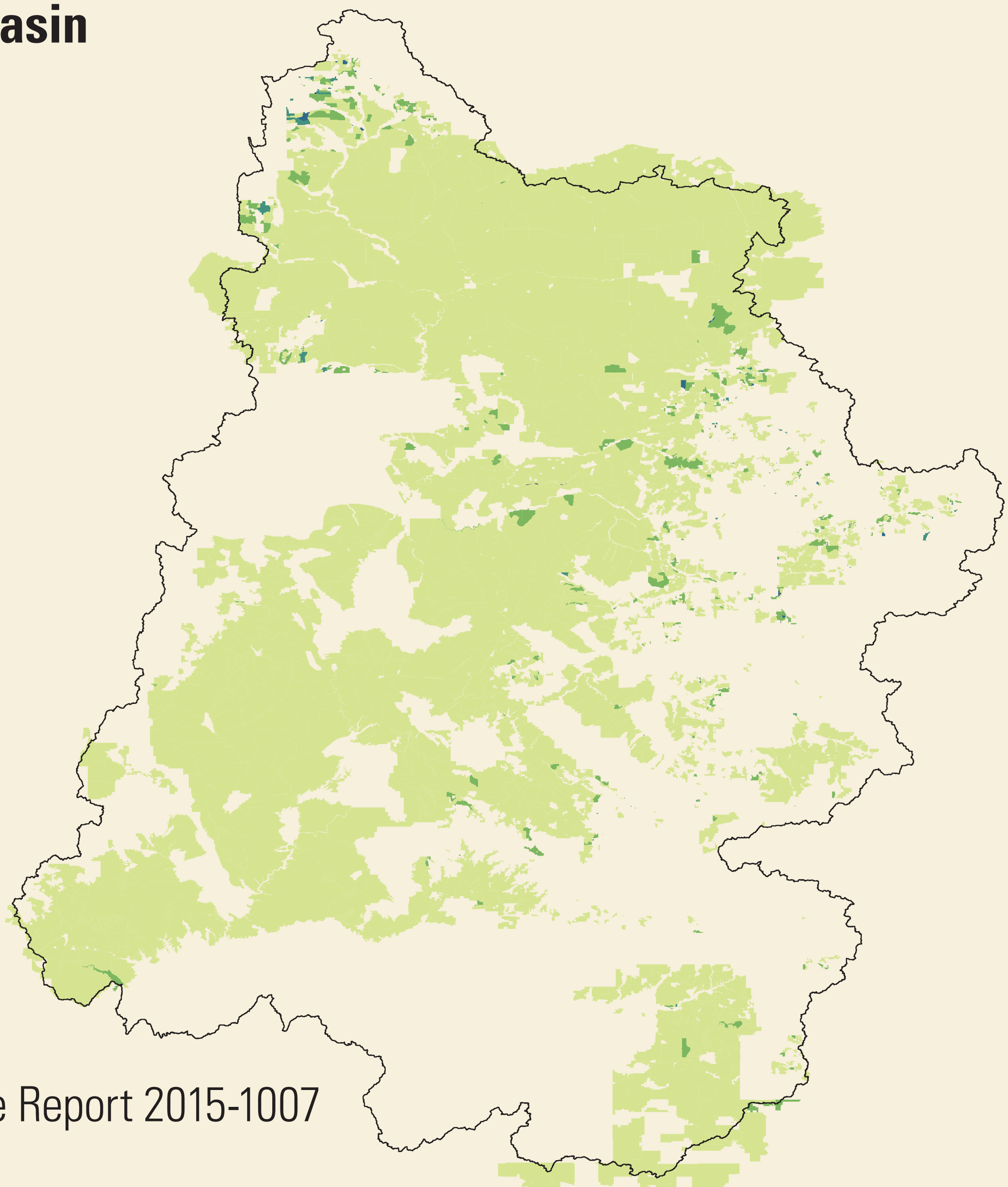
Prepared in cooperation with the Bureau of Reclamation

Geospatial Datasets for Assessing the Effects of Rangeland Conditions on Dissolved-Solids Yields in the Upper Colorado River Basin



Open-File Report 2015-1007

U.S. Department of the Interior
U.S. Geological Survey

FRONT COVER:
Grazing density (billed animal unit months per acre) on land managed by the Bureau of Land Management in the Upper Colorado River Basin in 2010. See figure 4 in report.

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SALLY JEWELL, Secretary

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Suggested citation:
Tillman, F.D, Flynn, M.E., and Anning, D.W., 2015, Geospatial datasets for assessing the effects of rangeland conditions on dissolved-solids yields in the Upper Colorado River Basin: U.S. Geological Survey Open-File Report 2015-1007, 21 p., *http://dx.doi.org/10.3133/ofr20151007.*

ISSN 2331-1258 (online)

Acknowledgments

This study was supported by the Colorado River Salinity Control Forum. Cole Rossi of the Bureau of Land Management (BLM) and Kossi Nouwakpo of the University of Nevada-Reno provided information and discussion on the impact of rangeland practices and conditions on dissolved-solids loading to streams and rivers. BLM GIS and rangeland specialists who assisted in the compilation of grazing information on BLM-managed land in the Upper Colorado River Basin include Lynnda Jackson, Bill Coulloudon, David Wilson, Jim Holden, David Sjaastad, John Pittman, Scott Clarke, Tara De Valois, Michael Jensen, Lynae Rogers, Angela Losasso, David Sinton, Matt Dupire, Roger Cumpian, Jeff Tafoya, Larry Lichthardt, Mark Goertel, Ron Dietz, George Soehn, Lisa Dilley, and Caleb Hiner. U.S. Forest Service (USFS) GIS and rangeland specialists who assisted in the compilation of grazing information on USFS-managed land in the Upper Colorado River Basin include Brian Goldberg, Paul Archual, David Cottle, Tom McClure, Dennis Cleary, Teresa Rhoades, Chad Horman, Candace Bogart, and Kevin Sanchez.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Mass	
ton per year (ton/yr)	0.9072	metric ton per year
	Energy	
kilowatt hour (kWh)	3,600,000	joule (J)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

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Geospatial Datasets for Assessing the Effects of Rangeland Conditions on Dissolved-Solids Yields in the Upper Colorado River Basin

By Fred D Tillman, Marilyn E. Flynn, and David W. Anning

Abstract

In 2009, the U.S. Geological Survey (USGS) developed a Spatially Referenced Regressions on Watershed Attributes (SPARROW) surface-water quality model for the Upper Colorado River Basin (UCRB) relating dissolved-solids sources and transport in the 1991 water year to upstream catchment characteristics**.** The SPARROW model focused on geologic and agricultural sources of dissolved solids in the UCRB and was calibrated using water-year 1991 dissolved-solids loads from 218 monitoring sites. A new UCRB SPARROW model is planned that will update the investigation of dissolved-solids sources and transport in the basin to circa 2010 conditions and will improve upon the 2009 model by incorporating more detailed information about agricultural-irrigation and rangeland-management practices, among other improvements. Geospatial datasets relating to circa 2010 rangeland conditions are required for the new UCRB SPARROW modeling effort. This study compiled geospatial datasets for the UCRB that relate to the biotic alterations and rangeland conditions of grazing, fire and other land disturbance, and vegetation type and cover. Datasets representing abiotic alterations of access control (off-highway vehicles) and sediment generation and transport in general, were also compiled. These geospatial datasets may be tested in the upcoming SPARROW model to better understand the potential contribution of rangelands to dissolved-solids loading in UCRB streams.

Introduction

More than 35 million people in the United States and 3 million people in Mexico depend on the Colorado River to supply their domestic and industrial water needs (Bureau of Reclamation, 2011; Colorado River Basin Salinity Control Forum, 2013). The Colorado River also supplies irrigation water for more than 4.5 million acres of land in the United States and Mexico, and generates about 12 billion kilowatt hours annually of hydroelectric power along the river and its tributaries (Colorado River Basin Salinity Control Forum, 2011). From its headwaters in the Rocky Mountains through seven states and Mexico, the Colorado River traverses more than 1,400 mi to the Gulf of California (fig. 1*A*). Dissolved-solids concentrations in the river increase from about 50 mg/L at the river headwaters to about 500 mg/L at Lees Ferry, Arizona, to about 850 mg/L where it crosses the United States border with Mexico (Anning and others, 2007). Annually, more than 9 million tons of dissolved solids flow past Hoover Dam (Anning and others, 2007).

It has been estimated that approximately 55–60 percent of the salinity (as measured by dissolved-solids load and concentration) in the Colorado River is from natural sources—primarily from saline spring discharge and the erosion of saline geologic formations that were deposited from ancient inland seas and waterways (Colorado River Basin Salinity Control Forum, 2013; Kenney and others, 2009). Dissolved-solids concentrations can also increase through human activities that increase loading (primarily irrigation of agricultural land, but also municipal and industrial development, as well as mining and drilling operations) and through accumulation (evaporation from reservoir operations). The Bureau of Reclamation estimates that high-salinity Colorado River water causes damages of more than 300 million dollars per year to users in the United States (Colorado River Basin Salinity Control Forum, 2013), largely from reduced agricultural crop yields and corrosion and plugging of pipes and water fixtures in housing and industry (Bureau of Reclamation, 2011).

In order to provide land and water managers in the area more information about the sources of dissolved-solids in Upper Colorado River Basin (UCRB) streams, in 2009 the U.S. Geological Survey (USGS) developed a Spatially Referenced Regressions on Watershed Attributes (SPARROW) surface-water quality model to relate dissolved solids loads from the 1991 water year to upland catchment attributes (Kenney and others, 2009). The 2009 UCRB SPARROW model focused on geologic and agricultural sources of dissolved solids in the basin and was calibrated to dissolved-solids loads estimated by Anning and others (2007) from 218 water-quality monitoring sites. The 2009 UCRB SPARROW model was developed by testing 37 parameters for significance in predicting annual dissolved-solids loads, including sources (geologic source groups, irrigated agricultural land groups, saline springs) and landscape transport characteristics (for example, catchment relief, percentage of area covered by barren land, precipitation;

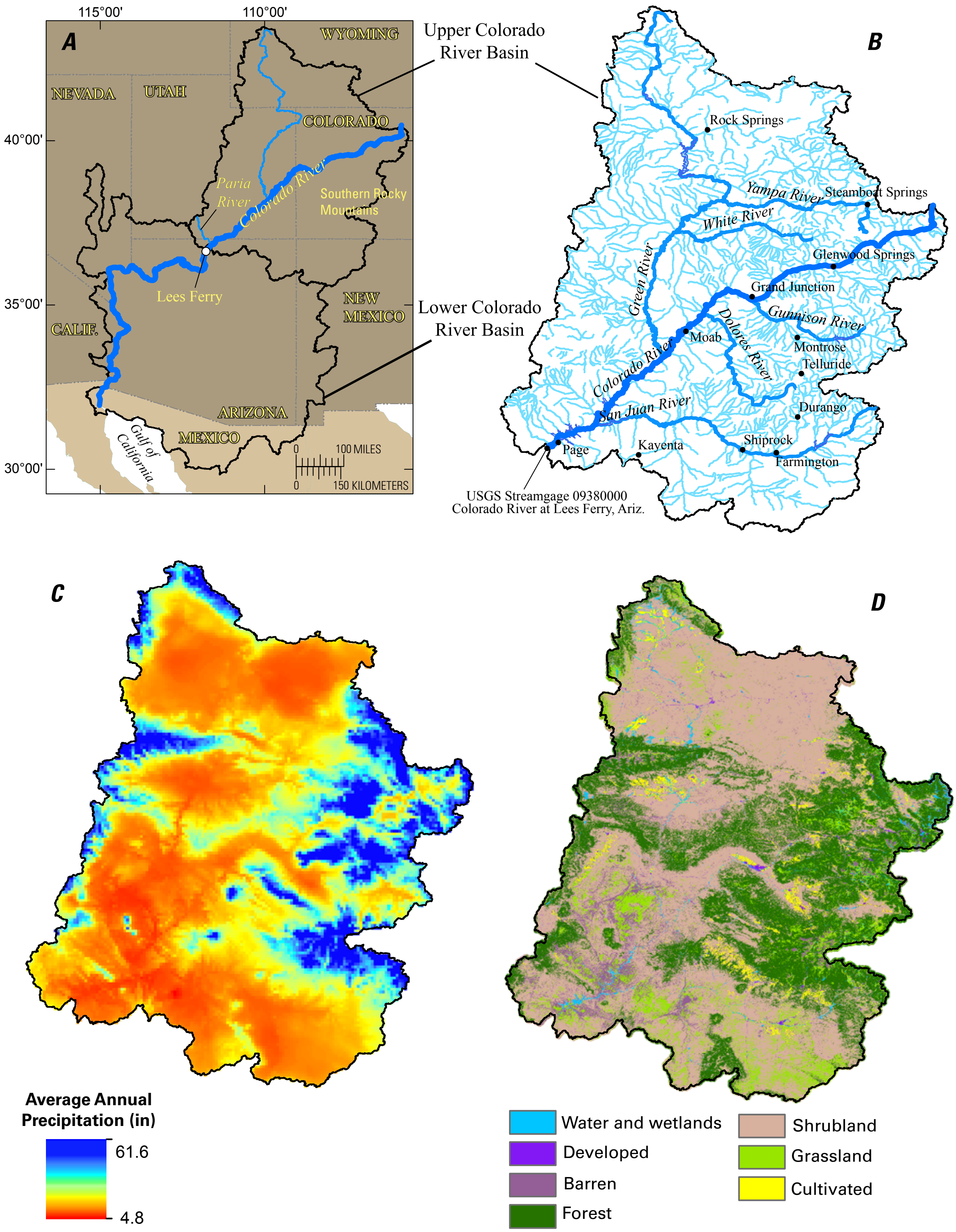


Figure 1. Maps of the Upper Colorado River Basin showing (*A*) its location, (*B*) major streams, (*C*) average annual precipitation (PRISM Climate Group, 2012), and (*D*) major land-cover classifications (Fry and others, 2011).

Kenney and others, 2009). Rangeland conditions were not among the parameters tested in the model. Standardized residuals from the 2009 UCRB SPARROW model are an indication of where predicted and observed dissolved-solids loads differ (fig. 2). Elevated residuals imply that the SPARROW model did not include adequate explanatory variables to accurately simulate observed dissolved-solids loads. Although 2009 SPARROW model residuals appear to be spatially unbiased in general, some patterns emerge when looking at residuals by 4-digit Hydrologic Unit Code (HUC4's; fig. 2). HUC4's with three of the four highest median negative residuals (where the SPARROW-predicted load was greater than the observed load) are also the three HUC4's with the greatest percentage of area described as Rangeland or Transitional Rangeland using the National Resources Inventory (NRI; Natural Resources Conservation Service, 1997) definition described below (figs. 2, 3). Three of the four HUC4's with the most sites with negative residuals are in the top four HUC4's in terms of NRI-defined Rangeland or Transitional Rangeland percent area (figs. 2, 3).

A new UCRB SPARROW model is planned to provide land and water managers with information on potential contributions to dissolved-solids loads and concentrations in UCRB streams from UCRB rangelands. The new UCRB SPARROW model will test additional parameters that include more detailed information on irrigation methods and indicators of rangeland conditions, among other improvements. Geospatial datasets relating to circa 2010 rangeland conditions are required for the new UCRB SPARROW modeling effort.

Purpose and Scope

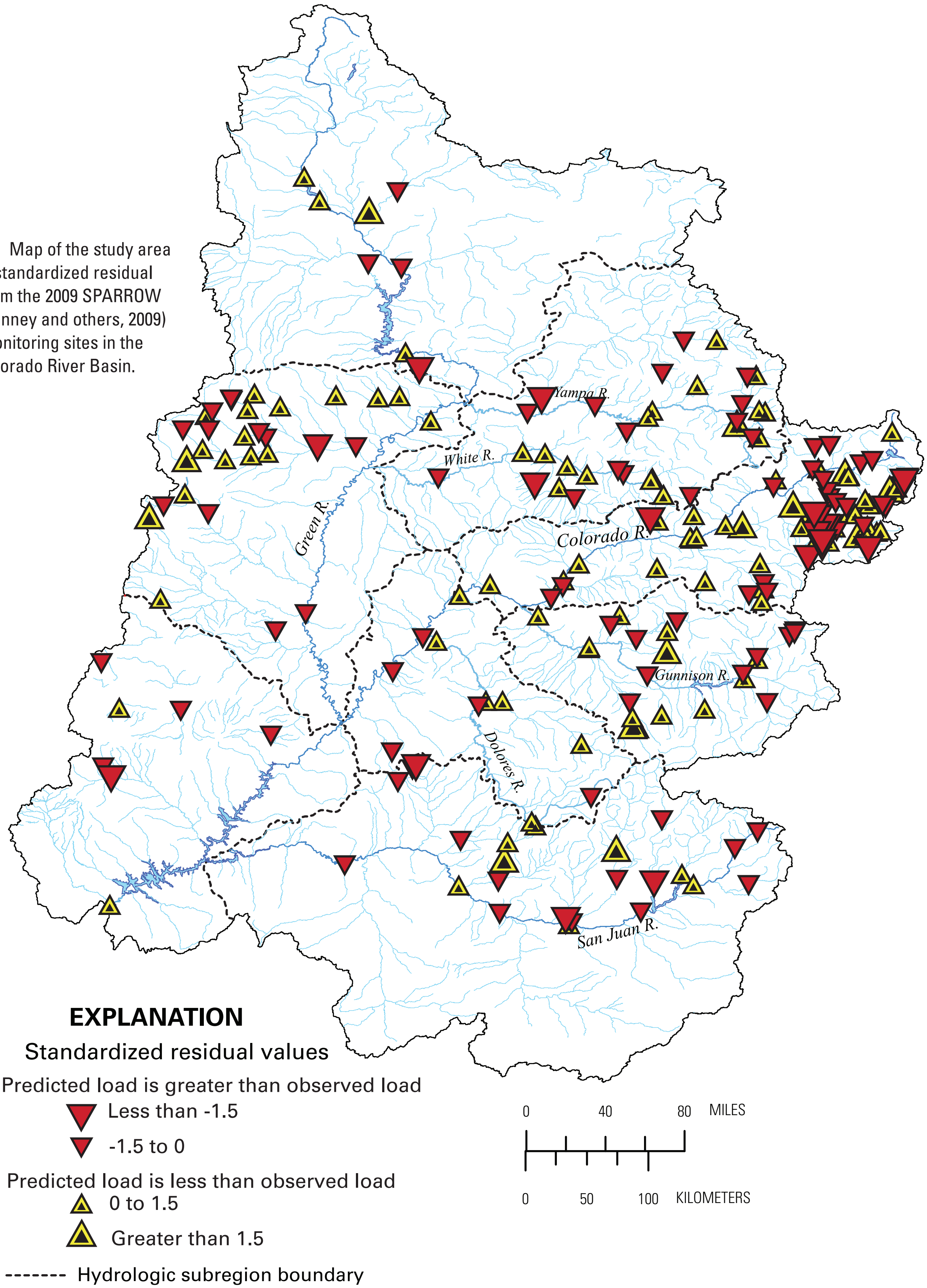
This report documents the compilation of geospatial data on UCRB rangeland conditions that potentially affect dissolved-solids concentrations and loads in UCRB streams. Such geospatial information can be digitally processed to represent catchment attributes and therefore will directly support future efforts to update and improve the UCRB dissolved-solids SPARROW model. The study area for this investigation of geospatial datasets on rangeland conditions is the Upper Colorado River Basin, and the temporal focus is on circa 2010 conditions.

Description of Study Area

The Colorado River Basin drains parts of Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada, California, and Mexico, and is divided into upper and lower basins at the compact point of Lees Ferry, Arizona, a location 1 mi downstream of the mouth of the Paria River (fig. 1*A*, 1*B*; Anderson, 2004). The Upper Colorado River Basin (UCRB) is defined for this study as the 113,406 mi^2 drainage area upstream of USGS streamflow-gaging station 09380000, Colorado River at Lees Ferry, Arizona (Hydrologic Region 14; fig. 1*B*). Major tributaries to the Colorado River in the Upper Basin include the Dolores, Green, Gunnison, San Juan, White, and Yampa Rivers (fig. 1*B*). Average annual precipitation ranges from less than 10 in. in low elevation areas to 39 in. or more in high elevation areas in the Southern Rocky Mountains (fig. 1*C*; PRISM Climate Group, 2012). UCRB land cover is predominately shrub/scrub and evergreen forest (Fry and others, 2011), with few high-density population centers (fig. 1*D*). Major dissolved constituents in UCRB streams are the cations calcium, magnesium, sodium, and potassium; the anions sulfate, chloride, and bicarbonate; and neutral silica (Liebermann and others, 1989). Important geologic sources of dissolved solids in the UCRB include the Upper Cretaceous Mancos Shale, the Paradox Member of the Pennsylvanian Hermosa Formation, and the Eocene Green River Formation (Liebermann and others, 1989).

Rangeland can be defined in a variety of ways and is often described using land cover, land use, potential vegetation, or administrative characteristics (Lund, 2007). A study by Reeves and Mitchell (2011) identifies more than 300 definitions of rangelands that have been used internationally. Reeves and Mitchell (2011) quantify rangeland area in the coterminous United States using two methods: (1) by applying the definition used by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) in its National Resources Inventory (NRI; Natural Resources Conservation Service, 1997), and (2) by applying the definition used by the U.S. Forest Service through the Forest Inventory and Analysis (FIA) program (U.S. Forest Service, 2010). The NRI model estimates area of three rangeland classes: rangelands, afforested rangelands, and transitory rangelands. Rangelands in the NRI definition are dominated by shrub or herbaceous vegetation and must contain suitable species for browsing or grazing (Reeves and Mitchell, 2011). Afforested rangelands are dominated by herbaceous or shrub species but are being encroached upon by forest (>25 percent tree cover). Transitory rangelands are dominated by herbs or shrubs, but the potential vegetation is classified as forest capable of supporting >25 percent tree cover (Reeves and Mitchell, 2011). The simpler FIA definition of rangeland, essentially nonforest areas that are not cultivated, produces only one rangeland class. Some differences are seen in the UCRB between the NRI and FIA models of rangeland. The NRI classification results in about 63,500 mi^2 of UCRB rangeland or transitional rangeland, whereas the FIA classification results in about 53,600 mi^2 of UCRB rangeland, with the largest difference, in Colorado, of about 36 percent (fig. 3). Owing to the lack of a universally accepted definition for rangelands, geospatial datasets potentially relevant to rangeland conditions that are documented in this report were not limited to particular UCRB rangeland areas, but were assembled for all available areas in the UCRB.

Figure 2. Map of the study area showing standardized residual values from the 2009 SPARROW model (Kenney and others, 2009) for 218 monitoring sites in the Upper Colorado River Basin.



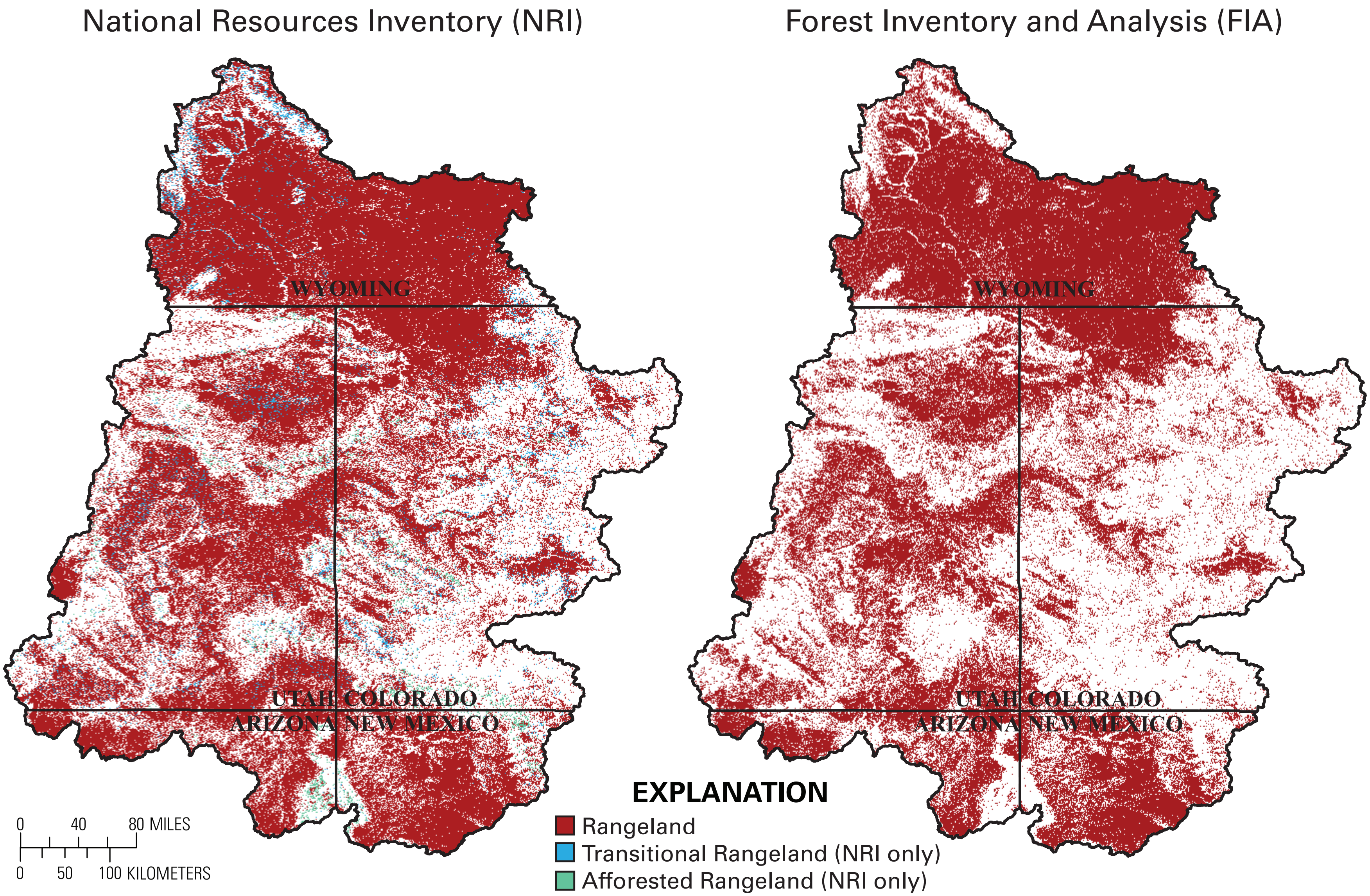


Figure 3. Maps of Upper Colorado River Basin rangelands classified by the National Resources Inventory (NRI; Natural Resources Conservation Service, 1997) and Forest Inventory and Analysis (FIA; U.S. Forest Service, 2010) definitions (Reeves and Mitchell, 2011).

Conceptual Model of Rangeland Contributions to Dissolved Solids in UCRB Streams

Dissolved solids may be transported from sources to streams by a combination of wind and (or) water processes. Dust from wind erosion of salt-laden sediments may be deposited directly on lakes and streams or be deposited on soil surfaces and subsequently transported to lakes and streams by runoff (Weltz and others, 2014). Dissolved solids may enter streams and rivers through groundwater, either as point sources (for example, saline springs) or as a diffuse source (base flow), or through surface runoff (Kenney and others, 2009). Water in groundwater and surface runoff sources of dissolved solids originates as either precipitation or irrigation water.

It is a common assumption that controlling soil erosion and sediment transport will reduce dissolved-solids transport to lakes and streams. Tillman and Anning (2014) investigated this hypothesis by developing multiple linear regression (MLR) models for dissolved-solids concentrations in UCRB streams and rivers. Data from more than 480 water-quality and streamgaging sites in the UCRB were evaluated, and MLR models of dissolved-solids concentrations were developed at 164 sites that had sufficient data. MLR models included a suspended-sediment explanatory variable to determine if it had significant predictive power on dissolved-solids concentrations. Results revealed 29 sites (18 percent) that indicate strong evidence of a relation between suspended sediment and dissolved solids and 39 sites (24 percent) that indicate moderate evidence of such a relation (Tillman and Anning, 2014). Dissolved-solids models of most of the sites showing strong or moderate evidence indicated a positive relation between suspended-sediment and dissolved-solids concentrations, and most of the sites showing strong or moderate evidence drain regions dominated by sedimentary rocks (Tillman and Anning, 2014). The evidence of a statistical relation between dissolved solids and suspended sediment in Tillman and Anning (2014) indicates that control of suspended sediment might result in a decrease in dissolved-solids concentrations in streams and rivers at some UCRB sites, but have little or no impact at others.

In 2014, scientists from the USDA's Agricultural Research Service and Natural Resources Conservation Service, the University of Nevada, Reno, and the Bureau of Land Management (BLM) compiled published studies on salinity mobilization and transport on rangelands (Gagnon and others, 2014) and produced a synthesis of findings from the 768 unique citations in the literature review (Weltz and others, 2014). Although the goal of the literature review and synthesis was to improve the understanding of dissolved-solids sources and transport mechanisms in UCRB rangelands, relevant research conducted outside the UCRB area, including international studies, was also included. Few published studies were found that directly addressed the impact of rangeland conditions on dissolved-solids delivery to surface waters. Most studies included in the literature review and summarized in the synthesis were investigations that addressed the impact of rangeland conditions on runoff, erosion, and sediment generation and transport.

Weltz and others (2014) summarize the published literature on impacts of rangeland conditions on dissolved solids or sediment transport and divide those impacts into two categories: abiotic alterations and biotic alterations. Abiotic alterations include practices such as contour furrowing, gully plugs, soil amendments, and access controls. *Contour furrowing* involves creating a series of ridges and furrows along the contours of the landscape, which may be effective in reducing runoff and enhancing infiltration (Weltz and others, 2014). *Gully plugs* are small earthen dams constructed in erosional drainages that provide grade control and sediment retention (Weltz and others, 2014). *Soil amendments* include superabsorbent polymers and gypsum, among other materials, and have been shown to improve soil hydrologic properties by increasing infiltration and soil-water storage and decreasing runoff. *Access controls* in rangelands refers mainly to the exclusion of off-highway vehicles (OHVs) from areas in order to reduce soil disturbance, land degradation, and erosion. Abiotic alterations that enhance infiltration or reduce runoff are assumed to reduce dissolved-solids loading to receiving waters, although infiltrating water that encounters easily dissolvable geologic material and then becomes base flow may increase loading. Biotic alterations summarized in Weltz and others (2014) include chaining, grazing, and the effects of fire. *Chaining* is the removal of brittle brush and woody plants by dragging a large, heavy chain from behind two tractor-type vehicles. No consistent differences in salt concentrations in surface waters draining chained and unchained areas were noted in the literature, although the ancillary effect of replacement of woody plants by grasses has been shown to reduce surface runoff. *Grazing* may influence runoff and sediment transport through the alteration of vegetation and through direct soil modification resulting from animal trampling. Heavy grazing that results in bare soil patches or in the replacement of tall- and mid-size grasses with short grasses will increase surface runoff and soil erosion. Increase in soil bulk density by animal compaction may lead to reduced infiltration and increased runoff and erosion. *Fire* can have different short- and long-term effects on runoff, soil erosion, and sediment transport. Loss of vegetation immediately following a fire may increase the soil's vulnerability to erosion, but the increased erosion potential wanes as vegetation is reestablished. A net decrease in runoff, erosion, and sediment transport may result if woody plant communities destroyed by fire are replaced by grasses or shrubs that increase ground cover and hydraulic roughness over prefire conditions.

Geospatial Datasets Describing UCRB Rangeland Conditions

Geospatial datasets were investigated to represent rangeland conditions described in Weltz and others (2014) for testing in the forthcoming SPARROW model. The search for suitable geospatial datasets was not limited to only rangeland areas but was extended to cover as much of the UCRB as possible. Geospatial information relevant to circa 2010 was prioritized, because this time period will be the focus of the updated SPARROW model. Geospatial datasets were sought that directly address a rangeland condition described in Weltz and others (2014) or that indirectly address the underlying process(es) associated with a rangeland condition (for example, potential increased runoff). Each dataset is discussed separately in this section and is available from the website for this report (*http://pubs.usgs.gov/of/2015/1007*). All datasets include metadata and spatial reference information.

Basinwide geospatial datasets were not located for all rangeland conditions described in Weltz and others (2014), specifically the abiotic processes of contour furrowing, gully plugs, and soil amendments. These activities are probably constrained to areas that are small relative to the size of UCRB catchments and would most likely be considered site-scale conditions or practices.

Bureau of Land Management Grazing

File Name: 2010_UCRB_BLM_Grazing_projected.zip

Description: This shapefile dataset includes information on the amount and location of grazing on land managed by the Bureau of Land Management (BLM) in the UCRB during 2010, and is directly related to the “grazing effects” biotic alteration in Weltz and others (2014). The shapefile contains 2,367 polygons of BLM grazing allotments within or bordering the UCRB (fig. 4). Attributes for the allotment polygons include the allotment name (ALLOT_NAME) and number (ST_ALLOT), the authorized number of “animal unit months” for the allotment (AUTH_AUMS), and the area of the allotment in both acres (AREA_acres) and square kilometers ($AREA\_km^2$).

Source and Processing of Geospatial Data: BLM does not make an annual count of the actual number of livestock that graze on BLM-managed lands because that number may vary from day to day and livestock are often moved around (*http://www.blm.gov/wo/st/en/prog/grazing.html*). Instead, BLM compiles “animal unit months” (AUMs) that take into account the number of livestock and the amount of time they spend grazing. An AUM is the amount of forage needed to sustain one cow and calf, one horse, or five sheep or goats for one month (*http://www.blm.gov/wo/st/en/prog/grazing.html)*.

A report on billed AUMs was obtained from the BLM Rangeland Administration System (RAS) for grazing year 2010, which runs from March 1, 2010 to February 28, 2011 (Lynnda Jackson, BLM, written communication, 2014). Nationwide BLM grazing allotment spatial data (shapefiles) were obtained from the BLM Geocommunicator website (*http://www.geocommunicator.gov/GeoComm/services.htm#Download*). A subset of UCRB grazing allotments was created from grazing allotments within the UCRB or intersecting the UCRB boundary. Billed AUMs were joined to UCRB grazing allotments in ArcGIS by the combination of 2-character state and 5-digit allotment numbers (for example, AZ05336). Several 2010 billed AUMs did not have corresponding allotments; each of these unassociated billed AUMs was investigated with assistance from BLM field offices in each of the five upper basin states. If the unmatched bill was within the UCRB, then either an allotment shapefile was obtained or the allotment number was corrected. In the spatially joined billed AUM shapefiles, the area of each grazing allotment was calculated using the ArcGIS “Calculate Geometry” function (AREA_acres and $AREA\_km^2$).

U.S. Forest Service Grazing

File Name: 2010_UCRB_USFS_Grazing_protected.zip

Description: This shapefile dataset includes information on the amount and location of grazing on land managed by the U.S. Forest Service (USFS) in the UCRB during 2010, and is directly related to the “grazing effects” biotic alteration in Weltz and others (2014). The shapefile contains 444 polygons of USFS grazing allotments within or bordering the UCRB (fig. 4). Attributes for the allotment polygons include the allotment name (RMU_NAME) and number (RMU_CN), the authorized number of animal unit months for the allotment (AUTH_AUMS), and the area of the allotment in both acres (AREA_acres) and square kilometers ($AREA\_km^2$). USFS-billed grazing is referred to as the “authorized” amount and is equivalent to BLM’s “billed” grazing (U.S. Government Accountability Office, 2005).

Source and Processing of Geospatial Data: UCRB grazing and allotment data were obtained by contacting USFS personnel in the three Forest Service regions that cover the UCRB. Shapefiles of grazing allotments were joined to Microsoft Excel reports of the amount of 2010 grazing by allotment number. As with the BLM, the USFS

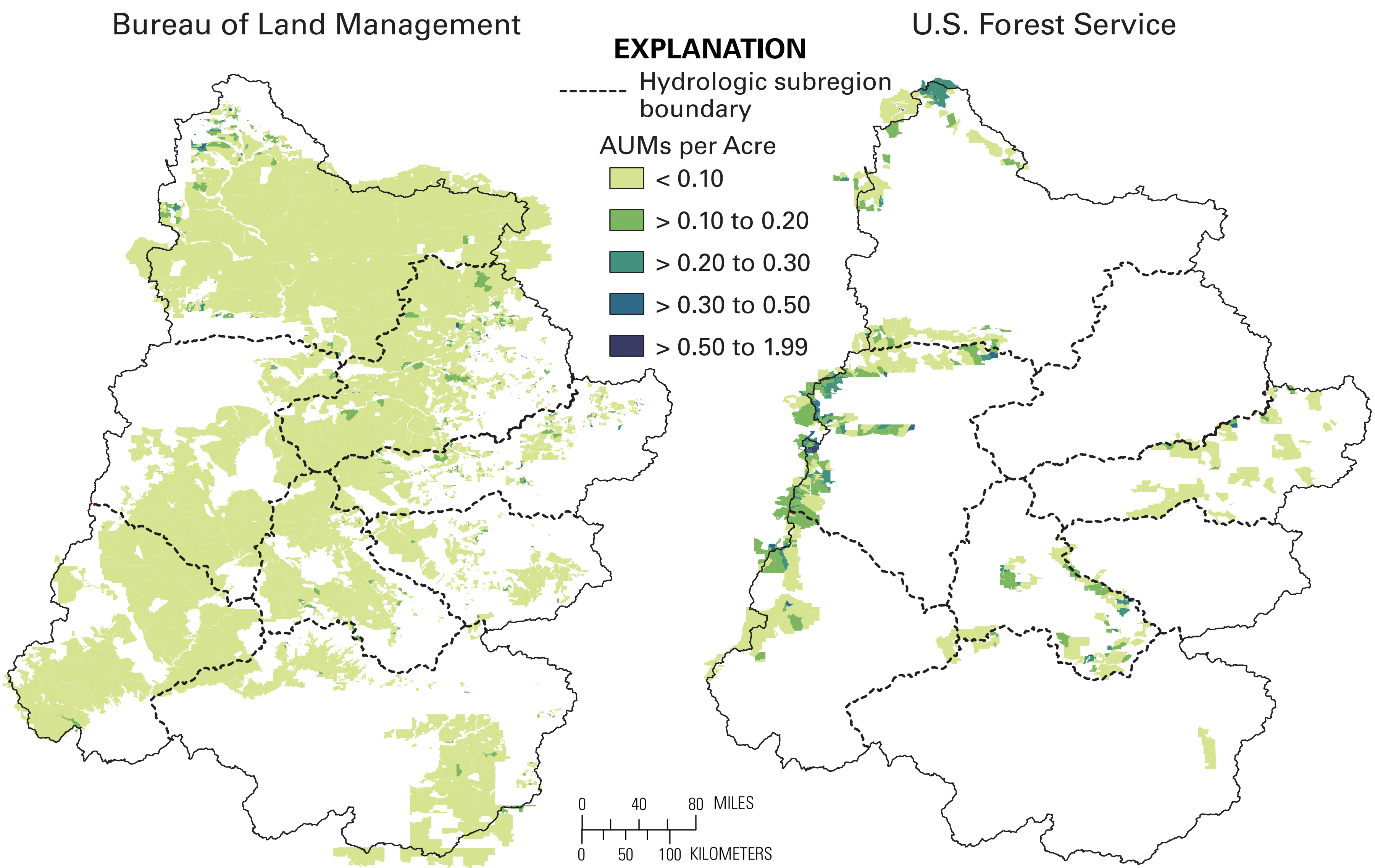


Figure 4. Maps showing animal unit months (AUMs) per grazing allotment acre for lands managed by the Bureau of Land Management (left) and by the U.S. Forest Service (right) in the Upper Colorado River Basin in 2010.

does not make an annual count of the actual number of livestock that graze on USFS-managed lands and instead compiles grazing information based on AUMs, using the same definition as BLM.

Land Disturbance

File Name: 1999-2010_UCRB_LandDisturbance.zip

Description: These layers include temporal and spatial information on disturbances to the landscape as a result of management activities or natural events. Two types of grids are presented: yearly disturbance grids for 1999–2010 and a composite grid of the yearly disturbance grids that summarizes vegetation disturbance for 1999–2010. Spatially, all grids cover the entire UCRB and have a 30-meter pixel resolution.

The disturbance grids include attribute values that are directly related to the “fire effects” biotic alteration in Weltz and others (2014), as well as attribute values that describe other types of landscape disturbances that may affect the generation and transport of sediment. Yearly disturbance grid attributes include the year in which the disturbance occurred, disturbance type, and the severity of the disturbance (table 1; LANDFIRE, 2014b). The composite vegetation disturbance grid attributes include a generalized disturbance type category, a disturbance level classification, and time from 2010 since the disturbance (table 2; LANDFIRE, 2014c).

Source and Processing of Geospatial Data: All land disturbance grids were obtained from LANDFIRE, a U.S. Department of Agriculture Forest Service and U.S. Department of the Interior shared program that provides landscape scale geo-spatial products (LANDFIRE, 2014a). The data were downloaded and processed using the LANDFIRE Data Access Tool (LFDAT), an ArcGIS toolbar that allows users to download selected LANDFIRE data layers as zipped files using a defined extent directly from ArcMap (LANDFIRE, 2014d). The size of the extent rectangle necessary to cover the UCRB required the requested layers to be divided into multiple pieces for downloading and thus resulted in multiple zipped files per layer. LFDAT’s Smart Assembler tool was used to batch unzip the files, merge the multiple-piece layers into a single layer, and reattach attribute fields to the output raster attribute tables (fig. 5).

Existing Vegetation Type and Cover

File Name: 2010_UCRB_VegTypeCover.zip

Description: These layers include information on the vegetation type and vegetation cover in 2010 in the UCRB. The 2010 existing vegetation cover (EVC) layer represents the vertically projected percent cover of the live canopy layer. The 2010 existing vegetation type (EVT) layer represents the species composition. Spatially, both grids cover the entire UCRB and have a 30-meter pixel resolution.

Although vegetation layers are not directly related to biotic alterations in Weltz and others (2014), the layers may be useful in the new UCRB SPARROW model because they provide a detailed view of 2010 vegetation conditions. Areas with minimal vegetation cover (for example, barren) may be combined with information on precipitation intensity (see description of rainfall-runoff erosivity factor below) to infer areas that may be susceptible to sediment generation and transport. The EVC layer includes a land-cover classification attribute that describes the percent of canopy cover separately for tree, shrub, and herbaceous life forms (table 3; LANDFIRE, 2014g). The EVT layer includes an attribute that contains the terrestrial ecological systems classification values developed by NatureServe for the Western Hemisphere; this classification system defines groups of plant community types (associations) that tend to co-occur within landscapes with similar ecological processes, substrates, and (or) environmental gradients (LANDFIRE, 2014e). In addition, the EVT layer contains attributes that have been cross-referenced to existing vegetation classifications. The EVT_ORDER, EVT_CLASS, and EVT_SUBCL attributes are based on the Federal Geographic Data Committee Vegetation Subcommittee’s vegetation classification standard and pertain to upper physiognomic levels of the National Vegetation Classification System hierarchy (LANDFIRE, 2014a). The SAF_SRM attribute is based on the floristic composition of each EVT and contains either the Society of American Foresters (SAF) and the Society of Range Management (SRM) cover type classifications for forested and rangeland types, respectively, or a general LANDFIRE “cover class” where pre-existing categories do not apply (table 4; LANDFIRE, 2014e; LANDFIRE, 2014f).

Source and Processing of Geospatial Data: Both the vegetation cover and vegetation type grids were obtained from LANDFIRE, a U.S. Department of Agriculture Forest Service and U.S. Department of the Interior shared program that provides landscape scale geospatial products (LANDFIRE, 2014a). The data were downloaded and processed using the LANDFIRE Data Access Tool (LFDAT), an ArcGIS toolbar that allows users to download selected LANDFIRE data layers as zipped files using a defined extent directly from ArcMap (LANDFIRE, 2014d). The size of the extent rectangle necessary to cover the UCRB required the requested layers to be divided into multiple pieces for downloading and thus resulted in multiple zipped files per layer. LFDAT’s Smart Assembler tool was used to batch unzip the files, merge the multiple-piece layers into a single layer, and reattach attribute fields to the output raster attribute tables (fig. 6).

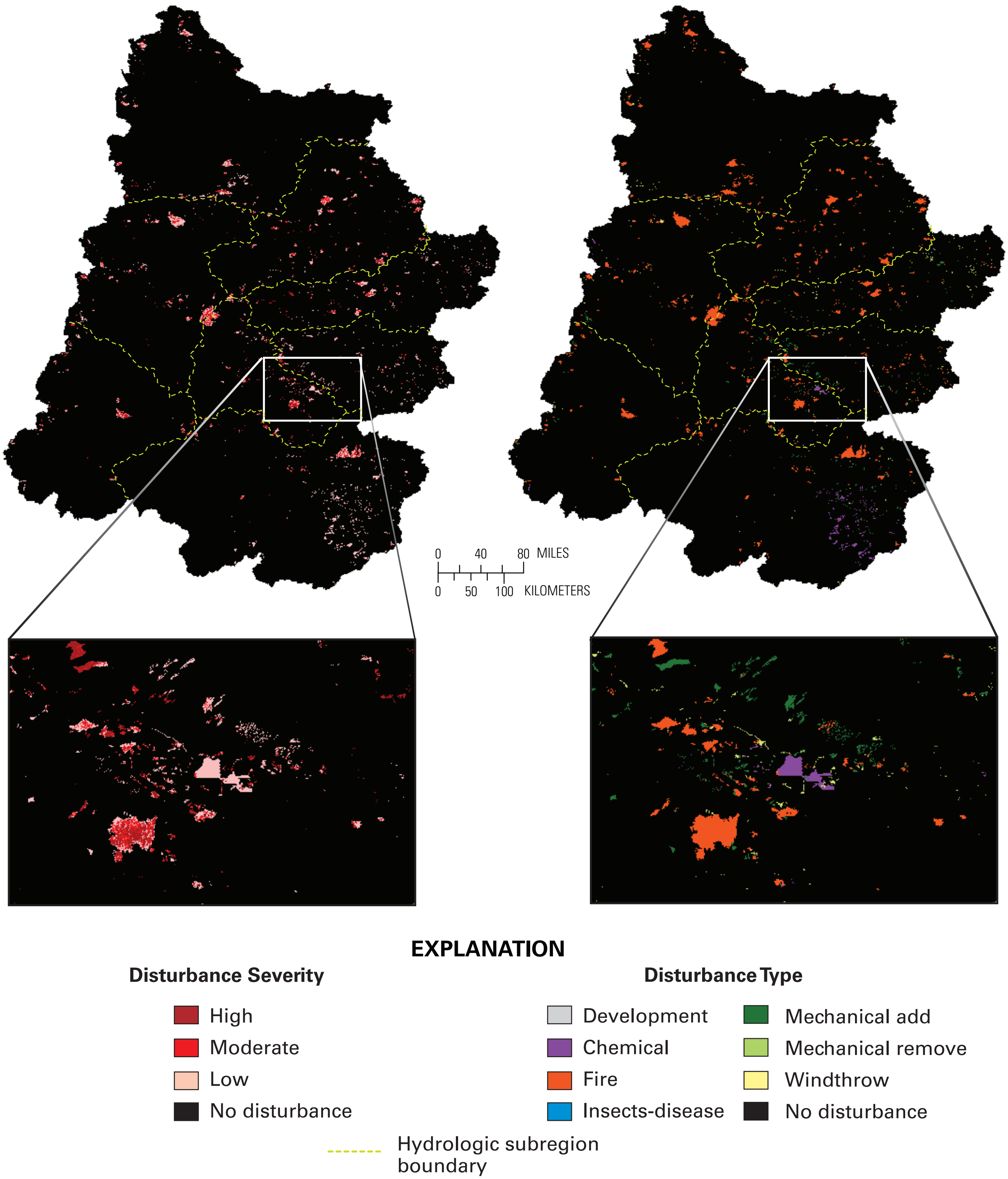


Figure 5. Maps depicting disturbance severity and disturbance type for Upper Colorado River Basin composite-vegetation disturbance in 1999–2010 from the land-disturbance dataset.

Table 1. Description of select attributes, yearly disturbance grids, 1999-2010_UCRB_LandDisturbance.zip

[Modified from LANDFIRE Disturbance 1999–2012 Attribute Data Dictionary (LANDFIRE, 2014b)]

Attribute name and description	Value	Description
DIST_YEAR – Year of disturbance	1999–2010	Approximate year in which the disturbance occurred.
DIST_TYPE – Disturbance type	Development	Conversion of natural lands into housing, commercial, or industrial building sites. Involves permanent land clearing.
	Clearcut	The cutting of essentially all trees, producing a fully exposed microclimate for the development of a new age class.
	Harvest	A general term for the cutting, felling, and gathering of forest timber. This value was assigned to events where there was insufficient information available to assign one of the two distinct values of *Clearcut* or *Thinning*.
	Thinning	A tree removal practice that reduces tree density and competition between trees in a stand.
	Mastication	Means by which vegetation is mechanically “mowed” or “chipped” into small pieces and changed from a vertical to horizontal arrangement.
	Other mechanical	Catch-all term for a variety of forest and rangeland mechanical activities related to fuel reduction and site preparation including: piling of fuels, chaining, lop and scatter, thinning of fuels, Dixie harrow, etc.
	Wildfire	An unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to suppress or put out the fire.
	Wildland fire use	The application of the appropriate management response to naturally ignited wildland fires to accomplish specific resource management objectives in pre-defined designated areas outlined in Fire Management Plans.
	Prescribed fire	Any fire ignited by management actions to meet specific objectives.
	Wildland fire	A catch-all term used to describe any non-structure fire that occurs in the wildland. This value was assigned to events where there was insufficient information available to assign one of the three distinct values of *Wildfire*, *Wildland Fire Use*, or *Prescribed Fire*.
	Weather	Weather related event, such as blowdown, hurricane, or tornado, that results in loss of vegetation.
	Chemical	Application of a chemical substance. This value was assigned to events where there was insufficient information available to assign one of the two distinct values of *Herbicide* or *Insecticide*.
	Insects	Infestations of unwanted insects, such as bark beetle, that can affect vegetative health.
	Disease	Infestations of disease, such as root rot, that can affect vegetative health.
	Insects/Disease	Infestations of insects and (or) disease that can affect vegetative health. This value was assigned to events where there was insufficient information available to assign one of the two distinct values of *Insects* or *Disease.*
	Herbicide	Application of a chemical substance used to kill or inhibit the growth of plants.
	Biological	The use of living organisms, such as predators, parasites, and pathogens, to control weeds, pest insects, or diseases.
	Unknown	Sources indicate that a disturbance occurred but causality is uncertain.
	NA	No disturbance.
SEVERITY – Severity of disturbance	Unburned/Low	General classification level associated with low or unburned landcover.
	Low	General classification level associated with low fire effect on landcover.
	Medium	General classification level associated with medium fire effect on landcover.
	High	General classification level associated with high fire effect on landcover.
	Increased green	Post-fire image indicates an increase in landcover greenness compared to fire image.
	No data	Area not mapped.

Table 2. Description of select attributes, composite vegetation disturbance grid, 1999-2010_UCRB_LandDisturbance.zip

[Modified from LANDFIRE Vegetation Disturbance Attribute Data Dictionary (LANDFIRE, 2014c)]

Attribute name and description	Value	Description
D_TYPE – General disturbance type category	No disturbance	No disturbance detected or reported.
	Fire	Any non-structure fire that occurs in the wildland.
	Mechanical add	Means by which vegetation is mechanically “mowed” or “chipped” into small pieces and changed from a vertical to horizontal arrangement.
	Mechanical remove	A general term for the cutting, felling, and gathering of forest timber.
	Windthrow	Weather-related event that results in loss of vegetation.
	Insects/Disease	Infestations of insects and (or) disease that can affect vegetative health.
	Chemical	Application of a chemical substance.
	Biological	The use of living organisms, such as predators, parasites, and pathogens to control weeds, pest insects, or diseases.
	Development	Conversion of natural lands into housing, commercial, or industrial building sites. Involves permanent land clearing.
D_SEVERITY – Classification level of disturbance	Low	General classification level associated with low effect on landcover.
	Medium	General classification level associated with medium effect on landcover.
	High	General classification level associated with high effect on landcover.
D_TIME – Time from 2010 since disturbance	One year	One year from 2010 since disturbance.
	Two to five years	Two to five years from 2010 since disturbance.
	Six to ten years	Six to ten years from 2010 since disturbance.

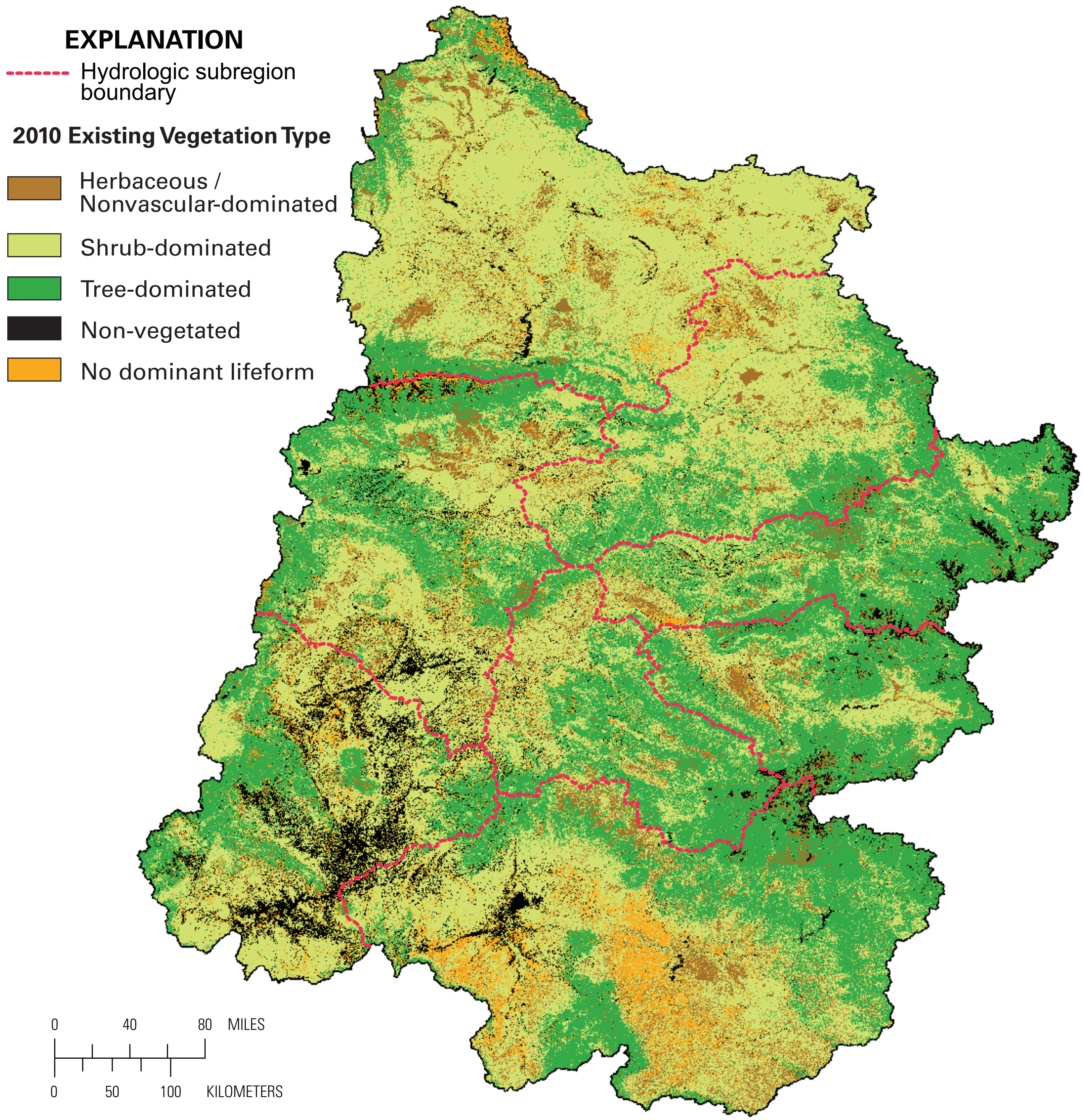


Figure 6. Map showing existing vegetation types in 2010 in the Upper Colorado River Basin from the vegetation type and cover dataset.

Table 3. Description of select attributes, existing vegetation cover 2010, 2010_UCRB_VegTypeCover.zip

[Modified from LANDFIRE Existing Vegetation Cover Attribute Data Dictionary (LANDFIRE, 2014g); NASS, National Agricultural Statistics Service; NLCD, National Land Cover Database]

Attribute name and description	Value	Description (source)
Value–Land cover classification	11	Open water (NLCD class)
	12	Snow/Ice (NLCD class)
	13	Developed-upland deciduous forest (NLCD class)
	14	Developed-upland evergreen forest (NLCD class)
	15	Developed-upland mixed forest (NLCD class)
	16	Developed-upland herbaceous (NLCD class)
	17	Developed-upland shrubland (NLCD class)
	21	Developed-open space (NLCD class)
	22	Developed-low intensity (NLCD class)
	23	Developed-medium intensity (NLCD class)
	24	Developed-high intensity (NLCD class)
	25	Developed-roads (NLCD class)
	31	Barren (NLCD class)
	32	Quarries-strip mines-gravel pits (NLCD class)
	61	NASS-vineyard (NASS class)
	63	NASS-vow crop-close grown crop (NASS class)
	64	NASS-vow crop (NASS class)
	100	Sparse vegetation canopy (NLCD class)
	101	Tree cover >= 10 and < 20% (LANDFIRE class)
	102	Tree cover >= 20 and < 30% (LANDFIRE class)
	103	Tree cover >= 30 and < 40% (LANDFIRE class)
	104	Tree cover >= 40 and < 50% (LANDFIRE class)
	105	Tree cover >= 50 and < 60% (LANDFIRE class)
	106	Tree cover >= 60 and < 70% (LANDFIRE class)
	107	Tree cover >= 70 and < 80% (LANDFIRE class)
	108	Tree cover >= 80 and < 90% (LANDFIRE class)
	109	Tree cover >= 90 and < 100% (LANDFIRE class)
	111	Shrub cover >= 10 and < 20% (LANDFIRE class)
	112	Shrub cover >= 20 and < 30% (LANDFIRE class)
	113	Shrub cover >= 30 and < 40% (LANDFIRE class)
	114	Shrub cover >= 40 and < 50% (LANDFIRE class)
	115	Shrub cover >= 50 and < 60% (LANDFIRE class)
	116	Shrub cover >= 60 and < 70% (LANDFIRE class)
	117	Shrub cover >= 70 and < 80% (LANDFIRE class)
	118	Shrub cover >= 80 and < 90% (LANDFIRE class)
	119	Shrub cover >= 90 and < 100% (LANDFIRE class)
	121	Herb cover >= 10 and < 20% (LANDFIRE class)
	122	Herb cover >= 20 and < 30% (LANDFIRE class)
	123	Herb cover >= 30 and < 40% (LANDFIRE class)
	124	Herb cover >= 40 and < 50% (LANDFIRE class)
	125	Herb cover >= 50 and < 60% (LANDFIRE class)
	126	Herb cover >= 60 and < 70% (LANDFIRE class)
	127	Herb cover >= 70 and < 80% (LANDFIRE class)
	128	Herb cover >= 80 and < 90% (LANDFIRE class)
	129	Herb cover >= 90 and < 100% (LANDFIRE class)

Table 4. Description of select attributes, existing vegetation type 2010, 2010_UCRB_VegTypeCover.zip

[Modified from LANDFIRE Existing Vegetation Type Attribute Data Dictionary (LANDFIRE, 2014e); LF, LANDFIRE; SAF, Society of American Foresters; SRM, Society of Range Management]

Attribute Name and Description	Value
EVT_ORDER—describes the dominant life forms (tree, shrub, dwarf shrub, herbaceous, or nonvascular) within the Vegetated Division of the hierarchy	Herbaceous / Nonvascular-dominated
	No dominate lifeform
	Non-vegetated
	Shrub-dominated
	Tree-dominated
EVT_CLASS—describes the level in the classification hierarchy defined by the relative percent canopy cover of the tree, shrub, dwarf shrub, herb, and nonvascular life form in the uppermost strata during the peak of the growing season (EVT_CLASS)	Herbaceous-grassland
	Closed tree canopy
	Dwarf-shrubland
	Herbaceous-shrub-steppe
	No dominant lifeform
	Non-vegetated
	Open tree canopy
	Shrubland
	Sparse tree canopy
	Sparsely vegetated
EVT_SUBCL—describes the predominant leaf phenology of classes defined by tree, shrub, or dwarf shrub stratum (evergreen, deciduous, mixed evergreen-deciduous)	Graminoid/Forb
	Deciduous open tree canopy
	Deciduous shrubland
	Developed
	Evergreen closed tree canopy
	Evergreen dwarf-shrubland
	Evergreen open tree canopy
	Evergreen shrubland
	Evergreen sparse tree canopy
	Herbaceous-grassland
	Mixed evergreen-deciduous open tree canopy
	Mixed evergreen-deciduous shrubland
	Non-vegetated
	Perennial graminoid grassland
	Perennial graminoid steppe
	Sparsely vegetated
SAF_SRM—describes a floristic-based composition using the combined classifications of the Society of American Foresters (SAF) and the Society of Range Management (SRM) cover type classifications for forested and rangeland types, respectively, or LANDFIRE "cover classes" where pre-existing categories do not apply	LF 20: Developed
	LF 33: Sparsely vegetated
	LF 41: Deciduous shrubland
	LF 42: Great Plains riparian
	LF 54: Introduced upland vegetation-herbaceous
	LF 58: Introduced woody wetlands and riparian vegetation
	LF 80: Agriculture
	No dominant lifeform
	Non-vegetated
	SAF 201: White spruce
	SAF 206: Engelmann spruce-subalpine fir
	SAF 208: Whitebark pine
	SAF 209: Bristlecone Pine
	SAF 210: Interior Douglas-Fir
	SAF 211: White Fir
	SAF 213: Grand Fir
	SAF 217: Aspen

Table 4.—Continued

Attribute Name and Description	Value
SAF_SRM—describes a floristic-based composition using the combined classifications of the Society of American Foresters (SAF) and the Society of Range Management (SRM) cover type classifications for forested and rangeland types, respectively, or LANDFIRE "cover classes" where pre-existing categories do not apply	SAF 218: Lodgepole Pine
	SAF 219: Limber Pine
	SAF 235: Cottonwood-Willow
	SAF 237: Interior Ponderosa Pine
	SAF 238: Western Juniper
	SAF 241: Western Live Oak
	SRM 106: Bluegrass Scabland
	SRM 107: Western Juniper-Big Sagebrush-Bluebunch Wheatgrass
	SRM 203: Riparian Woodland
	SRM 212: Blackbush
	SRM 311: Rough Fescue-Bluebunch Wheatgrass
	SRM 312: Rough Fescue-Idaho Fescue
	SRM 314: Big Sagebrush-Bluebunch Wheatgrass
	SRM 402: Mountain Big Sagebrush
	SRM 403: Wyoming Big Sagebrush
	SRM 405: Black Sagebrush
	SRM 406: Low Sagebrush
	SRM 409: Tall Forb
	SRM 410: Alpine Rangeland
	SRM 412: Juniper-Pinyon Woodland
	SRM 413: Gambel oak
	SRM 414: Salt Desert Shrub
	SRM 415: Curlleaf Mountain-Mahogany
	SRM 418: Bigtooth Maple
	SRM 421: Chokecherry-Serviceberry-Rose
	SRM 422: Riparian
	SRM 501: Saltbush-Greasewood
	SRM 502: Grama-Galetta
	SRM 503: Arizona Chaparral
	SRM 504: Juniper-Pinyon Pine Woodland
	SRM 505: Grama-Tobosa Shrub
	SRM 506: Creosotebush-Bursage
	SRM 507: Palo Verde-Cactus
	SRM 508: Creosotebush-Tarbush
	SRM 601: Bluestem Prairie
	SRM 604: Bluestem-Grama Prairie
	SRM 605: Sandsage Prairie
	SRM 606: Wheatgrass-Bluestem-Needlegrass
	SRM 611: Blue Grama-Buffalograss
	SRM 612: Sagebrush-Grass
	SRM 701: Alkali Sacaton-Tobosa Grass
	SRM 704: Blue Grama-Western Wheatgrass
	SRM 713: Grama-Muhly-Threeawn
	SRM 720: Sand Bluestem -Little Bluestem Dunes
	SRM 729: Mesquite
	SRM 730: Sand Shinnery Oak
	SRM 735: Sideoats Grama-Sumac-Juniper

2010 Roads

File Name: 2010_UCRB_Roads.zip

Description: This layer contains information about the location and type of roads in the UCRB in 2010. One value in the MAF/TIGER Feature Class Code (MTFCC) attribute field in the roads layer is S1500, named "Vehicular Trail (4WD)", and is described as "an unpaved dirt trail where a four-wheel drive vehicle is required" (table 5). The Vehicular Trail (4WD) attribute presents potential UCRB locations of off-highway vehicle use—an activity directly related to the "access controls" abiotic alteration in Weltz and others (2014) (table 5; fig. 7). The 2010 roads layer covers the entire UCRB.

Source and Processing of Geospatial Data: The 2010 roads layer files were obtained from the U.S. Census Bureau as individual county-based TIGER/Line® shapefiles (U.S. Census Bureau, 2012a).

Data in this layer are supplied as individual county-based zipped shapefiles. File names are in the format of tl_2010_#####_roads.zip, where #### is the two-digit state Federal Information Processing Series (FIPS) code followed by a three-digit county FIPS code (for code definitions, see *http://www.census.gov/geo/reference/codes/cou.html*).

Rainfall-Runoff Erosivity

File Name: UCRB_R-factor.zip
Description: This tabular dataset presents the 1971–2000 average annual rainfall-runoff erosivity factor (R-factor) for the UCRB. The R-factor is a measure of the cumulative erosive force of individual precipitation events (Daly and Taylor, 2002). All other factors being constant, sediment generation from precipitation is directly proportional to the product of the total kinetic energy of a storm and the storm's maximum 30-minute intensity. The mean annual R-factor is a sum of this product for all storms in a year, averaged over all years of record (Daly and Taylor, 2002). Although not directly related to biotic alterations in Weltz and others (2014), information on rainfall-runoff erosivity may be used with land-use information to evaluate areas with elevated sediment generation and transport potential. The unique COMID attribute in the R-factor tabular dataset was related to NHDPlus Catchments Version 1.1 (U.S. Environmental Protection Agency and U.S. Geological Survey, 2007) for the Upper Colorado River (fig. 8).

Table 5. Description of select attributes, 2010 UCRB Roads, 2010_UCRB_Roads.zip

[Modified from U.S. Census Bureau, 2012b]

Attribute name and description	Value	Description (source)
MTFCC—a 5-digit code to classify and describe geographic objects or features.	S1100	Primary Roads—Primary roads are generally divided, limited-access highways within the Interstate Highway system or under state management, and are distinguished by the presence of interchanges. These highways are accessible by ramps and may include some toll highways.
	S1200	Secondary Roads—Secondary roads are main arteries, usually in the U.S. Highway, State Highway, or County Highway system. These roads have one or more lanes of traffic in each direction, may or may not be divided, and usually have at-grade intersections with many other roads and driveways.
	S1400	Local Neighborhood Road, Rural Road, City Street—Generally a paved non-arterial street, road, or byway that usually has a single lane of traffic in each direction. Roads in this feature class may be privately or publicly maintained. Scenic park roads would be included in this feature class, as would (depending on the region of the country) some unpaved roads.
	S1500	Vehicular Trail (4WD)—An unpaved dirt trail where a four-wheel drive vehicle is required. These vehicular trails are found almost exclusively in very rural areas.
	S1630	Ramp—A road that allows controlled access from adjacent roads onto a limited access highway, often in the form of a cloverleaf interchange.
	S1640	Service Drive usually along a limited-access highway—A road, usually paralleling a limited access highway, that provides access to structures along the highway.
	S1710	Walkway/Pedestrian Trail—A path that is used for walking, being either too narrow for or legally restricted from vehicular traffic.
	S1730	Alley—A service road that does not generally have associated addressed structures and is usually unnamed. It is located at the rear of buildings and properties and is used for deliveries.
	S1740	Private Road for service vehicles (such as for logging, oil fields, ranches)—A road within private property that is privately maintained for service, extractive, or other purposes.
	S1750	Internal U.S. Census Bureau Use
	S1780	Parking Lot Road—The main travel route for vehicles through a paved parking area.
	S1820	Bike Path or Trail—A path that is used for manual or small, motorized bicycles, being either too narrow for or legally restricted from vehicular traffic.

Figure 7. Map showing four-wheel-drive vehicle roads in the Upper Colorado River Basin in 2010 (U.S. Census Bureau, 2012a).

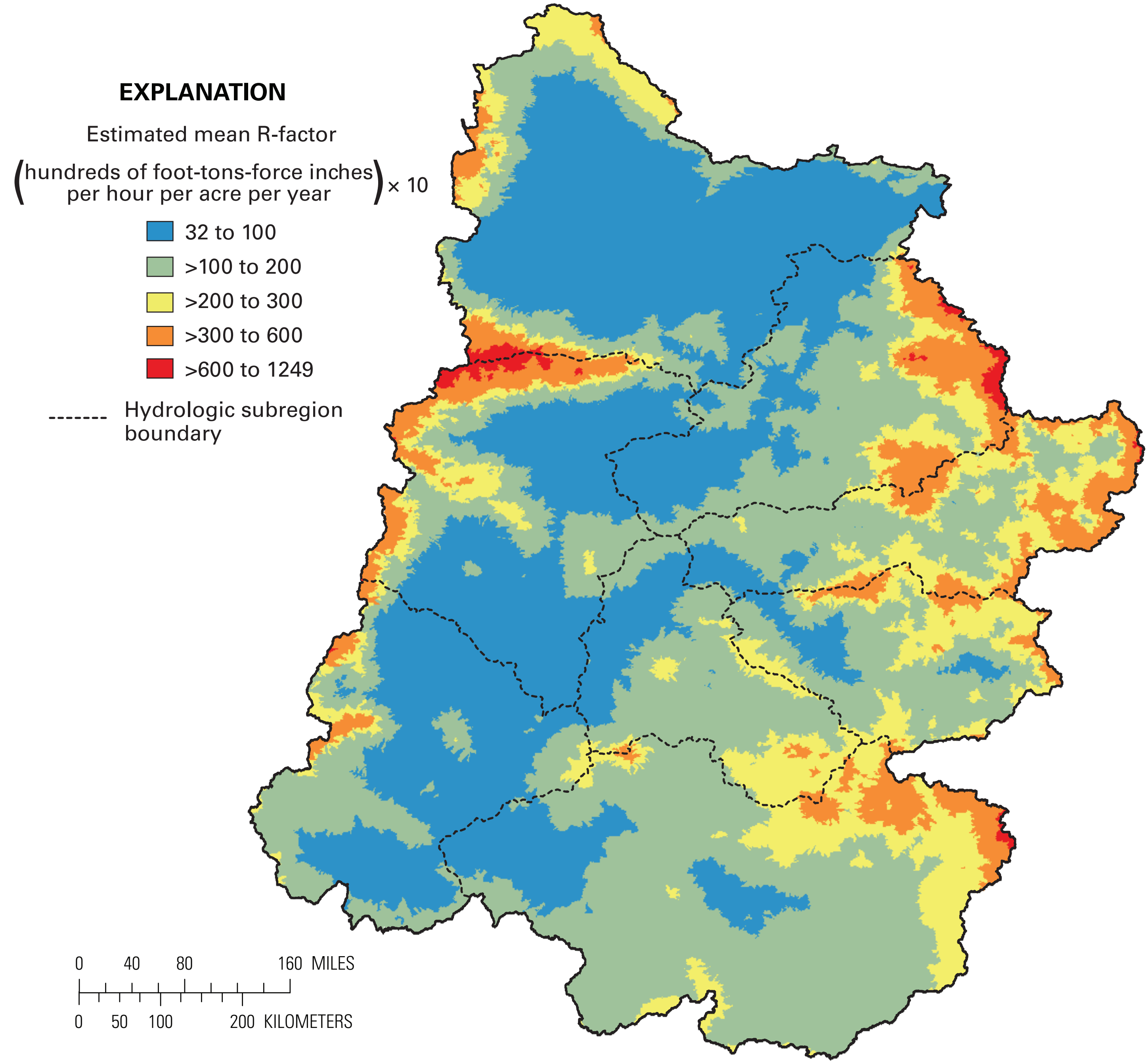


Figure 8. Map showing average annual rainfall-runoff erosivity factor (R-factor) for the Upper Colorado River Basin in 1971–2000.

Source and Processing of Geospatial Data: This tabular dataset was created by the USGS National Water-Quality Assessment Program from the source data of Daly and Taylor (2002) to estimate the average annual R-factor per watershed segment (Wieczorek and LaMotte, 2010).

Summary and Conclusions

High dissolved-solids concentrations in the Colorado River cause more than 300 million dollars per year in damages to water users in the United States (Colorado River Basin Salinity Control Forum, 2013). A 2009 study by the USGS used the Spatially Referenced Regressions on Watershed Attributes (SPARROW) surface-water-quality model to examine dissolved-solids supply and transport within the Upper Colorado River Basin. A planned update to the 2009 UCRB SPARROW model will examine potential contributions to dissolved-solids loading from irrigation and rangeland practices. Weltz and others (2014) detail rangeland conditions and practices that contribute to dissolved solids or sediment loading, including biotic and abiotic alterations. The present study compiled geospatial datasets for the UCRB that relate to the biotic alterations and conditions of grazing, fire and other land disturbance, and vegetation type and cover, the abiotic alteration of access control (off-highway vehicles), and sediment generation and transport in general. These geospatial datasets may be tested in the upcoming SPARROW model to better understand the potential contribution of rangelands to dissolved-solids loading in UCRB streams and rivers.

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Menlo Park Publishing Service Centers, California
Manuscript approved for publication January 13, 2015
Edited by Peter Stauffer
Design and Layout by Cory Hurd

USGS

Tillman and others—**Geospatial Datasets for Assessing the Effects of Rangeland Conditions on Dissolved-Solids Yields**—Open-File Report 2015-1007

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20151007