

# Between a Rock and a Dry Place

The Impact of Oil Shale Development and Climate Change on the Colorado River Basin Water Supply

August 2011



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## ACKNOWLEDGEMENTS

The Natural Resources Defense Council would like to thank the Pisces Foundation, the William and Flora Hewlett Foundation, the TOSA Foundation, and an anonymous donor for supporting NRDC's work on the intersection of water, climate, and energy issues.

We would like to thank Lawrence J. MacDonnell who contributed significantly to the sections on Colorado River Basin water rights. We also wish to thank Bart Miller and David Abelson with Western Resources Advocates whose work on oil shale and water issues in Colorado was an inspiration for this effort, and whose review and support of this report was invaluable.

This report also received substantial input and review from a number of individuals. Their participation contributed to the quality of the report and its recommendations. We acknowledge that they may not necessarily endorse all of the report recommendations, which are solely those of the Natural Resources Defense Council. In particular, we wish to thank our peer reviewers: John Leshy, Professor, Hastings College of the Law, University of California; Robert Glennon, Professor, University of Arizona College of Law; Robert Adler, Professor, University of Utah College of Law; Douglas Kenney, Research Associate, University of Colorado School of Law.

We also wish to thank Pam Adams, Carly Jerla, Alan Harrison, Shana Tighi, and many others with the Bureau of Reclamation for assistance with the data and photographer Garth Lenz, for use of his photos.

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# 1. EXECUTIVE SUMMARY

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Lake Powell, U.S. Geological Survey Department of the Interior (USGS)

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**A**s the price of oil increases, so does the interest in oil shale as a source of energy to fuel U.S. demand. Oil shale development has been explored for decades, but no viable industry has resulted due to overwhelming costs, technical challenges, and environmental impacts, not the least of which is the impact on water.

Oil shale is found largely in the arid northwestern region of Colorado; processing it requires significant amounts of water—on average, an estimated three to five barrels for each barrel of oil produced. A full-scale oil shale industry producing 1.55 million barrels of oil a day would require approximately 360,000 acre-feet of water a year—roughly one-and-a-half times the amount of water used by Denver per year. The water supply impact of this demand would not only affect agriculture and cities in the region, but could have an impact on all Colorado River Basin water users, even those as far away as Southern California.

Water is life in the arid West and already there is not enough to meet current demands. A 2011 analysis by the Bureau of Reclamation concluded that the Basin's water supply is over-allocated and that current demands are greater than long-term supplies. When the Colorado River Compact was signed in 1922, the estimated yield was 17.5 million acre-feet; however, the Bureau of Reclamation's 2011 analysis concluded that the long-term average yield is about 14.7 million acre-feet and average use since 2000 has been 15.3 million acre-feet. In the past, water supply impacts of droughts were buffered by large reservoirs on the Colorado River, but this may no longer be the case. The recent drought has resulted in Lake Mead dropping, in the fall of 2010, to levels not seen since 1937, when the reservoir was first filled. The future could bring even greater challenges.

Climate change is likely to further reduce the Colorado River Basin's water supply by 10 to 25 percent by 2050. The Bureau of Reclamation has also predicted a significant reduction in Colorado River flows. This drastic loss in water supply will create unprecedented challenges for cities and communities throughout the West.

Although the precise extent of global warming is unknown, a significant amount of additional warming is inevitable given current levels of greenhouse gases in the atmosphere. Therefore, oil shale development would further strain future water supplies already under pressure from a warming climate, current water use, and population growth.

Oil shale development would not only consume vast amounts of water, but it would also contribute appreciably to greenhouse gas emissions. Compared with conventional oil fuels, oil shale generates up to 73 percent more greenhouse gas pollution, which would, in turn, accelerate climate change and likely increase the impact on water supply to the region.

This report finds that oil shale development would exacerbate the looming water crisis in the Colorado River Basin in a number of ways:

### **The Colorado River Basin Is Already Oversubscribed**

In 1922, the average yield from the Basin was estimated to be 17.5 million acre-feet (maf). However, a 2011 study by the Bureau of Reclamation concluded that the long-term average natural flow at Lee Ferry is closer to 14.7 maf, and that since 2000, average annual use in the Basin has been 15.3 maf. Thus, for the past decade, water use has exceeded the river's flow.

### **Oil Shale Development Would Affect Colorado River Water Users Negatively**

A mid-range estimate suggests that oil shale development—including processing, energy supplies, and related development—could require more than 360,000 acre-feet of water per year, which is equal to one-and-a-half times the amount of water used by the city of Denver; large-scale oil shale use could use even more water—up to 1.4 million acre-feet per year. Reports by the Government Accountability Office (GAO) and others have concluded there is currently insufficient information to conclude with certainty that there is undeveloped water in the Basin. Oil shale development would thus compete with existing water users in several ways:

- Energy companies have purchased relatively senior water rights that they have not yet exercised; if they do so, most of that water is expected to come initially from agricultural water users in Colorado.

- The inflexible industrial demand of oil shale development would reduce the current potential for urban areas to purchase water from more flexible agricultural uses—indirectly reducing water available to Colorado's cities during dry periods.
- Water demand for oil shale could increase Upper Basin consumptive use, putting additional pressure on the Law of the River (Colorado River Compact of 1922 and subsequent agreements and decisions). Industrial use would reduce the flexibility for Upper Basin states to participate in a Basin-wide effort to reduce water use to a more sustainable level, creating an impact on Lower Basin states.

### **Climate Change Could Dramatically Reduce Existing Water Supplies**

Numerous scientific studies have concluded that climate change has already led to warming, especially in the Colorado River Basin, which has been warming more quickly than other parts of the West. The U.S. Climate Change Science Program has predicted runoff decreases of 10 to 25 percent by 2050, or roughly 5 to 12 times Denver's water use. A 2011 interim report on the Basin by the Bureau of Reclamation estimated that flows at Lee Ferry could decrease by 9 percent in this time period.

### **Natural Lands, Fish, and Wildlife Would Be Impacted**

Oil shale deposits occur in areas of Colorado, Utah, and Wyoming that are known for their natural beauty. Large-scale oil shale development would not only mar the landscape with industrial infrastructure but would also impact threatened species in the region. Increased water supply demands could impact tributaries like the Green River and impede efforts to restore four listed species in the Colorado River.

In addition, oil shale could negatively impact both surface and ground water quality. Tailings and processing waste are known sources of toxic pollutants if not contained. In situ processing requires heating and extracting liquefied oil at depths that could pollute groundwater aquifers.

### **Development Would Significantly Contribute to Greenhouse Gas Pollution**

Oil shale production and refining results in more greenhouse gas emissions than conventional oil fuels. Well-to-wheel greenhouse gas emission estimates for oil shale show it has 23 percent to 73 percent (1.2 to 1.7 times) more emissions compared with diesel.

## KEY RECOMMENDATIONS FOR PROTECTING WATER RESOURCES IN THE COLORADO RIVER BASIN

### 1. Develop State and Bureau of Reclamation Colorado River Basin Water Management Plans

- Basin states, individually and as a whole, should develop comprehensive water management plans that take into account current and likely future basin yields, protection of listed species, climate change, and future demand, including demand from potential oil shale development.
- The Bureau of Reclamation's Colorado River Basin Study should determine if there are any existing undeveloped surface and groundwater supplies that are in excess of the Upper Basin's compact obligations.
- The Basin Study should address factors such as projected population growth and the likely effects of climate change, as well as the potential impacts of large-scale oil shale development (including direct impacts to existing users and indirect impacts associated with hardening of demand and reduced flexibility).
- The Basin Study and state-level management plans should include the development of comprehensive water management strategies to manage long-term supplies, including opportunities to promote local, state, and regional conservation and water use efficiency.

### 2. Reconsider Oil Shale Development

- Based on the current information and existing technologies, proceeding with oil shale development would be inadvisable, given the significant impacts on water resources and the environment, particularly through increased greenhouse gas emissions.
- Oil shale is a poor economic investment, especially in the context of energy return, and a distraction at a time when the nation is transitioning to a clean energy economy. Any further exploration should begin with an analysis of potential impacts to water users, groundwater, and sensitive protected species, all in the context of a warming climate and the potential for a 10 to 25 percent reduction in Basin yield.
- Any research initiatives or commercial development should be limited to specific federal lands to ensure that sensitive lands and wildlife habitat are fully safeguarded from the likely and substantial impacts associated with such development.

### 3. Develop Climate Change Adaptation and Greenhouse Gas Reduction Efforts

- States that depend on the Colorado River Basin for their water supply should take immediate steps to implement comprehensive energy and climate policies. This should be accomplished by establishing regional greenhouse gas reduction efforts, including implementing more energy-efficient construction standards, and promoting smart growth planning to reduce vehicle miles.

### 4. Prioritize the Development of Clean and Efficient Energy

- Increasing energy efficiency reduces current and future demand and decreases energy production-related water consumption. Each state in the Basin should take steps to implement comprehensive and ambitious statewide energy efficiency programs and promote clean and water-efficient forms of energy such as wind, solar, and geothermal sources.

Map of the Upper and Lower Colorado River Basin



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## 2. INTRODUCTION

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The re-emergence of a prospective oil shale industry as a potentially significant provider of hydrocarbon energy raises a host of challenges. This report explores one of those challenges—oil shale development requires large quantities of water. The most developable deposits of U.S. oil shale are located in an area of the country with limited water resources (the upper Colorado River Basin in the states of Colorado, Utah, and Wyoming). Use of water from this system for oil shale development raises difficult questions for the seven states and two nations (United States and Mexico) whose water consumers rely heavily on this source.

This report explores some of the possible implications of committing a relatively modest but critical portion of the Colorado River Basin's limited and highly coveted water supply to develop potential sources of energy that would be economically and environmentally costly.

In the Piceance Basin of Colorado, where the richest oil shale deposits are found, the U.S. Geological Service estimates that there are more than one trillion recoverable barrels of oil-equivalent shale.<sup>1</sup> This is a theoretical source of energy, if proven technically recoverable, with significant hurdles to its use. A successful and economically competitive commercial oil shale operation has never been created, despite more than a half-century's worth of efforts to this end.

The climate impacts associated with accelerated greenhouse gas emissions from the development of oil shale would be vast and potentially not worth the gains from energy extracted.<sup>2</sup> The vast majority of this resource is under federal ownership; any foreseeable production process would render this public land uninhabitable for most of the flora and fauna that reside in the vicinity of these deposits.<sup>3</sup>

Of all of these impacts, the most significant may be the scarcity of water in the region combined with the relatively high water demands associated with oil shale production. The United States currently consumes approximately 18.7 million barrels of oil a day.<sup>4</sup> Based on a 2010 report by the GAO, a middle estimate of oil shale production would be about 1.55 million barrels of oil a day, which is only a theoretical number.<sup>5</sup> To obtain this level of production would require, on average, about 4.9 barrels of water for each barrel of oil. At 42 gallons per barrel, this use would equal 116 billion gallons per year, or approximately 360,000 acre-feet of water annually; the city of Denver uses about 234,000 acre-feet of water annually.<sup>6</sup>

Currently, there are growing uncertainties about the amount of water remaining for development in the states with lands in the upper portion of the Colorado River Basin because of reductions in estimates of the current reliable water supply in the Basin. The supply of water generated annually in the upper region of the Basin (the source of 80 to 85 percent of the Basin's supply) is enormously variable, but has averaged approximately 14.7 maf annually. The Bureau of Reclamation recently announced that existing uses in the Basin, including those by Mexico, have been 15.3 maf, which exceeds reliable supplies.<sup>7</sup>

The current situation is further complicated by the growing scientific consensus that global warming will further reduce water supplies in the Colorado River Basin.<sup>8</sup> Flow releases to protect and help recover listed fish species are other challenges that must be addressed in water resource management. Consequently, there are legitimate questions about how much undeveloped Upper Basin water, if any, is currently available for new uses.

Energy companies already have substantial claims to develop water for oil shale in the Upper Basin states.<sup>9</sup> Developing these relatively senior water rights claims would put oil shale use ahead of other new uses under the water right priority system.<sup>10</sup> If either existing or newly developed water supplies are dedicated to oil shale development, other new demands in the Upper Basin will face increased challenges, such as projected growth along Colorado's Front Range and Western Slope, and in the St. George area of Utah.

Also to consider are the many rules governing uses of Colorado River Basin water that affect Mexico, the separate states located in the lower and upper portions of the basin, and individual users—including the numerous Native American tribes with reservations in the Basin. One of the most important considerations of all is the allocation of rights established in the 1922 Colorado River Compact to consumptively use up to 16 million acre-feet of basin water in the United States, and the requirement obligating the Upper Basin to ensure that at least 75 million acre-feet of water pass Lee Ferry (the dividing point between the two regions) every consecutive 10-year period.<sup>11</sup>

This report consists of:

- An overview of oil shale, including emerging technologies for developing it and the many challenges it poses, including water needs.
- An accounting of basin water supplies and the evolving understanding of basin hydrology through the lens of scientific studies that reach beyond the historical record and include climate change.
- An introduction to the complex legal framework that governs uses of the Basin's water, including interstate compacts, decisions of the U.S. Supreme Court, and a treaty with Mexico. Also included is information about ongoing disputes over how much additional water is available for consumptive use in the Upper Basin under this legal framework.
- An exploration of how oil shale's very substantial new demands for water would fit into the aforementioned contested framework—especially in the context of a potentially shrinking water supply resulting from climate change.
- An analysis of the impacts water shortages, including those caused by oil shale development, would have on Mexico, urban users in Arizona, California, and Nevada, and other potential new uses in the Upper Basin.
- An evaluation of how these shortages might trigger prolonged and contentious fights over uses of Colorado River Basin water.
- Suggestions for ways that Basin water uses might be brought back into balance with water supplies.



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Shell Corporation's Mahogany Research Project in Northwestern Colorado's Piceance Basin

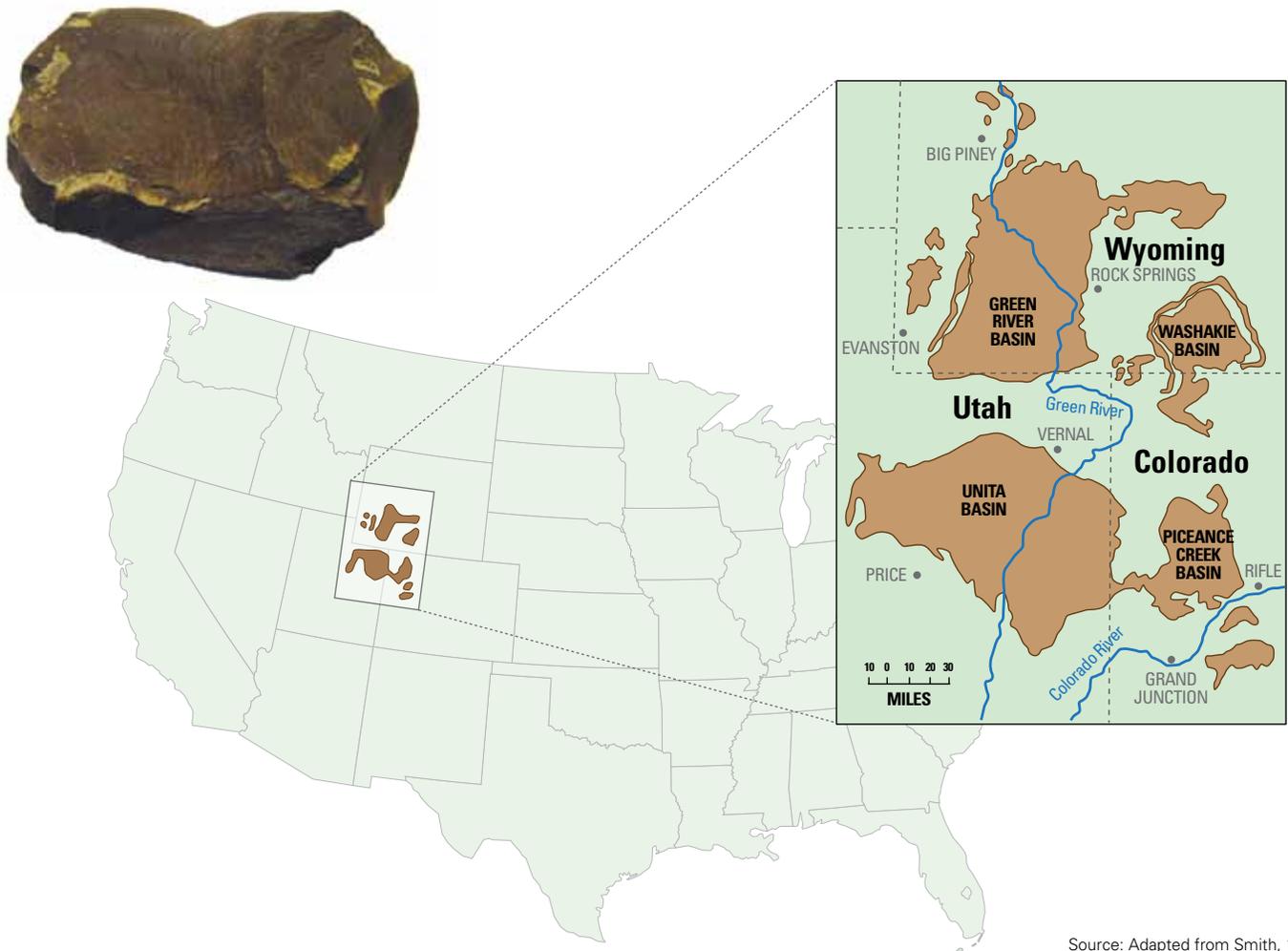
### 3. OIL SHALE DEVELOPMENT AND POTENTIAL ENVIRONMENTAL IMPACTS

#### Oil Shale Resources

Oil shale is “an immature rock source for petroleum” that is sedimentary and contains a solid bituminous material called kerogen; this substance, if heated as part of a chemical process, becomes a kind of liquid petroleum.<sup>1,2</sup> Essentially, oil shale is a source of petroleum that has yet to be naturally heated, or “cooked,” in order to transform kerogen into a liquid.<sup>3</sup> Oil shale, like other sources of petroleum, developed in “environments devoid of life.”<sup>4</sup> Water bodies deficient in both oxygen and sulfate accumulated dead organisms in bottom sediments.<sup>5</sup> The oxygen and sulfate-depleted environment preserved the organic material.<sup>6</sup> Over millions of years, heat and pressure transformed sediments into rock and the organic material into kerogen.

Although there are many small deposits of oil shale in the Green River Formation in Wyoming, the states of Colorado and Utah contain more than 60 percent of the known oil shale deposits in the entire world (Figure 1). The deposits of greatest interest to energy companies are located in the Piceance Basin of Colorado, the Uinta Basin of Utah, and the Green River and Washakie Basins of Wyoming. Approximately 70 percent of these deposits are located on federal lands, primarily managed by the Bureau of Land Management.<sup>7</sup> All of these areas are located in the upper Colorado River Basin.<sup>8</sup> (The development of tar sands in this region—a destructive method of extracting low-grade petroleum—would have additional impacts not analyzed in this report.)

Figure 1: Location of Main Oil Shale Deposits in the Upper Colorado River Basin



## A Flawed Process

The Green River Basin is home to the United States' most well-known oil shale formations—much of it also managed by the Bureau of Land Management (BLM). The economic and environmental hurdles associated with production have repeatedly precluded commercial viability; nevertheless, the Energy Policy Act of 2005 incorporated specific provisions that required the Department of Interior to develop a commercial leasing program in concert with an oil shale research, development, and demonstration program.<sup>9</sup>

In December 2007, the BLM published *Oil Shale and Tar Sands Programmatic Environmental Impact Statement (PEIS) and a Notice of Availability of Draft Oil Shale and Tar Sands Resource Management Plan Amendments to Address Land Use Allocations in Colorado, Utah, and Wyoming*.<sup>10</sup> These documents analyzed and authorized leasing of public lands for commercial oil shale development, and the BLM concluded that critical information regarding the nature of oil shale was too speculative to initiate a final decision on issuing commercial leases. In its preparation of these documents, the BLM abrogated its responsibility to conduct a “hard look” to fully disclose the cumulative impacts that a commercial oil shale industry would have on federal resources and the region as a whole.

The BLM issued a final rule on November 18, 2008 that allowed for the commercial leasing of oil shale and tar sands resources on federal land. Remarkably, the rule was issued despite the agency's finding that there was no information available to detail the future impacts of such a rule, “because there is no commercial oil shale industry in the United States, there is no data available on what, if any, extraction process will be commercially viable, and thus there is uncertainty about the precise impacts from commercial oil shale development.”<sup>11</sup>

On November 28, the BLM subsequently issued a Record of Decision approving changes to 12 resource land management plans and the PEIS.<sup>12</sup> Despite the lack of information acknowledged within the final rule, the BLM erroneously asserted that it understood with certainty the likely impacts that would occur to federal resources if commercial oil shale leasing were to proceed.

Because of these critical shortcomings, the Natural Resources Defense Council and its coalition partners filed litigation in 2009 challenging the implementation of the PEIS. In early 2011, the Department of Interior agreed to address many of the flaws associated with the statement. In short, the BLM will revisit many of these issues in order to ensure that future development of federal oil shale resources are planned in a manner consistent with current resource management planning guidelines. The settlement requires that the BLM fully assess and adopt additional management and performance measures to guarantee a more robust analysis of proposed oil shale actions. Notably, the BLM is also required to safeguard sensitive federal lands and habitat from future oil shale development.

Since this decision, much of the region has undergone a transformation due to a proliferation of increased oil and gas drilling. This process has fragmented critical wildlife habitats while contaminating air and water resources. An industrial-scale oil shale industry—predicated upon a deficient process that failed to safeguard resources or establish a diligent process to govern the development of the existing oil shale resource—would introduce environmental risks to the region that could dwarf the impacts caused by the current oil and gas expansion.

## The History of Oil Shale Development

Oil shale may have been used as a fuel source as early as 800 AD, and the Austrians recorded using oil shale as fuel beginning in 1350 AD.<sup>13</sup> However, the United States did not begin using oil shale for fuel until the 1800s.<sup>14</sup> The first retort process in this country was in Colorado in 1917, and modern commercial oil shale development, like that of other U.S. fossil fuels, follows a classic boom-and-bust cycle.<sup>15,16</sup> When traditional crude oil is abundant and prices are low, interest in commercial oil shale development declines, but when oil becomes scarce and prices rise, interest increases.

Efforts in the United States to develop oil shale increased sharply immediately following the 1973 Arab Oil Embargo, but faded away beginning in 1982 when crude oil's price and availability again became stable.<sup>17</sup> In the 1960s, oil shale-related projects for multiple purposes began in both Colorado and Utah, but none of those projects ever yielded results that led to commercial oil shale development.<sup>18</sup> Between 1973 and 1982, the energy industry, with the help of the federal government and often on federal lands, researched and developed technologies for oil shale mining and processing.<sup>19</sup>

In 2006 and 2007, the Secretary of the Interior leased federal land in Wyoming, Colorado, and Utah to private companies for research, development, and demonstration of technologies that are able to recover liquid petroleum from oil shale resources.<sup>20</sup> There are currently six leases, each with an initial term of 10 years and subject to extension if leaseholders can demonstrate progress with technologies that could be used in commercial oil shale production.<sup>21,22</sup> The BLM produced a programmatic environmental impact statement (PEIS) for a commercial oil shale and tar sands leasing program on federal lands pursuant to a directive in the Energy Policy Act of 2005.<sup>23</sup>

## CURRENT OIL SHALE PROCESSING TECHNOLOGIES

### Ex Situ Mining Processes

Oil shale must be extracted and processed to become a liquid substance that can then be further refined into a useable product;<sup>24</sup> it can be mined in two different ways—subsurface mining (called room and pillar) or open pit/strip mining.<sup>25</sup> Once the shale is removed from the ground, it is heated in a process called retorting; the resultant liquid substance must then be further refined in the same manner as ordinary petroleum.<sup>26</sup>

There are four basic recovery processes: modified in situ and a combined use of modified in situ and indirect-heated above ground retorting (combination).<sup>27</sup>

**1. Direct heated above ground retorting (direct AGR):** The shale oil is extracted from the ground. A heat carrier unit is then inserted directly into the mined material or the material is burned with a direct heat source until a liquid petroleum-like product forms.<sup>28</sup>

**2. Indirect heated above ground retorting (indirect AGR):** The extracted shale is heated using a source conducted through the retort wall, rather than applied directly to the shale.<sup>29</sup>

**3. Modified in situ processes:** The oil shale is drilled, crushed, and, in some cases, partially mined to create open areas in the shale.<sup>30</sup> These open areas allow for a more free flow of liquids and gases in the oil shale deposit, improving the amount of liquid produced from the shale.<sup>31</sup>

**4. The combination process:** This is a mix of the modified in situ process with either the direct or indirect AGR process to obtain more liquid that is also of a better quality.<sup>32</sup>

Currently, ex situ retorts are active in Estonia, Brazil, and China.<sup>33</sup> While the ex situ process has been practiced domestically in fits and starts, it has never been implemented successfully because of a number of unresolved liabilities. Although inefficient, the relative simplicity of the traditional ex situ process of an above ground retort, where the rock is exposed to extreme temperatures, has been the primary form of processing for more than a century.

One of the obstacles in mining and processing of oil shale is that it creates substantially more solid waste by volume than what is originally mined.<sup>34</sup> More troubling is that after the shale is retorted, the residual char, or spent shale, is chemically altered for the worse. The spent shale, transformed due to its exposure to high temperatures, contains a number of soluble inorganic compounds, including significant quantities of arsenic and selenium that may contaminate regional aquatic systems.<sup>35</sup> Compounding matters, spent shale also contains highly carcinogenic polycyclic aromatic hydrocarbons (PAHs).<sup>36</sup> (Toxic levels of PAHs were found in Green River Basin spent shale that was produced in the early 1980s).<sup>37</sup> Once the shale is removed from the ground, the liquid substance produced by retorting then must be further refined in the same manner as ordinary petroleum.<sup>38</sup>

### In Situ Oil Shale Production

During in situ oil shale processing and extraction, the retorting process occurs below the ground and the liquid produced by the retorting process is then withdrawn, using wells.<sup>39</sup> This process is still in the experimental stages;<sup>40</sup> Shell Oil is currently experimenting with an in situ oil shale process in Colorado, where the company drills approximately 2,000-foot-deep holes at 40-foot intervals, inserts electrical resistance heaters into the holes, and heats the oil shale for a period of several months at temperatures between 650 and 700 degrees Fahrenheit.<sup>41</sup> This heating process causes the oil shale to produce a petroleum-like liquid that may then be extracted using methods similar to that of a traditional oil well.<sup>42</sup> The process also includes development of an underground freeze wall intended to isolate the working area from adjacent groundwater.

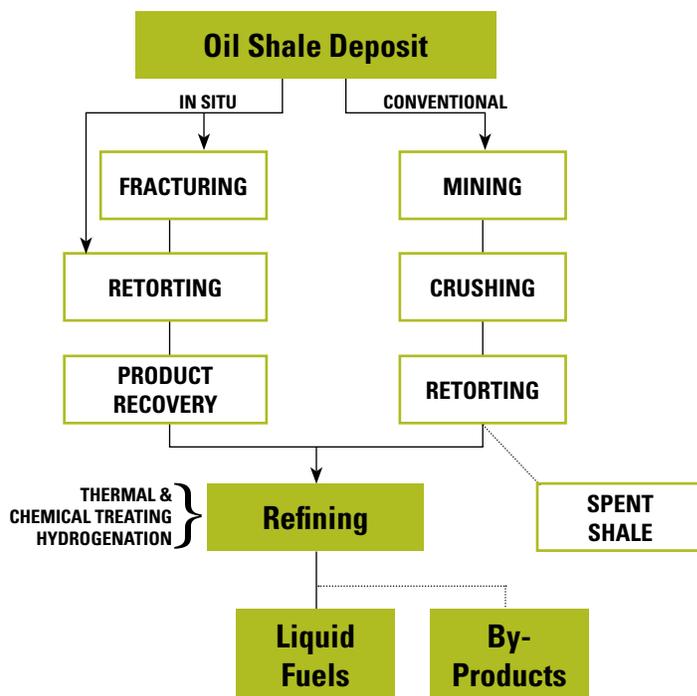
### Water Requirements

Water requirements associated with ex situ development also vary depending on the technology used.<sup>43</sup> Water would likely be used for a combination of the following purposes: “mining and oil shale retorting and upgrading; dust control during materials extraction, crushing, and transport; cooling and reclaiming spent shale; re-vegetation; and various plant utilities associated with power production and environmental control.”<sup>44</sup> The final BLM PEIS estimates that one barrel of oil produced using surface or underground mining and surface retorting will require between 2.6 and 4 barrels of water.<sup>45</sup>

Water requirements for in situ processing also are uncertain at this point.<sup>46</sup> A recent report by the GAO that reviewed a number of studies estimated that, on average, one barrel of oil required 4.8 barrels of water.<sup>47</sup> This estimate takes into account retorting, upgrading liquids, reclamation, power generation, and population growth associated with oil shale development.

Ultimately the water supply requirements for long-term oil shale development will depend on many factors, including the availability of water. The GAO’s report investigated a broad range of potential oil shale development scenarios based on reports from oil companies and the government. Using midrange estimates of producing 50,000 barrels per day using ex situ mining and 1.5 million barrel per day using in situ retorting, the GAO estimates the water supply need would be about 360,100 acre-feet of water per year, assuming average estimates of water requirements for each method. The agency’s maximum water needs estimate for large scale oil shale development is more than 1,400,000 acre-feet of water use per year (Tables 2 and 3).

**Figure 2: Oil Shale Production Processes**



Sources: U.S. Department of Energy. “Strategic Significance of America’s Oil Shale Resources, Vol. II, Oil Shale Resources, Technology and Economics.” Office of Deputy Assistant Secretary for Petroleum Reserves, Office of Naval Petroleum, and Oil Shale Reserves. Washington, D.C. March 2004.

**Table 1: Oil Shale Production Methods**

Method	Barrels of water needed for each barrel of oil produced using the method <sup>a</sup>	Carbon emissions produced by the retorting process in tons of carbon (CO <sub>2</sub> ) per barrel of oil produced <sup>b</sup>
Direct AGR	2.3 to 2.7	.18 to .42 tons CO <sub>2</sub> /barrel
Indirect AGR	4.2 to 5	.18 to .42 tons CO <sub>2</sub> /barrel
Combination	2.4 to 2.5	.18 to .42 tons CO <sub>2</sub> /barrel
MIS	2.1	.18 to .42 tons CO <sub>2</sub> /barrel
In Situ (Shell method)	Unknown, but probably less than half than the requirements for either the MIS or Combination methods	.67 to .81 tons CO <sub>2</sub> /barrel

\*Note: barrels of oil recovered from each resource cannot be determined or in most cases even estimated by the technology used. The quality, location, and richness of the oil shale resource itself is the most important factor in the determination of how much oil is recoverable from each resource, and will at least partially determine which technology is most feasible for recovery.

Source:

<sup>a,b</sup> OTA & Nowacki

**Table 2: Estimated Water Needs for Mining and Surface Retorting of Oil Shale by Industries of Various Sizes**

Size of industry (barrels of oil per day)	Minimum water needs (acre-feet per year) <sup>a</sup>	Average water needs (acre-feet per year) <sup>b</sup>	Maximum water needs (acre-feet per year) <sup>c</sup>
25,000 <sup>d</sup>	2,400	3,500	4,700
50,000 <sup>e</sup>	4,700	7,100	9,400
75,000	7,100	10,600	14,100
100,000	9,400	14,100	18,800
150,000 <sup>f</sup>	14,100	21,200	28,200

Sources: "A Better and Coordinated Understanding of Water Resources Could Help Mitigate the Impacts of Potential Oil Shale Development," United States Government Accountability Office, 2010.

<sup>a</sup> This scenario assumes 2 barrels of water are needed to produce 1 barrel of shale oil. All figures are rounded to the nearest 100 acre-feet.

<sup>b</sup> This scenario assumes 3 barrels of water are needed to produce 1 barrel of shale oil.

<sup>c</sup> This scenario assumes 4 barrels of water are needed to produce 1 barrel of shale oil.

<sup>d</sup> URS, the contractor of the state of Colorado, used this level as the minimum size for a mining operation with a surface retort.

<sup>e</sup> Several literature sources and oil shale companies cite this level as a reasonable commercial operation.

<sup>f</sup> GAO estimated industry size based on three operations of 50,000 barrels per day each.

**Table 3: Estimated Water Needs for In-Situ Retorting of Oil Shale by Industries of Various Sizes**

Size of industry (barrels of oil per day)	Minimum water needs (acre-feet per year) <sup>a</sup>	Average water needs (acre-feet per year) <sup>b</sup>	Maximum water needs (acre-feet per year) <sup>c</sup>
500,000	24,000	118,000	282,000
1,000,000	47,000	235,000	565,000
1,500,000	71,000	353,000	847,000
2,000,000	94,000	470,000	1,129,000
2,500,000 <sup>d</sup>	118,000	588,000	1,411,000

Sources: "A Better and Coordinated Understanding of Water Resources Could Help Mitigate the Impacts of Potential Oil Shale Development," United States Government Accountability Office, 2010.

<sup>a</sup> This scenario assumes 1 barrel of water is needed to produce 1 barrel of shale oil. All figures are rounded to the nearest 100 acre-feet.

<sup>b</sup> This scenario assumes 5 barrels of water are needed to produce 1 barrel of shale oil.

<sup>c</sup> This scenario assumes 12 barrels of water are needed to produce 1 barrel of shale oil.

<sup>d</sup> This oil shale company with whom we spoke estimated that an oil shale industry could grow to this level, based on analogy to oil sands being developed in Alberta, Canada.

## The Impact on Water Quality

■ Oil shale processing will lead to the possibility of both surface and groundwater contamination.<sup>48</sup> The final BLM PEIS identifies a dozen types of possible impacts to water quality associated with oil shale development.<sup>49</sup> Possible resulting contaminants include:<sup>50</sup>

- Suspended solids
- Oil and grease
- Dissolved gases, organics, and inorganics
- Trace elements and metals
- Trace organics and toxics

Mine drainage is the major source of concern, especially in Colorado, because the area where oil shale is located in Colorado also contains important sources of groundwater.<sup>51</sup> The groundwater in the Green River Formation may be quite extensive and, at this time, remains largely undeveloped. The groundwater of the Basin is used mostly for drinking and industrial purposes, and current use is estimated to be between 5,300 and 7,200 acre-feet of groundwater annually.

However, the total estimated groundwater yield from the Basin is between 50,000 and 100,000 acre-feet per year, suggesting that much greater groundwater development might be possible in the Green River Basin.<sup>52</sup>

Non-point-source pollutants are of particular concern because of the difficulty of controlling these sources; major sources of these pollutants will likely be leached from storage, spent shale materials, raw shale, and leftover organic and inorganic materials from in situ processes.<sup>53</sup> Previous experiments with in situ extraction in the region demonstrated that such a process could leave behind toxic char residues that are readily leached into the groundwater. In southwestern Wyoming, small-scale experiments resulted in significant water contamination from volatile organic compounds, including the presence of benzene and acetone.<sup>54</sup> Oil shale development is not expected to contribute directly to the salinity levels of water in the Colorado River Basin, but reduced flows caused by water extractions for oil shale development will tend to increase salinity concentrations.<sup>55</sup>

## Anvil Points—Abandoned Oil Shale Retorting Facility

The abandoned Anvil Points retorting facility near Rifle, Colorado, presents an obvious example of the water contamination issues characteristic of oil shale development. The experimental retort facility processed relatively small amounts of shale from 1947 to 1984. Leftover from that legacy was an abandoned and unwieldy pile of 60 tons of spent shale.<sup>56</sup> Much like hard rock mining, such waste poses a number of environmental hazards because of its propensity to leach toxic materials into the groundwater. In the case of Anvil Points, it has been 27 years since the facility was abandoned, and until recent cleanup efforts were initiated, those 60 tons had been leaching a number of critical inorganic elements into the region's surface water, practically unabated.

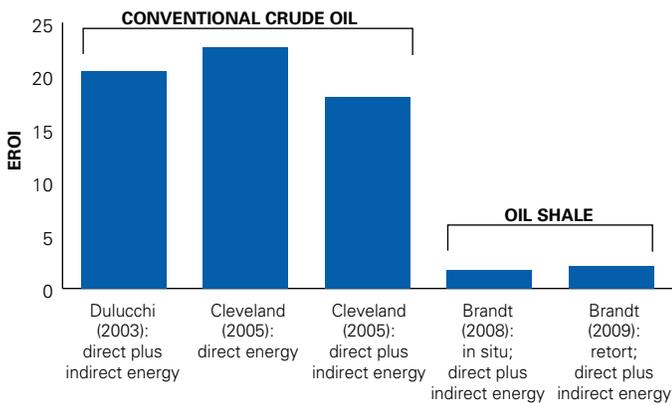
Foremost in the Anvil Points' leachate is the presence of arsenic that continues to discharge at quantities exceeding Colorado Water Quality Standards.<sup>57</sup> These 60 tons of spent shale waste have become a major environmental and financial liability for the state of Colorado and the federal government. Nearly \$65 million have been allocated to remediate the spent shale waste pile and the surrounding site.

As Anvil Points has demonstrated, the intrusion and exposure of water concentrates undesirable inorganic elements into quantities that pose critical problems for the overall welfare of an ecosystem.<sup>58</sup> This relatively modest amount of spent shale would be dwarfed by what has been proposed by the BLM for the future of the region. For example, the BLM estimates that one commercial retort facility in the region would produce upwards of 23 million tons of spent shale waste a year. Given the BLM's goal of a 50,000-barrels-per-day industry from retorting alone, as defined in the oil shale PEIS, more than 200 million tons of spent shale waste would be created annually.<sup>59</sup> Put another way, this level of production would result in the generation of 60 tons of waste—the amount of the shale waste at Anvil Points—every 10 seconds. With the generous volume of wastes produced by a retort facility, an industrial-scale operation would present considerable challenges to any effort to stabilize and manage the resultant waste stream. Based on experience to date, preventing the leaching of inorganic elements in a spent shale waste pile for a large facility appears to be a practical impossibility.

## Energy Requirements

Analyses have shown that the energy return on investment (EROI) for oil shale is quite low for both above ground retorting and in situ methods. A study in 2010 by one of the world's most respected experts in the EROI field documented that the EROI oil shale ratio ranged between 1:1 and 2:1—a ratio that is practically four times worse than what is found in conventional petroleum products.<sup>60</sup> In other scenarios, the associated demands for energy—especially electricity—substantially exceed the energy made available during the production process.<sup>61</sup> These analyses raise important questions about the potential of oil shale as a significant net energy source (Figure 3).

**Figure 3: Oil Shale EROI Data**



Source: Cutler J. Cleveland and Peter O'Connor, Western Resources Advocates, An Assessment of the Energy Return on Investment (EROI) of Oil Shale, June 2010 <http://www.westernresourceadvocates.org/land/pdf/oseroireport.pdf>

## Carbon Emissions

Regardless of whether oil shale is produced by above ground or in situ methods, its extraction and processing is very energy intensive and causes the emission of higher amounts of greenhouse gasses than conventional oil development.<sup>62</sup> Given the current experimental nature of the technology and the absence of large scale industrial production facilities, there are limited lifecycle assessments of greenhouse gas emissions from oil shale production.

The Natural Resources Defense Council has conducted an analysis of the existing data for oil shale based on demonstration and test project data. The most extensive analysis reveals that oil shale would produce 23 percent to 73 percent (1.2 to 1.7 times) more greenhouse gas emissions versus the average U.S. 2005 diesel baseline.<sup>63</sup>

Other analyses show even more dramatic greenhouse gas impacts from oil shale (Table 4). However, each oil shale technology can have a different carbon footprint that depends not only on the method used, but also on the primary source of energy input (e.g., coal, natural gas). For example, purchasing coal-fired electricity rather than co-generating electricity on-site may be more cost effective for facilities, but lead to higher lifecycle emissions.

**Table 4: Carbon Emissions of Oil Shale Production Compared with Other Forms of Energy**

Form of energy	Carbon emissions in refining resource measured by tons of carbon (CO <sub>2</sub> ) per barrel of oil
Oil shale	.18-.81 tons/barrel
Petroleum	.05 tons/barrel
Alberta Tar Sands	.08-.13 tons/barrel

Source: Anthony Andrews, Developments in Oil Shale, CRS Report for Congress, 2008

## Endangered Species

In oil shale development areas, there are:<sup>64</sup>

- Federally-listed endangered and threatened species
- State-listed endangered and threatened species
- Species that are candidates for some type of endangered, threatened, or watched listing
- Species of special concern
- BLM-designated species<sup>65</sup>

The final environmental impact assessment for oil shale development in the Colorado River Basin identifies 250 different species that are endangered, threatened, candidates, or otherwise protected at either the state or national level.<sup>66</sup> These species will be affected by pollution and changes to their habitat in the land and waters of the area, as well as noise disturbances, and the increased presence of people and industrial activities in potential oil shale development areas.<sup>67</sup>

The most notable presence in the area is that of four species of endangered fish found only in the large rivers of the Colorado River Basin.

A cooperative program to recover these species so they can be delisted has been in place for more than 20 years; substantial new development of water to support oil shale operations could hamper efforts to enhance and maintain the essential river habitat conditions and interfere with species recovery.

## Endangered Fish Recovery Program

Because of plummeting fish populations in the Colorado River system, in 1988 the governors of Colorado, Utah, and Wyoming, the Department of Interior, and the Western Area Power Administration signed an agreement to initiate the Upper Colorado River Endangered Fish Recovery Program. The program was designed to protect four endangered fish species—bonytail, Colorado pikeminnow, humpback chub, and razorback sucker. In order to bring about self-sustaining fish populations, the program calls for providing adequate flows, restoring habitat, increasing access to habitat, establishing hatcheries, and managing non-native fish species.<sup>68</sup>

The recovery program was developed after several decades of mismanagement by agencies in the region, which led to a dramatic drop in native fish populations. For example, in 1962, wildlife agencies deliberately used the chemical rotenone to wipe out native fish on the Green River. This attempt to replace native fish with rainbow trout resulted in approximately 450 tons of dead fish within three days.<sup>69</sup>

### BONYTAIL FISH POPULATIONS

© Joseph R. Tomelleri



**Bonytail:** The species was on the verge of extinction when the recovery program began. Because there were no

self-sustaining populations in the wild, a stocking program was implemented. More than 94,000 sub-adult fish were stocked between 2004 and 2009, but the survival rate for these fish has been poor. Although the recovery program does not currently have enough information about overall demographics, it still hopes to downlist the species by the 2020 deadline.

### RAZORBACK SUCKER FISH POPULATIONS

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**Razorback sucker:** The recovery program hopes to downlist the species in 2020 and has made some progress by

stocking hatchery-reared razorback sucker. Adult catch rates have increased slightly and hatchery-produced fish have started spawning in the wild. Still, despite the introduction of more than 250,000 hatchery-raised fish, overall population numbers have not improved significantly. The recovery program has yet to initiate population estimates for the species, but expects gradual progress towards the recovery goal.



Source: Colorado River Water Users Association, Colorado River Maps, 2007, <http://www.crwua.org/ColoradoRiver/RiverMap.aspx>. Last accessed July 2011.



Source: Colorado River Water Users Association, Colorado River Maps, 2007, <http://www.crwua.org/ColoradoRiver/RiverMap.aspx>. Last accessed July 2011.

## Endangered Fish Recovery Program continued

The Fish and Wildlife Service established initial recovery goals in 2002. A review and update of these goals is currently underway. The recovery program set a goal of up to 15 years to establish self-sustaining populations of bonytail and razorback sucker before the downlisting and delisting process could begin.

### SOURCES:

1. Upper Colorado River Endangered Fish Recovery Program and San Juan River Basin Recovery Implementation Program, 2009-2010 Highlights, <http://coloradoriverrecovery.org/general-information/general-publications/briefingbook/2009-2010Highlights.pdf>
2. Recovery Goals for Four Endangered Fishes of the Colorado River, Upper Colorado River Endangered Fish Recovery Program, August 2002, <http://coloradoriverrecovery.org/documents-publications/foundational-documents/recovery-goals.html>

### HUMPBACK CHUB FISH POPULATIONS

© Joseph R. Tomelleri



**Humpback chub:** Populations of humpback chub in the Upper Basin have been in decline in recent years, and the recovery program is likely to change the downlist deadline again, from 2013 to 2016.

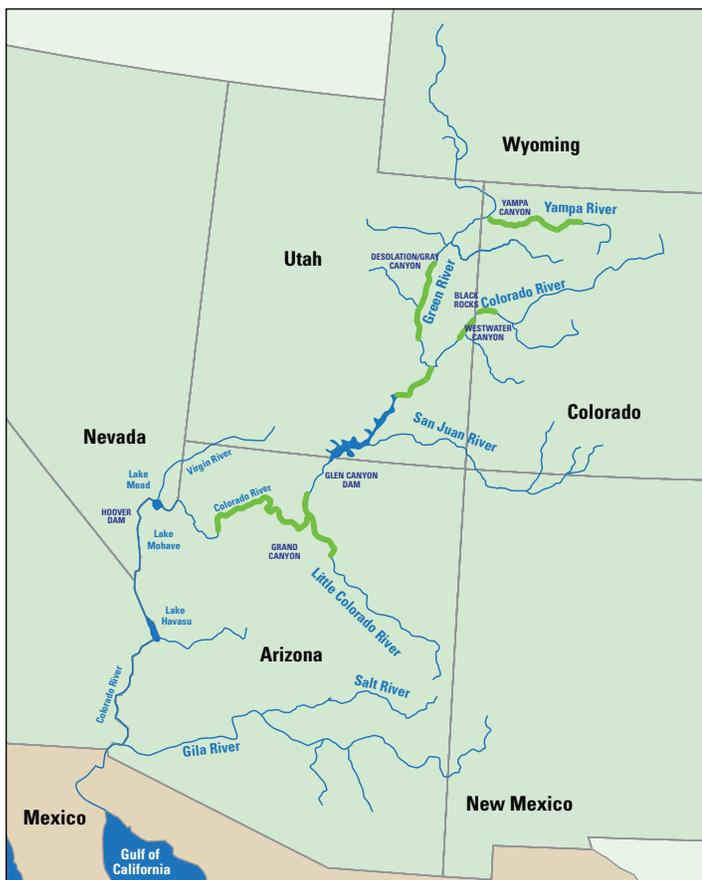
### COLORADO PIKEMINNOW FISH POPULATIONS

© Joseph R. Tomelleri



**Colorado pikeminnow:** There has been an increase in the overall population since 2004. It is estimated that

currently there are approximately 4,500 fish in the Upper Basin. If population numbers do not decline from current levels, the recovery program might be able to downlist the Colorado pikeminnow in 2013, as predicted.



Source: Colorado River Water Users Association, Colorado River Maps, 2007, <http://www.crvua.org/ColoradoRiver/RiverMap.aspx>. Last accessed July 2011.



Source: Colorado River Water Users Association, Colorado River Maps, 2007, <http://www.crvua.org/ColoradoRiver/RiverMap.aspx>. Last accessed July 2011.

## 4. COLORADO RIVER BASIN HYDROLOGY

The Colorado River Basin includes a drainage area of 242,000 square miles in the United States and 2,000 square miles in Mexico. Parts of seven states are included within the Basin, and its reliable supply of water has been the subject of intense interest since the early 1900s, when the U.S. government first began consistently measuring flows.

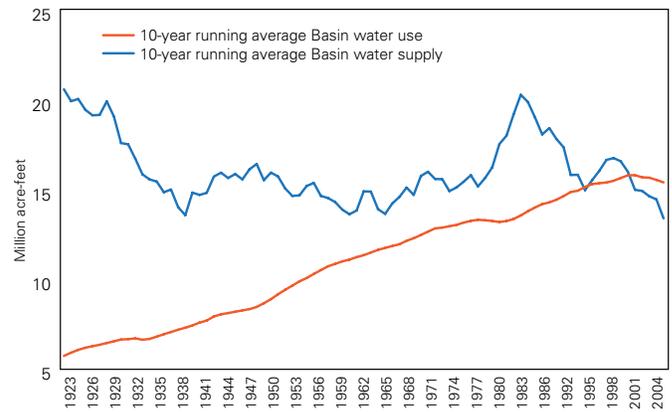
When commissioners from the seven Basin states met in 1922 to negotiate a compact allocating use of the Basin's water, they were told the Basin yielded, at that time, approximately 17.5 million acre-feet per year, not counting existing consumptive uses (including of the water of the Gila River Basin in New Mexico and Arizona), and other natural and human-caused depletions.<sup>1</sup> This estimate implied a "virgin" (not depleted) basin yield of more than 20 million acre-feet per year, of which the commissioners apportioned consumptive use of 16 million acre-feet.

By 1928, experts were already cautioning that these estimates were too high.<sup>2</sup> Thus began a pattern that was to be repeated over and over again—additional studies based on a longer time period suggest that a far more variable, and lower, reliable basin water supply is actually available for use.<sup>3</sup>

Subsequent analysis of prehistoric evidence provided an even more alarming picture. In 1976, Stockton and Jacoby reported results of an analysis of basin hydrology based on a study of tree rings that dated back to 1512.<sup>4</sup> Not only did this study confirm the existence of reoccurring, long-term periods of drought in the Basin, but it concluded that the reconstructed virgin flow at Lee Ferry over this much longer

time period was roughly 13.5 million acre-feet per year.<sup>5</sup> The study highlighted the unusually wet period in the Basin that happened to coincide with the collection of information used by the commissioners negotiating the 1922 Colorado River Compact.<sup>6</sup> The research also made clear that not only was average runoff in the pre-gauged era lower than over the past 100 years, but also that there were considerably longer periods with below-average runoff than experienced during the 20th century. In short, it showed that relying on historical records to predict future runoff was not adequate.

**Figure 4: Historical 10-Year Running Average Colorado River Basin Supply and Use**



Data Source: Data obtained through personal correspondence with the Bureau of Reclamation August 10, 2011.

# 5. CLIMATE CHANGE AND THE COLORADO RIVER BASIN

The Intergovernmental Panel on Climate Change (IPCC) reported in 2007 that “warming of the climate system is “unequivocal” and that it is “very likely” that the warming that has happened over the last half-century is the result of human produced greenhouse gas pollution.<sup>1</sup> While the IPCC reported an average increase of 1 degree Fahrenheit globally, the report noted that warming in the Northern Hemisphere has been 1.3 to 1.6 degrees Fahrenheit across the last 100 years. The warming of the Colorado River Basin area has been even higher, with the average temperature of the Colorado River Basin, from 2003 to 2007, 2.2 degrees Fahrenheit warmer than the average of the last century (Figure 5).<sup>2</sup>

Climate models project a continuation of the warming trend through the 21st century. Downscaled versions of these models predict substantially increased warming in the area of the Colorado River Basin, especially in its southern reaches.<sup>3</sup>

The effects of climate change on Colorado River Basin hydrology will further exacerbate the existing challenges of predicting runoff, over-allocation, and managing water supplies to meet growing needs.<sup>4</sup> Models are less consistent on the subject of precipitation. But even researchers who predict unchanged precipitation find decreased runoff, which is attributed to increased soil absorption and vegetative evapotranspiration because of higher summer temperatures.<sup>5</sup> While the effects of climate change within the Basin are variable and complex, the overwhelming consensus is that average annual flows in the Colorado River Basin will decline in the 21st century.<sup>6</sup>

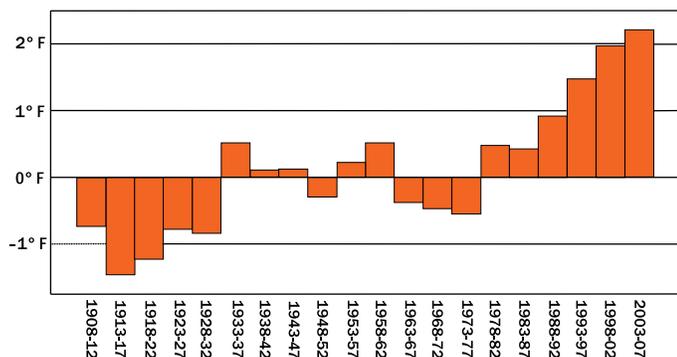
Studies of the effects of climate change on Basin hydrology date back to 1979, when Stockton and Boggess evaluated the effects of an assumed 2 degrees Centigrade increase in average basin temperature, and a 10 percent decline in precipitation, resulting in a 33 percent reduction

in virgin flow at Lee Ferry.<sup>7</sup> In 1983, Revelle and Waggoner concluded that Basin warming would result in a 40 percent reduction in flows at Lee Ferry.<sup>8</sup> Studies by Nash and Gleick in 1991 and 1993 found a 20 percent reduction in Lee Ferry flow.<sup>9</sup> In 2004, Christensen and others estimated a 17 percent reduction in total basin runoff by 2100.<sup>10</sup> In 2006, Hoerling and Eischeid projected a 45 percent reduction in Lee Ferry flows over 2035 through 2060.<sup>11</sup> Also in 2006, Christensen and Lettenmaier estimated an 11 percent reduction in total basin runoff by 2070 to 2099 (Figure 6).<sup>12</sup> In 2008, the U.S. Climate Change Science Program predicted runoff decreases of 10 to 25 percent by 2050—roughly 5 to 12 times Denver’s water use.<sup>13</sup> A 2011 interim report by the Bureau of Reclamation on the Colorado River Basin water supply estimated a 9 percent decrease in river flows at Lee’s Ferry within a 50-year time frame.<sup>14</sup>

A recent synthesis produced for the state of Colorado provides this summary: “Recent hydrologic studies on climate change in the Upper Colorado River Basin point to an expected decline in runoff by the mid-to-late 21st century...Those studies that explicitly calculate runoff report multi-model average decreases ranging from 6 percent to 20 percent by 2050 compared to 20th century conditions...”<sup>15,16</sup>

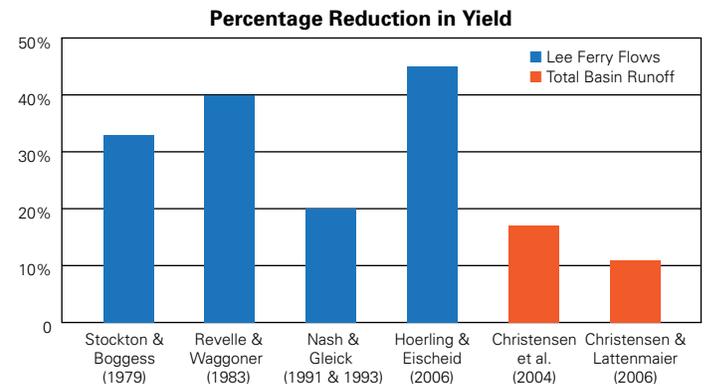
In sum, global warming is reducing the reliable supply of water in the Colorado River Basin. When these effects are added to information on recorded flows during the 20th century and flows reconstructed using tree rings that are now available, the result is a basin with far less water available in the future than was assumed for most of the 20th century. Most importantly, all evidence points to the conclusion that there will not be enough water available to meet commitments that have already been made—without the additional demands imposed by oil shale development.

**Figure 5: Temperature Change in the Colorado River Basin, 1908–2007**



Temperatures in the Colorado River Basin averaged over five years, compared to the average Basin temperature for 1901–2000. The average temperature for 2003–2007 was 2.2°F warmer than the historical average. Data from the National Oceanic and Atmospheric Administration’s climate division series. Analysis by the Rocky Mountain Climate Organization.

**Figure 6: Modeled Climate Change Impact to Colorado River Basin Runoff**



Climate Technical Work Group Report, October 2007. Final EIS–Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead

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## 6. COLORADO RIVER BASIN WATER ALLOCATIONS, USES, AND CONFLICTS

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### **The Colorado River Compact (1922)**

The concerns of slower-growing states in the Upper Basin that faster-developing, downstream states would claim most of the water of the Colorado River prompted interest in negotiating a compact governing uses of the Basin's water. When the commissioners of the seven basin states convened in Washington, D.C. under the chairmanship of Herbert Hoover, on January 26, 1922, they expected to negotiate a compact that would permanently apportion specific quantities of the water of the Colorado River Basin to each of the states for its consumptive use. Failure to agree on state allocations in the final agreement reached later that year in Santa Fe, New Mexico, led to the decision to divide the Basin into upper and lower regions (with Lee Ferry as the dividing point); each region was apportioned the perpetual beneficial consumptive use of 7.5 million acre-feet.<sup>1</sup>

To satisfy certain concerns of the Arizona commissioner, the negotiators added another provision authorizing the Lower Basin to consumptively use up to an additional 1 million acre-feet.<sup>2</sup> The presumption among many parties is that the million acre-feet was provided by tributary flows below Lee Ferry. Since approximately 80 to 85 percent of the water originates in the Upper Basin, the commissioners agreed that uses in this area would not reduce flows to less than 75 million acre-feet at the Lee Ferry dividing point over rolling 10-year periods;<sup>3</sup> the Colorado River Compact provided 8.5 million acre-feet of water for consumptive use in the Lower Basin.

### **Boulder Canyon Project Act (1928)**

To help regulate the highly variable flows of the Colorado River and ensure full water supplies for the Imperial Valley in California, Congress passed the Boulder Canyon Project Act in 1928.<sup>4</sup> The law authorized the construction of what became the Hoover Dam, as well as the All-American Canal, which enabled delivery of Colorado River water to the Imperial Valley through a canal located within the United States. The act also provided for ratification of the Colorado River Compact. Because Arizona had refused to ratify the compact, Congress authorized a six-state ratification process on the condition that California agree to limit its consumptive uses to 4.4 million acre-feet.<sup>5,6</sup> The Act also authorized the Secretary of the Interior to enter into contracts for the delivery of water from Lake Mead, the storage reservoir created by Hoover Dam.<sup>7</sup>

### **Treaty with Mexico (1944)**

In 1944, The United States agreed to ensure that at least 1.5 million acre-feet of Colorado River water would pass into Mexico annually.<sup>8</sup> The Colorado River empties into the Gulf of California—over millennia, unimpeded flows, heavy with sediments, created a vast delta with extensive wetlands that supported a unique set of ecosystems.<sup>9</sup> With the development of the Boulder Canyon Project and increasing consumptive uses in the United States, flows into Mexico began to decrease.<sup>10</sup> Treaty negotiators determined that demands in Mexico, primarily for irrigation of agricultural lands, already exceeded 1.5 million acre-feet.<sup>11</sup> The treaty included provision for additional uses up to 1.7 million acre-feet in times of surplus, and the possibility of reduced uses in the event of an “extraordinary drought.” As an international treaty, this obligation is paramount to all other uses of Colorado River water in the United States.

### **Upper Colorado River Compact (1948)**

In 1948, the states located within the Upper Basin negotiated a compact for allocating the 7.5 million acre-feet of consumptive use apportioned to the region under the 1922 compact.<sup>12</sup> Because of uncertainties about the availability of water, the states used a percentage-sharing formula, allocating 51.75 percent to Colorado, 11.25 percent to New Mexico, 23 percent to Utah, and 14 percent to Wyoming.

### **Colorado River Storage Project Act (1956)**

In 1956, Congress authorized construction of Glen Canyon Dam and several other storage projects located in the Upper Basin to better regulate flows of water in the Upper Basin and ensure deliveries to the Lower Basin.<sup>13</sup> Low flows during the generally dry 1930s had highlighted potential problems with meeting the running 10-year average flow requirement at Lee Ferry. Storage of water from wet years in Lake Powell for release in dryer, low-flow years was expected to ensure a reliable supply to the Lower Basin while allowing increased consumption in the Upper Basin.

### Arizona v. California (1963)

To resolve its long-running dispute with California about uses of the Lower Basin's compact apportionment, Arizona brought an original action in the U.S. Supreme Court in 1952. The court decided Congress had already apportioned the Lower Basin water in the Boulder Canyon Project Act (with California receiving annual consumptive use of 4.4 million acre-feet, Arizona 2.8 million acre-feet, and Nevada 300,000 acre-feet)<sup>14</sup> and that Congress had only apportioned the waters of the Colorado River mainstream, not the tributaries.

### Colorado River Basin Project Act (1968)

This act authorized construction of the Central Arizona Project (CAP) for delivering 1.2 million acre-feet of Colorado River water into the central and southern portions of Arizona, along with smaller projects in the Upper Basin.<sup>15</sup> Previous studies had determined there would be insufficient water for this project as Upper Basin uses increased. At California's insistence, the act included a provision subrogating CAP diversions to California's 4.4 million acre-foot right. The act required the Secretary of the Interior to establish long-range operating criteria for Lake Powell and Lake Mead.

### Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead, 2007 (Interim Guidelines)

Under the Supreme Court Decree in *Arizona v. California*, the secretary was authorized to make deliveries from Lake Mead to Arizona, California, and Nevada depending upon whether, in his or her judgment, there was sufficient available water to enable 7.5 million acre-feet of consumptive use of mainstream water.<sup>16</sup> In 2007, the secretary adopted the Interim Guidelines for water deliveries in the event of there not being enough water to meet 7.5 million acre-feet requirement. These guidelines govern the way that shortages are allocated, based on storage levels in Lake Mead, and were created in response to the most severe drought since record-keeping began in the late 1800s and early 1900s.<sup>17</sup> While "surplus" conditions were common prior to the recent drought, shortages now appear likely in the not-too-distant future.<sup>18</sup> Consequently, provisions have been made for allocating shortages of up to 500,000 acre-feet.

### Summary

Under the Law of the River (Table 5), provisions now exist for annual consumptive use of 17.5 million acre-feet of Colorado River Basin water—1.5 million in Mexico, 8.5 million in the Lower Basin, and 7.5 million in the Upper Basin. The Lower Basin, the U.S. Supreme Court determined, under "normal" conditions, would get a minimum of 7.5 million acre-feet, of which Arizona has the right to consume 2.8 million acre-feet per year from the Colorado mainstream, California 4.4 million acre-feet, and Nevada 300,000 acre-feet.<sup>19</sup> Upper Basin states have agreed by compact to apportion their 7.5 million acre-feet on a percentage basis. With congressional funding, the Bureau of Reclamation has constructed two major dams on the main Colorado—Hoover Dam and Glen Canyon Dam—and other projects that regulate flows, generate hydroelectricity, and deliver water to irrigation and urban users. After years of water supplies that exceeded demands, the United States has developed procedures under which water shortages will be managed.

Table 5: Law of the River

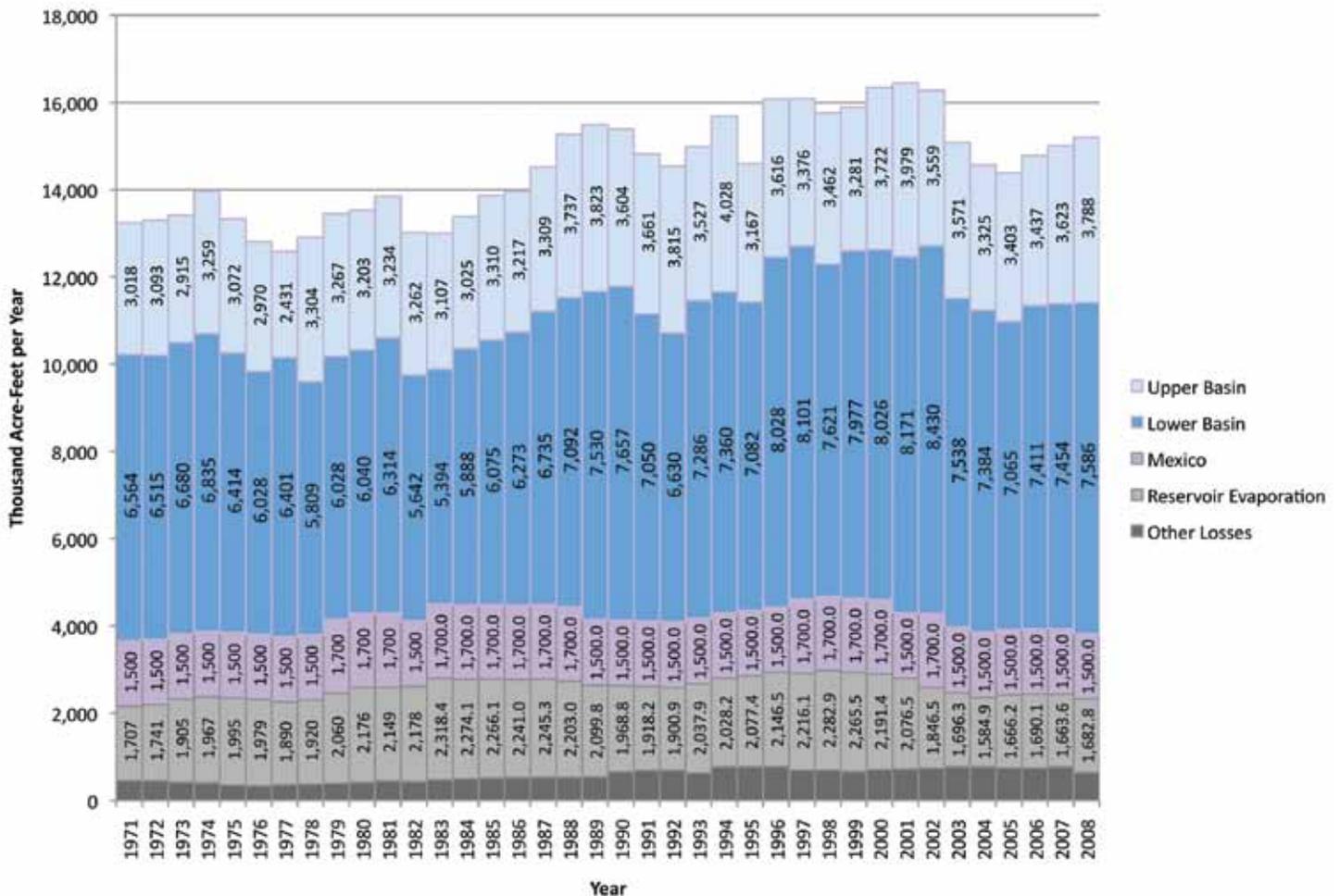
Name	Purpose	Date
Colorado River Compact	Allocated consumptive use of 7.5 maf to Upper and Lower Basins; Lower Basin given right to consume up to an additional 1 maf for a total of 8.5 maf of Lower Basin Consumptive use; Lee Ferry flow obligation of 75 maf/10 years	1922
Boulder Canyon Project Act	Authorized construction of Hoover Dam and All-American Canal	1928
Treaty with Mexico	Allocated 1.5 maf/year to Mexico	1944
Upper Colorado River Basin Compact	Divided Upper Basin uses among states	1948
Colorado River Storage Project Act	Authorized construction of Glen Canyon Dam	1956
<i>Arizona v. California</i>	Divided 7.5 maf of mainstream water among Arizona, California, and Nevada	1963
Colorado River Basin Project Act	Authorized Central Arizona Project	1968
Interim Guidelines	Allocated potential shortages in Lower Basin	2007

### Summary of Basin Water Uses and Losses

Actual uses of Colorado River Basin water vary somewhat from the allocation schedule established under the Law of the River. As documented in the Bureau of Reclamation's 2011 Colorado River Basin Water Supply and Demand Study,<sup>20</sup> from 2000 to 2008, the Upper Basin consumed on average approximately 3.6 million acre-feet annually, but the Lower Basin consumed on average about 7.7 million acre-feet annually. In addition, reservoir evaporation not attributable to consumptive uses in the Upper Basin accounted for approximately 725,000 acre-feet of losses annually;<sup>21</sup> reservoir evaporation in the Lower Basin approximated one million acre-feet of losses annually. Moreover, during this period,

an annual average of 1.54 million acre-feet of water passed to Mexico pursuant to the treaty. These actual uses are summarized in Figure 7. In short, the Upper Basin has not been using all of its allocation—that water is potentially available for use in the Lower Basin and Mexico. Other uses and losses totaled an annual average of 735,000 acre-feet. Total mainstream uses and losses averaged 15.3 million acre-feet<sup>22</sup> from 2000 to 2008, while the Bureau has determined that total mainstream supply averages 14.7 million acre-feet. These long-term trends are illustrated in Figure 4. In short, current levels of consumption exceed current average supplies. Lower Basin tributary uses and losses are not included in the above summary.

**Figure 7: Historical Colorado River Water Consumptive Use by Basin, Delivery to Mexico, Reservoir Evaporation, and Other Losses, 1971-2008**



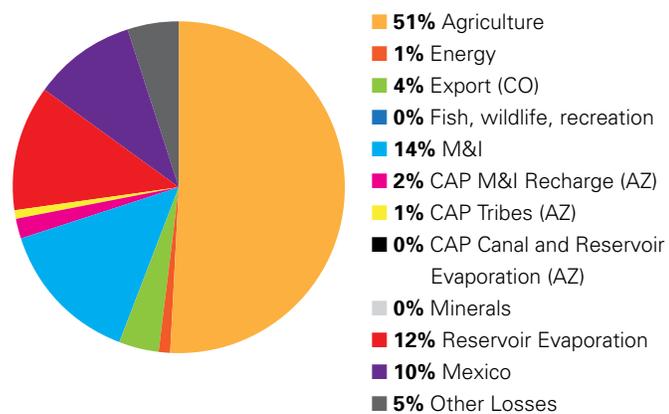
Source: Data and graphic from the U.S. Bureau of Reclamation's Colorado River Basin Supply and Demand Study Interim Report, released June 2011, and further personal correspondence with the Bureau August 10, 2011.

## Upper Basin Uses and Losses

As the compact negotiators anticipated in 1922, consumptive uses of water have been slower to develop in the Upper Basin than in the Lower Basin. From 2000 through 2008, agricultural uses accounted for the majority of the total consumption in the Upper Basin. Approximately 20 percent of total human-caused depletions of water in the Upper Basin (about 725,000 acre-feet ) are attributable to reservoir evaporation.

Colorado's total annual consumptive uses averaged just more than 2 million acre-feet during this period. Utah's uses averaged about 763,000 acre-feet per year. New Mexico consumed an average of 363,000 acre-feet annually. And Wyoming averaged about 387,000 acre-feet per year. Agriculture was the primary consumptive use, representing 69 percent of Colorado's use, 79 percent of Utah's use, 58 percent of New Mexico's use, and 85 percent of Wyoming's use in the highest water use year during this period. In total, the Upper Basin is presently consuming, on average, about 3.6 million acre-feet of its 7.5 million acre-foot apportionment.

**Figure 8: Average Basin Water Use by Sector**



*Source:* Data from the U.S. Bureau of Reclamation's Colorado River Basin Supply and Demand Study Interim Report, released June 2011, and further personal correspondence with the Bureau August 10, 2011.

## Lower Basin Uses and Losses

Lower Basin mainstream consumptive uses averaged about 7.7 million acre-feet per year from 2000 through 2008, 61 percent of which was consumed by California and about 36 percent by Arizona. Mainstream reservoirs added another one million acre-feet per year of losses through evaporation. In sum, consumptive uses plus evaporative losses totaled approximately 8.7 million acre-feet. Except for Nevada, agriculture was the primary consumptive use, representing 79 percent for California and 53 percent for Arizona, from the highest water use year for this period.

**Tributaries.** The Lower Basin tributaries include the Little Colorado, Virgin, Gila, and Bill Williams rivers. Due to problems associated with tributary consumptive uses and losses data, these significant uses and losses are not included in the historical use and loss data in the Bureau of Reclamation's 2011 report,<sup>23</sup> which are summarized in Figure 7. Tributary uses represent additional use by Lower Basin states.

## Water to Mexico

Between 2000 and 2008, Mexico received, on average, about 1.54 million acre-feet for its use under the treaty.

## Other Losses

In addition to Upper and Lower Basin demands, evaporation, and deliveries to Mexico, the Bureau's accounting also includes "other losses," which include operational inefficiencies and evapotranspiration by riverside vegetation. Operational inefficiency losses include water from irrigation districts that is too saline to be allowed to return to the river, as well as flows delivered to Mexico in excess of treaty requirements. Vegetation losses are estimated for portions of the Lower Basin along the Colorado River mainstream. These losses in the Upper Basin are implicitly included in the water budget through the natural flow computations, and therefore are not shown separately as losses. As a result, most of the "other losses" water is often included in the calculation of total Lower Basin depletions. From 2000 to 2008, these other losses averaged 735,000 acre-feet annually.

## Current Tensions between the Basins

The prolonged drought in the Basin that began in late 1999 heightened long-standing concerns about Basin water management and water use. Policymakers have been aware since at least the 1960s that the Upper Basin would not likely ever be able to use its 1922 compact apportionment of 7.5 million acre-feet and be able to meet its obligation to not reduce flows at Lee Ferry below 75 million acre-feet over rolling 10-year periods. The Bureau of Reclamation now estimates Upper Basin depletions cannot exceed 5.8 million acre-feet per year.<sup>24</sup>

The basis for this determination is the insufficiency of water yield in the Upper Basin, as evident in the more than 100-year hydrological record. Even with 60 million acre-feet of storage capacity in federal reservoirs in Upper Basin tributaries and on the mainstream, there is not enough water to ensure delivery of at least 1.5 million acre-feet to Mexico annually, provide mainstream Lower Basin users with enough water to enable consumptive use of 7.5 million acre-feet annually, provide for reservoir and channel losses of approximately 2 million acre-feet, and enable anything close to 7.5 million acre-feet of consumptive uses in the Upper Basin.

Because they are a national obligation, the treaty deliveries to Mexico can be regarded as holding the number one priority on the Colorado River.<sup>25</sup> Under the 1922 compact, other Basin uses are not generally prioritized.<sup>26</sup> Nevertheless, the compact provision obligating the Upper Basin not to reduce Lee Ferry flows below 75 million acre-feet over any 10-year period has the effect of ensuring that at least this amount of water reaches the Lower Basin in preference to any Upper Basin water uses that would diminish this amount. The effect is to enable continued uses from the mainstream in the Lower Basin as made possible by Lee Ferry flows, plus whatever flows enter the mainstream from tributaries in the Lower Basin. Upper Basin uses depend on the availability of water in excess of the flows that must pass Lee Ferry. Thus, as the level of such flows declines, less water can be depleted upstream—either through consumptive uses, reservoir evaporation, or otherwise.

Conversely, the more water passing Lee Ferry, the more uses can be satisfied in the Lower Basin. For most of the 20th century, when flows were relatively high and uses in the Upper Basin were low, there was a general abundance of water in the Lower Basin. Even when the U.S. Supreme Court in its 1963 *Arizona vs. California* decision determined Arizona could consumptively use 2.8 million acre-feet of water from the mainstream and essentially all the water in its tributaries, there still was enough water available for California to use the full 5.23 million acre-feet for which it had contracts from the United States.

As the Central Arizona Project was implemented and enabled Arizona to use its full 2.8 million acre-feet annually from the mainstream, Las Vegas' astonishing growth pushed Nevada's use up to its 300,000 acre-foot consumptive use entitlement, and Upper Basin uses slowly but steadily increased. It became evident that California would have to cut back its uses, from the 5.23 million acre-foot to which it had become accustomed to the 4.4 million acre-foot "basic" apportionment to which it had been limited in 1931 as part of the legislative bargain that enabled construction of Hoover Dam and the All-American Canal. After more than a decade-long effort, the Basin states (including California) and the United States implemented a process in 2001 to grant California a 15-year period in which to gradually cut back.<sup>27</sup>

The dry period that began in late 1999 had an impact—as storage levels in Lake Powell dropped precipitously, the secretary was forced to cut back releases from Lake Powell to the "minimum objective" level—8.23 million acre-feet.<sup>28</sup> First established in 1972, the minimum objective release is supposed to represent "normal" conditions in the Basin. It includes 7.5 million acre-feet, the annualized compact Lee Ferry flow obligation of 75 million acre-feet over 10 years,

and the 750,000 acre-feet representing half of the 1.5 million acre-foot treaty obligation to Mexico (less an assumed 20,000 acre-feet inflow from the Paria River below Glen Canyon Dam but above the Lee Ferry dividing point).

With only 8.25 million acre-feet passing from the upper to the Lower Basin, in 2003 the secretary reduced deliveries to California out of Lake Mead to the amount necessary to enable consumptive use of only 4.4 million acre-feet. Even with inflow from Lower Basin tributaries, depletions from Lake Mead of about 10.5 million acre-feet were needed to satisfy the 7.5 million acre-foot consumptive use demand from the Lower Basin mainstream, and also provide 1.5 million acre-feet to Mexico. In addition, another 1.5 million acre-feet was lost to reservoir evaporation, channel losses, salinity bypass flows, and excess water flowing to Mexico that could not be diverted. With outflows exceeding inflows, Lake Mead began to decline (Figure 10).

By 2004, the combined storage of Lakes Mead and Powell had dropped to 46 percent of capacity. Upper Basin states expressed their concern that no water should be released from Powell for the Mexican treaty obligation.<sup>29</sup> Upper Basin representatives long have objected to the Bureau of Reclamation's release of 750,000 acre-feet annually to supply half the Mexico water. Arizona counterattacked by challenging the manner in which the Bureau of Reclamation made its determination about how much water needed to be maintained in Lake Powell.<sup>30</sup> Ultimately, the states agreed to cooperate to develop a plan (effective until 2027) for increasing releases from Powell and allocating shortages up to 500,000 acre-feet.<sup>31</sup> The states also agreed to consult over differences and to begin renegotiating these criteria in 2020, in effect, concurring to put off their differences for an interim period during which, hopefully, no serious shortages occur. In October 2010, storage in Lake Mead dropped to its lowest level on record since first being filled in the 1930s.<sup>32</sup>

## Summary

Tensions in the Basin have been rising as uses and losses of basin water have reached levels that approach, and likely exceed, the Basin's supply. In the face of an ongoing drought that dates back to 1999, California has been required to give up use of about 900,000 acre-feet of Colorado River water; suppliers needed to find water from other sources. Nevada, on behalf of Las Vegas, continues to search for ways to increase its supply beyond its 300,000 acre-foot allocation. The Upper Basin faces the increasingly imminent prospect of reaching the limit of basin water it can develop and use, despite being well short of the apportionment it worked so hard to protect in the 1922 compact.

## 7. CONSIDERING THE FUTURE: OIL SHALE AND CLIMATE CHANGE

The development of oil shale deposits in the Upper Basin portends a new and substantial demand for Colorado River Basin water. Yet analysis of the effects of global warming within the Basin shows that Basin water supplies will continue to decline. This section of the report reviews how these two major developments fit into an already complex and challenging situation in the Basin. Below are summaries of two recent studies that examine the likely implications of climate change on meeting Basin water demands by the mid-21st century.

### Likely Shortages with Climate Change

Virtually all analyses of the effects of climate change on Colorado River Basin hydrology project decreases in flows. Several additional studies have explored the implications of reduced flows on meeting Basin water demands. Barnett and Pierce first investigated the likely effects, assuming flow reductions from the 20th century baseline, a period of runoff believed to be the wettest, on average, in the past 1,200 years, and then by assuming reductions from a hydrology adjusted to reflect paleoclimate analyses.<sup>1</sup>

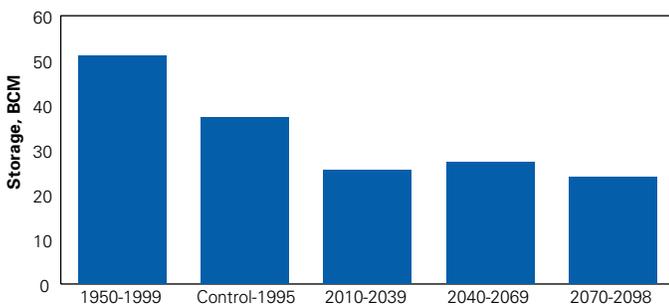
Assuming first a 10 percent reduction from 20th century hydrology, the researchers found that system supplies are inadequate to meet demands by 2040.<sup>2</sup> With a 20 percent reduction, shortfalls occur by 2025. Assuming the hydrology based on tree-ring analyses, the authors find “sustainable deliveries” that are approximately the amount of water being

used today—without any further reductions to account for global warming. Incorporating anthropogenic climate change-based reductions produces dramatic differences between demand and supply. The researchers concluded, “currently scheduled water deliveries from the Colorado system are not sustainable in the future if anthropogenic climate change reduces runoff even by as little as 10 percent.”<sup>3</sup> Under such a scenario, the researchers conclude, the long-term sustainable deliveries range from 11 to 13.5 million acre-feet per year.

In a separate study by Rajagopalan et al. completed at approximately the same time, the authors focused more on reservoir storage since it is essential to meet existing and projected Basin water demands.<sup>4</sup> This study incorporated a hydrology based on tree-ring analysis and applied a linear reduction in flows, assuming 10 and 20 percent reductions in runoff. The study showed a very low risk of depleting the reservoirs between 2008 and 2026, but the risk increases significantly beyond that time “as annual inflow is progressively depleted because of climate change at a time when demand is increasing.”<sup>5</sup> That risk is substantially higher with an assumed 20 percent reduction in runoff. The authors conclude, “The confluence of three factors, increasing delivery obligations anticipated because of population growth, the likelihood of multi-year droughts, and potential flow reduction due to climate change, poses an increasing threat to the water supply of the Colorado River system, especially after the mid 2020s.”<sup>6</sup>

These studies highlight the Basin’s dilemma—increasing demand and an inadequate supply. While Lower Basin consumptive uses from the Colorado River mainstream are not expected to increase, the Upper Colorado River Commission estimates that depletions in the Upper Basin will increase from about 4.543 million acre-feet in 2008 to 5.429 million acre-feet in 2060.<sup>7</sup> Water uses associated with oil shale development are expected to be a part of this growing demand. The studies also suggest that only reductions in these assumed future uses can keep the system in balance.

**Figure 9: Projected Changes in Average Total Colorado River Basin Reservoir Storage**



For downscaled climate simulations of the U.S. Department of Energy/National Center for Atmospheric Research Parallel Climate Model (PCM) based on projected ‘business-as-usual’ (BAU) greenhouse gas emissions and a control climate simulation based on static 1995 greenhouse gas concentrations, and an ensemble of three 105-year future climate. Simulations for three periods, and a comparison with observed historical (1950-1999) climate. From p. 21 of report.

Source: <http://www.nmdrought.state.nm.us/ClimateChangeImpact/completeREPORTfinal.pdf>

### The Distribution of Shortages

With storage capacity equaling four times annual flow, the Colorado River system has an unusual capacity to manage short-term shortages. In the past, this resiliency has provided comfort to Basin water users that usage was generally secure against year-to-year fluctuations in runoff. Agreement on the 2007 Interim Guidelines reflects an important shift in perspective—a willingness to contemplate shortages and run through the painful exercise of specifically allocating those shortages in the Lower Basin among particular users.<sup>8</sup> If the secretary were to determine that insufficient water was available to enable consumptive uses from the mainstream of 7.5 million acre-feet in Arizona, California, and Nevada, while also meeting the Mexico treaty delivery obligation of 1.5 million acre-feet, the following would occur:

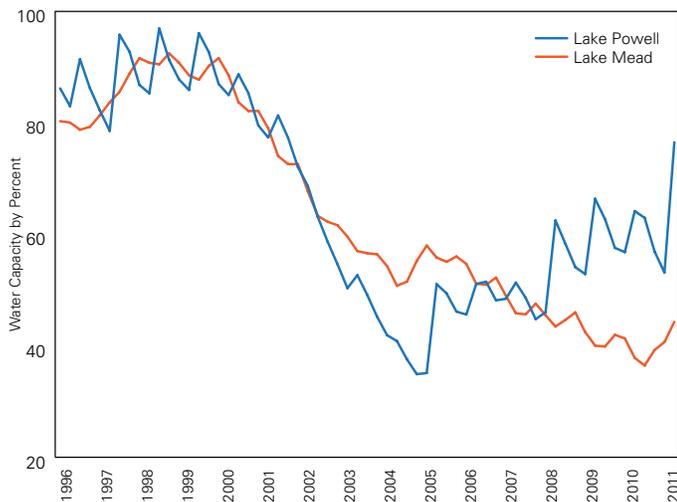
- Because Arizona agreed, in the Colorado River Basin Project Act, to subrogate its uses under the Central Arizona Project to California’s basic 4.4 million acre-foot entitlement, shortages would first be applied to Arizona’s post-1968 water rights.<sup>9</sup>
- The Interim Guidelines initiate reduced deliveries when January 1 storage levels in Lake Mead are at or below 1,075 feet—about 35 percent of active storage capacity.<sup>10</sup> Deliveries for consumptive uses would decline 333,000 acre-feet (320,000 acre-feet to Arizona and 13,000 to Nevada).

- For January 1 elevations at or below 1,050 feet, deliveries would decline by 417,000 acre-feet (400,000 to Arizona and 17,000 to Nevada).
- For January 1 elevations at or below 1,025 feet, consumptive uses would decline 500,000 acre-feet (480,000 to Arizona and 20,000 to Nevada). This is the lake elevation necessary for the Southern Nevada Water Authority to be able to extract its water from Lake Mead. There are to be additional consultations if the elevation drops below 1,025 feet.

One important variable is how Mexico would share in shortages. The Mexico treaty provides for reducing deliveries in the event of “extraordinary drought,” although no definition is provided. Under these circumstances, deliveries to Mexico are to be reduced in proportion to reductions in the United States. In the PEIS prepared to accompany development of the Interim Guidelines, the Bureau of Reclamation assumed that deliveries to Mexico would be reduced by one-sixth of the shortage, using the calculation that Mexico’s share is 1.5 million acre-feet of a total of 9.0 million acre-feet.<sup>11</sup> Thus a reduction of 500,000 acre-feet to mainstream users in the Lower Basin and including Mexico would be distributed as 400,000 to Arizona (80 percent), 83,350 to Mexico (16.67 percent), and 16,650 to Nevada (3.33 percent) (Table 6). The United States has begun negotiations with Mexico on how to share such shortages, but no resolution has been reached.

**Figure 10: Mead and Powell: Linked by Drought**

More than a decade of record drought on the Colorado River has put the squeeze on its two main reservoirs. Lake Powell hit an all-time low on April 8, 2005. Lake Mead declined more gradually, reaching its record low in November of 2010.



Citation: the *Las Vegas Review Journal*  
 Data Source: Bureau of Reclamation, Upper Colorado Region and Lower Colorado Region

**Table 6: Distribution of Shortages—Lower Basin**

Shortage Sharing by Percentages: Lower Basin and Mexico Assuming a Shortage of 500,000 Acre-feet		
	Stage I reduction sharing by %	Stage II reduction sharing by % when Arizona 4th Priority=0
Mexico	16.67%	16.67%
Arizona	80.00%	19.48%
Nevada	3.33%	3.33%
California	0	60.52%

In its Environmental Impact Statement (EIS), the Bureau of Reclamation also developed a detailed schedule of how shortages up to 2.5 million acre-feet would be allocated in the United States.<sup>12</sup> Initial shortages would be borne primarily by Arizona users with post-1968 water rights; these deliveries generally rely on the Central Arizona Project. Nevada users supplied by the Southern Nevada Water Authority (primarily Las Vegas) would also bear early shortages. As mentioned, shortages of 500,000 acre-feet (the maximum assumed under the Interim Guidelines) would be allocated as 400,000 to Arizona, 16,667 to Nevada, and 83,333 to Mexico. California would not begin to share shortages until it exceeds 1.2 million acre-feet. Under California law, these shortages would be allocated first to the Metropolitan Water District of Southern California (MWD), the entity that supplies most of the water to South Coast California cities, including Los Angeles and San Diego. As described in the EIS, shortages of 1.8 million acre-feet would include a reduction in consumptive use of 46,163 acre-feet in the MWD system; Arizona users would be reduced by 1,393,837 acre-feet and Nevada users by 60,000 acre-feet.<sup>13</sup> Within Arizona, Phoenix users would be reduced by about 170,000 acre-feet and Tucson users by about 140,000 acre-feet.<sup>14</sup> At a shortage of 2.5 million acre-feet, California users would be reduced by 469,453 acre-feet (450,412 to MWD), Arizona users by 1,530,547, and Nevada users by 83,333.

Shortages in the Lower Basin almost certainly mean reduced uses in the Upper Basin, which must be reduced any time the 10-year flows at Lee Ferry fall below 75 million acre-feet. Article IV of the Upper Colorado River Compact directs the Upper Colorado River Commission to determine each state's required curtailment of use so that the Lee Ferry flows are met.<sup>15</sup> In general, curtailments will be implemented in the same percentage as the previous year's state consumptive use bore to the total of all states' uses of Upper Basin water. Thus, if Colorado uses in the preceding year amounted to 51.75 percent of total Upper Basin consumptive uses, the commission would require Colorado to curtail uses necessary to produce 51.75 percent of the water needed to meet the Lee Ferry flow obligation.

Increasing consumption in the Upper Basin both increases the likelihood of Lower Basin shortages and curtailment of uses in the Upper Basin. Lower Basin mainstream uses are almost totally dependent on flows from the Upper Basin. Lee Ferry flows are a function of Lake Powell storage. Even at what had traditionally been the releases associated with "normal" conditions (8.23 million acre-feet), Lake Mead drops because annual depletions are 10.5 million acre-feet because of downstream consumptive use (and loss) requirements. Increasing consumption in the Upper Basin means less water in Lake Powell, the lake being lowered in an effort to maintain Lower Basin uses. The Lee Ferry flow obligation is almost certain to be unmet at some point—requiring Upper Basin uses to be substantially reduced.

## Other Issues Associated with Shortages

### The Upper Colorado River Endangered Fish Recovery Program.

<sup>16</sup> Under conditions of significant shortages, federal reservoirs in the Upper Basin will be forced to release most or all of their water to get water to Lake Mead. These reservoirs include, in addition to Lake Powell, the Colorado River Basin storage reservoirs of Flaming Gorge in Wyoming and Utah, the Aspinall Unit in Colorado, the Navajo Unit in New Mexico, and Green Mountain and Ruedi in Colorado. All these reservoirs except Powell are now operated mostly to provide stream flows that are beneficial to the needs of the four endangered species of native fish. For example, Flaming Gorge Reservoir controls the flows of the Green River—regarded by some as the only remaining viable habitat for populations of Colorado pikeminnow, razorback sucker, and humpback chub.<sup>17</sup> Adequate flows for protected fish in the critical 15 Mile Reach of the Colorado River below Grand Junction, Colorado, depend on releases from both the Green Mountain and Ruedi reservoirs. Remaining populations of endangered fish in the San Juan River depend on flows managed by Navajo Reservoir. Draining these reservoirs could have a serious impact on the long-standing efforts in the Upper Basin to bring the populations of these fish to sustainable levels.

**Salinity levels in the lower Colorado River.** Concentrations of salts in the Colorado River water are dependent on flow levels. As flows decline, concentrations increase. High salt concentrations can impair crop growth and increase treatment costs for drinking water and industrial uses.<sup>18</sup> The Bureau of Reclamation places the economic damages from uses of the river's saline water at about \$300 million per year.<sup>19</sup> Those costs are certain to increase as salinity concentrations increase. Moreover, under a minute to the Mexico treaty, the United States has committed that the water delivered to Mexico will meet certain standards.<sup>20</sup> In addition, water quality standards have been set for salinity levels at three locations in the Lower Basin. Flow reductions will strain the ability to meet these standards.



Yuma Desalination Plant

© U.S. Department of Interior Bureau of Reclamation

Drainage water from the Wellton-Mohawk Division of the Bureau of Reclamation's Gila Project east of Yuma, Arizona, is so saline it cannot flow down the Colorado River to Mexico without violating water quality standards established pursuant to the 1944 Mexico treaty. To keep these 100,000 acres of land in irrigation, Congress authorized construction of the Yuma Desalination Plant in 1974, a project completed in 1992 at a cost of \$250 million. Because plant operation is so expensive (it costs about \$484 per acre-foot), it was cheaper simply to divert the drainage water into the Santa Clara Slough and on into Mexico. While an unintended benefit has resulted in the expansion of highly valuable wetlands in Mexico, the United States receives no credit toward meeting its annual obligation to deliver 1.5 million acre-feet of water to Mexico in the Colorado River. As the Lower Basin faces the likelihood of shortages in the foreseeable future, water interests are now helping fund operation of the plant to make more water available for use.

**The search for sustainable uses of Colorado River Basin water.** The prolonged drought in the Basin since 2000 has made clear the seriousness of the dilemma—there is not enough reliable supply of water to meet even existing uses and losses of water in the Basin. Yet there are legally-based expectations (and investment-backed demands behind those expectations) to continue to expand consumptive uses in the Upper Basin. These uses include the considerable demands associated with oil shale and other energy development, as well as the growing populations in places like the Colorado Front Range and southern Utah. In addition, the Southern Nevada Water Authority (SNWA) continues to search for ways to increase its use of Basin water to supply the needs of the Las Vegas area.<sup>21</sup>

Looming over this already complicated picture is the advent of global warming and the growing scientific consensus that average runoff in the Colorado River Basin is likely to decrease in the years ahead—perhaps by 20 percent. The scientists who have considered this future agree that it is probably still manageable—if the necessary actions are taken now. Overpeck and Udall summarized:

*“Either way, it is sobering to consider published projections of future Colorado River flow given continued anthropogenic climate change: All studies published thus far point to continued declines in the river’s flow. Even assuming modest reductions in greenhouse gas emissions... the average annual flow of the Colorado could decrease by 20 percent by 2050. At the same time, the risk of all Colorado reservoir storage (3 to 5 years’ worth of water) drying up could increase to 3 chances in 10. Such change would have profound implications for the southwestern cities (such as Los Angeles, San Diego, Phoenix, Salt Lake City, and Denver) and the agricultural production areas (for example, in southern California and Arizona) that depend on water from the Colorado River.”<sup>22</sup>*

Barnett and Pierce concluded:

*“The problem is at our threshold and appears solvable, at least in the near term. But it needs to be addressed now.”<sup>23</sup>*

While it may be decades before it is established what effects global warming is having on Colorado River Basin water supplies, the one variable that can be managed now is water use. Historically, U.S. policies have favored encouraging consumptive use of Basin water to support growth and development. States have vied to increase their uses, in part to solidify their claims to Basin water. With generous federal funding, projects were built to enable uses that would otherwise have been economically impossible.

The process of matching use to reliable supplies began with the decade-long negotiations that led in 2001 to the “California Plan,” a way to reduce California’s uses from 5.3 million acre-feet per year to 4.4 million acre-feet.<sup>24</sup> Unanticipated drought forced implementation of this plan immediately, rather than over the intended phase-in period. Central to the plan was the voluntary reallocation of a portion of water historically used for irrigated agriculture to urban uses.<sup>25</sup>

A second step was taken with the development of the Interim Guidelines. In addition to shortage criteria and reservoir reoperations, the guidelines provide incentives for the Lower Basin states to find ways to generate “intentionally created surplus (ICS).”<sup>26</sup> An example is construction of the “Drop 2” reservoir on the All-American Canal that will enable regulation of water that would otherwise go to Mexico without credit for the treaty obligation.<sup>27</sup> In return for funding much of the cost of these facilities, the SNWA will receive the right to withdraw at least an additional 400,000 acre-feet from Lake Mead, at the rate of up to 40,000 acre-feet per year.

The challenge for Colorado River Basin water users is to decide how to integrate new uses in the Upper Basin into what appears to be a fully-allocated water supply. One option is simply to do nothing and allow new uses to go forward within each state’s priority system, and then to be prepared to curtail junior uses as necessary should there be a requirement to do so to meet the Lee Ferry flow obligation. In anticipation of such a curtailment, states (or water users themselves) could establish mechanisms by which senior (irrigation) uses would agree to forego uses to enable more economically valuable junior uses to continue.<sup>28</sup>

Water used for oil shale would not be among the most junior uses in Colorado, Utah, and Wyoming because substantially more senior claims already exist for such uses with priorities dating back to the 1950s.<sup>29</sup> In addition, energy companies have purchased very senior irrigation rights in western Colorado, which will be changed to use for oil shale as demands develop. Actual uses under these claims would be senior in priority to subsequent rights established to support new population growth in these states. Should there be a curtailment of uses required under the 1922 compact, the Upper Basin states may be faced with shutting off these urban uses while oil shale-related uses continue. Moreover, should recovery of any or all of the four Colorado River endangered fish species begin to falter for any reason, all water uses approved under the Upper Colorado River Endangered Fish Recovery Program are potentially at risk.<sup>30</sup>

Also of note is the nature of these new demands for water in the Upper Basin, which, for oil shale and urban growth, are not highly flexible. Once in place, demands are likely to grow—not decrease; these are “hard” demands, not compatible with being curtailed while agricultural demands are managed for shortages. Committing Colorado River Basin water to these uses almost certainly means other existing uses (likely for agriculture) will have to be reduced or ended. The process of making agricultural water available for new uses, especially tied to providing that water only in times of drought, has proven difficult. Permanent removal of water from agriculture continues to provoke controversy.

The most variable element is whether the Upper Basin will enforce a curtailment of water uses to meet the Lee Ferry flow requirement established in the 1922 compact. The states might decide instead to bring an action in the U.S. Supreme Court challenging enforcement of this provision.<sup>31</sup> Any such litigation is certain to be lengthy and expensive, and the outcome uncertain.

Another potential avenue would be for the states to seek to negotiate a more comprehensive agreement about river management to take into account present circumstances. Among the topics of such a negotiation would be future additional Upper Basin uses and the Mexico delivery obligation. The objective would be to reach agreement on a sustainable basin water budget that addresses the present sources of contention and provides more certainty for present and future Basin water users.

The Interim Guidelines have provided a window of opportunity for the Basin states and the United States to reflect on these issues and consider their options.<sup>32</sup> But in the interim, problems continue to build. New water demands continue to develop in the Upper Basin, with substantial investments being made to meet them.<sup>33</sup> Basin reservoir storage capacity remains at dangerously low levels. There is a growing sense that a crisis is lurking—it’s only a question of when. How will we respond?

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## 8. CONCLUSIONS

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### 1. Water supplies in the Colorado River Basin

- **The Colorado River Basin is over subscribed.** When the Colorado Compact was signed in 1922, the average yield from the Basin was estimated to be 17.5 million acre-feet (maf). Recent studies have indicated that the long-term average natural flow at Lee Ferry may be closer to 14.7 maf. For the past decade, water use in the Basin has exceeded available supply. The average annual use in the Basin has averaged 15.3 maf since 2000. Based on current use and the long-term average yield, there is not enough water to meet current demands. This increase in demand is the major cause of the reduction in Colorado River Basin storage in the past decade.
- **There is no solid basis to conclude that there is undeveloped water in the Colorado River.** Reports by the GAO and others have concluded there is insufficient information regarding current baseline conditions of groundwater and surface water in oil shale-bearing regions to conclude with certainty that there is undeveloped water.
- **Oil shale development would exacerbate existing water supply problems.** The Colorado River Basin is already facing major water supply challenges due to historical overestimates of average basin runoff, years of drought, and increasing demand. Large-scale oil shale processing and associated development would increase water supply demands, further exacerbating water management challenges and tensions among the compact states.

### 2. Oil shale development would impact Colorado River water resource use

- **Oil shale could represent a major new demand on water supplies.** A mid-range estimate suggests that oil shale development, including processing, energy supplies, and related development, could require over 360,000 acre-feet per year, roughly one-and-a-half times the water used by the city of Denver. Large-scale development of oil shale could require significantly more water.
- **Agriculture in Colorado would be hit hard.** Energy companies have already purchased relatively senior water rights which they have not yet exercised; if they do so and if subsequent analysis concludes that there is limited or no undeveloped water in the Upper Basin, most of that water is expected to come from agricultural water users.

- **Urban water agencies would have less ability to adapt to drought or climate change impacts.** Urban water users, particularly on Colorado's Front Range, would also face significantly increased water supply challenges, particularly in dry years due to hardening of demand related to the conversion of water supplies from flexible agriculture uses to relatively inflexible use by the oil shale industry.
- **Basin-wide tensions would be increased and flexibility would be decreased.** Large-scale oil shale development could increase consumptive use in the Upper Basin, increasing the challenges faced in ensuring long-term deliveries of water to the Lower Basin, as specified in the compact. This could increase the likelihood of a "call" on water by Lower Basin states. Adding a large, long-term, relatively senior and inflexible industrial use of water would also reduce flexibility as the Bureau of Reclamation and basin states begin to evaluate options to live within the long-term yield of the river.
- **Water supply impacts may be greater than currently predicted.** Estimates of water demand for oil shale processing vary widely, and the technology is in development. Therefore, the water demand for processing could prove to be higher than expected. Furthermore, information regarding currently available water supplies is insufficient to accurately assess the impact oil shale development will have on existing users.

### 3. Oil shale development would harm fish, wildlife, and water quality

- **Scenic natural lands, fish, and wildlife would be impacted by oil shale development.** Oil shale deposits occur in areas in Colorado, Utah, and Wyoming that are known for their natural beauty. Large-scale oil shale development would not only mar the landscape with industrial infrastructure, but also impact threatened species in the region. Increased water supply demands could impact tributary rivers like the Green River and make it more difficult to restore four listed species efforts on the Colorado River.
- **Oil shale has significant potential to negatively impact both surface and ground water quality.** Tailings and processing waste are known sources of toxic pollutants if not contained. In situ processing requires heating and extracting liquefied oil at depths that could pollute groundwater aquifers.

#### 4. Climate change will further reduce existing water supplies in the Colorado River Basin

- **The Colorado River Basin is already warming.** Numerous scientific studies have concluded that the climate has already begun warming and that the Colorado River Basin has been warming more quickly than other parts of the West.
- **Climate change will reduce Colorado River Basin water supplies.** Many studies have concluded that the Colorado River Basin is ground zero for the water management impacts of climate change. An already arid climate will become even warmer, reducing snow pack, increasing evaporation, and causing other changes. The U.S. Climate Change Science Program has predicted runoff decreases of 10 to 25 percent by 2050—roughly 5 to 12 times Denver’s water use. The Bureau of Reclamation has concluded that flows will decrease by 9 percent over the coming 50 years.

#### 5. Oil shale development would significantly contribute to greenhouse gas pollution

- **Oil shale production and refining results in significantly higher greenhouse gas emissions than conventional oil fuels.** Well-to-wheel greenhouse gas emission estimates for oil shale show it to have 23 percent to 73 percent (1.2 to 1.7 times) greater emissions in comparison to diesel.

## RECOMMENDATIONS

### 1. Improve Water Management

A comprehensive assessment is needed to quantify and characterize existing surface water supplies that could be used for oil shale development, particularly those that contribute significantly to meeting the Upper Basin’s compact obligations. Given the time required to develop large-scale oil shale resources, and the long-term nature of this use, this analysis should include the best available information regarding long-term water availability, particularly addressing the likely impacts of climate change. We recommend the following steps:

- **Investigation by the Bureau of Reclamation’s Colorado River Basin Study.** In addition to addressing factors such as projected population growth and the likely effects of climate change, the Bureau of Reclamation should also investigate the potential impacts of large-scale oil shale development, including direct impacts to existing users and indirect impacts associated with hardening of demand and reduced flexibility.
- **Develop new comprehensive state water management strategies.** The likely impacts of climate change and future urban development alone necessitate the preparation of local, state, and Basin-wide adaptation strategies, with a focus on increasing water use efficiency and maintaining healthy aquatic ecosystems. The Basin states individually and as a whole, in collaboration with the Bureau of Reclamation, should undertake analyses of the range of actions that are available to reduce water consumption basin- and state-wide 10 to 25 percent from current levels. This analysis should investigate options for limiting new consumptive uses and the potential for urban, agricultural, and industrial conservation. The most effective approach to this challenge would be a collaborative, Basin-wide effort to significantly increase water use efficiency. These investigations should include the potential impacts of oil shale development.
- **Protect groundwater.** Groundwater aquifers in oil shale regions should be modeled to assess the range of potential water quality impacts of groundwater contaminants related to oil shale production.

- **Determine potential oil shale-related water supply impacts on Upper Basin urban water users.** Long-term effects to major urban centers, such as Denver, should be investigated by local water agencies and the Colorado State Engineer/Division of Water Resources. This analysis should include potential impacts from increased demand, and demand hardening on the reliability of water supplies, particularly in sequential dry years.
- **Determine potential impacts on Upper Basin agricultural water use.** Agricultural water agencies and the Colorado State Engineer should cooperate to document the impacts to agricultural water users if oil shale water rights are exercised. This analysis should include an evaluation of the availability of undeveloped water in light of likely future climactic conditions.
- **Recycle and reuse wastewater and stormwater runoff.** In some regions, investments in wastewater recycling, urban stormwater management, and other tools offer the potential to increase water supplies and decrease pressure on Colorado River supplies. The potential of these tools should be evaluated across the Basin.

## 2. Do Not Pursue Oil Shale Development

Based on the current information about the wide range of environmental impacts and existing technologies, oil shale development should not be pursued. The costs are too high, and the benefits of increased energy are too small and easily made unnecessary with energy-efficiency measures. Further studies of oil shale must do more than merely overcome the technological challenges that have stopped the development of a full-scale industry. The significant environmental impacts of such development must be prevented. Such an industry must be investigated in the context of a climate that is already warming and will be made worse by oil shale development.

- **Analyze current and future water supply limits.** Analyses of potential oil shale development must take into account that the Colorado River Basin is already oversubscribed and adding a major new use will have broad negative impacts. Furthermore, climate change will likely decrease existing supplies by 10 to 25 percent.
- **Protect sensitive or protected lands from oil shale leasing.** The oil shale regions in the upper Colorado River Basin are home to some of the most spectacular landscapes in the nation, as well as to wildlife that is currently listed under the Endangered Species Act. Oil shale development should not

include lands occupied by or designated as critical habitat for threatened or endangered species, designated Areas of Critical Environmental Concern, or lands where oil shale development would permanently impair the productivity of the land or the quality of the environment.

## 3. Implement Climate Change Adaptation and Greenhouse Gas Reduction Efforts

States that depend on the Colorado River Basin for their water supply face significant challenges in the future as a result of unchecked climate change. To reduce those risks and to encourage other states and the federal government to take action, these states should take immediate steps to implement comprehensive energy and climate policies:

- **Implement regional greenhouse gas reduction efforts.** The Basin states should work together to reduce the future risk of climate change by implementing national and state-level legislation, and use existing legal authorities to reduce greenhouse gas emissions. Basin states should explore the potential for creating an enforceable state-level cap on carbon pollution, similar to California's AB 32.
- **Encourage green infrastructure and smart growth.** Require more energy-efficient construction to lower building-related emissions and promote smart growth planning within new and existing communities to reduce vehicle miles.

## 4. Support Clean and Efficient Energy

Increasing energy efficiency reduces demand and the need for additional energy production, such as oil shale development, and will also decrease water consumption related to energy production and reduce greenhouse gas emissions. Each state in the Basin should take steps to implement comprehensive and ambitious state-wide energy efficiency programs.

- **Prioritize energy efficiency.** Basin states should support increased automobile gas efficiency in order to reduce energy consumption and greenhouse gas emissions; in addition, these states should modernization building codes to reduce energy consumption related to buildings.
- **Promote cleanest forms of energy.** Promote low, or non-greenhouse gas-emitting and water-efficient sources of energy such as wind, solar, and geothermal sources that provide water supply, climate change, and energy-efficiency benefits.

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# SOURCES AND ENDNOTES

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## 2. Introduction

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#### 5. Climate Change and the Colorado River Basin

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## 6. Colorado River Basin Water Allocations, Uses, and Conflicts

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6. The Upper Basin states insisted California accept this limitation so there would be water available under the basic apportionment to the Lower Basin of 7.5 million acre-feet for Arizona and Nevada. The Upper Basin feared California would use so much water the other states would need to use water from the apportionment to the Upper Basin states.
7. In the 1930s, the secretary established contracts with California users totaling 5.3 million acre-feet of water. Then in the 1940s the secretary entered into contracts with Nevada for 300,000 acre-feet and Arizona for 2.8 million acre-feet.
8. Utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty between the United States of America and Mexico, February 3, 1944, <http://www.usbr.gov/lc/region/pao/pdfiles/mextrety.pdf>. Article 10 states: "the water allotted to Mexico under subparagraph (a) of this Article will be reduced in the same proportion as consumptive uses in the United States are reduced."
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14. *Arizona v. California*, 373 U.S. 551; 1963.
15. U.S. Department of the Interior, Bureau of Reclamation. Colorado River Basin Project: Objectives. [usbr.gov/lc/region/g1000/pdfiles/crbproj.pdf](http://usbr.gov/lc/region/g1000/pdfiles/crbproj.pdf). Accessed July 30, 2011.
16. U.S. Department of the Interior. Record of Decision: Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead. Washington, DC; December 2007. [usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf](http://usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf). Accessed July 30, 2011.

17. From October 1, 1999 through September 30, 2007, storage in Colorado River reservoirs fell from 55.8 maf (approximately 94 percent of capacity) to 32.1 maf (approximately 54 percent of capacity), and was as low as 29.7 maf (approximately 52 percent of capacity) in 2004." According to the Upper Colorado River Commission, "the average natural flow since the year 2000 (2000-2009, inclusive) is 11.982 maf, the lowest ten-year average in over 100 years of record keeping on the Colorado River." Sixty-First Annual Report of the Upper Colorado River Commission, Salt Lake City, Utah, September 30, 2009, p. 73.
18. The Bureau of Reclamation is considering implementing the shortage criteria in 2011. Felicity Barringer, "Water Use in Southwest Heads for a Day of Reckoning," *New York Times*, September 28, 2010, p. A14.
19. Presumably, the use of the additional 1 million acre-feet apportioned to the Lower Basin under the compact occurs in the tributaries. In fact, consumptive uses in the tributaries already are more than twice this amount.
20. U.S. Department of the Interior, Bureau of Reclamation. Colorado River Basin Water Supply and Demand Study Interim Report. June 2011. <http://www.usbr.gov/lc/region/programs/crbstudy/Report1/TechRptC.pdf>. Except as noted, all of the following depletions numbers are from this document.
21. Upper Basin evaporation numbers were derived from the Bureau of Reclamation's Colorado River System's Consumptive Uses and Losses Reports, 1996-2000, 2001-2005 (provisional), and 2006-2010 (provisional, with data only available through 2008). Total evaporation data was obtained from the Bureau of Reclamation's Colorado River Basin Supply and Demand Study Interim Report, released June 2011, and our further correspondence with the Bureau August 10, 2011. Lower Basin evaporation numbers were not available in the Consumptive Uses and Losses Reports past 2000, and were therefore derived by subtracting Upper Basin evaporation from the total evaporation.
22. Data derived from the Colorado River Basin Water Supply and Demand Study Interim Report Number 1, Bureau of Reclamation, June 2011 and further correspondence with the Bureau of Reclamation August 10, 2011.
23. U.S. Department of the Interior, Bureau of Reclamation. Colorado River Basin Water Supply and Demand Study Interim Report Number 1. Technical Report C, p. C-22. June 2011.
24. Bureau of Reclamation, Hydrologic Determination 2007: Water Availability from the Navajo Reservoir and the Upper Colorado River Basin for Use in New Mexico. [usbr.gov/lc/envdocs/eis/navgallup/FEIS/vol1/attach-N.pdf](http://www.usbr.gov/lc/envdocs/eis/navgallup/FEIS/vol1/attach-N.pdf). Accessed July 30, 2011.
25. A treaty obligation is national law that, under the U.S. Constitution, has priority over conflicting state laws.
26. The exception is what are called "present perfected rights"—water in the Colorado River Basin placed to beneficial use prior to signing of the 1922 compact.
27. Lochhead, James S. An Upper Basin Perspective on California's Claims on Water from the Colorado River, Part I: The Law of the River. *University of Denver Law Review*. 2001. [lochhead\_01.pdf].
28. Secretary Norton cut off deliveries to California under the Interim Surplus Guidelines in 2003 to force parties within the state to reach agreement on quantification of water rights. Then drought forced a continuation of these reduced deliveries so California has only been receiving its basic apportionment of 4.4 million acre-feet annually since that time.
29. Letter from Scott Balcomb et al., "Governors' Representatives on Colorado River Operations of the States of Colorado, Wyoming, New Mexico, and Utah" to Herb Guenther et al., "Governors' Representatives of the States of Arizona, California, and Nevada," October 7, 2004.
30. W. Patrick Schiffer, et al., "From a Colorado River Compact Challenge to the Next Era of Cooperation Among the Seven Basin States," 49 *Ariz. L. Rev.* 217 (2007). Arizona argued storage levels should not be protected for power generation purposes, the Upper Basin depletion schedule was too high, and the assumption regarding the amount of storage in Powell necessary to protect Upper Basin uses should be re-determined annually.
31. Stockton and Boggess, 1979. This and other studies are summarized in Appendix U of "Climate Technical Work Group Report, Final Environmental Impact Statement," Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Mead and Lake Powell, October 2007.
32. Brean, H. Drought-stricken Lake Mead falls to level not seen since 1937. *Las Vegas Review-Journal*, October 19, 2010.

## 7. Considering the Future: Oil Shale and Climate Change

- 1-3. Barnett TP, Pierce DW. Sustainable Water Deliveries from the Colorado River in a Changing Climate. *Proc. Nat'l Academy Sciences*. 2009; 7,334-7,336.
- 4-6. Rajagopalan B et al. Water Supply Risk on the Colorado River: Can Management Mitigate?" *Water Resources Research*. 2009: 201.
7. Appendix C, "Upper Basin States Depletion Schedules, Final Environmental Impact Statement," Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead, Bureau of Reclamation <http://www.usbr.gov/lc/region/programs/strategies/FEIS/Vol2Front.pdf> Note that the commission's analysis of Upper Basin depletions is higher than the total estimated by the Bureau of Reclamation in its Consumptive Uses and Losses report. The Commission now estimates depletions in 2060 will be 5.573 million acre-feet, personal communication, Doug Kenney, September 20, 2010.
8. It is worth noting, however, the Interim Guidelines still contemplate additional water allocations if "surplus" conditions exist. Moreover, the Upper Basin made a major concession by allowing "equalization" releases from Lake Powell at considerably lower storage levels than it had previously agreed to. Thus, for example, under the Interim Guidelines the secretary may release up to 9.5 million acre-feet from Powell when it is only at about 15 percent of capacity to keep Mead above the elevation necessary to enable Nevada to extract water (elevation 1025, which equates to about 20 percent of storage capacity).
9. *Arizona v. California*, 373 U.S. 551; 1963, Section 301 (b): "Article II (B) (3) of the decree of the Supreme Court of the United States in Arizona against California (376 U.S. 340) shall be so administered that in any year in which, as determined by the Secretary, there is insufficient mainstream Colorado River water available for release to satisfy annual consumptive use of seven million five hundred thousand acre-feet in Arizona, California, and Nevada, diversions from the mainstream for the Central Arizona Project shall be so limited as to assure the availability of water in quantities sufficient to provide for the aggregate annual consumptive use by holders of present perfected rights, by other users in the State of California served under existing contracts with the United States by diversion works heretofore constructed, and by other existing Federal reservations in that State, of four million four hundred thousand acre-feet of mainstream water, and by users of the same character in Arizona and Nevada. Water users in the State of Nevada shall not be required to bear shortages in any proportion greater than would have been imposed in the absence of this subsection 301(b). This subsection shall not affect the relative priorities, among themselves, of water users in Arizona, Nevada, and California which are senior to diversions for the Central Arizona Project, or amend any provisions of said decree."
10. U.S. Department of the Interior. Record of Decision: Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead. Washington, DC; December 2007.
- 11-14. U.S. Department of the Interior, Bureau of Land Management. Oil Shale and Tar Sands Final Programmatic Environmental Impact Statement. 2008. <http://ostseis.anl.gov/eis/guide/index.cfm>; Accessed July 29, 2011.
15. The Engineering Advisory Committee of the Upper Basin Commission is working to prepare guidelines for implementing a compact curtailment. See State of Wyoming, Colorado River Compact Administration Program, p. 5. [seo.state.wy.us/PDF/CU\\_Plan\\_Final.pdf](http://seo.state.wy.us/PDF/CU_Plan_Final.pdf)
16. Upper Colorado Endangered Fish Recovery Program. [www.coloradoriverrecovery.org/](http://www.coloradoriverrecovery.org/)
17. U.S. Department of the Interior, Bureau of Reclamation. Flaming Gorge Dam Environmental Impact Statement. January 22, 2007. [usbr.gov/uc/provo/rm/fgeis/fgeis\\_background.html](http://usbr.gov/uc/provo/rm/fgeis/fgeis_background.html). Accessed July 30, 2011.
- 18,19. U.S. Department of the Interior, Bureau of Reclamation. Quality of Water, Colorado River Basin: Progress Report No. 22. [usbr.gov/uc/progact/salinity/pdfs/PR22.pdf](http://usbr.gov/uc/progact/salinity/pdfs/PR22.pdf).
20. U.S. Department of the Interior, Bureau of Reclamation. International Boundary, United States and Mexico, Minute 242. [usbr.gov/lc/region/pao/pdffiles/min242.pdf](http://usbr.gov/lc/region/pao/pdffiles/min242.pdf). Accessed August 1, 2011.
21. Nevada is entitled to consumptive use of only 300,000 acre-feet per year from the Colorado River. The remarkable (and initially unanticipated) growth of Las Vegas has pushed consumption to this ceiling.
22. Overpeck J, Udall B. Dry time ahead. *Science*. 2010;328:1642-1643. <http://www.sciencemag.org/content/328/5986/1642.short>. Accessed August 1, 2011.
23. Barnett TP, Pierce DW. Sustainable Water Deliveries from the Colorado River in a Changing Climate. *Proc. Nat'l Academy Sciences*. 2009; 7,334-7,336.
24. Lochhead, James S. An Upper Basin Perspective on California's Claims on Water from the Colorado River, Part I: The Law of the River. *University of Denver Law Review*. 2001 [lochhead\_01.pdf].
25. Department of the Interior. Testimony of Bennett W. Raley, Assistant Secretary before the Committee on Resources, Subcommittee on Water and Power, United States House of Representatives on Implementation of the California Plan for the Colorado River: Opportunities and Challenges, La Quinta, California, June 14, 2002. [doi.gov/ocl/2002/calplan.htm](http://doi.gov/ocl/2002/calplan.htm) Accessed August 1, 2011.

26. As summarized by the Southern Nevada Water Authority, there are four general ways in which such “surplus” water may be created: 1) Tributary Conservation: allows a water user to follow water rights in tributaries of the Colorado River that were in use prior to the effective date of the 1928 Boulder Canyon Project Act and transport this water to the Colorado River for credit; 2) Imported ICS: allows a Colorado River contract holder to convey non-Colorado River water to the Colorado River for credit; 3) System Efficiency: allows a user to fund a system efficiency project that would conserve Colorado River water. The project must increase the amount of water available in the United States and a portion of the saved water would be credited to the user funding the project; and 4) Extraordinary Conservation: allows a water user to implement a project, such as land fallowing or canal lining, to conserve water through extraordinary measures which would increase Lake Mead levels.
27. U.S. Department of the Interior, Bureau of Land Reclamation. Drop 2 storage reservoir project: questions and answers. [usbr.gov/lc/region/programs/drop2/faqs.html](http://usbr.gov/lc/region/programs/drop2/faqs.html) Updated February 2009. Accessed August 1, 2011.
28. The Colorado River Water Conservation District has proposed such a plan. See Peter Fleming, Colorado River Compact Curtailment Alternative PowerPoint presentation, Schmueser Gordon Meyer Fall Forum, October 30, 2009. [sgm-inc.com/happenings/2009\\_fall\\_forum/](http://sgm-inc.com/happenings/2009_fall_forum/). Accessed August 2, 2011.
29. Western Resource Advocates, “Oil on the Rocks: Oil Shale Water Rights in Colorado (2009). [westernresourceadvocates.org/land/wotrreport/index.php](http://westernresourceadvocates.org/land/wotrreport/index.php) See. Ruple JC, Keiter RB, Water for Commercial Oil Shale Development in Utah: Allocating Scarce Resources and the search for new sources of supply. *Land, Resources & Env'tl L.* 2010;95:35. [epubs.utah.edu/index.php/jlrel/article/viewArticle/278](http://epubs.utah.edu/index.php/jlrel/article/viewArticle/278).
30. The depletions associated with these uses are regarded as jeopardizing the continued existence of the listed species of fish that still inhabit portions of the Colorado River Basin. They are allowed to continue under the program as a “reasonable and prudent alternative” so long as the populations of protected fish meet certain targets over time.
31. There are several plausible legal grounds on which the Upper Basin might bring such a challenge. For example, see Carlson JU, Boles, Jr. AE. Contrary Views of the law of the Colorado River: An examination of rivalries between the upper and lower Basins. *Rocky Mt Min L Inst.* 1986: 21-1.
32. The Bureau of Reclamation has funded a two-year study of basin issues, to be completed in January 2012 that involves all the basin states; see U.S. Department of the Interior, Bureau of Land Reclamation. *Colorado River Basin Water Supply and Demand Study*. June, 2011. [usbr.gov/lc/region/programs/crbstudy/Report1/StatusRpt.pdf](http://usbr.gov/lc/region/programs/crbstudy/Report1/StatusRpt.pdf).
33. The Million Conservation Group has applied for a 404 permit necessary to construct a pipeline from Flaming Gorge Reservoir and the Green River to the Colorado Front Range that would deliver 240,000 acre-feet per year. <http://www.nwo.usace.army.mil/html/od-tl/eis/RWSP-EIS.html>. The state of Utah is moving ahead with a pipeline that would carry about 100,000 acre-feet of water from Lake Powell to the St. George, Utah, area; see <http://www.lakepowellpipeline.org/>.







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