The preliminary results were used in the example Google Earth Engine application shown in **Figure 3**. During the actual project execution stage, this prototype model will be recreated, recalibrated, and validated with the best available geospatial data and calibration constraints (based on the suggestions of our technical advisors and a Bureau of Reclamation scientist; discussed in a later section). As such, once the final version of the model is set in the web-based HydroFlame, stakeholders can construct scenarios and run simulations without having to do tedious calibrations.

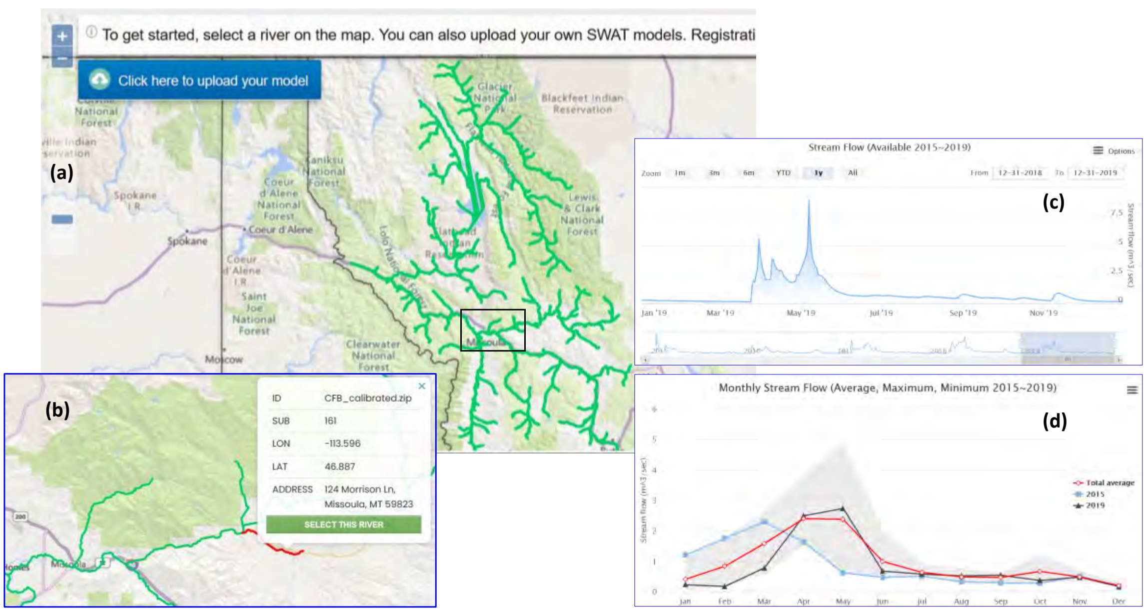


Figure 3. An example Google Earth Engine application for hydrologic visualization of the Clark Fork Basin: (a) interactive GIS map interface allowing stakeholders to browse and select any stream segment, (b) upon selection, the interface shows a representative geolocation (e.g., zip code, nearby street address), (c) interactive streamflow time-series with zoom-in/zoom-out options, and (d) interannual and seasonal streamflow comparison. Based on a prototype SWAT model developed by the project team.

1.2.3.3 Representation of Fire Disturbance in SWAT model: As we noted in section 1.2.1, commonly used hydrologic models do not account for disturbance events, such as wildfire, despite fires potential to substantially change vegetation condition. Therefore, we will develop a SWAT model which can account for fire disturbances by incorporating fire induced changes in remote sensing data products, LAI, ET, and SW, and simulate the corresponding changes in hydrologic flows. **The integration of remotely sensed LAI, ET, and SW data in our Clark Fork SWAT model will follow proven, widely accepted techniques.** Literature suggesting the efficacy of these techniques for improved hydrologic model predictability are discussed in section 1.5.3 (C.1).

Nonetheless, the USGS Landsat Burned Area product and MODIS Burned Area product (MCD64) will be used to define burned area extent within the Clark Fork Basin, while the impact of each fire event will be characterized using LAI, ET and SW data. The burned area products will enable us to attribute the changes in LAI, ET, and SW to specific fire events as well as characterize how burn size, timing, and watershed position influences the impact of the fire event on streamflow. In essence, such characterizations will produce quantitative evidence of how effectively LAI, ET, and SW can serve as a fire disturbance proxy for commonly used hydrologic models.

While our methodology will continue to evolve, our tangible initial work for HydroFlame's development, clearly indicates the potential for successful materialization of this proposal.

1.3 Project Location

The study area of this project is a 49,500 km^2 portion of Hydrologic Unit Code 170102 draining into the Clark Fork river near Plains, Montana (referred to as the Clark Fork Basin; **Figure 4**). The area considered in this project, however, excludes (i) the 6000 km^2 Lower Clark Fork

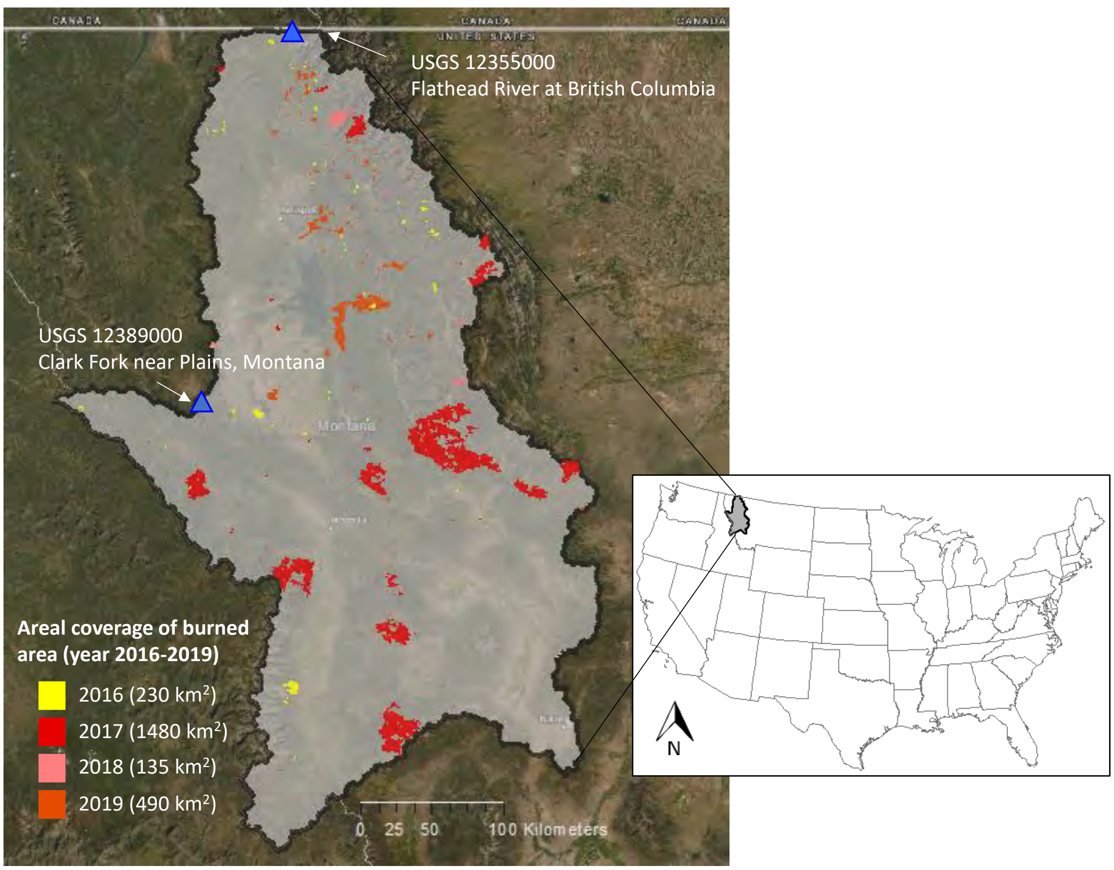


Figure 4. Study area: the 49,500 km^2 Clark Fork Basin, draining into Clark Fork River near Plains, Montana. The streamflow data available from the gage station at Flathead River (British Columbia, Canada) will be used in the project's modeling work as an inflow boundary condition. The map also shows recurring fire events based on a recent Landsat data analyses conducted by this project's technical coordinator.

subcatchment – the downstream-most portion of the Clark Fork Basin, draining the area between Plains and Lake Pend Oreille near Sandpoint, and (ii) the 1700 km^2 Flathead River subcatchment in British Columbia, Canada. This basin, being the largest in the state by water volume, supports more than

The Clark Fork Basin was chosen for this project because of two reasons:

(i) Drought and wildfire have been posing significant impact on the basin's river network. Our **project's technical coordinator Vanderhoof identified a high frequency of fire events in the Clark Fork Basin using Landsat data**, revealing 2500 km^2 burned area between 2016 and 2019 (see Hawbaker et al., 2020; **Figure 4**). Especially, the 2017 fire events in this basin became the top priority fire in the nation (see Rice Ridge fire: https://en.wikipedia.org/wiki/Rice_Ridge_Fire). Wildfire is major source of disturbance in the Clark Fork Basin making it an ideal study area for this project.

(ii) This basin offers abundance of streamflow and sediment data though more than 20 USGS gage stations (not shown in the map below). The long-term continuous data availability in these gage stations could be a critical resource for validating model results at an actionable scale especially in drought-prone lower order streams.

(iii) The basin has enthusiastic and engaged stakeholders and partners most located in Missoula, Montana, which is centrally located within the basin. We have been fortunate to receive support for this project from the City of Missoula, Missoula Valley Water Quality District, Clark Fork Coalition, The Nature Conservancy (which owns former timberlands within the basin). The needs and knowledge provided by these organizations will be critical as the project develops and modeled scenarios are refined.

1.4 Data Management Practices

Our project team is strongly committed to providing open-access to data products, software tools, and model results (note, our proposed HydroFlame tool will be web-based and open-access).

(i) Geospatial and time-series data: The data products will be released to the public via open access data repositories such as HydroShare (https://www.hydroshare.org/). We will follow the Dublin Core protocol (https://dublincore.org/) to collect metadata. Note, this project will entirely rely on widely accepted open-access datasets (e.g., remotely sensed data from NASA), which undergo unique quality control-quality assurance procedures. Further, collection of field data is not within the scope of this project. Given the above, an extensive quality control-quality assurance program will not be necessary in this project. However, all data products generated in this project will undergo a suite of diagnostics before being released to the public.

(ii) Reproducible codes: Majority of software codes developed in this project will be in Google Earth Engine (https://earthengine.google.com/). The codes will be hosted on GitHub with necessary documentation and tutorials. The project managers will continue to maintain the packages on GitHub beyond the project period.

(iii) Model storage and sharing: The SWAT model and its configurations (related to the four use-cases highlighted in objective 2), along with all inputs and outputs will be made publicly available via SWATShare (https://mygeohub.org/groups/water-hub/swatshare_landing).

(iv) Link to access the proposed HydroFlame tool: The project managers will coordinate with its local partners (Clark Fork Coalition and/or City of Missoula) to have a dedicated URL for HydroFlame.

1.5 Evaluation Criteria

1.5.1 Evaluation Criterion A – Benefits to Water Supply Reliability

A.1. Describe the **water management issue(s)** that your project will address. For example, will your project address water supply shortfalls or uncertainties, the need to meet competing demands for water, complications arising from drought, conflicts over water, or other water management issues? Describe the severity of the water management issues to be addressed through your project.

Our project will address uncertainties in assessing surface water quantity and quality arising from frequent wildfires and droughts. As shown in **Figure 4**, our project location Clark Fork Basin in Montana has been experiencing recurring wildfires and droughts in consecutive years, with nearly 1500 km^2 area burnt (3% of total basin area) in 2017 alone. Given the scientific evidence found across the western United States (Hallema et al., 2017; Holden et al., 2011; Wine and Cadol, 2016), it is highly likely that these recurring events are altering the basin's streamflow and sediment transport, thus increasing uncertainties in overall water supply.

According to Montana Department of Natural Resources and Conservation (DNRC), more than 90% of Clark Fork's total water supply contributes to hydropower generation by the Thompson Falls Dam. The dam, located in the Lower Clark Fork subcatchment (immediately downstream of our project location), is one of the most significant hydropower facilities in Montana. Therefore, water supply uncertainties, e.g., altered dam inflow due to fire disturbances in upstream hydrologic conditions and reduced dam height due to increased sediment transport, will pose considerable threat to the future of the state's hydropower management.

The Clark Fork river network is also a major source of water for irrigated agriculture. Through our initial remote sensing work and collaborative discussions with our local project partners City of Missoula, Missoula Valley Water Quality District, Clark Fork Coalition, and The Nature Conservancy, we found that some of the recent major fire events occurred in hillslopes that are near small depressional surface water storage systems and irrigated lands (further discussed in section 1.5.1 (A.4) with graphical illustrations). Under these conditions, the competition between meeting irrigation demands and maintaining fisheries (Clark Fork's native trout), aquatic habitat, and watershed health is creating conflicts among stakeholders. This has led Montana DNRC to state the following in its *Water Supply Report for Water Availability and Mitigation Options*: "water availability for new uses, including development, population growth, and fishery restoration is short in supply in the Clark Fork Basin".

To sustain the potential effects of climate trends on future water supplies, the Clark Fork Basin Task Force's *Water Plan 2014* recommended the use of natural infrastructure (e.g., wetlands and depressions in the valleys and along the floodplains) for increased surface water storage. There is no data to confirm whether and to what extent these natural infrastructures continue to be useful for water storage in postfire hydrologic conditions. Nonetheless, there has been no basin-scale initiative to specifically address wildfire hydrologic effects across the Clark Fork river network. Our project will be the first to fill this gap and help stakeholders to make informed management decisions both locally and regionally year in and year out into the future.

A.2. Explain **how** your project will address the water management issues identified in your response to the preceding bullet. In your response, please explain how your project will contribute to one or more of the following water management objectives and provide support for your response: **a.** water supply reliability, b. management of water deliveries, c. water marketing activities, **d.** drought management activities, e. conjunctive use of ground and surface water, f. water rights administration, g. ability to meet endangered species requirements, h. watershed health, i. conservation and efficiency, or j. other improvements to water supply reliability.

We will test four use-cases addressing the emergent water supply uncertainties in the Clark Fork Basin, and therefore justify our project's direct contribution to **water supply reliability and drought management activities**. The four use-cases include the following:

(i) simulate daily and seasonal streamflow and sediment load across a large river network, both immediately and over the long-term after a wildfire event,

(ii) quantify the uncertainty in post-fire streamflow predictions and show how and to what extent the proposed tool can improve model reliability,

(iii) compare before- and after-fire scenarios, identifying areas that may need management interventions for post-fire streamflow recovery, and

(iv) simulate and quantify the compound impacts of past/recurring wildfire events, droughts, and future climate projections on surface water storage especially in the headwater subcatchments.

The proposed HydroFlame tool will make fire- and drought-relevant remotely sensed "big data" Findable, Accessible, Interoperable, and Reproducible (FAIR) to ensure their maximum utilization in water management. With this new capacity, stakeholders can easily integrate remotely sensed data with a hydrologic model, simulate hydrologic effects of wildfire disturbances, and therefore generate reliable estimates of streamflow and sediment across the Clark Fork river network. Furthermore, **HydroFlame will pave the way for next-generation drought management in the Clark Fork Basin by delivering numbers, graphs, and maps at variable actionable scales**. Specifically, stakeholders using HydroFlame will be able to analyze and compare streamflow and sediment outputs across three different spatial scales: stream-segments, communities, and regions within the basin. These outputs will also be available at three temporal-scales: immediately after a wildfire or drought event, over the long-term after an event, and at a distant future based on climate change projections. In summary, our work will improve water supply reliability and drought management activities in the Clark Fork Basin by (i) simulating the right amount of water in right place though a realistic model, (ii) filling critical data gaps both spatially and temporally, and (iii) translating these outputs to the stakeholders in a user-friendly manner.

A.3. Describe **to what extent** your project will benefit one of the water management objectives listed in the preceding bullets. In other words, describe the significance or magnitude of the benefits of your project, either quantitatively or qualitatively, in meeting one or more of the listed objectives.

The project team recently produced some preliminary results based on a protype Clark Fork Basin SWAT model (revisit our methodology in section 1.2.3.2). The sole purpose of this preliminary modeling work was to gain some quantitative evidence of the extent to which the proposed HydroFlame tool would reduce water supply uncertainties arising from wildfire disturbances.

Figure 5 compares streamflow simulations between a conventional and a remote sensing-integrated SWAT model immediately after a historic fire event in the Clark Fork Basin. While both models were constructed with identical geospatial data and weather forcing, the respective **streamflow outputs were 10-75% different**. What was also noteworthy was the spatial distribution confirming how wildfire could alter downstream streamflow over a vast area even though fire occurrences could be in hillslopes and/or headwater catchments. Further, while fire events can induce dramatic changes to vegetation (e.g., **Figure 2**) and associated ET and SW, drought events can cause basin-wide reductions in vegetation, impacting ET, SW and streamflow (Bachmair et al., 2018). The integration of remotely sensed data products enables a model to capture these heterogeneities.

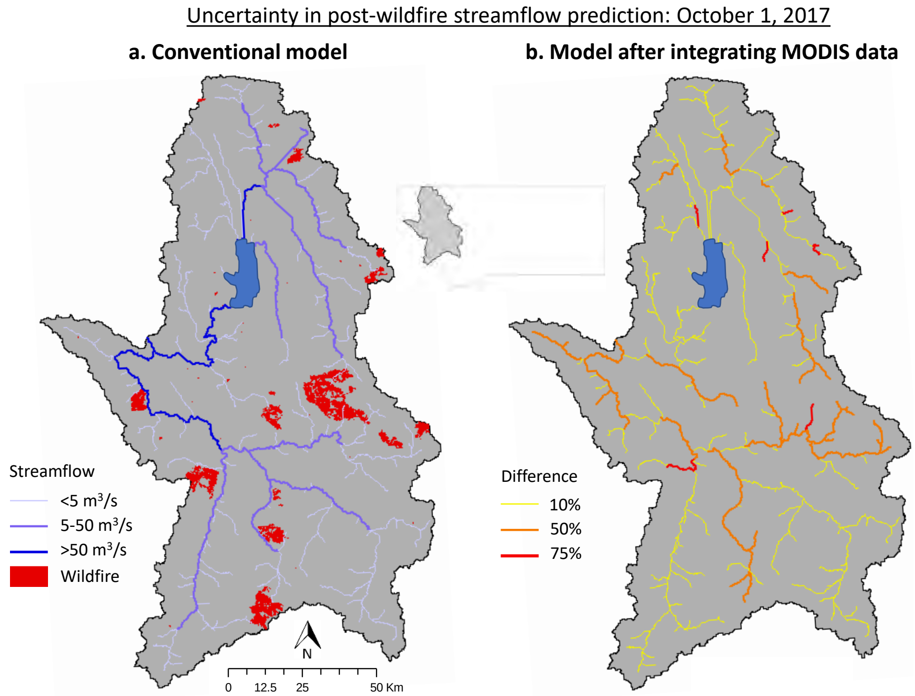


Figure 5. Streamflow in Clark Fork Basin (October 1, 2017) following the historic Rice Ridge fire. Based on a prototype SWAT model recently set by the project team. Integration of MODIS Leaf Area Index data shows 10-75% difference (b) from a model that does not capture wildfire disturbances (a).

Some of these major fire events in the Clark Fork Basin occurred in hillslopes that are near small depressional surface water storage systems and irrigated lands. **Figure 6** presents a unique perspective of wildfire-effects on such headwater surface storage systems using SWAT simulated sediment data. Following the changes in streamflow, Clark Fork Basin showed significantly increased sediment load after a wildfire event. Our preliminary results as shown in Figure 6 indicate that **increased sediment load could reduce the surface water storage capacity of floodplains, riparian buffers, wetlands, and other depressional systems available in abundance in some of Clark Fork's headwater subcatchments**. Knowing where and to what extent these surface storage systems are impacted due to wildfire-related hydrologic changes and sediment movement will improve water supply reliability and drought management activities.

A.4. Explain how your project **complements** other similar applicable to the area where the project is located. Will your project complement or add value to other, similar efforts in the area, rather than duplicate or complicate those efforts? Applicants should make a reasonable effort to explore and briefly describe related ongoing projects.

Local, state, federal agencies, and nongovernmental organizations in Montana are responding to drought and climate change through management decisions focusing on improved resiliency on public lands and waterways. Our discussions with these agencies confirmed that an initiative specifically focusing on developing a web-based tool for simulating and visualizing hydrologic effects of wildfire at large river network-scale (main objective of this project) does not yet exist in the state. We, therefore, made a consolidated effort by engaging with local, state, federal agencies, and nongovernmental organizations across five states: Montana, Wyoming, Idaho, Washington, Colorado, and Nebraska.

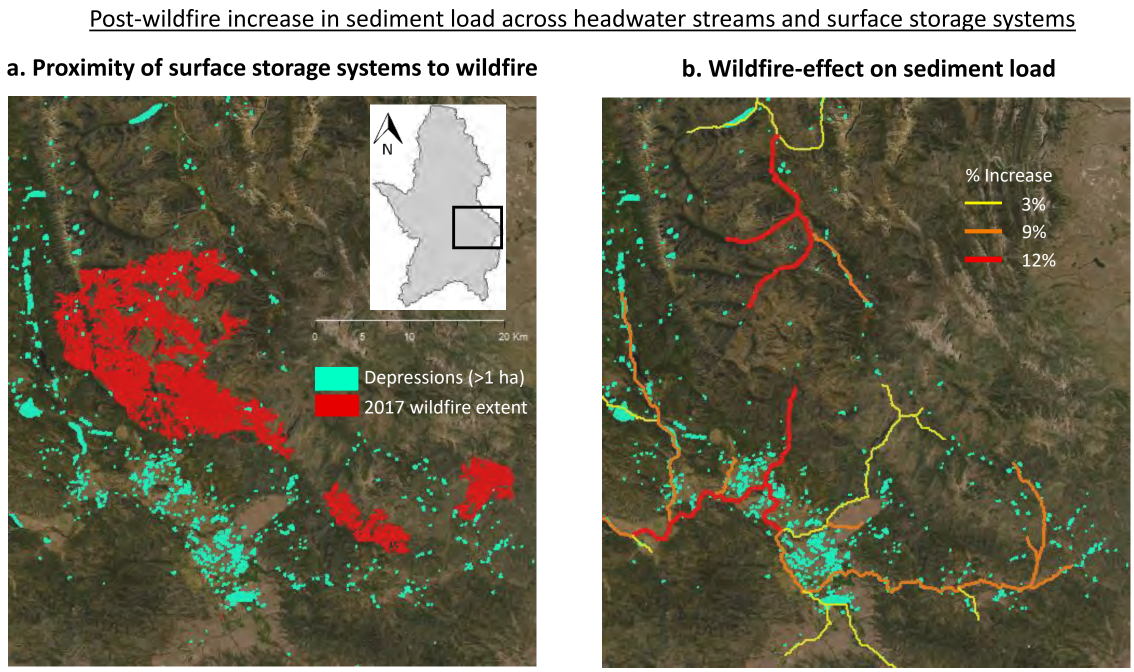


Figure 6. *Model simulations after a wildfire event show potential increase in sediment areas with high potential of surface storage.*

We found that the following initiatives are complementary to our proposed project.

(i) USGS streamstats Fire-Hydro tool (https://test.streamstats.usgs.gov/fire-hydro-demo/) – a prototype project to link fire perimeters with estimates of watershed drainage area, gage stations etc. via statistical approaches.

(ii) LANDFIRE (https://www.landfire.gov/) – A suite of remotely sensed products produced by USGS and US Forest Service (USFS) to simulate the impact of fire and other disturbances on vegetation and fuel loads.

(iii) USFS's Missoula Fire Science Laboratory (https://firelab.org/) – Conduct research and develop management tools and applications focused on fire and fuel management, smoke emissions, and fire ecology, including national wildfire hazard potential products.

(iv) Clark Fork Coalition (https://clarkfork.org/) – An organization focused restoring degraded waterways, and engaging local communities across the Clark Fork River Basin (hence, one of our local partners).

(v) The Missouri Headwaters Drought Resilience Demonstration Project (https://uppermissouriheadwaters.org/drought-resiliency/) – An effort focused on developing drought plans, implementing local projects to enhance water storage, and developing a tool to track river condition in an adjacent watershed.

The above-mentioned initiatives either produce and compile data on watersheds, fire risk and fire impacts (i, ii, iii) or are focused on engaging local communities (iv, v). However, none of the efforts discussed work to integrate the impacts of drought, wildfire, streamflow, and sediment across the Clark Fork Basin. Therefore, **our proposed work will not duplicate any of these initiatives. There is rather a great potential for integrating local experience from organizations like the Clark Fork Coalition, and data products produced by NASA, USGS and USFS into our proposed HydroFlame tool**.

1.5.2 Evaluation Criterion B – Need for Project and Applicability of Project Results

B.1. Will the project result in an applied science tool(s) or information that is readily applicable, and highly likely to be used by water resource managers in the West?

Our initial progress (see Figures 2-6) clearly indicates the potential for making the project readily "operational" for water resource managers and stakeholders in the Clark Fork Basin. Our methodology is based entirely on open-source data, models, and web-based platforms (e.g., Google Earth Engine, Texas A&M High Performance Computing Center). We are also proposing to use proven, widely accepted techniques. These are the ingredients of making a web-based such that it can be executed rapidly after deployment modified as necessary and maintained easily over a long period of time.

B.1.a. Explain **who** has expressed the **need** and describe **how** and **where the need** for the project was identified (even if the applicant is the primary beneficiary of the project). For example, was the need identified as part of a prior water resources planning effort, determined through the course of normal operations, or raised by stakeholders? Provide support for your response (e.g., identify the entities that have expressed a need or cite planning or other documents expressing a need for the project).

Vanderhoof and Rajib become involved in drought-focused research in western Montana through an US EPA Region 8 RARE Grant in 2016, "Building Resiliency and Watershed Prioritization Using Natural Water Storage Techniques." This research was a collaboration between USGS, EPA, and The Nature Conservancy to examine impacts of stream restoration activities (Vanderhoof and Burt, 2018) and evaluate the relative impact of climate and agricultural irrigation on riparian corridors (Vanderhoof et al., 2019). As part of this research project, **Vanderhoof and Rajib participated in the Upper Missouri Headwaters Basin Task Force Meeting in Bozeman, Montana in November 2017.** This meeting brought local, state, and federal government entities together with local stakeholders and non-governmental organizations to brainstorm approaches and develop partnerships to build watershed resiliency to drought. The meeting invoked cross-disciplinary discussions on wildfire, drought, climate change, and streamflow, laid out a foundation for project managers to find suitable local partners and technical advisors, and served as the initial motivation for developing this proposal.

After developing the basic proposal concepts, Rajib and Vanderhoof discussed the proposed research project with local collaborators including the City of Missoula, Missoula Valley Water Quality District, Clark Fork Coalition, and Nature Conservancy who were able to clarify the need for evaluating and predicting the impact of drought and wildfire on streamflow and confirm the potential value of developing an online tool, usable by the City government and non-governmental organizations.

In addition to our project development initiatives highlighted above, there have been recent water resources planning efforts specifically focusing on the Clark Fork Basin that clearly identified the need for our project. Some of these efforts are outlined below:

(i) ClimateWise: Missoula County in Montana assessed how a changing climate might affect Clark Fork river network and subcatchments encompassing Missoula County, using science and local expertise in a community-based process called ClimateWise. The ClimateWise process included an analysis of local climate change model projections and a community workshop for a variety of stakeholders. **Our partners City of Missoula and Missoula Valley Water Quality District were members of ClimateWise steering committee**. The ClimateWise findings acknowledged the need for our project by pinpointing the complex synergy between water supply, wildfire, flooding, and water quality (https://climatewise.org/projects/905-missoula-county).

(ii) Lolo Watershed Climate Change Vulnerability Assessment: The US Forest Service, specifically the Lolo National Forest (LNF), performed a watershed vulnerability assessment investigating on how local streams will respond to a warming climate. **Our local community partner Clark Fork Coalition was a co-investigator of the LNF project**. The report culminated from this project outlined how an integrated approach such as the one we proposed here would help guide future land management decisions with regards to maintaining resilient watersheds. The report also emphasized on user-friendly translation or data visualization such that managers in LNF or the Clark Fork Basin in general can use assessment results in numerous ways, including prioritization of streams/subcatchments for risk reduction, restoration emphasis, short and long-term strategies, identification of data needs, education and outreach opportunities, among others (https://www.fs.usda.gov/main/lolo/workingtogether). We proposed to add a web-based data visualization component in HydroFlame (e.g., **Figures 3**) following the above recommendations.

(iii) Missoula Community Climate Smart Action Plan: The Missoula Community Climate Smart Action Plan, a collaborative initiative by the City of Missoula, University of Montana, and various conservation groups, stated the following: "The combined impacts of increased temperatures, changes in streamflow and spring runoff, increased wildfire, and shifts in aquatic and terrestrial species have begun to shift forest landscapes and the overall composition of ecosystems. Modelled projections and recent experience indicate that some components have and will change at an unprecedented rate with negative consequences, such as longer wildfire seasons" (p. 41). The plan also recommended "expanded water-focused education initiatives" and "more funding to prevent and mitigate effects of flooding after fire" (p. 46-47). The draft plan can be accessed from: https://www.ci.missoula.mt.us/DocumentCenter/View/31466/MissoulaCommunity_ClimateSmartActionPlan_v1-0?bidId. **Our local community partner Clark Fork Coalition served as lead facilitator for the creation of Missoula Community Climate Smart Action Plan**.

The need for our project was asserted in regional planning efforts as well. For example, the Washington Silver Jackets Post-wildfire Flood Committee is building an outreach plan around the increased flood risks associated with wildfire. The committee also acknowledges the need for a web-based fire-flood visualization platform (https://silverjackets.nfrmp.us/State-Teams/Washington). **US Army Corps of Engineers–Seattle District, the technical advisor of our project, serves in this committee as the coordinator of Washington Silver Jackets**.

B.1.b. Will the results of your project inform water resource management actions and decisions **immediately** upon completion of the project, or will additional work be required?

Yes. To ensure this, stakeholder training is included as one of our project objectives.

B.1.c. If applicable, will the results of your project be transferrable to other users and locations? Note: not all water management solutions are transferrable.

The remote sensing inputs and/or hydrologic simulation outputs produced from our project will be specific to Clark Fork Basin, hence these will not be transferrable. The HydroFlame tool, however, can be reproduced for any other basin with minimal effort. We explain HydroFlame's transferability/reproducibility in the following.

(i) As discussed in our tool development methodology (section 1.2.3.1), the two end components of HydroFlame, i.e., data discovery and data visualization will be based on Google Earth Engine, which will allow these components to be expanded by adding emerging remotely sensed wildfire datasets (see the work of our technical coordinator Vanderhoof in **Figure 4**) whenever such datasets become available after quality assurance.

(ii) The two central components of HydroFlame, i.e., data-model integration and simulation and data-model library, will be responsible for computation and storage tasks and hence these will be initially hosted at the Texas A&M High Performance Computing Center (HPCC). At a later stage after project completion, these two components can be hosted at any other web-based platform recommended by the Bureau of Reclamation with minimal re-programming.

Given the above, it is not an overstatement to say that the proposed HydroFlame tool can be the building block of an integrated fire and water management framework for the western United States.

B.1.d. If the applicant is not the primary beneficiary of the project (e.g., Category B applicant), describe how the project beneficiaries have been or will be involved in planning and implementing the project?

As noted in section 1.5.2 (B.1.a), project managers Rajib and Vanderhoof have been engaged in scientific discussions and planning with these partners and advisors since November 2017. Correspondingly, the projected managers organized virtual meetings in March-April 2021 to outline project objectives, deliverables, and respective role of each team member. How each of these partners and advisors will be involved in implementing the project is elaborated below.

(i) City of Missoula: Our Category A partner City of Missoula (through letter of participation from **Morgan Valliant**) commit to participate in all planning and coordination meetings in the first year and provide inputs to the project's model calibration-validation and tool development tasks. In the second year, City of Missoula will receive $4,500 from this project funding through an agreement with the Texas A&M University, Kingsville. The city will use this funding to organize a stakeholder training workshop for the dissemination of project outcomes.

(ii)The Clark Fork Coalition: The Clark Fork Coalition (CFC) is a river conservation organization of some 2,700 members, dedicated to protecting clean water and restoring healthy rivers throughout the Clark Fork watershed for the past 30 years. During the 2-year project period, CFC will work closely with the project managers to lead the outreach efforts and coordinate three virtual

workshops: one workshop in the first year of the project to include stakeholders' input in the tool design and two workshops in the final year of the project for output dissemination and stakeholder trainings. In this role, CFC will contribute to both development and dissemination of the project. CFC (through letter of support from **John DeArment**) is committing an in-kind contribution of $3,000 to conduct these activities.

(iii) Missoula Valley Water Quality District: The Missoula Valley Water Quality District is a local government agency with an interlocal agreement between the City of Missoula and the County of Missoula. The Water Quality District (though letter of support from **Travis Ross**) commits to collaborating with project managers on the evaluation of a prototype HydroFlame tool and testing its functionalities from stakeholders' point of view before making the tool available online. The Water Quality District also commits to participating in stakeholder training program organized during the project dissemination stage.

(iv) The Nature Conservancy: The Nature Conservancy (TNC) of Helena, Montana (a 501(c)(3) nongovernmental organization), through letter of support from **Nathan Korb**, commits to participating in project development by testing the proposed tool and ground-truthing its outputs. TNC will also participate in project dissemination by assisting in the preparation for stakeholder training sessions.

(v) US Army Corps of Engineers – Seattle District: The Seattle District of US Army Corps of Engineers (US ACE) maintains US ACE's jurisdiction on the Clark Fork Basin. In its role as Washington Post-wildfire Flood Committee participant, US ACE-Seattle District will serve in this project as a technical advisor. US ACE-Seattle District (through letter of support from **Travis Ball**) commits to assisting us in setting up the Clark Fork SWAT model by providing relevant technical instructions. US ACE-Seattle District will also join stakeholder meetings organized by the project team throughout the project duration.

(vi) Oak Ridge National Laboratory: The Oak Ridge National Laboratory (ORNL), with support from the Department of Energy, is developing energy-water digital platform to help the hydropower stakeholders make data-driven decisions. Because our project's outcomes can be beneficial to hydropower stakeholders, ORNL offers to serve in this project as a technical advisor. ORNL (through letter of support from **Debjani Singh**) commits to providing technical advice on geospatial and hydrological data management, quality assurance, and standardized data sharing and visualization protocols. It will also guide the project team to ensure that the proposed tool has a reproducible computational framework.

Project managers Rajib and Vanderhoof also coordinated with stakeholders beyond the geographical extent of one basin (Clark Fork, Montana). During the planning stage, Rajib and Vanderhoof communicated with the following agencies (and personnel) and incorporated most of their inputs into this proposal: (i) Wyoming Department of Environmental Quality (Jennifer Zygmunt), (ii) Wyoming Water Development Office (Barry Lawrence), (iii) Wyoming Game & Fish Department (Del Lobb), (iv) North Platte Natural Resources District, Nebraska (John Berge), (v) EPA Region 8 (Tina Laidlaw), and (vi) US Army Corps of Engineers – Omaha District (Kellie Bergman).

1.5.3 Evaluation Criterion C – Project Implementation

C.1. Briefly describe and provide support for the approach and methodology that will be used to meet the objectives of the project.

As we noted in section 1.2.3, our technical approach and methodology are based on proven, widely accepted research. However, for further justification, below we reintroduce specific topics and provide supporting information based on peer-reviewed literature and our own work.

(i) Detecting fire disturbances: Our approach of using remotely sensed Leaf Area Index (LAI), evapotranspiration (ET), and soil wetness (SW) data to detect fire disturbances is fully supported by recent NASA findings (Kumar et al., 2020; Sazib et al., 2018). Hydrologic modeling studies focusing on post-wildfire effects are therefore increasingly using these estimates to constrain model simulations in different parts of the world (see the works of Van Eck et al., 2016 on Europe and Saksa et al., 2019 on California, United States).

(ii) Integration of remotely sensed data and hydrologic models: We will apply a widely accepted technique called "direct insertion", which replaces the model's simulated LAI, ET, and SW using the corresponding remotely sensed data at every simulation time-step and across all the spatial units in the model (e.g., grid-cell or subcatchment). Project manager Rajib published several peer-reviewed journal articles on this direct insertion approach; each of those studies showed notable improvement in model's overall physical realism after integrating spatially distributed and temporally continuous remotely sensed data (see, e.g., Rajib et al., 2018, 2020).

(iii) SWAT as a suitable model for simulating hydrologic effects of wildfire: Selecting SWAT for our hydrologic modeling task is justified because of the following two reasons: (a) it is one of the few models which can be installed and simulated via web-based platforms associated with cloud/high performance computing resources (see Rajib et al., 2016), and (b) there is a recent trend of using SWAT for modeling post-wildfire streamflow and sediment in complex terrain watersheds (see the work of Loiselle et al., 2020 for Canadian Rocky Mountains).

(iv) Google Earth Engine and Texas A&M HPCC: Project managers Rajib and Vanderhoof extensively worked on Google Earth Engine (see Rajib's preliminary work for this project in **Figures 2-3**; also see Vanderhoof's work on wetlands and disturbances (Vanderhoof et al., 2020). Naturally, GEE was chosen for HydroFlame's development because it ensures total platform independence requiring no computational resource and software installation needs for managing "big data" at the user ends – a sustainable approach for implementing a tool for rural western United States communities. Texas A&M University's High Performance Computing Center (HPCC) is suitable for our simulation and storage purposes because this HPCC is doing similar works for other federally funded projects, including Rajib's current Department of Defense project on SWAT modeling (Federal Award Identification Number (FAIN): W912HZ2020071). Texas A&M is committed a significant cost-share ensuring the best possible utilization and maintenance of HPCC for the tasks specified in this project.

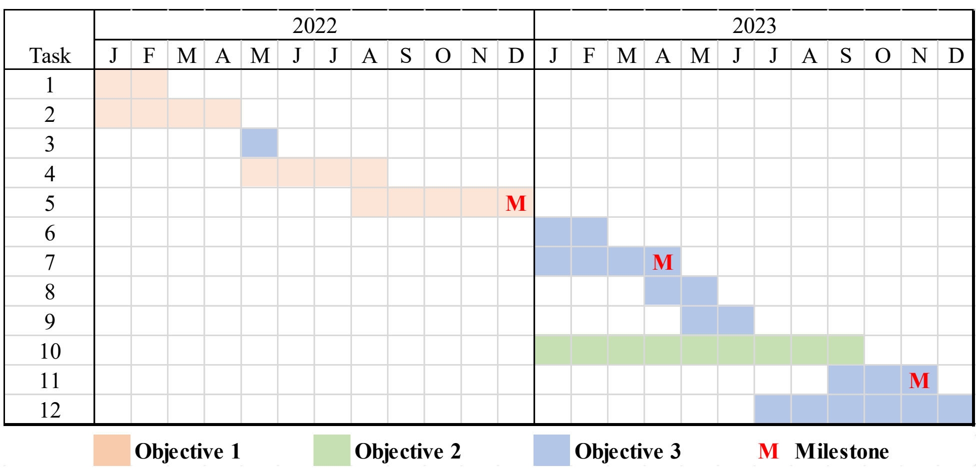
C.2. Describe the work plan for the project. Include an estimated project schedule that shows the stages and duration of the proposed work, including major tasks, milestones, and dates.

As outlined in section 1.2.2, this project has three objectives: (i) HydroFlame development, (ii) HydroFlame application on four use-cases, and (iii) dissemination. The three objectives are divided into 12 tasks (**Tables 2-3)**. Project managers Rajib, Vanderhoof, and the personnel recruited in Rajib's research group at Texas A&M will be conducting these tasks, with Vanderhoof being in a coordinating role specifically for the technical tasks (objectives 1-2). Tasks related to objective 3 (dissemination) will involve organizational effort of local partners.

Table 2. Project tasks.

Objective	Tasks	
1	Task 1.	Contracting Bureau of Reclamation scientist
1	Task 2.	Clark Fork SWAT model reconstruction, calibration, validation
3	Task 3.	Stakeholder workshop 1 (virtual): assessing stakeholder needs for tool development; organized by Clark Fork Coalition
1	Task 4.	HydroFlame development: data discovery and data visualization
1	Task 5.	HydroFlame development: data-model integration and simulation, data-model library
3	Task 6.	Coordination meeting 1 (virtual): model and tool evaluation by project partners and technical advisors
1	Task 7.	Reclamation meeting 2 (virtual): model and tool evaluation by Reclamation scientist
3	Task 8.	Stakeholder workshop 2 (virtual): training on tool functionalities; organized by Clark Fork Coalition
3	Task 9.	Stakeholder workshop 3 (virtual): training on tool functionalities; organized by Clark Fork Coalition
2	Task 10.	Simulation of use-cases 1-4
3	Task 11.	Stakeholder workshop 4 (onsite): stakeholder training on tool's application (use-cases 1-4), discuss future directions; organized by City of Missoula
3	Task 12.	Scientific communication (submission for peer review)

Table 3. Project timeline.



C.3. Provide a summary description of the products that are anticipated to result from the project. These may include data, metadata, digital or electronic products, reports, and publications. Note: using a table to list anticipated products is suggested.

While the most important product of this project will be the HydroFlame tool, potentially available through an open-access web URL, there will be additional products as listed below (not an exhaustive list):

(i) HydroFlame tutorials: Instruction materials, presentation files, and youtube videos demonstrating the functionalities and applications of HydroFlame.

(ii) Fire-relevant remotely sensed data: Collection of remotely sensed LAI, ET, and SW data, and associated USGS Landsat Burned Area product and MODIS Burned Area product (MCD64) (e.g., **Figure 4**) that are required to construct the four use-cases listed under objective 2 (section 1.2.2).

(iii) Hydrologic time-series/maps showing fire-effects: Data/GIS maps showing streamflow and streamflow changes resulting from specific fire events (e.g., **Figures 5-6**)

(iv) Python and R scripts: All associated scripts that are required to reproduce HydroFlame architecture.

(v) SWAT model: The Clark Fork SWAT model along with all input files.

C.4. Identify staff with appropriate credentials and experience and describe their qualifications. Describe the process and criteria that will be used to select appropriate staff members for any positions that have not yet been filled. Describe any plans to request additional technical assistance from Reclamation or via a contract.

Adnan Rajib, Ph.D. is an Assistant Professor in the Department of Environmental Engineering at the Texas A&M University, Kingsville. He has worked extensively on large-scale hydrology and water quality modeling, hydrologic impacts of climate and land use change, big data informatics, and data visualization. His notable research contributions include leading the development of the Ohio Basin Flood Prediction Framework and coordinating the NOAA National Water Center Innovators Program for National Water Model experiments. As part of his recent federally funded project, Rajib is leading a collaboration with NASA Applied Sciences Division, EPA Office of Research and Development, and US Army Engineer and Research Development Center to apply remotely sensed data for improved hydrology and water quality modeling in the Missouri River Basin in the western United States.

Melanie Vanderhoof, Ph.D. is a Research Geographer with the USGS based in Denver, Colorado. She has extensive experience applying diverse sources of remotely sensed data to study wetlands, river, and lake dynamics, as well as map burned area and track post-fire recovery. She also has extensive experience developing algorithms within Google Earth Engine that have been applied at regional scales including the Upper Missouri in the western United States. Vanderhoof has previously collaborated with EPA Region 3, EPA Region 8, EPA Office of Research and Development and The Nature Conservancy, among others, for projects focused on surface water resources. On the fire side of her research, she supports USGS's Landsat Burned Area product development, and has published efforts that track rates of post-fire recovery across the western United States. She is currently collaborating with U.S. Fish and Wildlife Service and Tall Timbers Research Station to enhance the usefulness of national data products to better meet the needs of land managers.

Rajib and Vanderhoof will serve as the project managers. Vanderhoof will be appointed as the Technical Coordinator of this project through a contractual agreement between Texas A&M University, Kingsville and USGS. The project funding will also create mentored positions for one full-time doctoral research assistant and one part-time undergraduate research assistant at the Texas A&M University, Kingsville.

A small portion of the budget was allocated to execute a contract and request **technical assistance from the Bureau of Reclamation**. An appropriate Reclamation scientist will be identified during the first 60 days of project execution.

C.4.a. Have the project team members accomplished projects similar in scope to the proposed project in the past either as a lead or team member?

Rajib is currently the Principal Investigator of a 5-year project funded by the Department of Defense (DOD) (Federal Award Identification Number (FAIN): W912HZ2020071). One of the objectives of this DOD project is to develop remote sensing-integrated hydrologic modeling for better predictions of flood and drought impacts across the Missouri river network. A major portion of this project also involves development of web-based visualization tools and educational materials for stakeholder training. Rajib is also working as the Principal Investigator of a 2-year project funded by Texas Water Development Board (TWDB). The objective of this TWDB project is to develop web-based data-model integration tool for user-friendly flood inundation modeling. Therefore, Rajib has the experience of managing federal and state-funded projects that are similar in scope to the proposed project.

Vanderhoof serves as a Team Member for the Landsat Science Product Team, which produces national Level-3 Science Products for the Landsat archive. Her research experience in remote sensing, Google Earth Engine, water and fire makes her well-suited to be the technical coordinator of the proposed project. Most of the research projects that she has led have been regional in nature and therefore similar in scope to the proposed project.

C.4.b. Is the project team capable of proceeding with tasks within the proposed project immediately upon entering into a financial assistance agreement? If not, please explain the reason for any anticipated delay.

Yes.

1.5.4 Evaluation Criterion D – Dissemination of Results

D.1. Describe how the tools, frameworks, or analyses being developed will be disseminated, communicated, or made available to water resources managers who may be interested in the results.

D.1.a. If the applicant is the primary beneficiary of the project, explain how the project results will be communicated internally, and to interested stakeholders and interested water resources managers in the area, if appropriate.

The applicant is not the primary beneficiary.

D.1.b. If the applicant is not the primary beneficiary of the project (e.g., universities or research institutes), describe how project results will be communicated to project partners and interested water resources managers in the area.

Dissemination is one of the three objectives of this project. Therefore, all four local government/community partners included in this proposal commit to actively lead, organize, and run a targeted dissemination effort. This dissemination effort will mainly include three virtual workshops and one onsite workshop. These workshops will include live demonstration of the proposed HydroFlame tool, stakeholder training using relevant instructional/reading materials, and discussion on the tool's practical applications beyond what is covered in project objectives. Specific themes of these workshops are outlined in the project's workplan (**Table 2**). Role of local partners in materializing this dissemination plan is highlighted in their respective support letters. All the instruction materials and presentation files used in these workshops will be made publicly available through HydroShare for future use. Additionally, the project managers will aim towards publishing their work in a peer-review journal to outreach to a broader scientific community.

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Project Budget

Funding Plan

The non-federal portion of the budget will be obtained from Texas A&M University, Kingsville ($105,209) and third-party in-kind contribution of Clark Fork Coalition, Montana ($3,000; see attached support letter).

Budget Proposal

Budget Table 1. Total project cost table

Source	Amount
Cost to be reimbursed with the requested federal funding	$107,645
Cost to be paid by the applicant	$105,029
Value of third-party in-kind contribution	$3,000
Total project cost	$215,674

Budget Table 2. Budget proposal

Budget item description	Computation		Quantity type	Total cost
	$/unit	Quantity		
Salaries and Wages				
Adnan Rajib, Project Manager	$8334 with 3% increase in year 2	4.5	months	$38,061
Graduate Research Assistant	$1150	24	months	$27,600
Undergraduate Research Assistant	$10	250	hours	$2,500
Fringe benefits				
Adnan Rajib, Project Manager	18.5% of salary+ health insurance $771/month			$10,511
Doctoral research assistant	3% of salary + health insurance $279/month			$7524
Undergraduate research assistant	3% of salary			$75
Equipment				
Cost of Texas A&M High Performance	$19000	2	year	$38,000

Computing Center (HPCC)				
Contractual				
Melanie Vanderhoof, Project Manager & Technical Coordinator				$20,000
Bureau of Reclamation Scientist				$2000
City of Missoula				$4500
Third-party in-kind contribution				
Clark Fork Coalition				$3000
Others				
Travel				$2500
Student tuition				$15600
			Total Direct costs	$171871
Indirect costs				
Type of rate	38%	$115271	Negotiated rate	$43803
			Total estimated project costs	215674

Budget Narrative

- Salaries and Wages

Dr. Adnan Rajib, Assistant Professor, Texas A&M University Kingsville
Project Manager
Cost-share

Texas A&M University Kingsville will provide 25% of Dr. Rajib's 9-month academic salary for each year as cost-share. With a 3% salary increase in years 2, total salary requested for Dr. Rajib is $38,061, calculated from a 9-month annual base salary of $75,000.

Graduate Research Assistant (GRA), Texas A&M University Kingsville

One full-time GRA will be recruited at Texas A&M University Kingsville for 24 months using the federal funding (from January 1, 2022). The GRA will commit 12 months of effort per year throughout the project duration. The salary of the GRA will be $1,150/month throughout his/her 24-month appointment. The university does not allow salary inflation rate for GRAs. Therefore, the total salary requested for one PhD student is $27,600. The GRA will also be awarded full in-state tuition fees (see below).

Undergraduate Research Assistant (UGRA), Texas A&M University Kingsville

One UGRA will be recruited using the federal funding to assist project manager Rajib in model input processing tasks, with a contract of 10 hours work/week for 5 months in year 1 of the project. Therefore, the total salary requested for one undergraduate RA is $2,500.

- Fringe Benefits

Dr. Adnan Rajib, Assistant Professor, Texas A&M University Kingsville
Project Manager
Cost-share

The rate of fringe benefits for Dr. Rajib is 18.5% of salary. The health benefit is $771/month. Therefore, the total fringe benefits for Dr. Rajib, prorated based on his duration of involvement (see above), is $10,511.

Graduate Research Assistant (GRA), Texas A&M University Kingsville

The rate of fringe benefits for the GRA is 3% of salary. The health benefit is $279/month. Therefore, the total fringe benefits for the GRA, prorated based on his/her duration of involvement (see above), is $7,524.

Undergraduate Research Assistant (UGRA), Texas A&M University Kingsville

The rate of fringe benefits for the GRA is 3% of salary. Hourly basis employment of UGRA is not considered allowable for health insurance benefits. Therefore, the total fringe benefits for the UGRA, prorated based on his/her duration of involvement (see above), is $75.

- Equipment

Cost-share

The Texas A&M University, Kingsville High Performance Computing Center will provide $38,000 as cost-share based on a unit cost of $19,000/year. This estimate is based on the cost of operating the facilities on an annual basis and includes salary of system administrator, cost of hardware maintenance, and cost of computation.

- Contractual

Dr. Melanie Vanderhoof, Research Geographer, USGS
Project Manager and Technical Coordinator

Dr. Vanderhoof will be appointed as the Technical Coordinator for this project using the federal funding via a contractual agreement between USGS and Texas A&M University, Kingsville. In this role, Vanderhoof will receive $20,000 calculated as $7479/year and 33.7% overhead.

Bureau of Reclamation Scientist

As recommended in the notice of funding opportunity, this project budgets $2000 of its federal funding to request technical assistance from a Reclamation scientist.

City of Missoula

City of Missoula – the Category A partner of this proposal will receive $4500 of federal funding through a contractual agreement with Texas A&M University, Kingsville. City of Missoula will use this funding to organize one onsite workshop in year 2 of the project (see attached support letter).

- Third-party in-kind contribution

Clark Fork Coalition (CFC)
Cost-share

CFC – a local community partner in this proposal committed $3000 of in-kind contribution calculated as the cost of organizing three virtual workshops (see attached support letter).

- Others

Travel

$2,500 is requested from the federal funding for domestic travel in year 2 of the project. The funds will support project manager Rajib and the GRA to attend the onsite workshop in Missoula in year 2 of the project (see above).

Student tuition

An in-state tuition fee is budgeted for the GRA using the federal funding and considering his/her full-time 24 month enrollment. The total tuition fee for the GRA, assuming enrollment in January 2022 (year 1 of the project) and graduation in December 2023 (year 2 of the project), is estimated as $15,600.

Indirect cost

Texas A&M University, Kingsville's indirect cost (IDC) rate for on-campus research is 38% of the Modified Total Direct Cost (MTDC). Based on $115271 MTDC, the total IDC is $43,803.

The total direct ($171,871) and indirect cost ($43,803) for this project is estimated as $215,674.

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Environmental and Cultural Resources Compliance

Not applicable

Required Permits or Approvals

Not applicable

MISSOULA
CITY OF MISSOULA
Ecosystem Services Division
100 HICKORY STREET • MISSOULA, MT 59801 • (406) 552-6253 • FAX: (406) 327-2140

4/20/2021

Dr. Adnan Rajib
Texas A&M University
Kingsville

REF: Letter of Participation for proposal "Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool"

Dr. Rajib,
I, on behalf of the City of Missoula, write this letter to express my intent to participate with your team in the proposed project titled: "*Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool*" .

The City of Missoula recently adopted a community-wide climate resiliency plan and is currently conducting multiple projects, processes and maintence activities along the Clark Fork River and several of its tributaries. Some specific projects include dam removals on Rattlesnake Ck. (a major tributary); construction of Clark Fork River recreational access and riverbank restoration; and maintence of several levees and related stormwater infrastructure. All of these projects are approached through the lens of climate resiliency and environmental stewardship. All of our community planning and maintenance projects will require a greater understanding of the Clark Fork River basin, good data and robust models. The proposed project matches our ongoing efforts and plans to make the City of Missoula climate resilient.

City of Missoula agrees to the submittal of the proposal to Bureau of Reclamation and commits to participate in the project during January 2022-December 2023 as the **Category A** partner. Specifically, City of Missoula will participate in all planning and coordination meetings organized by the project team in year 1 and provide inputs to the project's model calibration-validation and tool development tasks. In year 2, City of Missoula will host a stakeholder training workshop for dissemination of project outcomes.

I will be City of Missoula's point of contact for this project.

Morgan Valliant
Ecosystem Services Superintendent,
City of Missoula
100 Hickory St.
Missoula Mt. 59801
(406) 552-6263
valliantm@ci.missoula.mt.us

CLARK FORK COALITION P.O. Box 7593, Missoula, MT 59807 ph. 406-542-0539

April 19, 2021

Grants Review Panel
WaterSMART - Applied Science Grants Program
US Bureau of Reclamation

Dear members of the review panel:

I am pleased to provide this letter to confirm our participation in the proposed project titled "*Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool*".

The Clark Fork Coalition is a river conservation organization of some 2,700 members, dedicated to protecting clean water and restoring healthy rivers throughout the Clark Fork watershed for the past 30 years. The proposed project aligns well with our priorities and offers a pathway to directly involve stakeholders in wildfire and drought hydrologic impact modeling in the Clark Fork Basin.

During the 2-year project period, CFC will work closely with the project investigators. We will lead the outreach efforts to coordinate three virtual workshops: one workshop in the first year of the project to include stakeholders' input in the tool design and two workshops in the final year of the project for output dissemination and stakeholder trainings. CFC will offer an in-kind contribution of $3,000 to conduct the above-specified outreach activities.

Once again, I offer CFC's strong support for this proposal. Thank you for your consideration.

Sincerely,

John DeArment

John DeArment
Science Director
406-542-0539 ext. 211
406-546-2318 (cell)
john@clarkfork.org

Missoula Public Health
City-County Health Department

Missoula City-County Health Department
WATER QUALITY DISTRICT
301 West Alder Street | Missoula MT 59802-4123
www.missoulacounty.us/HealthDept
Phone | 406.258.4890
Fax | 406.258.4781

April 19, 2021

Program Manager
WaterSMART - Applied Science Grants Program US
Bureau of Reclamation

Dear Program Manager:

I am writing to convey the support and participation of the Missoula Valley Water Quality District in the proposed project titled "Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool". This project addresses aspects discussed in Missoula's Climate Resiliency Plan. With regards to aquatic systems, the plan states, *Reduced summer stream flows together with hotter summers will lead to increased water temperatures, which are detrimental to several aquatic species, including trout, and to the recreational fishing industry that depends on healthy and robust fisheries.* Understanding the effect of fire on water resources is important, just as understanding how the frequency and duration of rain events affects flood elevations.

The Missoula Valley Water Quality District is a local government agency whose mission is to protect and improve surface and groundwater quality within the Missoula Valley. This proposed project is well-aligned with our mission by improving water resource information and contributing to climate resilience within our basin. The project will ultimately provide state and local agencies and non-governmental organizations with a web-based tool for hydrologic assessments which will have immediate benefits in understanding the hydrologic response of wildfires on our water resources.

The Water Quality District commits to participating in stakeholder training and collaborating with principal investigators on testing the tool. We look forward to collaborating with the project team and hope that you will consider their proposal.

Sincerely,

Travis Ross
Missoula Valley Water Quality District

The Nature Conservancy of Montana
32 South Ewing Street
Helena, MT 59601

Tel (406) 443-0303
Fax (406) 443-8311

nature.org

April 19, 2021

Program Manager
WaterSMART - Applied Science Grants Program
US Bureau of Reclamation

Dear Program Manager:

On behalf of The Nature Conservancy (TNC), I write this letter of participation confirming my engagement in the proposed project titled "Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool".

This proposed project is well-aligned with TNC's current conservation and management initiatives in Montana including forest restoration, improving water resources, and climate resilience in the Clark Fork Basin and other watersheds in Montana. The project has the potential to bring tangible improvements in water supply reliability in the Clark Fork Basin by providing state and local agencies and non-governmental organizations with a web-based tool for post-wildfire hydrologic change assessments will have immediate benefits for rural communities. Lessons learned through this collaborative process will guide similar efforts in other basins in the future.

TNC will participate in project development by testing the proposed tool and ground-truthing its outputs. TNC will also participate in project dissemination by assisting in the preparation for stakeholder training sessions.

I look forward to collaborating with the project team and hope that you will consider their proposal.
Sincerely,

Nathan Korb
Freshwater Director
nkorb@tnc.org

DEPARTMENT OF THE ARMY
SEATTLE DISTRICT, CORPS OF ENGINEERS
P.O. BOX 3755
SEATTLE, WASHINGTON 98124-2255

April 15, 2021

US Bureau of Reclamation
WaterSMART - Applied Science Grants Program

Dear members of the grants committee,

The US Army Corps of Engineers (US ACE) - Seattle District strongly supports the proposed project: **"**Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool"**.** Our support is based on the merit of the proposal which, in our understanding, would be highly beneficial to both Army Corps and Bureau of Reclamation. Acceptance of this proposal will help us develop an active collaboration with the interdisciplinary project team to secure reliable streamflow predictions in the Clark Fork Basin in response to changing environments.

In its role as a WA Post Wildfire Flood Committee participant US ACE -Seattle District – specifically, the District's Silver Jackets Coordinator, with help from the Flood Risk Management team **–** will assist the project team in setting up their hydrologic model by providing relevant technical instructions. Throughout the duration of the project, US ACE - Seattle District will also join stakeholder meetings organized by the project team and advice the development of the proposed remote sensing integration tool. Please note that US ACE's participation in this project does not involve any financial contribution.

Questions or concerns regarding this letter of support should be directed to Mr. Travis Ball, PE, Chief Hydraulic Engineer and Silver Jackets Coordinator, Seattle District, at (206) 764-3277.

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Date: 2021.04.15 10:59:29 -07'00'

Travis Ball
Chief **–** Hydraulic Engineering Section
4735 East Marginal Way S
Seattle WA 98134
206-764-3277
travis.d.ball@usace.army.mil

PO Box 2008
Oak Ridge, TN 37831-6290
(865) 241-2111 | debd@ornl.gov

To, April 19th , 2021

Dr. Adnan Rajib
Department of Environmental Engineering
Texas A&M University
Kingsville, TX 78363

REF: Letter of Support for proposal "Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool"

Dear Dr. Adnan Rajib,

In this letter, myself from Oak Ridge National Laboratory (ORNL) is expressing my willingness to collaborate with you for the proposed project titled**:** *"Making Post-wildfire Hydrologic Change Assessment Efficient by Developing A Web-based Remote Sensing-integrated Hydrologic Modeling Tool"*

The proposed project could fill a much-needed information-gap by developing a web-based data-model integration and visualization tool that would produce rapid assessments of impacts of post-wildfire hydrologic changes. At ORNL, with support from the Department of Energy, I lead the HydroSource energy-water digital platform designed to help the hydropower community make data driven decisions and we frequently apply computational techniques to evaluate the effects of landscape and climatic changes on hydrologic flows for effective management of hydropower projects across the United States. Therefore, the proposed project will be beneficial to ORNL's hydropower research portfolio and to the Bureau of Reclamation's Applied Sciences Program.

Additionally, ORNL also maintains one of the NASA earth information Distributed Active Archive Centers (DAACs), and therefore is well-suited to collaborate with the project team on data management and visualization tasks. **I will guide the development and progress of the proposed web-based tool by providing technical advice on geospatial and hydrological data management, quality assurance, and standardized data sharing and visualization protocols. I will also guide the project team to ensure that the proposed tool has a reproducible computational framework such that it can be efficiently reused by watershed managers across the western United States.** However, ORNL does not have any financial commitment to the project team.

Sincerely,

Debjani Singh

Debjani Singh, PhD
Research Scientist, Environmental Sciences Division
Ingest Lead, ORNL DAAC
Oak Ridge National Laboratory
https://hydrosource.ornl.gov/
https://daac.ornl.gov/