QUANTIFYING WATER SUPPLY AND DEMAND ACROSS NATIONAL FOREST SYSTEM LANDS WITHIN THE CLARK FORK RIVER WATERSHED, MONTANA

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

Terms Associated with Water Rights

Elements of a Water Right from Montana Department of Natural Resources

FLOW RATE – the maximum flow rate at which water can be diverted from the source. Usually described in gallons per minute or cubic feet per second.

PERIOD OF DIVERSION – period of the year during which water is allowed to be diverted from the source; this may differ from the period of use if water is stored.

PERIOD OF USE – period of the year during which the water is allowed to be used.

PLACE OF USE (POU) – place where the water is put to beneficial use. This location information is described by legal land description (township, range, and section).

POINT OF DIVERSION (POD) – where water is first diverted from the source. For instream purposes, this may be a reach rather than a point.

PRIORITY DATE – for Statements of Claim, this is the date the water was first put to beneficial use. For New Appropriations, this is the date the application for water use was received by DNRC.

PURPOSE – the beneficial use of the water. Includes, but is not limited to: domestic, commercial, industrial, irrigation, livestock, mining, municipal, power generation, instream fishery, geothermal heating and cooling, and mitigation.

SOURCE – can be a surface water source (stream, river, lake, undeveloped spring) or groundwater source (well, developed spring).

VOLUME – the maximum volume that can be diverted or used during the Period of Use.

Terms Associated with Geospatial Information Systems

ESRI Definitions of common GIS Terms

ATTRIBUTE – nonspatial information about a geographic feature in a GIS, usually stored in a table and linked to the feature by a unique identifier. For example, attributes of a river might include its name, length, and sediment load at a gauging station.

CLIP – Analysis tool used to cut out a piece of one dataset using one or more of the features in another dataset as a cookie cutter. This is particularly useful for creating a new dataset—also referred to as a study area or area of interest—that contains a geographic subset of the features in another, larger dataset.

FEATURE CLASS – homogeneous collections of common features, each having the same spatial representation (such as points, lines, or polygons) and a common set of attributes (for example, a line feature class for representing road centerlines)

FIELD – a column in a table that stores the values for a single attribute.

INTERSECT – Analysis tool used to compute a geometric intersection of the input features. Features or portions of features that overlap in all layers or feature classes will be written to the output feature class.

JOINING – appending the fields of one table to those of another through an attribute or field common to both tables. A join is usually used to attach more attributes to the attribute table of a geographic layer.

MERGE – Data management tool use to combine multiple input datasets into a single, new output dataset. This tool can combine point, line or polygon feature classes or tables.

PARAMETER – variables that are set as model parameters appear as tool parameters when the model is run as a geoprocessing tool, allowing you to specify different data or values for your model to process than what was specified when the model was created.

RECORD – a row in a table

SELECTED RECORDS – a subset of records that match a desired spatial or attribute selection criteria.

SPATIAL JOIN – Analysis tool used to join attributes from one feature to another based on the spatial relationship. The target features and the joined attributes from the join features are written to the output feature class.

SUMMARY STATISTICS – Analysis tool used to calculate summary statistics for fields in a table. The output table value will consist of fields containing the result of the statistical operation. The following statistical operations are available with this tool: sum, mean, minimum, maximum, range, standard deviation, count, first, last, median, variance, and unique.

TABLE – a set of data elements arranged in rows and columns. Each row represents a single record. Each column represents a field of the record. Rows and columns intersect to form cells, which contain a specific value for one field in a record.

ABSTRACT

Water supply and demand across the western United States has been a source of contention since westward expansion. As climate change become more prevalent, the timing and quantity of water supply is changing and the demand for water is increasing. In the western US, water supply is divided among water users using the prior appropriation doctrine of "first in time, first in right" meaning those that used the water first historically have the priority to use the water when supply is low. Many headwater streams that supply water to downstream users originate on National Forest System lands. These small streams are critical habitat for many aquatic species and knowing how water in these headwater areas is allocated compared to water supply is important for land managers. Therefore, my study quantified water supply and demand on National Forest System lands using water rights spatial data and modeled historical streamflow rates. I developed a "Water Rights Selection Tool" to determine (1) points of diversion described on National Forest System lands within each state designated water Adjudication basin, (2) total allocated flow of those water rights based on watershed boundaries at the hydrologic unit code 10 level, and (3) total water supply on National Forest System lands using modeled flow metrics data. The output from the tool is a combined spatial data set that includes total allocated flow and total model estimated flow in each watershed. The percent allocated of each watershed was calculated from that data. The Clark Fork Study Area was chosen as the pilot location. It consisted of 30 watersheds within three Adjudication basins that make up the mainstem of the Clark Fork River in western Montana. I found that seven of 30 watersheds within the Clark Fork Study area were over-allocated on National Forest System lands meaning that more water was allocated to beneficial uses than estimated water supply available within that watershed. The Little Thompson River watershed had the highest level of over-allocation at 638%. Although the tool was successful at determining points of diversion, total allocated flow, and total water supply, several improvements need to be made before using it for wider replication across National Forest System lands.

INTRODUCTION

The headwaters of many streams in the western United States fall within the boundaries of National Forest System (NFS) lands. Not only do these headwater streams provide critical habitat for aquatic species (Meyer et al., 2007), but they also provide water for many human beneficial uses downstream. Meeting the needs of aquatic ecosystems and water users depends on the balance of supply and demand. The amount of water that an individual or entity can use depends on the amount of water allocated to them based on several factors. In the western U.S., states own the waters within state boundaries but allocate said water to individual users based on a seniority priority system. In principle, available water is managed by state agencies to ensure that watersheds are not over-allocated and that each water user has enough water for their specific purpose. In practice, many states have a history of over-allocating watersheds especially as communities grow and demand for water increases. When a stream is over-allocated, it means that more water has been allocated to water users than the stream can provide. Over-allocation may result in little to no water remaining in the stream when all beneficial uses are being met or some users left without adequate water.

Climate change adds another complication as demand increases and timing and quantity of water supply changes. States are responsible for regulating water use and demand; consequently, federal agencies such as the United States Department of Agriculture's (USDA) Forest Service, historically have not determined how water is specifically allocated on federal lands, resulting in significant knowledge gaps. Growing concerns about over-allocation of water have highlighted the need to determine how water is allocated on NFS lands. In addition to quantifying whether water from NFS lands is over-allocated, estimates of supply versus demand can help inform future land management decisions and, if used in conjunction with other sensitivity assessments, could help land management agencies protect the important ecological services that these headwaters streams provide. Therefore, my project aims to quantify water allocated on NFS lands using water rights point of diversion and place of use data and compare it to estimated water supply for stream segments on NFS lands. The next sections provide background on western water supply, water rights, and the concept of over-allocation.

Note on U.S. Customary Units:

Throughout this paper, I use U.S. Customary Units to be consistent with the agencies that are responsible for collecting and publishing the data I analyzed, Montana Department of Natural Resources and Conservation, Montana Department of Revenue, Montana State Library, and US Geological Survey, and to facilitate communication with water users. The units used most widely for management purposes in the Clark Fork Study Area, and in the US, are cubic feet per second and gallons per minute for flow rate, acre-feet per year for large volumes of water and acres for land area. My intended audience includes USDA's Forest Service agency colleagues, Montana State agencies, and water users who use U.S. Customary Units.

BACKGROUND

Western U.S. Water Supply and the Role of the Forest Service

The western US relies on snow received during the winter months as the primary source of water during the spring and summer runoff season (Leppi et al., 2011). Snowpack is measured each year during the winter months and measurements are used to calculate the amount of water the snow can supply for the upcoming season. These calculations of water supply are used to forecast potential drought and inform management decisions as they relate to water needs throughout a region. Agricultural entities often use predicted water supply to determine when and how much water to use during the growing season. Not only do people rely on this water for municipal needs, irrigation, and stock use, but many aquatic plants and animals depend on this seasonal pattern of streamflow for reproduction and survival (Ficke et al., 2007).

Climate change is expected to not only change the type of precipitation received in the western US – snow versus rain – but also the timing of precipitation and snowmelt during the runoff season. In general, more winter precipitation is expected to fall as rain in the future than historically (Dai et al., 2004; Hamlet et al., 2005; Knowles et al. 2006), and the snow that is received is expected to melt earlier in the spring runoff season (Hamlet et al., 2005; Mote et al., 2005). With this earlier snow melt there will be a shift in the hydrologic regime of many rivers and streams with increases in spring flow and decreases in summer flow (Cayan et al., 2001; Dettinger and Cayan, 1995; Regonda et al., 2005; Stewart et al., 2005). Some of these changes have already been documented across the western US with rising air temperatures and a decrease in snow water equivalent (Mote, 2003; Mote et al., 2005) as well as an increase in precipitation as rain (Knowles et al., 2006) and earlier snowmelt (Moore et al., 2007; Stewart et al., 2005).

The USDA’s Forest Service, a federal agency, manages approximately 193 million acres of public lands across the U.S. In the western US, NFS lands comprise 19.2% of the total land area (Liu et al., 2022). These federal forest lands contain many headwater streams that provide critical habitat for aquatic species and water for human uses. Many sensitive species of aquatic organisms rely on cold, snowmelt dominated streams for reproduction and survival (Mullan et al., 1992). Species in Montana such as the threatened bull trout (*Salvelinus confluentus*) (U.S. Fish & Wildlife Service) and species of concern, the westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) (Montana Fish, Wildlife and Parks, 2023), rely on small third- and fourth-order streams for spawning and rearing (Montana Bull Trout Restoration Team, 2000; Young, 1995). Spawning and rearing of bull trout, specifically, occurs in small, high-order streams and requires clear, cold water as well as other specific habitat requirements (Montana Bull Trout Restoration Team, 2000). Westslope cutthroat trout spend most of their lives in small tributaries and spawn in headwater streams from March to July (Mullan et al., 1992; Young, 1995). These headwater streams not only provide habitat to aquatic species, but also provide water for drinking and other beneficial purposes to communities downstream. In 2017, approximately 39% of the total population in the continental U.S. derived more than 10% of their surface drinking water supply from NFS and other forest lands. NFS lands specifically, provided 46.3% of surface water supply in the western US (Liu et al., 2022). Climate change and population growth are expected to worsen stress over water resources throughout the US (Liu et al., 2022; Sun and Vose, 2016), thus increasing the importance of managing the water resources on and emanating from NFS lands to maintain the critical ecosystem services and beneficial uses provided by those waters.

Water Allocation in the Western US

In the western US, water use is governed by the prior appropriation doctrine which establishes the concept of "first in time, first in right" and means that those who first put a source's water to beneficial use have the right to use said water before those who later withdrew water from the same source (Craig, 2020). Implementing this doctrine during western settlement was complicated because federal entities were responsible for dividing up the land for the people, but the states were responsible for the division of water. This lack of consistency between the division of land and water caused many issues regarding interstate watersheds, i.e., how to apportion the water between states, whether the federal government could obtain reserved water rights for uses such as parks, monuments, and Indian reservations, as well as how to adjudicate federal rights (MacDonnell, 2015). In 1952, the McCarran Amendment determined that all federal water rights would be adjudicated by the states, and they were not immune to adjudication. The McCarran Amendment also set the basis for each state to determine certain elements about each water right such as point of diversion, amount of water, type of use, place of use and priority date so that all rights could be administered in relation to one another (MacDonnell, 2015). With so many entities involved in the west with regards to water rights, a complicated situation continues to this day.

The Snake River Basin of southern Idaho illustrates some of the complexities of ongoing efforts to sort out water rights in the west. The Snake River originates in southwestern Wyoming and flows west across Idaho eventually joining the Columbia River in southern Washington. Water from the Snake River irrigates 3 million acres of cropland in Idaho and serves the municipal needs of two million people (Slaughter et al., 2012). The river is fully allocated, meaning the entire supply is “spoken for” in terms of legal water rights, and almost completely diverted at Milner Dam, near Twin Falls, Idaho. This diversion and others have been in place since the area was settled meaning large amounts of water were put to beneficial use prior to determining the actual supply of the river with long-term discharge measurements. Water rights for surface and groundwater continued to be granted as development of the basin proceeded and, in many areas, more legal water rights have been granted than can be met by supply. This prior appropriation and historical use of water has led to the Snake River being fully appropriated and leaves questions regarding the continued utility of prior appropriation. The Snake River Basin Adjudication started in 1987 and was finalized in 2014. This 24-year process involved the adjudication of 139,000 water rights and involved 90% of water used in Idaho (Browne and Ji, 2023). Post-adjudication and $94 million dollars later (Browne and Ji, 2023), complications still exist among water users due to the scarcity of water in the Snake River Basin (Idaho Department of Water Resources, 2022).

Montana Water Rights

Building on existing law and precedent, the Montana constitution of 1972 provided the foundation of water law within the state. It established that all waters were property of the state and could be used by the people for many different beneficial purposes. It also determined that each water use right was considered property which could be transferred and sold from one owner to the next. Water rights also extend to rights-of-way to move water over lands of others and create reservoirs for water storage. On July 1, 1973, the Montana Water Use Act established a filing system for all Montana water rights and paved the path for the adjudication of all historical use water rights that existed before the signing of the act (Water Rights in Montana, 2018). It required that all persons with water rights put to beneficial use before July 1, 1973, file a statement of claim to describe their water rights, with an April 30, 1982, deadline set by the Montana Supreme Court. This process began the Montana Adjudication which is still ongoing to this day and is administered by the Montana Department of Natural Resource and Conservation (MTDNRC) and a state Water Court.

The MTDNRC is the state agency responsible for examining and administering all legal water rights including historical rights put to beneficial use before to July 1, 1973 and newly appropriated rights such as water use permits and groundwater certificates. The agency also provides technical assistance to the Montana Water Court regarding pre-July 1, 1973 water rights as they continue through the adjudication process. MTDNRC is also responsible for maintaining the centralized water rights record system which houses all documents pertinent to each water right. Documents housed in the water rights record system include the original statement of claim or application for water right, ownership updates and a summary of each water right known as the "abstract" which describes the eight key elements of the water right.

The eight key elements of each water right include the source, purpose, priority date, point of diversion, place of use, flow rate, volume, period of diversion, and period of use (Water Rights in Montana, 2018). Each element is described in more detail in the list below:

- The source of the water is the stream, river, lake, or groundwater, including wells and springs, from where the water is diverted.
- The purpose of the right is how the water is put to beneficial use such as mining, irrigation, domestic, or stock use along with many other purposes.
- The priority date is the date that the water was first put to beneficial use.
- The point of diversion is the point at which water is diverted from the source using a specific means of diversion such as a headgate or pump.
- The place of use is the location that the water is put to beneficial use such as a domestic household or irrigated crops.

- The flow rate and volume quantify how much water can be used. The flow rate is the maximum rate at which water can be diverted from the source and the volume is the maximum amount of water that can be diverted in a calendar year.
- The period of diversion and period of use are the period of the year when the water is diverted and used, respectively.

Both the point of diversion and place of use can include an entire reach of a stream, for example, when livestock are drinking directly from a source. These same elements of a water right are consistent across most prior appropriation states, but specific details vary among states.

At the federal level, the USDA's Forest Service is just one agency that is involved in the Montana adjudication process either with claims owned by the USDA's Forest Service or claims owned by private individuals that are legally described on NFS lands. The Northern Region Regional Office in Missoula, Montana houses the water rights and uses program for the entire Northern Region and is responsible for researching and investigating all water rights claimed on NFS lands. The water rights and uses team works in conjunction with the MTDNRC, the Montana Water Court and private entities to resolve objections and issues pertaining to water rights. The goal of the water rights and uses program is to protect and manage the water resources on NFS lands as they pertain to USDA's Forest Service water rights and the rights of others.

OBJECTIVES

My objectives for this project were to develop a method to compare legally allocated water rights to estimated water supply using a specific watershed to serve as a pilot study for future replication on other NFS lands. I aimed to develop a geoprocessing tool that would quantify total allocated water and compare it to total estimated water supply across NFS lands to be used as an additional sensitivity assessment in conjunction with other assessments such as streams with threatened and endangered aquatic species, streams designated as impaired by the state of Montana and the USDA's Forest Service watershed condition framework for priority watersheds. The data I determined were needed and the steps I used to accomplish this task are listed below and in Figure 1.

1. Determine a location to serve as the pilot study.
2. Determine data needed to complete the analysis.
    a. Water Rights spatial data containing the eight key elements of each right.
    b. Watershed boundary Spatial Data
    c. Adjudication Basin Spatial Data
    d. USDA's Forest Service Administrative Boundary Data
    e. USDA's Forest Service Range Grazing Allotment Data
    f. Spatial representation of streamflow and water runoff statistics needed to estimate water supply.
3. Development of the Water Rights Selection Tool
    a. Estimate available water supply on NFS lands.
    b. Identify water rights with Points of Diversion on NFS lands.
        i. Select desired Water Rights using a series of selection processes and geoprocessing steps.

ii. Estimate water consumed by stock drinking directly from the source which required a separate process compared to other consumptive water rights.

iii. Estimate Total Flow of Consumptive Water Rights, not including water rights for stock drinking directly from the source.

c. Compare estimated water supply to consumptive water rights by joining the data into one spatial feature class and calculating percent allocated.

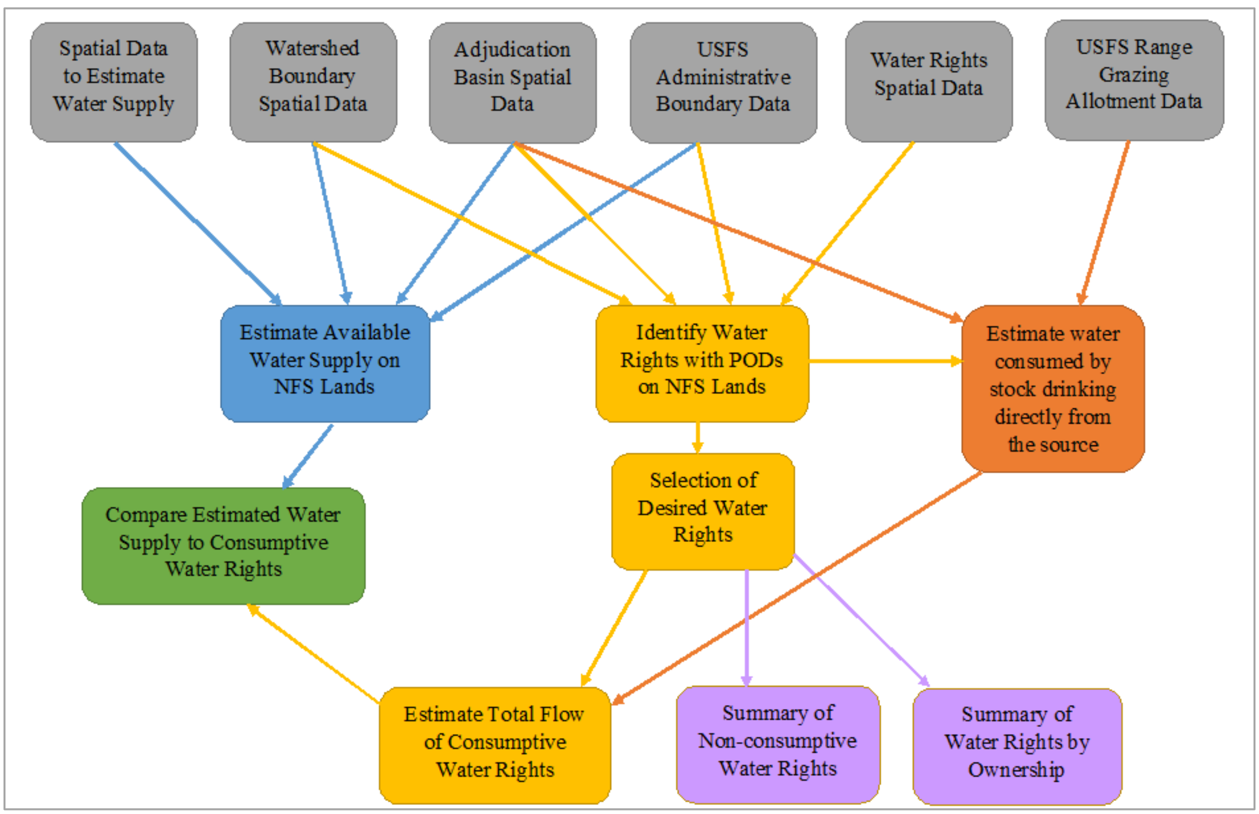

Figure 1. Flow chart of data and steps necessary for analysis of total water allocated compared to estimated water supply on NFS lands. Abbreviations: POD (Point of Diversion).

METHODS

Extent and Scale: Clark Fork River Watershed

I chose the Clark Fork River watershed in western Montana as the location for this pilot study. The river's headwaters are located near Anaconda, Montana and the Clark Fork begins at the confluence of Silver Bow Creek and Warm Springs Creek. It then flows to the northwest and collects waters from the Blackfoot, Bitterroot, and Flathead Rivers before finally spilling into Lake Pend Oreille in northern Idaho (Figure 2). The Clark Fork River flows through cities including Deer Lodge, Missoula, and Saint Regis and is a popular river for fishing, floating and other recreational activities. The river is home to many aquatic species such as non-native brown trout and rainbow trout and native species such as bull trout, westslope cutthroat trout, mountain whitefish, and northern pike minnows (Montana Fish, Wildlife and Parks, 2019). As mentioned above bull trout are listed as threatened under the Endangered Species Act (U.S. Fish & Wildlife, 2023) and westslope cutthroat trout are considered a species of concern in Montana (Montana Field Guide, 2023). Although bull trout are considered rare in most of the mainstem Clark Fork River, isolated populations are found in headwater tributaries, and they are considered common in the Blackfoot and Flathead Rivers (Montana Fish, Wildlife and Parks, 2023). Westslope cutthroat trout are considered rare in the mainstem and headwaters of the river but abundant in many tributaries in the middle and lower Clark Fork (Montana Fish, Wildlife and Parks, 2023). Both species rely on cold water streams for survival and reproduction.

Average annual flow of the Clark Fork River ranges from 266 cubic feet per second (cfs) in the upper portion of the river to 7,156 cfs in the lower portion. Average peak flow for the river ranges from 1, 072 cfs in the upper portion to 36,570 cfs in the lower portion of the river (Table 1).

Table 1. Flow Rate statistics for the Clark Fork River at three USGS gage stations along the river corridor.

	Average Annual Flow Rate (cfs)	Average Peak Flow Rate (cfs)
USGS Gage Station 12342400 Clark Fork at Deer Lodge MT	266	1,072
USGS Gage Station 12340500 Clark Fork above Missoula MT	2,964	15,421
USGS Gage Station 12354500 Clark Fork at St. Regis MT	7,156	36,570

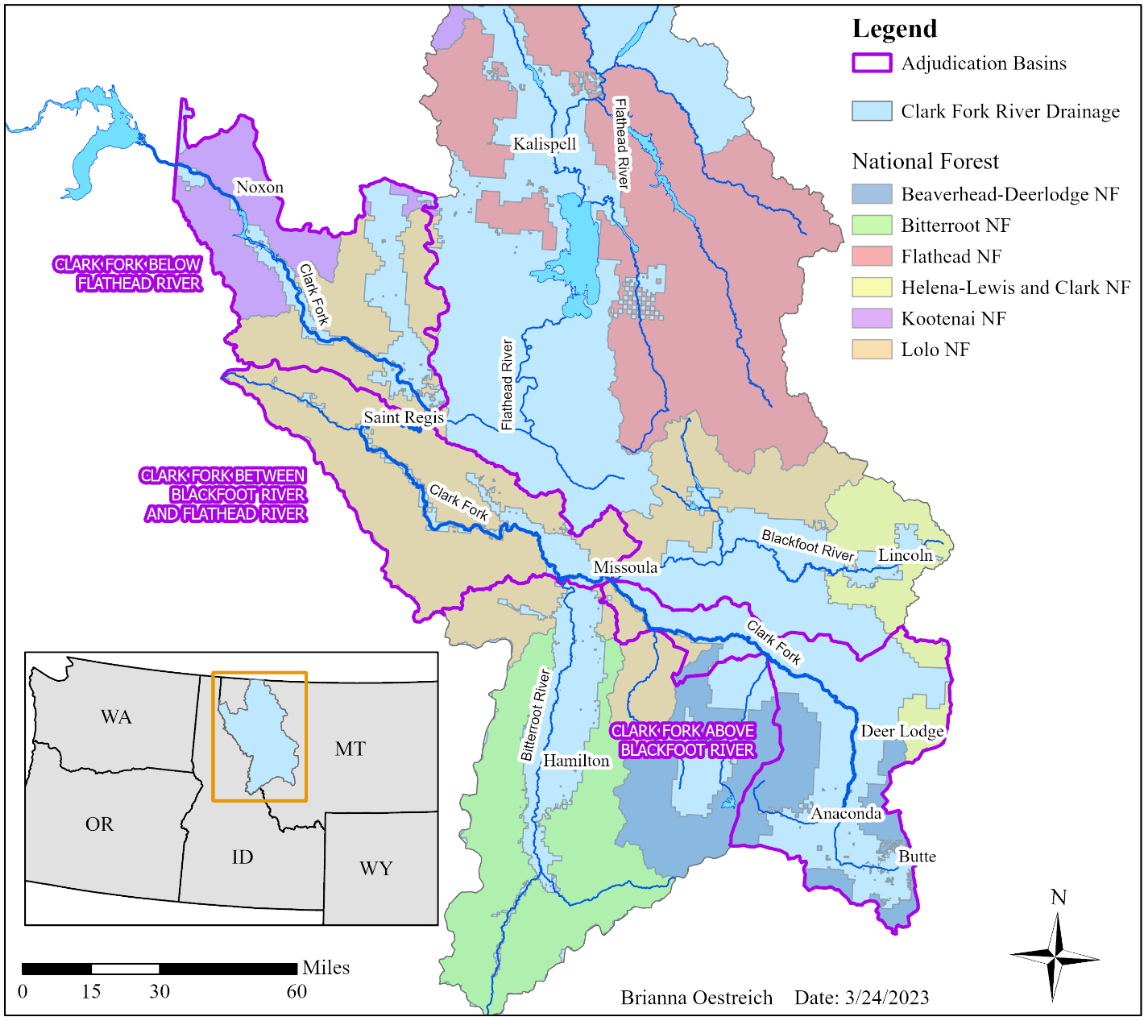

Figure 2. Clark Fork River Drainage and Adjudication Basins used for analysis located in western Montana.

The entire Clark Fork River drainage is comprised of 12 Adjudication basins which are loosely based on the sub-basin or hydrologic unit code (HUC) 8 level (approximately 445,000 acres) with some modifications made by MTDNRC for adjudication purposes. The Adjudication basins that contain the mainstem of the Clark Fork River and that I used in this analysis are basin 76G, Clark Fork River above Blackfoot River, basin 76M, Clark Fork between Blackfoot River and Flathead River, and basin 76N, Clark Fork below Flathead River. These three Adjudication basins that I will refer to as the Clark Fork Study Area span across four National Forests, the Beaverhead-Deerlodge, Helena-Lewis and Clark, Kootenai, and Lolo (Figure 2). Land ownership across the Clark Fork Study Area is comprised mainly of Federal land with 2.3 million acres or 57% of the land being managed by federal entities. Approximately 1.7 million acres or 40% of the land is owned by private entities and 120 thousand acres or 3% is managed by Montana state agencies (Figure 3). Of the approximately 4 million acres of land within the Clark Fork Study Area, 62% of the land cover is classified as forest, 19% is classified as shrub/scrub, 12% is classified as herbaceous and the remaining 7% is a mix of open water, developed land, barren land, hay/pasture, cultivated crops, and wetlands (Figure 4). NFS and forested lands in the Clark Fork Study area are primarily located at higher elevations where the headwaters of streams originate. Contrasted to private lands which are primarily located in the valley bottoms where the agriculture and rangeland is mapped.

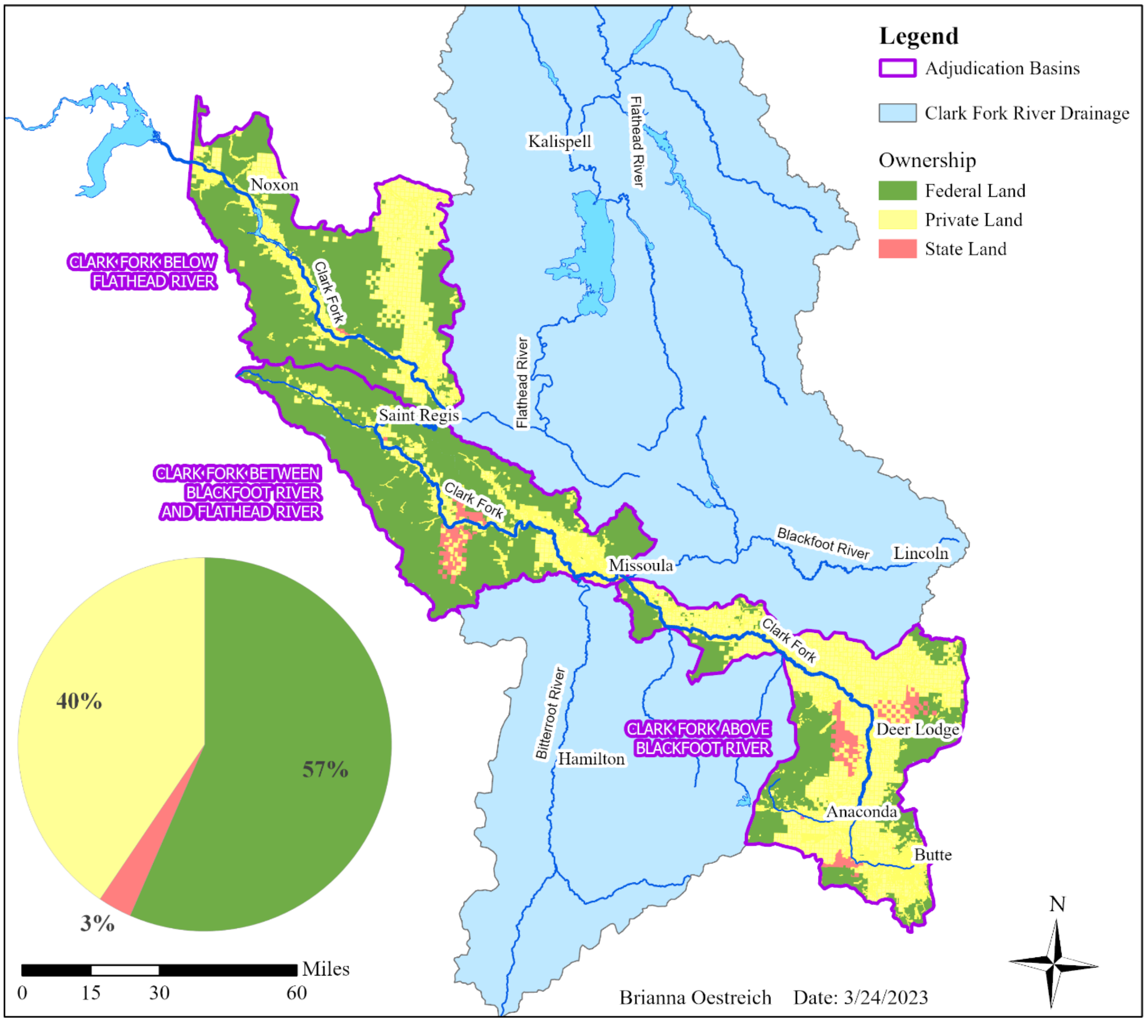

Figure 3. Ownership for the Clark Fork Study Area calculated from Montana Cadastral land ownership data for the year 2023 (Montana State Library, 2023, MSDI).

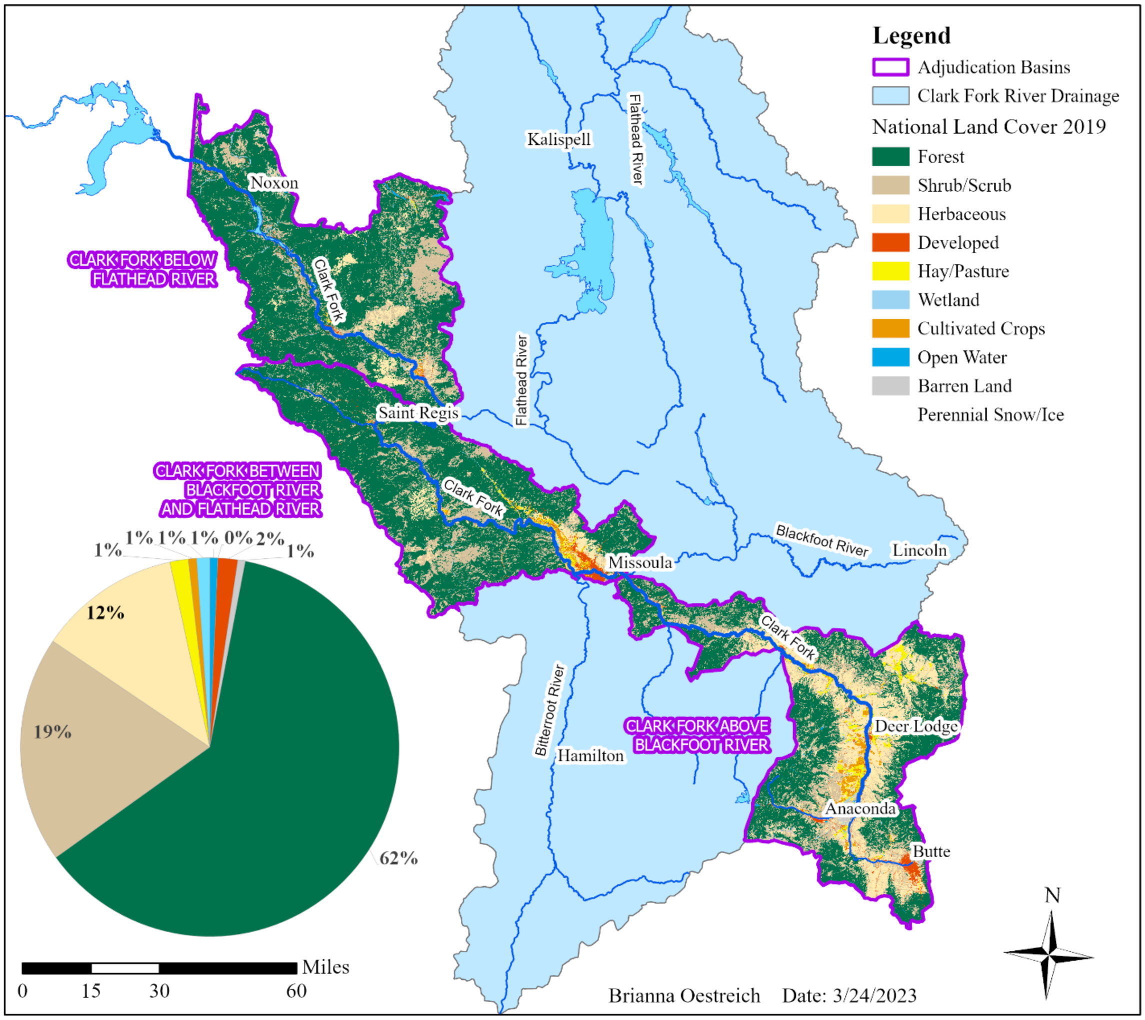

Figure 4. Land cover data for the Clark Fork Study Area calculated from the National Land Cover Database raster imagery for the year 2019 (USGS Multi-Resolution Land Characteristics Consortium, 2019).

Water Rights Selection Tool Development

Water rights data were provided by MTDNRC and downloaded from the Montana State Library Geographic Information page for Montana Water Rights (Montana State Library, 2022). The data were the most recent available and were uploaded to the Montana State Library website on August 1, 2022. The downloaded data included six feature classes total which contained two versions of the water rights. One version of the water right was the most recently authorized adjudication version, and the other was the public version of the water right (Montana State Library, 2023). The six feature classes included two feature classes that contained point spatial data to represent the points of diversion of each water right, two feature classes that contained polygon spatial data to represent the places of use of each water right, and two feature classes that contained point spatial data that represent the location of reservoirs associated with water rights. The points in the point of diversion and reservoir spatial data are placed at the center of the legally described location listed on the water right abstract. The legal description of a water right's point of diversion, place of use, and reservoir, if applicable, is listed as a township, range, and section sometimes followed by a quarter, quarter, quarter of the given section. This quartering approach divides the section into 64 squares that are 10 acres each. An example of a legal description would be the NE¼ SW¼ NE¼ of Section 32 in Township 9 North, Range 6 West (Figure 5). Some water rights are described more accurately or refined and may be described down to a 10-acre area (quarter, quarter, quarter section) while others may be broader in their description and only be described to a 160-acre (quarter section) or 640-acre area (entire section). The two feature classes I used for this analysis were the WR1_POD, point of diversion feature class, and WR1_POU, place of use feature class. These two feature classes contain the most recently authorized adjudication version of each water right and therefore are the most appropriate for this analysis (Montana State Library, 2023). The WR1_POD and WR1_POU feature classes contain all information that pertain to each water right which includes the eight key elements of the water right: source, purpose, priority date, point of diversion, place of use, flow rate, volume, period of diversion, and period of use.

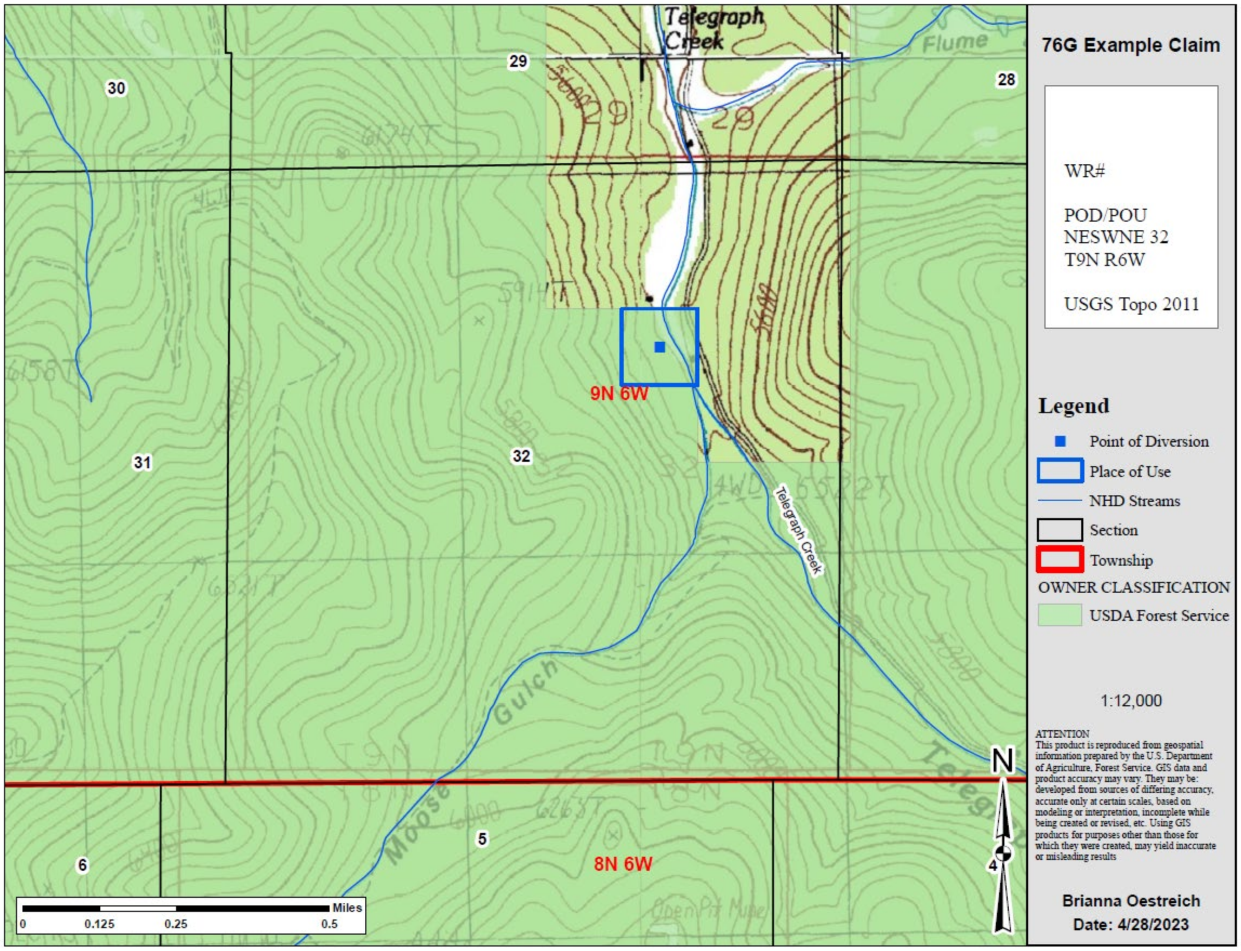

Figure 5. Example Map showing a Legally Described Water Right. The point of diversion is placed at the center of the legally described location and the place of use is a polygon around the legally described location. In this example, the legal description for this water right would be read as the Northeast quarter of the Southwest quarter of the Northeast quarter of Section 32 in Township 9 North, Range 6 West.

To develop the Water Rights Selection (WRS) Tool, I used ModelBuilder in ESRI ArcGIS Pro Version 2.9 to build a geoprocessing workflow that automates the selection of water rights points of diversion and determines water supply on NFS lands within a given Adjudication Basin. The workflow of the WRS Tool is divided into three parts. The first is to determine all points of diversion on NFS lands using a variety of selection processes as well as other geoprocessing tools to join data together when necessary. Only consumptive water rights were used to determine total water legally allocated on NFS lands. I developed a separate process in the WRS Tool to estimate water allocated for stock drinking directly from the source because the water rights spatial data does not include an associated flow rate for these claims (Figure 6).

The second part of the WRS Tool uses the points of diversion generated in the first part to calculate the total consumptive flow rate of water allocated on NFS lands within each HUC10 watershed (approximately 124,000 acres) that make up the selected Adjudication basin. The third part of the WRS Tool determines water supply on NFS lands and produces a final output polygon feature class with both allocated water and estimated water supply on NFS lands within each HUC10 watershed. I used the Clark Fork River above Blackfoot River (76G) Adjudication basin to develop the WRS Tool and once it was finalized, I processed the data for the other two Adjudication basins, 76M and 76N. The rest of the Methods section explains details of the geoprocessing tool and data corresponding to the workflow shown in Figure 6. Background information regarding the data used to determine total estimated water supply can be read in the "Data used to Determine Water Supply of NFS Lands" section.

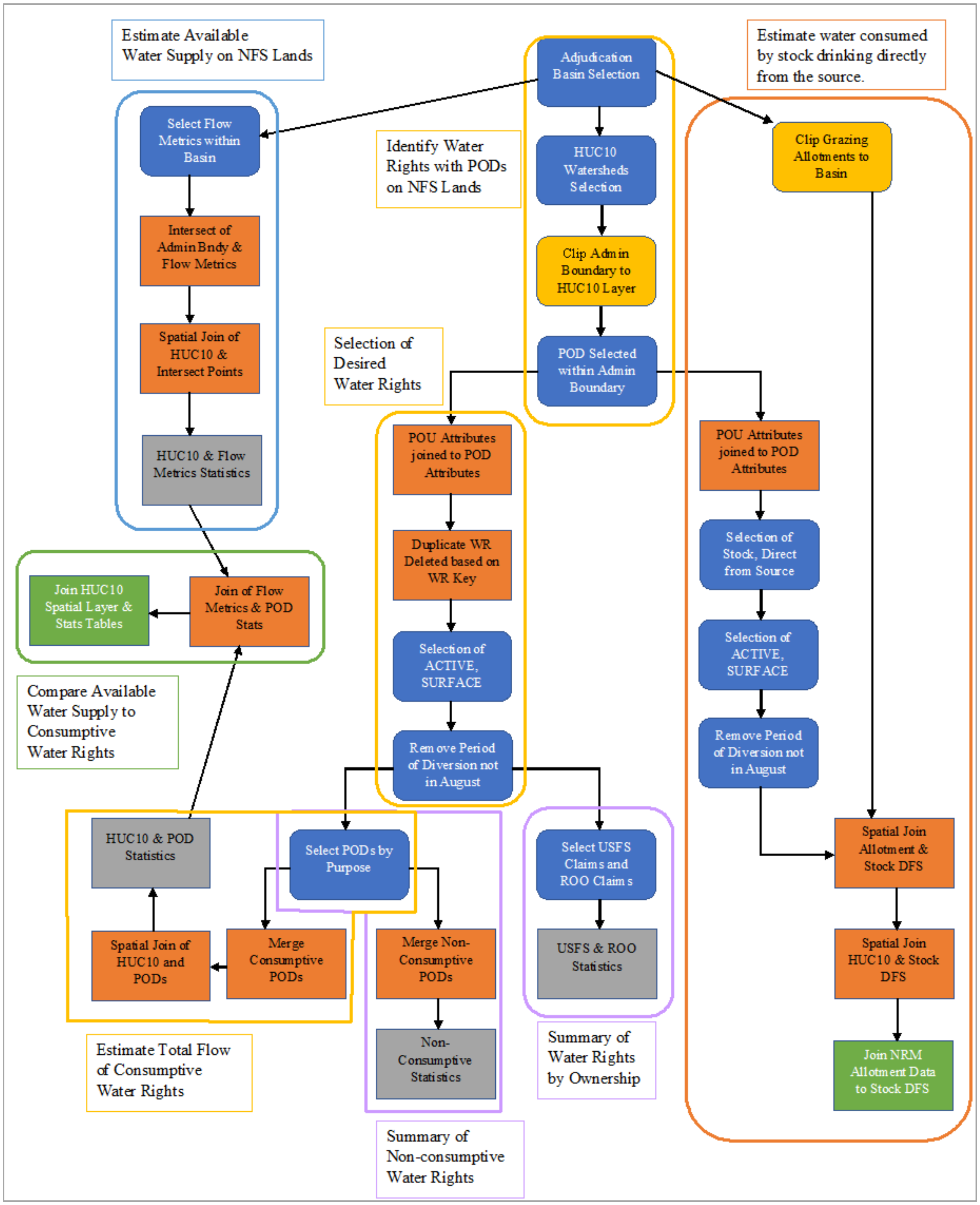

Figure 6. Water Right Selection Tool processes to compare estimated available water supply to consumptive water rights on NFS lands. Abbreviations: POD (Point of Diversion), POU (Place of Use), WR (Water Right), ROO (Rights of Others), DFS (Direct from Source).

Workflow of the Water Rights Selection Tool

The first part of the WRS Tool is to determine all points of diversion located upstream of the administrative forest boundary regardless of land ownership. To do this, I created a list of all the Adjudication basins on NFS lands contained in a parameter that linked to the Adjudication basin polygon feature class. Creating this linkage allowed me to enter the Adjudication basin of interest and the selection process of everything within that Adjudication basin would be automated upon running the WRS Tool. After the Adjudication basin is entered and selected, the WRS Tool selects all HUC10 watersheds, within the selected Adjudication basin. Next the National Forest administrative boundary layer is clipped to the HUC10 watershed layer and then points of diversion are selected within the clipped administrative boundary. In the first trials of the tool, I applied a 300-foot buffer to the selection within the administrative boundary to ensure points of diversion within private inholdings would be selected. However, I found that points of diversion downstream of the administrative boundary were also being selected that were within 300 feet, so I removed the buffer. A better way to select points of diversion upstream of the administrative boundary to include those within inholdings should be developed for future processing.

Once all points of diversion were selected within the administrative boundary, the WRS Tool automates a complex series of selections and geoprocessing steps to generate the specific data needed to determine total allocated water on NFS lands. First, fields from the place of use feature class were joined with the points of diversion feature class to ensure all eight key elements of each water right were included in one feature class. Joined fields included purpose, irrigation type, maximum acres, flow rate in gallons per minute, flow rate in cubic feet per second, volume in acre-feet per year, and acreage. Next, I removed duplicate water rights using the state assigned numeric water right key. The water right key is an identification number unique to each water right and consists of the water right number followed by the version number (Montana State Library, 2023). Once duplicates were removed, the selected data were further reduced to only those water rights that had a status of active and a source type of surface water. I removed all water rights with a source type of groundwater due to the different physical and administrative issues that they pose compared to surface rights. August was chosen as the target month due to the low flows often experienced during that period in streams across the western US. Therefore, I removed all water rights from the point of diversion feature class with a period of diversion that did not include August. For this analysis, I only used periods of diversion observed in the Clark Fork Study Area in the selection process. For future replication using the WRS Tool, it will be important to generate a more comprehensive list of periods of diversion that could be applied across all Montana Adjudication Basins.

Determining Water Allocated to Consumptive Water Rights

The second part of the WRS Tool is to quantify water allocated to consumptive water rights, meaning water rights that consume the diverted water by evapotranspiration or other losses, and calculate the total allocated flow rate for those water rights.

After the water rights that did not include August in the period of diversion were removed, I selected water rights based on each designated purpose and exported a separate point feature classes for each purpose. The six main feature classes generated were mining, irrigation, domestic, developed stock, stock direct from source, non-consumptive miscellaneous, and consumptive miscellaneous. Developed stock as the name implies are developed sources where water is diverted from a surface source and transferred to a different location for the livestock to use, some common developments include a stock tank or an irrigation ditch. These water rights have an associated flow rate in the spatial data and can therefore be quantified using that flow rate. Direct from source stock use means that stock drink directly from the source. These water rights have a standard flow rate of 30 gallons per day per animal unit set by MTDNRC and do not include a quantifiable flow rate in the spatial data. These water rights required a separate analysis to determine total implied flow rate based on the number of animal units in each HUC10 watershed. I describe this procedure in detail below in the “Determining Water Allocated to Livestock Direct from Source Water Rights” section. Non-consumptive miscellaneous water rights included those with the purpose of fishery and instream fishery. These claims do not consume water and their primary purpose is for keeping water in the stream. Consumptive, miscellaneous claims included those with a purpose of fish and wildlife, industrial, municipal, power generation, and recreation along with any other purpose not included in mining, irrigation, stock, and domestic (Table 2).

Table 2. Number of water rights on NFS Lands by purpose for the Clark Fork Study Area.

Purpose	Number of Water Rights
Consumptive Uses	
Commercial	13
Domestic	217
Fire Protection	2
Fish Raceways	3
Fish and Wildlife	46
Industrial	11
Institutional	6
Irrigation	586
Lawn and Garden	14
Multiple Domestic	5
Municipal	13
Other Purpose	1
Power Generation	20
Recreation	91
Stock	722
Unknown	4
Non-Consumptive Uses	
Fishery	19
Instream Fishery	33
Mining	153
Power Generation, Non-consumptive	3
Total	1,962

Once all purposes of use were identified, I merged the consumptive water rights into one point feature class and generated a summary statistics table. I used this table to determine the total legally allocated flow rate, and later compared it to physically available water within the associated HUC10 watershed. The consumptive water rights that I merged into one point feature class included purposes such as irrigation, domestic, developed stock, and consumptive miscellaneous. I also generated a point feature class and summary statistic table containing all non-consumptive water rights which included mining, fisheries, and instream fisheries claims. Summary statistic tables were also generated for water rights owned by the USDA's Forest

Service and those owned by others besides the USDA's Forest Service known as "rights of others" (ROO). Next, I spatially joined consumptive water rights points of diversion with the HUC10 watershed polygons to generate a polygon feature class. This feature class contained all the HUC10 watershed attribute data and the associated consumptive water rights attribute data within each HUC10 watershed.

Determining Water Allocated to Livestock Direct from Source Water Rights

Again, stock water claims where the stock drink directly from the source do not have a quantifiable flow rate in the spatial data. Therefore, another method was needed to determine water allocated for those water rights. The USDA's Forest Service range program manages allotments used by permittees for the purpose of grazing their livestock. Each permittee is allowed to graze a certain number of livestock in each allotment each year, and this is documented in the Natural Resource Manager (NRM) database by personnel on each National Forest. Therefore, the allocated flow rate can be quantified using the number of animal units within each allotment within each HUC10 watershed. The use of NRM grazing allotment data to determine water consumed by livestock required me to develop a different process in the Water Rights Selection Tool. Before removing duplicates based on water right key, I exported a separate feature class because some water rights may be found in two adjacent allotments, and it was critical to ensure that all water rights in each allotment were carried forward. For this feature class, I only included water rights with a purpose of stock and a means of diversion of Livestock Direct from Source. Like the methods described above, I only included active water rights that use surface water and removed water rights not used in August. I clipped the northern region grazing allotment layer to the adjudication basin layer and spatially joined the stock direct from source points of diversion with the allotment layer. Next, I spatially joined the point of diversion layer with the HUC10 watershed layer so that each water right included the allotment and HUC10 watershed information that it fell within. I downloaded actual detailed livestock use data from the NRM database for all allotments across the Northern Region. I removed all allotments with a status of CLOSED and generated a summary table for the allotments within the Clark Fork Study Area. This table included the average number of animal units within each allotment based on the data submitted in NRM. Using the average number of animal units and the state standard of 30 gallons per day per animal unit, I calculated the flow rate in gallons per minute and cubic feet per second for each allotment. Given the state standard of 30 gallons per day per animal unit, one animal unit would be allotted approximately 6.9×10^{-4} gallons per minute or 0.3 cubic feet per second of water per day. After the allocated water per animal unit was calculated, I joined the tabular data with the spatial data based on allotment name so that each water right had an associated allocated flow rate based on animal units. The resulting attribute data were then copied to an excel spreadsheet and the total consumptive flow rate was calculated for each allotment and then for each HUC10 watershed.

After the consumptive water rights layer and the stock direct from source layer were exported, I used them in conjunction with estimated water supply data to determine whether certain watersheds were over- or under-allocated with respect to the water rights described on NFS lands.

Data used to Determine Water Supply on NFS Lands

To determine water supply on NFS lands, I used historic (1977-2006) stream flow estimates generated by the USDA’s Forest Service Rocky Mountain Research Station (RMRS) and Office of Sustainability and Climate (OSC) (USDA Forest Service Office of Sustainability and Climate 2022). Although direct streamflow measurements would be the ideal for determining water supply, gaps in spatial coverage and periods of record make that impractical. Stream gaging stations on large streams and rivers measure flow from major watersheds in the region, but streamflow is not measured in most small watersheds at the spatial scale needed for this analysis. In an effort to provide continuous flow estimates and projection for managers, RMRS and OSC used the Variable Infiltration Capacity (VIC) model to simulate historic and future daily stream flows based on meteorologic climate predictions (Wenger et al., 2010). The VIC model has historically been used at broad scales with watersheds greater than 10,000 km^2 (Wenger et al., 2010), and climate model projections are also typically at a broad scale with spatial resolutions of 100 km or more (Vano et al., 2020). To predict stream flow more accurately for smaller drainage basins, climate projections were downscaled using the Bias Correction and Spatial Disaggregation (BCSD) method to a 1/8 degree (approximately 12 km) (USDA Forest service, 2022; Wood et al., 2004). These downscaled climate projections allowed the VIC model to simulate drainage areas less than 2,500 km^2 more accurately.

The RMRS/OSC modeling team produced historic streamflow simulations using a combination of low-elevation streamflow gaging station data and estimates of high-elevation temperature and precipitation data (Wenger et al., 2010). The modeled streamflow estimates have been attributed to the National Hydrography Dataset (NHD) Plus version 2 stream reaches (McKay et al., 2012; USDA Forest Service, 2022). Streamflow in each stream reach was estimated as the total of local inputs within the reach as well as contributions from upstream reaches and tributaries. Results of the streamflow metrics model were validated by RMRS and

OSC (Wenger et al., 2010) using observed hydrographs produced by the U.S. Geological Survey (USGS) for gaging stations located in the simulated drainages. The estimated streamflow metrics were the most consistent and readily accessible data available at the scale necessary for comparison to water rights data. The RMRS/OSC methods for estimating streamflow are well documented, have been peer reviewed and are available across the entire Clark Fork Study Area. The modeled streamflow estimates are available to the public and accessible to USDA's Forest Service employees through the current GIS software making it an ideal candidate for this analysis. To determine water supply on NFS lands, the historic streamflow estimates were used in the WRS Tool for comparison to the consumptive water rights data.

Determining Water Supply on NFS Lands

The third part of the WRS Tool is to determine estimated water supply on NFS lands and compare the data with the consumptive water rights data from the previous steps. To complete this task, I first had the WRS tool clip the RMRS/OSC historic streamflow metrics data to the Adjudication Basin boundary. Then I used the GIS intersect tool to place a point at each location where the streamflow metrics flow line crosses the administrative boundary. The flow rate data for that reach segment were then added to the attribute table for the intersection points. Next, I spatially joined the intersection points to the HUC10 watershed that each point fell within, and a summary statistics table was generated to determine total estimated flow rate within each HUC10 watershed for the months May through September. The summarized estimated flow rate table was then joined with the consumptive water rights table based on the HUC10 watershed identification number to produce one table that included estimated water supply and consumptive allocated flow legally described on NFS lands. The combined table was then joined with the HUC10 watershed spatial data, and a percent allocated field was added for future calculations.

Upon review of the combined estimated flow rate for each HUC10 watershed, I discovered that multiple intersection points were placed on some flow lines that crossed an administrative boundary in multiple places. In some cases, the multiple points were associated with only one attribute because all points were on the same reach segment. However, in other cases, the flow rate from upstream tributaries were counted multiple times depending on the number of intersection points. I found that this overestimated the flow rate for the stream and skewed the data due to duplication of upstream input. To correct the estimated flow for each HUC10 watershed, I created a separate output that contained the intersection points after they had been joined with the HUC10 watershed data. I copied the intersection point data to an excel spreadsheet and manually removed duplicate attributes. In most cases, I only used the farthest downstream point to determine the flow rate for each stream reach upstream of the administrative boundary. To avoid double counting of all upstream tributaries to the Clark Fork River, I removed most intersection points on the Clark Fork River itself. In some areas where the Clark Fork River did flow through NFS lands, two intersection points were placed on the administrative boundary, one at the upstream intersection point and one at the downstream intersection point. To again avoid double counting of the upstream inputs to this section of the Clark Fork, I subtracted the upstream estimated flow values from the downstream estimated flow values to obtain only the stream inputs for that segment of the Clark Fork River. The total estimated flow for all HUC10 watersheds was then re-calculated in the excel spreadsheet and I adjusted the spatial data to reflect the new corrected calculations.

Once the estimated total flow rate for each HUC10 watershed was corrected in the spatial data, I added the livestock consumptive use estimates to the attribute table. From there I calculated percent allocated for each HUC10 watershed by adding the consumptive water rights total flow rate to the livestock consumptive use estimates and dividing it by the estimated total flow rate for each HUC10 watershed.

RESULTS

Water Allocated on NFS Lands

There were 1,186 consumptive water rights, 564 stock direct from source water rights, and 208 non-consumptive water rights described on NFS lands within the Clark Fork Study Area. Out of the 564 stock direct from source claims, 189 did not fall within an allotment and were removed from the analysis because a flow rate could not be calculated for those claims. This left 375 stock direct from source claims that were considered in the analysis. Total estimated water supply on NFS lands was 3,080 cfs for the Clark Fork Study Area. With 1,605 cfs allocated to consumptive water rights, and 0.17 cfs allocated to stock direct from source water rights, the Clark Fork Study Area was 52% allocated with respect to consumptive uses (Table 3).

Table 3. Summary of consumptive, stock direct from source, and non-consumptive water rights compared to total estimated water supply on NFS lands within the Clark Fork Study Area.

	Number of Water Rights	Total Allocated Flow (cfs)
Consumptive Water Rights	1186	1,605
Stock Direct from Source	375	0.17
Non-consumptive Water Rights	208	1,850
Total Water Supply		3,080

There are 30 HUC10 watersheds within the Clark Fork Study Area that make up the mainstem of the Clark Fork River. Out of the 30 watersheds, seven were more than 100% allocated on NFS lands meaning that total water allocated to consumptive water rights was greater than the total water supply. Four out of the 30 watersheds were 75-100% allocated, three were 50-75% allocated, four were 25-50% allocated, and 12 were 0-25% allocated (Figures 7, 8). Five of the seven watersheds that were over-allocated were in Adjudication basin 76G, Clark Fork River above Blackfoot River which constitutes the headwaters of the Clark Fork River. The other two over-allocated watersheds were in Adjudication basin 76N, Clark Fork River below Flathead River. The four watersheds nearing full allocation were in Adjudication basins 76G and 76M, Clark Fork River between Blackfoot and Flathead River (Figure 8).

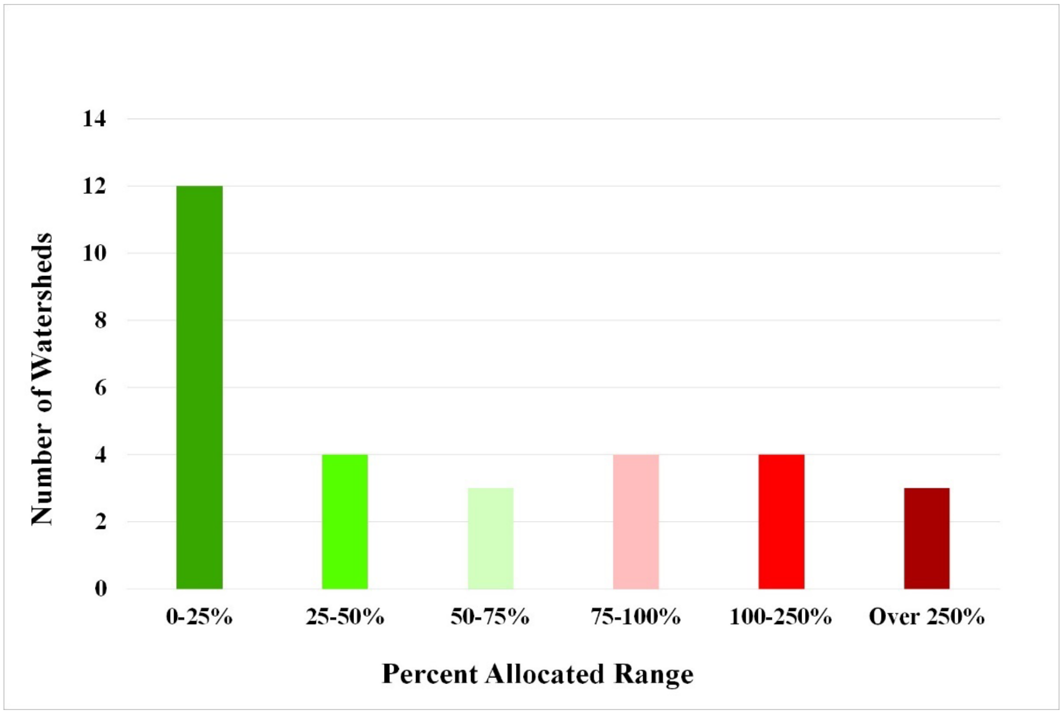

Figure 7. Percent allocated ranges for HUC10 watersheds within the Clark Fork Study Area. Nineteen watersheds ranged from 0-75% allocated while 11 watersheds ranged from 75% to over 250% allocated.

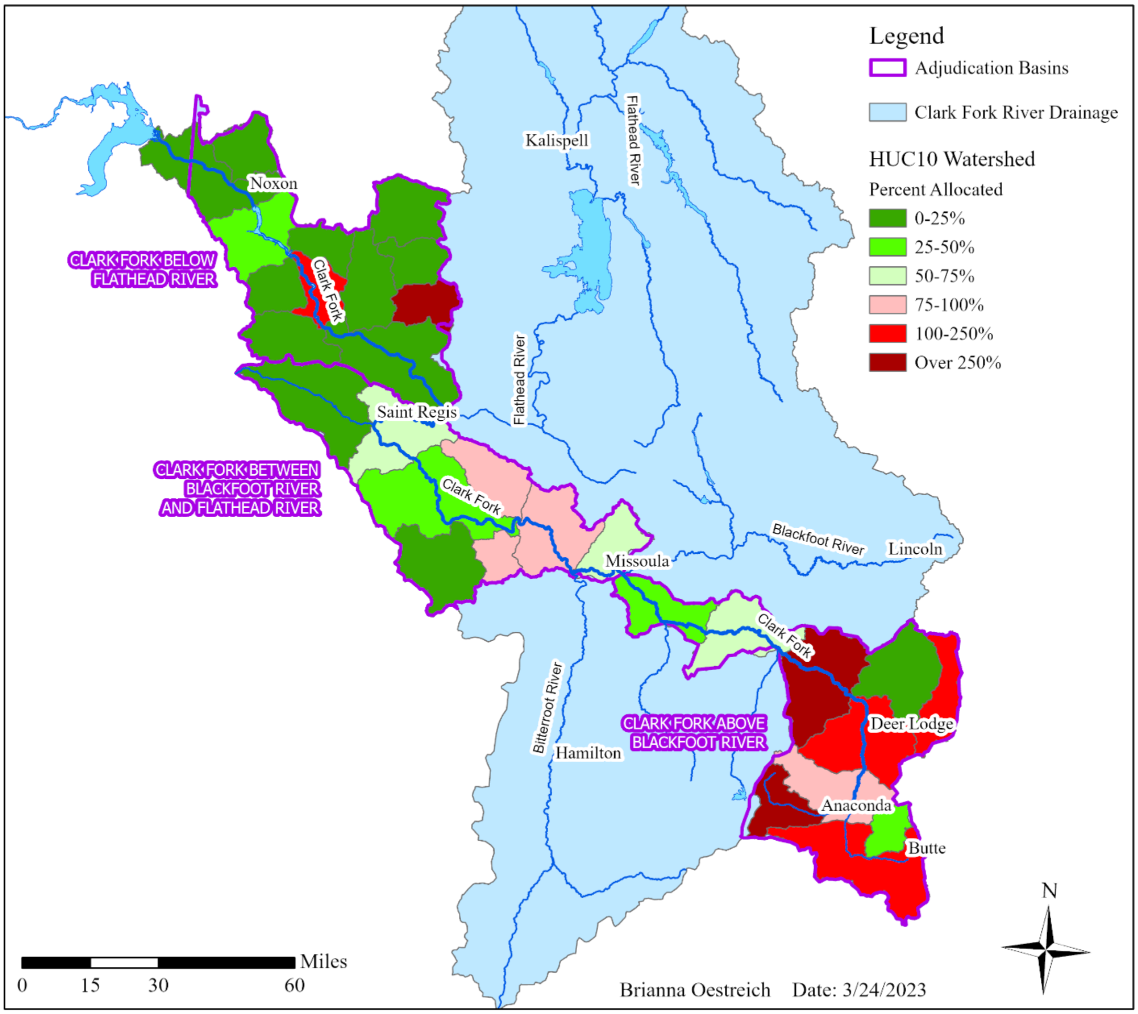

Figure 8. HUC10 Watersheds within the Clark Fork Study Area ranged from 0 to over 250% allocated with most watersheds in the 0-25% range, four watersheds nearing full allocation, and seven watersheds over 100% allocated. Blue areas were outside the study area.

Adjudication Basin 76G, Clark Fork River above Blackfoot River

There are ten HUC10 watersheds within Adjudication basin 76G which constitutes the headwaters of the Clark Fork River. Six of the watersheds within the Adjudication basin were over-allocated or nearing full allocation on NFS lands. The two most over-allocated watersheds were Warm Springs Creek at 433% allocated and Gold Creek-Clark Fork at 302% allocated. The three watersheds in the 100-250% allocated range were the Headwaters Silver Bow Creek at 126%, Upper Little Blackfoot River at 136%, and Town of Deerlodge-Clark Fork at 202%. Only one watershed was in the 75-100% allocated range, Warm Springs Creek-Clark Fork at 76% allocated. The remaining four watersheds were less than 75% allocated and included Browns Gulch, Lower Little Blackfoot River, Bear Creek-Clark Fork, and Cramer Creek-Clark Fork (Figure 9, Table 4). In total, Adjudication basin 76G was 185% allocated, meaning that more water has been allocated to consumptive water rights than estimated water supply.

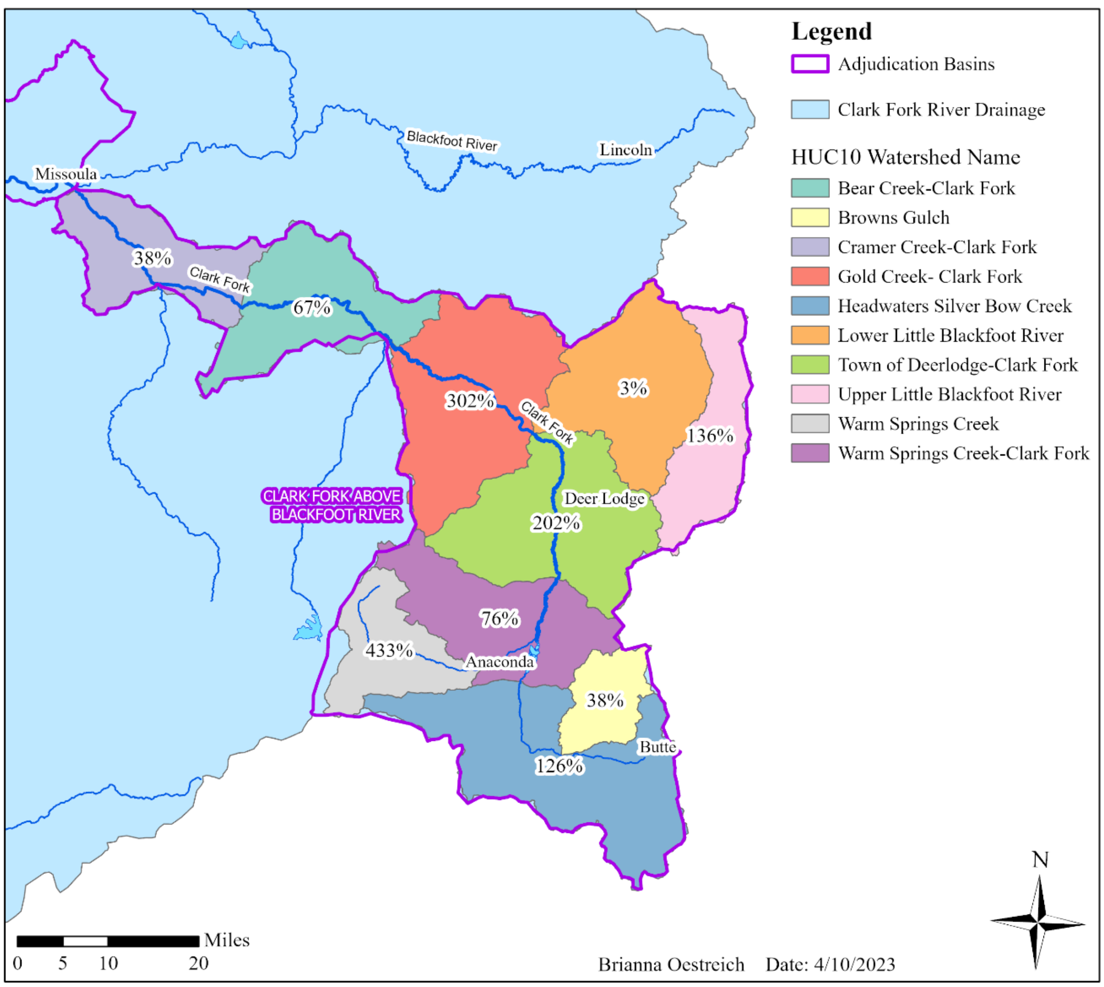

Figure 9. HUC10 Watersheds within Adjudication Basin 76G, Clark Fork River above Blackfoot River. Percentage values represent percent allocated water within each watershed.

Table 4. Total Mean August Flow, Total Allocated Flow and Percent Allocated for HUC10 Watersheds located within Adjudication Basin 76G, Clark Fork River above Blackfoot River.

HUC10 Watershed ID	HUC10 Watershed Name	Total Mean August Flow (cfs)	Total Allocated Flow (cfs)	Percent Allocated
1701020101	Browns Gulch	19	7.3	38
1701020102	Headwaters Silver Bow Creek	36	46	126
1701020103	Warm Springs Creek	71	306	433
1701020104	Warm Springs Creek-Clark Fork	54	42	76
1701020105	Upper Little Blackfoot River	47	64	136
1701020106	Lower Little Blackfoot River	24	0.62	3
1701020107	Town of Deerlodge-Clark Fork	44	88	202
1701020108	Gold Creek- Clark Fork	52	157	302
1701020206	Bear Creek-Clark Fork	22	15	67
1701020214	Cramer Creek-Clark Fork	28	11	38

Adjudication Basin 76M, Clark Fork River between Blackfoot and Flathead Rivers

Out of the eight HUC10 watersheds in Adjudication basin 76M, none were over 100% allocated, but three watersheds were in the 75-100% allocated range on NFS lands. Those watersheds were, Mill Creek-Clark Fork at 98%, Ninemile Creek at 81%, and Petty Creek at 88%. Two watersheds, Rattlesnake Creek-Clark Fork and Dry Creek-Clark Fork were in the 50-75% allocated range at 58% and 71%, respectively. The remaining three watersheds, Fish Creek, Trout Creek-Clark Fork, and Saint Regis River were less than 50% allocated (Figure 10, Table 5). In total, Adjudication basin 76M was 34% allocated meaning estimated water supply was more than water demand for consumptive water rights.

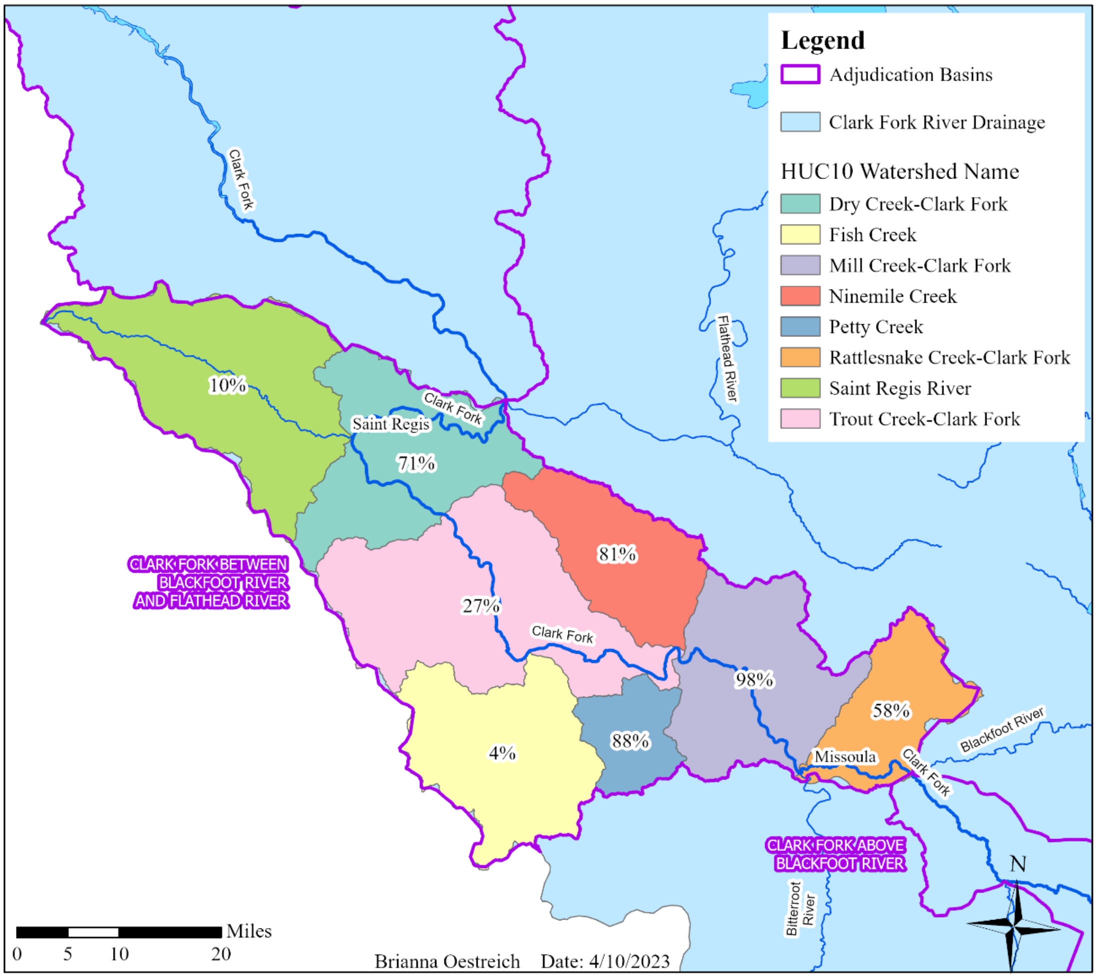

Figure 10. HUC10 Watersheds within Adjudication Basin 76M, Clark Fork River between Blackfoot and Flathead Rivers. Percentage values represent percent allocated water within each watershed.

Table 5. Total Mean August Flow, Total Allocated Flow and Percent Allocated for HUC10 Watersheds located within Adjudication Basin 76M, Clark Fork River between Blackfoot and Flathead Rivers.

HUC10 Watershed ID	HUC10 Watershed Name	Total Mean August Flow (cfs)	Total Allocated Flow (cfs)	Percent Allocated
1701020401	Rattlesnake Creek-Clark Fork	69	40	58
1701020402	Mill Creek-Clark Fork	58	57	98
1701020403	Ninemile Creek	77	62	81
1701020404	Petty Creek	44	39	88
1701020405	Fish Creek	224	9.4	4
1701020406	Trout Creek-Clark Fork	271	73	27
1701020407	Saint Regis River	304	29	10
1701020408	Dry Creek-Clark Fork	136	97	71

Adjudication Basin 76N, Clark Fork River below Flathead River

Out of the twelve HUC10 watersheds located in Adjudication basin 76N, two were over 100% allocated on NFS lands: Little Thompson River at 638% and Upper Noxon Reservoir at 219%. Only one watershed was within the 25-50% allocated range, which was Lower Noxon Reservoir at 31%. The remaining watersheds, Upper Thompson River, Middle Thompson River, Lower Thompson River, Lynch Creek-Clark Fork, Prospect Creek, Beaver Creek, Vermilion River, Bull River, and Cabinet Gorge Reservoir-Clark Fork were all less than 25% allocated (Figure 11, Table 6). In total, Adjudication basin 76N was 31% allocated meaning that estimated water supply was more than water demand for consumptive water rights.

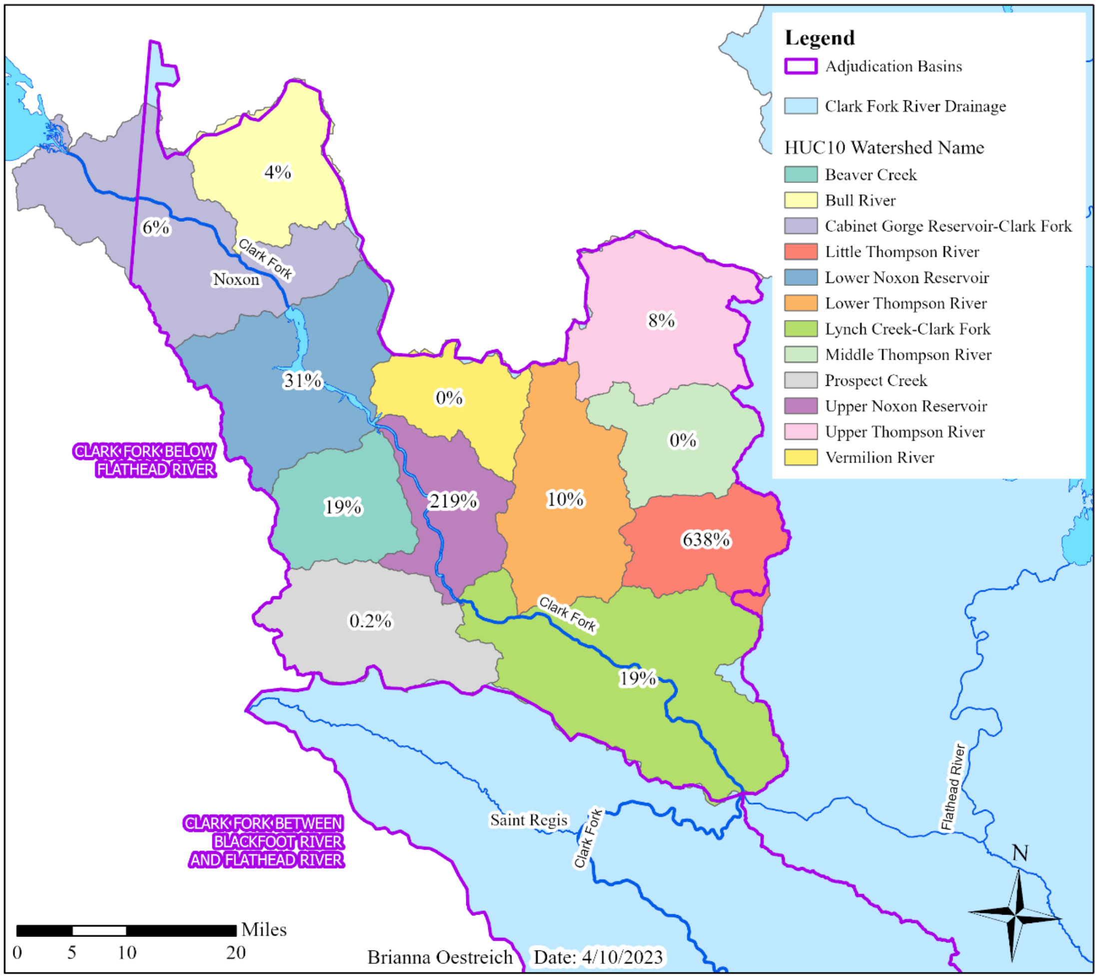

Figure 11. HUC10 Watersheds within Adjudication Basin 76N, Clark Fork River below Flathead River. Percentage values represent percent allocated water within each watershed.

Table 6. Total Mean August Flow, Total Allocated Flow and Percent Allocated for HUC10 Watersheds located within Adjudication Basin 76N, Clark Fork River below Flathead River.

HUC10 Watershed ID	HUC10 Watershed Name	Total Mean August Flow (cfs)	Total Allocated Flow (cfs)	Percent Allocated
1701021301	Upper Thompson River	44	3.7	8
1701021302	Middle Thompson River	29	0	0
1701021303	Little Thompson River	27	173	638
1701021304	Lower Thompson River	144	15	10
1701021305	Lynch Creek-Clark Fork	108	21	19
1701021306	Prospect Creek	132	0.31	0.2
1701021307	Beaver Creek	80	15	19
1701021308	Vermilion River	110	0	0
1701021309	Upper Noxon Reservoir	66	144	219
1701021310	Lower Noxon Reservoir	198	61	31
1701021311	Bull River	146	6.0	4
1701021313	Cabinet Gorge Reservoir-Clark Fork	414	25	6

Water Right Ownership - Who is Using the Water?

A total of 1,962 water rights were described on NFS lands across the Clark Fork Study Area. The most water rights described on NFS lands were in Adjudication basin 76M with a total of 930 water rights. Adjudication basin 76G had the next highest number of water rights described on NFS lands at 650 water rights. Adjudication basin 76N had the least number of water rights described on NFS lands at 382 water rights.

Most of the water rights described on NFS lands in each basin were owned by private entities. Private entities owned a total of 1,392 water rights across the Clark Fork Study Area.

The highest number of water rights owned by private entities was in Adjudication basin 76M with 725 water rights. State entities owned the least number of water rights in each basin with a total of 103 water rights across the Clark Fork Study Area. The highest number of water rights owned by state entities was in Adjudication basin 76M at 50 water rights. Federal entities, including the USDA's Forest Service owned a total of 482 water rights across the Clark Fork Study Area with the highest number of 255 water rights owned in Adjudication basin 76G (Figure 12).

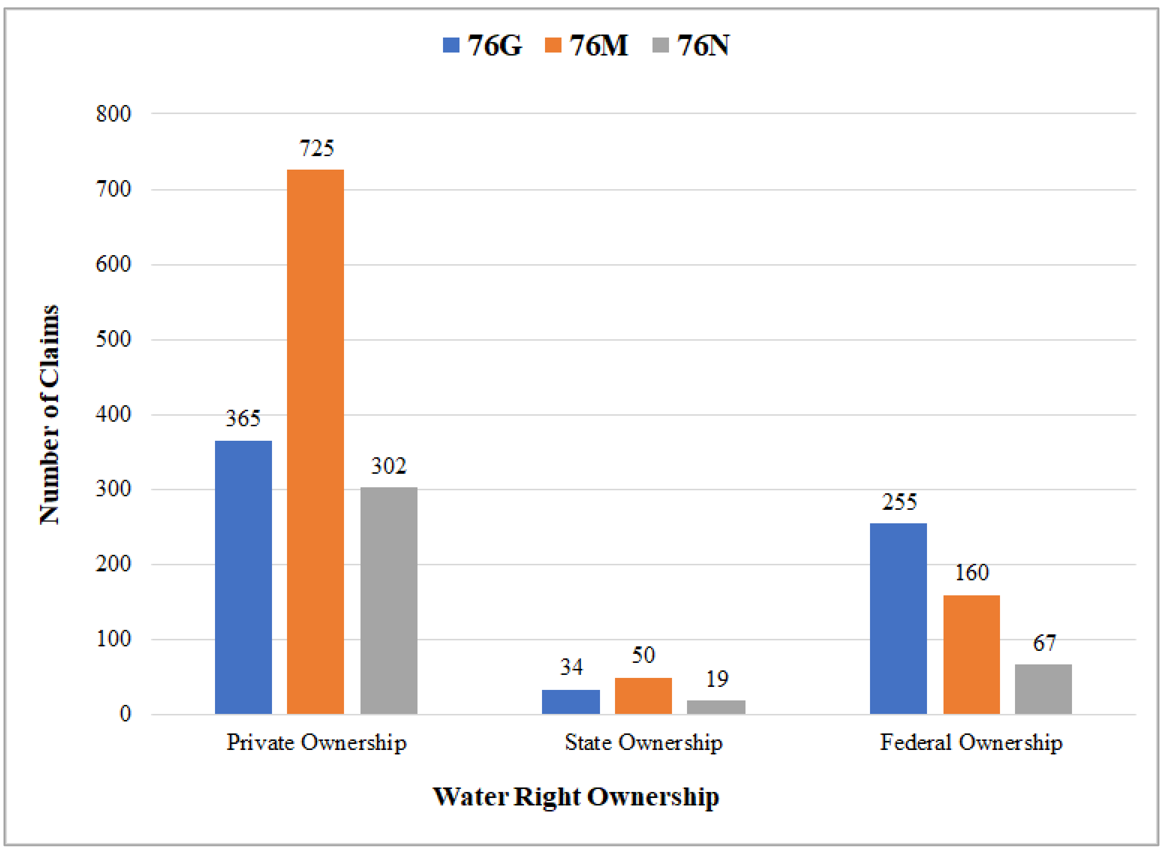

Figure 12. Number of water rights owned by private, state, and federal entities across the Clark Fork Study Area.

Water Rights Purpose - What is the Water Used for?

A total of 1,561 consumptive water rights were described on NFS lands across the Clark Fork Study Area. The highest number of consumptive water rights was in Adjudication basin 76M with 696 water rights. Adjudication basin 76N had the least amount of consumptive water rights described on NFS lands with 316 water rights. Adjudication basin 76G was in the middle with 549 consumptive water rights described on NFS lands. Most of the water rights across the Clark Fork Study Area were used for the purpose of irrigation, domestic, developed stock, and stock direct from source uses. The highest number of claims in adjudication basin 76G were for the purpose of stock direct from source with 294 claims (Figure 13) and the highest number for adjudication basins 76M and 76N were for the purpose of irrigation with 325 and 100 claims respectively (Figure 14).

The highest amount of water allocated in each adjudication basin was for the purpose of irrigation with 472 cfs allocated in 76G, 308 cfs allocated in 76M, and 321 cfs allocated in 76N. Flow allocated for irrigation purposes accounted for 69% of the total water allocated for consumptive purposes (Figure 15). Adjudication basin 76G also had 219 cfs allocated for industrial purposes which was the fourth highest flow rate allocated across the three adjudication basins. Industrial uses in Adjudication basin 76G include manufacturing of silane gas for semiconductors, glass products, and solar applications (REC Silicon 2023) as well as ore concentrators (Montana Resources 2023). All other purposes across the Clark Fork Study Area had less than 35 cfs allocated for each purpose. Although there were a high number of water rights for stock drinking directly from the source in Adjudication basin 76G, the flow rate allocated was less than 1 cfs. Due to the lack of data in the USDA’s Forest Service NRM database for range allotments, flow allocated to stock direct from source water rights could not be determined for adjudication basins 76M and 76N (Figures 13, 14).

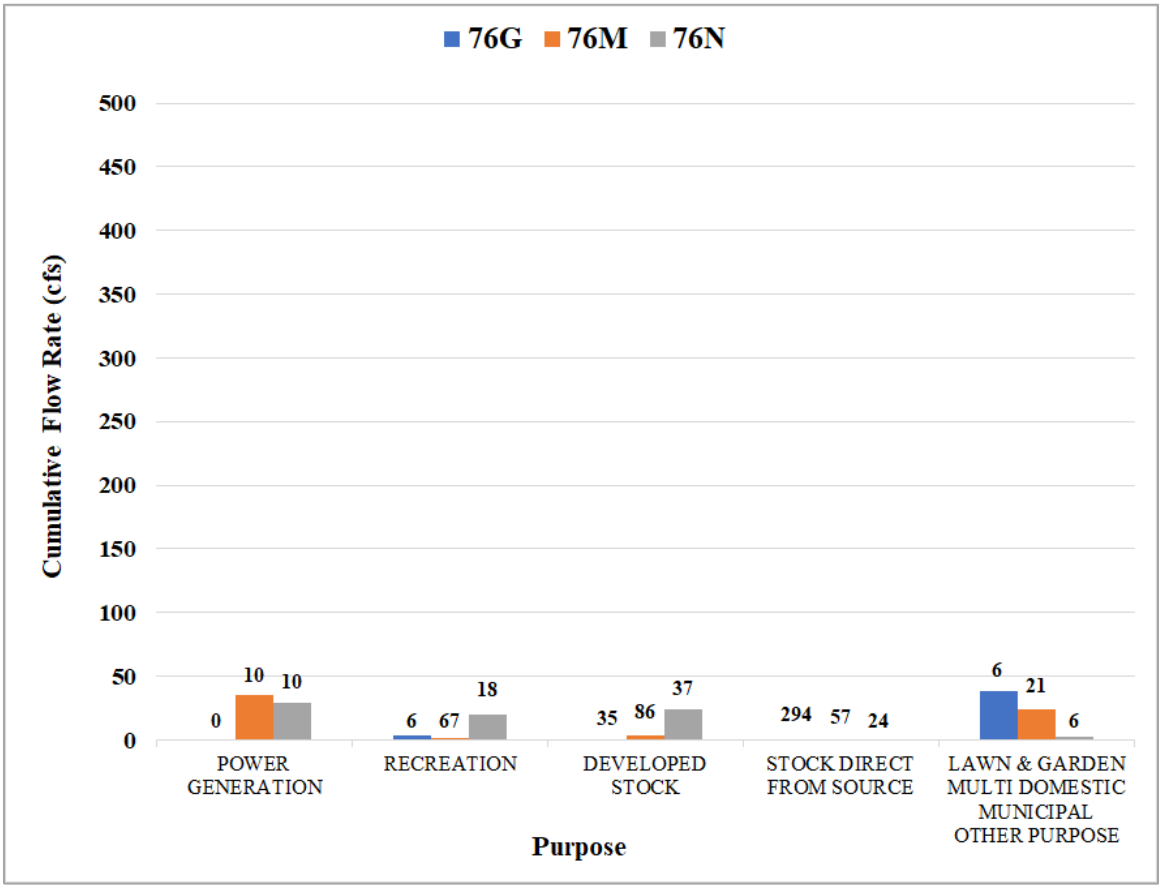

Figure 13. Total flow rate allocated for each minor purpose across the Clark Fork Study Area. The number shown above each bar is the number of water rights used for each purpose within the associated Adjudication basin.

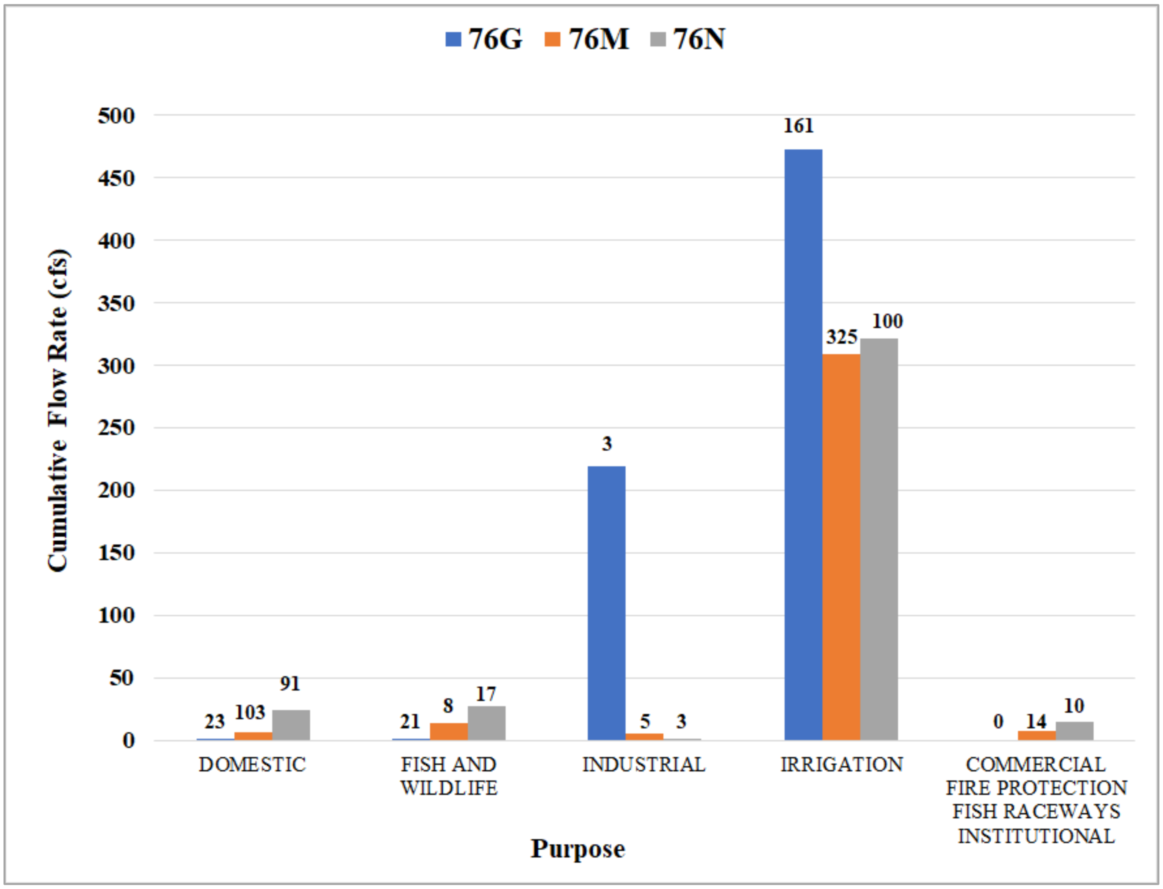

Figure 14. Total flow rate allocated for each major purpose across the Clark Fork Study Area. The number shown above each bar is the number of water rights used for each purpose within the associated Adjudication basin.

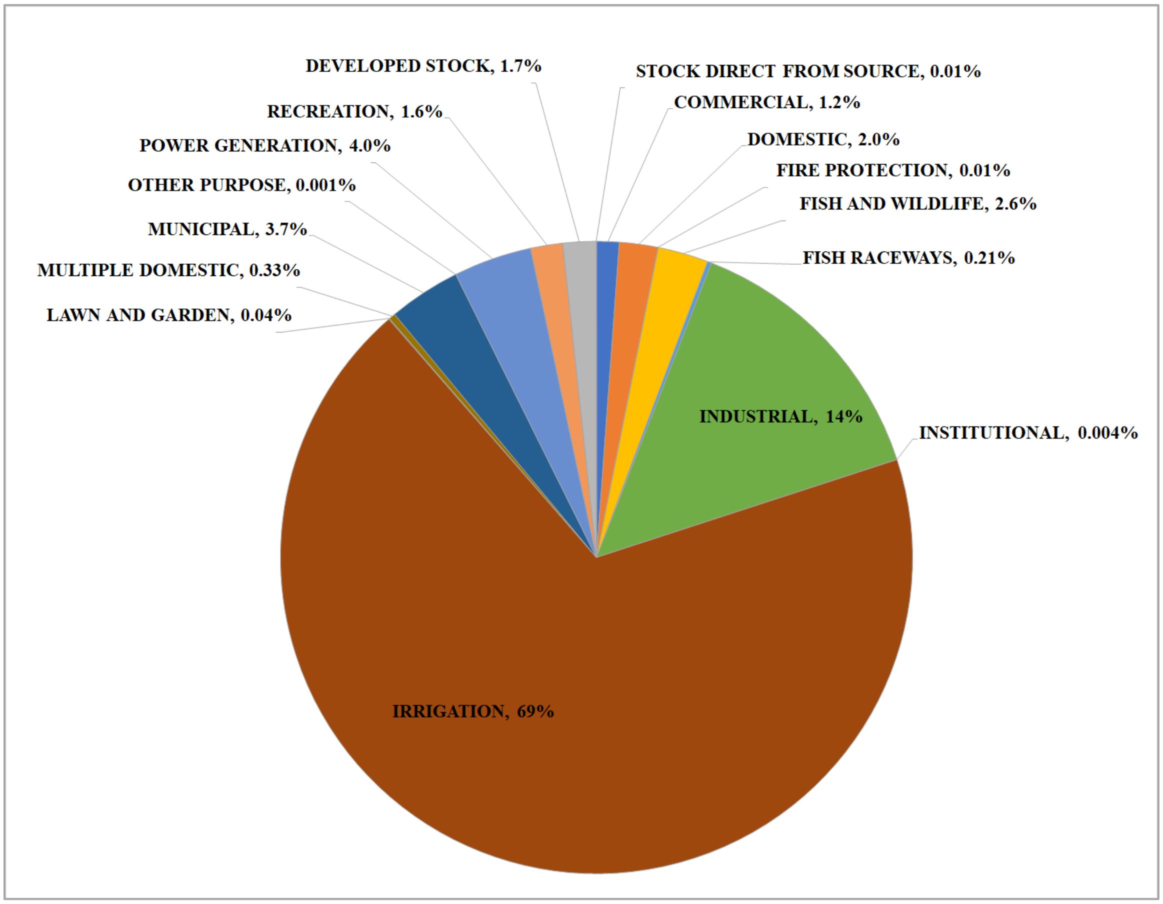

Figure 15. Percentage of total flow for all consumptive purposes in the Clark Fork Study Area.

DISCUSSION

Water Rights Selection Tool Development

The WRS Tool I developed was successful in determining points of diversion on NFS lands and comparing water allocated to water supply. There are some procedures, however, that need to be improved before expanding the analysis to other areas. As discussed in the methods section, the process to determine flow allocated to livestock direct from source water rights involved downloading data from the USDA's Forest Service NRM database that contained actual use details about grazing allotments. Not all grazing allotments were included in the NRM database, and many had not been updated recently. Due to the lack of data, the consumptive use of livestock direct from source claims were not calculated resulting in zero values. A second issue that arose while determining water allocated on NFS lands was removing periods of diversion that did not include August. There are many different periods of diversion, and they can differ for each claim. For this analysis, only the periods of diversion within the Clark Fork River watershed were reviewed to determine what needed to be removed or retained. Future analysis will require a more comprehensive, definitive evaluation of periods of diversion. The final issue with the WRS Tool was determining total water supply on NFS lands based on the point where each stream exited the administrative boundary. Many streams in the analysis area crossed an administrative boundary multiple times and therefore had multiple, duplicate intersection points with associated flow rates, which led to an overestimation of water supply. These duplicate points were removed manually, and the flow rate for each HUC10 watershed was recalculated and adjusted in the spatial data. For future replication a more efficient and definitive way to remove duplicate points is needed.

Future Replication

Overall, the portion of the WRS Tool developed to determine points of diversion on NFS lands was successful. Improvements need to be made for future replication to ensure points of diversion within private inholdings are selected and included in the final output. This will ensure that all water rights potentially affecting NFS lands are selected for use in the analysis. Improvements also need to be made to the period of diversion selection to exclude any period of diversion outside of the target analysis period. Both improvements will likely require specific scripts or codes to be generated to complete these tasks in a more efficient manner.

Before proceeding with future processing, the importance of including stock direct from source claims should be evaluated. Due to the lack of consistent data in the USDA's Forest Service NRM database, the determination of consumptive use by stock also lacks consistency. For future replication, either the data for the allotments needs to be updated by the forest units or the stock direct from source water rights should be removed from the analysis. Due to the small amount of flow allocated to stock direct from source claims, often less than 1 cfs, the removal of these claims would not lead to a drastic under-estimation of water allocated on NFS lands. Determining the importance of stock direct from source claims would ensure the analysis stays consistent across all adjudication basins in future replication.

As discussed previously, the determination of water supply on NFS lands needs to be addressed. When the intersection tool was used to determine points where the streamflow metrics flow line crossed the administrative boundary there were stream segments that crossed multiple times and thus had multiple intersection points. In some areas, the flow line crossed the administrative boundary within the same reach and only one attribute was included in the output dataset. However, in other areas the flow line was crossed in multiple stream reach segments which duplicated portions of the flow upstream of those points. These duplicated points had to be manually removed via an excel spreadsheet output and the total water supply on NFS lands for each HUC10 watershed was recalculated and adjusted in the spatial data. For future replication, removing these duplicate points manually would be time consuming and inefficient. This process needs to be automated with a script to increase the efficiency and consistency of the WRS Tool.

Once these adjustments have been made, the WRS Tool will be suitable for wider use and replication.

Allocation of Water on NFS Lands

At the Adjudication basin level, the Clark Fork Study area was 52% allocated on NFS lands. Adjudication basin 76G was 185% allocated, 76M was 34% allocated, and 76N was 31% allocated on NFS lands. Refining allocation to the HUC10 watershed level showed that seven watersheds specifically within Adjudication basins 76G and 76N were over-allocated on NFS lands during periods of low streamflow. The over-allocation during periods of low streamflow in those watersheds could indicate the needs of aquatic species are not being met. Often when low streamflow occurs during the month of August, air temperatures are also high which can increase water temperatures. An increase in water temperature decreases the amount of dissolved oxygen that the water can maintain which can negatively impact aquatic species (U.S. Geological Survey, 2018).

Although this analysis shows that some watersheds are over-allocated on NFS lands it is not necessarily indicative of what is happening on non-FS lands within the Clark Fork Study Area. The Upper Clark Fork Drainage which includes Adjudication basin 76G, is considered a closed basin due to a legislative closure (Montana Department of Natural Resource and Conservation, 2016). This type of closure is enacted by law in highly appropriated basins and prohibits new applications and state water reservations except in certain situations. The Upper Clark Fork Drainage was closed in 1995 and the only exceptions for new appropriations include: Environmental response actions filed before January 1, 2000, stock use permits, permits to store water, power generation at existing hydroelectric dams, and groundwater appropriations

(Montana Department of Natural Resource and Conservation, 2016). This legislative closure likely indicates that Adjudication basin 76G as well as other Adjudication basins in the Upper Clark Fork Drainage could be at or near full appropriation. No such closures exist for Adjudication basins 76M or 76N meaning that it is unlikely that either are at or near full appropriation.

As seen in Figure 3, there is much more private land in Adjudication basin 76G than in either 76M or 76N. Much of the private land is bordered by forested lands increasing the potential that water would need to be diverted from forest lands to private lands possibly leading to over-allocation on NFS lands. There is also a greater amount of hay/pasture and cultivated crops in Adjudication basin 76G (Figure 4), which could also necessitate greater water diversion off NFS lands compared to Adjudication basins 76M and 76N.

Sources of Error

Although the WRS Tool I developed determines points of diversion on NFS lands from the data available, the tool cannot ensure that the data are accurate. In the MTDNRC water rights database, points of diversion are placed at the center of the legal description on the abstract. The legal description is given as the township, range, and section as well as the quarter, quarter, quarter of that section. If the point of diversion is described down to a 10-acre area (quarter, quarter, quarter section) and falls on NFS lands there is a high likelihood that the point of diversion is in fact on NFS lands and that it will be associated with the correct stream segment in the geospatial database. However, in some cases the point of diversion is more broadly described and may include the entire section (640 acres) or only the first quarter of the section (160 acres). In this case if the point of diversion falls on NFS lands but the entire section or quarter section includes both private and NFS lands, there is the potential that the point of diversion is not on NFS lands. Although the WRS Tool selects all points of diversion that fall within the administrative boundary, it cannot use the legal description to determine whether the point of diversion is on NFS land.

Another potential source of error would be errors that exist in the MTDNRC water rights database including inaccurate legal descriptions. In some cases, the point of diversion may be described in the wrong quarter section, the wrong section or even the wrong township or range. Many of the water rights within the state of Montana were filed before the use of GPS was common and the locations were estimated based on a map and entered by hand. The WRS Tool does not determine the accuracy of the described locations. Given these two main sources of error it is important to note that the WRS Tool only provides a broad overlook of the water potentially allocated on NFS lands. To determine the exact allocation on NFS lands, a much more in-depth tool and methodology, likely requiring some field verification, would need to be developed.

As mentioned above, the WRS Tool provides an estimation of water allocated on NFS lands based on a legal right and it does not determine actual use of water on NFS lands. It would be very difficult and time consuming to determine actual water use on NFS lands due to the extensive filed verification and record keeping that would be necessary. The WRS Tool provides a method that can be used in determining where priority areas are for field verification and could aid in the efforts of determining actual use on NFS lands in the future. While the WRS Tool provides a systematic and rational approach to determining water allocated on NFS lands there is a certain amount of uncertainty associated with the results that cannot be determined using traditional statistical methods.

Although the RMRS/OSC streamflow metrics data was ideal for the purpose of this analysis, it has some level of uncertainty associated with the estimated flow rates. In Wenger et al. (2010), which describes the methods used for the original study for the Pacific Northwest region, the estimated flow rates are said to be less accurate at high and low flows. However, the streamflow metrics used in this analysis were from the updated 2022 version which expanded the analysis across the contiguous US and used updated climate scenarios and metrics for flow estimates (USDA Forest Service 2022). The exact levels of uncertainty associated with the high and low flow data in the 2022 estimations are unknown, but one could assume there is a similar level of uncertainty to the original data. Due to the potential uncertainty of low flow estimates in the streamflow metrics data, there is also uncertainty with total estimated water supply on NFS lands although the exact level is unknown.

While the WRS Tool only provides an overview of potential allocation on NFS lands with some level of uncertainty, it holds great potential value for water resource management. It could be used to determine watersheds where aquatic species may be at risk due to over-allocation during periods of low streamflow and help inform management decisions for those areas. It could also be used in conjunction with other state and federal sensitivity assessments that evaluate water quality and identify priority watersheds for restoration work. The WRS Tool could also be used in determining the future impacts of climate change as it pertains to water allocated on NFS lands. The RMRS/OSC streamflow metrics data not only includes historic stream flow estimations but also includes future predictions for the mid-century (2030-2059) and end-of-century (2070-2099) time periods. The WRS Tool when used in conjunction with the future flow predictions could help to inform management decisions as it pertains to climate change and water use on NFS lands.

CONCLUSION

The Water Right Selection tool was developed in this pilot study to determine points of diversion on National Forest System lands, calculate total allocated flow based on those points of diversion, and determine total estimated water supply on National Forest System lands using water rights spatial data as well as modeled streamflow metrics data. The tool was successful in completing these tasks; however, improvements need to be made to use it more successfully for future replication across other National Forest System lands. Once improved the tool can be used along with other sensitivity assessments to help land managers refine project needs and prioritize project areas. The tool can also be used in conjunction with the future predicted streamflow metrics for mid-century and end-of-century to determine how climate change is expected to affect the water supply and demand issues that already plague the western US.

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