VULNERABILITY ASSESSMENT OF STREAMFLOWS, NATIVE FISH, AND RIPARIAN CORRIDORS: FOUR CORNERS AND UPPER RIO GRANDE REGIONS OF THE SOUTHERN ROCKIES LANDSCAPE CONSERVATION COOPERATIVE

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Cover photos: Cottonwood Creek, UT (D. Max Smith), New Mexico jumping mouse (US Forest Service Region 3), Rio Grande cutthroat trout (Photo Craig D. Young)

I. Literature and Status Review of Focal Resources: Stream Flows, Native Fish, and Riparian Corridors

Geographic focus

This overview is focused on the Four Corners and the upper Rio Grande regions within the Southern Rockies Landscape Conservation Cooperative (SRLCC) footprint. Specific focus is on the basins of the Little Colorado River, the San Juan River, and the upper Rio Grande (Figure 1). These basins contain tributary streams and mainstem rivers, which naturally differ in environmental conditions. Tributary streams extend from mid elevations of basins to the headwaters where they support fishes adapted to cold, clear water. Mainstems include the lower sections of the San Juan River, Little Colorado River, Rio Grande, and Pecos River. Mainstems and lower portions of tributary streams support species adapted to frequent fluctuations in stream velocity, temperature, and turbidity. Riparian ecosystems occur along mainstems and tributaries, but their structure and composition varies with elevation and geological settings.

Methods

We identified locally significant resources and their management issues by taking part in adaptation forum workshops in 2016. A forum for the Four Corners region was held May 4 and 5 in Durango, CO, and a forum for the Upper Rio Grande was held May 10 to 11 in Albuquerque, NM. Participant representing numerous management agencies and landowners discussed issues affecting native fish, aquatic and riparian habitats, and consumptive water use. Using workshop notes as guidelines, we reviewed literature to build a summary of resource issues specific to each basin. We focused on three topics: (1) general importance of streamflows to riparian and aquatic ecosystems, (2) management issues for native fishes, and (3) management issues for riparian corridors.

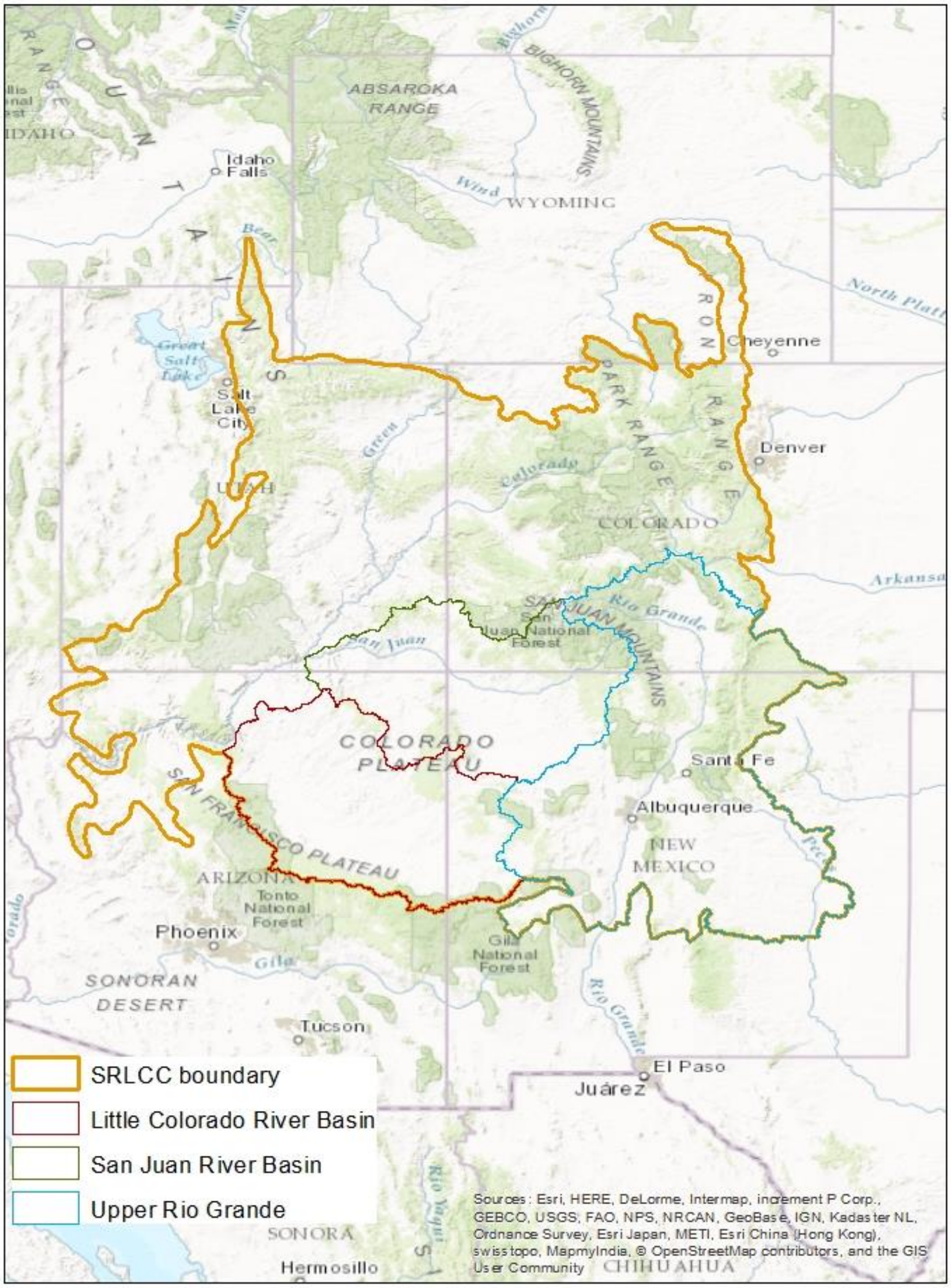

Figure 1. Southern Rockies Landscape Cooperative (SRLCC) boundaries and focal areas addressed this assessment.

Current status and distribution of resources

Streamflows and associated ecosystems

In the Four Corners and Upper Rio Grande, streams and adjacent lands are prized for the habitat they provide to wildlife including native fish and migratory birds. These ecosystems are managed by private landowners, state and federal agencies, and several indigenous nations. Aquatic and riparian resources are therefore protected by a patchwork of laws. Instream flows are regulated by state and federal agencies, water districts, and municipalities in accordance with interstate compacts and international treaties (Summit 2013, Phillips et al. 2011). At the Federal level, aquatic and wetland ecosystems are primarily protected by the Clean Water Act. Riparian and wetland areas are protected in National Forest lands by management rules including National Environmental Policy Act and the National Forest Management Act, and by the use of best management practices, which establish aquatic management zones along streams (NRC 2002, USFS. 2012). Terrestrial riparian habitats receive federal protection where they are designated as habitat for federally threatened or endangered species. Threatened and endangered species are found in each of the three basins, along with species proposed for federal listing and species of concern (Tables 1 and 2).

States have the authority to enforce the clean water act and enact stricter standards (ELI 2008). Agencies comply through various means, including protection of riparian areas and wetlands. Riparian areas have less federal protection than wetlands, but can be protected through several mechanisms on state and private land (NRC 2002). Indigenous nations have management and enforcement authority as well. For example, important wildlife habitat and sensitive areas are mapped and protected on the Navajo Nation (NNDWF 2008).

Native fish

Federally threatened and endangered fishes are found in each of the three basins, along with species proposed for federal listing and species of concern (Table 1). Though research and management may be a low priority for unlisted species that are not mentioned in this report, there is interest among agencies and conservation groups in preventing declines. Below are management statuses of species in each basin.

Little Colorado River Basin

The Little Colorado River originates in the White Mountains of eastern Arizona and flows northeast to its confluence with the Colorado River in the Grand Canyon. The Little Colorado River tributary streams contain several federally threatened and endangered species. Populations of Apache trout (scientific names in tables 2 and 3) are found in the Little Colorado River headwaters, but critical habitat has not been designated (USFWS 2010). Apache trout populations are not self-sustaining in these tributaries and are currently maintained by hatchery reintroductions (Minckley and Marsh 2009).

The Little Colorado River spinedace is also threatened in the upper reaches of the Little Colorado River and its tributaries, with three streams designated as critical habitat (USFWS 2008). The endangered Zuni bluehead sucker subspecies has critical habitat designated in small tributaries of the Little Colorado River in eastern Arizona and western New Mexico (USFWS 2015).

The federally endangered humpback chub spawns in the mainstem Little Colorado River near the Colorado River confluence. This portion of the river, fed by large springs, is protected as a critical spawning site for the species (Kaeding and Zimmerman 1983, Gorman and Stone 1999).

San Juan River Basin

The San Juan River extends from the San Juan Mountains west to its inlet into Lake Powell. The Colorado River cutthroat trout occurs in coldwater tributaries in Colorado, where it is listed as sensitive. Though not federally protected, interstate conservation agreements and strategies have been developed for this subspecies (CRCTCT 2006). Good or excellent habitat for cutthroat trout is present in the San Juan Basin (Hirsch et al. 2013), but populations are small, more fragmented, and at high risk relative to other Colorado River basins (Williams et al. 2009, Haak et al. 2010).

Roundtail chub, flannelmouth sucker, and bluehead sucker, collectively known as the three-species, occupy both mainstem and tributary streams in the San Juan River Basin (Gido et al. 1997). Bluehead sucker is listed as a species of concern in Utah. Flannelmouth sucker is listed as a species of concern in Utah and a species of special concern in Colorado. Roundtail chub is listed as endangered in New Mexico, a species of concern in Utah, and a species of special concern in Arizona and Colorado. The three-species are also present in mainstems and tributary streams of the Little Colorado River Basin, though current distribution of roundtail chub is poorly known (Karpowitz 2006). As with cutthroat trout, interstate agreements have been developed for these species, but management objectives are not as well-defined.

The federally endangered razorback sucker and Colorado pikeminnow are found in the mainstem San Juan River and the lower portions of its tributaries (Platania et al. 1991, Cathcart et al. 2015). The lower stretch of the San Juan River from Lake Powell upstream to Farmington, NM is designated as critical habitat for these big-river fishes (USFW 1994).

Upper Rio Grande

The upper Grande region includes headwaters of the Rio Grande, Canadian River, and Pecos River, along with the upper portions of the Rio Grande and Pecos River mainstems. Several populations of the Rio Grande cutthroat trout, listed as sensitive by Colorado and New Mexico, are found in tributary streams. This subspecies is listed as a species of concern by these states, which have developed a conservation agreement and strategy to address declines (RGCTCT 2013). The U.S. Fish and Wildlife Service determined this subspecies is not currently warranted for listing as threatened (USFWS 2014a).

The Rio Grande Chub and Rio Grande Sucker historically occupied tributary streams of the Rio Grande Basin (Calamusso et al. 2002). The sucker is listed as endangered by the state of Colorado. The chub is listed as a species of special concern by Colorado and as sensitive by New Mexico. The USFWS recently found that both species are warranted for listing (USFWS 2016a).

Two federally endangered mainstem fishes are found in the Rio Grande Basin. The wild population of the Rio Grande silvery minnow is confined to a section of the Rio Grande mainstem from Cochiti Dam south to Elephant Butte Reservoir (USFWS 2007). This section has been designated as critical habitat (USFWS 2003). The federally threatened Pecos bluntnose shiner currently occupies two sections of the Pecos River, which are designated as critical habitat, south of Fort Sumner in New Mexico (Hubbs et al. 1992).

Sport fishes

In each basin, native and nonnative species are managed for sports fisheries. Revenue from these fisheries is used to manage sensitive, threated, and endangered species. Native sportfish include Rio Grande cutthroat trout, Colorado River cutthroat trout, and Apache trout. Nonnative sportfish include warm water species such as northern pike (*Esox lucius*) and smallmouth bass (*Micropterus dolomieu*) and cold water species such as brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), and rainbow trout (*Oncorhynchus mykiss*). Introduced warm water species have been targeted for removal to aid the recovery of endangered big-river fishes (Carpenter and Mueller 2008). Introduced cold water species, on the other hand, remain managed to meet recreational and economical goals in tributary streams.

Riparian corridors

Riparian corridors occur where the transition zone from aquatic to terrestrial ecosystems supports unique vegetation communities that provide habitat for resident and migratory wildlife. Riparian corridors are protected as critical habitat for the Southwestern Willow Flycatcher (*Empidonax traillii extimus*) and New Mexico jumping mouse (*Zapus hudsonius luteus*), which are federally endangered, and the federally threatened yellow-Billed Cuckoo (*Coccyzus americanus*) (USFWS 2013, 2014b,c, 2016b). Critical habitat for the Willow Flycatcher and New Mexico Jumping Mouse are present in each basin. Critical Habitat for the Yellow-billed Cuckoo is present in the San Juan Basin and Upper Rio Grande. Management objectives include protection and expansion of riparian vegetation within critical habitats, but few management objectives exist for riparian corridors outside of critical habitat designations.

General requirements

Trout and other tributary fishes

In general, cutthroat trout and Apache trout require cold, clear water and stream heterogeneity to complete their life cycles (Cantrell et al. 2005, Pritchard and Cowley 2006, Young 2008).

Stream temperatures influence spawning behavior, reproductive success, and adult survival (McCullough 1999, Pankhurst and Munday 2011). As stream temperatures warm above 20^{o} C, stresses accumulate and mortality rates increase (Underwood et al. 2012, Recsetar et al. 2014). Temperatures above 7^{o} C are required for recruitment. Ideal temperatures are in the range of 9-15 degrees throughout the year (Table 3).

Water temperature and clarity are maintained by physical factors that include overhanging banks and riparian vegetation. Bank stability is provided by a combination of herbaceous and woody riparian plants. For example, plant communities dominated by sedges (*Carex* spp.) and willows (*Salix* spp.) provide the greatest bank stability ratings, with root structures that create overhanging banks (Winward 2000). Willows, other shrubs, and trees provide shade, which is essential for maintaining low stream temperatures during summer months (Beschta 1997). A mix of stream features such as pools, riffles, and runs is needed to provide foraging opportunities and cover for various age classes throughout the year (Horan et al. 2000, Harig and Fausch 2002). Other important forms of heterogeneity include beaver dams, instream wood, and boulders (Stumpff and Cooper 1996, Cantrell et al. 2005, Petre and Bonar 2017). These features help salmonids survive fluctuations in stream volume and air temperature. Clean gravel beds are used as spawning sites by several species.

Tributary habitats for suckers, Rio Grande chub, and Little Colorado River spinedace are similar to those of cutthroat trout and Apache trout. Important habitat features include clear water, pools, riffles, overhanging banks and vegetation, and stream beds with fine gravel or cobbles (Minckley and Carufel 1967, Ptacek et al. 2005, Rees et al. 2005, Rees and Miller 2005).

Mainstem fishes

The fishes inhabiting large, mainstem rivers require a variety of instream features that are maintained by a natural flow regime. Slow-moving side channels, pools, and inundated floodplains are essential feeding and brood-rearing habitats for Colorado pikeminnow, flannelmouth sucker, Pecos bluntnose shiner, razorback sucker, Rio Grande silvery minnow, and roundtail chub (Hatch et al. 1985. Stanford 1994, Rees et al. 2005, Cowley 2006, SJRBIP 2006, Magaña, 2012). Areas of exposed gravel, cobble, and boulders are used as spawning sites (Kaeding and Zimmerman 1983, Gorman and Stone 1999). Undammed stream reaches are essential for the pelagic-spawning Rio Grande silvery minnow and Pecos bluntnose shiner and for migratory species such as Colorado pikeminnow and razorback sucker (Stanford 1994).

Riparian Corridors

Many riparian ecosystems are composed of woody and herbaceous plants which provide foraging and nesting sites for breeding birds including the federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*) and the threatened western population of yellow-billed cuckoo (*Coccyzus americanus)* (Friggens and Finch 2015; Smith and Finch 2014). These ecosystems are also essential as migration corridors and year-round habitats for a variety of taxa (Skagen 1998, Dybala et al. 2015). Composition and structure of vegetation is a critical component of riparian habitat because many breeding and migratory species show preference for certain types of plant (Walker 2008, McGrath et al. 2009, Smith and Finch 2017,).

Opportunities for reproduction of woody plants are limited along aridland streams (Cooper et al. 1999). Pioneering species such as cottonwoods and willows (*Salix* spp.) have short-lived seeds that will not establish unless they settle on damp and exposed substrates. Other riparian trees such as boxelder (*Acer negundo*) have large seeds with long viability periods and the ability to establish in shaded sites with ground cover, though damp conditions are required to induce germination (Dewine and Cooper 2007; Katz and Shafroth 2003).

Occasional flooding creates conditions required for germination of woody plants. Periods of heavy precipitation or snowmelt result in flows that scour vegetation and litter, re-route stream channels, and deposit sediment. In the wake of these floods lie sites that are devoid of competing vegetation and ideal for germination of cottonwoods, willows, and other taxa (Auble and Scott 1998). Seed dispersal of cottonwood, willow, and saltcedar typically coincides with the drawdown of spring floods, when these sites are left exposed (Braatne et al. 1996; Sher et al. 2002). Following establishment, cottonwoods and willows require a connection between their roots and the groundwater table to ensure growth and survival (Busch et al. 1992; Snyder and Williams 2000). At many streams, high flows are needed to recharge aquifers and maintain this connection (Stromberg 2001). Reduction in streamflow volume can reduce recharge rates, causing dieback and drought mortality. Through these influences on reproduction and survival of woody vegetation, stream characteristics such as magnitude and timing of peak discharge exert great control over the composition of riparian ecosystems and wildlife communities (Brand et al. 2008; Merritt and Bateman 2012).

Issues and threats

Stream flows and associated ecosystems

Surface flows

In our focal area, surface flows are generated from a combination of precipitation runoff, snowmelt runoff, and groundwater discharge (Webb et al. 2007, Elias et al. 2015). Most stream channels have intermittent or ephemeral flows, meaning that they only contain surface water in response to runoff from precipitation or snowmelt. Perennial reaches of mainstems and tributaries are largely limited to areas where groundwater discharge can maintain baseflows during dry periods (Hart et al. 2002, Plummer et al. 2004, Zeigler et al. 2013). The many intermittent or ephemeral reaches lose surface flows to natural hydrology or modifications such as impoundments, diversions, and groundwater withdrawal.

Throughout the region, most precipitation falls in the winter or late summer (Table 4). Winter storms deliver rain in the low elevations and snow in the upper elevations. Thunderstorms associated with the summer monsoon can deliver larger amounts of precipitation than winter storms, but are typically more spatially and temporally variable.

Monsoon thunderstorms are particularly important to surface flows in the lower portions of the basins (Figure 2). Depending on location and weather patterns, annual peak flows can result from snowmelt or precipitation (Webb et al. 2007).

The White Mountains of eastern Arizona hold most of the snowpack that contributes to peak flows in the Little Colorado Basin. Snowmelt runoff is also delivered to the basin by streams draining north from the Mogollon Rim. Snowmelt from the San Francisco Peaks primarily moves through the basin as groundwater (ADEQ 2009). The San Juan Mountains of southeastern Colorado hold most of the snowpack that contributes to peak flows in the San Juan River Basin and the Upper Rio Grande (Elias et al. 2015). Snowpack in the headwaters of the San Juan River and Upper Rio Grande are typically larger than those of the Little Colorado Basin Headwaters (Figure 2). As a result, flows are of greater volume and permanence in the mainstem San Juan River and Rio Grande (Figure 3). The Sangre de Cristo Mountains and several smaller ranges contribute snowmelt to the Upper Rio Grande region as well, but typically hold less snow than the San Juan Mountains (Phillips et al. 2011).

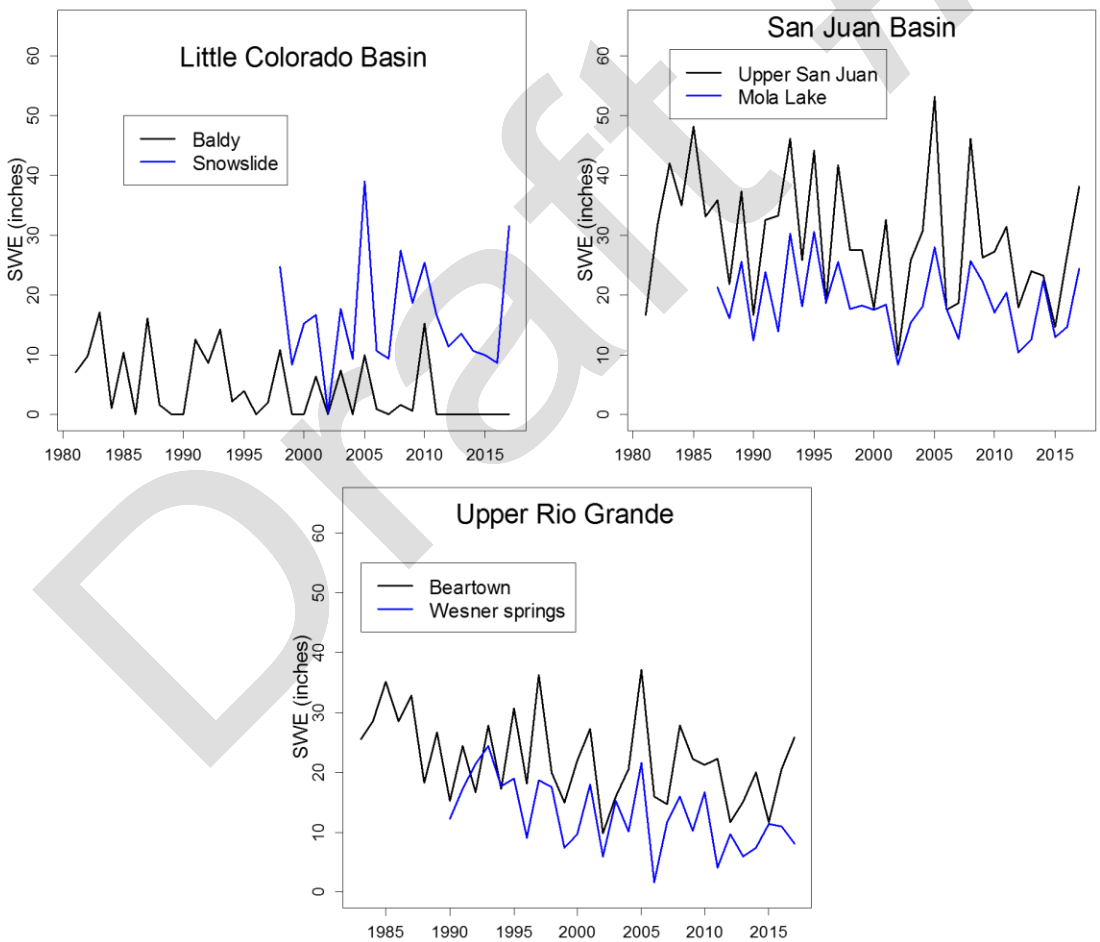

Figure 2. Snow water equivalent (SWE) measured at SNOTEL sites in our three SRLCC focal areas.

There are numerous anthropogenic influences on stream flows in the SRLCC. There is a long history of water diversion for agriculture in the Upper Rio Grande (Phillips et al. 2011). An infrastructure of acequias, dams, and canals has altered the volume, timing, and quality of flows from the headwaters to the lower mainstem. Euro-American settlement of the Little Colorado River Basin and San Juan River Basin occurred later than in the Upper Rio Grande, but their tributary streams were heavily dammed and diverted in the 19th and 20th centuries (Rinne and Minkley 1985). Larger dams were constructed on the San Juan River and Rio Grande mainstems in the late 20th century. Operation of these dams has resulted in significant changes to the hydrological regimes and riparian ecosystems (Molles et al. 1998, Webb 2007).

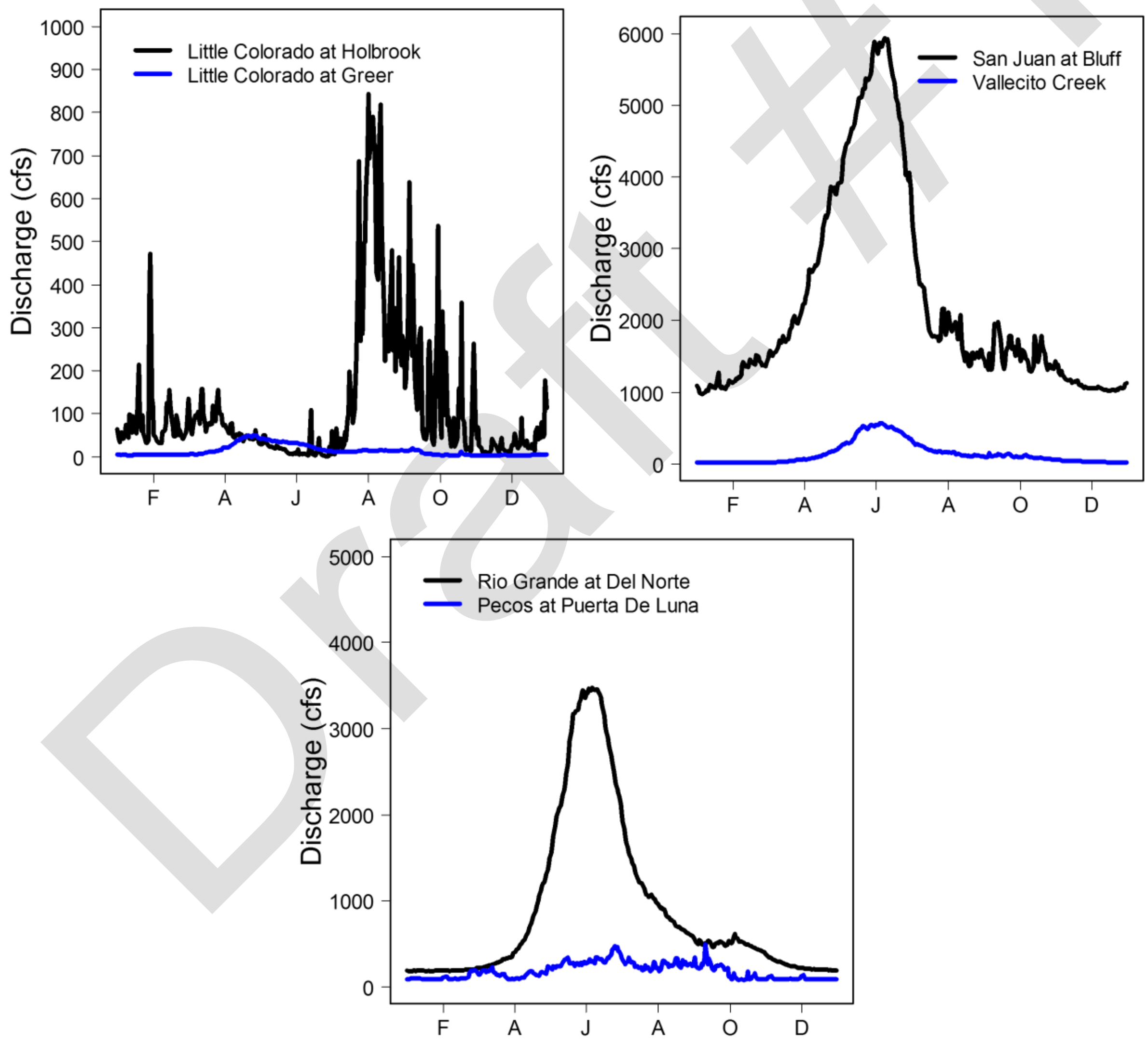

Figure 3. Stream flow volume (mean daily discharge for ordinal date) measured across years at stream gage sites in our three SRLCC focal areas.

Land cover changes
Surface flow dynamics are influenced by terrestrial vegetation. Development and forest clearing decrease rates of interception and infiltration, leading to increased rates of runoff, decreases in groundwater recharge, and changes in timing and volume of surface flows (Wyatt et al. 2015). Forests in the American Southwest are also being altered by drought-driven outbreaks of insects, disease outbreaks, and wildfires (Breshears et al. 2005, Savage et al. 2013). Nationwide, developed land cover has increased in riparian zones, directly affecting riparian ecosystems and indirectly affecting streamflows (Jones et al. 2010). Another influence of land cover change is deposition of dust from disturbed areas onto snowpacks, which accelerates runoff in the Colorado Basin and other areas (Painter et al. 2010, Livneh et al. 2015). Energy development influences water quality and availability in the region as well (Vengosh et al. 2014).

Groundwater
Groundwater dynamics influence aquatic and riparian ecosystems in each basin. The Little Colorado River Basin has an underlying aquifer, known as the C aquifer, which discharges surface flows at springs, the largest of which, in the Blue Springs area, maintain perennial flows in the lower 13 miles of the Little Colorado River (Hart et al. 2002). Several aquifers underlie the Rio Grande and San Juan Basins as well (Welder 1986, Wilkins 1998). Groundwater withdrawal influences the volume of both groundwater and surface water, impacting aquatic and riparian ecosystems at southwestern streams (Stromberg et al. 2005). Groundwater use is unregulated in many areas and has recently increased throughout the southwest in response to lowered availability of surface flows (Phillips et al. 2011, Castel et al. 2014).

Aquatic and riparian ecosystems
Riparian and aquatic organisms have habitat requirement that are critically tied to characteristics of natural flow regimes such as volume and timing (Poff et al. 1997). Though storms can produce peak flows throughout the year, annual peaks in discharge volume usually coincide with runoff from snowmelt in spring (Tremble 1993). Accordingly, life cycle traits of numerous organisms are synchronized with peak flows (Bunn and Arthington 2002). In the southwestern U.S., reproduction of riparian vegetation occurs following flood scour and is synchronized with drawdown (Mahoney and Rood 1998). In the same river systems, spawning of fishes coincides with external cues including water temperature and flow volume (Nesler et al. 1988, Probst and Gido 2004, Cowley 2006). Responses to temporal stimuli such as peak flows have evolved to ensure that reproduction occurs when multiple environmental conditions are optimal (Lam 1983). A shift in timing of these cues could lead to reproduction occurring under suboptimal conditions (Nesler et al. 1988).

In addition to timing, flow volume is critical to survival and reproduction of plants and animals in streams and riparian areas. High flows recharge surface water and groundwater, and deliver nutrients, thereby helping to maintain these ecosystems. Cottonwoods, willows, and other riparian plants require periodic high flows for successful germination and establishment

(Baker 1990, Stromberg 1997). High flows are required to create and maintain gravel beds, pools, and side channels that are used by fish in tributaries and mainstems (Gorman and Stone 1999, Horan et al. 2000, USFWS 2002). Flow volume is a limitation on spawning success for many native fishes. For example, Nesler et al. (1988) identified a threshold of 55-65 cubic meters per second for initiation of spawning behavior by Colorado pikeminnow in the Yampa River. Reduction of volume below this threshold could limit reproduction of this and other endangered species.

Native fishes

In general, there are two major threats to the native fishes covered in this assessment: introductions of nonnative fishes and changes to habitat brought upon by stream modifications (Table 1).

Introduced species effects

In parts of the southwest, abundance and species richness of nonnative fishes exceeds that of native fishes, resulting in the greatest obstacle to recovery of imperiled species (Minkley and Marsh 2009). Both tributary and mainstem fishes have had population declines resulting from predation by nonnative fishes (Behnke 1992, Carpenter and Mueller 2008). In addition to predation, nonnative species threaten native populations through competition, hybridization, and transfer of parasites. These consequences of nonnative introductions have been documented in the tributaries and mainstems of the Little Colorado, San Juan, and Rio Grande basins (Bestgen and Platania 1991, Blinn et al. 1993, Marsh and Douglas 1997, Calamusso et al. 2002, Pritchard and Cowley 2006, Stone et al. 2007, Young 2008). Barriers such as dams keep introduced species from tributaries but present a conservation tradeoff by isolating populations of native fish and excluding them from high-quality habitat (Fausch et al. 2009).

Stream modifications

Tributary streams in each basin have been affected by human activities such as flow modification, livestock grazing, and timber harvest. Dams and impoundments block migration pathways and create habitat for nonnative species. Diversions for irrigation and other uses can increase water temperatures and reduce the amount of habitat available for spawning and other stages of the life cycle. The combined effects of dams, diversions, and nonnative fishes have resulted in habitat fragmentation and isolation of populations of cutthroat trout, Apache trout, Little Colorado River spinedace, and several unlisted species (Rinne and Minckley 1985, Minckley and Marsh 2009).

Livestock grazing can result in destabilization of banks, leading to a loss of shading and hiding cover for cold-water fishes. Timber harvest can also reduce shading and stream complexity. Following decades of grazing and timber harvest, forest streams have been restored through the establishment of livestock exclosures and riparian buffers (Robinson et al. 2004).

Habitat in mainstem streams has been impacted by major dams such as Navajo Dam on the San Juan River and Cochiti Dam on the Rio Grande. These dams alter the temperature, volume, and timing of flows downstream (Lamarra 2007, Finch et al. 2014). Such changes disrupt spawning cues, remove spawning substrates, and increase mortality for mainstem fishes (Stanford 1994, Ward et al. 2016). Decreased flow volume also limits the amount of slow-moving water in side channels, which are used as rearing areas for young (Gido et al. 1997). Dams have become migration barriers for Colorado pikeminnow and razorback sucker, limiting their distribution. The life cycle of the pelagic-spawning of the Rio Grande silvery minnow and Pecos bluntnose shiner have been disrupted by dams as well (Cowley 2006, Robertson 1996). In recent years, dam releases have been prescribed to mimic natural flow regimes, increasing spawning opportunities for downstream fishes (Probst and Gido 2004, Magaña 2012).

Riparian corridors

Riparian ecosystems have been heavily altered by human activities following Euro-American settlement of the American Southwest. Changes to streamflows and floodplains and introduction of nonnative species have influenced composition and condition of plant and animal communities.

Throughout the region, streamflows are regulated by dams and reservoirs, channelization, groundwater withdrawal, and surface flows diversion (Phillips et al. 2011; Summit 2013). Peak discharge magnitude, timing, and duration are now altered from historical conditions at many streams. In addition, sediment accumulates upstream from dams while sediment-poor water incises channels below dams, disconnecting floodplains and increasing the depth to groundwater (Novack 2006). Along streams such as the Rio Grande, levees currently prevent channels from meandering across their natural floodplains. Many streams have banks stabilized by nonnative vegetation or have been armored by riprap or jetty jacks, limiting the ability of channels to naturally adjust to changes in stream flow (Smith and Finch 2017).

Riparian ecosystems have also been influenced by introduction of livestock grazing and nonnative plant species. Cattle in particular are drawn to areas near streams, where they can reduce cover of herbaceous and woody riparian vegetation (Kauffman and Krueger 1984). As a result, habitat for breeding and migratory birds is diminished (Krueper et al. 2003). Nonnative woody plants such as saltcedar and Russian olive are often the dominant species in riparian corridors (Friedman et al. 2005). Spread of these species is promoted by changes to streamflow, groundwater, and floodplain dynamics (Everitt 1998, Nagler et al. 2011). Removal of invasive species is ongoing through mechanical clearing and biological control. There is concern, however, that these activities alter the structure of riparian corridors to the detriment of wildlife habitat and ecological processes (Smith et al. 2009a, Hultine et al. 2010) Additional nonnative plants have spread into riparian corridors particularly near landscaped urban areas. Associated animal species, such as European Starlings, invade as well, affecting native wildlife through competition and predation.

Wildfire can benefit riparian ecosystems along mountain streams, where fire is part of the natural disturbance regime (Kleindl et al. 2015). Along regulated low elevation streams, however, native woody plants do not recover from fire as well as Russian olive, saltcedar, and other nonnative species (Busch 1995, Smith and Finch 2017). As a result, reduction of fuel loads is a priority along streams such as the Middle Rio Grande in central New Mexico.

Throughout the western US, land cover in floodplains has been converted from riparian vegetation to agriculture or to urban development (Macfarlane et al. 2016). In many cases, water seeping from irrigation canals supports riparian vegetation. Changes in water conveyance, such as canal lining, have reduced seepage and have the potential to reduce the cover and extent of riparian vegetation in modified floodplains (Summit 2013). As human population growth continues in the American Southwest, additional pressure will be placed on riparian ecosystems in the region (Garfin et al. 2014, Smith and Finch 2016).

Issues and threats impacted by or related to climate change

Stream flows

There are numerous studies projecting climate change effects on water resources in the Four Corners and Upper Rio Grande. Three patterns have emerged from these projections: (1) decrease in streamflow volume resulting from factors that include reduced snowpack, increased evaporation, and increased evapotranspiration (Christensen et al. 2004, Cayan et al. 2010, Gutzler 2013, Seager et al. 2013); (2) shifts to earlier peak flows, especially in streams with a large snowmelt component (USBOR 2013, Smith and Finch 2016); and (3) increasing variability of flows resulting from precipitation events such as monsoon and winter storms (Perry et al. 2012, Cook and Seager 2013). These changes will have direct and indirect consequences for native fish and riparian ecosystems.

Native fishes

Tributary habitat

Mountain tributary streams are strongholds for imperiled cold-water species but are vulnerable to increases in water temperature (Isaak et al. 2010). Increases in temperature could decrease suitable habitat for cold water species, such as cutthroat trout, at the downstream limit of their range, but could also increase availability of upstream habitat by warming portions that were previously too cold, making them suitable for reproduction and survival (Harig and Fausch 2002, Isaak and Hubert 2004), but upstream portions may have suboptimal habitat features (Zeigler et al. 2012). For Apache trout and cutthroat trout, warming of mean August temperatures beyond 11^{o} C would reduce reproductive success. Warming of maximum temperatures into the upper 20s would decrease survival of young and adults.

Stream temperature and photoperiod are cues to initiate spawning (Behnke 1992). Warming could shift spawning to earlier dates, with consequences that are largely unknown

(Zeigler et al. 2012).Warming-induced population risk is greater for populations affected by dispersal barriers and introduced species, such as those in the San Juan Basin and Upper Rio Grande (Roberts et al. 2013, Zeigler et al. 2012).

Riparian vegetation provides critical tributary habitat in the form of shade and bank stability. Climate-induced changes to riparian vegetation include mortality from increased severity of floods, droughts, and wildfires (Williams et al. 2009). Loss of riparian vegetation from these disturbances could decrease water quality via stream warming and sedimentation.

Mainstem habitat

There is limited information available for climate change impacts on mainstem fishes. Changes in flows have been predicted under numerous climate change scenarios, however, and these changes would influence water volume, water quality, and instream habitats. Increasingly severe droughts, coupled with flow modifications, could lead to extinction of native species in desert rivers (Ruhi et al. 2015). There are upper thermal limits for reproduction of mainstem fishes (Table 3), but, with reservoirs releasing cooled water, it is unlikely that climate change would influence populations through stream warming.

Disease

Changes in water quality influence infection rates of aquatic organisms. For example, prevalence of whirling disease, which causes lethal infections in Apache trout and cutthroat trout, increases with water temperature in tributary streams (de la Hoz Franco and Budy 2004, DuBey et al. 2007). Results of these studies suggest that increasing water temperatures could challenge the trout populations through increased transmission of whirling disease.

Nonnative species

Introduced fish include warm water fishes that can invade streams that are warmed, as well as cold water species, such as brook trout, that have similar requirement as Apache trout and cutthroat trout. Increased stream temperatures could force upstream spread of nonnative warm water fish, making native fishes vulnerable to predation, competition, and hybridization (Wenger et al. 2011).

Riparian corridors

Climate-induced changes to streamflow are expected to influence riparian ecosystems in several ways. For native vegetation such as cottonwoods and willows, changes in volume and timing of streamflows could limit reproduction, increase drought mortality, and decrease ability to recovery from wildfires relative to nonnative vegetation (Smith et al. 2009b, Perry et al. 2012). Floods resulting from high-severity monsoons could induce late summer germination of nonnative plants to the exclusion of native species (Dewine and Cooper 2007; Fenner et al. 1985, Katz and Shafroth 2003). These impacts would have cascading effects on the plants and animals dependent on riparian corridors.

Critical attributes

Assessment

There are numerous methods currently used to evaluate the condition of aquatic and riparian resources. Methods used to asses native fish populations include surveys for native and nonnative species; examination of habitat structure, composition, and occupancy; measurements of reproductive success; examinations of diet and predation; and monitoring of disease prevalence. Spatial assessments are conducted using species distribution models and anthropogenic threat indices (Whittier and Sievert 2014, Sievert et al. 2016).

Given the importance of water to agriculture and municipalities, stream flow assessment has been ongoing for over 100 years in the southwestern United States. Streams have historically been measured to allocate water for consumptive use and to protect property from flood damage. More recently, assessments have focused on aquatic and riparian ecosystems. Hydrological variables typically measured include discharge volume, acre feet, stage height, bankful stage, and flood stage. There are long (>100 years) records of these measurements at some stream gage sites (Phillips et al. 2011). Networks of stream temperature measurement have been recently established throughout the western United States. Recent developments in spatial modeling have allowed estimation of discharge and temperature at unmeasured streams (Issak et al. 2010, 2015) as well.

Several groups have developed models for predicting changes in stream flow characteristics. Models simulate runoff generated under future climate scenarios. Miller et al. (2011) predicted significant decreases in stream flow in low elevation and latitude areas, such as the San Juan River Basin. Vano and Lettenmaier (2014) used a different approach to model streamflow changes in the Colorado Basin. Model projections generally predict increases in temperature, changes in precipitation, and decreases in surface flows, but with substantial uncertainties (Vano et al. 2014). Changes in hydrological variables have been examined to link current and projected effects of climate change with changes in fish populations and riparian resources (Zeigler et al. 2012, Smith and Finch 2016).

In recent decades, numerous studies have focused on condition of riparian vegetation, particularly along streams that support threatened and endangered species. Topics of study include nonnative plant invasions, response to stream modifications, wildfire recovery, and effects of land use including livestock grazing (Poff et al. 2011). Spatial data are increasingly used to model the historical and current extent of riparian ecosystems and to identify causes of departure from natural conditions (Macfarlane et al. 2016 Salo and Theobald 2016).

Ongoing activities

There are numerous activities involving assessment and management of native fish in the SRLCC (Table 5). Management activities include habitat restoration and implementation of flow releases to mimic historical conditions and assist recovery of mainstem fishes (Robertson 1996, Probst and Gido 2004). There are also activities involving assessment of water resources, both for human needs and for riparian ecosystems (Table 6).

Spatial data

Spatial data involving stream flow characteristics and riparian cover are publicly available (Table 7). Data involving distribution and habitat quality of native fishes is available for some species in certain locations, but compilation of these data across the SRLCC is still needed.

Table 1. Status of fish species of concern in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande regions.

Species	Watershed(s)	Primary habitat	Status	Primary threats	Measures taken
Apache trout (*Oncorhynchus apache*)	LCRB	Tributary streams	Federally threatened	Introduced species; changes in streamflow characteristics; streambank habitat; and water quality	Federal protection, no critical habitat
Humpback chub (*Gila cypha*)	LCRB	Mainstem rivers	Federally endangered	Stream volume and temperature changes; loss of connectivity	Federal protection, critical habitat designated
Little Colorado River spinedace *(Lepidomeda vitata*)	LCRB	Tributary streams	Federally threatened	Introduced species; loss of connectivity; changes in streambank habitat and water availability	Federal protection, critical habitat designated
Zuni Bluehead Sucker (*Catostomus discobolus yarrowi*)	LCRB	Tributary stream	Federally endangered	Introduced species; changes in habitat and streamflow characteristics; restricted distribution	Federal protection, critical habitat designated
Roundtail Chub (*Gila robusta*)	LCRB/SJRB	Mainstem rivers / tributary streams	State-listed	Introduced species; loss of connectivity; changes in stream characteristics	Interstate conservation agreement; proposed for listing
Bluehead sucker (*Catostomus discobolus*)	LCRB/SJRB	Mainstem rivers / tributary streams	State-listed	Introduced species; loss of connectivity; changes in stream characteristics	Interstate conservation agreement

Flannelmouth sucker (*Catostomus latipinnis*)	LCRB/SJRB	Mainstem rivers / tributary streams	State-listed	Introduced species; loss of connectivity; changes in stream characteristics	Interstate conservation agreement
Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*)	SJRB	Tributary streams	State-listed	Introduced species; loss of connectivity; changes in streambank habitat and water quality	Interstate conservation agreement
Colorado pikeminnow (*Ptychocheilus lucius*)	SJRB	Mainstem rivers	Federally endangered	Loss of connectivity; changes in streamflow characteristics	Federal protection, critical habitat designated
Razorback sucker (*Xyrauchen texanus*)	SJRB	Mainstem rivers	Federally endangered	Loss of connectivity; changes in streamflow characteristics	Federal protection, critical habitat designated
Rio Grande cutthroat trout (*Oncorhynchus clarkii virginalis*)	URG	Tributary streams	State-listed	Introduced species; loss of connectivity; changes in streambank habitat and water quality	Interstate agreement
Rio Grande chub *(Gila pandora)*	URG	Mainstem rivers / tributary streams	State-listed	Introduced species; loss of connectivity; changes in streamflow characteristics	Proposed for listing
Rio Grande silvery minnow *(Hybognathus amarus)*	URG	Mainstem rivers	Federally endangered	Introduced species; loss of connectivity; changes in streamflow characteristics	Federal protection, critical habitat designated
Rio Grande Sucker (*Catostomus plebeius)*	URG	Tributary streams	State-listed	Introduced species; loss of connectivity; stream channel modification	Proposed for listing

Pecos bluntnose shiner (Notropis simus pecosensis)	URG	Mainstem rivers	Federally threatened	Introduced species; loss of connectivity; changes in streamflow characteristics	Federal protection, critical habitat designated

Table 2. Threatened and terrestrial riparian species in the Little Colorado Basin, San Juan Basin, and Upper Rio Grande

Species	Status	Primary threats	Measures taken
Yellow-billed Cuckoo (*Coccyzus americanus*)	Threatened	Loss of riparian habitat from stream modification, livestock use, and nonnative vegetation; fragmentation of populations	Critical habitat proposed for sections of the San Juan Basin and Upper Rio Grande
Willow Flycatcher (*Empidonax traillii extimus*)	Endangered	Loss of riparian habitat from stream modification and livestock use; fragmentation of populations	Critical habitat designated in Little Colorado Basin, San Juan Basin, and Upper Rio Grande
New Mexico jumping mouse (*Zapus hudsonius luteus*)	Endangered	Loss of riparian habitat from stream modification and livestock use; fragmentation of populations	Critical habitat designated in Little Colorado Basin, San Juan Basin, and Upper Rio Grande

Table 3. Known thermal requirements for fishes in the Four Corners and Upper Rio Grande regions. Data were obtained from species profiles compiled by USFWS, USFS, and other agencies.

	Temperature (C)				
Species	Minimum for reproduction	Ideal for reproduction	Upper limit for reproduction	Ideal for adults	Upper limit for survival
Colorado Pikeminnow	16	20-25	30	--	--
Humpback Chub	16	--	--	--	--
Razorback Sucker	8	20-21	25	21-22	--
Rio Grande silvery minnow	--	20-24	--	--	--
Roundtail chub	17	23	30-40	23	--
Bluehead sucker	8	20-21	26	19-20	27
Flannelmouth sucker	11	20	--	26	30
Rio Grande Sucker	--	11-16	--	--	--
Apache Trout	8	9-11	--	--	27
Colorado River cutthroat trout	8	9-11	--	13-15	26
Rio Grande cutthroat trout	7.8	9-11	--	--	23-25

Table 4. Mean precipitation measured at weather stations in the Little Colorado Basin (LCB), San Juan Basin (SJB), and Upper Rio Grande (URG). Data are available online from the Western Regional Climate Center (http://www.wrcc.dri.edu/summary/).

Station name	Basin	Period	Elevation	Mean precipitation (Inches)												
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Greer	LCB	1904-2014	8490	1.5	1.4	1.5	0.8	0.7	0.8	4.3	4.4	2.1	1.8	1.2	1.8	22.4
Winslow AP	LCB	1893-2016	4882	0.5	0.5	0.5	0.4	0.3	0.3	1.2	1.4	0.9	0.7	0.5	0.6	7.6
Silverton	SJB	1899-2016	9426	1.7	1.8	2.3	1.7	1.5	1.4	2.7	3.1	2.8	2.3	1.5	1.8	24.5
Bluff	SJB	1911-2016	4315	0.7	0.7	0.6	0.5	0.4	0.2	0.7	0.8	0.9	0.9	0.6	0.7	7.8
Hermit 7 ESE	URG	1920-2016	9006	0.8	0.8	1.1	1.2	1.2	0.9	2.2	2.4	1.7	1.6	0.9	0.9	15.7
Albuquerque AP	URG	1897-2016	5311	0.8	0.8	1.1	1.2	1.2	0.9	2.2	2.4	1.7	1.6	0.9	0.9	15.7

Table 5. Ongoing activities related to climate change assessment or study of native fish in the focal area.

Agency/organization	Brief description	Taxa	Geographic focus	Duration and Stage (complete, initiated)	Why this activity?
Upper Colorado River Endangered Fish Recovery Program	Coordination of recovery among a large group of agencies and interests	Humpback chub, bonytail chub, Colorado pikeminnow, and razorback sucker	Upper Colorado Basin	Ongoing	To put aside differences and work collaboratively to recover endangered fishes
San Juan River Basin Recovery Implementation Program	Restoration of habitat and populations of endangered fishes	Colorado pikeminnow, razorback Sucker,	San Juan River Basin	Ongoing	To recover populations while maintaining water development and treaty agreements
USGS, USFWS, USACE, USFS	Multi-agency efforts to assist recovery of the endangered mainstem fishes	Rio Grande silvery minnow, Pecos bluntnose shiner	Upper Rio Grande	Ongoing	Recovery efforts involve multiple stakeholders and water management entities
TNC New Mexico	Mapping fire risk for Grande Rio Cutthroat trout habitat	Rio Grande cutthroat trout	Upper Rio Grande	Ongoing	This work is part of a habitat data assessment for New Mexico Game and Fish
CRCT Recovery Team	Partnership of state, federal, and tribal agencies working to address threats to cutthroat trout populations	Colorado River cutthroat trout	Upper Colorado River Basin	Ongoing	The recovery team has developed conservation strategies and agreements to prevent listing of the species

RGCT Recovery Team	Partnership of state, federal, and tribal agencies working to address threats to cutthroat trout populations	Rio Grande cutthroat trout	Upper Rio Grande Basin	Ongoing	The recovery team has developed conservation strategies and agreements to prevent listing of the species
Western Native Trout Initiative	A public-private fish habitat partnership that works collaboratively to conserve, protect, restore, and recover native trout species	Native trout species	12 western states	Ongoing	To combine science-based assessments with expert and local knowledge to establish joint priorities for native trout conservation at a landscape scale
National Fish Habitat Action Plan	Non-regulatory partnership among multiple groups that funds restoration and protection efforts at landscape scales	Native and sport fish	United States	Ongoing	To protect, restore and enhance the nation's fish and aquatic communities through partnerships that foster fish habitat conservation and improve the quality of life for the American people.
Dolores River Anglers and Trout Unlimited	Collaborative assessment of Climate Change and the Upper Dolores Watershed	Native and wild Trout	Dolores River and tributaries	Completed in 2016	A decision support framework was designed to examine impact of climate change on trout habitat and populations

University of Missouri, Western Association of Fish and Wildlife Agencies, and Western Native Trout Initiative	Conservation assessment of native fish in the Upper Colorado Basin	Native fish	Upper Colorado River Basin	Completed in 2014	A conservation index was developed to identify focal conservation areas, identify conservation strategies, and compare and contrast factors influencing conservation value.

Table 6. Ongoing activities related to climate change assessment or study of stream flows and riparian ecosystems in the focal area.

Agency/organization	Brief description	Geographic focus	Duration and Stage (complete, initiated)	Why this activity?
Western Water Assessment	Assessments prepared by a group of academic researchers	Colorado	Completed in 2014 and 2015	To provide an overviews of key vulnerabilities that climate variability and change will pose for Colorado's economy and resources.
Colorado Water Institute	Academic group analyzing current and projected hydrology and climate data	Colorado	Ongoing	The institute focuses water experts on issues affecting Coloradans
New Mexico State University and University of New Mexico	Results from studies on impacts of global warming on New Mexico's water resources	Rio Grande Basin	Ongoing	New Mexico's social, environmental, and economic systems are vulnerable to increasing water scarcity in an over-allocated system.
US Bureau of Reclamation	West-wide climate risk assessment	Western states	Ongoing	Climate and hydrology model projections are developed to identify climate change-related risks to water supplies and other resources
USFS Rocky Mountain Research Station	Synthesis of literature that assesses the vulnerability of western	Southern Rockies LCC	Completed in 2015	This review was conducted to assess the utility of current methods and

	U.S. aquatic systems to climate change			measures and determine what is still needed to improve knowledge of climate change impacts for hydrologic cycles, water quality, and aquatic ecosystems
USFS Pacific Northwest Research Station	Watershed climate change vulnerability pilot studies	United states	Completed in 2013	Pilot assessments were performed in 11 National Forests to provide management recommendations to anticipate and respond to projected climate-hydrologic changes.
U.S. Forest Service NORWEST	Development of models to predict changes in stream temperature, flow, volume, and other variables	Western States	Ongoing	Open-access data is provided to foster research and collaborative efforts that enhance conservation and management of aquatic resources.
Colorado Natural Heritage Program	Climate change vulnerability assessments of terrestrial ecosystems including riparian areas and wetlands	San Juan Mountains/Tres Rios	Completed in 2014	To determine how vulnerable ecosystems are to substantial climate change and report confidence in vulnerabilities
Mountain Studies Institute	Climate change vulnerability	San Juan Mountains	Completed in 2012	To connect science with stakeholders

	assessment of terrestrial ecosystems including riparian areas and wetlands			
Theobald lab, Colorado State University	Several projects to map riparian and wetland habitats and evaluate vulnerability	Southern Rockies LCC	Ongoing	To provide tools to measure fragmentation and loss of riparian and wetland habitat and to evaluate vulnerability
Rocky Mountain Research Station	Vulnerability assessment of riparian obligate species to the interactive effect of fire, climate and hydrological change	Middle Rio Grande, NM	Completed in 2014	This assessment was developed to integrate data from multiple sources to improve predictions of climate impacts for wildlife species; and to provide data on climate and related hydrological change, fire behavior under future climates, and species' distributions for use by researchers and resource managers.
Navajo Nation Department of Fish and Wildlife	Land use planning to protect fish and wildlife resources including riparian ecosystems	San Juan River and Little Colorado River Basins	Ongoing	Wildlife land use and sensitive areas were mapped to guide development and protect resources

Table 7. Available spatial data for native fish, stream flows, and riparian resources in the SRLCC.

Name	Website	Type of data	What is available
US Forest Service Western US Stream Flow Metric Dataset	https://www.fs.fed.us/rm/boise/AWAE/projects/ modeled_stream_flow_metrics.shtml	Projected changes in volume and timing of stream flows	Downloads for all western states
US Forest Service NORWEST modeled stream temperatures	https://www.fs.fed.us/rm/boise/AWAE/projects /NorWeST/ModeledStreamTemperatureScenarioMaps.shtml	Projected temperatures for stream reaches	Downloads for all western states
Arizona Department of Water Resources	http://www.azwater.gov/azdwr/gis/	Density of wells and other infrastructure	Statewide downloads
Colorado Department of Natural Resources	http://cdss.state.co.us/GIS/Pages/GISDataHome.aspx	Density of wells and other infrastructure	Statewide downloads
New Mexico Office of the State Engineer	http://gisdata-ose.opendata.arcgis.com/	Density of wells and other infrastructure	Statewide downloads
Utah Division of Water Rights	http://www.waterrights.utah.gov/gisinfo/wrcover.asp	Density of wells and other infrastructure	Statewide downloads
USGS Karst Map	https://water.usgs.gov/ogw/karst/kig2002/jbe_map.html	Mapped subsurface heterogeneity	Nationwide downloads
USEPA stream impairment data	https://www.epa.gov/waterdata/ waters-geospatial-data-downloads	303(d) listed impaired waters	Nationwide downloads

NFHAP assessment data	https://ecosystems.usgs.gov/fishhabitat/ ; http://www.fishhabitat.org/	Human disturbance index	Nationwide downloads
LANDFIRE existing vegetation cover	https://www.landfire.gov/vegetation.php	Existing vegetation type and cover, derived from remote sensing	Nationwide downloads
LANDFIRE biophysical setting	https://www.landfire.gov/vegetation.php	Pre Euro-American vegetation types, estimate with biophysical models	Nationwide downloads
USFWS Critical habitat distributions	https://ecos.fws.gov/ecp/report/table/critical-habitat.html	Critical habitat for threatened and endangered species	Nationwide downloads
NSIDC snow measurements	http://nsidc.org/data/docs/noaa/g02158_snodas_snow_cover_model/	Snow cover variables	Downloads available for northern North America
FISHNET2 native and nonnative fish distribution records	http://fishnet2.net	Georeferenced specimen records	Nationwide downloads

II. Vulnerability Assessment of Focal Resources: Streamflows, Native Fish, and Riparian Corridors

Assessment format

Following information received at adaptation forums and out literature review, we determined that there are three topics deserving of individual assessment within the Four Corners and Upper Rio Grande regions. These topics are: (1) streamflows essential to aquatic and riparian ecosystems, (2) coldwater fish habitat, and (3) riparian corridors. Our assessment starts with a general examination of streamflows, focusing on vulnerability of flows that create and maintain habitat for native fishes and riparian plants and animals. We then conduct and more-specific examination of habitat variables for native fish, primarily trout, which inhabit coldwater tributaries. Finally, we examine variables influencing the plant and animal communities associated with riparian corridors, which form along mainstems and lower potions of tributary streams. The fish and riparian assessments each contain indicators that were used in the flows assessment, as well as indicators unique to these topics.

Methodological approach

Background

Vulnerability assessments are a critical component in adaptive management planning and risk analysis. An assessment of vulnerability can identify relative impacts from disturbance and the source of those impacts, thereby facilitating the identification and prioritization of management strategies. Vulnerability is a key concept for assessing climate impacts to natural resources and have been adopted by the Forest Service and other agencies as a primary mechanism for developing effective adaptation options to manage natural resources under climate change.

As commonly applied to climate change issues, vulnerability assessments provide a structure for organizing complex information and addressing uncertainty (IPCC 2007). Although there are various definitions, vulnerability is generally thought of as the susceptibility of a target to negative impacts from some disturbance (Fussel 2007, Hinkel 2011). Assessment of climate change vulnerability typically considers three elements: exposure, sensitivity, and adaptive capacity (Glick et al. 2011). Exposure is the magnitude of climate and climate-related phenomena (e.g., fire, floods) whereas sensitivity (i.e., response to exposure) and adaptive capacity (i.e., ability to cope with negative impact) are traits or conditions that predict how a target will respond to that disturbance. These definitions can vary according the goals and the target of an analysis. For instance, sensitivity may represent the innate traits or qualities of a target that increase the likelihood it will experience a negative response. Alternatively, sensitivity may represent the potential cost of a disturbance (e.g. watershed values - Furniss et al., 2013). Adaptive capacity can be identified as the intrinsic and/or externally driven mechanisms that represent the potential for a target or system to withstand a disturbance.

Many species specific assessments define adaptive capacity through the identification of intrinsic traits, whereas landscape assessments often include externally driven sources of adaptive capacity such as landscape context and potential for management intervention (). For the SRLCC assessments we specify definitions and criteria that are inclusive and adaptable to multiple scales of assessment and uses (Table 8).

Table 8. Framework for assessing vulnerability of focal resources in the Southern Rockies Landscape Conservation Design.

VA Element	Definition	Examples	Indicators
Exposure	External threat to the target species, system, or place	• Human Impacts • Natural disturbances • Climate change	• Urbanization • Wildfire potential • Departure in temperature
Sensitivity	Qualities that make the target more susceptible to negative impacts from disturbance or threat	• Traits associated with increased negative response • Indicators of potential cost of disturbance	• Narrow physiological threshold • Degree of departure from reference condition • Presence of T&E • High value watersheds
Adaptive Capacity	The ability of the target to cope with disturbance or threat	• Traits/conditions associated with resilience • Potential for successful management intervention	• Wide physiological tolerance • Diverse prey base • Capacity to implement conservation action (e.g. land ownership profile) • Protected areas • Effective management options available (e.g. thinning can alter wildfire outcome)

Structure

Vulnerability assessments take a wide range of forms and approaches (Glick et al. 2011). The most effective vulnerability assessments are tailored to address specific objectives of resource managers or others who will use the information for management decisions (Friggens et al., 2013). For the assessments of focal resources with the Southern Rockies Landscape Conservation Cooperative, we identified a Vulnerability Assessment (VA) framework that could be used to identify relevant information and assign it to the appropriate measure of vulnerability (Table x). The VA framework contains an inclusive list of potential measure of vulnerability that relate to both species specific and landscape considerations. We use this framework to identify datasets and analyses that could inform our assessment as an indicator of one of the vulnerability elements. Once we have compiled relevant and meaningful indicators, we estimate vulnerability as the collective impact of exposure and sensitivity weighted against adaptive capacity (Figure 1x). Vulnerability is then visualized by comparing the impact scores with adaptive capacity scores using the matrix (Figure 2x). This system provides considerable flexibility so that assessments can identify vulnerability across diverse focal resources and be quickly tailored to user needs.

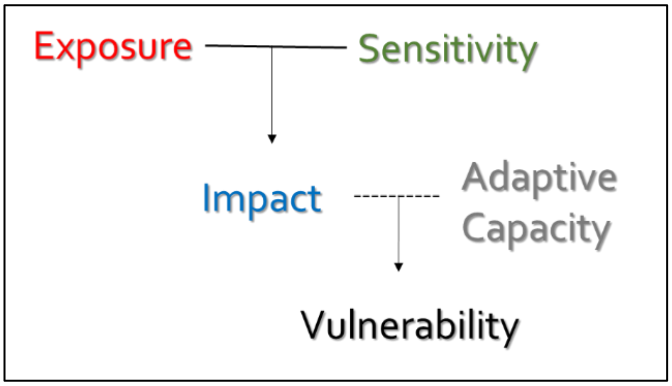

Figure 4. Structure underlying the estimation of vulnerability. Exposure and Sensitivity collectively represent Impact to a resource of interest. Adaptive capacity modulates this impact resulting in more or less vulnerability. In the system used in this assessment, we create scores representing the cumulative impact of disturbances and sensitivities (Impact) and Adaptive Capacity and then compare relative Impact and Adaptive Capacity values to generate Vulnerability Classes.

Vulnerability		**Impact (E+S) Value**				
Adaptive Capacity		**1**	**2**	**3**	**4**	**5**
	1	**11**	**12**	**13**	**14**	**15**
	2	**21**	**22**	**23**	**24**	**25**
	3	**31**	**32**	**33**	**34**	**35**
	4	**41**	**42**	**43**	**44**	**45**
	5	**51**	**52**	**53**	**45**	**55**

Vulnerability
Minimal
Low
Moderate
High
Very High

Figure 5. Matrix of Impact versus Adaptive Capacity Scores. Indicators are summed to give total scores for Exposure (E), Sensitivity (S), and Adaptive Capacity (AC). Exposure and Sensitivity are added together to represent impact and all values are rescaled to a 1-5 range. Impact increases as values increase along the horizontal and Adaptive Capacity increases as values increase along the vertical. Vulnerability is determined by the relative Impact versus Adaptive Capacity of the Focal Resource according to these potential combinations.

Measuring Vulnerability- The framework identified in Table x, encompasses the overarching structure to the assessment process. Several steps are involved in the use of this framework to generate vulnerability assessment projects.

1) We identified relevant data that relate to potential threats or issues, state of the focal resource, and traits or conditions that influence how that resource will respond to disturbance.

We call these data indicators. For each focal area, we considered a diverse set of data and analysis and selected those that had some capacity to represent the potential disturbance or response of a resource to a disturbance. We collected some information on potential stressors and threats during conversations during Adaptation Forums. Additional threats or stressors were identified from other assessments or primary literature.

2) For each indicator, we determine whether it is most appropriately used to measure exposure, sensitivity or adaptive capacity. Depending on the focal resource, some indicators maybe appropriately used to measure potential for more than one vulnerability element. For instance, road density, a common measure of human disturbance and activity might be considered under exposure. Alternatively, roads can also represent a barrier to movement and contribute to a focal resources sensitivity to disturbance. The assignment of a particular dataset to a particular element was made based on the relationship of the focal resource to that data and where it was determined the measure would provide the most meaningful output.

3) Once identified and assigned to a vulnerability element, a threshold of effect was determined for each indicator. This threshold was the cutoff value based on the original range of data values that would determine whether an area was consider affected or not. For exposure values that represented a meaningful impact were given a score of 1. Similarly, values of data within datasets contributing to sensitivity were assigned a value of 1 where they were considered to represent a condition of increased potential negative response or cost. Adaptive capacity represents resilience and data values that could be inferred to represent greater resilience were assigned a 1. For each element, scores were added to create cumulative indices representing Exposure, Sensitivity, and Adaptive Capacity. Exposure and Sensitivity scores were combined to create an impact score (Figure 1x) and this was compared to Adaptive Capacity to generate vulnerability scores (Figure 2x).

Spatial units

This assessment is focused on two geographic areas. The Four Corners region consists of the San Juan River Basin and the Little Colorado River Basin in their entirety. The Upper Rio Grande regions primarily consists of Rio Grande Basin in Colorado and much of New Mexico. This region also includes portions of streams in the Pecos River, Arkansas River, and Canadian River basins.

Our smallest spatial units are stream segments and their corresponding catchments, which were developed by National Hydrography Dataset. These units have been used in previous stream and watershed assessments, making it easy for us to join spatial data from various sources. We used the NHDplus catchment as a spatial unit for streamflows because upslope processes, such as land cover and groundwater pumping, influence the volume and timing streamflows. We used the NHDplus flowlines to represent stream segments in the fish habitat and riparian corridor analyses because of the linear nature of these resources.

To create our base files, we downloaded catchment and flowline shapefiles from the NHDplus websites NHDplus version 2: http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php). We clipped these shapefiles to the boundaries of each geographic area. The catchment base file, representing both regions, contained 121823 catchments ranging from 0.001to 1026 km^2 in area.

We created separate base files for coldwater fish habitat and riparian corridors. We clipped the NHDplus flowlines shapefile to the regional boundaries. We removed the artificial features and streams that are unlikely to support native trout and species with similar habitat requirements. The flowline types retained for the analysis were streams (Fcode 46000), perennial streams (FCode 46006), and artificial paths (FCode 55800). The resulting base file contained 35524 stream segments ranging in length from 0.001 km to 33 km. We created flowline basemaps with the intent to include all stream segments with the potential to support coldwater tributary fishes. We acknowledge, however, that the map includes segments that are not coldwater fish habitat.

For riparian corridors, we a greater number of flowline types because, under certain conditions, intermittent and ephemeral streams can support riparian vegetation. The flowline types retained for the analysis were streams (Fcode 46000), intermittent streams, (FCode 46003), perennial streams (FCode 46006), ephemeral streams (FCode 46007), and artificial paths (FCode 55800). The resulting base file contained 61859 stream segments ranging in length from 0.001 km to 33 km. As with the coldwater fish basemap, this basemap includes segments that do not support riparian vegetation.

Indicator variables

We selected indicator variables based on results of our literature review, variables used in previous assessments and peer-reviewed literature and limiting factors discussed by managers at the 2016 adaptation forum workshops (Tables 9, 10, and 11).

We aimed to use spatial datasets covering the full extent of our region, but variables reflecting projected changes in streamflows were not available for all streams, somewhat limiting the extent of our assessment. We used presence/absence scoring of exposures, sensitivities, and adaptive capacities, an approach that has been found to perform well in vulnerability assessments of streams (Paukert et al. 2011). If catchments or stream were missing data from any of the indicators, they were labeled as having incomplete data.

Exposure indicators

Streamflows

1. Change in mean annual flow

Source: US Forest Service Western US Stream Flow Metric Dataset

Description: Difference between mean cumulative streamflows projected for historical and future periods (in cubic feet per second), included as an indicator of future change in volume.

Justification: Perennial flows are required by all fish species. Peak flows induce reproductive behavior of many fishes, provide instream habitat for spawning, and facilitate reproduction and survival of riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002).

Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 global climate models (GCMs) was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). We calculated the difference between projections for the period of 1977-2006 and the period of 2030-2059. We reclassified this variable to equal 1 if difference between historical projections and future projections was ≤ 1 cfs.

Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

2. Change in mean summer flow

Source: US Forest Service Western US Stream Flow Metric Dataset

Description: Difference between mean daily streamflows projected for historical and future periods (in cubic feet per second), used as an indicator of future change in volume.

Justification: Perennial flows are required by all fish species. Reliable summer flows are essential for survival of native fish and riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002).

Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). We calculated the difference between the projected historical period and the 2040 period (2030-2059). We reclassified this variable to equal 1 if difference between historical projections and future projections was ≤ 1 cfs.

Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

3. Change in mean flow mass timing

Source: US Forest Service Western US Stream Flow Metric Dataset

Description: Difference between dates of center of flow timing (in ordinal water day) projected for historical and future periods, used as an indicator of future change in peak discharge timing.

Justification: Timing of high flows influences reproductive success of fish, riparian plants, and other organisms associated with streams in the American Southwest (Mahoney and Rood 1998, Nesler et al. 1988).

Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml Center of flow timing projected for stream segments during the period of 1977-2006. We calculated the difference in projected center of flow timing from projected historical period and the 2040 period (2030-2059). We reclassified this variable to equal 1 if change towards earlier center of flow mass timing is at least 14 days**,** a period of length we feel could influence both reproductive success of fish and riparian vegetation.

Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

4. Urban development

Sources: National Land Cover Dataset

Description: Percent of catchment area classified as developed land use

Justification: Urban development influences streamflow volume and timing of fluctuation through increasing impermeability of surfaces (Poff et al. 2006). Streamflows in the Southwest are also affected when surface water is diverted and groundwater is withdrawn for municipal and industrial use (Abruzzi 1985, Caskey et al. 2015).

Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If total low-, medium-, and high-intensity developed land cover was greater than or equal to 30%, the catchment was coded as 1.

5. Agriculture cover

Sources: National Land Cover Dataset

Description: Percent of catchment area classified as hay or crop land use

Justification: Agricultural practices can decrease streamflows through a number of mechanisms including diversion of surface flows for irrigation, withdrawal of groundwater for irrigation, and reduction of watershed infiltration and storage (Poff et al. 2006).

Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If total hay and crop cover was greater than or equal to 30%, the catchment was coded as 1.

6. Impervious surfaces

Sources: U.S. Environmental Protection Agency

Description: Mean imperviousness of anthropogenic surfaces within catchment

Justification: Urbanization has increase the area of surfaces that prevent infiltration of water into the soil. As a result, streams flood more rapidly and have lower baseflows tha stream in undeveloped watersheds (Poff et al. 2006, Theobald et al. 2009)
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If percent imperviousness was greater than 0, the catchment was coded as 1.

7. Density of dams
Sources: U.S. Environmental Protection Agency
Description: Density of georeferenced dams (dams/km^2) within a catchment's watershed
Justification: The widespread construction of dams has had numerous and well-documented effects on streamflows in the Southwest. These effects include decreases in peak flows, increases in baseflows, and changes in timing of short and long-term fluctuations in discharge volume (Graf 1999, Magilligan and Nislow 2005).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If density of dams was greater than 0 in the watershed, the catchment was coded as 1.

8. Canal density
Source: National Hydrography Dataset
Description: Density of NHDPlus line features classified as canal, ditch, or pipeline (km/km^2) within the catchment's watershed
Justification: By diverting and returning surface flows, diversion canals can reduce surface flows, decrease surface flows, and alter the timing of their fluctuations (Caskey et al. 2015).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If density of canals was greater than 0 in the watershed, the catchment was coded as 1.

9. Groundwater use
Sources: Multiple state agencies
Description: Density of wells (number/km^2) in reported by state water management agencies within catchments
Justification: Groundwater withdrawal influences the volume of both groundwater and surface water, impacting aquatic and riparian ecosystems at southwestern streams (Stromberg et al. 2005). Withdrawal increases in response to declining surface flows, creating stress on aquatic and riparian communities during periods of drought (Mix et al. 2012, Castle et al. 2014).
Data compilation: Arizona wells: Data are from the Arizona Groundwater Well Site Inventory, which is a statewide database that contains well locations, construction, and water level

measurements for wells that have actually been located and sampled in the field originally by the USGS and since 1990 by Arizona Department of Water Resources.
Colorado wells: Dataset of well applications in Colorado. The information is from HydroBase, the Department of Water Resources master database. We selected applications whose current status is “well constructed” to include in the shapefile.
New Mexico wells: The New Mexico Office of the State Engineer Point of Diversions layer includes well locations, surface declarations, or surface permits. These data were extracted from the OSE W.A.T.E.R.S. (Water Administration Technical Engineering Resource System) database and geo-located (mapped).
Utah Wells: We selected points representing wells using the category “UNDERGROUND” from the point of diversion shapefile produced by the Utah Division of Water Rights. The WRPOD shapefile is a complete record of point of diversion locations taken from the Division's day to day operating database.
We merged data from the four states into a single shapefile. Using a spatial join, we calculated the number of wells in each catchment. Given the widespread presence of wells in the regions, we examined the data for a cut off value that indicated substantial groundwater use in a catchment. If density of wells was greater than or equal to 100, the catchment was coded as 1.
Uncertainties: Criteria used for identifying and classifying wells differ among state.

Coldwater fishes

1. Change in mean annual flow

Source: US Forest Service Western US Stream Flow Metric Dataset
Description: Difference between mean cumulative streamflows projected for historical and future periods (in cubic feet per second), included as an indicator of future change in volume.
Justification: Perennial flows are required by all fish species. Peak flows induce reproductive behavior of many fishes, provide instream habitat for spawning, and facilitate reproduction and survival of riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002).
Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). We calculated the difference between projections for the period of 1977-2006 and the period of 2030-2059. We reclassified this variable to equal 1 if difference between historical projections and future projections was ≤ 1 cfs.
Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

2. Change in mean summer flow

Source: US Forest Service Western US Stream Flow Metric Dataset
Description: Difference between mean daily streamflows projected for historical and future periods (in cubic feet per second), used as an indicator of future change in volume.
Justification: Perennial flows are required by all fish species. Reliable summer flows are essential for survival of native fish and riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002).
Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). We calculated the difference between the projected historical period and the 2040 period (2030-2059). We reclassified this variable to equal 1 if difference between historical projections and future projections was ≤ 1 cfs.
Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

3. Change in cold water temperature
Source: U.S. Forest Service NORWEST stream temperature projections
Description: Difference in projected mean August water temperatures for historical and future periods, used as an indicator of future change habitat suitability
Justification: Stream temperatures influence spawning behavior, reproductive success, and adult survival of native fish (McCullough 1999, Pankhurst and Munday 2011).
Data compilation: Spatial statistical stream network models were used to apply mean August water temperature to stream reaches. Models contained 12 variables. Two variables (air temp and stream discharge) were calculated at the scale of basin. An additional 10 variables were calculated at the scale of reaches or catchments. Climate projections included A1B emissions scenarios applied to 10 GCMs selected because of low bias across the region. A relationship of changes in air temperature to changes in stream temperature was applied across each basin and an adjustment was made for each segment, reflecting the observation that cooler stream warm more slowly than warm streams. We reclassified this variable to equal 1 if projected water temperatures for a stream segment were within the temperature range of ideal trout habitat during the 1993-2011 period (9-11 degress C), but were too warm during the 2030-2059 period (> 11 degrees C).
Uncertainties: Modelers did not predict changes for individual reaches, but applied a uniform percent increase to each basin.

4. Pollution sources in catchment
Source: U.S. Environmental Protection Agency

Description: Density of permitted NPDES (National Pollutant Discharge Elimination System) sites, Superfund sites, and TRI (Toxic Release Inventory) sites within catchments
Justification: Pollution is one of the primary limiting factors in habitat for trout and other freshwater fishes (Esselman et al. 2011, DRACTU 2016).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If total density of NPDES, TRI, or Superfund pollution sites (# / km^2) was greater than 1 in the catchment, the stream segment was coded as 1.

5. Road density
Source: U.S. Census Bureau
Description:Density of roads (2010 Census Tiger Lines) within catchment
Justification: Roads contribute to sediment loads in streams and prevent natural channel dynamics in floodplains (DRACTU 2016, Macfarlane et al. 2016)
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If density of roads (km / km^2) in catchment was greater than or equal to 10, the stream segment was coded as 1.

6. Density of road crossings
Source: US Census Bureau
Description: Density of roads-stream intersections (2010 Census Tiger Lines-NHD stream lines) within catchment
Justification: Road crossings can function as dispersal barriers to native fish and can degrade water quality through introduction of sediment (DRACTU 2016).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If density of road/stream intersections (# / km2) in catchment was greater than or equal to 30, the stream segment was coded as 1.

7. Kffactor in catchment
Source: U.S. Environmental Protection Agency
Description: The Kffactor is used in the Universal Soil Loss Equation (USLE) and represents a relative index of susceptibility of bare, cultivated soil to particle detachment and transport by rainfall within a catchment's watershed.
Justification: This index reflects potential for sedimentation, which is a primary limiting factor in trout habitat (DRACTU 2016).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream

segment. If Kffactor score in catchment was greater than or equal to 4.0, the stream segment was coded as 1.

8. Nitrogen deposition
Source: National Atmospheric Deposition Program
Description: Annual gradient map of preciptiation-weighted mean deposition for ammonium ion and nitrate ion concentration wet deposition for 2008 in kg/ha/yr, within catchment
Justification: Water chemistry is a limiting factor for native fish (DRACTU 2016). N deposition can lead to acidification and euthrophication of water bodies including streams (Pardo et al. 2011).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. We used precipitation-weighted mean deposition for inorganic nitrogen wet deposition from nitrate and ammonium for 2008 in kg of N/ha/yr, within catchment as an indicator of atmospheric nitrogen pollution. Critical loads of inorganic N vary among Rocky Mountain landscapes from 1.5 to > 10.0 (Nanus et al. 2011). Barron et al. (2011) set a critical threshold for alpine streams in Colorado to be 2.0. We set our cut off to be greater or equal to 3.0 to account for differences in elevations and land covers. If nitrogen was equal to or greater than or equal to 3.0, the stream segment was coded as 1.

Riparian corridors
1. Change in mean annual flow
Source: US Forest Service Western US Stream Flow Metric Dataset
Description: Difference between mean cumulative streamflows projected for historical and future periods (in cubic feet per second), included as an indicator of future change in volume.
Justification: Perennial flows are required by all fish species. Peak flows induce reproductive behavior of many fishes, provide instream habitat for spawning, and facilitate reproduction and survival of riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002).
Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). We calculated the difference between projections for the period of 1977-2006 and the period of 2030-2059. We reclassified this variable to equal 1 if difference between historical projections and future projections was ≤ 1 cfs.
Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

2. Change in mean summer flow

Source: US Forest Service Western US Stream Flow Metric Dataset

Description: Difference between mean daily streamflows projected for historical and future periods (in cubic feet per second), used as an indicator of future change in volume.

Justification: Perennial flows are required by all fish species. Reliable summer flows are essential for survival of native fish and riparian vegetation (Mahoney and Rood 1998, Nesler et al. 1988, Gorman and Stone 1999, Horan et al. 2000, USFWS 2002).

Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). We calculated the difference between the projected historical period and the 2040 period (2030-2059). We reclassified this variable to equal 1 if difference between historical projections and future projections was ≤ 1 cfs.

Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

3. Change in mean flow mass timing

Source: US Forest Service Western US Stream Flow Metric Dataset

Description: Difference between dates of center of flow timing (in ordinal water day) projected for historical and future periods, used as an indicator of future change in peak discharge timing.

Justification: Timing of high flows influences reproductive success of fish, riparian plants, and other organisms associated with streams in the American Southwest (Mahoney and Rood 1998, Nesler et al. 1988).

Data compilation: The Western Stream Flow Metric team generated historical data by using PRSIM products. Projections were generated using the A1B emissions scenario. Output from 10 CMIP3 GCMs was downscaled using the delta method. The VIC method was used to translate climate data into streamflow (USFS 2015).

We downloaded data from the Western US Stream Flow Metrics website (https://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml Center of flow timing projected for stream segments during the period of 1977-2006. We calculated the difference in projected center of flow timing from projected historical period and the 2040 period (2030-2059). We reclassified this variable to equal 1 if change towards earlier center of flow mass timing is at least 14 days**,** a period of length we feel could influence both reproductive success of fish and riparian vegetation.

Uncertainties: Only one emissions scenario (A1B) was used. The 10 GCMs were selected because they showed the lowest bias across the region of interest.

4. Riparian vegetation decrease

Source: LANDFIRE
Description: Indicator of decrease in riparian cover relative to natural conditions
Justification: Areas with reduced cover of native riparian vegetation have lower bank stability and stream shading, both of which are important components of native trout habitat (Beschta 1997, Winward 2000, DRACTU 2016).
Data compilation: We created this shapefile using methods similar to those developed the Riparian Condition Assessment Tool (Mafarlane et al. 2016). We calculated percent riparian cover for each catchment using the LANDFIRE Existing Vegetation Type layer. We also calculated the amount of riparian cover expected under pre-Euro-American influences using the LANDFIRE Biophysical Setting layer, which represents vegetation cover predicted by modeling natural conditions. We calculated a riparian departure index for each catchment by dividing existing riparian cover by modeled riparian cover. We linked catchment data to their associated stream segments. If departure index was less than 0.67 for the catchment, the stream segment was coded as 1.

5. Urban development
Sources: National Land Cover Dataset
Description: Percent of catchment area classified as developed land use within a 100-m buffer of NHD streams
Justification: Urban development influences streamflow volume and timing of fluctuation through increasing impermeability of surfaces (Poff et al. 2006). Streamflows in the Southwest are also affected when surface water is diverted and groundwater is withdrawn for municipal and industrial use (Abruzzi 1985, Caskey et al. 2015).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If total low-, medium-, and high-intensity developed land cover was greater than or equal to 30% in the buffer, the stream segment was coded as 1.

6. Agriculture cover
Sources: National Land Cover Dataset
Description: Percent of catchment area classified as hay or crop land use within a 100-m buffer of NHD streams
Justification: Agricultural practices can decrease streamflows through a number of mechanisms including diversion of surface flows for irrigation, withdrawal of groundwater for irrigation, and reduction of watershed infiltration and storage (Poff et al. 2006).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If total hay and crop cover was greater than or equal to 30% in the buffer, the stream segment was coded as 1.

7. Density of dams
Sources: U.S. Environmental Protection Agency
Description: Density of georeferenced dams (dams/km^2) within a catchment's watershed
Justification: The widespread construction of dams has had numerous and well-documented effects on streamflows in the Southwest. These effects include decreases in peak flows, increases in baseflows, and changes in timing of short and long-term fluctuations in discharge volume (Graf 1999, Magilligan and Nislow 2005). Altered hydrological conditions lead to reductions in native riparian vegetation and increases in nonnative species (Cooper et al. 1999, Dewine and Cooper 2007, Mortenson and Weisberg 2010).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If density of dams was greater than 0 in the watershed, the stream segment was coded as 1.

8. Nonagriculture nonnative introduced or managed vegetation
Sources: National Land Cover Dataset
Description: Percent nonagriculture nonnative introduced or managed vegetation landcover type reclassed from LANDFIRE Existing Vegetation Type (EVT), within 100-m buffer of NHD stream lines
Justification: The presence of nonnative vegetation is an indicator that natural hydrology and disturbance patterns have been altered alongside streams (Everitt 1998, Stromberg et al. 2009).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If percent cover was greater than or equal to 30% in the buffer, the stream segment was coded as 1.

Sensitivity variables
Streamflows
1. Snowpack variability
Description: Coefficient of variation of snow-water equivalent measured in catchments across the years 2004-2015
Source: National Oceanic and Atmospheric Administration Snow Data Assimilation System (SNODAS)
Justification: Peak surface flows in the Rio Grande and San Juan Basins are typically associated with runoff from snowmelt in their headwaters (Smith and Finch 2016). If year to year variation in the amount of water stored in snowpack is high, streams will have greater sensitivity to warming, drought, and diversion of surface flows.

Data compilation: We downloaded SNODAS data from the from the National Snow and Ice Data Center website (http://nsidc.org/data/G02158). The dataset consisted of 12 raster files representing April 1 snow water equivalent, in meters, for the years 2005 to 2015. We used the zonal statistics tool to calculate the total SWE within each catchment for each year. We calculated mean and coefficient of variation across years. If coefficient of variation was greater than or equal to 2.0, the catchment was coded as 1.

2. Housing unit density
Sources: U.S. Census Bureau
Description: Mean housing unit density (housing units/km^2) within a catchment's watershed
Justification: Housing density reflects changes in the landscape associated with growth of human populations (Weidner and Todd 2011).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If density of housing units was greater than or equal to 5 in the watershed, the catchment was coded as 1.

3. Population density
Sources: US Census Bureau, STREAMCAT
Description: Mean populating density (people/km^2) within watershed
Justification: Through development and water use, the growing population in the Southwest is reducing the volume of streamflows (Abruzzi, Garfin et al. 2014). Catchments with larger population sizes are likely to intercept or extract greater amounts of water than smaller populations.
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If population density was greater than or equal to10 in the watershed, the catchment was coded as 1.

4. Threatened and endangered fish species
Sources: U.S. Fish and Wildlife Service
Description: Presence of threatened or endangered fish species in a catchment's streams
Justification: We determined that catchments of streams containing federally protected species are highly sensitive to changes in land use and climate that result in changes to streamflows.
Data compilation: We downloaded critical habitat shapefiles for individual threatened or endangered species from the USFWS website (https://ecos.fws.gov/ecp/report/table/critical-habitat.html). We used a spatial join to determine the number of species with critical habitat in the catchment. The catchment was coded as 1 if critical habitat for at least one threatened or endangered species was present.

5. Sensitive fish species

Sources: FISHNET2 and Wild Trout Streams databases
Description: Presence of sensitive fish species in a catchment's streams
Justification: We determined that catchments of streams containing sensitive fish species are highly sensitive to changes in land use and climate that result in changes to streamflows.
Data compilation: We downloaded distribution data for native, non-listed trout, suckers, and chubs from the FISHNET2 collections database (http://fishnet2.net) and the Wild Trout Streams database (http://wildtroutstreams.com/). We used a spatial join to determine the number of species with records in the catchment. The catchment was coded as 1 if critical habitat for at least one threatened or endangered species was present.
Uncertainties: Some records are several decades old and current distribution data are generally limited. Extirpations or range expansions hay have taken place. Collection effort and documentation is likely uneven among areas.

6. Terrestrial riparian threatened and endangered species
Source: U.S. Fish and Wildlife Service
Description: Presence of threatened or endangered terrestrial riparian species in a catchment
Justification: We determined that catchments of streams containing federally protected species are highly sensitive to changes in land use and climate that result in changes to streamflows.
Data compilation: We downloaded critical habitat shapefiles for individual threatened or endangered species from the USFWS website (https://ecos.fws.gov/ecp/report/table/critical-habitat.html). We used a spatial join to determine the number of species with critical habitat in the catchment. The catchment was coded as 1 if critical habitat for at least one threatened or endangered species was present.

Coldwater fishes
1. Native trout species
Sources: FISHNET2, U.S. Fish and Wildlife Service, and Wild trout streams
Description: Indicator that a stream segment is currently occupied by native trout (Apache trout, Colorado River Cutthroat trout, or Rio Grande Cutthroat)
Justification: Stream segments where native trout are known to persist contain barriers, natural or anthropogenic, that prevent predation, hybridization, and competition from nonnative salmonids (Harig and Fausch. 2002). Because of their high conservation value, these streams are highly sensitive to changes in land use and climate that result in habitat changes.

Data compilation: We used a combination of collections data, critical habitat shapefiles, and fishing information to identify the presence of native trout in each catchment. We downloaded data from the USFWS website (https://ecos.fws.gov/ecp/report/table/critical-habitat.html), the FISHNET2 collections database (http://fishnet2.net), and the Wild Trout Streams database (http://wildtroutstreams.com/). We used a spatial join to determine if trout were present in catchments. We linked catchment data to their associated stream segments. The stream segment was coded as 1 if a native trout was present.

Uncertainties: Some records are several decades old and current distribution data are generally limited. Extirpations or range expansions hay have taken place. Collection effort and documentation is likely uneven among areas.

2. Non-trout sensitive species
Sources: FISHNET2 database
Description: Presence of state-designated sensitive cold water species in a stream segment
Justification: We determined that segments of streams containing sensitive fish species are highly sensitive to changes in land use and climate that result in habitat changes.
Data compilation: We downloaded data on the distribution of native suckers, and chubs from the FISHNET2 collections database (http://fishnet2.net). We used a spatial join to determine the number of sensitive species in catchments. We linked catchment data to their associated stream segments. The stream segment was coded as 1 if at least one species was present.
Uncertainties: Some records are several decades old and current distribution data are generally limited. Extirpations or range expansions hay have taken place. Collection effort and documentation is likely uneven among areas.

3. Non-trout threatened and endangered species
Sources: U.S. Fish and Wildlife Service
Description: Presence of federally threatened or endangered cold water fish species in a stream segment
Justification: We determined that segments of streams containing federally protected species are highly sensitive to changes in land use and climate that result in habitat changes.
Data compilation: We downloaded critical habitat shapefiles for individual threatened or endangered species from the USFWS website (https://ecos.fws.gov/ecp/report/table/critical-habitat.html). We used a spatial join to determine if non-trout species with critical habitat were present in catchments. We linked catchment data to their associated stream segments. The stream segment was coded as 1 if at least one species was present.

4. Riparian vegetation decrease
Source: LANDFIRE
Description: Indicator of decrease in riparian cover relative to natural conditions
Justification: Areas with reduced cover of native riparian vegetation have lower bank stability and stream shading, both of which are important components of native trout habitat (Beschta 1997, Winward 2000, DRACTU 2016).
Data compilation: We created this shapefile using methods similar to those developed the Riparian Condition Assessment Tool (Mafarlane et al.). We calculated percent riparian cover for each catchment using the LANDFIRE Existing Vegetation Type layer. We also calculated the amount of riparian cover expected under pre-Euro-American influences using the LANDFIRE Biophysical Setting layer, which represents vegetation cover predicted by modeling natural conditions. We calculated a riparian departure index for each catchment by dividing existing riparian cover by modeled riparian cover. We linked catchment data to their associated stream

segments. If departure index was less than 0.67 for the catchment, the stream segment was coded as 1.

5. Catchment elevation
Sources: USGS
Description: Mean elevation (meters) of NHDplus catchment
Justification: Previous stream assessments have determined that sensitivity to effects of climate change decreases with increasing elevation (DRACTU 2016, Rice et al. 2017).
Data compilation: We downloaded used a USGS digital elevation model from the Databasin website (https://databasin.org/). We used the spatial analyst tool to calculate mean elevation of catchments. We identified catchments with mean elevation below 7500 feet (2286 meters) as more sensitive to climate change effects, following the cut off value identified by DRACTU (2016) in their assessment of Dolores River trout populations. We linked catchment data to their associated stream segments. If mean catchment elevation was less than 2286 meters, the stream segment was coded as 1.

6. Density of dams in watershed
Source: U.S. Environmental Protection Agency
Description: **Description**: Density of georeferenced dams (dams/km^2) within a catchment's watershed
Justification: Though dams can provide barriers to nonnative fish invasions, they also fragment native populations (Fausch et al. 2009). Upstream dams can prevent access to upper reaches of streams that may serve as refugia in a warming climate. Dams also alter natural hydrological processes that create instream habitat, aid reproduction, and support riparian ecosystems (Graf 1999, Magilligan and Nislow 2005).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If density of dams was greater than 0 in the watershed, the stream segment was coded as 1.

7. Wildfire risk
Source: U.S. Forest Service Fire Modeling Institute
Description: Percent of catchment classified as high or very high wildfire hazard potential
Justification: High-intensity wildfires have significant impacts on habitat of isolated trout populations (Sedell et al. 2015). Impacts include loss of riparian vegetation, stream warming, increased surface flows, landslides, and sedimentation.
Data compilation: We obtained a raster of wildfire hazard potential for the SRLCC. We used the Tabulate Area tool to calculate total area under each hazard potential category within catchments. We combined high and very high into a single class. We linked catchment data to their associated stream segment. If high/very high cover was greater than or equal to 30% of a catchment, the stream segment was coded as 1.

Riparian corridors

1. Wildfire risk

Source: U.S. Forest Service Fire Modeling Institute

Description: Percent of catchment classified as high or very high wildfire hazard potential

Justification: Along regulated low elevation streams, native woody plants do not recover from high-intensity wildfires as well as nonnative species such as Russian olive and saltcedar (Busch 1995, Smith et al. 2017). For many wildlife species, the quality of riparian habitat decreases as a result.

Data compilation: We obtained a raster of wildfire hazard potential for the SRLCC. We used the Tabulate Area tool to calculate total area under each hazard potential category within catchments. We combined high and very high into a single class. We linked catchment data to their associated stream segment. If high/very high cover was greater than or equal to 30% of a catchment, the stream segment was coded as 1.

2. Terrestrial riparian threatened and endangered species

Source: U.S. Fish and Wildlife Service

Description: Presence of threatened or endangered terrestrial riparian species in a catchment

Justification: We determined that segments of streams supporting federally protected species are highly sensitive to changes in land use and climate that result in habitat changes.

Data compilation: We downloaded critical habitat shapefiles for individual threatened or endangered species from the USFWS website (https://ecos.fws.gov/ecp/report/table/critical-habitat.html). We used a spatial join to determine the number of species with critical habitat in the catchment. The catchment was coded as 1 if critical habitat for at least one threatened or endangered species was present.

3. **Deciduous or wetland riparian vegetation cover**

Source: National Land Cover Dataset

Description: Percent of catchment classified as deciduous forest, woody wetland, or herbaceous wetland within 100m riparian buffers

Justification: In the Arid West, stream segments that support wetlands and deciduous plants are critical landscape features for migratory and resident wildlife species (Skagen 1998, Smith and Finch 2014). Given their rarity in the landscape and their dependence on limited water supplies, these ecosystems are highly sensitive to changes in land use and climate (Rice et al. 2017).

Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). We linked catchment data to their associated stream segment. If combined deciduous forest, woody wetland, or herbaceous wetland land cover was greater than or equal to 30% in the buffer, the stream segment was coded as 1.

Adaptive capacity variables
Streamflows
1. Herbaceous wetland cover
Sources: National Land Cover Dataset
Description: Percent of catchment area classified as herbaceous wetland land cover
Justification: Herbaceous wetlands, such as mountain fens and wet meadows, increase the water storage capacity of watersheds (Chimner et al. 2010, Ramstead et al. 2012).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If herbaceous wetland land cover was greater than 0, the catchment was coded as 1.

2. Reservoir storage
Sources: U.S. Army Corps of Engineers National Inventory of Dams
Description: Capacity of reservoirs (m^3/ km^2) in a catchment's watershed
Justification: Though dams have altered streamflow characteristics of many streams, high volume of reservoir storage gives the potential to mimic natural flows for adaptive management of aquatic and riparian ecosystem restoration (Probst and Gido 2004).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If total volume of storage in the watershed was greater than or equal to 100, the catchment was coded as 1.

3. Catchment relief
Sources: U.S. Geological Survey
Description: Difference between maximum and minimum catchment elevation (m)
Justification: We include catchment relief as an indicator of landscape steepness and stream gradient. We assume that adaptive management activities are easier to conduct in accessible terrain and low gradient streams.
Data compilation: We downloaded used a USGS digital elevation model from the Databasin website (https://databasin.org/). We used the spatial analyst tool to calculate maximum and minimum elevation of catchments. If the difference between maximum and minimum elevation was less than 500, the catchment was coded as 1.

4. Subsurface heterogeneity
Source: US Geological Survey
Description: Percent of catchment with underlying karst or psuedokarst
Justification: The underlying geology of a region influences groundwater recharge, groundwater discharge, and the transmission of surface water and groundwater (Ford and Williams 2013, Hartmann et al. 2017). In the Southwest, subsurface heterogeneity includes karst systems composted of soluble carbonate bedrock and pseudokarst systems composed of

volcanics, sedimentary rocks, and evaporates capable of conveying groundwater (Weary and Doctor 2014). The distribution of these systems influences groundwater and surface water dynamics, as well as vulnerability and resistance of aquifers to groundwater withdrawal and climate change (Hartmann et al. 2017). In areas with no subsurface heterogeneity, sensitivity of flows to changes in temperature, precipitation, and surface water use is greater.

Data compilation: We downloaded the USGS national karst map (https://water.usgs.gov/ogw/karst/kig2002/jbe_map.html), derived primarily from maps prepared by the individual States. These data were compiled to delineate the distribution of karst and potential karst and pseudokarst areas of the United States. We used a spatial join to determine if karst or psuedokarst (subsurface heterogeneity) was present in catchments. If subsurface heterogeneity was greater than or equal to 30%, the catchment was coded as 1.

Uncertainties The karst map data are preliminary, and there is an expectation of upgrade in content, quality, and resolution in future versions. These data were compiled from multiple sources at various spatial resolutions. Because of differences in projection and scale of the various geologic datasets, spatial errors and location inconsistencies are particularly noticeable along some State boundaries, particularly coastlines and riparian borders.

Coldwater fishes

1. Current cold water temperatures projections

Source: U.S. Forest Service NORWEST stream temperature projections

Description: Indicator of potential expansion of coldwater fish habitat as a result of warming

Justification: Some stream section are currently too cold in the summer for successful reproduction of native trout (Roberts et al. 2013). These sections may become essential spawning sites in a warmed climate (Issak and Hubert 2004, Harig and Fausch 2002).

Data compilation: Spatial statistical stream network models were used to apply mean August water temperature to stream reaches. Models contained 12 variables. Two variables (air temp and stream discharge) were calculated at the scale of basin. An additional 10 variables were calculated at the scale of reaches or catchments. Climate projections included A1B emissions scenarios applied to 10 GCMs selected because of low bias across the region. A relationship of changes in air temperature to changes in stream temperature was applied across each basin and an adjustment was made for each segment, reflecting the observation that cooler stream warm more slowly than warm streams. We reclassified this variable to equal 1 if projected water temperatures for a stream segment were below the temperature range of ideal trout habitat (9-11 degress C) during the 1993-2011 period.

2. Riparian vegetation increase

Source: LANDFIRE

Description: Indicator of decrease in riparian cover relative to natural conditions

Justification: Restoration practices such as revegetation and livestock exclusion improve bank stability and shading along streams, both of which are important components of native trout habitat (Hough-Snee et al. 2013, Sievers et al. 2017).

Data compilation: We created this shapefile using methods similar to those developed the Riparian Condition Assessment Tool (Mafarlane et al. 2016). We calculated percent riparian cover for each catchment using the LANDFIRE Existing Vegetation Type layer. We also calculated the amount of riparian cover expected under pre-Euro-American influences using the LANDFIRE Biophysical Setting layer, which represents vegetation cover predicted by modeling natural conditions. We calculated a riparian departure index for each catchment by dividing existing riparian cover by modeled riparian cover. We linked catchment data to their associated stream segments. If departure index was greater than one for the catchment, the stream segment was coded as 1.

3. Riparian shading cover

Source: LANDFIRE

Description: Percentage of catchment covered by shade-providing riparian trees and shrub

Justification: Riparian vegetation helps to maintain coldwater fish habitat by shading streams (DRACTU 2016). Stream segments shaded by riparian trees and shrubs may warm more slowly than segments lacking this vegetation (Beschta 1997).

Data compilation: We used LANDFIRE Existing Vegetation Type data Existing Vegetation Cover data to create a raster of riparian tree and riparian shrub cover. To do this, we reclassified EVT cells as 1 for riparian cover types and 0 for others. We reclassified EVC cells as 1 for tree and shrub cover types and 0 for others. We used raster calculator to multiply the layers, resulting in a layer of riparian tree and shrub cover. We next made a raster representing NHDplus flowlines (streamriver and artificial path). We used the extract by mask tool to select riparian cover cells that were adjacent to flowlines (providing shading cover). We used zonal statistics to calculate the total area of shading cover provided by riparian vegetation in each catchment. We linked catchment data to their associated stream segments. If amount of cover was greater than or equal to 10% of the catchment, the stream segment was coded as 1.

4. Reservoir storage

Sources: U.S. Army Corps of Engineers National Inventory of Dams

Description: Capacity of reservoirs (m^3/ km^2) in a catchment's watershed

Justification: Though dams have altered streamflow characteristics of many streams, high volume of reservoir storage gives the potential to mimic natural flows for adaptive management of aquatic and riparian ecosystem restoration (Probst and Gido 2004).

Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If total volume of storage in the watershed was greater than or equal to 100, the catchment was coded as 1.

5. Stream gradient
Sources: U.S. Geological Survey
Description: Change in stream segment elevation within a catchment
Justification: Streams segments with high slopes can prevent fish migrations or range shifts. High stream gradients can also hinder adaptive management efforts (DRACTU 2016).
Data compilation: We downloaded used a USGS digital elevation model from the Databasin website (https://databasin.org/). We used extract by mask tool to extract DEM cells representing stream elevations, using a flowline raster. To obtain slope, we divided the difference between maximum and minimum elevation by the flowline length. If slope was greater than or equal to 20, the stream segment was coded as 1.

6. Beaver capacity
Source: National Land Cover Dataset
Description: Indicator that a stream segment has capacity for beaver dams
Justification: In semiarid regions, beaver dams enhance adaptive capacity of trout habitat through numerous means including lowering of water temperatures, restoration of natural floodplain dynamics, addition of stream heterogeneity, and creation of barriers to nonnative fish invasion (Stumpff and Cooper 1996, Pollock et al. 2015). Presence of woody vegetation is the primary control on the capacity of a stream to support construction of beaver dams (Macfarlane et al. 2017).
Data compilation: We combined land cover data and flowline, slope (calculated as described above). We downloaded vegetation data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If percent deciduous forest vegetation cover, a measurement of food and building material, was greater than 0 the 100m riparian buffers of a catchment and slope was less than 20%, the stream segment was coded as 1.
Uncertainties: We did not include variables such as low flow volume and peak flow volume, which influence whether dams can be built or how long they will persist. An analysis including these data for the state of Utah can be found at http://brat.joewheaton.org/brat-data/utah-brat.

7. Herbaceous wetland cover
Source: National Land Cover Dataset
Description: Percent of catchment area classified as herbaceous wetland land cover
Justification: Herbaceous-dominated wetlands stabilize stream banks, store water that will contribute to surface slows, and improve to water quality (Micheli and Kirchner 2002, Chimner et al. 2010, Ramstead et al. 2012).
Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If herbaceous wetland land cover was greater than 0, the catchment was coded as 1.

8. Public land ownership
Source: U.S. Geological Survey
Description: Area within catchment managed for biodiversity by Federal, state, local, or tribal agencies
Justification: Land management agencies are under directives to protect habitat for native fishes (ELI 2008, USFS. 2012). We assume that successful management for adaptive capacity is more likely in stream segment surrounded by publicly-owned land.
Data compilation: We downloaded data from the USGS Protected Areas Database of the United States (https://gapanalysis.usgs.gov/padus/data/download/). We selected features to create a shapefile of polygons representing areas owned and managed by government agencies (federal, state, local, and tribal). We used the intersect tool to calculate the area of these lands within catchments. We linked catchment data to their associated stream segments. The stream segment was coded as 1 if at least 70% was government land.

9. Protected land designation
Source: U.S. Geological Survey
Description: Area within catchment managed to maintain a natural state
Justification: Streams with high levels of protection, such as those in wilderness areas and national parks, have fewer anthropogenic impacts than those surrounded by multiple-use lands. We assume that successful management for adaptive capacity is most likely where land has been managed to maintain a natural state.
Data compilation: We downloaded data from the USGS Protected Areas Database of the United States (https://gapanalysis.usgs.gov/padus/data/download/). We selected features to create a shapefile of polygons representing areas with GAP status of 1 or 2, which indicate that an area has permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state. We used the intersect tool to calculate the area of these lands within catchments. We linked catchment data to their associated stream segments. The stream segment was coded as 1 if at least 70% was government land.

10. Spring density
Sources: NHDplus
Description: Density of springs in a stream segment's catchment (#/ km^2)
Justification: Springs perform key functions in coldwater fish habitat, including maintenance of flows in perennial streams and stream temperature regulation (Winter 2007, Torgersen et al. 1999).
Data compilation: We downloaded the NHDplus point shapefiles for each basin in the region, merged the data into a single shapefile, and selected the springseep features for export. We used a spatial join to calculate the number of springs in each catchment. We linked catchment data to their associated stream segments. If spring density was > 0, the stream segment was coded as 1.
Uncertainties: As with most inventories, the NHDplus spring database is likely incomplete.

Riparian corridors

1. Catchment elevation

Sources: USGS

Description: Mean elevation (meters) of NHDplus catchment

Justification: Adaptive capacity of riparian ecosystems is reduced at lower elevations because riparian vegetation is heavily dependent on surface flows, there are more invasive species present, and there is a greater number of human land use impacts (Rice et al. 2017).

Data compilation: We downloaded used a USGS digital elevation model from the Databasin website (https://databasin.org/). We used the spatial analyst tool to calculate mean elevation of catchments. We identified catchments with mean elevation below 7500 feet (2286 meters) as more sensitive to climate change effects, following the cut off value identified by DRCTU (2016) in their assessment of Dolores River trout populations. We linked catchment data to their associated stream segments. If mean catchment elevation was greater than 2286 meters, the stream segment was coded as 1.

2. Reservoir storage

Sources: U.S. Army Corps of Engineers National Inventory of Dams

Description: Capacity of reservoirs (m^3/ km^2) in a catchment's watershed

Justification: Though dams have altered streamflow characteristics of many streams, high volume of reservoir storage gives the potential to mimic natural flows for adaptive management of aquatic and riparian ecosystem restoration (Probst and Gido 2004).

Data compilation: We downloaded data, which were summarized for NHDplus catchments, from the USEPA National Aquatic Resource Surveys website (https://www.epa.gov/national-aquatic-resource-surveys/streamcat). If total volume of storage in the watershed was greater than or equal to 100, the catchment was coded as 1.

3. Public land ownership

Source: U.S. Geological Survey

Description: Area within catchment managed for biodiversity by Federal, state, local, or tribal agencies

Justification: Land management agencies are under directives to protect habitat for native fishes (ELI 2008, USFS. 2012). We assume that successful management for adaptive capacity is more likely in stream segment surrounded by publicly-owned land.

Data compilation: We downloaded data from the USGS Protected Areas Database of the United States (https://gapanalysis.usgs.gov/padus/data/download/). We selected features to create a shapefile of polygons representing areas owned and managed by government agencies (federal, state, local, and tribal). We used the intersect tool to calculate the area of these lands within catchments. We linked catchment data to their associated stream segments. The stream segment was coded as 1 if at least 70% was government land.

4. Protected land designation

Source: U.S. Geological Survey

Description: Area within catchment managed to maintain a natural state
Justification: Streams with high levels of protection, such as those in wilderness areas and national parks, have fewer anthropogenic impacts than those surrounded by multiple-use lands. We assume that successful management for adaptive capacity is most likely where land has been managed to maintain a natural state.
Data compilation: We downloaded data from the USGS Protected Areas Database of the United States (https://gapanalysis.usgs.gov/padus/data/download/). We selected features to create a shapefile of polygons representing areas with GAP status of 1 or 2, which indicate that an area has permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state. We used the intersect tool to calculate the area of these lands within catchments. We linked catchment data to their associated stream segments. The stream segment was coded as 1 if at least 70% was government land.

Results

Four Corners stream flows

There were 15,350 catchments with complete data in the Little Colorado Basin and 17,127 in the San Juan Basin.

Exposure

In the Four Corners region, widespread sources of exposure include impervious surfaces, dams, projected changes in mean annual flow in both basins, and projected decreases in mean summer flows and change to earlier flows in the San Juan Basin (Table 12).

Percentage of catchments with high or very high cumulative exposure scores is greater in the San Juan Basin (5%) than in the Little Colorado Basin (1%). There are, however, greater amounts of water traveling as surface flows in the San Juan Basin. Areas with high to very high exposure include the Little Colorado River, catchments draining the San Francisco Peaks near Flagstaff, AZ, the San Juan River, and its tributaries including the Mancos River, the La Plata River, the Animas River, and the Los Pinos River (Figure 6).

Sensitivity

In each basin, sensitivity scores are relatively low, with no catchments scoring above moderate in the Little Colorado Basin and less than 1% of catchments scoring high or very high in the San Juan Basin. The most widespread source of high sensitivity is snowpack variability (Table 13). The presence of endangered species and sensitive fish increases sensitivity scores in less than 5% of catchments in either basin. Areas with moderate to very high sensitivity include the headwaters of the upper Little Colorado, catchments south of the San Francisco Peaks near Flagstaff, AZ, the mainstem San Juan River, and San Juan River tributaries including McEmlo Creek and the Animas River (Figure 7).

Adaptive capacity

Adaptive capacity scores are generally higher in the Little Colorado Basin than in the San Juan Basin, driven in large part by the Little Colorado's greater area of subsurface heterogeneity (Table 14). High or very high adaptive capacity scores are present in 6% of Little Colorado catchments and in 2% of San Juan catchments. These areas include the mainstem Little Colorado River, catchments in Little Colorado River watersheds including Show Low Creek and Clear Creek, catchments in San Juan River watersheds including Chinle Wash, and catchments of the mainstem San Juan River (Figure 8).

Overall trends

Areas with high to very high vulnerability include catchments draining the San Francisco Peaks near Flagstaff, catchments of the upper San Juan River, and catchments of San Juan tributaries including the Animas River and the Piedra River (Figure 9). Many of these catchments are impacted by snowpack variability, projected decreases in summer and annual flows, impervious surfaces, and dams.

Potential conservation opportunity areas include the Little Colorado River headwaters in the White Mountains, several Little Colorado tributaries, and the mainstem San Juan River (Figure 10). Streams in the Little Colorado Basin have high value scores associated with subsurface heterogeneity and volume of reservoir storage. Streams in both basins have high value scores associated with the presence of threatened, endangered, and sensitive species.

Upper Rio Grande stream flows

There were 27,577 catchments with complete data in the Upper Rio Grande region.

Exposure

Widespread exposures in the Upper Rio Grande include projected decrease in mean summer flow, impervious surfaces, and dams (Table 12). Less than 1% of catchments have high or very high exposure scores. Areas with high to very high exposure include the San Luis Valley in Colorado, catchments of the Purgatoire River, and catchments of the Rio Grande and tributaries, including the Rio Chama (Figure 11). Streams in this basin have a long history of alteration by dams and diversions.

Sensitivity

The most widespread source of sensitivity is snowpack variability (Table 13). Less than 1% of catchments have high or very high sensitivity scores. Areas with high to very high scores include catchments of Rio Grande tributaries near Taos, Chicorica Creek, and the mainstem Rio Grande below the confluence of the Jemez River (Figure 12).

Adaptive capacity

Widespread contributions to adaptive capacity include high reservoir storage, low catchment relief, and subsurface heterogeneity (Table 14). Cumulative adaptive capacity scores are high or very high in 4% of Upper Rio Grande catchments. Areas with high to very high adaptive capacity include the San Luis Valley, the Purgatoire River, the mainstem Pecos River, the Rio San Jose, and the Jemez River (Figure 13).

Overall trends

Areas with high vulnerability include catchments in the San Luis Valley and the Middle Rio Grande valley near Albuquerque (Figure 14). Impacts in these areas include projected decrease in mean summer flows, agricultural land cover, and impervious surfaces.

Potential areas of conservation opportunity include the Canadian River headwaters, the Rio Chama, the mainstem Rio Grande near Albuquerque, and portions of the Pecos River (Figure 15). High value scores are associated with subsurface heterogeneity, herbaceous wetlands, reservoir storage, and the presence of threatened and endangered species.

Four Corners coldwater fish

There were 489 stream segments with complete data for coldwater fish habitat in the Little Colorado Basin and 2,098 segments with complete data in the San Juan Basin.

Exposure

Widespread sources of exposure include projected decrease in mean annual flow projected in the Little Colorado Basin and projected decrease in mean summer flow in the San Juan Basin (Table 15). Nitrogen deposition is also indicated as a widespread exposure in the San Juan Basin.

Cumulative exposure scores are generally greater in the San Juan Basin than in the Little Colorado Basin: (Table 15). Areas with high to very high exposure include one segment of the West Fork Little Colorado River, several segments among the headwaters of the San Juan River, and San Juan River tributaries including the Animas River and the Piedra River (Figure 16).

Sensitivity

Contributions to stream segment sensitivity include presence of threatened, endangered, and sensitive fishes (Table 16). In each basin, less than 10% of stream segments have native trout. In the San Juan Basin, 10% have non-trout sensitive species. The Little Colorado basin has fewer sensitive fish species, but is the only basin supporting threatened or endangered tributary fishes. More-widespread sensitivity sources include decrease in riparian vegetation, low catchment elevation, dams, and high/very high fire risk.

Cumulative sensitivity scores are somewhat similar between basins, with 18% of segments ranked as high or very high in the Little Colorado and 13% ranked as high or very high in the San Juan. Areas with high/very high sensitivity include the upper Little Colorado River and headwater streams, Little Colorado tributaries including Show Low Creek and Clear Creek, and numerous San Juan River tributaries and headwater streams (Figure 17).

Adaptive capacity

Adaptive capacity is high or very high at 6% of stream segments in the San Juan Basin and at 1% of stream segments in the Little Colorado Basin. Factors contributing to high adaptive capacity include cold stream temperatures in the San Juan Mountains, high reservoir storage, and low stream gradients (Table 17). Areas with high to very high adaptive capacity scores include tributaries to the upper Little Colorado River and numerous headwater streams in the San Juan Mountains in Colorado (Figure 18).

Overall trends

Coldwater stream segments with high or very high vulnerability are found in the upper Little Colorado River and its tributaries and several San Juan basin headwater streams (Figure 19). Impacts to these segments include projected increases in water temperature, projected decreases in flows, and nitrogen deposition.

Potential areas of conservation opportunity include a few stream segments in the White Mountains and Zuni Mountains of the Little Colorado Basin and numerous stream segments in the San Juan Mountains of the San Juan Basin (Figure 20). High value scores are associated with the presence of native trout, threatened, endangered, or sensitive fish species, and protected land in the Little Colorado Basin. Beaver capacity, protected land, and low stream temperatures contribute to high value scores in the San Juan Basin.

Upper Rio Grande coldwater fish

There were 4,815 stream segments with complete data in the Upper Rio Grande region.

Exposure

The most widespread source of exposure in the Upper Rio Grande is projected decrease in mean summer flow (Table 15). Less than 1% of streams segments have high or very high exposure. These segments are located among Rio Grande tributaries in the San Juan Mountains and among the Pecos River headwaters in the Sangre De Christo Mountains (Figure 21).

Sensitivity

Native trout and sensitive tributary fishes are present in less than 10% of stream segments (Table 16). Widespread sources of sensitivity include riparian vegetation decrease and low elevation. Less than 5% of stream segments have high or very high sensitivity scores. These segments include portions of the upper Rio Grande near Taos, NM, the Rio Chama, the Jemez River, and the Galinas River (Figure 22).

Adaptive capacity

Widespread sources of adaptive capacity include cold stream temperatures, high reservoir storage, low stream gradient, capacity to support beaver dams, herbaceous wetland cover, and protected land (Table 17). Adaptive capacity is high or very high at 7% of the region's stream segments. These segments include Rio Grande headwaters in the San Juan and Sangre De

Christo Mountains in Colorado, Rio Grande tributaries in the San Pedro Mountains, and tributaries to the Rio Grande and Pecos River in the Sangre De Christo Mountains near Santa Fe (Figure 23).

Overall trends

Coldwater stream segments with high or very high vulnerability are found in headwaters of the Arkansas River in Colorado, headwaters of the Canadian and Pecos Rivers in New Mexico, and Rio Grande headwater streams in both states (Figure 24). Widespread impacts to these segments include projected decrease in stream flow, projected increase in water temperatures, and decreases in riparian vegetation.

Concentration of stream segments with high potential conservation opportunity are located at Rio Grande headwaters in the San Juan Mountains, the Pecos River headwaters in the Sangre de Christo Mountains, and the San Pedro Mountains in northern New Mexico (Figure 25). Many of these segments have cold water temperatures, capacity for beaver dams, and are located in protected areas, such as wildernesses.

Four Corners riparian corridors

There were 14,805 stream segments with complete data in the Little Colorado Basin and 16,283 segments with complete data in the San Juan Basin.

Exposure

In the Little Colorado and San Juan basins, widespread sources of exposure include dams and decreases in riparian vegetation (Table 18). Additional widespread exposures in the San Juan basin include projected decreases in mean annual flow and mean summer flow, projections of earlier peak flows, and introduced vegetation. Cumulative exposure scores are generally higher for stream segments in the San Juan Basin than in the Little Colorado Basin (Table 18) Stream segments with high to very high exposure scores include portions of mainstem Little Colorado River and some of its tributaries, the upper San Juan River, and San Juan tributaries including the Animas River (Figure 26).

Sensitivity

Widespread sources of sensitivity include high/very high wildfire risk in the Little Colorado Basin and deciduous or wetland vegetation in The San Jan Basin (Table 19). A greater percentage of stream segments had high or very high sensitivity scores in the San Juan Basin (4%) than in the Little Colorado Basin (1%). These stream segments include portions of the mainstem Little Colorado River and its headwaters, the mainstem San Juan River, and San Juan tributaries in the Abajo Mountains of Utah and the San Juan Mountains of Colorado (Figure 27).

Adaptive capacity

Adaptive capacity scores were overall greater in the San Juan Basin (3% high or very high) than in the Little Colorado Basin (1% high or very high). The San Juan Basin has many stream segments at high elevations and with high reservoir storage in their watersheds (Table 20). Public land ownership was widespread for stream segments in both basins. Stream segments with high to very high adaptive capacity scores include portions of Little Colorado River tributaries near the White Mountains and San Francisco Peaks in Arizona, Little Colorado River tributaries near the Zuni Mountains in New Mexico, San Juan River tributaries near the Abajo Mountains in Utah and San Juan River headwaters in the San Juan Mountains (Figure 28).

Overall trends

Riparian corridors with high or very high vulnerability are found along the Little Colorado River mainstem, Little Colorado River tributary streams near Flagstaff, AZ, the upper San Juan River, and lower portions of San Juan River tributaries (Figure 29). Impacts to these stream segments include change to volume and timing of flows, decrease in riparian vegetation, dams, and development/agricultural land use.

Potential areas of conservation opportunity include stream sections such as Little Colorado tributary streams near the White Mountains and San Francisco Peaks, San Juan River tributaries near the Abajo Mountains in Utah, and numerous tributaries to the San Juan River in Colorado (Figure 30). Riparian corridors with high value support threatened or endangered species and are located at high elevation and/or on protected land.

Upper Rio Grande riparian corridors

There were 26,340 stream segments with complete data in the Upper Rio Grande region.

Exposure

Widespread sources of exposure include projected decrease in mean summer flows, dams, and decrease in riparian vegetation (Table 18). Less than 1% of stream segments have high or very high exposure scores. These segments include portions of the Rio Grande and its tributaries in Colorado and the Purgatoire River in Colorado (Figure 31).

Sensitivity

Widespread sources of sensitivity include High/very high fire risk and deciduous or wetland vegetation in the riparian zone. Sensitivity scores are high or very high in 2% of stream segments (Table 19). These segments include portions of the Rio Grande and Conejos River in the San Luis Valley, portions of the Rio Grande in New Mexico, Rio Grande tributary streams in the Nacimiento Mountains of New Mexico, and portions of the lower Pecos River (Figure 32).

Adaptive capacity

Adaptive capacity is high for stream segments at high elevation, with high reservoir storage and segments surrounded by government and/or protected land (Table 20). High or very high adaptive capacity scores are indicated at 6% of stream segments. These segments include portions of Rio Grande tributaries draining the San Juan Mountains and Sangre De Christo

Mountains in Colorado, the Rio Chama, Rio Grande tributaries draining the San Pedro Mountains, and tributaries of the Pecos and Canadian Rivers draining the Sangre De Christo Mountains (Figure 33).

Overall trends

Riparian corridors with high vulnerability scores are located in the San Luis Valley of Colorado and along the Purgatoire River, the Rio Chama, and the Rio Grande (Figure 34). Impacts in these areas include dams, decrease in riparian vegetation, introduced vegetation, and development/agricultural land use.

Potential areas of conservation opportunity include the San Luis Valley of Colorado, the San Pedro Mountains of New Mexico, the Rio Grande, and some of its tributaries south of Albuquerque (Figure 35). Riparian corridors with high value scores supported threatened or endangered species, had high reservoir storage in their watersheds, and were located at high elevation and/or on protected land.

Conclusions

It is well-established that volume and timing of streamflows influence survival and reproduction of native fish, riparian vegetation, and other resources in the Four Corners and Upper Rio Grande. In both regions, water resources are over-allocated in most years. Prioritization and creative strategies are therefore necessary to manage streamflows for the maintenance of native fish populations and riparian corridors. Priorities and strategies should vary among the regions we assessed because of differences in geology, land use history, management practices, and distribution of imperiled species.

The Little Colorado River Basin contains federally protected fish and riparian species in tributary and mainstem streams. Groundwater dynamics are a large component of aquatic and riparian ecosystems because extensive aquifers and karst systems underlie the basin. Perennial surface flows are also limited by the lack of extensive, high-elevation mountain ranges relative to the San Juan Basin and Upper Rio Grande. Threatened and endangered fish are therefore confined to stream segments fed by substantial groundwater discharge. Examples include populations of Apache trout in the White Mountains, Zuni bluehead sucker in the Zuni Mountains, and humpback chub in lower Little Colorado River. The extent of riparian corridors is limited and discontinuous in this basin because streams, many of which have intermittent or ephemeral segments, have been dammed and diverted following Euro-American settlement in the late 1800s.

Because of the extensive San Juan Mountain headwaters, streams in the San Juan River Basin have a greater surface flow component than those in the Little Colorado Basin. Threatened, endangered, and sensitive species are more widely distributed, providing greater opportunities for conservation. Navajo Dam and other alterations, however, are sources of exposure for mainstem aquatic and riparian ecosystems. Exposure to tributary ecosystems are largely associated with climate-induced changes in volume, timing, and temperature of streamflows. Adaptive capacity is high in some San Juan Mountains stream segments as a result of capacity for beaver dams and low summer stream temperatures.

The Upper Rio Grande region has a longer history of Euro-American stream alteration than the Four Corners region. Several mainstem fishes are now extinct, but threatened and endangered species are still present in the Rio Grande and Pecos River. Threats to fish and riparian resources in these areas include numerous dams, diversion of surface flows for agriculture, nonnative species, and climate-induced decreases in surface flows. Threats to sensitive tributary fishes include climate-induced changes to volume and temperature of streamflows. As with San Juan tributary streams, capacity for beaver dams and low summer water temperatures provide high adaptive capacity in portions of the Rio Grande headwaters.

Our assessment yielded several locations where vulnerability is high for streamflows, coldwater fish habitat, and riparian corridors. Such areas include the San Francisco Peaks, the upper San Juan River and tributaries, the San Luis Valley, and the mainstem Rio Grande. Several of these areas are critical habitat for threatened and endangered species, in addition to sensitive fishes and other species of concern.

Locations that emerged as potential areas of conservation opportunity include streams in the White Mountains in the Little Colorado Basin, the mainstem San Juan River, the San Juan Mountains, the Sangre de Christo Mountains, the San Pedro Mountains in New Mexico, and the mainstem Rio Grande. Threatened and endangered species that will benefit from conservation of these areas are Apache trout, Little Colorado River Spinedace, Rio Grande silvery minnow, Yellow-billed Cuckoo, Willow Flycatcher, and New Mexico jumping mouse. Numerous sensitive species and species of concern will also benefit from conservation of these areas.

We acknowledge that the selection of our indicators and data transformations largely influenced our assessment results. Potential indicators are limited by the quality and extent of available data. We found that insufficient spatial data exists for important indicators such as groundwater availability, nonnative fish distribution, diseases, and condition of riparian vegetation. As these data become available, we will identify additional connections between streams, native fish, and riparian corridors to help prioritize management of these resources.

Table 9. Indicators used to evaluate exposures for fish, flows, and riparian ecosystems.

Indicator	Units	Range of values	Binomial code	Source
Projected change in mean annual flow volume for 2040	Cumulative cubic meters per second (cms)	-190 - 1487.1	1 if projected cms 2040 – projected cms historical ≤ -1	USFS RMRS Western Streamflow Metric dataset
Projected change in mean summer flow volume for 2040	Mean daily cubic meters per second (cms)	-6151.8 – 43.7	1 if projected cms 2040 – projected cms historical ≤ -1	USFS RMRS Western Streamflow Metric dataset
Projected change in cold water temperature for 2040	Degrees Celsius	0 – 1.6	1 if projected mean August stream temps are ideal for trout (9-11 degrees C) from 1993 to 2011, but are above 11 degrees in 2040	USFS RMRS NORWEST stream temperature projections
Pollution sources in catchment	Density of NPDES, TRI, and Superfund pollution sites (# / km^2)	0 - 19	1 if combined density > 0	EPA FRS, compiled in the STREAMCAT database
Road density in catchment	Density of roads (km / km^2) in catchment	0 - 19	1 if road density ≥ 10	USCB TIGER, compiled in the STREAMCAT database
Road crossings density in catchment	Density of road/stream intersections (# / km2) in catchment	0 - 555.6	1 if road crossing density ≥ 30	USCB TIGER, compiled in the STREAMCAT database
Nitrate and ammonium deposition in precipitation	kg / ha / year in catchment	0.8 – 11.9	1 if N deposition ≥ 3	NADP, compiled in the STREAMCAT database
Kffactor of watershed	Kffactor is an index representing susceptibility of bare, cultivated soil to particle detachment and transport by rainfall within watershed	0-0.51	1 if Kffactor ≥ 4.0	STREAMCAT database

Well density	Number of wells per km^2 in catchment	0 – 1111.1	1 if well density ≥ 100	State water agencies in AZ, CO, NM, and UT
Urban development	Percent of catchment classified as developed high, medium, or low intensity land use	0-100	1 if % developed ≥ 30	NLCD, compiled in the STREAMCAT database
Agriculture cover	Percent of catchment classified as hay or crop land use	0-100	1 if % agriculture ≥ 30	NLCD, compiled in the STREAMCAT database
Impervious surfaces	Mean percent imperviousness of anthropogenic surfaces within catchment	0 – 67	1 if % imperviousness > 0	STREAMCAT database
Dams	Density of dams (# / km^2) in a catchment's watershed	0 – 1.2	1 if density > 0	STREAMCAT database
Canals	Density of canals (km / km^2) in a catchment's watershed	0 – 12	1 if density > 0	STREAMCAT database
Stream flow timing	Projected change, in ordinal water day, in center of flow mass timing from the historical period (1977-2006) to the 2040s (2030-2059)	-27.9 – 6.9	1 if change ≤ -14	USFS RMRS Western Streamflow Metric dataset
Riparian vegetation departure (decrease)	Riparian departure index represents departure of riparian vegetation from modeled, pre-	0 – 9145	1 if index < 0.67	Calculated using LANDFIRE EVT data

	Euroamerican conditions. Values range from 0 (complete loss) to one (no change), to greater than one (increase in riparian vegetation)			
Urban development in riparian buffers	Combined percent of catchment classified as low, medium, or high-intensity land use within a 100-m buffer of NHD streams	0-100	1 if % developed ≥ 30	NLCD, compiled in the STREAMCAT database
Agriculture cover in riparian buffers	Combined Percent of catchment classified as hay or crop land use within a 100-m buffer of NHD streams	0-100	1 if % agriculture ≥ 30	NLCD, compiled in the STREAMCAT database
Nonagriculture nonnative introduced or managed vegetation	Percent nonagriculture nonnative introduced or managed vegetation landcover type within catchment and within 100-m buffer of NHD stream lines	0-100	1 if % cover ≥ 30	LANDFIRE, compiled in the STREAMCAT database

Table 10. Indicators used to evaluate sensitivities for fish, flows, and riparian ecosystems.

Indicator	Units	Range of values	Binomial code	Source
Projected change in cold water temperature for 2040	Degrees Celsius	0 – 1.6	1 if projected mean August stream temps are ideal for trout (9-11 degrees C) from 1993 to 2011, but are above 11 degrees in 2040	USFS RMRS NORWEST stream temperature projections
Riparian vegetation departure (decrease)	Riparian departure index represents departure of riparian vegetation from modeled, pre-Euroamerican conditions. Values range from 0 (complete loss) to one (no change), to greater than one (increase in riparian vegetation)	0 – 9145	1 if index < 0.70	Calculated using LANDFIRE EVT data
Mean catchment elevation	Meters	496.5-4052.1	1 if elevation < 2286	USGS DEM
Dams	Density of dams (# / km^2) in a catchment's watershed	0 – 1.2	1 if density > 0	STREAMCAT database
Wildfire hazard potential	Percent of catchment classified as high or very high wildfire hazard potential	0 – 100	1 if % ≥ 30	Fire Modeling Institute, USFS
Native trout presence	Indicator that a stream segment is currently occupied by native trout	0, 1	1 if a native trout species is present	FISHNET2 database, Wild Trout Streams database

	(Apache trout, Colorado River Cutthroat trout, or Rio Grande Cutthroat)			
Non-trout sensitive species presence	Presence of state-designated sensitive cold water species in a stream segment	0-4	1 if ≥ 1 sensitive species is present	FISHNET2 database
Non-trout threated and endangered species presence	Presence of federally threatened or endangered cold water fish species in a stream segment	0, 1	1 if a threated or endangered species is present	USFWS
Snowpack variability	Coefficient of variation for April 1st snow water equivalent for the years 2004-2015	0.14 – 3.5	1 if CV ≥ 2.0	NSIDC
Housing unit density	Mean housing unit density (housing units/square km) within watershed	0 – 1059	1 if density ≥ 5	USCB, compiled in the STREAMCAT database
Population density	Mean populating density (people/square km) within watershed	0 – 1972	1 if density ≥ 10	USCB, compiled in the STREAMCAT database
Threatened and endangered fish species	Presence of threatened or endangered fish species in a catchment's streams	0, 1	1 if a threated or endangered species is present	USFWS
Sensitive fish species	Presence of sensitive fish species in a catchment's streams	0, 1	1 if a sensitive species is present	FISHNET2 database, Wild Trout Streams database

Threatened and endangered riparian species	Presence of threatened or endangered terrestrial riparian species in a catchment	0, 1	1 if a threated or endangered species is present	USFWS
Deciduous or wetland riparian vegetation cover	Percent of catchment classified as deciduous forest, woody wetland, or herbaceous wetland within 100m riparian buffers	0 – 100	1 if % ≥ 30	NLCD, compiled in the STREAMCAT database

Table 11. Indicators used to evaluate adaptive capacities for fish, flows, and riparian ecosystems.

Indicator	Units	Range of values	Binomial code	Source
Current cold water temperatures projections	Degrees Celsius	3.1 - 29.95	1 if temperature < 9	USFS RMRS NORWEST stream temperature projections
Riparian vegetation departure (increase)	Riparian departure index represents departure of riparian vegetation from modeled, pre-Euroamerican conditions. Values range from 0 (complete loss) to one (no change), to greater than one (increase in riparian vegetation)	0 – 9145	1 if index > 1	Calculated using LANDFIRE EVT and BPS data
Herbaceous wetland cover	Percent of watershed area classified as herbaceous wetland land cover	0 – 100	1 if cover > 0	NLCD, compiled in the STREAMCAT database
Riparian shading cover	Percentage of catchment covered by shade-providing riparian trees and shrub	0 – 100	1 if % ≥ 10	Calculated using LANDFIRE EVT and EVC data
Slope	Change in stream segment elevation within a catchment	0 – 374.5	1 if slope ≥ 20	USGS DEM, NHD

Reservoir storage	Capacity of reservoirs (m^3/ km^2) in a catchment's watershed	0 – 18,736,449	1 if volume ≥ 100	NID, compiled in the STREAMCAT database
Public land ownership	Area within catchment managed for biodiversity by Federal, state, local, or tribal agencies.	0 – 100	1 if ≥ 70% of catchment is protected public land	USGS PADUS
Protected land designation	Area within catchment managed to maintain a natural state	0 – 100	1 if ≥ 70% of catchment is managed for biodiversity	USGS PADUS
Beaver capacity	Indicator that stream segment has capacity for beaver dams	0, 1	1 if slope is less than 20% and deciduous vegetation is present in riparian buffers	USGS DEM and NLCD, compiled in the STREAMCAT database
Subsurface heterogeneity	Percentage of catchment with underlying karst or psuedokarst	0 – 100	1 if % ≥ 30	USGS
Catchment relief	Difference between maximum and minimum catchment elevation (m)	0-1996	1 if relief < 500	USGS DEM
Reservoir storage	Capacity of reservoirs (m^3/ km^2) in a catchment's watershed	0 – 18,736,449	1 if volume ≥ 100	NID, compiled in the STREAMCAT database
Herbaceous wetland cover	Percent of catchment area classified as herbaceous wetland land cover	0 – 100	1 if cover > 0	NLCD, compiled in the STREAMCAT database

Mean catchment elevation	Meters	496.5-4052.1	1 if elevation < 2286	USGS DEM
Springs in catchment	Density of springs in a stream segment's catchment (#/ km^2)	0-50.5	1 if density >0	NHDplus

Table 12. Percentages of catchments affected by streamflow exposure indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Exposure category	Little Colorado	San Juan	Upper Rio Grande
Decrease in mean annual flow	9%	10%	7%
Decrease in mean summer flow	2%	11%	11%
Change in mean flow mass timing ≥ 14 days earlier	<1%	11%	6%
Urban development ≥ 30%	<1%	<1%	<1%
Agriculture cover ≥ 30%	<1%	5%	2%
Impervious surfaces ≥ 0	13%	16%	14%
Dams in watershed	10%	13%	11%
Canal density > 0	<1%	1%	<1%
Well density ≥ 100	<1%	<1%	<1%

Table 13. Percentages of catchments affected by streamflow sensitivity indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Sensitivity category	Little Colorado	San Juan	Upper Rio Grande
Snowpack variability ≥ 2.0	12%	16%	15%
Housing unit density ≥ 5	3%	6%	6%
Population density ≥ 10	4%	6%	6%
Threatened and endangered fish species in catchment	1%	4%	1%
Sensitive fish species in catchment	<1%	4%	2%
Terrestrial riparian threatened and endangered species in catchment	1%	3%	3%

Table 14. Percentages of catchments affected by streamflow adaptive capacity indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Adaptive capacity category	Little Colorado	San Juan	Upper Rio Grande
Herbaceous wetland cover in catchment	3%	3%	8%
Reservoir storage ≥ 100	9%	13%	11%
Catchment relief < 500	99%	92%	90%
Subsurface heterogeneity ≥ 30%	45%	11%	25%

Table 15. Percentages of stream segments affected by coldwater fish habitat exposure indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Exposure category	Little Colorado	San Juan	Upper Rio Grande
Decrease in mean annual flow	50%	38%	13%
Decrease in mean summer flow	18%	52%	46%
Increase in cold water temperature	0	4%	5%
Pollution sources in catchment	0	<1%	<1%
Road density ≥ 10	1%	<1%	<1%
Density of road crossings ≥ 30	1%	<1%	<1%
Kffactor ≥ 4.0	0	2%	1%
Nitrogen deposition ≥ 3.0	5%	14%	7%

Table 16. Percentages of stream segments affected by coldwater fish habitat sensitivity indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Sensitivity category	Little Colorado	San Juan	Upper Rio Grande
Native trout species in catchment	6%	7%	5%
Non-trout sensitive species in catchment	4%	10%	4%
Non-trout threatened and endangered species in catchment	6%	0	0
Riparian vegetation decrease	72%	88%	90%
Catchment elevation < 2286	62%	54%	33%
Dams in watershed	58%	35%	31%
High/very high wildfire risk > 30%	44%	26%	14%

Table 17. Percentages of stream segments affected by coldwater fish habitat adaptive capacity indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Adaptive capacity category	Little Colorado	San Juan	Upper Rio Grande
Current cold water temperatures projections	<1%	12%	11%
Riparian vegetation increase	1%	1%	1%
Riparian shading cover ≥ 10%	1%	1%	1%
Reservoir storage ≥ 100	56%	35%	30%
Flowline slope < 20%	99%	97%	99%
Beaver capacity	2%	41%	43%
Herbaceous wetland cover in catchment	10%	5%	20%
Public land ownership ≥ 70%	60%	76%	55%
Protected land designation ≥ 70%	3%	13%	13%
Springs in catchment	10%	6%	6%

Table 18. Percentages of stream segments affected by riparian corridor exposure indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Exposure category	Little Colorado	San Juan	Upper Rio Grande
Decrease in mean annual flow	9%	10%	7%
Decrease in mean summer flow	2%	11%	11%
Change in mean flow mass timing ≥ 14 days earlier	1%	11%	6%
Riparian vegetation decrease	67%	70%	79%
Agriculture cover in riparian buffer ≥ 30%	<1%	5%	3%
Urban development in riparian buffer ≥ 30%	4%	6%	5%
Dams present in watershed	10%	13%	11%
Introduced or managed vegetation in riparian buffer ≥ 30%	5%	10%	7%

Table 19. Percentages of stream segments affected by riparian corridor sensitivity indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Sensitivity category	Little Colorado	San Juan	Upper Rio Grande
High/very high wildfire risk > 30%	18%	8%	10%
Terrestrial riparian threatened and endangered species in catchments	<1%	3%	3%
Deciduous or wetland riparian vegetation cover in catchment	1%	11%	9%

Table 20. Percentages of stream segments affected by riparian corridor adaptive capacity indicators in the Little Colorado River Basin, San Juan River Basin, and Upper Rio Grande.

Adaptive capacity category	Little Colorado	San Juan	Upper Rio Grande
Catchment elevation ≥ 2286	8%	13%	34%
Reservoir storage ≥ 100	9%	13%	11%
Public land ownership ≥ 70%	73%	82%	50%
Protected land designation ≥ 70%	1%	5%	7%

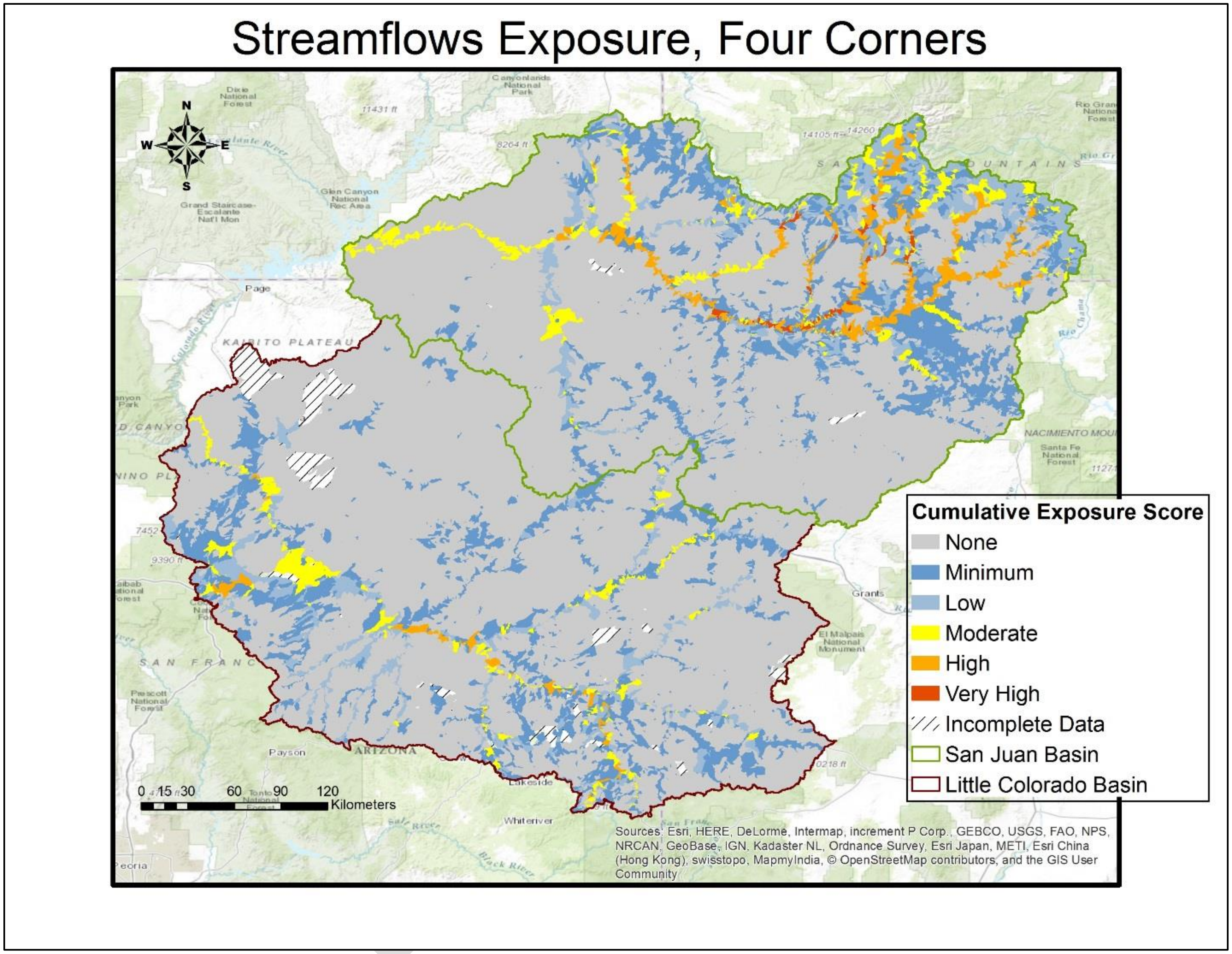

Figure 6. Cumulative exposure map for catchments in the Four Corners region of the Southern Rockies LCC

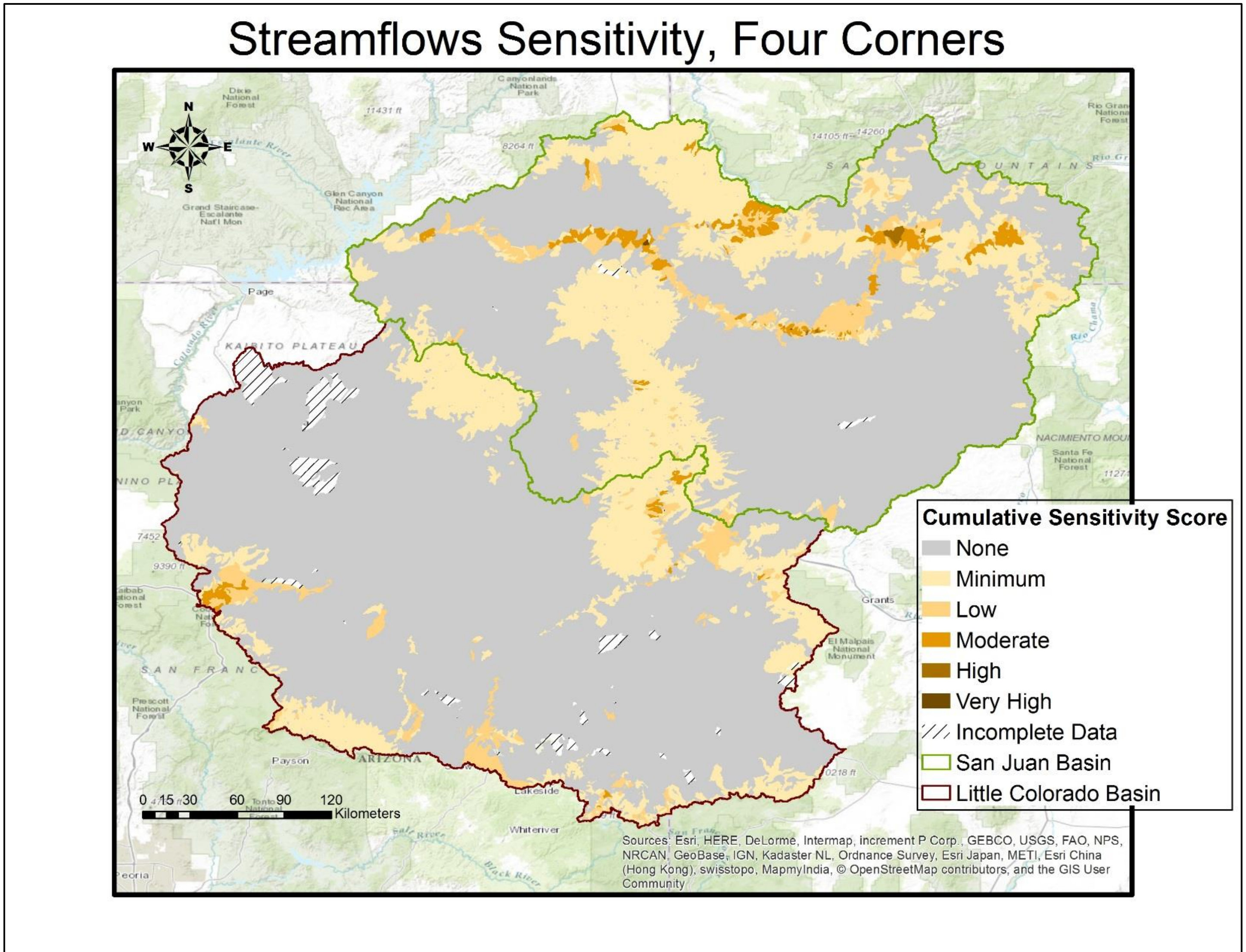

Figure 7. Cumulative sensitivity map for catchments in the Four Corners region of the Southern Rockies LCC.

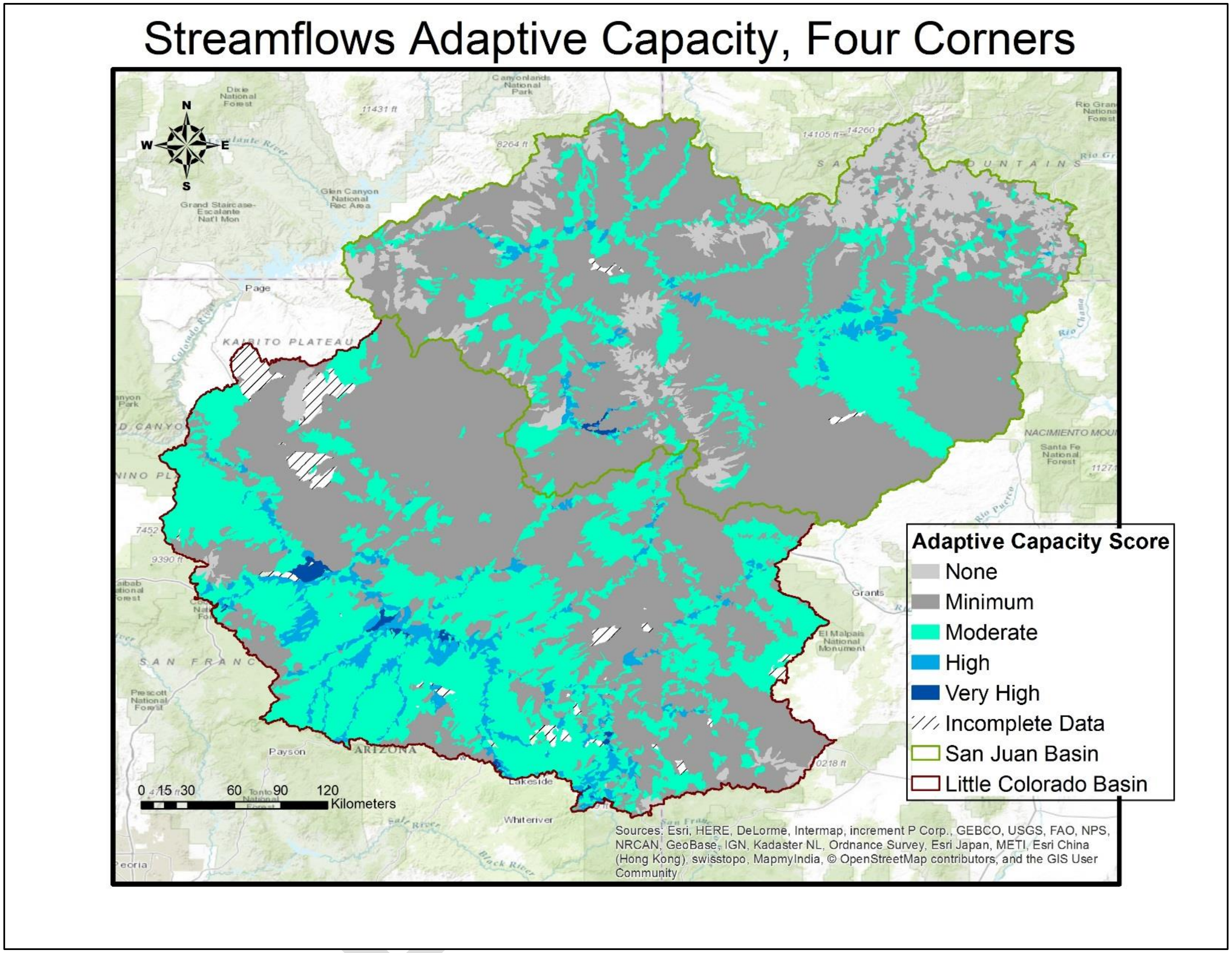

Figure 8. Cumulative adaptive capacity map for catchments in the Four Corners region of the Southern Rockies LCC.

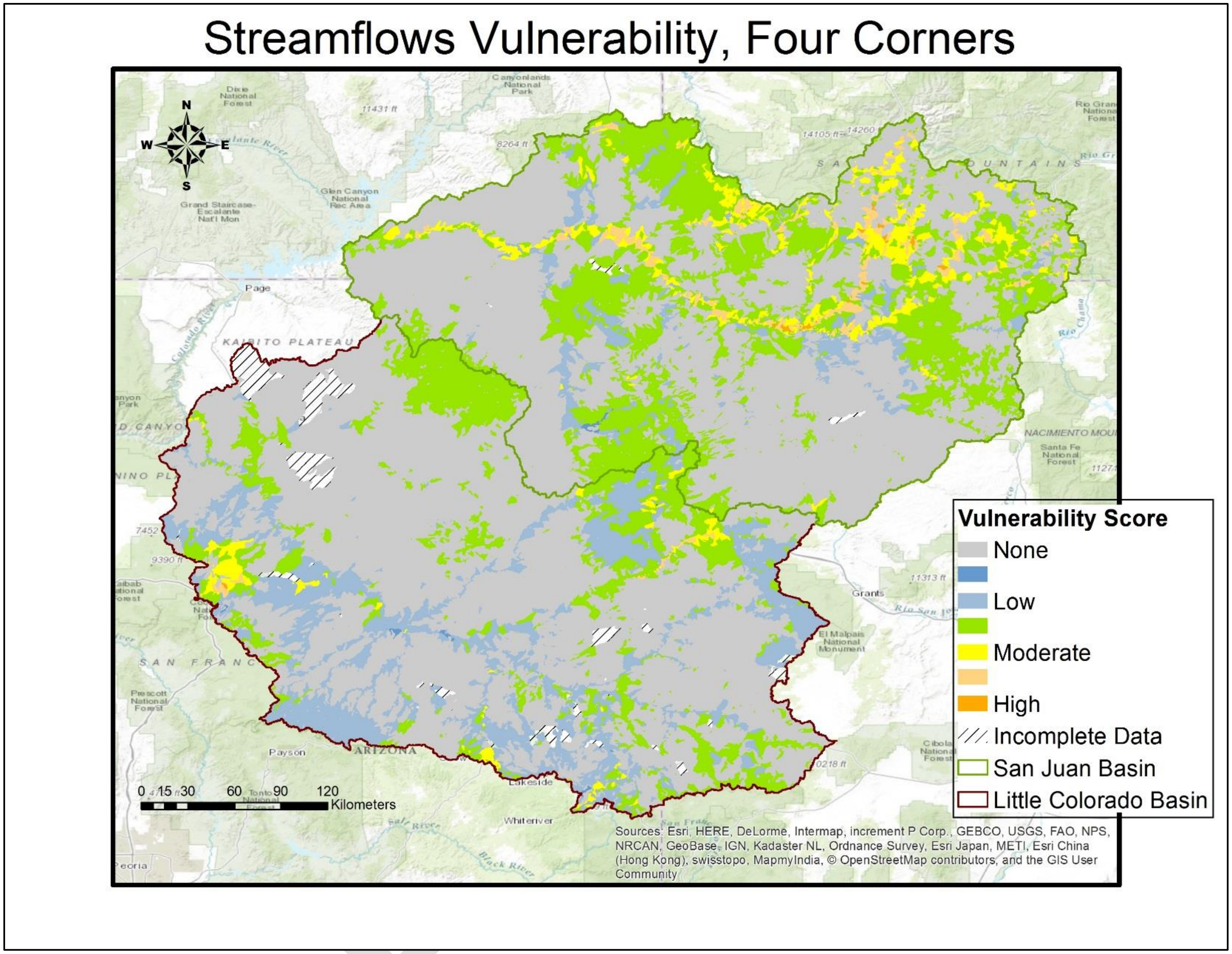

Figure 9. Vulnerability map for catchments in the Four Corners region of the Southern Rockies LCC.

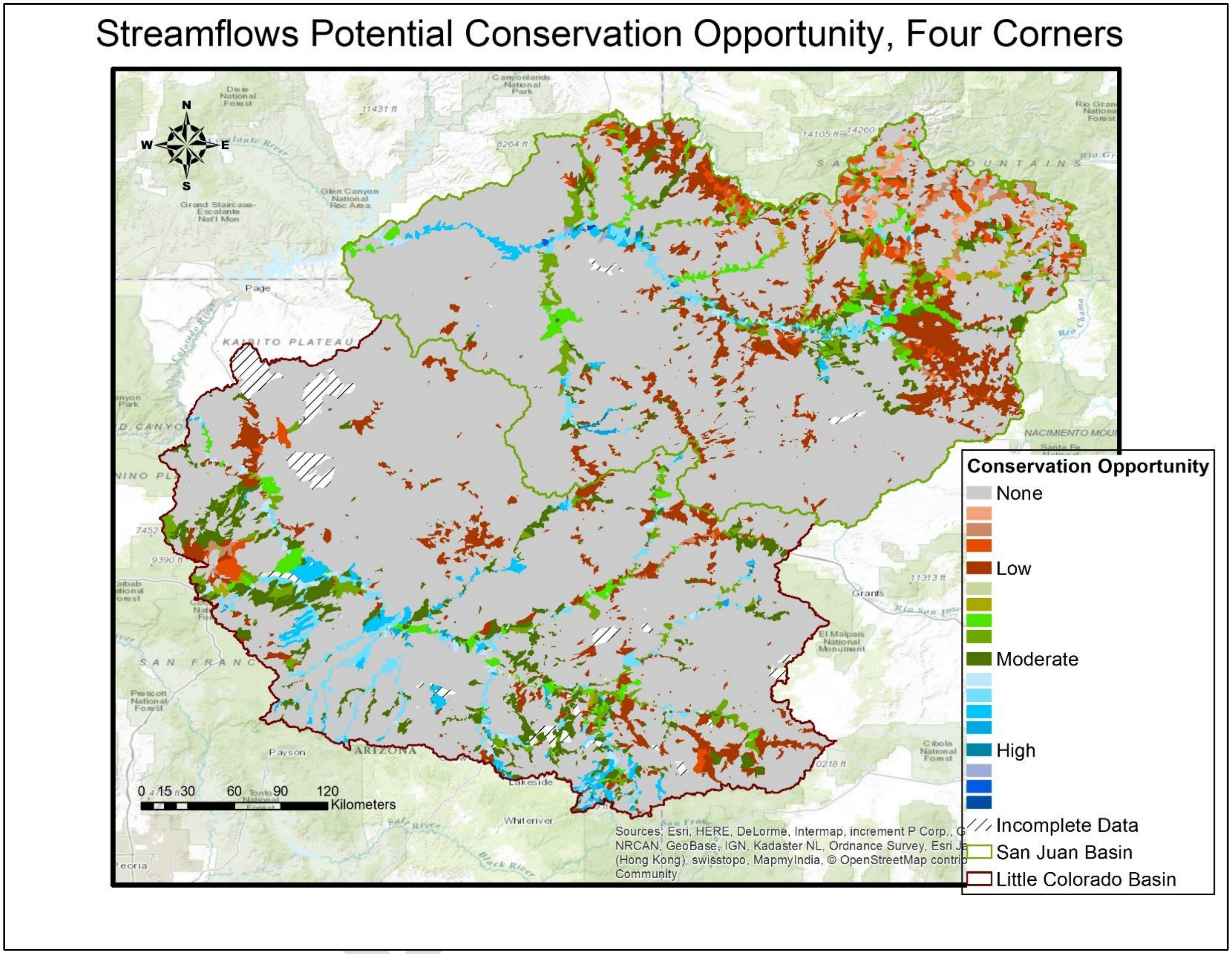

Figure 10. Conservation opportunity map for catchments in the Four Corners region of the Southern Rockies LCC.

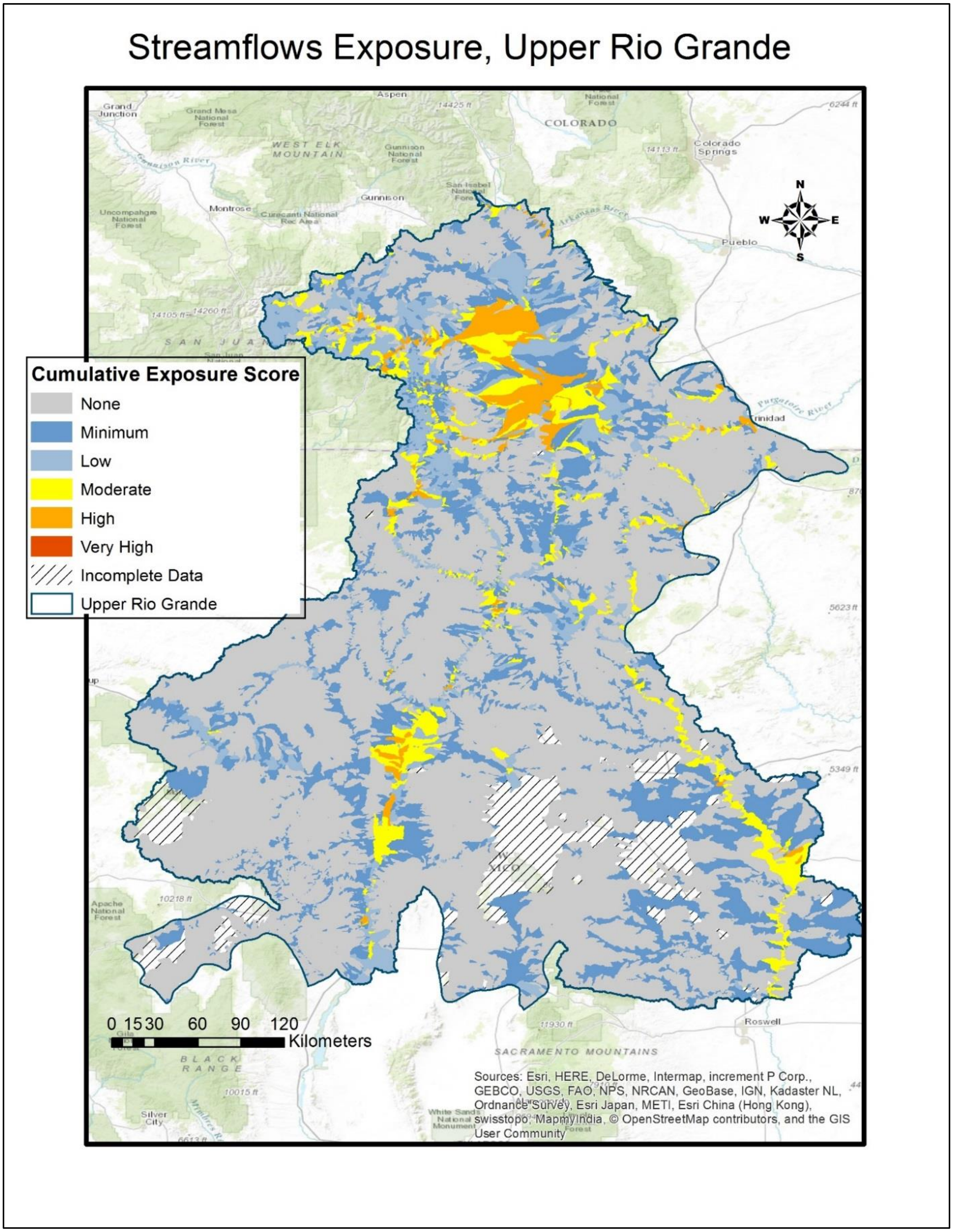

Figure 11. Cumulative exposure map for catchments in the Upper Rio Grande region of the Southern Rockies LCC**.**

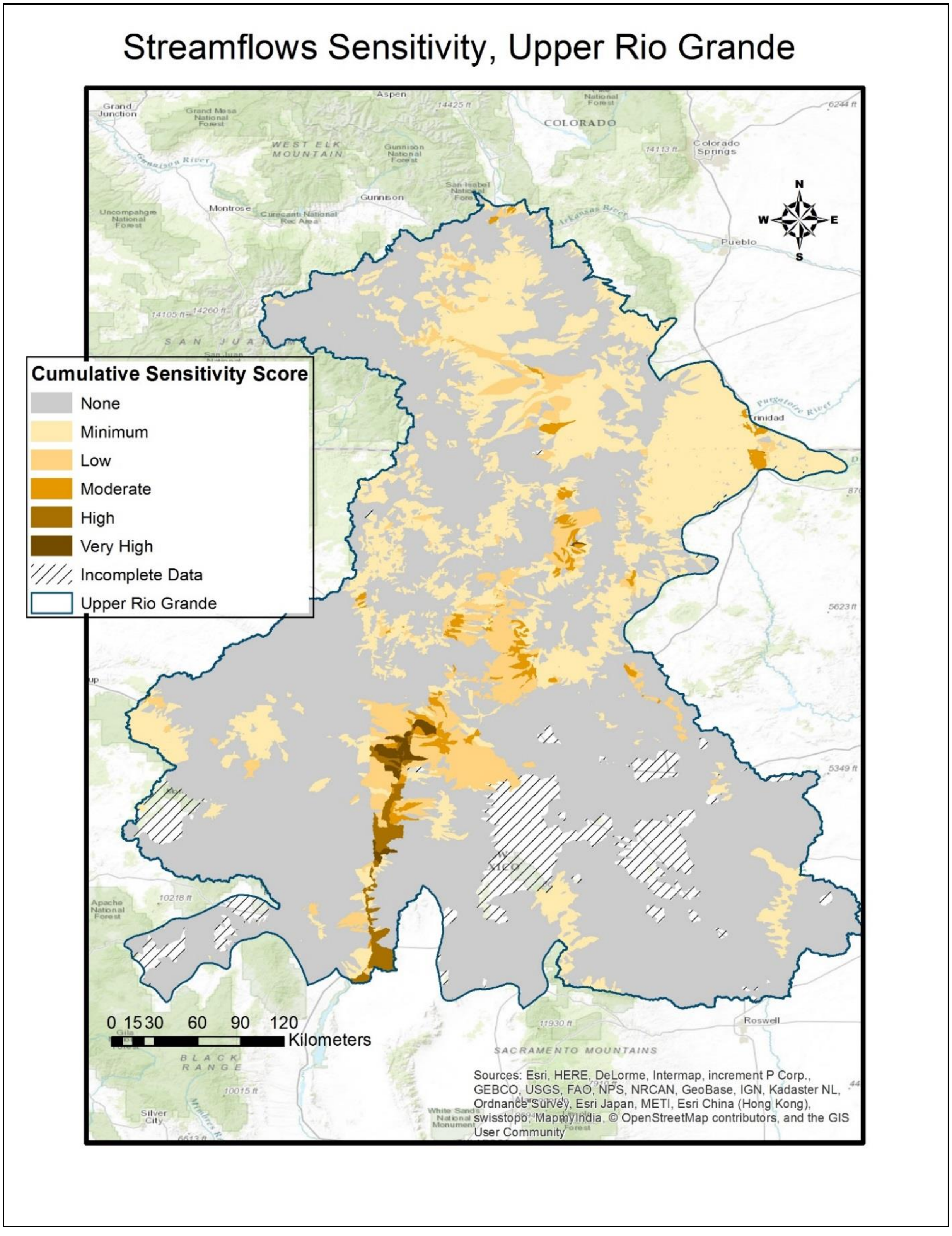

Figure 12. Cumulative sensitivity map for catchments in the Upper Rio Grande region of the Southern Rockies LCC

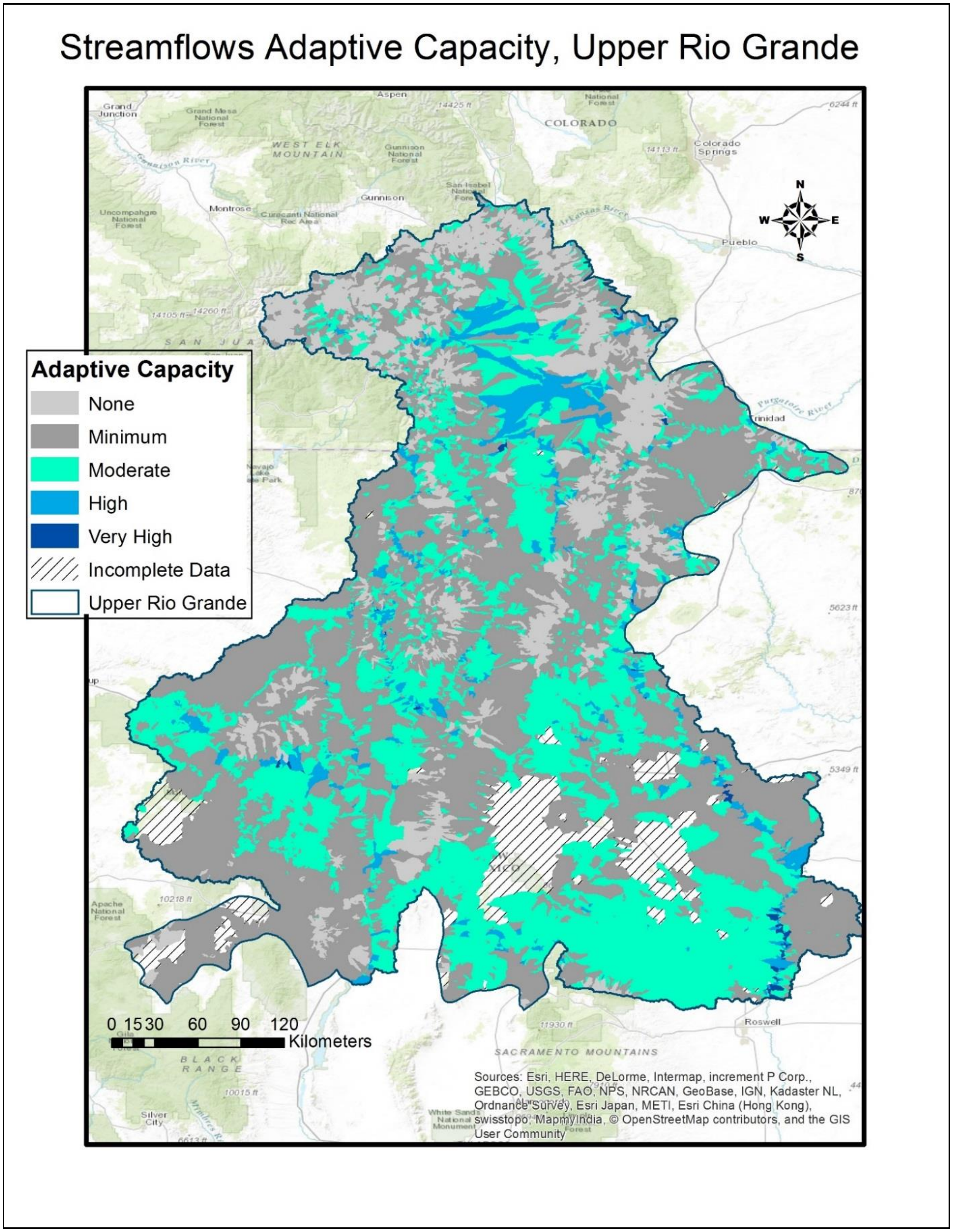

Figure 13. Cumulative adaptive capacity map for catchments in the Upper Rio Grande region of the Southern Rockies LCC**.**

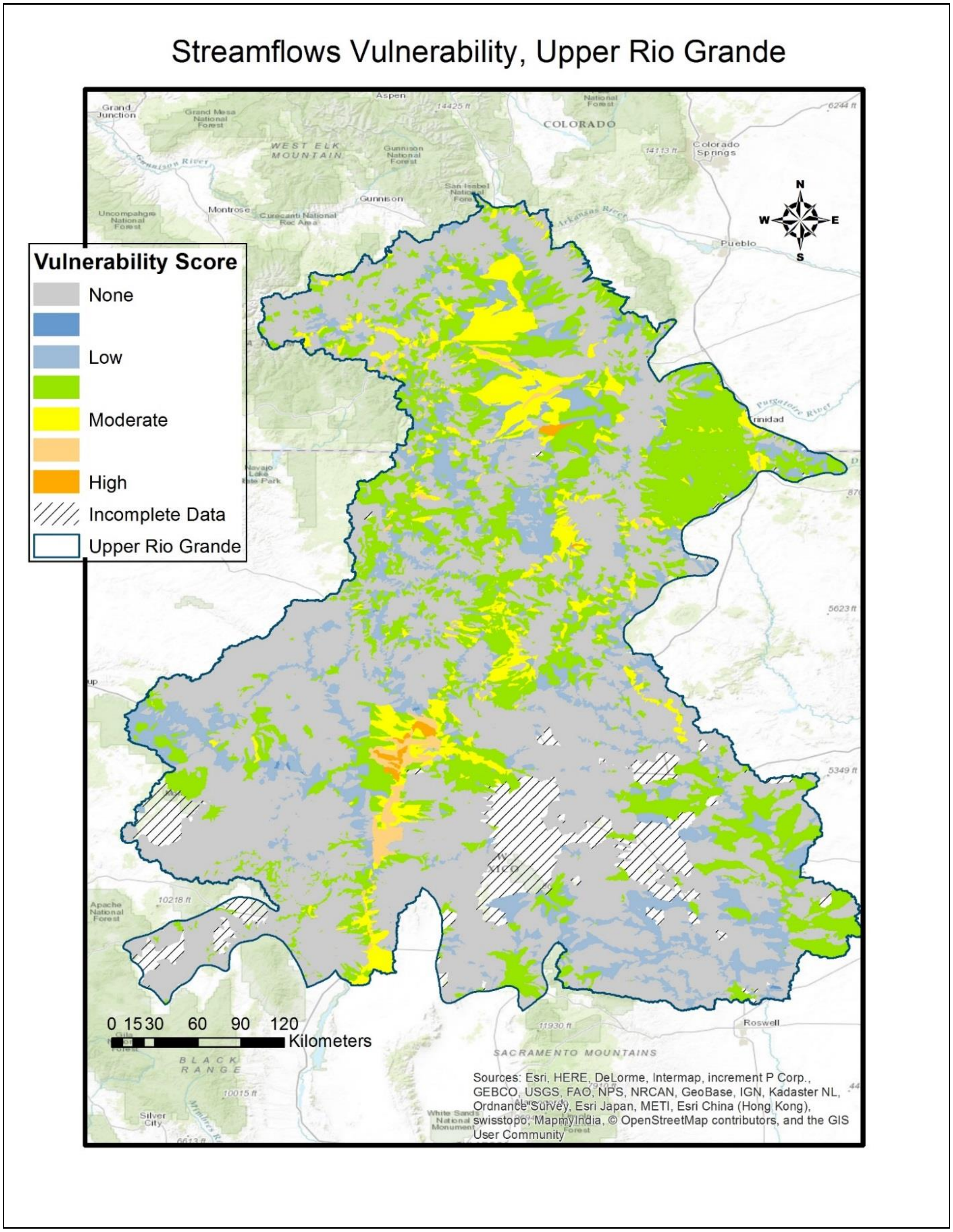

Figure 14. Vulnerability map for catchments in the Upper Rio Grande region of the Southern Rockies LCC.

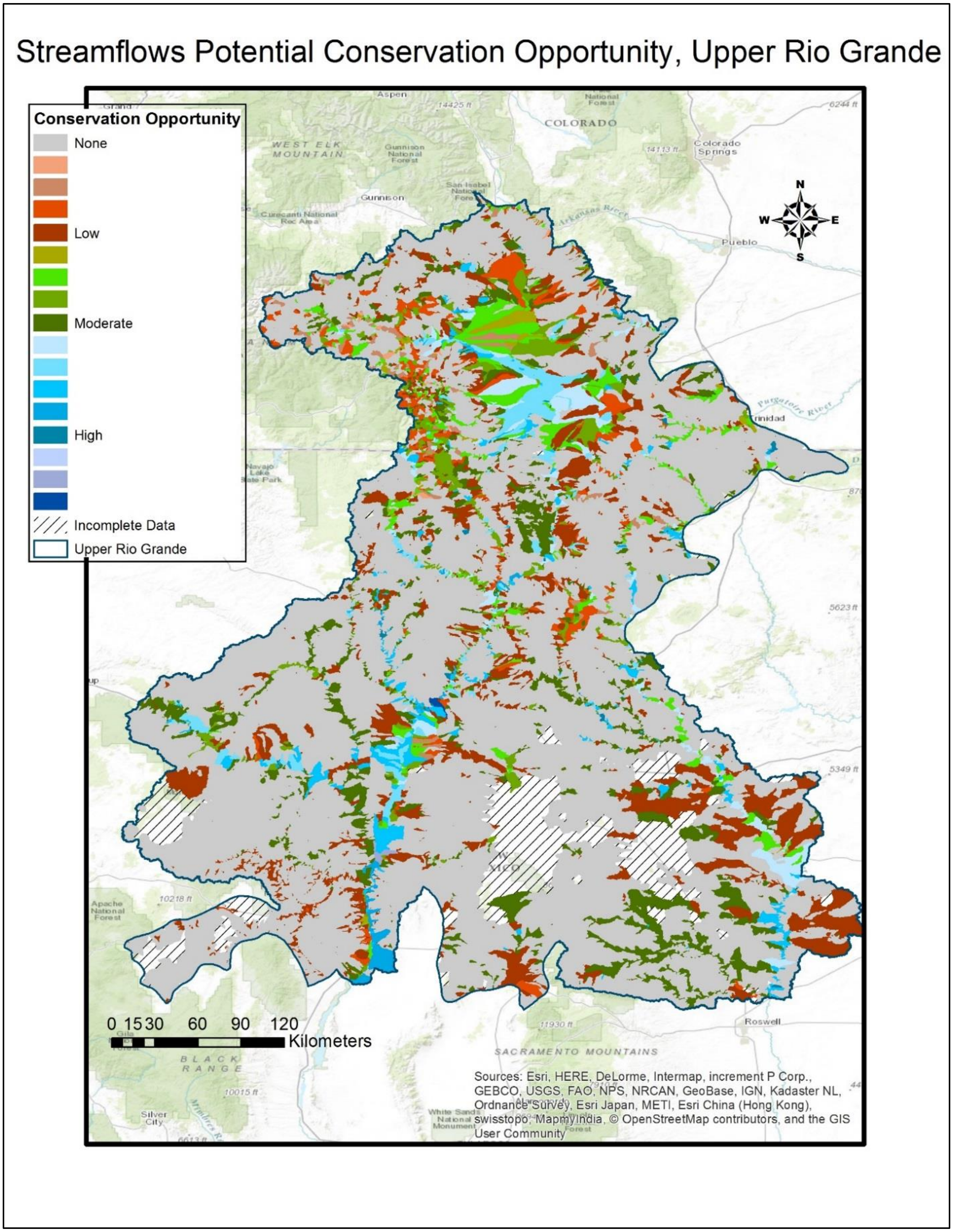

Figure 15. Conservation opportunity map for catchments in the Upper Rio Grande region of the Southern Rockies LCC**.**

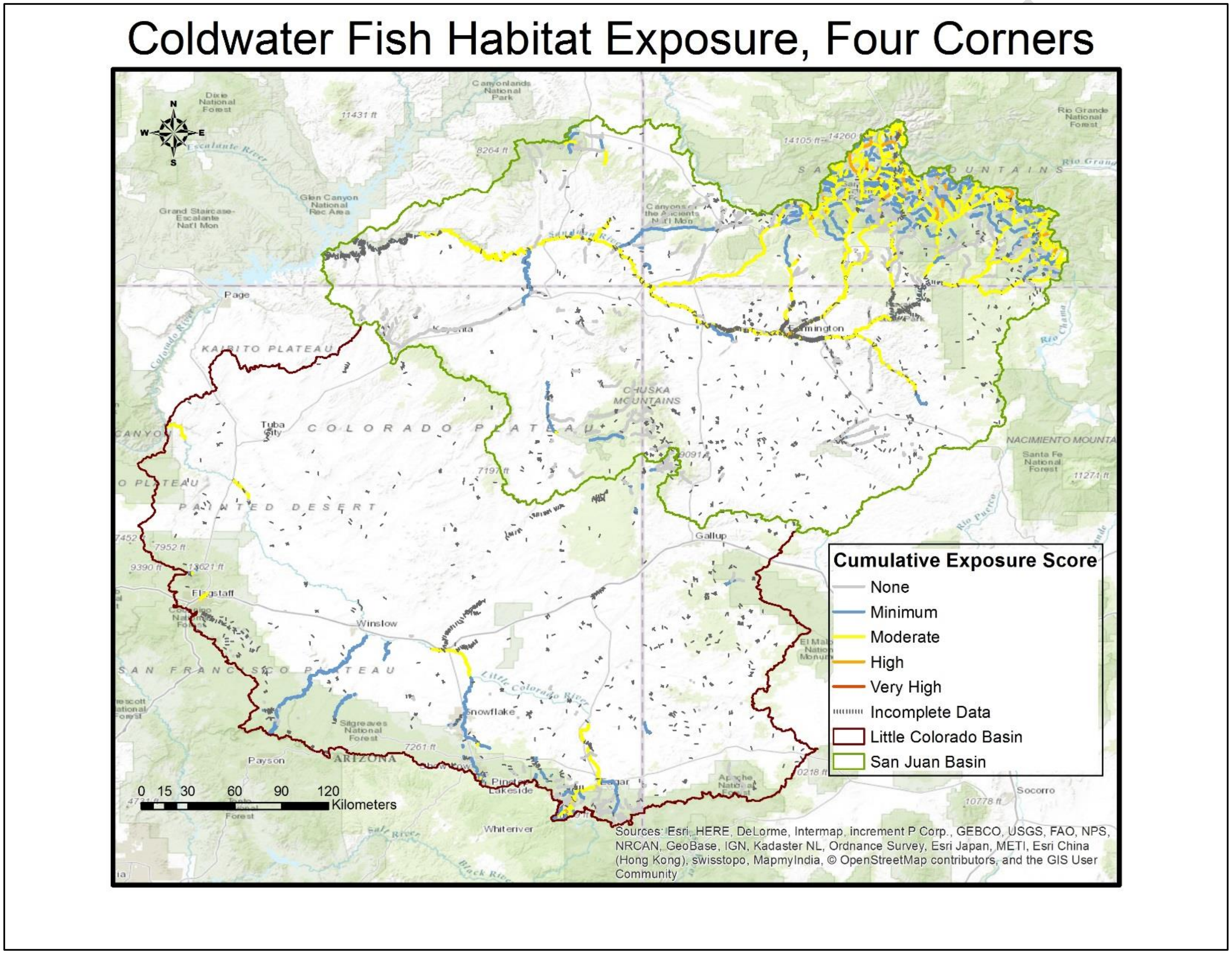

Figure 16. Cumulative exposure map for coldwater stream segments in the Four Corners region of the Southern Rockies LCC.

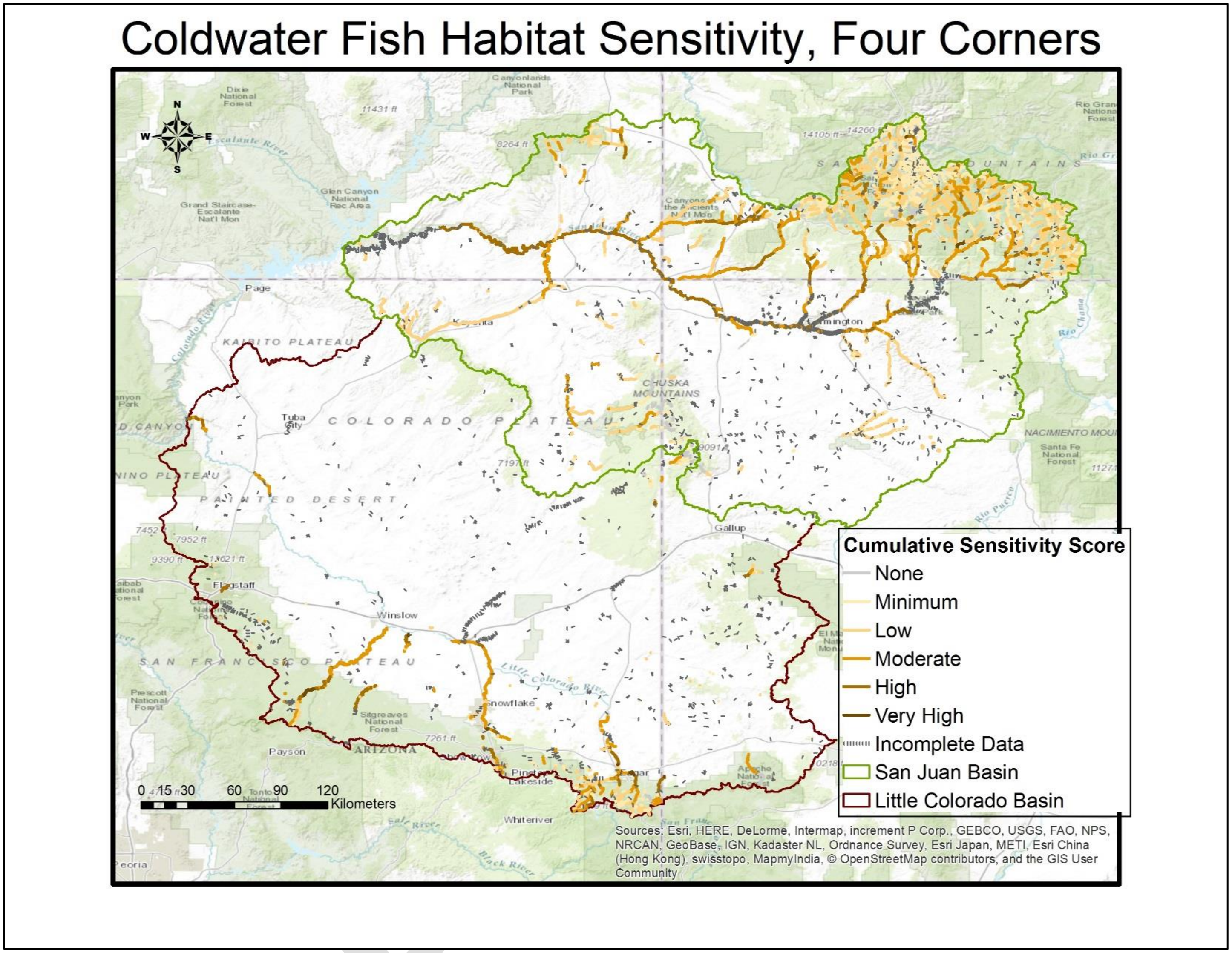

Figure 17. Cumulative sensitivity map for coldwater stream segments in the Four Corners region of the Southern Rockies LCC.

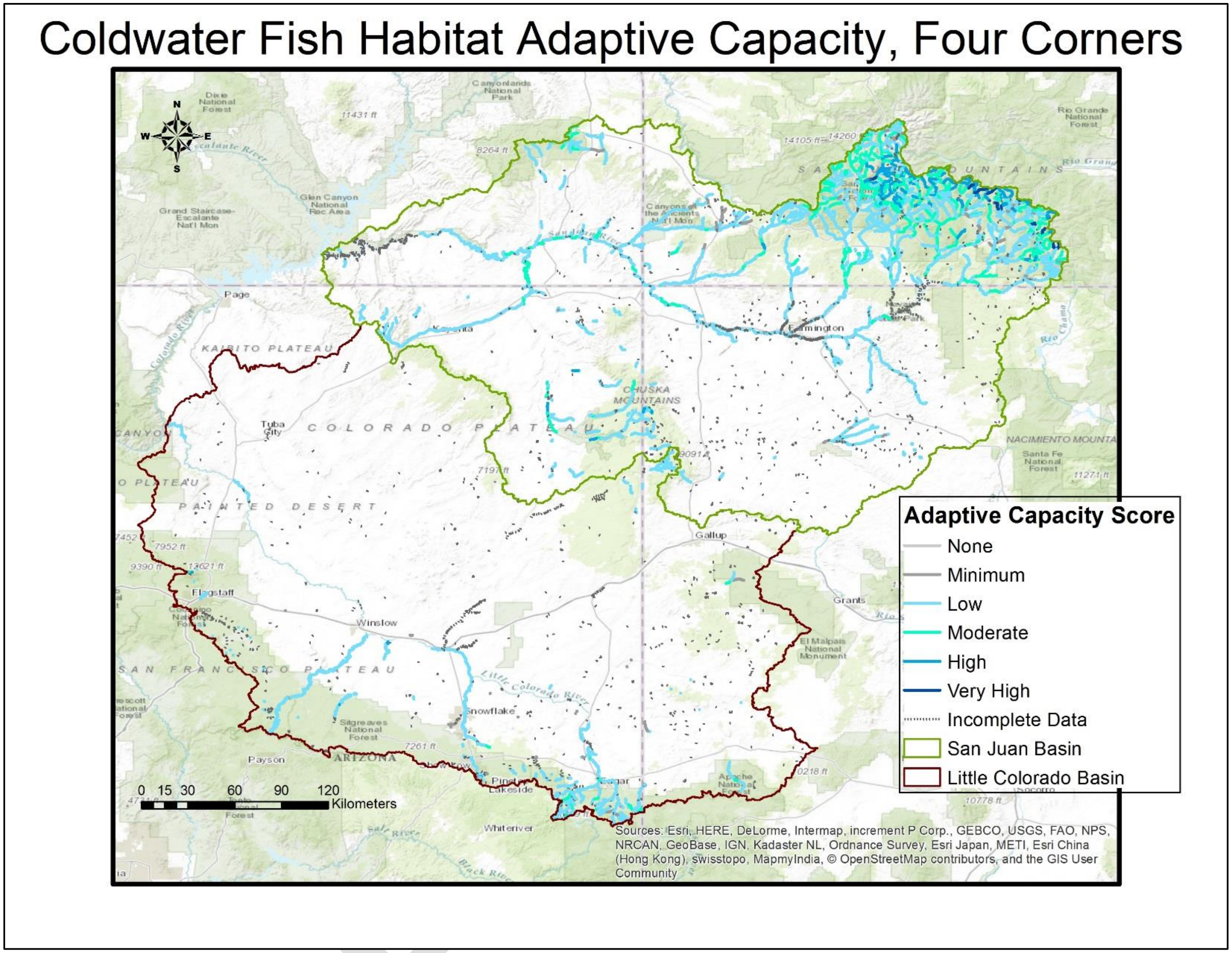

Figure 18. Cumulative adaptive capacity map for coldwater stream segments in the Four Corners region of the Southern Rockies LCC.

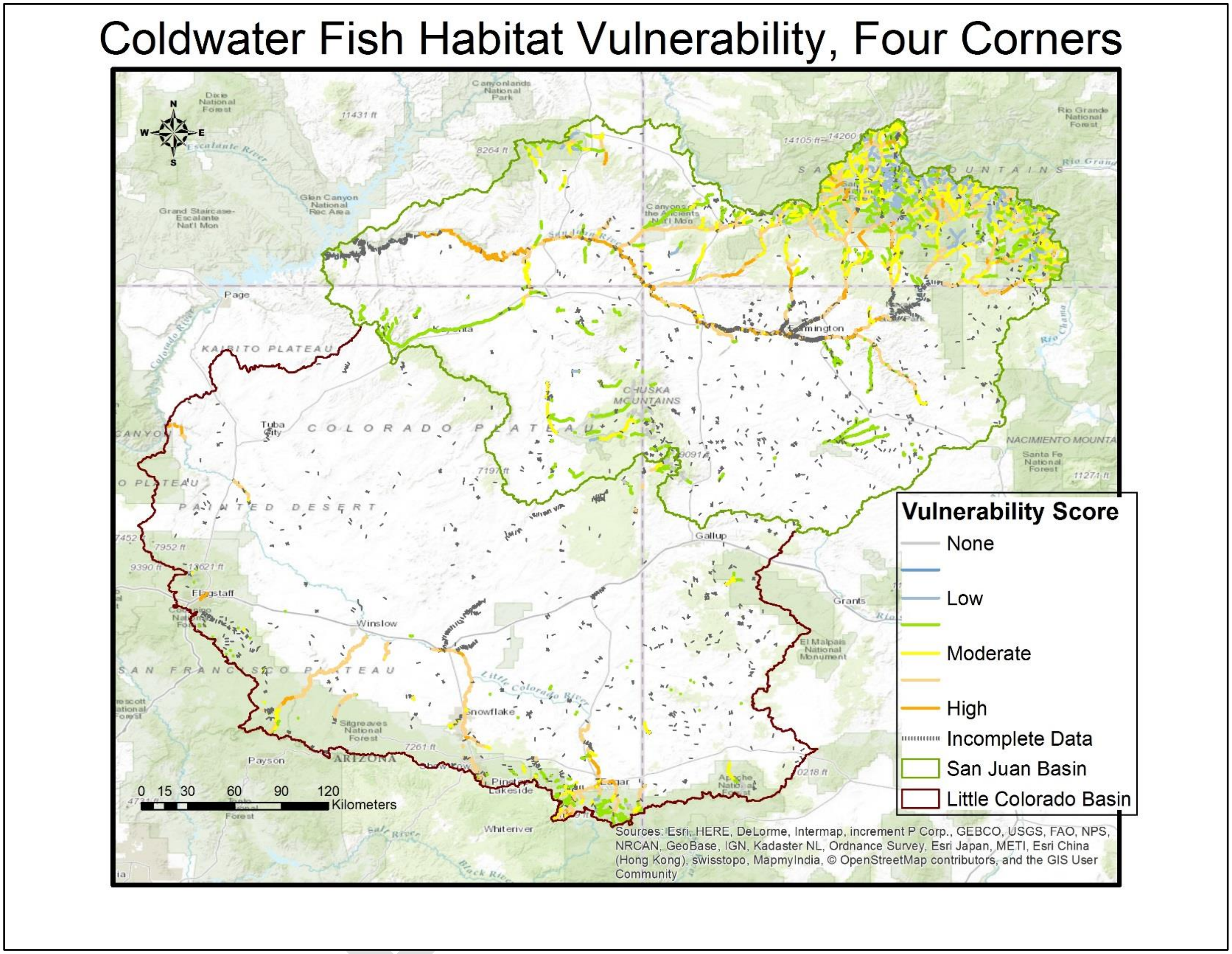

Figure 19. Vulnerability map for coldwater stream segments in the Four Corners region of the Southern Rockies LCC.

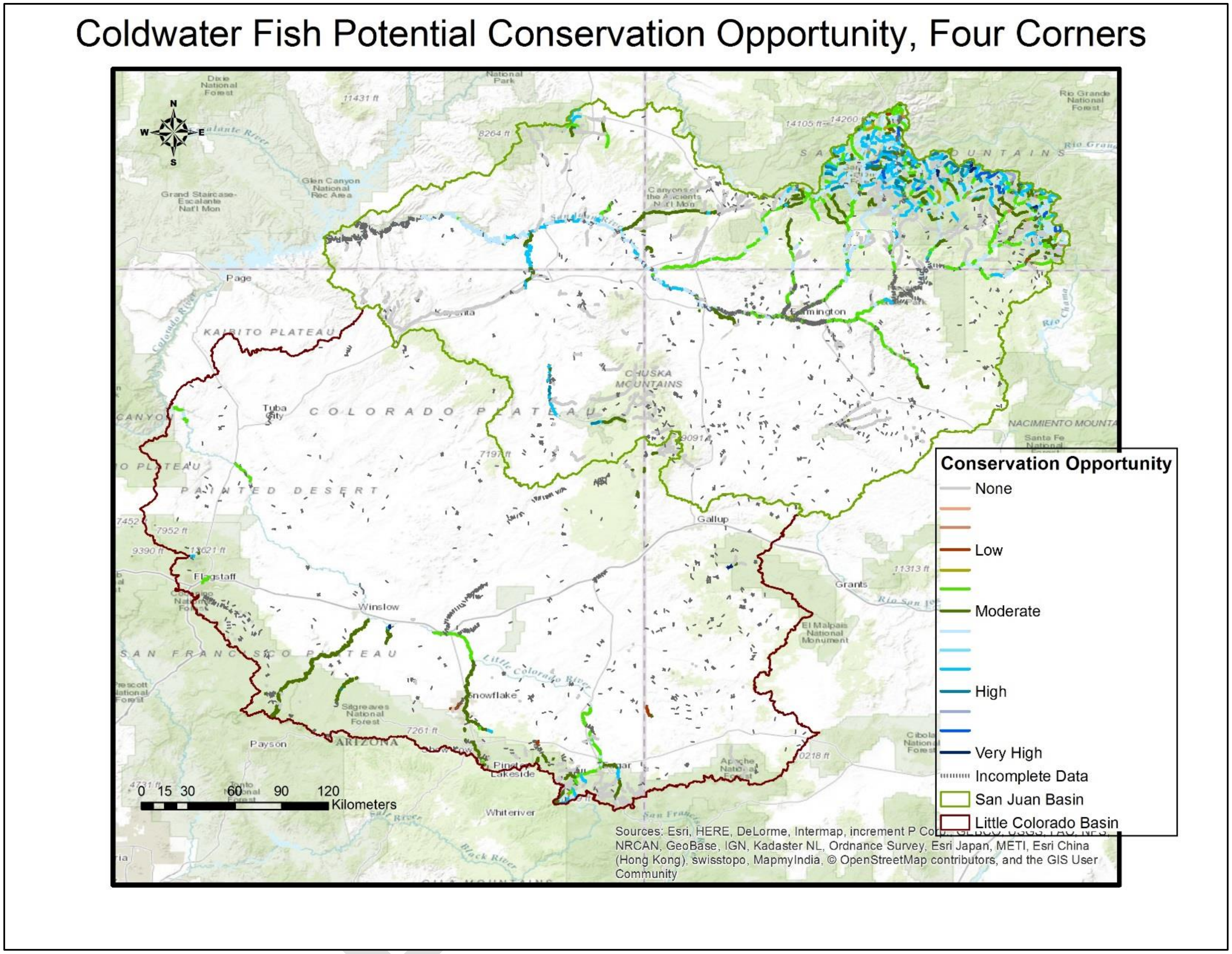

Figure 20. Conservation opportunity map for coldwater stream segments in the Four Corners region of the Southern Rockies LCC.

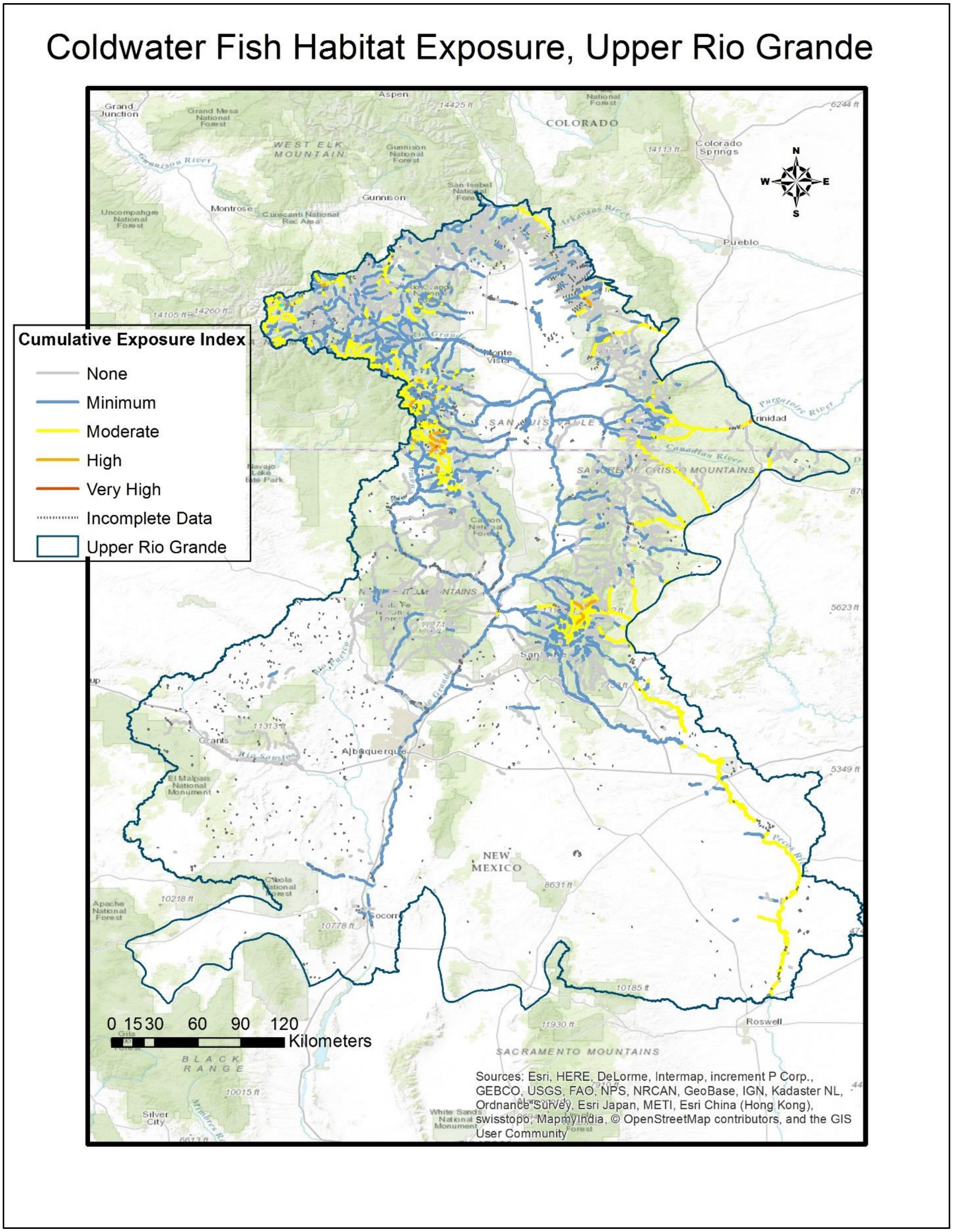

Figure 21. Cumulative exposure map for coldwater stream segments in the Upper Rio Grande region of the Southern Rockies LCC.

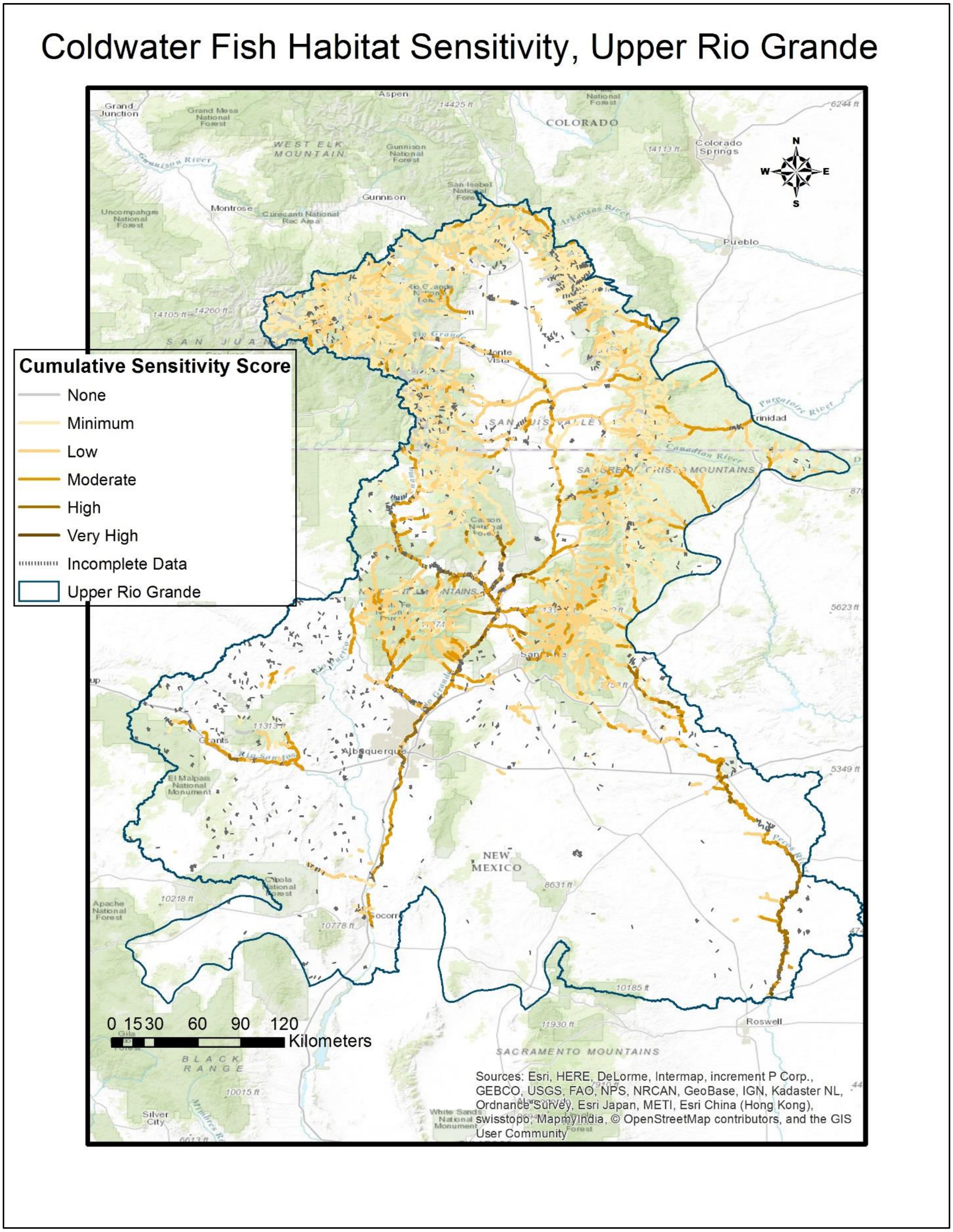

Figure 22. Cumulative sensitivity map for coldwater stream segments in the Upper Rio Grande region of the Southern Rockies LCC.

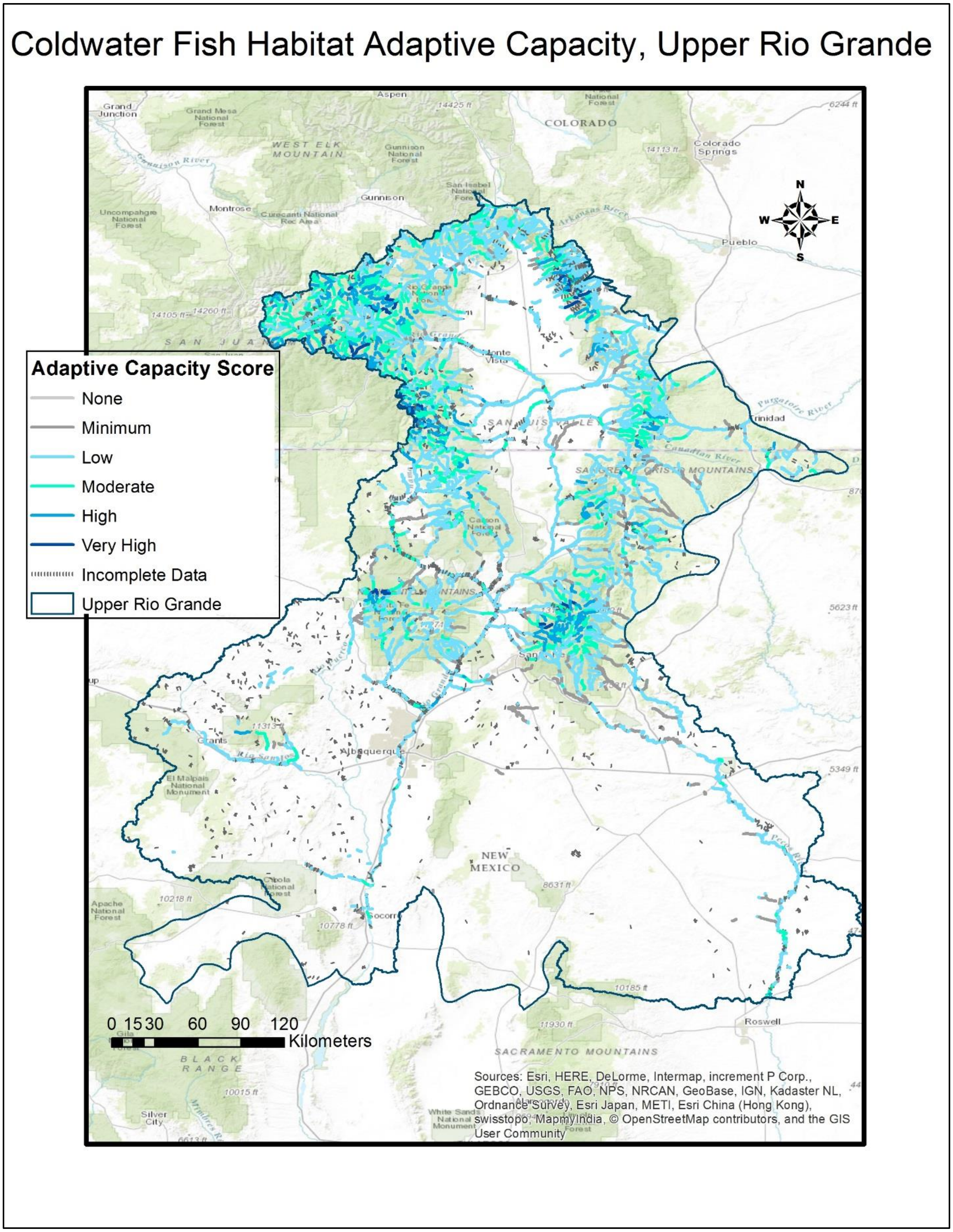

Figure 23. Cumulative adaptive capacity map for coldwater stream segments in the Upper Rio Grande region of the Southern Rockies LCC.

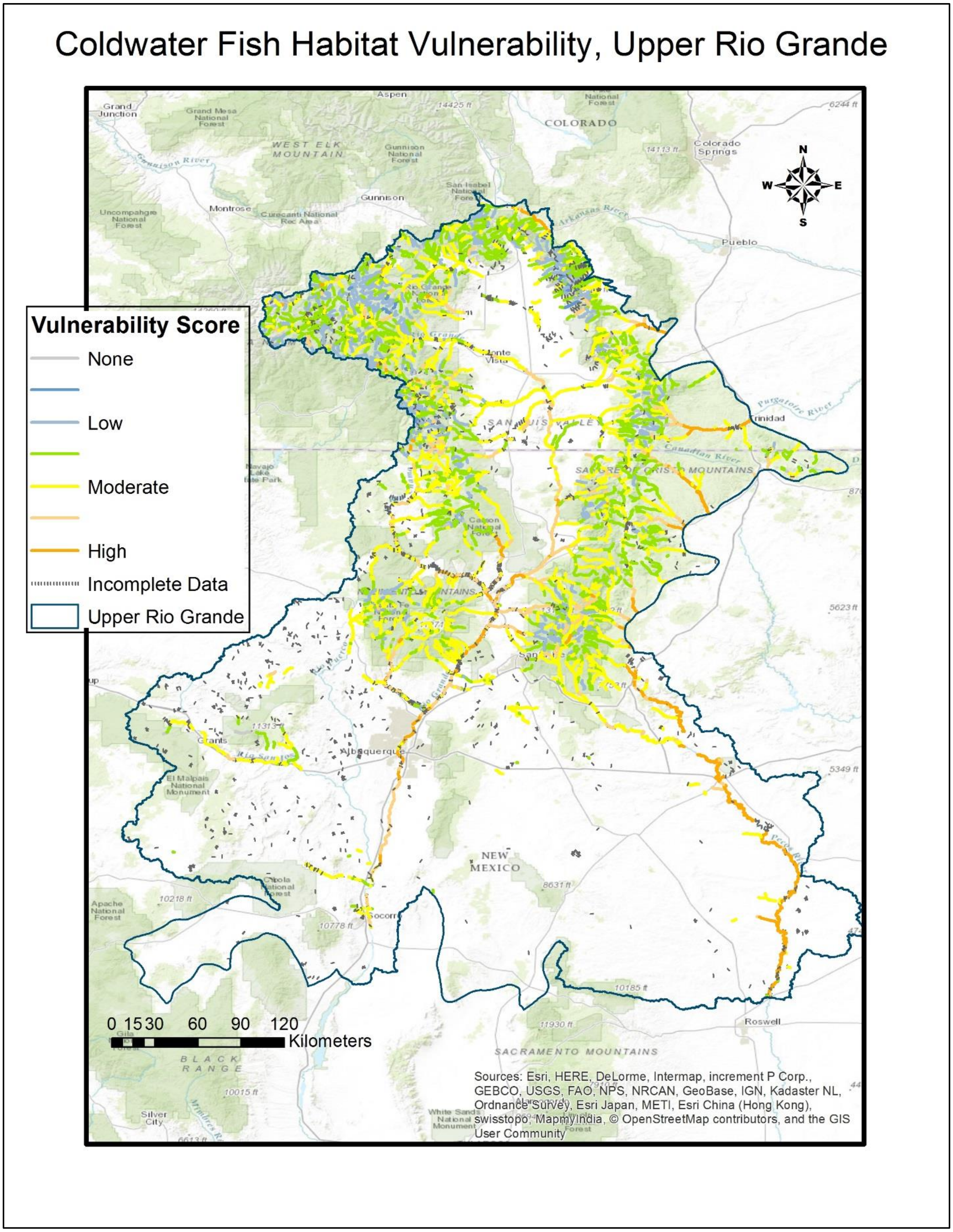

Figure 24. Vulnerability map for coldwater stream segments in the Upper Rio Grande region of the Southern Rockies LCC.

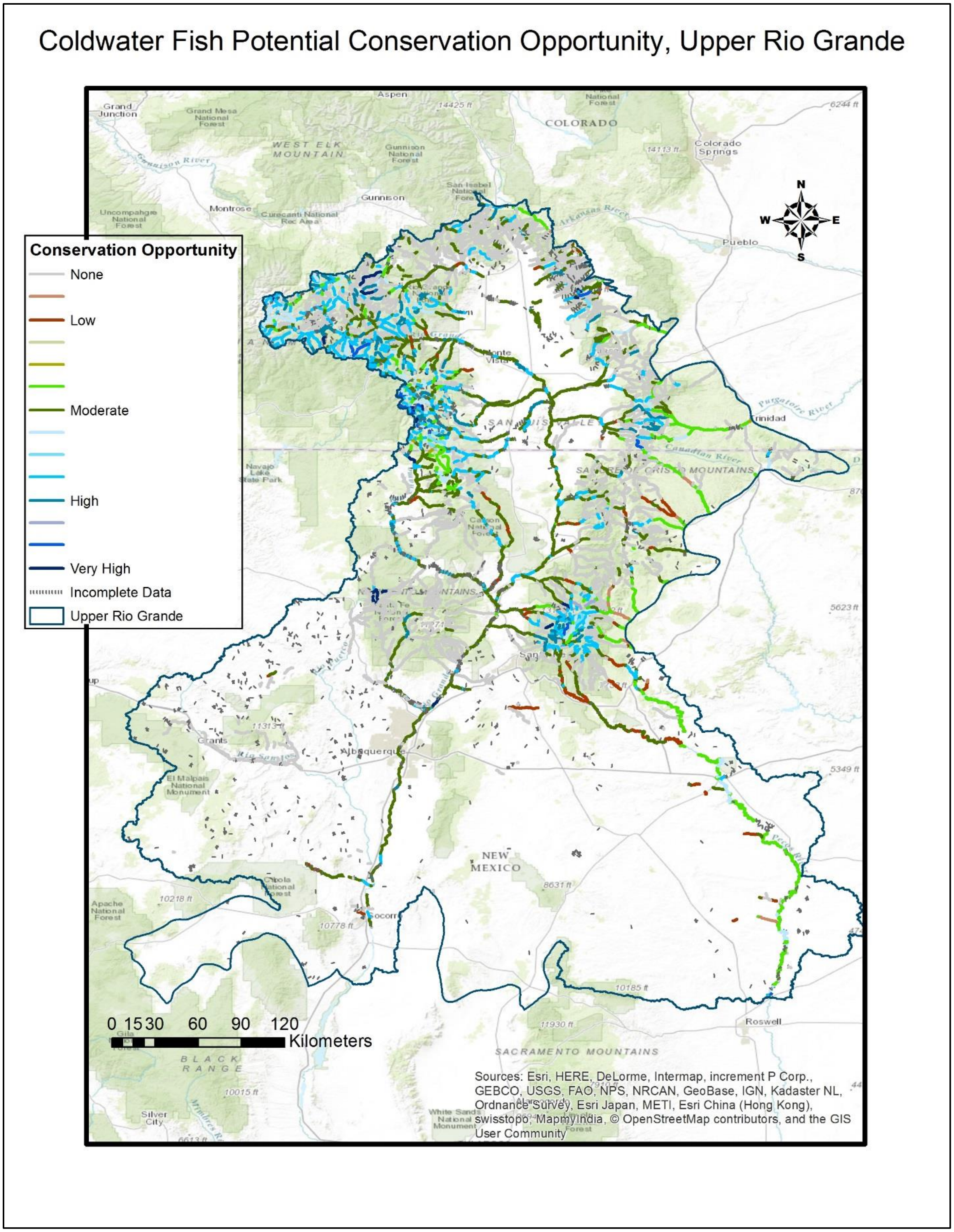

Figure 25. Conservation opportunity map for coldwater stream segments in the Upper Rio Grande region of the Southern Rockies LCC.

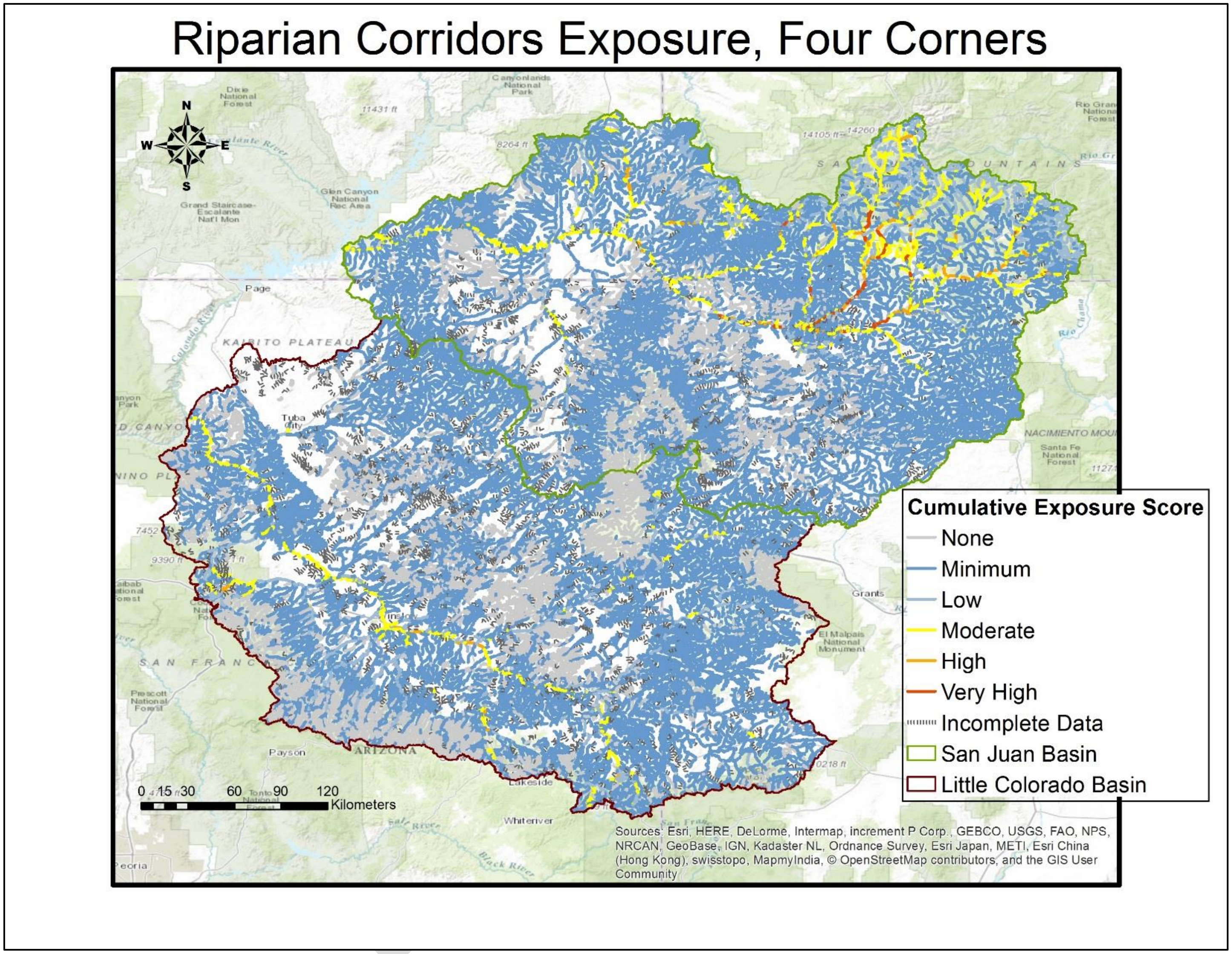

Figure 26. Cumulative exposure map for riparian corridors in the Four Corners region of the Southern Rockies LCC.

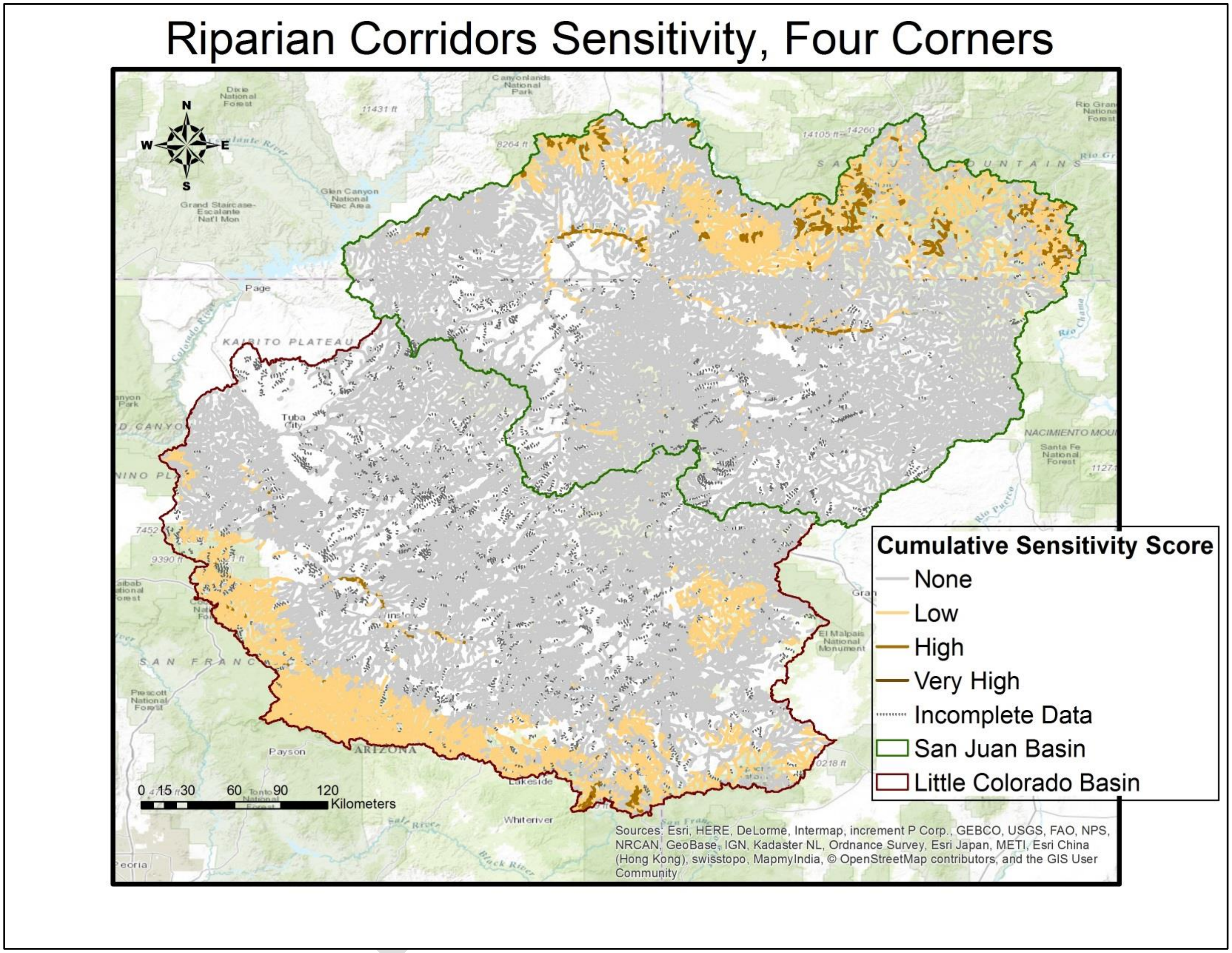

Figure 27. Cumulative sensitivity map for riparian corridors in the Four Corners region of the Southern Rockies LCC.

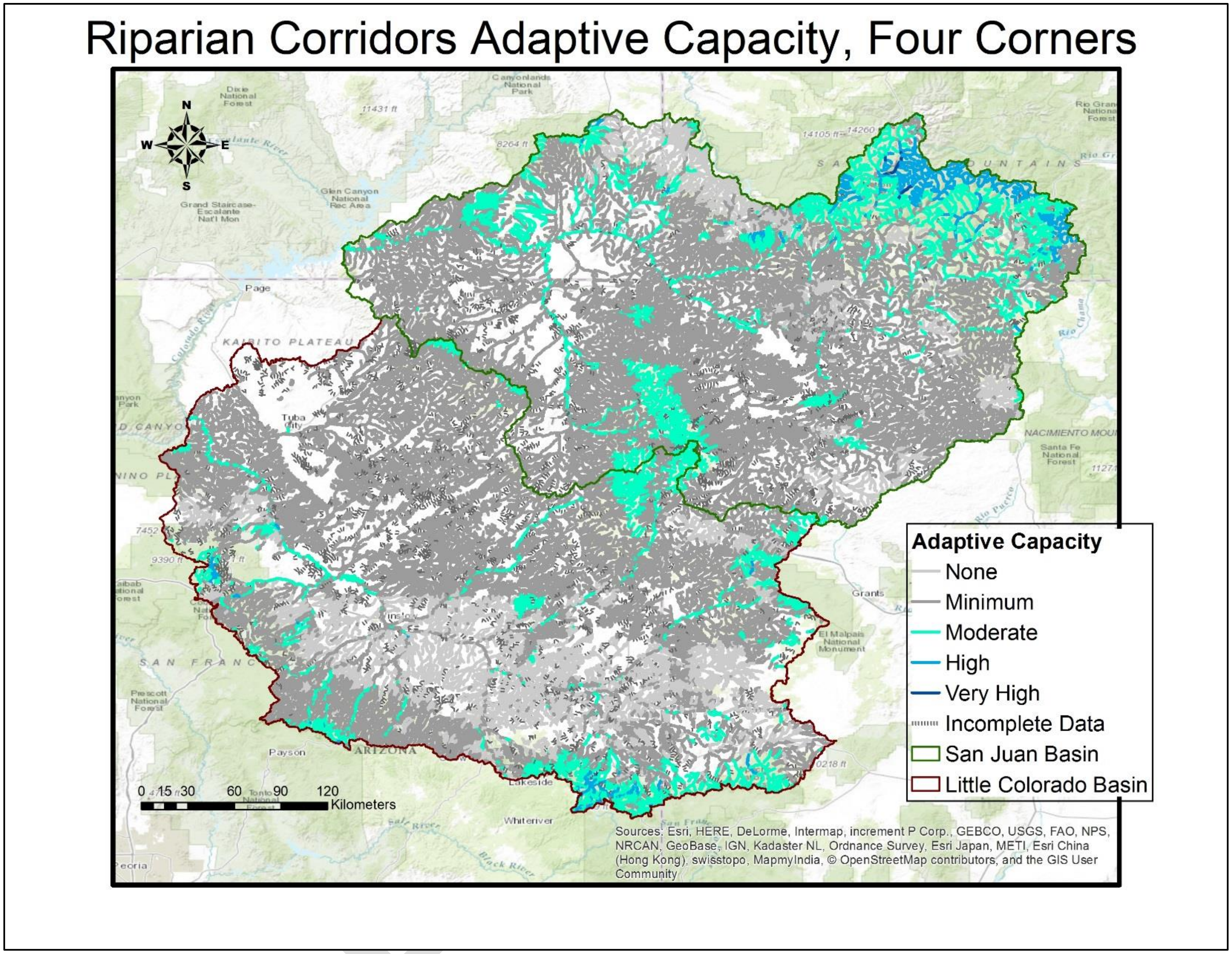

Figure 28. Cumulative adaptive capacity map for riparian corridors in the Four Corners region of the Southern Rockies LCC.

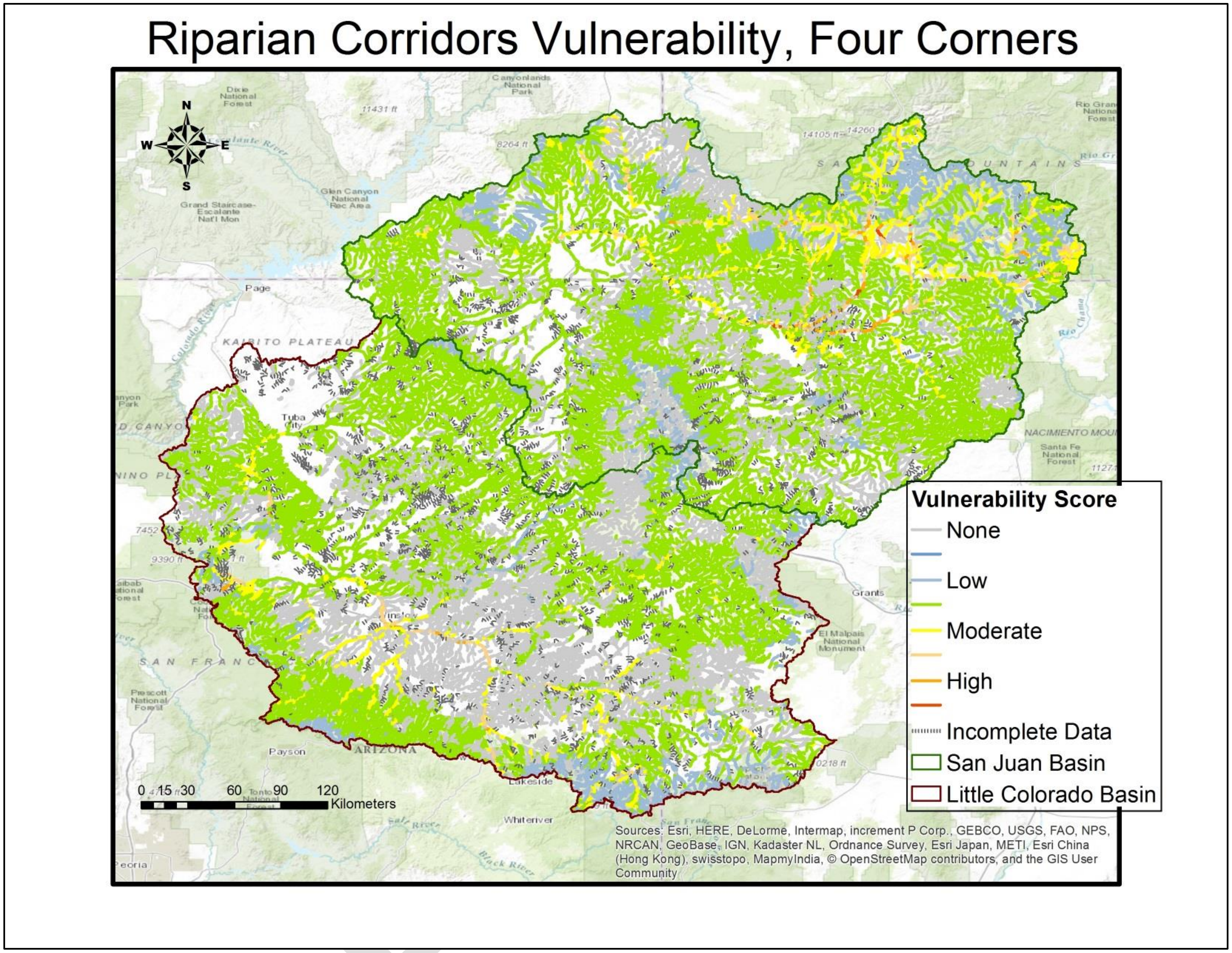

Figure 29. Vulnerability map for riparian corridors in the Four Corners region of the Southern Rockies LCC.

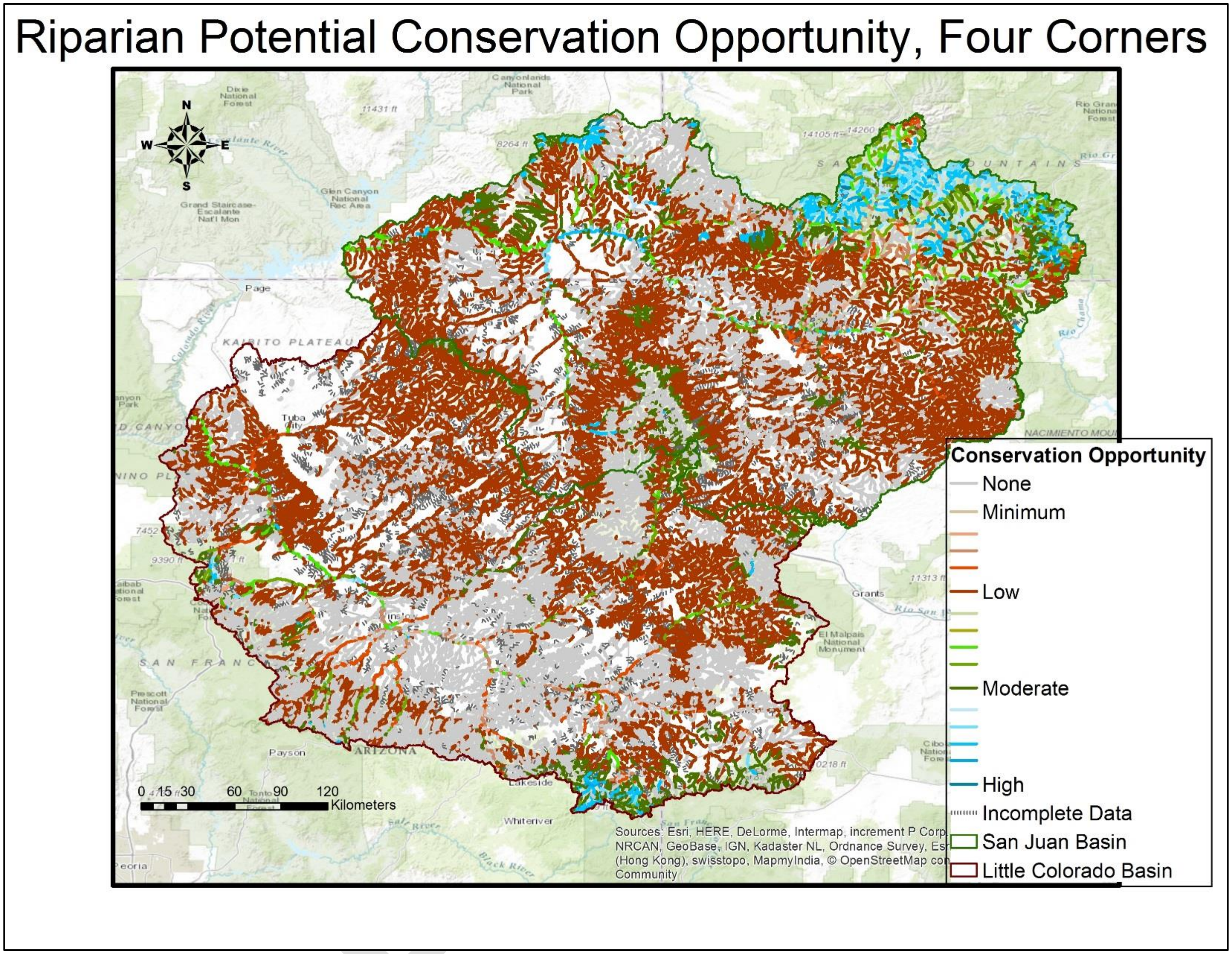

Figure 30. Conservation opportunity map for riparian corridors in the Four Corners region of the Southern Rockies LCC.

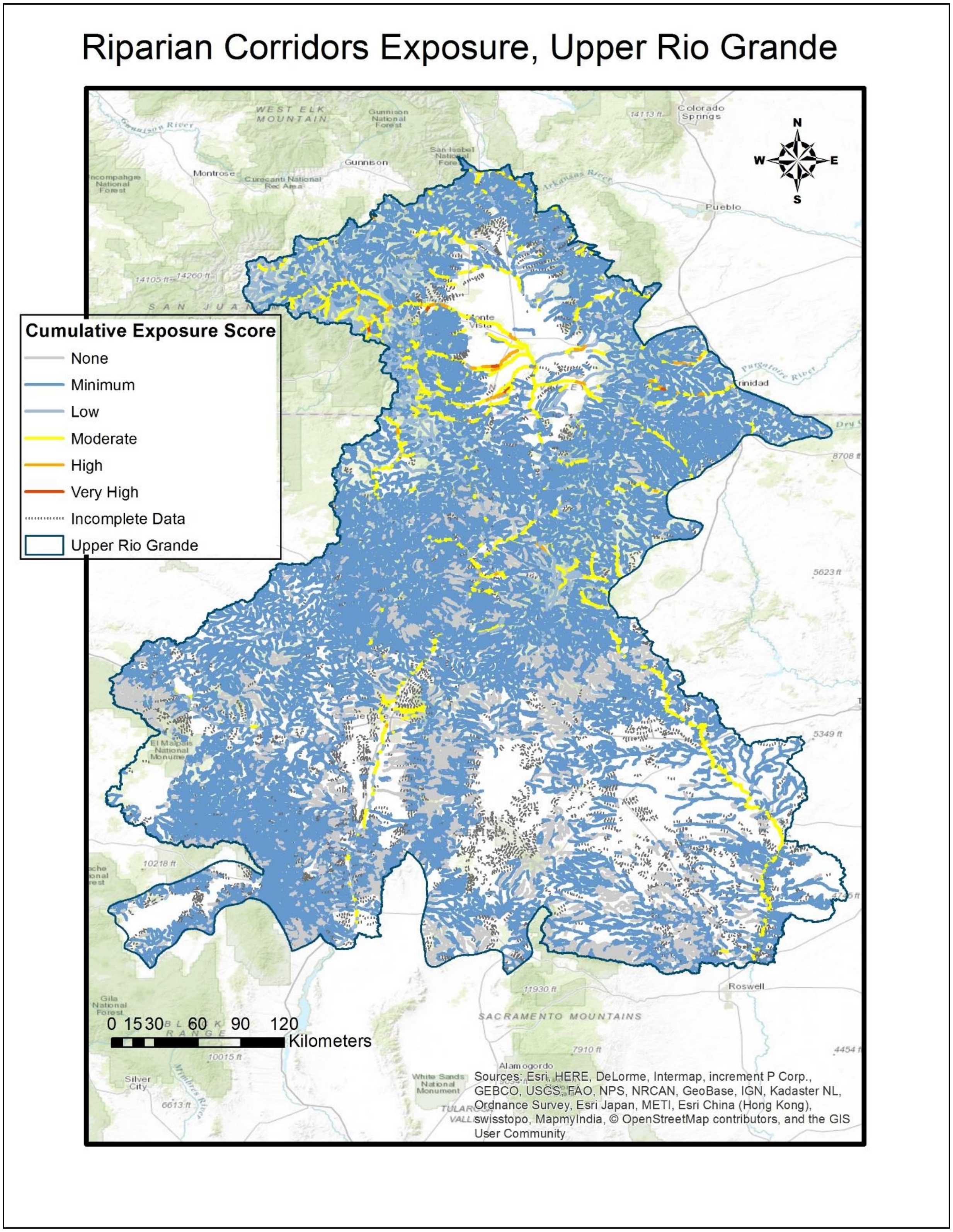

Figure 31. Cumulative exposure map for riparian corridors in the Upper Rio Grande region of the Southern Rockies LCC.

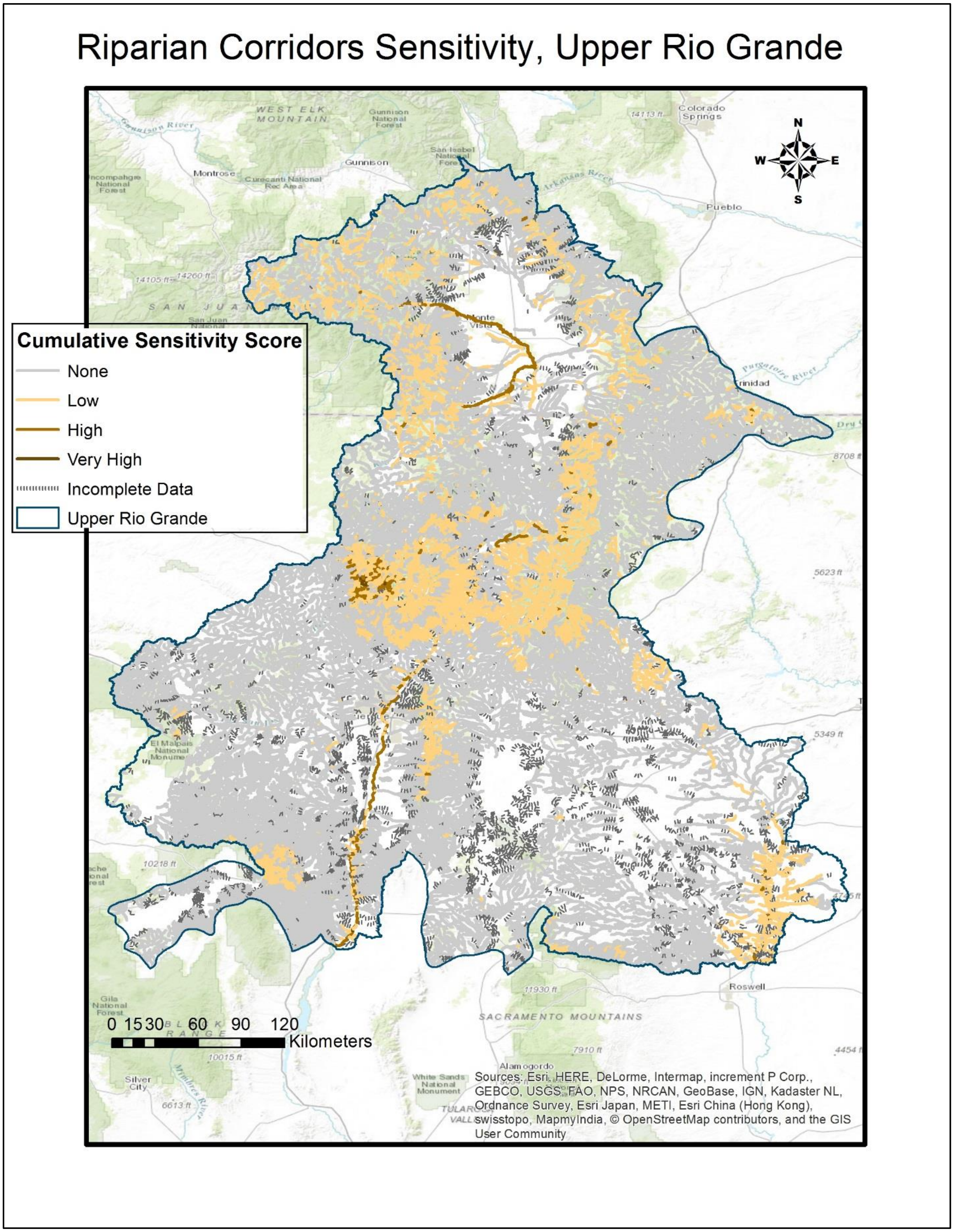

Figure 32. Cumulative sensitivity map for riparian corridors in the Upper Rio Grande region of the Southern Rockies LCC.

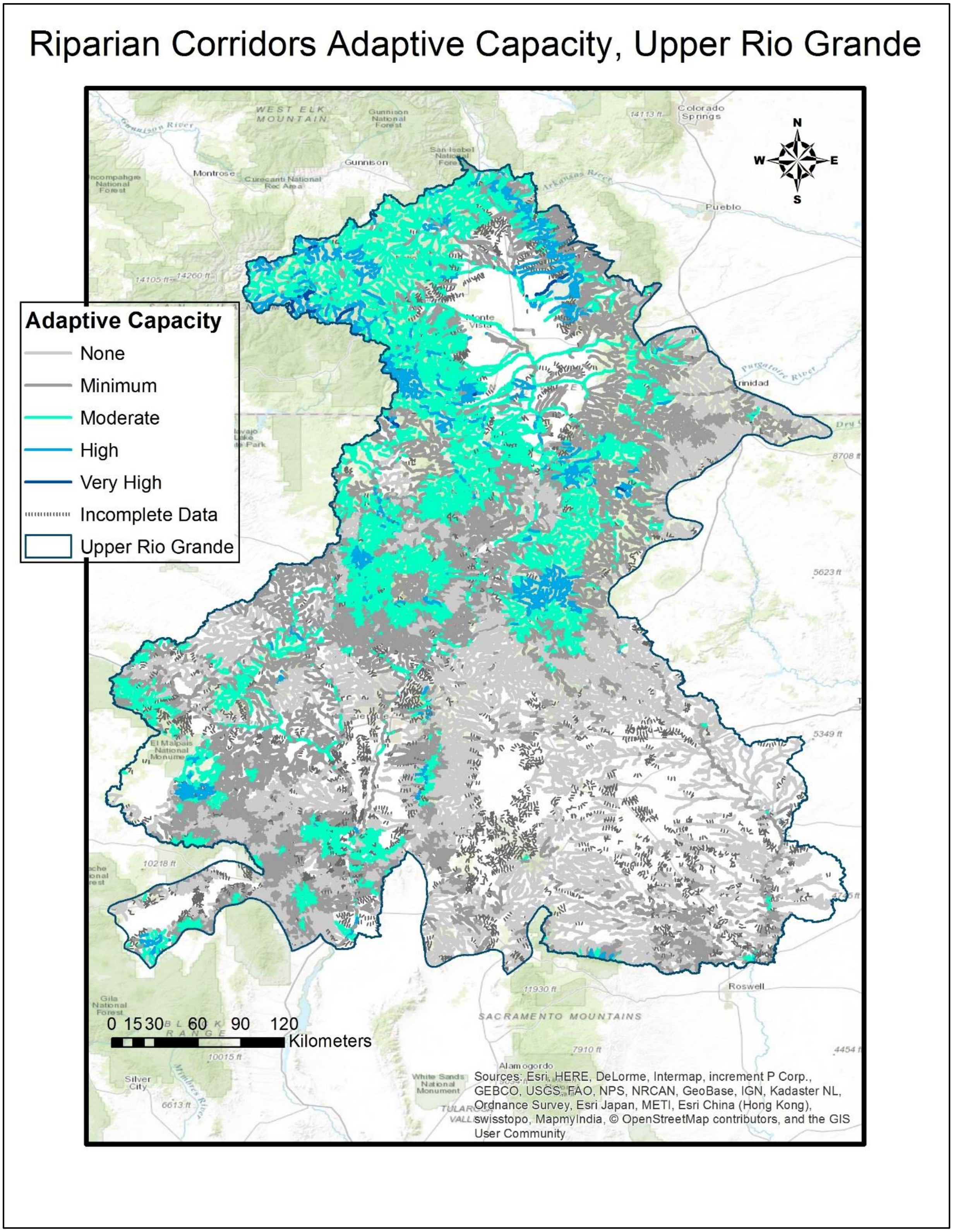

Figure 33. Cumulative adaptive capacity map for riparian corridors in the Upper Rio Grande region of the Southern Rockies LCC.

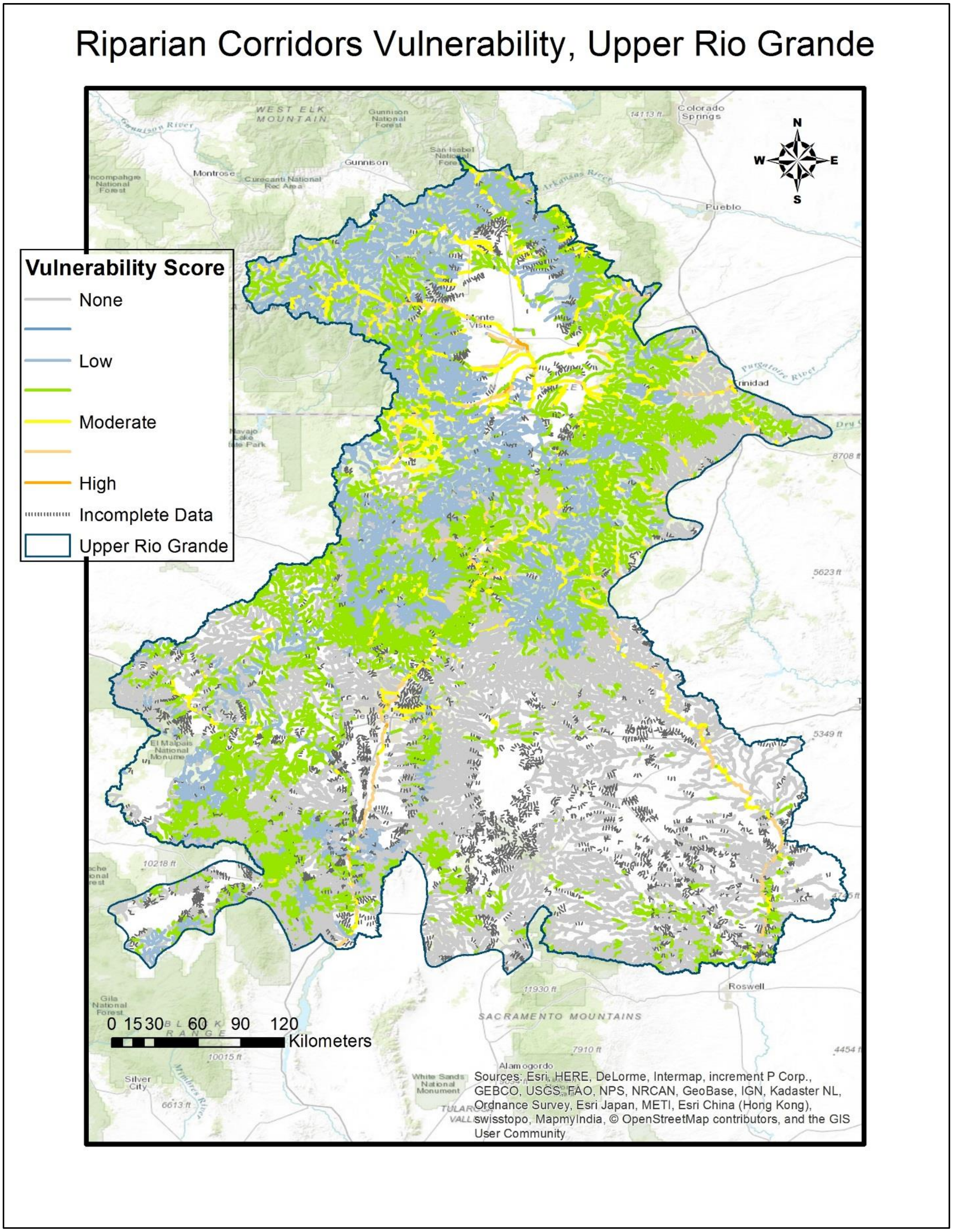

Figure 34. Vulnerability map for riparian corridors in the Upper Rio Grande region of the Southern Rockies LCC.

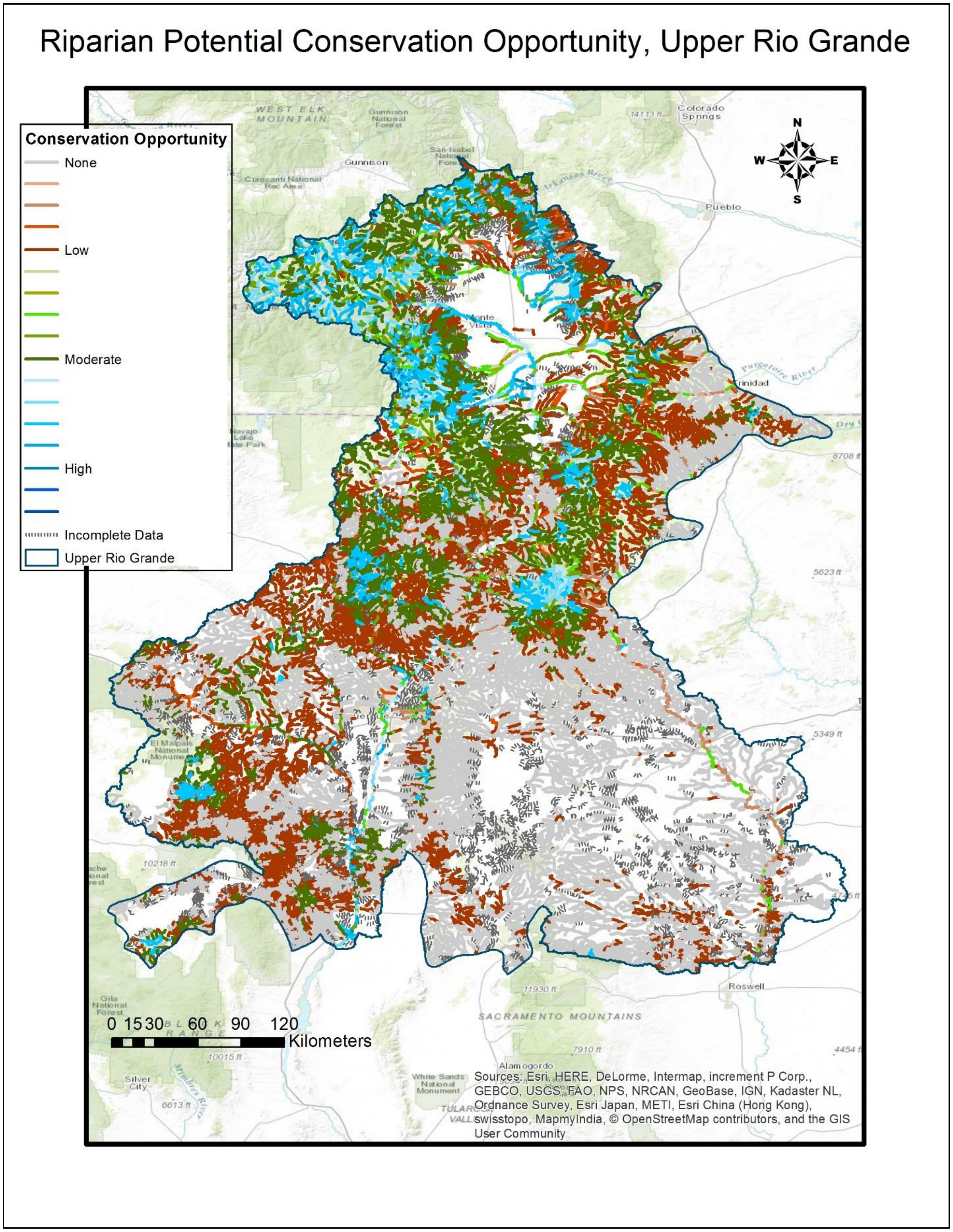

Figure 35. Conservation opportunity map for riparian corridors in the Upper Rio Grande region of the Southern Rockies LCC.

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