COLORADO MESA
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SCIENTIFIC
AND TECHNICAL
REPORT NO. 2
MARCH 2016

Riparian groundwater and baseflow studies in the Upper Colorado River Basin

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Acknowledgements: Financial support for this study came from the U.S. Geological Survey's ecosystems mission area WaterSMART funds for ecological flows work in the Colorado River Basin. The authors and the Hutchins Water Center at CMU would also like to thank Abe Springer, David Susong and Melissa Masbruch for their peer review of the report and helpful comments and discussion on earlier drafts.

Suggested citation: Reynolds, L.V. and Shafroth, P.B., 2016, Riparian groundwater and baseflow studies in the Upper Colorado River Basin: Ruth Powell Hutchins Water Center at Colorado Mesa University Scientific and Technical Report No. 2, 8 p.

Cover photo: Surface Creek near Cedaredge, CO, which drains the southeastern flank of Grand Mesa and is tributary to Tongue Creek and the Gunnison River.

Photo credit: L. Reynolds, September 2010.

Executive summary

As part of an ongoing effort to understand baseflow in the Upper Colorado River Basin (UCRB) and implications for stream-dependent ecosystems, we conducted a brief review of literature related to groundwater and baseflow in the UCRB. We included primary literature, federal and state resources, databases and gray literature studies on groundwater, baseflow, and springs in the UCRB region. This review provides examples of the types of groundwater and baseflow studies published for the UCRB with sections on whole-basin studies, catchment and reach studies and their locations, water quality studies, studies adjacent to the UCRB, state and federal groundwater resources, and finally a discussion of potential further directions. Despite the limited nature of the review, we summarize numerous studies related to groundwater in the UCRB which will be valuable to researchers interested in groundwater and baseflow dynamics in the region.

Introduction

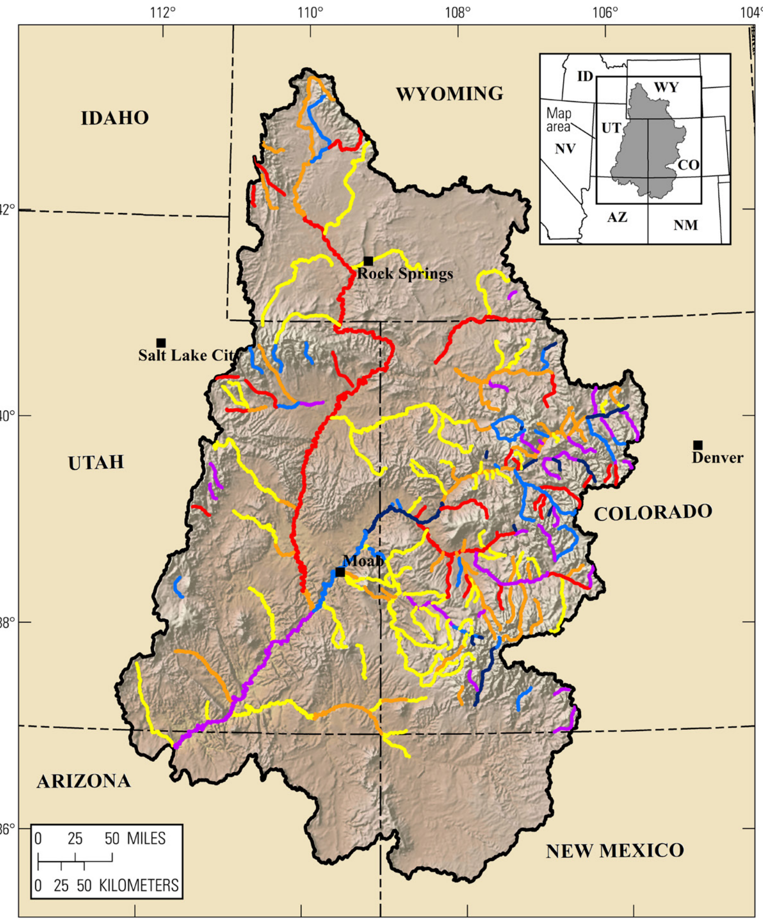
Groundwater is inherently difficult to study due to its hidden, underground nature and is often treated as a black box in water budget and water cycle analyses. However, groundwater can be an important contributor to streamflow in geologic settings where a stream is in contact with an aquifer (a geologic formation capable of storing, transmitting and yielding exploitable quantities of water; (Knighton, 1998; WMO, 2012)). Aquifers, as underground storage reservoirs of groundwater, are inherently dynamic (Castle et al., 2014) and therefore streams can gain or lose water to an aquifer, depending on season, streamflow levels and groundwater levels (Winter et al., 1998). Baseflow is the component of streamflow attributable to groundwater inputs and is defined as "discharge which enters a stream channel mainly from groundwater, but also from lakes and glaciers, during long periods of drought" (WMO, 2012). Understanding riparian groundwater and baseflow dynamics is essential for understanding how streamflow will behave under future climate conditions (Holman, 2006; Castle et al., 2014) and how stream-dependent ecosystems will respond to future hydrologic conditions (Green et al., 2011; Merritt and Bateman, 2012).

To understand baseflow in the Upper Colorado River Basin (UCRB), we conducted a brief review of literature related to groundwater and baseflow in the UCRB. Our methods included internet and database searches for primary literature studies on groundwater, baseflow, and springs in the UCRB, the Colorado Plateau, and within the states of the basin (Colorado, Utah, Wyoming, Arizona and New Mexico). We also searched state and federal resources, databases and gray literature studies on groundwater in the UCRB. Although we have compiled many relevant studies and resources, this review is limited in scope and could be expanded.

Whole-basin scale studies

Several studies have addressed aquifer dynamics and baseflow at large scales. At the national scale, Wolock developed a raster grid of interpolated base-flow index values which can be used within the UCRB (Wolock, 2003). More recently, Castle and others (2014) estimated annual groundwater fluctuations for both the Upper and Lower Colorado River Basin for years 2004-2013 using remotely sensed data and showed how groundwater extraction can have a dramatic effect in drought years (Castle et al., 2014). Focusing on the upper basin, Miller and others (2014) at the U.S. Geological Survey's Utah Water Science Center (UWSC) evaluated groundwater and baseflow components on larger rivers across the UCRB (Miller et al., 2014). Their study looked at baseflow using a chemical hydrograph separation methodology. They investigated sites on large, snowmelt-dominated rivers using specific conductance to identify baseflow (Miller et al., 2014).

In another study, the UWSC compiled 235 baseflow discharge estimates from existing studies at multiple scales into a geospatial database for the UCRB (Garcia et al., 2014). Although most of the data are from large rivers, there are several small streams included, so this is a viable resource for information on some small (mostly 3rd-4th order) streams **(Figure 1).** The most extensive coverage is in the state of Colorado, mostly due to one study on groundwater and salinity (Warner et al., 1985). To access their extensive bibliography, please see the online resources associated with Garcia et al. (2014).



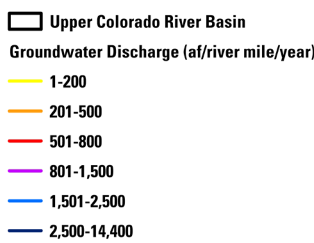


Figure 1 - Estimates of groundwater discharge (acre-feet/river mile/year) for stream reaches where information was found in a literature review by Garcia et al. (2014) in the Upper Colorado River Basin. More details about each study and specific methods used to estimate groundwater discharge for a given reach can be found in Garcia et al. (2014) and the associated geodatabase.

The UWSC is also currently working on developing time-series estimates of baseflow on 230 stream gages, mostly on larger rivers, but also on some small streams. These new time- series data will be available in a manuscript expected to be published sometime in 2015-16. They are also developing a new model of baseflow in the UCRB which should also become available sometime in 2015-16 (D. Susong, pers. comm.).

Catchment and reach-scales

There are several case studies that offer information on groundwater and baseflow at smaller scales **(Table 1, Figure 2)**. For example, groundwater and streamflow dynamics of the Colorado River headwaters in the Kawuneeche Valley have been studied extensively (Woods et al., 2006; Westbrook et al., 2006; Kaczynski et al., 2014). This work included installation of groundwater wells that could be used to understand trends in groundwater over decades (Kaczynski et al., 2014). North Walton Creek, in the Rabbit Ears Pass watershed near Steamboat Springs, was also intensively instrumented to study groundwater flow (with a focus on water quality) during snowmelt (Peters and Leavesley, 1995). Further south, a detailed groundwater analysis was conducted on Tongue Creek which drains the south flank of Grand Mesa, Colorado (Lazear, 2006). More broadly, geology, spring discharge and groundwater flow were studied across the whole Grand Mesa which straddles the Gunnison and Colorado River Basins (Lazear, 2008).

Uinta Basin

There are a number of studies investigating geology and groundwater in the Uinta Basin and Wasatch Plateau surrounding the town of Vernal, UT (Mayo et al., 2003). Information on groundwater dynamics can sometimes be gleaned from these geology-focused studies. For example, a study of CO_2 in groundwater near Green River, UT details the surrounding hydrogeology along Salt Wash (tributary to

Table 1 - Catchment and reach-scale studies of groundwater and baseflow stream hydrology in the Upper Colorado River Basin. See Figure 2 for study locations on a map.

GROUNDWATER STUDY LOCATIONS		
MAP NUMBER	STREAM/ CATCHMENT	CITATIONS
1	Kawuneeche Valley, Colorado River, CO	(Woods et al., 2006; Westbrook et al., 2006; Kaczynski et al., 2014)
2	North Walton Creek, CO	(Peters and Leavesley, 1995)
3	Tongue Creek, CO	(Lazear, 2006)
4	Grand Mesa, CO	(Lazear, 2008)
5	Cement Creek, CO	(Walton-Day et al., 2012)
6	Upper Snake River, CO	(Crouch et al., 2013)
7	Blue River, CO	(Kaushal et al., 2006)
8	Salt Wash, UT	(Kampman et al., 2009)
9	Courthouse Wash, UT	(Kirby et al., 2013)
10	Moab-Spanish Valley, UT	(Lowe et al., 2007)
11	Grand County, UT	(Eisinger and Lowe, 1999)
12	Little Grand Wash springs	(Dockrill and Shipton, 2010)
13	Salt and Indian Creeks	(Bishop, 1996)
14	Gypsum Canyon Watershed, UT	(Reitman et al., 2014)
15	Dakota-Burro Canyon, UT	(Kirby, 2008)

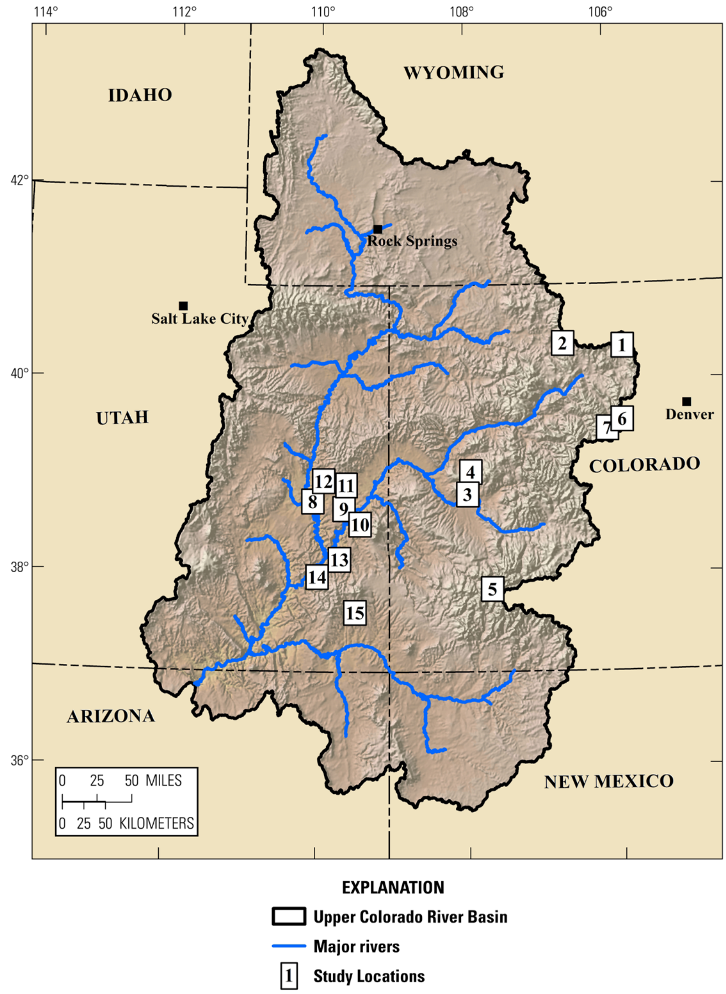


Figure 2 - Locations of catchment and reach-scale studies of groundwater and baseflow stream hydrology in the Upper Colorado River Basin. See Table 1 for citations corresponding to numbered locations.

the Green River upstream of the San Rafael River confluence) (Kampman et al., 2009). Where groundwater monitoring wells have been placed in the floodplain, these data are useful for understanding riparian ecohydrology (Miller, 1983).

Southeastern Utah

The state of Utah in collaboration with the USGS in 2012, drilled a monitoring well into sandstone bedrock to tap aquifers north of Moab. These aquifers outlet at Courthouse Wash Boundary Spring and feed the headwaters of Courthouse Wash (Kirby et al., 2013). Data from this well can be accessed through the state of Utah's groundwater database online (http://temp.geology.utah.gov/databases/groundwater/map.php?proj_id=3). Due to human demand on aquifers near Moab, the state of Utah has studied the hydrogeology of the Moab-Spanish Valley as well as throughout Grand County (Eisinger and Lowe, 1999; Lowe et al., 2007). Recharge to the aquifers in this area occurs mostly through infiltration of precipitation and infiltration of streamflow in losing stream reaches. Near the Colorado and Green Rivers, aquifer discharge is mostly to these large rivers but other sources of discharge include evapotranspiration, springs, and wells for human use (Eisinger and Lowe, 1999; Lowe et al., 2007). A more detailed study on geology and faulting north of Moab explains groundwater emergence through springs along the Little Grand Wash fault (Dockrill and Shipton, 2010).

A report investigating potable groundwater sources near the southeast corner of Canyonlands National Park revealed two aquifers. Recharge to these aquifers is primarily through local precipitation and from the largest, nearly perennial streams, Salt and Indian Creeks (Bishop, 1996). Also near Canyonlands National Park, a study describes geology and groundwater flow in the Gypsum Canyon watershed, which lies between the Colorado River and the Abajo Mountains.

The study investigates geology, groundwater elevations, groundwater flow and the locations of springs throughout the watershed (Reitman et al., 2014).

Just south and east of Gypsum Canyon, the Dakota-Burro Canyon aquifer feeds springs near Blanding, UT (Kirby, 2008). In addition to natural discharge via springs, extraction for wells and agriculture consumption are significant sources of discharge from the aquifer. Recharge to the aquifer occurs through infiltration of precipitation and through seepage from unlined canals and ditches in this area (Kirby, 2008). Further south and east, an analysis of aquifer dynamics surrounding the four-corners area of southern Utah provides groundwater discharge estimates to major perennial streams in that area (Thomas, 1989).

Water quality studies

Small scale studies in the basin that investigate water quality often analyze groundwater dynamics as well. For example, one study at a mine-contaminated site in the Cement Creek catchment (tributary to the upper Animas River, north of Silverton, CO) also determined baseflow (Walton-Day et al., 2012). A similar study investigating sources of zinc contamination in the Upper Snake River (tributary to Dillon reservoir on the Blue River, CO) provides information about baseflow and groundwater sources for this stream (Crouch et al., 2013). Another study on a tributary to the Blue River, CO, analyzed nitrogen enrichment in the stream and sampled ground water wells for nitrogen, but did not report ground water levels (Kaushal et al., 2006).

Studies in catchments adjacent to the UCRB

There are also case studies in nearby catchments outside the UCRB that may have geology that is analogous to catchments inside the UCRB such as Loch Vale and Handcart Gulch, both in the headwaters of the adjacent South Platte River Basin (Clow et al., 2003; Manning and Caine, 2007). In the neighboring Saguache catchment on the east side of the continental divide, researchers investigated spring flow generation, finding that no springs are consistently 100% groundwater fed (Frisbee et al., 2013). Each spring sampled had at least partial contribution of young precipitation water. These results suggest that spring flow is not always a good proxy for groundwater flow (Frisbee et al., 2013). The same researchers investigated baseflow in Saguache Creek and found that the proportional contribution of groundwater to streamflow increases as the size of the watershed increases, and also as time since snowmelt runoff increases (Frisbee et al., 2011, 2012). Thus, groundwater discharge is a higher percentage of flow in the summer and fall/winter, than it is in the spring during runoff (Frisbee et al., 2011, 2012). This conclusion was also supported by results at larger scales in the UCRB (Miller et al., 2014). Alternatively, although neighboring catchments may have similar geologic characteristics, valley morphology (e.g., wide alluvial versus

Table 2 - Online resources for groundwater wells of the Upper Colorado River Basin.

ONLINE RESOURCES FOR GROUNDWATER WELLS	
STATE	**RESOURCE**
Utah	**Interactive map portals with point water withdraw locations including groundwater wells and springs:** http://waterrights.utah.gov/gisinfo/maps/default.asp http://maps.waterrights.utah.gov/EsriMap/map.asp?layersToAdd=StreamAlteration
	Groundwater aquifers: http://www.ngwa.org/PublishingImages/States/Utah.jpg
	Utah Geological Survey publications: http://geology.utah.gov/library/
Colorado	**Static map of groundwater wells:** http://cdss.state.co.us/onlineTools/Documents/StatewideWells.pdf
	Interactive map of water rights including groundwater wells: http://water.state.co.us/DataMaps/GISandMaps/MapViewer/Pages/FAQ.aspx
	Interactive map of groundwater well applications, regardless of whether they received a permit or not: http://www.water.state.co.us/DataMaps/GISandMaps/AquaMap/Pages/default.aspx **FAQs and legend:** http://165.127.23.41:8000/documentation/aquamap_faqs.pdf http://165.127.23.41:8000/documentation/aquamap_legend.pdf
	GIS layers including groundwater well applications: http://water.state.co.us/DataMaps/GISandMaps/Pages/GISDownloads.aspx
	Static map of groundwater aquifers: http://www.ngwa.org/PublishingImages/States/Colorado.jpg
Wyoming	**GIS layer of point locations for groundwater well permits:** http://seo.wyo.gov/documents-data/maps-and-spatial-data
Arizona	**Online groundwater and groundwater well data:** https://gisweb.azwater.gov/waterresourcedata/default.aspx
New Mexico	**Geospatial data including Office of the State Engineer (OSE) groundwater well data:** http://www.ose.state.nm.us/GIS/geospatial_data.php

narrow bedrock canyon) may be more of a determinant of groundwater dynamics and baseflow, as was found in the adjacent Wind River Mountains, WY (Jin et al., 2012).

Federal and state resources

The USGS has groundwater monitoring wells across the nation and provides well data online (http://waterdata.usgs.gov/nwis/gw). Where these wells are in the floodplain, the data will be relevant to stream hydrology. The wells within the UCRB are especially concentrated in the Uinta Basin, the Moab Valley, the Uncompahgre River Valley, the Upper Green River, WY, and near Farmington, NM. State government websites are also good resources for groundwater information. Each state in the UCRB has online resources for groundwater wells and some states offer their published groundwater studies online as well **(Table 2)**. Utah in particular offers access to several studies published by the Utah Geological Survey investigating groundwater.

Further directions

In our review of groundwater literature in the UCRB, we found information regarding larger rivers in the basin and also fine-scale information for a few catchments and smaller stream reaches in the basin, however, these findings are limited in scope, and other reports can be found for the UCRB. Further reading of the total maximum daily load (TMDL) literature might reveal more studies on water quality that may have information on groundwater and baseflow. Authors of studies with groundwater monitoring wells could be contacted to access data and for potential resampling of the wells if the wells are still in place. It would also be useful to search for more studies on wetlands in the basin, which may provide information about groundwater hydrology and geology. Lastly, it would be worthwhile to interview staff in the US Forest Service, Bureau of Land Management, National Park Service, and state land managers who may have information and knowledge about published and unpublished studies on groundwater dynamics on their lands within the UCRB.

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