National Forest Roadless Areas and Clean Water

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Cover:
A forest stream in an inventoried roadless area, Colorado.
Photo: Nelson Guda

Contents

Executive Summary

Roadless area watersheds provide abundant and reliable supplies of clean water to downstream areas. Development of roadless areas degrades water quality and the reliability of water supplies. This report provides conservative estimates of the value of inventoried roadless areas (IRAs) in national forests for clean water and associated water resource benefits. At a time of rising demand and shrinking supply because of climate change, those values are crucial to people and to fish and wildlife. Our findings apply to intact watersheds throughout the western United States, with particular emphasis on Colorado, where there is pressure to develop IRAs. After the state of Colorado requested exemptions to the 2001 Roadless Conservation Rule, the U.S. Forest Service (USFS) recently issued a new federal proposal that would grant numerous exemptions for development within Colorado Roadless Areas (CRAs). These exemptions include permanent and temporary roads; logging as far as 1.5 miles from at-risk communities with Community Wildfire Protection Plans (or even farther if the regional forester determines that there is a significant threat); oil and gas leases; coal mining in the North Fork; and linear construction zones for electricity and telecommunications, pipelines and water conveyances. The agency also introduced an upper-tier roadless category with fewer exemptions and used an updated inventory of roadless lands to add new areas and remove those parcels containing roads as identified under new forest plans.

Although this report focuses on IRAs, it also emphasizes the importance of uninventoried roadless areas under 5,000 acres, which cover an area roughly 1½ times that of the total IRA network. Those smaller roadless areas also play an important role in maintaining reliable supplies of high-quality water and protecting aquatic ecosystems. We provide five key findings and supporting recommendations on the protection of watershed values as the highest and best use of IRAs and of roadless areas in general.

Key Finding #1: Roadless Areas Offer Exceptional Watershed Benefits

IRAs provide a valuable and increasingly rare benefit: abundant, clean and naturally reliable water. This resource helps municipal and rural communities; agricultural and industrial interests; flood control; in-stream aquatic recreation; aquifer recharge; fisheries; ecosystems; resident and migratory waterfowl and other birds; endangered species; and, increasingly, local economies. These benefits accrue nationally and at the local and regional levels and include flood and drought protection.

National Benefits of Clean Roadless Area Water

At least 124 million Americans benefit from water from national forests, a significant portion of which is high-quality water originating in roadless areas. The value of high-quality IRA water to Americans nationwide is estimated in the billions of dollars annually. Among the benefits:

- National forests provide about 14 percent of the nation's runoff with an estimated net value $4 billion to $27 billion. IRAs represent about one-third of national forest land (58 million of 193 million acres) and thus contribute significantly to the overall runoff volume and value.

Inventoried roadless areas in Colorado include Reno Mountain (top), East Willow (middle), and Thompson Creek (foreground). Photo: Nelson Guda

- According to USFS data, IRAs are found in 661 of the 914 national forest watersheds, with 55 percent of the 661 watersheds acting as source areas for facilities that treat drinking water and distribute it to the public.

- The cost savings to water treatment plants and highway departments from avoiding sedimentation caused by logging in IRA watersheds is estimated at up to $18 billion annually.

- Roadless areas are estimated to provide $490 million annually in waste treatment services through recovery of mobile nutrients and cleansing of the environment, both processes that involve water flow through IRA watersheds.

Regional Benefits of Clean Roadless Area Water

- Roadless areas provide myriad ecosystem benefits regionally and locally. Most notably, they contribute clean water to communities in the West and Southwest. Among the benefits:

- In the Rockies, much of the utilized stream flow is derived directly from watersheds with IRAs (which cover roughly a quarter of Colorado's headwaters).

- Annually, IRAs in Colorado are estimated to provide the equivalent of nearly 2½ times Denver's annual water use.

- IRAs in New Mexico provide a water quality benefit estimated at up to $42 million annually.

Flood Control Protections of Roadless Areas

The intact watersheds of IRAs are especially important in reducing the frequency and intensity of flooding nationally, with cost savings of billions of dollars annually from averted floods and associated sedimentation problems. This benefit will only rise in value as climate change drives more floods in certain regions. Among the affected areas:

- Salem, OR, spent approximately $100 million on new treatment facilities after logging in upper watersheds created conditions leading to mass sedimentation in its watershed following storms in 1996.

- Seattle deferred a $150 million filtration plant expenditure through an intensive watershed rehabilitation program that will decommission 300 miles of road over a 10-year period, fix road erosion problems and limit access and high-risk sedimentation/fire activities within the watersheds.

- Cities and states are spending millions annually on dredging reservoirs and channels to increase capacity or enable navigation.

IRA water greatly benefits outdoor recreation and the people who engage in or earn their living from such recreation. For example:

- The nation's roadless areas are estimated to generate $600 million annually from recreation. Many visitors are attracted to wildlands because of clean and abundant water—a dwindling resource as logging and road building continue across mountain landscapes and as droughts from a changing climate intensify in much of the West.

- New Mexico IRA water provides an estimated active outdoor recreation benefit of $27 million and a passive use benefit of $14 million annually.

- Passive use values (i.e., the intrinsic value of wilderness, wildlands and benefits for the future) for the nation's roadless areas are estimated at $280 million annually.

Clean water from IRAs also maintains healthy fisheries, such as salmon and trout fisheries, sustains viable aquatic ecosystems and helps protect threatened species and ecosystems. Indeed, IRAs act as the last refuge for many salmon and trout populations, as well as a diversity of endangered freshwater species. IRAs act as fishery strongholds and are essential in maintaining viable fish populations and restoring salmon and trout fisheries.

Key Finding #2: Many Roadless Areas Are Important Sources of Drinking Water

Although IRAs occur across extensive areas in some regions, their coverage across a large portion of prime hydrologic real estate—headwaters and upper watersheds—makes them particularly valuable for providing reliable supplies of clean water. In Colorado, for instance, IRAs occur in the headwaters of all major drainages, covering roughly a third of all upper watersheds in the state. Indeed, most IRAs are located in mountainous terrain in Oregon, Idaho, New Mexico, Utah, Montana, California and Washington and most other states where they are inventoried. This extensive coverage of IRAs in headwaters, and the fact that they are often the last well-functioning watersheds within larger landscapes of degraded lands, makes them hydrologic hot spots: areas of relatively small spatial extent that have a disproportionately important role in producing abundant and reliable clean water.

- For many major drainages—entire watersheds of major rivers, such as the Columbia River basin—IRAs and other wilderness areas represent the last few percentages (typically 1 to 5 percent) of "properly functioning" hydrologic land. Losing the last functional watersheds in any given drainage causes major losses in surrounding water resource benefits.

Key Finding #3: Developing Roadless Areas Degrades Water Quality

IRAs Protect Fragile Ecosystems

In addition to their keystone location within watersheds, roadless areas typically encompass the most fragile of natural landscapes, montane forests and meadows, and their superb watershed function is strongly dependent on a very low level of disturbance. Road building and other forms of intensive management in roadless areas degrade their ability to provide clean water for downstream communities over the short and long term. Logging, prescription logging (e.g., post-disturbance, fire-risk reduction, forest health, beetle control), grazing, mining and especially road building are responsible for a number of undesirable conditions. They cause chronic and acute sedimentation of aquatic ecosystems, alter overland flow and stream structure and change a range of physical and biological features, resulting in more frequent and intense floods and less available water throughout the year, increased stream and ambient temperatures, and elevated turbidity levels. Among the consequences:

- If the natural vegetation and soils of upper watersheds within IRAs are disturbed even moderately, the authors predict average turbidity levels more than 100 percent above estimated levels for undisturbed watersheds, along with more frequent and intense turbidity spikes, which are a major source of excess costs to municipal water supply departments.

- Unlike roadless watersheds with intact natural vegetation, intensively managed watersheds also produce less *available* water (average monthly usable raw water) because of intensified high flows with high turbidity and exacerbated low flow conditions. The monthly reliability of water is also diminished.

Key Finding #4: Demand for Water Is Increasing in the West

Population in the West is projected to increase by 300 percent within just 30 years, with similar increases in demand for water. Urban and exurban areas are growing exponentially, including communities adjacent to wilderness areas and IRAs. The demand for water in Colorado alone is expected to triple by 2050. Similarly, the number of people relying on national forest water has doubled in Oregon in the past 30 years, and 86 percent of the population of Washington relies on national forest water to some degree.

Key Finding #5: Rising Demand and Climate Change Will Diminish Water Supply

The dramatic population growth in the West is concurrent with a change in the climate, which is becoming hotter and drier in many places. Temperatures are increasing, snowpacks are declining (up to 40 percent by 2050 in some ranges such as the Sierra Nevada) and melting sooner, and drought and summer water deficits are more frequent and longer. Stream flow reductions ranging from 10 percent to 35 percent have been projected for the Western states over the next half-century as a consequence of climate change. Municipal water districts consider a 10 percent drop in stream flow to be calamitous. Under this emerging scenario, clean IRA water will become increasingly valuable.

Solution: A Light Hydrological Footprint in Roadless Areas

Roadless areas should be managed in the same way that municipalities are increasingly managing their watersheds: with a light ecological and hydrological footprint combined with hydrologic restoration through decommissioning or, preferably, obliteration of roads.

The most cost-effective and prudent approach to maintaining water supplies in the face of population growth and climate change is to manage upper watersheds in a roadless condition with undisturbed natural vegetation. The high and long-term economic cost of degrading clean water for millions of people is argument enough for not meddling with the current roadless area network at the national or state level. Development of CRAs would primarily provide opportunities for short-term gains, but the substantial and long-term impacts on water quality and availability would be detrimental. Roadless areas will become increasingly important as their total watershed value eclipses the more limited use of oil, gold and other extractable natural resources.

Introduction

Inventoried roadless areas (IRAs) on national forest lands were not originally preserved to protect critical sources for freshwater. They are areas that are especially difficult to exploit or make a living in—typically steep, rocky and mountainous terrain with deep snow and long winters—that remained relatively unroaded and unprotected when the federal inventory of roadless areas occurred more than 30 years ago (U.S. Forest Service 1972, 1979; Alexander and Gorte 2008; Anderson 2008). IRAs—formally defined as areas of at least 5,000 acres on national forest lands that have been relatively unroaded and unlogged in the past 50 years—typically occur at middle to high elevations, the upper watersheds of major streams and rivers (USFS 2001). These large blocks of minimally disturbed environments became associated with wilderness and other outdoor recreation values or are seen by some as a government "lockup" of profitable resources. Yet Americans are now very fortunate to have these relatively pristine areas, which have proved to be exceptionally important for providing clean, abundant and inexpensive water for millions of people, a value often underappreciated by the public and underestimated by land management agencies.

Roadless area water from IRAs, wilderness areas, and national and state parks is a rare and valuable commodity. If all urban centers derived their water from such watersheds, billions of dollars would be saved each year from reduced costs for cleaning of water, dredging of dams and waterways, flood control, transport of water, and health care (Sechhi *et al.* 2005). Although most of the natural landscape in the United States was altered long ago (Heilman *et al.* 2002), several major regions with high-quality roadless area water remain and are beneficial to people because they are likely to have intact hydrological systems. These regions include the Rockies, the New Mexico Highlands, the southern Appalachians, the High Sierras of California, the Tongass National Forest, and the Cascades and Klamath-Siskiyou regions.

Opening IRAs to road building and other forms of land use and development would compromise their ability to provide clean water for downstream communities (see review by Trombulak and Frissell 2000). For example, under a request from the state of Colorado (2010), the federal proposal to manage CRAs (USFS 2011) would allow exemptions for permanent and temporary roads, logging as far as 1.5 miles from at-risk communities with Community Wildfire Protection Plans (or even farther if the regional forester determines there is a significant threat); oil and gas leases; coal mining in the North Fork area; and linear construction zones for electricity and telecommunications, pipelines and water conveyances. Such actions, if approved, could result in cumulative water treatment costs to state and local budgets and degrade a wide range of natural benefits provided by IRAs (Box 1), including longer-term economic benefits to local communities.

To estimate the potential costs of degrading high-quality IRA water, we will consider the following questions:

- How much water is derived from IRAs and directly used by people?
- How much does IRA water influence the quality (e.g., turbidity, suspended solids and bed load) and availability (e.g., total flow, peak flow levels, seasonal patterns of available water) of the overall water supply for a given watershed?
- How sensitive is IRA water quality and availability to different forms and levels of watershed disturbance, both natural and anthropogenic (associated with human activities)?

- How many people, industries and economies benefit from IRA water?
- If IRA watersheds are disturbed through human activities, are there costs associated with alteration of water quality and availability?
- How important is IRA water in the face of greatly increasing demand for water, and hotter and drier conditions over most of the West from a changing climate?
- What are the actions that should be taken now to sustain the benefits of IRA water?

For this discussion, the focus is primarily on Western states, with specific attention to Colorado because of the pending federal proposal initiated by the state to enter federal roadless areas (USFS 2011). This report is organized into three major sections, with key findings provided in each: (1) roadless areas' critical role in provision of clean water; (2) the value of clean and abundant water from roadless areas; and (3) skyrocketing demand for water exacerbated by climate change.

BOX 1

General ecosystem services and benefits related to water that are provided by undisturbed IRAs and watersheds (derived from Hrubes *et al.* 1979, Greenway 1996, Costanza *et al.* 1997, Talberth and Moskowitz 1999, Government Accountability Office 2000, Heal 2000, Loomis and Richardson 2000, Sedell *et al.* 2000, Krieger 2001, Dombeck 2003, Shanley and Wemple 2003, Berrens *et al.* 2006).

Off-Stream Benefits

- maintains low treatment costs for water for all beneficiaries
- maintains low price per unit volume costs for water for all beneficiaries
- high quality and abundant drinking water for rural communities and municipal water supplies
- high quality water for agricultural and industrial purposes
- high quality water for downstream livestock production
- high quality water for reduced health care and epidemic control
- reduced costs of flood damage and flood control; enhanced local economies and property values
- community benefits including jobs, income, favorable trends for key economic indicators, and economic sustainability and stability
- recharging of groundwater aquifers
- healthy terrestrial and riparian ecosystems and their component species, sustained ecological and evolutionary processes, resilient ecosystems

In-Stream Benefits

- healthy aquatic ecosystems
- recovery of endangered species and protection of refugia
- diverse and productive fisheries
- high quality habitat for wildlife, including migratory waterfowl and game and non-game species
- aquatic recreation such as swimming, rafting, and boating; enhancement of hiking and camping
- the inherent value of 'wild rivers' and 'wilderness' (including passive use benefits such as option, bequest, and existence values)
- moderation of runoff and stream flows (e.g., lower peak flows, higher low flows, and year-round water)
- soil stabilization and erosion control
- scientific value (intact watersheds are very rare today)
- maintain sediment production to streams at normal background rates
- reduce potential for damage to downstream properties and water users during periods of high flow
- breakdown and containment of waste and toxins (e.g., atmospheric, prior use)


Photo: Nelson Guda

The Ragged Mountain inventoried roadless area, Colorado.

I. Roadless Areas Are Critical for Clean Water

Major Findings

- The location of most IRAs in headwaters (upper watersheds) and their montane habitats provides high-quality water of extraordinary value.
- Americans use a significant volume of IRA water, roughly one-third of which comes from national forest lands, which account for 15 percent of the nation's runoff.
- Uninventoried roadless areas under 5,000 acres, which cover an area 1½ times that of IRAs, also maintain high-quality water and protect aquatic ecosystems.
- Even a small disturbance of the intact montane vegetation characteristic of most IRAs can result in significant impacts on water quality and availability and aquatic ecosystems.
- Roads and road building, even if they are temporary or long-term temporary roads, can be particularly damaging to the hydrologic integrity of IRA watersheds.
- Keeping IRAs in a roadless state is the best management approach to maintain high-quality and available water downstream. Tree cutting and thinning may compromise water supplies and elevate fire risk when road building is involved.

Roadless Areas Are Source Areas for Clean Water

Mountains supply a disproportionate amount of water to their watersheds relative to lowland areas. The greatest amount of annual precipitation within a drainage typically occurs at high and middle elevations, and the snows that accumulate there can provide year-round stream flow, which in the West is the lifeline for agriculture and other water users. The ecological and biophysical conditions of the upper reaches of watersheds are especially important for determining the quality of downstream water. Fragile montane vegetation, erosive soils and steep slopes prone to landslips and mass erosion receive high annual precipitation and are often extremely susceptible to disturbance. This vital location—upper watersheds in mountains (the hydrologic "bread and butter" of watersheds [Frissell and Carnefix 2007])—is precisely where the vast majority of IRAs are located. Indeed, more than half of the nation's roadless areas are over 7,000 feet in elevation (USFS 2000). The rest of the national forests' "working forests"—densely roaded, intensively managed landscapes that are, unfortunately, closely correlated with heavily sediment-laden streams and dramatic changes in flow regimes (Espinosa *et al.* 1997, Trombulak and Frissell 2000, Center for Biological Diversity *et al.* 2001, Coffin 2007, Frissell and Carnefix 2007)—are nearly always found in lower and less steep terrains.

The headwater location and sensitive nature of the montane habitats characteristic of most IRAs are of extraordinary value in providing high-quality water for their size. Importantly, IRAs represent some of the last opportunities to maintain healthy watersheds. The vast majority of major watersheds in the country are in a poor state of ecological and hydrological health, despite best management practices (BMPs) and guidelines to reduce impacts on aquatic ecosystems and water quality (e.g., Karr and Dudley 1981, Lynch and Corbett 1990, MacDonald *et al.* 1991, Riedel *et al.* 2003, Rashin *et al.* 2006).

Although not formally inventoried, roadless areas under 5,000 acres also contribute significantly to maintaining water resources and protecting aquatic ecosystems, particularly in situations where they encompass entire tributary watersheds (Henjum *et al.* 1994, Beschta *et al.* 1995, Greenwald 1998, WWF and CBI 2004). Combined, these smaller roadless areas constitute a large portion of the roadless wildlands in this country. For example, Oregon contains 2.6 million acres of unroaded and uninventoried areas that are typically less than 5,000 acres in size, compared with 2 million acres of IRAs (Strittholt *et al.* 2004). Smaller, uninventoried roadless areas occur largely in headwaters, as do IRAs. Certainly, the larger size of individual IRAs enhances their hydrologic qualities, but the extensive coverage of smaller roadless areas across landscapes allows these areas collectively to provide water resources on par with those of formal IRAs. Efforts to inventory and protect these smaller roadless areas should be increased to protect water supplies.

Roadless Areas Encompass a High Proportion of Clean Water Sources

The coverage of IRAs across a large portion of prime hydrologic real estate—headwaters—is what makes them critically important for water. IRAs occur across large areas of several regions. In Idaho, for example, 32 percent of the land area is in an unroaded state and 17 percent is in IRAs (Anderson 1997, Trout Unlimited 2004a). Their predominance in headwater areas confers their hydrologic importance. IRAs occur in upper watersheds (headwaters) of all major drainages in Colorado, and the majority of IRAs are in mountainous terrain in Colorado, Oregon, Idaho, New Mexico, Utah, Montana, California, Washington and most other states (such as Appalachian Mountain states) where they are inventoried. In Colorado, IRAs cover approximately 30 percent of the national forest lands in the state (4.4 million acres) and nearly 25 percent of its headwaters, defined as the watersheds above 7,000 feet, based on visual estimation of maps. (Roaded national forest and Bureau of Land Management lands, wilderness areas, national and state parks and some private land make up the remainder). Denver, for instance, derives its water from several drainages in the Rocky Mountains within which IRAs cover approximately 25 percent of the headwaters.

The volume of stream flow potentially influenced by the condition of IRAs is also substantial. National forests provide approximately 14 percent of the nation's runoff (Sedell *et al.* 2000), and IRAs, covering nearly a third of national forests, are responsible for a sizable proportion of this volume (Anderson 1997; USFS 2000). The USFS (2000) estimates that IRAs are part of 661 of the 914 national forest watersheds, with 55 percent of the 661 acting as source areas for facilities that treat and distribute drinking water to the public.

Regional estimates of IRA stream flow are in the same range as national estimates. For example, IRAs account for an estimated 33 percent of all national forest stream flow in New Mexico (Berrens *et al.* 2006). In the major watersheds west of the Rockies, national forests, including their IRAs, provide 33 percent of the runoff (Sedell *et al.* 2000). National forests in California and Washington make up 20 percent of each state yet supply 50 percent of the runoff (Sedell *et al.* 2000). In the middle Rocky Mountains (the Rocky Mountain USFS Administrative Region of Colorado, Kansas, Wyoming, Nebraska and South Dakota), national forests produce 9 million acre-feet of stream flow. This volume is equivalent to about 88 percent of Colorado's total estimated annual stream flow of 10 million acre-feet (Doyle and Gardner 2010, sourced from the Office of the State Engineer, Colorado Division of Water Resources). Given the proportional coverage (one-third of the area) of IRAs in headwaters, one can conservatively assume that at least one-quarter of Colorado's annual stream-flow volume, or 2.5 million acre-feet, is derived directly from IRAs. This represents a considerable volume of water, especially when placed in the context of Denver and its suburbs' treated water demand of 630,000 acre-feet in 2010 (Doyle and Gardner 2010). (Note: Denver Water [2010] states 190,271 acre-feet for the Denver service area.)

Much of the West's stream flow is withdrawn for off-stream use. For example, in the Upper Colorado Region (a USFS Water Resource Region [Sedell *et al.* 2000]), 55 percent of the stream flow is withdrawn. This substantial contribution to stream flow by IRAs is characteristic of all regions where they occur (Box 2).

BOX 2

The Importance of Roadless Area Water for Colorado

We ran a Geographic Information System (GIS) analysis designed to calculate the area of IRAs in water source areas (i.e., watersheds that provide water to a public water source). The specific methods are described in Appendix 1. The analysis was designed to determine the watershed value of IRAs and what would potentially be degraded if IRAs are declassified.

Major Findings

IRA Extent in Colorado's Surface Water Source Areas (SWSAs)

1. IRAs occur in headwaters of all major drainages in Colorado, and on average IRAs constitute 25% of SWSAs with IRAs. Some small SWSAs are entirely within IRAs. IRAs cover about 25% of the headwaters of Denver's watersheds.

2. 302 of the 399 (77%) SWSAs examined (i.e., the majority of montane areas in Colorado) overlapped with IRAs.

3. IRAs are often in steep terrain—25% of Colorado's watersheds are greater than 30° slope, and 5% of these have IRA status. Colorado leads the nation in acreage of IRAs on steep erosive soils.

Potential Water Resource Impacts of Disturbing Colorado IRAs

4. Degrading the hydrologic properties of an intact IRA or network of IRAs through even moderate disturbance to natural vegetation and soils will result in a decrease of available water of at least several percent (i.e., the average monthly treatable water available for use). A decrease of 1% of stream flow in Colorado rivers is considered a major challenge to water supply, and a 10% decrease could be calamitous (Doyle and Gardner 2010).

5. If Denver's IRAs are disturbed, the estimated average increase of turbidity (an indicator of total suspended solids) from 5 NTU (nephelometric turbidity units) to 10 NTU at Denver's raw water intakes would result in an estimated $6 million in added treatment costs, depending on type, intensity, and frequency of disturbance.

6. Denver Water serves 1.3 million people in the Denver metropolitan area, which was 25% of the state's 2010 population (Denver Water 2010), a 30% increase since 1970. Another 2 million people are expected in Colorado within two decades (Doyle and Gardner 2010).

7. Many of Colorado's communities and economic sectors benefit greatly from clean and reliable IRA water, including municipal water supplies, outdoor recreation, fisheries, hunting, property values and agriculture.

Surface Water Source Areas

8. 399 SWSAs in montane and foothill areas of Colorado were analyzed.

9. 302 SWSAs have IRAs.

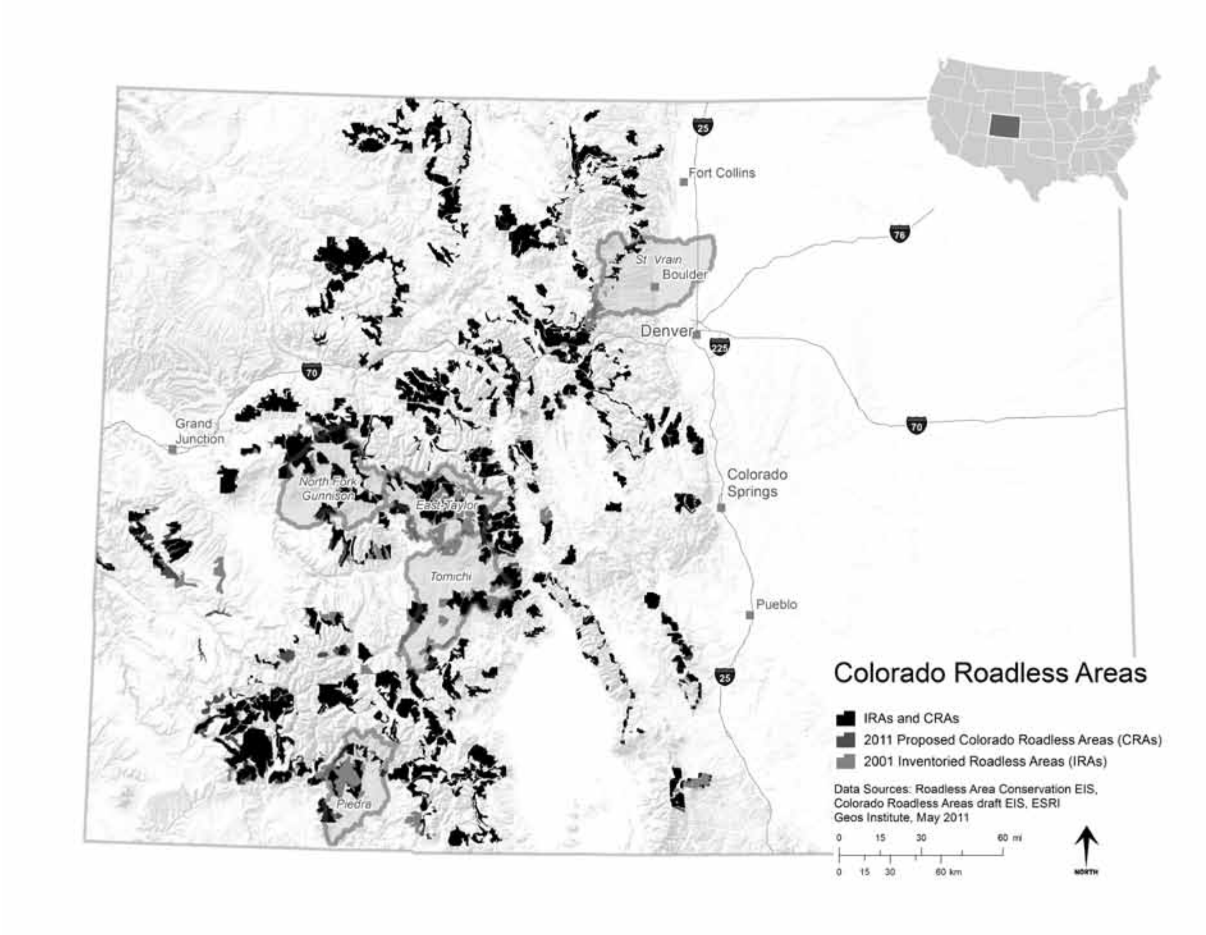

Figure 1. Location of inventoried roadless areas (IRA 2001) and proposed Colorado Roadless Areas (USFS 2011).

Estimating the Impact of Degrading Roadless Areas

How much disturbance can IRAs withstand before significant and costly impacts on water occur downstream? The answer lies partly in how much alteration of water quality and changes to flow regimes occur for any given type, intensity and periodicity of watershed disturbance or combination of disturbances. One must then relate those changes to the type and scale of impacts on the benefits accrued from clean, available and reliable water.

The many in-stream benefits include healthy aquatic ecosystems; recovery of endangered species; diverse and productive fisheries; high-quality habitat for wildlife, including migratory waterfowl; in-stream aquatic recreation such as swimming, rafting, and boating; and the inherent value of wild rivers and wilderness. Off-stream benefits include flood control and amelioration, water for agricultural and industrial purposes, enhanced local economies and property values, recharging of aquifers, and provision of drinking water for rural communities and municipal water supplies (see Talberth and Moskowitz 1999, GAO 2000, Loomis and Richardson 2000 2001, Sedell *et al.* 2000, Krieger 2001, Berrens *et al.* 2006). The economic and quality-of-life consequences from a given impact on water can then be estimated for different benefits (e.g., Walsh *et al.* 1981, 1984, Loomis 1988, 2005, Gilbert *et al.* 1992, Berrens *et al.* 1996 and 2006, Loomis and Richardson 2000, Sonoran Institute 2000, Strittholt and DellaSala 2001, Krieger 2001, Colby and Wishart 2002, Strittholt *et al.* 2004).

Roadless Area Water Is Highly Sensitive to Disturbance

Even a small disturbance (a small area affected, low-intensity activity and/or a single event) to the intact montane vegetation characteristic of most IRAs can result in significant impacts on water quality and availability and aquatic ecosystems. A few infrequently used roads or linear construction zones, such as water conveyances, power/communications lines, pipelines (Colorado, State of 2010), a seemingly small herd of cows grazing in riparian habitats, or a single fire-risk or tree "epidemic" management prescription to a natural forest (with its attendant access roads) can have a major effect. They can bleed fine sediment into streams and rivers, produce ongoing landslips and mass erosion, compact soils, and create runoff patterns that erode slopes and turn spongy watersheds into muddy tailraces during storm events and snow melt. Intact natural vegetation is highly effective at moderating sediments and water flow, but when it is affected by roads, logging, grazing, mining and other land uses, ecologically and hydrologically significant changes in water quality and flow regimes can be expected (e.g., Ziemer 1981a).

Hydrologists have long suggested that not until 10 percent of a watershed is altered can downstream effects on human infrastructure be discerned. Decades of studies on the biological consequences of watershed disturbance have shown, however, that even small disturbances can have profound and long-lasting biological impacts (e.g., reduction in biodiversity, damage to fish and fisheries, loss of invertebrates). Several studies examining the sensitivity of intact watersheds and aquatic ecosystems have been conducted at the ecoregion scale across multiple watersheds with a range of conditions, conferring heightened confidence in observed trends. For example, McIntosh *et al.* (1995) evaluated the Columbia River basin and found that natural pool habitats, which are important for healthy fisheries and aquatic ecosystems, remained within a natural range of variation only where entire watersheds, or at least the headwaters, were roadless or wilderness.

Small Disturbances Equal Big Impacts

From a water quality and stream-flow perspective, recovery even from a single low-level disturbance is actually quite slow in montane and mid-elevation habitats, such as those characteristic of Colorado's IRAs (Platts and Nelson 1985, Boise National Forest 1993, McIntosh *et al.* 1994 and 1995), in contrast to long-standing notions of high forest resilience (Noble 1965, Hirt 1996) and "immaculate recovery" (Rhodes *et al.* 1994, Espinosa *et al.* 1997). Even small areas of disturbance within a watershed can yield significant erosion above estimated natural background levels. For example, in Northern California, Durgin *et al.* (1989) sourced 100 percent of the excess erosion in the watershed studied to 12 percent of the area and found that roads, which covered 4 percent of the area, generated 76 percent of the excess. Road densities of less than 1 mile per square mile are correlated with degradation of aquatic ecosystems (Henjum *et al.* 1994). The lesson here is that even small areas of low-intensity disturbance (logging, road building or other forms of development or management) within a watershed, depending on soil types, slope gradients, topographic position and type of activity, can have major and long-term impacts on IRA water.

Roads

Roads are often major drivers of water and aquatic ecosystem degradation, with multiple mechanisms and synergistic effects (Beschta 1978, Forman and Alexander 1998, Lugo and Gucinski 2000, Trombulak and Frissell 2000, Gucinski *et al.* 2001, Coffin

2007). Logging roads have been linked to great increases in erosion rates and sediment delivery to streams—up to 850 percent over rates in undisturbed habitat (Fredricksen 1970, Megahan and Kidd 1972, Brown 1980, Amaranthus *et al.* 1985, Bilby *et al.* 1989, King 1989, Haynes and Horne 1997, Jones *et al.* 2000, Wemple and Jones 2003)—with long-term and often catastrophic impacts on stream biota, aquatic ecosystems and water quality. Bull trout (*Salvelinus confluentus*), a sensitive indicator of habitat degradation from excessive fine sediments, do not occur in watersheds with more than 1.7 miles of road per square mile in the interior Columbia River basin (Haynes and Horne 1997, Hitt and Frissell 2000). Watersheds with road densities greater than 3 miles of road per square mile were deemed "not properly functioning" in federal salmon habitat guidelines (NMFS 1996). Road building can be particularly degrading to water quality in states such as Colorado, which leads the nation in IRA acres with a high susceptibility to landslides (USFS 2000, pp. 3-38).

Construction and maintenance of roads—even a few of them, particularly in steep terrain—are often incompatible with water quality goals. Municipal water districts know this well and have active programs to decommission and obliterate roads and limit traffic on access roads in key watersheds (Lane and Sheridan 2002, Seeds 2010). The impacts of temporary roads (USFS 2011) are similarly negative (USFS 2000) and may be more so because they are typically poorly designed, located, constructed or maintained. Much of the excess sediment yield derives from road construction; chronic erosion occurs for years even without vehicle traffic because of altered hydrology; and the long-term potential for mass erosion events already has been established through construction (Megahan *et al.* 1979, Megahan and Bohn 1989). Improved road designs help (e.g., Furniss *et al.* 1991), but they still can raise sediment levels 50 percent over natural sediment yields (Megahan *et al.* 1992), and few roads are slated for improvement or even maintenance under tight agency budgets.

Just how severely roads degrade the ecology, geomorphology and hydrology of watersheds depends on many factors (Megahan 1972ab, 1983, 1984a; Luce and Black 1999; Wemple *et al.* 2001; Luce 2002; Sheridan *et al.* 2006; Sheridan and Noske 2007), including:

- Density and location of roads. Roads that parallel or cross streams; are built in inner gorges, swales and break-in-slopes, steep headwater sites and emergent groundwater locations; or are farther downslope are, in general, particularly damaging.
- Number of stream crossings, road interception of overland or subsurface flow, road and culvert design.
- Type of road surfacing.
- Frequency, intensity and seasonality of use and road surface type.
- Synergistic effects with other land uses such as grazing and logging.
- Soil type, vegetation and geomorphology of each watershed.

Decommissioned, obliterated and revegetated roads can help reduce accelerated erosion problems if mass erosion issues are effectively addressed, although such reductions are usually challenging and expensive to carry out (Reid and Dunne 1984, Harr and Nichols 1993, McCaffery *et al.* 2007). Indeed, mass erosion and sedimentation events, such as landslides (including collapsing road cuts, fills and stream banks), shallow debris slides, deep-seated slumps and rapid debris flows, are catalyzed by the building of roads in watersheds and contribute greatly to the degradation of water quality. Megahan and Kidd (1972b) estimated that 71 percent of excess sediment production in the Idaho batholith was due to mass erosion and that 88 percent of landslides were associated with roads (Megahan *et al.* 1978; Weaver *et al.* [1998] report 65 percent and 72 percent in two subset Idaho basins). Mass soil movements have been estimated to be 30 to 750 times greater in roaded than in unroaded watersheds (Sidle *et al.* 1985, Swanson *et al.* 1987). Even a few roads can create conditions favorable for chronic mass erosion events that heavily contribute to acute and long-term degradation of water quality (e.g., excess sediment, turbidity, fine sediments) and availability (e.g., shallow channels, loss of pools, channel alteration, reduced summer flows). Furniss *et al.* (1991) report that mass soil movements continue for decades after road construction. Roads also channel runoff locally, increasing peak flow levels (Ziemer 1981b). Just a few problem sites on these few roads can have major impacts on IRA water and downstream water supplies.

Roads also accumulate chemicals and toxins from vehicles, spills and road maintenance that chronically enter aquatic ecosystems or create spikes in toxicity after long dry spells or during snowpack melting (Spellerberg 1998, Furniss *et al.* 2000). Further, roads are commonly used by cattle and wildlife and can facilitate dispersal of *E. coli, Giardia* and *Leptospira* pathogens into the downstream water supply (e.g., Appelbee *et al.* 2005). Roads also facilitate dispersal of invasive species, including pathogens such as Port Orford cedar root disease (Jules *et al.* 2002), into otherwise intact ecosystems.

Logging

Logging can accelerate erosion mainly through felling, yarding, skidding, burning and use of associated roads and landings (Lewis 1998). Mechanisms include loss of soil stability from roots; altered overland and subsurface drainage patterns and rates; decreased infiltration and percolation; mass failures, such as landslips, uprooted trees and ongoing blowing down of trees; direct litter and soil horizon disruption and compaction; and ongoing erosion from road surfaces (Fowler *et al.* 1987, Gardner and Chong 1990, Keppeler *et al.* 1994, Lewis 1998). From a water perspective, logging and associated road building may act in concert as major disturbances to natural vegetation, soil horizons and watershed hydrology (Anderson *et al.* 1976, Geppert *et al.* 1984, Anderson and Potts 1987, Chamberlin *et al.* 1991, Furniss *et al.* 1991), even when low-intensity, best-practice and least-impact methods are employed (Megahan 1987, Burroughs and King 1989, Rhodes *et al.* 1994, Espinosa *et al.* 1997, Sato 2006, Hotta *et al.* 2007, Turton *et al.* 2009).

Measured rates of accelerated surface and/or mass soil erosion and subsequent stream sedimentation from logging and road building range from 45 percent to 376 percent over natural sediment levels, with elevated levels lasting for decades and in-stream storage and transport much longer (Burns 1972, King 1993, Rhodes *et al.* 1994, Lewis 1998, Zégre 2008). Roads and landings, and the associated mass erosion events commonly associated with them, contribute high proportions of the additional sediment, up to 90 percent of it in some cases (Swanson and Dyrness 1975, McCashion and Rice 1983). Channel morphology and function can also be altered by logging roads, sedimentation and changes in flow regimes (e.g., Wemple *et al.* 1996). Logging also removes fire-resistant trees, leaves behind flammable slash, and results in densely packed and flammable tree plantations, creating conditions that promote more-frequent wildfires that can degrade the hydrological properties of watersheds.

Logging in Camouflage: Post-Disturbance, Fire-Risk Reduction, Forest Health and Beetle Management

Logging by any name is still logging from a stream's perspective, regardless of management need. A variety of impacts on aquatic ecosystems, hydrology and water quality occur from these activities and, as with logging and road building, even a single low-intensity action across small areas can have significant and long-term impacts on water resources (Waters 1995, Kattleman 1996, DellaSala *et al.* 2003, Karr *et al.* 2004, Beschta *et al.* 2004, Lindenmayer *et al.* 2004, DellaSala *et al.* 2006). Increased soil compaction, topsoil erosion and sediment loads, and erosive high flows are some of the ecological and hydrological consequences of typical forest prescriptions.

Vegetation and snowpack prescriptions are often considered as potential management options for enhancing runoff yields (Rothacher 1965, Evans and Patric 1983, Harr 1983, Kattleman *et al.* 1983, Troendle and King 1987, Mohammed and Tarboton 2008), but the position of the USFS (Sedell *et al.* 2000) and other analysts is that any additional yields would either be minimal or not worth the costs and collateral impacts on watersheds (Male and Gray 1981, Bosch and Hewlett 1982, Ziemer 1987, Keppeler and Ziemer 1990). Logging and thinning reduce the biomass of vegetation and, consequently, the amount of evapotranspiration, resulting in greater annual runoff up to a point. However, monthly summer runoffs can be lower, because water is no longer stored and released slowly from undisturbed natural vegetation. In addition, peak flows are typically greater and more frequent in disturbed watersheds, increasing the times when raw water intakes and storage facilities cannot make use of available runoff, especially if it has high turbidities associated with flood events. Finally, when mesic, late-successional forests are disturbed or lost in watersheds across broad landscapes, local precipitation patterns can be altered because of fewer and less intense thunderstorms being generated and, subsequently, lower local annual or summer precipitation.

Fire

Hydrological Impacts of Fire

More frequent wildfires in upper watersheds are a significant threat to water quality—and to people and property—because they contribute to sedimentation and changes in natural community composition and vegetation structure by resetting succession to early stages. Wild or prescribed fires remove vegetative cover and woody debris and disrupt soil and litter horizons. Processes of interception, percolation, and infiltration of precipitation are altered with these changes, and erosion and mass erosion events can increase dramatically, often through post-fire debris flows and landslips (DeBano 1979, Helvey 1980, Wells *et al.* 1987, Collins and Pess 1997, DellaSala and Frost 2001, Martin and Moody 2001, Ice *et al.* 2004, Karr *et al.* 2004, Odion *et al.* 2004, DellaSala *et al.* 2006). A wide range of post-fire ecological impacts have been documented in aquatic ecosystems, including elevated temperatures because of low summer flows, scouring of channels, and elevated sedimentation (Gresswell 1999, Bisson *et al.* 2003, Minshall 2003, Dunham *et al.* 2003, Karr *et al.* 2004, DellaSala *et al.* 2006, Lindenmayer and Noss 2006, Noss *et al.* 2006, Reeves *et al.* 2006).

Repeated burning of natural IRA vegetation through wildfires or prescribed fire will reduce the ability of an upper watershed to retain water and moderate erosion. A single wildfire affects watershed on a scale of years, but repeated burns create chronic problems and, like logging and roads, affect watersheds on a scale of decades. Even a few fire events in close succession will significantly damage the hydrologic properties of an IRA. Maintaining IRA watersheds in an undisturbed natural state, or as close to one as possible, will also help confer resistance and resilience to fire in the face of warmer and drier conditions associated with climate change. However, fires within their natural range of variation can have beneficial effects for aquatic ecosystems in the long term if post-fire logging and road building are not permitted (e.g., Reeves *et al.* 1995).

Post-Fire Logging Impacts

Removal of post-fire trees (also known as salvage logging) and woody debris is particularly damaging to aquatic ecosystems, because such logging removes the large wood and other legacies that benefit aquatic ecosystems and because recently burned areas are already prone to high erosion and mass erosion events (Beschta *et al.* 1995 and 2004, Reeves *et al.* 1995, Stephens 1998, Weatherspoon and Skinner 1999, DellaSala *et al.* 2004 and 2006, Lindenmayer *et al.* 2008, Lindenmayer and Noss 2006, Reeves *et al.* 2006). Post-disturbance logging also involves road building (accompanied by its negative impacts on water quality), disrupts natural regeneration and can increase the severity of future fires (Donato *et al.* 2006, Thompson *et al.* 2007).

Fire-Risk Prescriptions

The tree cutting and thinning included in the federal proposal for Colorado—up to 1.5 miles within a Community Protection Zone, or farther if the regional forester determines there is a significant threat—are supposed to reduce the wildfire hazard to at-risk communities and municipal water supply systems (USFS 2011). However, there can be significant watershed consequences. Forestry activities and other forms of development and roaded landscapes are correlated with increases in anthropogenic (human-caused) fire ignitions and reduced return intervals for fires throughout the West (Wildland Resource Center 1996, Oppenheimer 2000, DellaSala and Frost 2001, Naficy *et al.* 2010). This includes tree removal and thinning activities that involve road building to reduce wildfire risk. Both activities exacerbate erosion as well. Forests that have been thinned also dry out more quickly, retain less moisture and can have a greater abundance of more-ignitable fuels in the form of weeds and early successional plants, resulting in longer high fire-risk windows during the year. Moreover, thinning in high-elevation forests, where many roadless areas occur, is not likely to alter fire behavior appreciably. In fact, it can have greater impacts on ecosystems than fires themselves, because upper montane forests in places such as Colorado are composed of lodgepole pine (*Pinus contorta*), spruce (*Picea engelmannii*) and fir (*Abies spp*.) forests that burn intensely and infrequently as part of their historic fire regimes. The period of fire suppression, for instance, has been less than the fire return intervals in these forest types,-- and thus fire suppression has not altered fire behavior (Black *et al.* 2010). In addition, in the Rockies, climate, not fuel, is a major driver of fire behavior, although thinning in low- to mid-elevation ponderosa pine and mixed-conifer forests with a history of fire suppression and human disturbances (i.e., logging, grazing) may be restorative, particularly when combined with road obliteration and other restoration actions. In these cases, treatment efficacy depends on a narrow window (generally 10 years or so) in which reduced fuel loadings are most likely capable of altering fire behavior, should a fire occur (Rhodes and Baker 2008).

In sum, restoration-based treatments, including fuels reduction (thinning), should be targeted in areas where they are needed most: currently degraded, fire-prone roaded areas, especially those in the developed wildlands-urban interface where loss of property and human life is of greatest concern. Only 8 million of the 58.5 million acres of roadless lands nationwide are identified as high-fire-risk areas that may require non-commodity-based thinning of small trees (USFS 2000). The Roadless Area Conservation Rule provides sufficient discretion for agencies to address these situations on federal lands effectively without having to introduce new provisions from the states.

Significant hydrological impacts are a consequence of increasingly frequent and intense fires. The strong association of road building—regardless of whether it is connected to fire-reduction activities—with fire argues for prohibition against road building within IRAs. Management activities intended to reduce wildfire risk should be implemented without roads and only if they will not alter the hydrological properties of vegetation or a watershed.

Grazing

Grazing significantly increases fine sediments and sediment delivery compared to ungrazed watersheds (Fleischner 1994). For instance, in rangeland systems of Colorado and Idaho, grazing has been associated with an increase in sediment delivery of up to 80 percent or more in some cases (Lusby 1970, MacDonald *et al.* 1991, Platts 1991, Boise National Forest 1993). Because cattle concentrate in riparian areas (Platts and Nelson 1985, Kauffman *et al.* 1983, Platts 1991), even low stocking rates can have severe impacts on water resources and aquatic ecosystems. In addition, depending on frequency, timing, intensity and duration of grazing pressure, impacts on IRAs include damage to upland plant communities; channel erosion; reduced summer flows; bank instability; sedimentation, particularly of fine sediments that are associated with many ecological and water quality problems; loss of riparian habitats; compaction of soils; and reduced infiltration into soils through channel and rille formation (Gifford and Hawkins 1978, Kauffman *et al.* 1983, Platts and Nelson 1985, MacDonald *et al.* 1991, Platts 1991, Boise National Forest 1993, Rhodes *et al.* 1994, Greenwald 1998). Decades of livestock grazing within IRAs has also increased fire risk as native grasses that once carried ground fires are replaced with trees and shrubs that carry fires into tree crowns. Now, when wildfires occur within grazed IRAs, depending on plant associations and fire regime types, they have a much greater hydrologic impact than do the historical cool, low-burning ground fires. Cattle can also introduce bacteria into the water supply and are efficient vectors for the spread of invasive plants that can alter the hydrologic features of natural communities if they begin to dominate ecosystems. Overall, grazing is incompatible with managing IRAs for high water quality.

Oil and Gas Development and Mining

Historically, mining has delivered more sediment to streams per unit area disturbed than other extractive activities and can have a long legacy of impact from abandoned sites (USFS 1981, Nelson *et al.* 1991, Morton *et al.* 2004). Significant problems also occur with oil and gas development, including gas extraction through hydraulic fracturing that is responsible for significant ground and surface water pollution. Current practices create very high densities of wellheads and direct impacts on large proportions of landscapes (Weller *et al.* 2002, Morton *et al.* 2004, Pew Environment Group 2008). The benefits of water from IRAs will quickly be degraded if oil and gas mining is allowed in IRAs, with relatively small economic gain from the miniscule amounts of recoverable oil in roadless areas. Morton *et al.* (2004) estimate that IRA-derived oil would meet U.S. oil consumption for only 21 to 24 days. The potential impacts on water quality from road building, extraction activities, pipelines and pollution is so great compared with the gain that it should not even be described as a tradeoff, but rather another form of intensive mining (Fight *et al.* 1978).

Erosion From Off-Road Vehicles

Off-road vehicles (ORVs) are an increasingly popular form of outdoor recreation in the United States. Roadless areas continue to be important destinations for ORV enthusiasts and hunters who use ORVs. However, ORV use is increasingly associated with erosion and water quality problems within IRAs as the numbers of people using them increase; as sensitive habitats such as riparian areas and montane meadows are affected; and as best practices for ORV use, such as staying on established routes and restricting use during wet conditions, are not followed. ORV trails can damage sensitive montane vegetation and contribute sediments and turbidity to IRA streams over decades (Switalski and Jones 2009). ORVs should be prohibited from IRAs to protect water quality, or limited during benign weather conditions to low-intensity use, such as hunting or other situations in which erosion impacts are minimal.

Downstream Impacts From Eroding Roadless Areas

Although IRAs can make up a relatively small proportion of the area of major drainages, excess sediment (i.e., the amount above what would normally occur for an undisturbed watershed) from IRA disturbance can be significant and important for water quality downstream (Karr and Schlosser [1978] review of watershed management impacts). Once fine sediments are in transport, they are difficult to remove. This is especially the case when raw water intakes and reservoirs are located in mountains and foothills, as are those of many major urban areas (Geppert *et al.* 1984, Rice 1991, Ziemer *et al.* 1991, Megahan *et al.* 1992, Rhodes *et al.* 1994, Lewis 1998, Ercelawn 1999, Megahan and Hornbeck 2000). The long legacy of upper watershed disturbance on downstream water derives from storm events that periodically resuspend and transport sediments that are trapped behind woody debris and stored in channels in tributaries (Hagans *et al.* 1986, Grant and Wolff 1991). The cumulative downstream impacts are probably grossly underestimated in many studies, in part because of this pattern of tributary storage of sediment and long-term transport processes downstream (Rice and Lewis 1991, Ziemer *et al.* 1991, Jones *et al.* 2009).

The Thompson Creek inventoried roadless area, Colorado.

II. How Valuable Is Clean and Abundant Water From Roadless Areas?

Major Findings

- The value of high-quality IRA water to Americans nationwide is estimated in the billions of dollars annually for a wide range of water resource benefits.
- It is estimated that water treatment plants and highway departments can save as much as $18 million a year by avoiding sedimentation caused by logging in IRA watersheds.
- Wilderness areas, including IRAs, generate $600 million annually from outdoor recreation.
- If the natural vegetation and soils of upper watersheds within IRAs are even moderately disturbed (i.e., less than a quarter of their area), average levels of turbidity are projected to be more than 100 percent above estimated levels for undisturbed watersheds (along with associated suspended solids), accompanied by more frequent and intense spikes in turbidity/suspended solids.
- More frequent and intense spikes in flood events and turbidity/suspended solids are a major source of excess costs to municipal water supply budgets.

Drinking Water Is a Watershed Issue

The drinking water issue alone should compel cities, states, decision-makers and the public to maintain the current management of IRAs, mandate restoration within them, designate new ones in critical watersheds and resist any proposed activities that would disrupt IRA landscapes and aquatic systems. Common sense demands that IRAs be managed in the same way that municipal water districts are moving toward managing key watersheds: a very light footprint and enhanced hydrologic health through the restoration of natural habitats and removal of roads.

People Benefit From Roadless Area Water

In the 48 contiguous states, 15 to 18 percent of the nation's runoff is sourced from national forests, and roughly a third of that is derived from IRAs (Sedell *et al.* 2000). Sedell *et al.* (2000) estimate that more than 3,400 communities in 33 states rely on national forest drinking water. Some of these communities are highly populous in Colorado, the Pacific Northwest, California and other states, so that modest number translates to at least 124 million people (Sedell *et al.* 2000). Denver has a population of 1.2 million (25 percent of the state's 2010 population [Denver Water 2010]), a 30 percent increase since 1970, and an additional 2 million people are expected in Colorado within two decades (Doyle and Gardner 2010). The number of people relying on national forest water has doubled in Oregon in the past 30 years, and 86 percent of the population of Washington state relies on national forest water to some degree (Sedell *et al.* 2000). Indeed, the population throughout the West is projected to increase by 300 percent by 2040 (Sedell *et al.* 2000) with growth in urban and exurban settings (Theobald 2005). Given the broad coverage of IRAs across the mountains of the West, millions of Americans benefit directly and indirectly from the clean water these areas provide, and many more Americans will benefit from or need this resource in the near future.

Turbidity, Suspended Solids and Availability

Off-stream uses of IRA water are for drinking, agriculture and industry. Two features of the water are especially important for its quality and cost: turbidity/total suspended solids and availability.

Turbidity and Suspended Solids

Turbidity is a measure of the cloudiness of the water, measured in nephelometric turbidity units (NTU) based on the scattering by particles—suspended clay, silt, finely divided organic matter, algae and other microorganisms—of a light beam passed through the water (Sattersfield 2006). Turbidity is often used as an indicator of the combined mineral and organic suspended solids (total suspended solids) and sediment load in streams at turbidities of less than 100 NTU (Kunkle and Comer 1971, Beschta 1980, Kerr 1995, Ziegler 2002, Seeds 2010).[1] Turbidity is considered a primary pollutant under the Safe Drinking Water Act, because there is a correlation between turbidity levels and suspended fine sediments that can harbor pathogens (Tracy *et al.* 1966, LeChevallier *et al.* 1991, Schwartz *et al.* 2000, Seeds 2010, LeChevallier and Norton 1993) and reduce the effectiveness of disinfection treatments (LeChevallier *et al.* 1981). It also can act to form disinfection byproducts (EPA 2002a) and carry nutrients, pesticides, heavy metals and other toxic chemicals (Hart 1982, Lick 2008, Seeds 2010). Unpleasant odor and taste can also be associated with excessive turbidity in drinking water.

1 Although turbidity purports to measure approximately the same water quality property as total suspended solids (TSS), the latter is more useful for water quality assessments because it provides an actual weight of the particulate material present in the sample. In water quality monitoring situations, a series of more labor intensive TSS measurements will be paired with relatively quick and easy turbidity measurements to develop a site-specific correlation. Once it is satisfactorily established, the correlation can be used to estimate TSS from more frequently made turbidity measurements, saving time and effort. Because turbidity readings are somewhat dependent on particle size, shape, and color, this approach requires calculating a correlation equation for each location. Further, situations or conditions that tend to suspend larger particles through water motion (e.g., increase in a stream current or wave action) can produce higher values of TSS not necessarily accompanied by a corresponding increase in turbidity. This is because particles above a certain size (essentially anything larger than silt) are not measured by a bench turbidity meter (they settle out before the reading is taken) but contribute substantially to the TSS value.

The Environmental Protection Agency (1998, 2001, 2002ab, 2004) sets allowable turbidity in drinking water at 0.3 NTU in 95 percent of samples for conventional and direct filtration and 1 NTU in 95 percent of samples for membrane, cartridge, slow sand, and diatomaceous earth filtration. However, turbidity levels of 0.2 NTU and above have been implicated in gastrointestinal disorder outbreaks in urban areas (Schwartz *et al.* 2000), so the EPA standards should be viewed as relatively lenient. When raw water has high turbidity, water treatment facilities must carry out a range of treatments to reduce NTU levels to acceptable standards, including various combinations and sequences of raw water intake maintenance, flocculent/coagulation agents, chemical feeds, flash mix, sedimentation and rapid pressure or slow sand filtration (Sattersfield 2006, Seeds 2010). Treatment plants with pressure and slow sand filtration have to shut down operations when raw water turbidity exceeds 5 NTUs, but plants with pre-filtration or pre-sedimentation basins or advanced filtration systems can deal with higher levels (5 to 100 NTUs), although these latter systems are often too expensive for smaller water districts (Seeds 2010).

BOX 3

Oregon Department of Environmental Quality definitions for turbidity status of raw water for evaluating water districts:

Low Turbidity Status
Turbidity baseline lower than 5 NTU 50% or more of the time

High Turbidity Status
Turbidity baseline lower than 5 NTU less than 50% of the time

Occasional Spikes
Sudden increases in turbidity that exceed 5 NTU occurring less than 30 times/year

Frequent Spikes
Sudden increases in turbidity that exceed 5 NTU occurring more than 30 times/year

Source: J. Seeds 2010

Water districts view turbidity levels above 5 NTUs as "turbidity spikes." Public water supply annual water profiles are evaluated on the basis of background turbidity levels, the frequency and periodicity of days with turbidity spikes, and the number of days that treatment plants must shut down (for example, Seeds 2010, Box 3). Turbidity levels of 5 NTU and greater are implicated in decreases in clear-water aquatic ecosystem productivity and stress to salmonids (NMFS 1995).

Natural disturbances in roadless areas, such as erosion, landslides, windthrow, fires and floods, can produce downstream spikes in turbidity, but these are typically infrequent (Fowler and Heady 1981, Reeves *et al.* 1995 and 2006, Waters 1995, Gomi *et al.* 2004, 2005) and the impacts are short-term on aquatic ecosystems and turbidity levels (Edgington 1984, Seeds 2010). Logging, road building, grazing and other exploitations can increase the intensity and frequency of spikes in turbidities (sediment loads and suspended sediments) well above natural ranges of variation and can create chronically higher background turbidity levels downstream (Brown and Krygier 1971, Grizzel and Beschta 1993, Reiter *et al.* 2009). Many spikes are probably the result of sediment that was deposited on the streambed by erosion and then remobilized as flows rise. Thus management activities have a double impact: the initial impact when the eroded soil enters the stream, and subsequent impacts when that soil is remobilized whenever flows come up (J. Seeds, personal communication 2010). A very large proportion (80 percent or more) of the sediment transported by a stream or river typically occurs in just a few storm events each year. Those storm events are missed by most standard water quality sampling protocols and are missed completely in standard turbidity tracking.

IRAs that cover upper watersheds—and most of them do—are fundamental in helping to maintain low background turbidity levels and infrequent spikes downstream at raw water intakes. Where land use activities throughout the remainder of a watershed are producing increasingly undesirable turbidity conditions, IRAs are helping to dampen the overall impact, depending upon their relative runoff contribution.

Although Lewis (1998) estimates that main-stem rivers in Northern California typically attain excess sediment levels in the range of 25 percent above background levels regardless of the contribution of upstream tributaries, the fact that most water districts source water far upstream in montane streams and reservoirs means that the loss of water quality benefits from IRAs could result in dramatic increases (25 percent or more) in water turbidity levels and spikes. Seeds' summary (2010) of several Oregon public water supplies reveals a trend toward increasingly higher background turbidities, more days with turbidity spikes and treatment plant shutdowns, and more-frequent extreme spikes (up to 300+ NTU) for many districts with patchworks of managed and less-disturbed watersheds. These are driven to a large degree by storm-related erosion events precipitated by past and present roads and logging operations.

For example, Falls City, OR, received a spike in turbidity of 50 NTU immediately after a logging operation in its water intake watershed in November 2006. Districts with multiple water sources and those that were engaged in watershed protection and restoration fared better than others in general. Background turbidities of 5 to 7 NTUs (~100 percent over background NTU levels) have been observed for several Oregon watersheds for at least five years after logging events, with a marked increase in turbidity spike levels and frequencies (Seeds 2010). The number of days of high turbidity and plant shutdowns are most relevant for treatment costs.

A conservative estimate for the increase in turbidity stemming from the disturbance of an average IRA would be an increase in average daily turbidity to 7 NTU per water volume and an increase in the level and frequency of turbidity spikes. A turbidity "stress" level of 10 NTU is used in cost estimations in the next section; it should be noted that impacts can be severe at levels lower than 10 NTU. This value averages elevated background turbidities and turbidity spikes, as well as partial recovery to lower turbidity levels documented over time (a decade plus) if vegetation is allowed to recover and problem sites are fixed (McCaffery *et al.* 2007, Eastaugh *et al.* 2008, Seeds 2010). Although the increased number of days with turbidity spikes and their high NTU turbidities are the key determinants in assessing increased costs of water treatment, a paucity of information relating these to additional costs presents serious challenges.

Water Availability

In addition to elevating turbidity and suspended solids, logging, road building, grazing and other activities that modify natural vegetation and hydrology in watersheds increase the intensity and frequency of peak flow conditions and flood events, reduce pool abundance, reduce channel depth and increase summer flow deficits (e.g., Duncan 1986, Wright *et al.* 1990, McIntosh *et al.* 1995, Jones and Grant 1996, Grant *et al.* 2008). Relative to roadless watersheds with intact natural vegetation, "managed" watersheds (areas logged and heavily roaded) produce less available water (the total amount of treatable raw water available per month) because of these intensified high flows and exacerbated low flow conditions. The lower evapotranspiration rates associated with lower biomass in managed versus unmanaged watersheds can result in more total annual stream flow up to a point (e.g., loss of mesic habitats across landscapes can affect local precipitation patterns, and older forests use less water than younger forests [Hicks *et al.* 1991, Jones and Post 2004, Moore *et al.* 2004, Perry 2007]). The water from managed watersheds is of lower quality (e.g., elevated background turbidity and suspended solids and more turbidity spikes), however, and runs off more quickly so that there are lower summer flows downstream. Water treatment facilities have to shut down during high turbidity conditions—commonly associated with intensified peak flows—and spend more money to treat or import water (e.g., Dearmont *et al.* 1998, Lewis *et al.* 2001). Moreover, higher sedimentation rates can fill up reservoirs more quickly, reducing the volume of stored water

(Ambers and Wemple 2008, Seeds 2010). During low water periods, water quality can deteriorate because of higher temperatures and increased biological activity, and water deficits create a range of financial and technical problems, including negative impacts on fisheries and in-stream recreation such as boating and rafting (e.g., Brown 1999) and costs associated with importing and diverting water. From a water availability perspective, roadless areas function like sponges and managed landscapes like water slides.

How much of a decrease in available water would occur if roadless areas were developed? The answer for any given watershed or water district depends on a range of factors, including watershed size, water volumes used, water treatment, available storage, and dispersal facilities in place. Other factors include forest age (older upland and riparian forests consume less water [Hicks *et al.* 1991, Jones and Post 2004, Moore *et al.* 2004, Perry 2007]), rainfall and snowpack patterns, the proportion of secondary and tertiary watersheds that are in montane versus lowland settings, and the relative proportion of IRAs to non-IRA sub-watersheds within a larger drainage. However, based on first principles and multiple empirical and theoretical studies about landscape-scale hydrology of watersheds from around the world, the trend is that less available water will be derived from IRAs for public water supplies, agriculture, industry and recreation if these intact watersheds are disturbed. Given that IRAs make up roughly a third of national forests and a significant portion of upper watersheds in many regions, and that many public water supplies derive their water from montane versus lowland intakes, one can conservatively estimate that disturbing an IRA or network of IRAs would result in a decrease of available water of at least several percent. A decrease of 1 percent of stream flow in Colorado rivers is considered a major challenge to water supply and a 10 percent decrease calamitous (Doyle and Gardner 2010). Careful studies are required to better understand this relationship, especially in light of projected reductions of precipitation and stream flow (up to 35 percent decrease projected) in the West from climate change (e.g., Brown 2008, Saunders *et al.* 2008).

Pronounced Negative Impacts From Losing the Last Intact Tributaries

IRAs and other wildlands represent "islands" within a sea of compromised and degraded watersheds at landscape and regional scales (Frissell 1992, Forman 1999, Baker and Knight 2000, Strittholt and DellaSala 2001, VanShaar *et al.* 2002, Beschta *et al.* 2004), and represent less than 5 percent of the area of most major drainages (for example, the entire Columbia River or Missouri River basin). Most national forest lands, and private lands more so, are highly degraded from a hydrologic standpoint. Logging has dominated the landscape, and the total miles of roads on USFS lands are now greater than the total miles of the U.S. interstate highway system, with more than 2.8 million acres of inventoried roadless areas degraded over the past two decades (i.e., before the Roadless Conservation Rule of 2001) on USFS lands alone (Greenwald 1998). However, the extensive coverage of IRAs and other wildlands across mountains with their key hydrologic properties (again, IRAs make up roughly a third of national forest lands and upper watersheds in many regions) means that they are hydrologic hot spots, natural areas with relatively small spatial extent that have a particularly important role in producing clean and available water within a given watershed.

For many major drainages (e.g., entire major river basins), national forest IRAs represent the last 1 to 5 percent of properly functioning hydrologic land (note that they still represent a significant proportion of upper watersheds). As in many other biophysical and ecological processes, losing the very last percentages of intact habitat or population results in increasingly severe impacts to terrestrial and aquatic systems as critical areas dwindle and fragment further (Lindenmayer and Fischer 2006). Thus, IRAs are both hydrologic hot spots and, as the lands around them become degraded, hydrologic refugia within watersheds with an enormously important role in keeping clean and available water flowing. When the last functional refugia in any given drainage are lost, significant losses in water resource benefits also are likely. Although agriculture and urbanization can greatly alter stream flows, the prudent and precautionary approach to protecting water supplies would be to protect the last high-quality water-producing lands. This makes especially good sense in the face of changing climates and increasing demand.

The High Cost of Losing Roadless Area Water

General Economic Benefits of Roadless Area Water

Water from wildlands is exceptionally valuable, whether one looks at economic benefits to jobs and income, willingness to pay for benefits, average values, or the marginal value of water (Brown 2000, Sedell *et al.* 2000). The USFS estimates the value of the water derived from national forests in 2000 at more than $3.7 billion (Sedell *et al.* 2000, Dombeck 2003). Krieger (2001) values national forest water at $27 billion annually, and calculations of the water treatment value alone of national forests ranges from $490 million (Loomis 2005) to $18 billion (Krieger 2001). Loomis (1988) estimated that savings from avoiding sedimentation from logging in national wildlands would range from at least $130,000 to as much as $260,000 annually to local towns associated with just one small national forest of 631,000 acres. Given the 47 million acres of wilderness in the United States, this was extrapolated to national cost savings of $9 billion to $18 billion for local treatment plants and highway departments. Costanza *et al.* (1997) assign a value of $35 per acre for temperate forests for waste treatment benefits by recovering mobile nutrients and cleansing the environment, with much of this process involving the movement of water through watersheds. Roadless areas are estimated to provide $490 million in waste treatment benefits annually (Loomis and Richardson 2000).

Valuations from the Southwest region echo the national significance of IRA water. Berrens *et al.* (2006) estimate a water quality benefit from New Mexico IRAs (1.6 million acres) of $35 million and potentially up to $42 million with a proposed expanded IRA network (for use benefits alone), with clean and abundant water contributing to an estimated outdoor recreation benefit of $27 million and a $14 million passive use benefit annually. Sedell *et al.* (2000) estimate for the Southwest an average marginal value of stream flow for in-stream (fisheries, recreation, boating, other forms of recreation, property values, etc.) and off-stream use (public supply, domestic use, commercial use, irrigation, livestock, industrial use, mining and hydroelectric power) of approximately $205 million per year.

Unit valuations of national forest water range from $47 per acre-foot of water for consumptive uses and $20 for in-stream flow (Berrens *et al.* 2006) to stream-flow valuations in Colorado of up to $940 per acre-foot of water (Talberth and Moskowitz 1999), compared with a 1978 average value of $2 per acre-foot of flow for all water nationally. The economic effect of roadless areas, in general, on jobs and income in New Mexico are calculated at 938 jobs and $23 million in personal income annually (Berrens *et al.* 2006), though the direct and indirect contribution from IRA water has not been disaggregated.

These valuations consistently caution that their figures are underestimates for a variety of reasons, and possibly gross underestimates (see Sedell *et al.* 2000, Berrens *et al.* 2006). *In short, high-quality roadless area water nationwide is worth millions to billions of dollars annually to millions of Americans, a fact that has largely been ignored in federal roadless area valuations (GAO 2000, USFS 2000). Compromising the hydrologic benefits of IRAs, as presented in the Colorado federal proposal (UFSF 2011), for example, could result in significant economic losses from diminished water quality, depending on the level of development, and such losses should be factored into cost-benefit analyses before development projects are even considered.*

Estimating Potential Costs of Disturbing Roadless Areas for Off-Stream Water Use at the Watershed Scale

Chronic elevated turbidity and spikes (episodic high levels) in turbidity in raw water intakes in the mountains or in main-stem rivers associated with disturbed tributaries can increase water treatment costs over time through increasing average daily costs for treatment, treatment costs for turbidity spikes, replacement costs for plant parts damaged by turbidity, and treatment plant shutdown days. Additional costs could include more requirements for retrofitting facilities or developing new treatment facilities, intakes and storage areas, and staff time for monitoring and maintenance. In particular, major spikes in turbidity, suspended sediments, and dissolved organic compounds associated with storm events and related mass erosion incidents can overwhelm water treatment capacities and be a major source of financial strain on municipal budgets. The effects of storm events are exacerbated by upper watershed disturbance, such as forestry activities and roads (Grizzel and Beschta 1993). Indeed, spike turbidity and erosion events are likely to be the single most important driver of unacceptable cost increases for water treatment and reservoir maintenance downstream (e.g., Seeds 2010) if IRAs are further disturbed as proposed in recent state IRA petitions. This is because actions required to prevent or rectify frequent mass erosion events are exceptionally costly.

The acute conditions precipitated by episodic, but frequent, storm events are most critical in the IRA water debate. However, elevated background and spike turbidity, chronic and acute sedimentation, and reduced water availability all represent added costs to public water systems, and, consequently, federal, state, municipal and personal budgets (Forster *et al.* 1987, Holmes 1988, Dearmont *et al.* 1998, Postel and Thompson 2005, Freeman *et al.* 2008).

At a watershed scale, one can get a sense of the potential costs from losing IRA water by examining examples of defensive (averting) spending. How much does it cost, for example, to put in place technological substitutes, such as water treatment plants, to take the place of water purification services of forested watersheds? This approach typically represents the lower end of the value scale because it relies on the least costly alternative rather than the maximum willingness to pay. Again and again, we find that technological substitutes are imperfect compared with benefits from nature (Krieger 2001). For example, Salem spent approximately $100 million on new treatment facilities after logging in upper watersheds created conditions leading to mass sedimentation in its watershed following storms in 1996 (Talberth and Moskowitz 1999). New York City spent $1.4 billion on 80,000 acres of forested watershed in the Catskills to protect its water supply (NRC 2000). Portland, OR, spends $920,000 annually to protect its Bull Run watershed, helping to avoid a $200 million expenditure for a new filtration plant after logging in the watershed halved the reservoir capacity within eight years (Reid 1998, Larson 2009). Seattle deferred a $150 million filtration plant expenditure through an intensive watershed rehabilitation program that will decommission 300 miles of road over a 10-year period, fix road erosion problems and limit access and high-risk sediment/fire activities within the watershed (Seeds 2010). Municipal water districts typically seek the least costly path based on objective fiscal analyses, so it seems clear that, in the case of watersheds, prevention—maintaining watershed health through protection and restoration—costs significantly less than the cure.

One can also estimate the costs to local water districts if raw water turbidities increase, spikes become more frequent, sediment begins to overload storage capacity, and water becomes less available. For small community public water systems, budgets are tight, and the communities can ill afford to absorb substantial cost increases or upgrades. A range of costs are associated with elevated turbidity and sediments, including dredging of reservoirs, impoundments and intake pools; increased use of flocculation/coagulation chemicals; new filter systems for chronic turbidity; new intake structures or development of new water sources; and increased staff time for monitoring, maintenance, inspection and permitting (Seeds 2010). In addition, there are short-term public health risks associated with loss of a water supply, poor capacity to remove toxins or pathogens, potential deficits in water for firefighting, and costs to buy outside water, if required (Seeds 2010).

The specific water treatment cost increase linked to higher turbidities depends on the organic load, sediment load, concentration of inorganic substances such as manganese, water temperature, hydraulic load of the treatment plants, staff time costs, and varying costs of chemicals and electricity. Nationally, the average cost to municipalities for turbidity treatment activities because of soil erosion has been estimated at $113 per million gallons of water (Holmes 1998). Forster *et al.* (1987) arrived at $92 per million gallons, and $74 per million gallons was calculated by Dearmont *et al.* (1998). The chemical costs for treatment for Denver Water are $65 and $85 per million gallons treated, but when labor, power, repairs and other factors are added in, the cost of treatment averages about $200 per million gallons. Estimates of elasticities for turbidity (i.e., the percentage change in cost for a 1 percent change in turbidity) range from 0.07, 0.119, 0.27 to 0.33 (Clark *et al.* 1985, Forster *et al.* 1987, Holmes 1988, Moore and McCarl 1987, Dearmont *et al.* 1998).

Using a conservative elasticity of 0.75 (i.e., a 1 percent increase in turbidity increases treatment costs by three-fourths of a percent [using the Denver Water inclusive cost estimate of $200 per million gallons]), and given an average post-disturbance background/spike turbidity of 10 NTUs from a compromised watershed (i.e., 100 percent over an EPA-defined high level of turbidity of 5 NTU), one can get an estimate of the scale of costs associated with degrading IRA water: $300 per million gallons of water. Denver treated about 60 billion gallons in 2009 (Denver Water 2010). An increase of average turbidity from 5 NTU to 10 NTU would result in an estimated $6 million in added treatment costs. A conservative division of this by a third, to account for the proportional coverage of IRAs in upper watersheds, would still require an additional $2 million in treatment costs for Denver Water. Clearly, a wide range of variables is not considered in this calculation, yet it is indicative of the scale of cost to major urban areas of losing high-quality IRA water. Nationally, losing the hydrologic function of IRAs would cost cities, states and the U.S. government billions of dollars annually. This is on the basis of the quality of raw intake water for drinking water alone.

The Costs of Less Water

The potential costs of a decline in available water because of IRA disturbance is challenging to estimate because of a lack of data on the range of stream-flow reductions associated with altering upper watersheds, let alone the subset of IRAs. Moreover, water deficits will depend much upon alternative sources of water, the extent and distribution of IRAs in a given upper watershed, water district storage capacities, and the seasonal profile of available water for each water district, among other factors. However, most raw water is sourced from the mountains in IRA regions, so some fiscally significant reductions in available water are to be anticipated, and water shortages are already being documented in numerous drainages throughout the West, a pattern consistent with both watershed degradation and climate change predictions. As an example of the scale of fiscal impact, consider a modest $50 per acre-foot of water (an acre-foot is equal to 325,851 gallons of water) for a unit valuation. (This is considered a modest unit cost, as some water values in the West are over $1,500 per acre-foot [Mohammed and Tarboton 2008].) Then a 10 percent reduction in Denver's treated water volume (60 billion gallons) is roughly equivalent to a unit water valuation loss of $1 million, although the real costs are probably much higher because of actions necessary to make up for a water supply deficit. Again, multiple factors have not been accounted for in this estimate and it probably is a gross underestimate, but it suggests that a decline in available water will be costly, given the greatly increasing demand for and escalating shortages of water.

In-Stream and Off-Stream Benefits Other Than Drinking Water

Intact Roadless Area Vegetation Controls Floods and Downstream Sediment

The National Forest System was established initially in response to damaging and costly floods that followed widespread logging and large-scale fires, largely as a result of human activities (Steen 1991, Anderson 2008). IRAs continue to perform that original function in a significant way (Harr *et al.* 1975, Swanson and Dyrness 1975, Swanston and Swanson 1976, Sessions *et al.* 1987, Benda and Dunne 1987, Weaver and Hagans 1996, Weaver *et al.* 1998). If IRAs were logged or intensively disturbed, dramatic and damaging flooding might well be in the headlines for years.

Flood damage and high sedimentation are enormously costly for municipal budgets (Moore and McCarl 1987, Donald *et al.* 1997, Talberth and Moskowitz 1999, Seeds 2010). For example, logging in the watershed of Salem was cited as the cause of heavy sedimentation in the water supply after major storms in 1996 (Weaver and Hagans 1996, Donald *et al.* 1997, Johnson *et al.* 1997, Schwickert and Mauldin 1997, GAO 1998, Robison *et al.* 1999, Skaugset and Wemple 1999, Talberth and Moskowitz 1999). The city had to spend $700,000 for a temporary pretreatment plant, $200,000 for treating turbid water, $1.2 million on a permanent pretreatment plant, $100 million on new treatment plants, and $3.2 in annual running costs. Dredging of reservoirs to increase capacity and of channels to enable navigation is costing cities, states and taxpayers millions annually.

Extensive disturbance to vegetation in upper watersheds is strongly linked to more intense and frequent flooding events and acute and chronic sedimentation (Morrison 1975, Swanston and Swanson 1976, Megahan *et al.* 1979, Furbish and Rice 1983, Bohn and Megahan 1991, Van Lear *et al.* 1995, Jones and Grant 1996, Donald *et al.* 1997, McClelland *et al.* 1997, Robison *et al.* 1999, Grant *et al.* 2008). Although the federal proposal for CRAs does not include activities that would result in wholesale vegetation loss, even modest logging levels, coupled with road building, mining, oil and gas development, and other forms of development, would result in elevated sedimentation and alteration of flow regimes, including potentially more floods, for decades.

Outdoor-Based Benefits: Vitality and Stability for Local Communities

The comparative benefits to local economies of wildland- and outdoor-based industries (e.g., hunting, fishing, rafting, boating, hiking, etc.) and passive use (e.g., tourism, retirement, property values) associated with clean water, versus the effects of extractive industries (e.g., mining, hydropower, grazing, resorts, logging), have been well-documented. For examples, see Keith and Fawson 1995, Power 1996, Gillian and Brown 1997, Loomis 1999, Loomis *et al.* 1999, McGranahan 1999, Southwick Associates 2000, Krieger 2001, NSFHWAR 2001, Rosenberger and Loomis 2001, IAFWA 2002, Kim and Johnson 2002, Lorah and Southwick 2003, Starbuck 2003, USFWS 2003, Trout Unlimited 2004ab, Kim and Wells 2005, Loomis 2005, Racevskis 2005, Berrens *et al.* 2006, and NMGDF 2006. Considerable economic benefits are being derived from a range of nonmarket goods associated with clean and abundant water from wildlands (Loomis and Richardson 2000, 2001, Krieger 2001, Berrens *et al.* 2006). Berrens *et al.* (2006) calculate that $374 million in national income is supported annually by roadless area recreation ($8.84 per acre of roadless land), and Loomis and Richardson (2000) estimate that recreation in U.S. wilderness areas, including IRAs, is worth $600 million annually. For many visitors, much of this attraction to wildlands is directly or indirectly associated with the presence of clean and abundant water (USFS 2001). Contingent value analyses indicated that households are willing to pay $35 to $95 per year to preserve natural stream flows for aquatic species in rivers in Colorado, New Mexico and Montana, respectively (Brown 1992, Duffield 1992, Berrens *et al.* 1996).

Salmon, Trout and Endangered Species Cost Savings

Millions of dollars are spent annually in this country on the rehabilitation of salmonid (trout and salmon) habitats, populations and fisheries. Intact watersheds, such as those associated with IRAs, continue to function as strongholds for these threatened fish (Henjum *et al.* 1994, Huntington 1995, 1998, NRC 1996, Trombulak and Frissell 2000, Center for Biological Diversity *et al.* 2001, Oechsli and Frissell 2002, Strittholt *et al.* 2004, Petersen 2005). If IRAs are developed, subsequent increased sedimentation may reduce salmonid egg survival, in addition to loss of stream complexity (for example, pools and riffles, large woody debris, altered channel and bank complexity, passage obstruction, channel widening and shallowing, reduced shade). Other effects include reduced flows, larger flood events, low oxygen, elevated temperatures, and altered food webs that greatly increase restoration costs or preclude recovery altogether (Cedarholm *et al.* 1981, Bisson and Sedell 1984, Beschta *et al.* 1987, Bjornn and Reiser 1991, Frissell 1992, NMFS 1995 and 1996, Espinosa *et al.* 1997, Bash *et al.* 2001, CBD *et al.* 2001, Frissell and Carnefix 2007, Karr *et al.* 2004, Strittholt *et al.* 2004). A threshold of 20 percent fine sediment over natural conditions has been recommended as the maximum that allows for salmonid persistence (Rhodes *et al.* 1994, Espinosa *et al.* 1997), a challenging target given the high sediment increases associated with even low levels of road building, logging, grazing and other disturbance and the fact that recovery is quickly reversed with periodic impacts (Espinosa *et al.* 1997).

Continued logging, road building and grazing in national forests are often in direct conflict with government efforts to restore salmon and trout fisheries (Boise National Forest 1993, Rhodes *et al.* 1994, Beschta *et al.* 1995, 2004, Huntington 1995, NMFS 1995, 1996, Espinosa *et al.* 1997, Lindenmayer *et al.* 2004, EPA 2005). Securing strongholds for fish within IRAs at least will sustain critical source pools if realistic restoration efforts occur in the future (Naiman *et al.* 1992, Henjum *et al.* 1994, Frissell and Bayles 1996, NMFS 1996, Frissell 1997, Reeves *et al.* 1997, Niemi *et al.* 1999, DellaSala *et al.* 2003).

The relatively healthy aquatic ecosystems of many IRAs also function as refugia for threatened and endangered species. Like salmonids, other native fish species and freshwater biota are similarly stressed by changes in stream temperature, loss of habitat complexity, sedimentation, and flow regimes (Cordone and Kelley 1961, Bjornn *et al.* 1974 and 1977, Klock 1985, Corn and Bury 1989, Newcombe and MacDonald 1991, Cover *et al.* 2008). Freshwater species are among the most threatened on the continent, with more than 300 species listed or proposed for listing under the Endangered Species Act and more than 37 percent of native fish species at risk of extinction (Nature Conservancy 1996, Abell *et al.* 2000, DeVelice and Martin 2001, WWF and CBI 2004). Maintaining IRA freshwater habitats in good condition prevents legislated expenditures and costly litigation related to the restoration of habitats and populations of federal and state listed species. Restoring aquatic habitats and their threatened species has proven to be very expensive and requires a long-term commitment (Reeves *et al.* 1991, NRC 1992, Anderson *et al.* 1993, Hitt and Frissell 2000, Loucks *et al.* 2003, Beschta *et al.* 2004).

Growing Recognition of the Economic Value of Wildlands

The economies of local communities in proximity to IRAs and in regions with concentrations of IRAs and other wildlands will continue to outperform those that are not (Kriesel *et al.* 1996, Duffy-Deno 1997 and 1998, Power 2000, Southwick Associates 2000, EcoNorthwest 2001, Lewis *et al.* 2002 and 2003, Phillips 2004ab), even if the considerable economic benefits of natural services from IRAs continue to go largely unreported by management agencies (USFS, BLM) and the U.S. government limits their valuations to the loss of revenue from extracted commodities. (For IRA examples, see Fight *et al.* 1978, Forest Ecosystem Management Assessment Team 1993, GAO 2000, Loomis and Richardson 2000, USFS 2000, Krieger 2001, Heinzerling and Ackerman 2004, Berrens *et al.* 2006; see broader benefit evaluations, such as Haynes and Horne 1997, Rudzitis and Johnson 2000, Cordell and Chamberlain 2004, McLain and Jones 2005.) Passive use values (i.e., the intrinsic value of wilderness, wildlands and benefits for the future) for the nation's roadless areas are estimated at $280 million annually (Loomis and Richardson 2000). Without even considering drinking water, the clear trend is that local, urban area, state and regional economies enjoy significant economic benefits associated with high-quality water and associated water resources from within IRAs and other wildland protected areas.

Photo: Nelson Guda

Columbines at the base of aspen trees in the Springhouse Creek inventoried roadless area, Colorado.

III. Climate Change and the Skyrocketing Demand for Water

Major Findings

- Stream-flow reductions ranging from 10 to 35 percent have been projected for the Western states over the next half-century as a consequence of climate change. A 10 percent drop in stream flow is considered calamitous by most municipal water districts.
- Population in the West is projected to increase 300 percent within 30 years, with similar increases in demand for water.
- The most cost-effective and prudent approach to maintaining water supplies in the face of population growth and climate change is to manage headwaters (upper watersheds) in a roadless state with undisturbed natural vegetation.

Even if dramatic increases in water demand and drier conditions from climate change were not realities, disturbing the hydrologic role of IRAs would still be a short-sighted financial and management decision. Given that those conditions are realities (Intergovernmental Panel on Climate Change 2001, Udall and Bates 2007, Saunders *et al.* 2008), degrading the watershed function of IRAs would be potentially catastrophic at a time of global climate change. Rural and urban communities will increasingly need IRAs because of increased populations and decreased water supplies in many places over the next few decades. Even if IRAs are left intact, the challenges ahead are enormous. Exacerbating these challenges or losing options by squandering some of the last hydrologically intact areas is clearly not in the best interest of the nation.

Dramatic Increases in Demand for Water

The population in the West is projected to increase by 300 percent by 2040 (Sedell *et al.* 2000). Urban areas and exurban areas are growing exponentially, including communities adjacent to wilderness areas and IRAs (Theobald 2005). Colorado is expected to have water deficits of 630,000 acre-feet within 20 years because of an anticipated 50 percent population growth, and the population is projected to double again by 2050, with a tripling of demand for water (Colorado Water Conservation Board 2009, Doyle and Gardner 2010). Population and communities are expanding everywhere IRAs are located, and the demand for water and water-based recreation is consistently going up, often dramatically (Frederick 1991, Foster 2009, Brown 1999). Actions that can be taken to help maintain water supply for a period include conservation, recycling, improved treatment and delivery technologies, increased storage, resolution of water rights conflicts, and establishment of more conservation-friendly rate structures (Snover *et al.* 2003, Denver Water 2010, Doyle and Gardner 2010, Seeds 2010). Another option is agriculture-urban water transfers, although considerable negative impacts on agriculture are associated with such transfers (Doyle and Gardner 2010). However, the projected increasing demand and drying conditions in drought-prone regions threaten to overwhelm their positive contributions to water availability.

Less Water From a Changing Climate

Climate change is predicted to lead to hotter and drier conditions in much of the western United States (IPCC 2001, Hayhoe *et al.* 2004, Milly *et al.* 2005, Seager *et al.* 2007, Cayan *et al.* 2006, Hall *et al.* 2008, Bates *et al.* 2008, Diffenbaugh *et al.* 2008, Environmental Defense Fund 2009, Foster 2009). Glaciers are melting (Brahic 2007) and snowpack is reduced (up to 40 percent by 2050 in California [California Department of Water Resources 2008]), with earlier snowmelt (Stewart *et al.* 2004, Mote *et al.* 2008a, Knowles *et al.* 2006, Kaufman 2008, Casola *et al.* 2009). Dramatic regional shifts in seasonal temperatures, evapotranspiration, precipitation and stream-flow patterns are predicted, including warmer and wetter winters (which translates into less storage of available water) and hotter and drier summers (Cayan *et al.* 2001, Meehl and Tebaldi 2004, Regonda *et al.* 2005, Dettinger *et al.* 2007, Redmond and Abatzoglou 2007, Barnett *et al.* 2008, Bates *et al.* 2008, Hall *et al.* 2008, Mote *et al.* 2008a, Saunders *et al.* 2008, Dulière *et al.* 2009, Luce and Holden 2009, Zhang *et al.* 2009). All of these changes will contribute to less available water in already drought-prone regions of the West. (Hamlet and Lettenmaier 1999, Saunders *et al.* 2008 provide a good review of climate change projections and the evidence for changing conditions for the Western states.) Although models depict some coastal areas and pockets in the Northwest becoming wetter (Mote *et al.* 2008b, Salathé *et al.* 2008), stream flow has shown significant declines in that region over the past several decades (Luce and Holden 2009).

Most of the West is already experiencing less snow, more winter rain events, reduced summer flows, higher temperatures with consequential higher evapotranspiration, increased peak winter flows, and more intense summer droughts—all trends that reduce available water and that have been linked to a changing climate driven by human activities (Barnett *et al.* 2008, Mohammed and Tarboton 2008, Miller *et al.* 2010). Where heavier rainfalls and more intense and frequent flash floods occur, these conditions are not likely to contribute to a stable surface water supply or recharge of groundwater aquifers. Wildfires and mountain pine beetle outbreaks (correlated to rising temperatures [Schoennagel *et al.* 2004, Saunders *et al.* 2008, Black *et al.* 2010]) are expected to increase and affect more of the landscape, further degrading the hydrologic state of upper watersheds. Moreover, during the 20th century, stream flow in Colorado was estimated to be the highest it has been in half a millennium based on tree-ring analyses (Stockton and Jacoby 1976, Webb *et al.* 2004). This pattern has raised expectations of abundant water and highlights the natural variability and vulnerability of water supplies in the state.

Many of the benefits of IRA water besides drinking water are being affected by changing climate, including fisheries, river-based recreation, and a wide range of in-stream and off-stream benefits (Saunders *et al.* 2008). Assigning potential economic losses and financial stress to climate change-related reductions in water quality and availability is difficult, given the many factors at play in a watershed or region, but stream-flow reductions of 10 to 35 percent are projected (even with mediation from groundwater [Tague *et al.* 2008]), and significant reductions related to climate change have been documented (Barnett and Pierce 2009). Snowpack volume and snowmelt timing are already strongly affected; storm events and wildfires are occurring more frequently in places (Westerling *et al.* 2006); and less water is available in summer (Saunders *et al.* 2008). Such high percentage volume reductions are dire to public water systems and to city managers, farmers, ranchers and firefighters (Doyle and Gardner 2010). More frequent and intense flood events also have been predicted in some places (Raff *et al.* 2009) despite the drying conditions and will escalate costs for flood control, repair and reconstruction, and insurance rates (GAO 2007). Severe and unprecedented droughts already have a grip on much of the West (Drechsler *et al.* 2006, Saunders *et al.* 2008).

The specter of skyrocketing water demand and a hotter and drier climate cannot be ignored in the debate over IRA water, because such factors can work in concert to create a grim scenario of rising demand and shrinking supply. The wisdom of protecting IRAs as the last redoubts of hydrologic integrity is multiplied greatly because of the pivotal role that IRAs provide as climate change insurance.

Conclusions

The reasonable and precautionary approach to roadless areas and their valuable water is to manage them as municipalities manage their water-supply watersheds: a light ecological and hydrological footprint and active hydrological restoration through decommissioning and obliterating roads and engaging in other restoration actions (Barten *et al.* 1998, NRC 2000, Payne *et al.* 2004, Gallo *et al.* 2005, Postel and Thompson 2005, Seeds 2010). This approach is also the most financially responsible, cost-effective and risk averse for those concerned about a reliable supply of abundant clean water.

The management goal would be to maintain ecological and hydrological parameters within IRAs at levels that fall within natural ranges of variation. This would require the following conservation measures:

- Maintain the areas' status as federal IRAs (eventually including unroaded areas on national forest and Bureau of Land Management lands, which hold similar benefits) and give them protections equivalent to those of federal wilderness areas. Wherever possible, add more roadless areas to the inventoried network, even those under 5,000 acres, which collectively rival the formal IRA network in acreage and contribution to maintaining clean water and aquatic ecosystems.
- Avoid trading out IRAs for protection of unroaded areas, because development of the former has economic costs that will result in cumulative losses to the IRA network.
- Restrict logging,[2] road building, forest prescriptions (salvage logging, forest health logging, fire risk logging [with roads, as opposed to thinning without road building], mountain pine beetle logging), mining, pipelines and rights-of-way, grazing, hydropower, and any other development activities that would require road building or maintenance or hydrologically significant disturbance of natural vegetation or soils.
- Decommission and obliterate existing roads and actively revegetate them with native plant species (Switalski *et al.* 2004, Seeds 2010). These actions will contribute significantly to restoring the hydrologic health of IRA watersheds.
- Where roads exist and cannot be removed, fix chronic and mass erosion problems.
- Restrict access during high fire-risk conditions through seasonal closures.
- Restrict certain non-extractive activities that are associated with high fire risk and chronic erosion, such as ORV use.
- Prohibit livestock grazing within IRAs, especially within riparian areas and wetland habitats.
- Evaluate trails that contribute to excess erosion and close or relocate them to less erosive paths.
- Actively restore riparian habitats and other degraded vegetation types with the goal of natural structure and composition of native communities.

- Based on plant association group and local conditions, emphasize late-successional natural communities within the IRA to maintain high-quality water and provide long-term stability to plant communities, which release water more slowly over time than watersheds with younger vegetation.

- Actively control invasive plants that affect hydrological processes.

- Evaluate all approved activities for impacts on hydrological conditions, vegetation, erosion, runoff and aquatic habitats. Make interest groups and the public aware of best practices and regulations and enforce them effectively.

- Develop and implement a simple and cost-effective hydrologic monitoring system for all IRAs. Rhodes *et al.* (1994) emphasize that all the pieces—including water temperature, fine sediment levels, stream flows—need to be in place to retain healthy aquatic ecosystems.

- Create an ecological, hydrological and water benefit report card for each IRA to inform all stakeholders, including public water systems, the public, government, natural resource agencies, hunters, fishermen, hikers, landowners, local communities, NGOs, industry partners and scientists.

- Designate all perennial and non-perennial streams and rivers in wilderness areas and roadless areas as outstanding national resource waters. New Mexico requested this designation for all perennial and non-perennial streams and rivers in headwaters of national forest lands, as well as state lands (Matlock 2010).

Expanding the roadless area network to cover a greater proportion of upper watersheds would result in major gains to hydrologic integrity and water quality and availability. Importantly, roadless tracts of less than 5,000 acres need to be inventoried, classified and managed as IRAs (Henjum *et al.* 1994, Rhodes *et al.* 1994), because collectively they provide a very large contribution to hydrologic integrity of tributaries and broader watersheds, and losing them would have enormous ecological and hydrologic impacts.

Most importantly, the federal proposal for Colorado's roadless areas seeks to change the status and management of IRAs and has the potential to result in hydrologic degradation that could cause irreparable harm to the multiple benefits of roadless area water and the people who depend on it.

Appendix 1: Colorado Inventoried Roadless Area Water Assessment

Richard Nauman and Jessica Leonard, Geos Institute

The extent and location of Colorado's existing Inventoried Roadless Areas (IRAs) were analyzed within the context of 399 single water source points in Colorado obtained with permission from the state of Colorado.

Abbreviations

Surface Water Source Area = SWSA
Inventoried Roadless Area = IRA
Colorado Roadless Area = CRA

Input

Data from Colorado's Source Water Assessment and Protection (SWAP) Program were provided by John M. Duggan, Colorado's SWAP coordinator. We focused our efforts on the 399 geodatabases contained in the SRCID_Geodatabases folder. Each geodatabase contained data layers for a single water source point (sw1_source) and its associated water source area (sw9_swaa).

Processes

The Colorado SWAP data set was challenging to analyze, because each water source is stored in a separate geodatabase, and custom software tools were created to work with the data.

The basic tool followed this procedure:

For each geodatabase in the SRCID_Geodatabases folder:
Clip IRA to SWSA.
If there is IRA in the SWSA, copy geodatabase to new folder.
Calculate area of IRA in SWSA and write to text file.
Calculate area of SWSA and write to text file.
The proportion of IRA in each SWSA was then calculated.

Forty records were reviewed by displaying layers in ArcMap and visually checking the area of SWSA and area of IRA. All area calculations appeared to be correct from visual inspection of the data.

Outputs

Final Table: Colorado_SW_IRA_areas_15sept2010.xlsx

Fields

SYSTEM_ID—Water system ID number.

SWSA_AREA—Area of surface water source area [SWSA] in hectares.

IRA_AREA—Area of IRA in SWSA in hectares.

PROPORTION_IRA—Proportion of SWSA that is IRA.

SYS_NAME—System name—this came from the original dataset.

SRC–Unknown—this came from the original data set but appears to be the name of the water source.

COUNTY—County where intake is located.

Results

SWSAs and IRAs

- 399 SWSAs in Colorado.
- 302 SWSAs have IRA.
- The six SWSAs that have IRA but no CRA have small amounts of IRA (1-22 ha).
- Mean proportion of IRA in SWSAs = 25 percent.

Data Limitations

- Our summary is limited to SWSAs with IRA. At the completion of this report (May 2011), the 2008 petition was issued as a federal proposal on April 15, 2011 (USFS 2011), and thus we did not include the CRA comparisons that were made initially using these 2008 data sets.

Files

- Input: \GIS_Data \Roadless\CO_Water_Data\SRCID_Geodatabases
- Final output: \GIS_Data\Roadless\CO_Water_Data\Processor_Output\Colorado_SW_IRA_areas_15sep2010.xlsx
- The 302 geodatabases used in the analysis: \GIS_Data\Roadless \CO_Water_Data\Geodatabases_with_ira
- ArcGIS map used for QA/QC review: Colorado_SW_1sept2010.mxd

Software Tools

Watershed_Tool_25Aug2010.py

Copies geodatabases in Colorado files that have IRA to a new folder. It sums the area of the water source area file and IRA in each source area and writes the values to a *.txt (comma delimited) file along with the water source ID from the base name of the geodatabase.

get_other_fields_tool.py

This tool was used to get a couple of fields from the SW point table. The two tables were then joined manually in xls.

Challenges

Our initial attempts to estimate flow at surface water intakes that originate on IRA were unsuccessful. Resolution of flow estimates in the NHD plus data set was insufficient to differentiate flow changes over relatively short distances. IRAs are very small relative to the scale of the NHDplus dataset.

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Opposite page: Aspen trees in the Clear Creek inventoried roadless area, Colorado. Photo: Nelson Guda

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