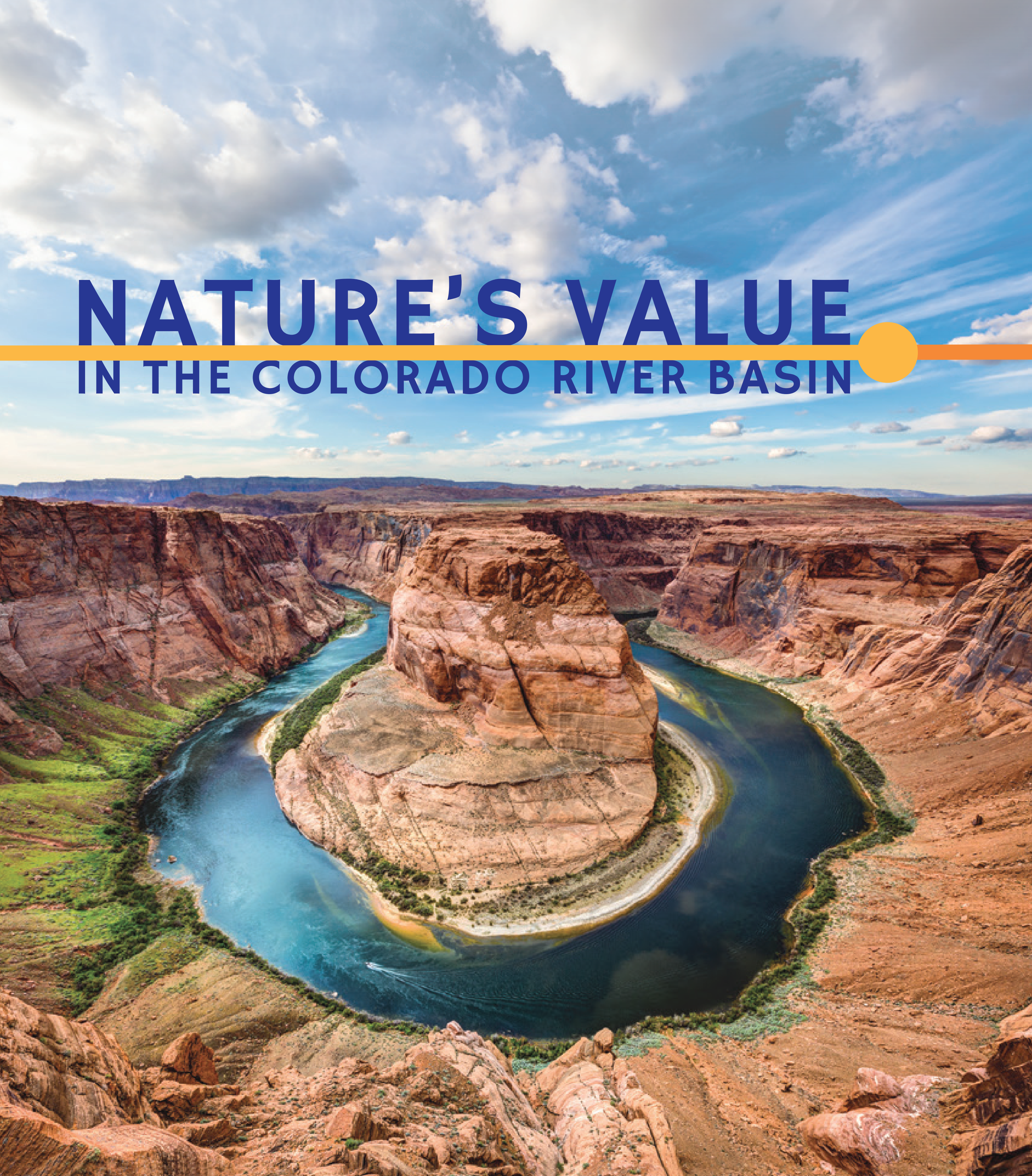
NATURE'S VALUE
IN THE COLORADO RIVER BASIN



EARTH ECONOMICS

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On December 15, 2015 this report was modified to reflect updated water use data in the Colorado River Basin. Since 2005, water use in agricultural, municipal, and industrial sectors in the Basin decreased by over 3 million acre-feet. With updated USGS data from 2005 to 2010, this report reflects a decrease in water supply value.

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ABSTRACT

This study presents an economic characterization of the value of ecosystem services in the Colorado River Basin, a 249,000 square mile region spanning across mountains, plateaus, and low-lying valleys of the American Southwest. Colorado River Basin ecosystems provide a suite of ecosystem services including drinking and irrigation water, flood control, and world-renowned recreational opportunities. This study calculates the economic value provided by these ecosystems. We used existing studies on the value of ecosystem services for land cover types found in the basin; these land cover types were assessed using Geological Information System (GIS) data. Several new primary values for ecosystem services in the Colorado River Basin were also derived as part of this study. The natural benefits (ecosystem services) examined in this study include potable water, irrigation water, carbon sequestration, flood risk reduction, water filtration, wildlife habitat, soil erosion reduction, soil formation, raw materials, food, recreation, air quality, and aesthetic value.

This report highlights the scale of value provided by the landscape of the Colorado River Basin. Whether land is in private or public ownership, that value, in the form of water supply, flood risk reduction, recreation, and other benefits, is distributed across the landscape. The economic vitality of communities depends upon it. Healthy natural systems provide vast economic value, and investing in natural capital provides a high rate of return. Understanding the scale of value provided in the Colorado River Basin provides incentive for investing in healthy landscapes, healthy rivers, and healthy communities.

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EXECUTIVE SUMMARY

Economies need nature. Economic development and quality of life depend upon "natural capital." Natural capital, which includes forests, farms, grasslands, rangelands, rivers, lakes, and wetlands, is produced by ecosystems: plants, animals, and smaller living things that interact with air, water, and soil. Natural capital produces economically valuable tangible goods, such as food, water, timber and fish, as well as less tangible but still vitally important services, including flood risk reduction, drinking water filtration, recreation, and aesthetic value.

This is readily apparent in the spectacular Colorado River Basin (frequently referred to in this report as "the Basin"). If the natural capital of the Colorado River Basin were appraised like a business, based on the value of the goods and services it provides, how much would it be worth? This study is the first valuation of the many natural goods and services of the Colorado River Basin.

The data utilized for this valuation included studies on the value of ecosystem services for land cover types found in the basin. These land cover types, such as grasslands, wetlands, and riparian areas, were determined using Geological Information System (GIS) data from the US Geological Survey. The economic benefits provided by each land cover type were valued in dollars using a benefit transfer methodology. Like a house or business appraisal, this method utilized previous valuation studies in locations comparable to the Colorado River Basin. Dollar values for each natural benefit/ land cover combination were estimated using one or more of nine valuation techniques, including market pricing, cost avoidance, travel cost, and contingent valuation. Several new primary values for ecosystem services in the Colorado River Basin were also derived as part of this study.

The natural benefits (ecosystem services) examined in this study include potable water, irrigation water, carbon sequestration, flood risk reduction, water filtration, wildlife habitat, soil erosion reduction, soil formation, raw materials, food, recreation, air quality, and aesthetic value.

Results show that ecosystems in the Colorado River Basin provide between $56.5 billion and $466.5 billion in economic benefits every year. These benefits extend well beyond the boundary of the basin, to the region and globe. For example, people in Denver and Los Angeles live outside the Basin but receive water from it.

The range of values represents an appraisal of the Basin's natural capital. The range is wide, and will narrow with more primary valuations and greater GIS data specificity, just as a closer inspection will improve the estimated value of a house. Currently, the low end of the range represents a baseline value and an underestimate of the true value. This is because, among 21 valuable ecosystem service categories identified as present in the Basin, only between 0 and 7 were valued for each land cover type. Snowpack is valuable for water storage, and desert crust has erosion control benefits, but neither has studies estimating that value.
So, though they are important for drought reduction, water supply, habitat, recreation, and energy generation, some ecosystem service categories and land cover types have a zero value in this study.

Treating natural capital as an economic asset that provides a stream of benefits over time, similar to factories, apartment buildings, roads, and other built infrastructure, provides a method for estimating an asset value for natural capital. This is like using apartment rental payments (flow of value) to estimate the total value of an apartment building (asset value). However, natural systems are different from built capital because whole river basins are seldom bought or sold.

Based on the ecosystem services examined and treated like an asset with a lifespan of 100 years, **the Colorado River Basin has an asset value between $1.5 trillion and $11.5 trillion** at a 4.125 percent discount rate.[i] Unlike built capital, which is seldom productive for 100 years, natural systems can be self-maintaining and have far longer productive lifespans. The Colorado River Basin has provided food and water to people for thousands of years. Thus, these estimates are conservative. Using a 0 percent discount rate, which recognizes the renewable nature of natural capital and assumes that people in the future will receive the same level of benefits (a more likely scenario for natural capital), and considering this value over the next 100 years, **the asset value is between $5.8 trillion and $46.9 trillion**.

The analysis of natural capital is relatively new, but it is well accepted and increasingly used by large private companies, federal and state agencies, and policy makers at all levels of government. For example, the Federal Emergency Management Agency (FEMA) has applied ecosystem service values for all flood and hurricane mitigation in the United States, including Hurricane Sandy and the recent 2013 Colorado floods. FEMA is the first federal agency to incorporate annual ecosystem service value into benefit cost assessments.

In 1934, the new economic measures such as gross national product, inflation, unemployment, money supply, income, and asset reporting for private companies provided values that seemed astoundingly large, at the time. Better measures and better access to more accurate information allowed private investors and public officials to make more prudent investments and decisions based on established valuation methods. Today 6.4 million private companies in the United States all report their earnings and assets. Yet, the clear economic benefits and asset values provided by natural systems, such as the Colorado River Basin, have registered little or no value until now.

AT A GLANCE VALUE OF THE BASIN

$56.5 BILLION TO 466.5 BILLION — ANNUAL VALUE

$1.5 TRILLION TO $11.5 TRILLION — ASSET VALUE, 4.125%

$5.8 TRILLION TO $46.9 TRILLION — ASSET VALUE, 0%

HOW TO USE THIS REPORT

- Utilize these values in benefit/cost analysis and rate of return on investment calculations for small- and large-scale natural and built infrastructure projects. This helps avoid "infrastructure conflict" where storm water projects may exacerbate flooding or loss of groundwater recharge. This reduces overall costs and taxes.
- Incorporate estimates of value into federal, state, and local planning and decision making. This report provides these estimates, which enable understanding of the scale of value provided by natural and working lands. This is necessary for a successful Colorado River Basin approach to water, flood risk reduction, farming, and other economic drivers.
- Innovate on investment. For example, Los Angeles residents pay for the cost of pipes, but nothing on the bill is for the natural infrastructure in the Colorado River Basin that provisions the actual water. New financing mechanisms will benefit both urban consumers and rural producers of water supply and other ecosystem services.

i A discount rate of 4.125 percent is used by the Army Corps of Engineers and was adopted for this report. For more information on the use of this discount rate, see the section on Asset Value in Part 4.

SUMMARY OF RECOMMENDATIONS

- **Invest in natural capital.** The Colorado River Basin's natural capital has a large asset value and high rate of return. Investments in natural capital deliver 21 categories of economic benefits to rural and urban communities including water supply, flood risk reduction, recreation, and healthier ecosystems.
- **Adapt to water realities.** Rising water scarcity in the Colorado River Basin and the fact that the Basin does not deliver a set amount of water requires flexibility and constant adaptation. There should be further work to refine understanding of the full stocks and flows. Continuing demand-side actions to better allocate water for maintaining healthy rivers, agriculture, municipal, and industrial uses are essential.
- **Bring ecosystem service valuation into standard accounting and decision-making tools.** This report can be used to inform accounting changes, rate of return on investment calculations, and benefit/cost analyses for private and public entities.
- **Improve incentives for investment.** Incentives that bring investment back to the Basin need to be advanced. For example, a natural capital charge on water bills in Los Angeles for the natural systems that produce water in the Colorado Basin.
- **Conduct a more detailed valuation, mapping, and modeling of key ecosystem services.** Better mapping and modeling of water supply, flood risk reduction, and more provides critical information to citizens and businesses. A more detailed analysis can be used to make more cost-effective investments across the landscape.
- **Improve the management of natural assets.** "Lose an ecosystem service, gain a tax district." A systems approach with economic incentives improves natural asset management. Floods can be reduced while groundwater is recharged. There are many opportunities that bring greater investment into rural areas and provide benefits throughout the Basin.
- **Apply the dollar values in this report.** This appraisal of value is legally defensible and applicable to decision-making at every jurisdictional level. For example, some values from this report can be used in FEMA's benefit/cost toolkit for pre- and post-disaster mitigation.

Economics is about understanding value, effectively deploying investment, raising prosperity, and securing economic and ecological resiliency. This report highlights the scale of value provided by the landscape in the Colorado River Basin. Whether land is in private or public ownership, that value, in the form of water supply, flood risk reduction, recreation, and other benefits, is distributed across the landscape. The economic vitality of communities depends upon it. Healthy natural systems provide vast economic value, and investing in natural capital provides a high rate of return. Understanding the scale of value provided in the Colorado River Basin provides incentive for investing in healthy landscapes, healthy rivers, and healthy communities.

THE ECONOMIC VITALITY OF COMMUNITIES DEPENDS UPON THE VALUES DISTRIBUTED ACROSS LANDSCAPES.
ABOVE: BOULDER CITY AND LAKE MEAD.

Part I

THE COLORADO RIVER BASIN: WHAT IS IT WORTH?

Economies are housed within natural landscapes. Consider the people, cities, and infrastructure housed within the Colorado River Basin. Every barn, building, or business resides in the valleys, mountains, and hills of this spectacular natural landscape.

The Colorado River Basin extends about 249,000 square miles (642,000 square kilometers) across mountains, plateaus, and low-lying valleys of the American Southwest. It overlaps Colorado, Utah, Wyoming, Nevada, New Mexico, Arizona, and California; the river's final stretch before reaching the Gulf of California crosses into Mexico, defining the border between the Mexican states of Sonora and Baja California.

"It's priceless." That would be a common answer of residents. Yet, priceless has two meanings. While the intrinsic value of the Colorado Basin's natural systems may be too great to estimate, the practically applied value is often zero. The Colorado Basin is deteriorating, particularly the water resources and riparian areas. Thus pricelessness may not be a practical value when it comes to daily decisions about where to put a parking lot, or how much water the Colorado River keeps.

Like a human life, the Basin is priceless, and without its water, life would not exist. However, people also work, and the value of that work may be measured in a paycheck or with other economic measures. This report is not about the priceless nature of the Colorado River Basin, but about the valuable economic work that its natural systems

FIGURE 1 MAP OF THE COLORADO RIVER BASIN

Source: cc by Shannon1 via Wikimedia Commons

HOW MUCH IS THE COLORADO RIVER BASIN WORTH?

provide to people, including water, recreation, habitat, and flood risk reduction. These practical values can be used to help improve investment and recognition of the economic benefits that healthy natural systems provide.

If the landscape is healthy, economies can thrive. If the landscape is degraded, economies fail. Water is a critical asset to both economic development and quality of life in the Colorado River Basin. The quantity, quality, timing, and flow of water is essential to natural infrastructure along the Colorado River, together with the biological community of living organisms including plants, animals, and smaller living beings. Water is just one of many linked economic goods and services that watersheds or large basins like the Colorado provide to people.

A healthy watershed and the ecosystems and communities it houses deliver a steady stream of benefits to residents. Degraded watersheds naturally provide fewer economic and ecological benefits. Healthy watersheds and river basins are essential for creating a stable, resilient, and prosperous economy. Treating our watersheds as valuable natural capital assets enables investments at the right scale to promote a healthy state that provides sustainable ecosystem services.

The Basin has experienced rapid growth. Some of the Basin's largest cities include Tucson (524,000)[1], Las Vegas (596,000)[2], and Phoenix (1.4 million)[3]. Overall, about 40 million people depend on the Colorado River and its tributaries for drinking, showering, washing clothes, and watering lawns. This includes important population centers lying outside the Basin: Los Angeles, Denver, Albuquerque, and Salt Lake City. Businesses throughout the Basin—including breweries, refineries, and clothing makers—also depend on Colorado River water to make products and create profit.

At the heart of any river basin is the river. Diversions from the Colorado River for agriculture total about 78 percent of the Colorado River's entire flow,[4] almost 4 trillion gallons per year. Water is pumped via tunnels through the Continental Divide to the vast irrigated plains of northern Colorado, where it grows low-cost, quickly maturing crops like alfalfa and corn.

A substantial portion of the Colorado River water is used haphazardly—growing turf grass in the desert and allowing water to evaporate as it sits in reservoirs, irrigation ditches, and swimming pools. The Basin's water is also reused frequently as it flows through miles of agricultural lands. As irrigation water seeps from fields back into the river it often brings unwelcome soluble minerals, dissolving large amounts of salt and other minerals that leach from soils, and carrying them into the river. Dams, reservoirs, and diversions remove water, alter flow regimes, and threaten to destroy or degrade some ecosystems. Additionally, wildlife is endangered due to diminishing wetlands as the river no longer fills them. Wildlife is threatened or endangered because water, habitat, and food become scarcer. Substantial ecosystem service value is being lost due to growing demand and pressures on Colorado River water.

Measuring the economic benefits of ecosystem services is essential to long-term, sustainable management of the Colorado River. The benefits of ecosystem services are similar to the economic benefits traditionally valued by economists, such as the services of skilled workers, buildings, and infrastructure. In most cases, ecosystems are the only systems that can produce these goods and services, unlike their built counterparts. The loss of ecosystem services decreases economic benefits. Economic impacts of further damage to the Basin would result in water scarcity, job loss, higher infrastructure costs, and loss of property due to storm events such as flooding. It is often impractical, generally undesirable, and at times absolutely impossible to replace valuable natural systems with more costly and less efficient built capital substitutes. When ecosystems are valued as assets and brought into the light of economic decision-making, these cost-effective goods

and services are more likely to be retained and continue to provide real returns to citizens, private companies, and government.

Water dependent cities and industries are threatened in light of growing pressures on a limited water supply, growing demand for water, and the uncertain future effects of climate change on snowpack and other precipitation in the Basin. This report provides an outline of a Basin-wide valuation, with a focus on key ecosystem services such as water supply, waste filtration, soil erosion, recreation, habitat, and moderation of floods, which will provide a foundation for sustainable management of this important natural resource.

CHARACTERIZING THE COLORADO RIVER BASIN

The Colorado River Basin is traditionally divided into two regions: the Upper Basin, draining about 45 percent of the total surface area, and the Lower Basin, draining about 55 percent.

The dividing point between two is at Lees Ferry in Arizona. The Upper Basin includes the portions of the watershed in Colorado, Wyoming, and parts of Arizona, New Mexico, and Utah. The Lower Basin includes most of Arizona, parts of New Mexico and Utah, and the portions of the watershed in Nevada, California, and the Mexican States of Sonora and Baja California.

The contributions of water to the Colorado River across the landscape are unequal, with about 75 percent of its flow originating in the Upper Basin where high mountains intercept moisture-bearing winds to trigger precipitation.[5]

Federal policy defines the boundaries of the Colorado River Basin and its various subdivisions using Hydrologic Unit Codes (HUC), so that these subdivisions standardize the locational description of all water-related data. The HUC system recognizes the primary division of the Basin into upper and lower basins, and further subdivides these regions into sub-basins. The Colorado River Basin sub-basins are outlined in Table 1 below.

TABLE I CROSSWALK BETWEEN BASIN NAMES IN THIS REPORT AND HYDROLOGIC UNIT CODE SUB-BASINS

THIS REPORT	HUC REGIONS AND SUB-REGIONS
Upper Colorado River Basin	**14 Upper Colorado River**
Upper Colorado River Basin	1401 Colorado Headwaters 1402 Gunnison 1403 Upper Colorado and Delores
Green River Basin	1404 Great Divide and Upper Green 1405 White and Yampa 1406 Lower Green
Lake Powell Basin	1407 Upper Colorado and Dirty Devil
San Juan River Basin	1408 San Juan
Lower Colorado River Basin	**15 Lower Colorado River**
Lake Mead Basin	1501 Lower Colorado and Lake Mead*
Middle Colorado River Basin	1502 Little Colorado*
Lower Colorado River Basin	1503 Lower Colorado
Gila River Basin	1504 Upper Gila 1505 Middle Gila 1506 Salt 1507 Lower Gila
Colorado River Basin in Mexico	**1508 Sonora**

Source: http://cfpub.epa.gov/surf/locate/index.cfm

Sub-Basins

As described above, the Colorado River Basin is a massive, incredibly diverse area. It can be divided into hydrological sub-basins according to HUC classifications at a more manageable scale with more internally common characteristics.

Landscape

The biophysical landscape of the Colorado River Basin is comprised of geology and landforms, hydrology, and biogeography.[6] Each is described on the following pages.

TABLE 2 DESCRIPTIONS OF COLORADO RIVER SUB BASINS

SUB-BASIN	NOTABLE FEATURES	NOTES
Upper Colorado River Basin (Upper Basin)	**Major Cities:** Grand Junction, CO; Moab, UT **Reservoirs:** Blue Mesa **Tributaries:** Gunnison, San Miguel, Dolores **Notable Public Land:** Black Canyon of the Gunnison National Park **Water Resources:** Mostly high-quality water, with relatively little sediment provides small areas of flood-plain irrigation	The Upper Colorado Basin includes the Colorado headwaters, and is mostly in the Rockies. Reservoirs in this area supply substantial amounts of water to the Denver area and beyond thanks to inter-basin water transfer systems. The Upper Colorado contributes about 42% of the River's flow at Lees Ferry (the point dividing the Upper and Lower portions of the Basin).
Green River Basin (Upper Basin)	**Major Cities:** Rock Springs, WY **Reservoirs:** Flaming Gorge, Strawberry **Tributaries:** Green, Big Sandy, Black's Fork, Yampa, White, Duchesne, San Rafael **Notable Public Land:** Dinosaur National Monument **Water Resources:** Significant amounts of water, some irrigation, wilderness rivers	The Green River is the largest tributary of the Colorado, by volume. It originates in the Wind River Mountains of Wyoming, and contributes 34% of the Colorado's total water at Lees Ferry.
San Juan River Basin (Upper Basin)	**Major Cities:** Farmington, NM **Reservoirs:** Navajo **Tributaries:** Animas, Chaco, Chinle **Notable Public Land:** Mesa Verde National Park **Water Resources:** Irrigation water for the Navajo Nation, heavy sediment concentrations	The San Juan River originates in the Rocky Mountains, though much of it flows through the Colorado Plateau region. It contributes 15% of the River's water at Lees Ferry.
Lake Powell (Upper Basin)	**Major Cities:** Page, AZ **Reservoirs:** Lake Powell **Tributaries:** Dirty Devil, Fremont, Escalante **Notable Public Land:** Arches National Park, Canyonlands National Park, Glen Canyon National Recreation Area, Rainbow Bridge National Monument **Water Resources:** Heavy sediment concentrations, relatively little water for irrigation or urban use, wilderness terrain	Formed behind the massive Glen Canyon Dam, Lake Powell is the second largest artificial lake in the United States—second only to Lake Mead, just downstream.

TABLE 2 CONT. DESCRIPTIONS OF COLORADO RIVER SUB BASINS

SUB-BASIN	NOTABLE FEATURES	NOTES
Middle Colorado River Basin (Lower Basin)	**Major Cities:** Winslow, AZ; Gallup, NM **Tributaries:** Little Colorado, Puerco, Oraibi Wash, Kanab Wash **Notable Public Land:** Grand Canyon National Park, Grand Staircase-Escalante National Monument **Water Resources:** The main stem of the Colorado is a simple conduit of water in this region; tributaries contribute relatively little water and much sediment	The stretch between America's two largest dams also hosts her most famous natural wonder, the Grand Canyon. Environmental battles that broke out with regard to this stretch of the river captured the attention of the nation.
Lake Mead Basin (Lower Basin)	**Major Cities:** Las Vegas, NV; Henderson, NV; St. George, UT **Reservoirs:** Lake Mead **Tributaries:** Virgin, Muddy, White **Notable Public Land:** Lake Mead National Recreation Area **Water Resources:** Source of little water, region of little irrigation; increasing demands for urban use in Las Vegas strains available water resources	The largest man-made lake in America, Lake Mead has a storage capacity of nearly thirty million acre-feet of water, though the lake seldom approaches these levels now. Las Vegas is the closest of several large cities that draw on its water.
Lower Colorado River Basin (Lower Basin)	**Major Cities:** Bullhead City, AZ; Lake Havasu City, AZ; Prescott, AZ **Reservoirs:** Lake Mohave, Lake Havasu **Tributaries:** Bill Williams **Notable Public Lands:** Mojave National Preserve **Water Resources:** The Colorado River is a losing stream here, meaning that its discharge decreases relative to added runoff as a result of evaporation, withdrawals, and low precipitation levels in lower-elevation deserts	The Lower Colorado River Basin is low desert country where hot, arid conditions prevail. Mountains and broad desert valleys make up the landscape away from the river. Recreational use focuses on the river and its reservoirs.
Gila River Basin (Lower Basin)	**Major Cities:** Phoenix, AZ; Scottsdale, AZ; Mesa, AZ; Tucson, AZ; Yuma, AZ **Reservoirs:** Painted Rock, Theodore Roosevelt Lake, San Carlos Lake **Tributaries:** Gila, Salt, San Pedro, Verde, San Francisco, San Simon, Santa Cruz, Agua Fria **Notable Public Land:** Saguaro National Park, Organ Pipe Cactus National Monument **Water Resources:** Major consumption by Phoenix and Tucson of available water, with most of the remainder used for irrigation along the Gila River; agricultural leaching and runoff adds salt to surface and groundwater.	Both the most populous and most agriculturally productive of the Colorado River sub-basins, the Gila Basin is also one of the most arid regions of not only the Basin, but the country. The Phoenix metro areas one of the largest in the nation.

TABLE 2 CONT.	DESCRIPTIONS OF COLORADO RIVER SUB BASINS	
SUB-BASIN	**NOTABLE FEATURES**	**NOTES**
Mexico	**Major Cities:** San Luis Río Colorado **Tributaries:** Sonora **Notable Public Land:** El Pinacate and Gran Desierto de Altar Biosphere Reserve **Water Resources:** Extensive crop irrigation for export produce	The Mexican region of the Colorado River Basin was once a lush delta, host to birds, wildlife, and many plants. Over the 20th century, it became a desert, with the waters of the Colorado seldom reaching the gulf. Recent international efforts including a release of water from upstream hold promise for the delta's rebirth.

Source: http://cfpub.epa.gov/surf/locate/index.cfm

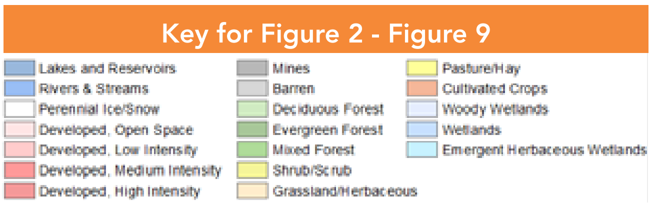


FIGURE 2 MAP OF THE UPPER COLORADO RIVER SUB-BASIN

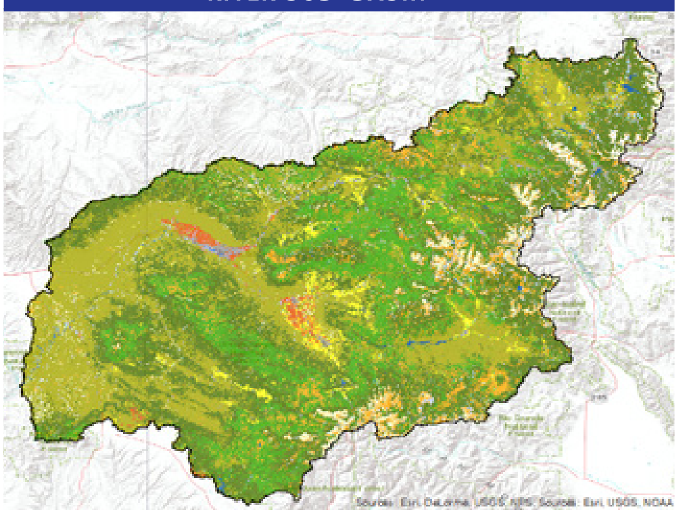


FIGURE 3 MAP OF THE GREEN RIVER SUB-BASIN

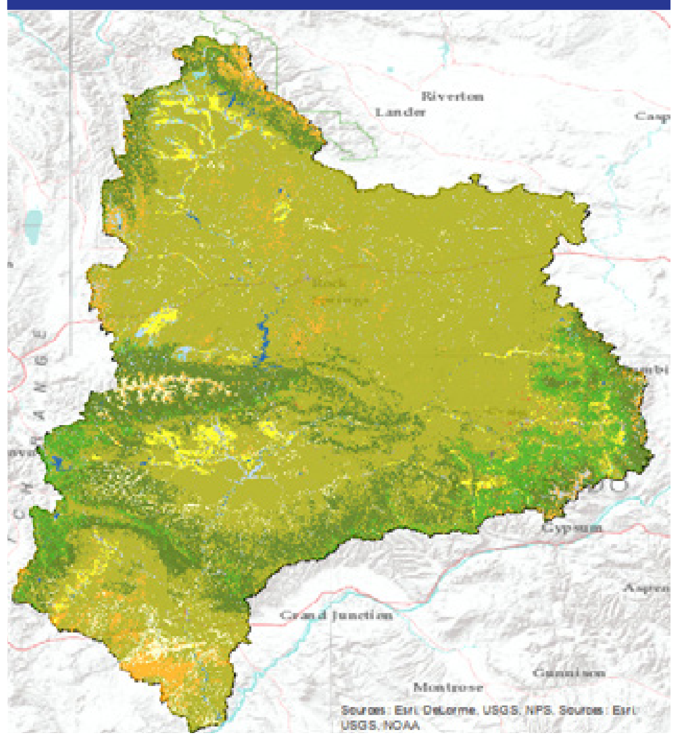


FIGURE 4 MAP OF THE SAN JUAN RIVER SUB-BASIN

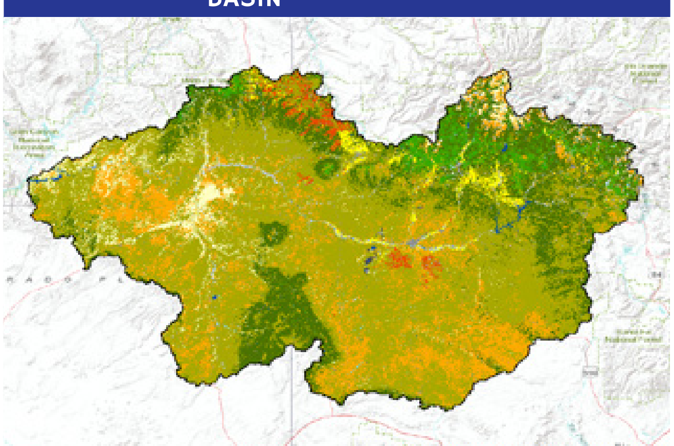


FIGURE 5 MAP OF THE MIDDLE COLORADO RIVER SUB-BASIN

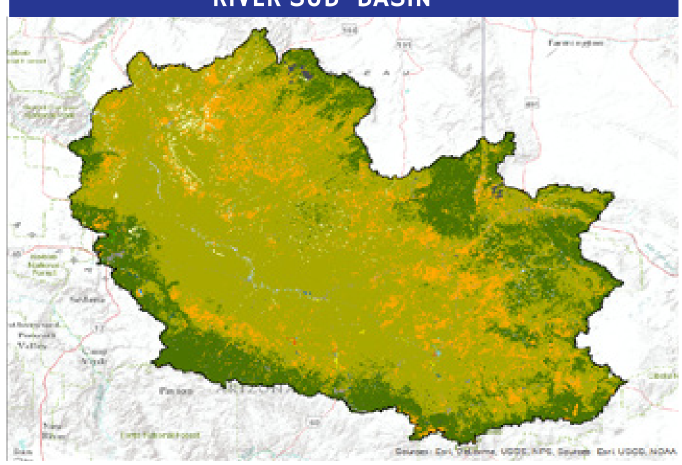


FIGURE 6 MAP OF THE LAKE POWELL SUB-BASIN

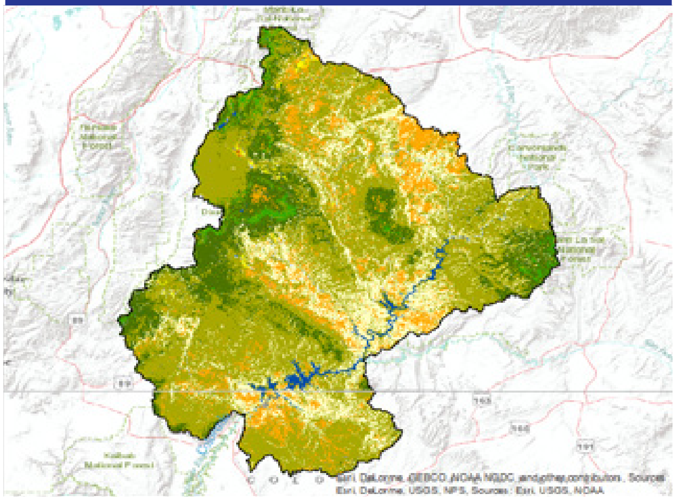


FIGURE 7 MAP OF THE LAKE MEAD SUB-BASIN

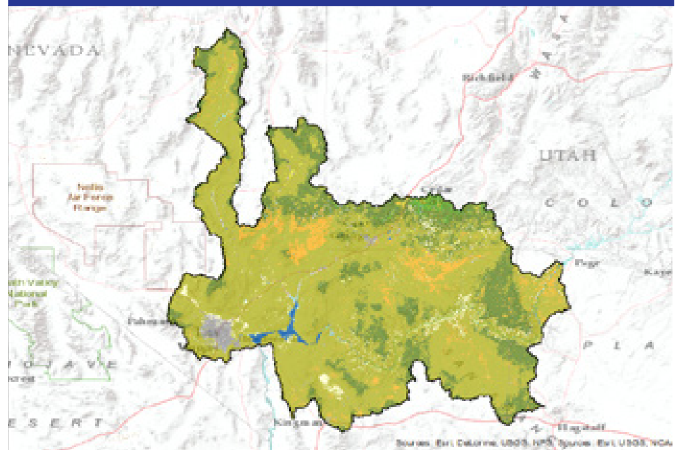


FIGURE 8 MAP OF THE GILA RIVER SUB-BASIN

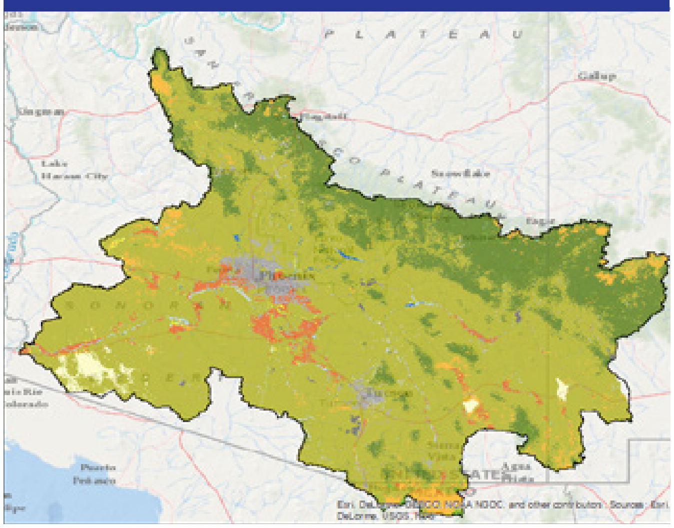
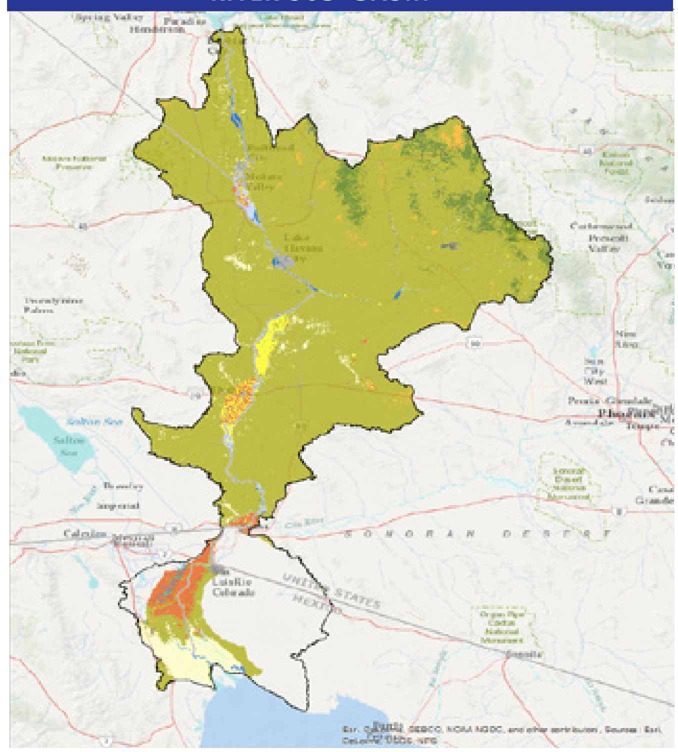


FIGURE 9 MAP OF THE LOWER COLORADO RIVER SUB-BASIN



Geology and Landforms

The geology and landforms of the Colorado River Basin are parts of three physiographic provinces: Rocky Mountains, Colorado Plateau, and Basin and Range. Internally, each province has broadly similar geologic materials, soils, and landforms, and the provinces are distinctly different from each other.

Rocky Mountains. The Central and Southern Rocky Mountains dominate the headwaters regions of the Upper Colorado Basin in the Green, Colorado, and San Juan River Basins. The terrain of these mountainous areas includes crystalline rocks such as granite, with considerable folding and faulting to create complex geology. Soils are generally thin, and although the mountains produce the majority of the overall Colorado River Basin's water runoff, they produce only minor amounts of sediment.[7]

The landforms of the Rocky Mountain province are primarily mountains sculpted by repeated glaciations, and they are characterized by steep slopes. Peaks are often above 13,000 feet in elevation above sea level, so these mountains intercept considerable precipitation, especially as snowfall in winter. The terrain includes river valleys, but they are relatively narrow and have floodplains that are generally no more than a few channel-widths wide.

Colorado Plateau. Unlike the Rocky Mountain province that extends far beyond the Colorado River Basin, most of the Colorado Plateau is contained within the basin. The plateau province lends its geology and landforms to the central and southern parts of the Upper Colorado River Basin and to the northern part of the Lower Colorado River Basin. The plateau province consists of terrain developed on relatively flat-lying or gently folded sedimentary rocks that are geologically younger than those of the Rocky Mountains. These sedimentary rocks give the region a layer-cake appearance with alternating beds of sandstone, shale, and limestone forming relatively flat surfaces above steep canyon walls carved by the region's rivers. Volcanic rocks occasionally occur as basalt flows forming caps atop some surfaces, while small intrusions of basalt or granite form the cores of small mountain ranges.[8] Although the Plateau province does not generally reach the great elevations of the Rocky Mountains, some mountains and plateaus top out at over 11,000 feet above sea level.

The landforms of the Colorado Plateau are the result of erosion of its geologic materials by its rivers. The resulting landscape is a striking terrain of spectacular canyons, plateaus, mesas, and mountains. Valley floors contain some stored sediments with small floodplains, and sharply defined cliffs often separate river valleys from the surrounding terrain.

Basin and Range. The Basin and Range province is characteristic of the southernmost portion of the Colorado River Basin, and includes the parts of Arizona, Nevada, and California lying to the sound and west of Arizona's Mogollon Rim. Geologic faulting left uplifted granitic blocks that form widely spaced mountain ranges, with the intervening valleys formed by downthrown blocks. As the mountains have eroded, they have shed their materials into the valleys, filling them with sediment to depths of 10,000 feet or more. These enormous valleys with their porous geologic materials formed great reservoirs of groundwater that supported the early Anglo-American development in this arid region.[9]

The terrain of the Basin and Range includes "Sky Islands" mountains, reaching elevations of nearly 10,000 feet above sea level, with isolated woodlands and forests housing animals unique among desert regions. The valley floors between the mountains are broad, flat expanses underlain by sandy soils with broad, shallow rivers and large floodplains. Alluvial fans spread outward from the bases of the mountain ranges that are often outlined by fault zones. Such valley floors serve as the sites of the two largest cities of the Colorado River Basin, Phoenix and Tucson.

Hydrography

The Colorado River Basin has three primary sources of water in the Upper Basin: the Colorado, Green, and San Juan rivers; and two in the Lower Basin, the Little Colorado and Gila rivers. Natural lakes are few and small, but the Basin includes several artificial lakes that are among the largest reservoirs in North America. The Colorado River of the Upper Basin is a gaining stream, meaning that as it flows southward to Lees Ferry near the Grand Canyon, it gains increasing amounts of water in the downstream direction. From that point onward, however, the Colorado River is a losing stream, meaning that as it continues to flow west and south toward its delta in Mexico, the river carries less and less water. Losses are primarily the result of diversions for irrigation that reduce Basin flows and runoff by about 64 percent,

and evaporative loss (particularly from reservoir surfaces) that accounts for about 32 percent. Most years, the Colorado River retains insufficient flow to reach its natural end in the Gulf of California.[10]

The Green River drains the northernmost portion of the Colorado River Basin, rising from precipitation and snowmelt in the Wind River Mountains of western Wyoming. The Green River flows generally southward from the Rocky Mountains onto the Colorado Plateau (with an easterly detour around the east-west trending Uinta Mountains of Utah). One of its major tributaries is the undammed Yampa River that rises in Colorado's Rocky Mountains. The Green and Colorado rivers join at the confluence in Canyonlands National Park, Utah. Although the Green River drains about 18 percent of the Colorado River Basin by land area, it supplies about 34 percent of the flow of the Colorado River at Lees Ferry (the boundary between the Upper and Lower Basins), along with about 15 percent of its sediment load.[11]

The Colorado River above the confluence was originally known as the Grand River. It supplies about 42 percent of the flow of the Colorado River at Lees Ferry, but only about 8 percent of its sediment, reflecting of the role that the Colorado Rocky Mountains play in capturing precipitation for runoff in a granitic terrain that sheds little. The San Juan River contributes 15 percent of the flow at Lees Ferry, but supplies 38 percent of the sediment because it flows through sediment-rich areas of the Colorado Plateau. The Lake Powell Basin is dominated by the Colorado Plateau landscape, contributing 9 percent of the water, but 40 percent of the sediment for the river at Lees Ferry.[12]

Below Lees Ferry in the Lower Colorado River Basin, the Colorado River receives only minor amounts of water from the Little Colorado and Paria rivers that join it in the Grand Canyon, and the Virgin River that joins it just below the Grand Canyon. The Gila River, rising near the Arizona-New Mexico border, is the largest Lower Basin tributary, but its contribution of water to the main river is equal to only about 8 percent of the total flow.

A substantial water-control infrastructure alters the pre-development flows of water (and sediment) in the basin. Although the Colorado River is sometimes characterized as one of the most regulated rivers in the world, the degree of control is not as great as many European rivers, or for rivers such as the Tennessee River in the United States. The combined Upper and Lower basins contain more than 1,600 dams of all sizes; the 10 largest dams have reservoirs with capacities greater than one million acre-feet of water. Table 3 shows a list of the largest dams in the Colorado River Basin. The large dams of the Basin can store about 2.5 to 3 years' flow of the entire river, though there rarely is enough flow to fill them all to capacity.[13]

Biogeography

Three biomes are represented in the Basin: alpine tundra at the highest elevations on mountain peaks and plateau summits, temperate mountain forests on intermediate mountains and plateaus, and deserts at the lowest elevations (shown in Table 4). The tundra and forests occur in northern headwaters regions and in association with high plateaus in the Lower Basin. Primary components of the forests include Douglas fir, subalpine fir, and

TABLE 3 LARGEST DAMS IN THE COLORADO RIVER BASIN

DAM	RESERVOIR	RIVER	STATE	DATE COMPLETED	STORAGE (ACRE-FEET)
Hoover	Lake Mead	Colorado	AZ/CA	1936	28,945,000
Glen Canyon	Lake Powell	Colorado	AZ	1964	26,214,900
Flaming Gorge	Flaming Gorge Reservoir	Green	WY	1964	3,788,800
Theodore Roosevelt	Theodore Roosevelt Lake	Salt	AZ	1911*	2,910,200
Painted Rock	Painted Rock Reservoir	Gila	AZ	1960	2,491,700
Davis	Lake Mohave	Colorado	AZ/CA	1950	1,818,300
Navajo	Navajo Lake	San Juan	NM	1963	1,708,600

Engelmann spruce, but ponderosa pine is also common, especially at lower elevations and along the southern rim of the Colorado Plateau in north-central Arizona.[14]

Desert shrublands and piñon-juniper woodlands are the most common vegetation communities in the Colorado River Basin, mostly found within the elevation band of about 5,000–10,000 feet (1,500–3,000 meters). They include some higher altitude areas such as in the Wyoming basins, but their most common expression is as plateau woodlands in the Middle Colorado River Basin, and as low desert shrublands at the southern end of the Basin. Iconic species of these shrublands include sagebrush, piñon pine, and juniper in higher elevations, and creosote bush, desert holly, and cacti at the lower elevations.

Riparian communities in higher elevations commonly have cottonwood, birch, aspen, and several varieties of small willows. In the elevation band about 6,000–6,500 feet (1,800–2,000 meters) cottonwood and willow gallery forests were common, though they can occur at higher and lower elevations as well in some areas of the Basin. A large portion of these forests were harvested by Anglo-American settlers in the 1800s and in some cases replaced by the exotic invasive tamarisk in 1900s. These forests still exist as low desert riparian vegetation, as long as there is a water supply to support them.

TABLE 4 BIOMES AND TERRESTRIAL ECOREGIONS OF THE COLORADO RIVER BASIN

BIOMES	ECOREGIONS (ID NUMBER AND NAME)
Tundra	Not mapped
Temperate Mountain Forest	43 South Central Rocky Mountain Forests
	44 Wasatch and Uinta Montane Forests
	45 Colorado Rockies Forests
	46 Arizona Mountains Forests
	47 Madrean Sky Islands Montane Forests
Desert	77 Wyoming Basin Shrub Steppe
	78 Colorado Plateau Shrublands
	79 Mojave Desert
	80 Sonoran Desert

ECOSYSTEM SERVICES OF THE COLORADO RIVER BASIN

Ecosystem goods and services are defined as the benefits people derive from ecosystems. Humans need ecosystem services to survive: breathable air, drinkable water, nourishing food, flood risk reduction, water quality treatment, and stable atmospheric conditions are all examples of nature's services. These economically valuable "gifts of nature" are often taken for granted. These ecosystem services provide a foundation for economic activity. All the energy and materials used to produce manufactured goods and services, such as cars, chairs and computers are originally derived from nature.

A factory is the built capital asset that, with the input of resources and labor, produces cars. So too, natural capital such as forests and wetlands are the capital assets that produce ecosystem goods and services. Natural capital includes the planet's reserve of water, air, land, biodiversity, renewable resources, and non-renewable resources. Like other forms of capital, natural capital provides a flow of goods and services—the difference is these benefits stem from natural systems in the environment and are provided for free and in perpetuity, if natural capital assets are healthy.

Natural capital provisions ecosystem services, and is comprised of ecosystems that result from interactions between natural processes of biological communities of living organisms and their physical environment. Natural capital continuously produces suites of goods and services, rather than single products.

For example, forest ecosystems with plant and animal communities, soils, slopes, and hydrological systems are one category of natural capital. Forests intercept rainfall, increase infiltration into the soil, and regulate peak water flows, functions which then provide the service of flood risk reduction downstream. If the natural capital assets were to be damaged or destroyed, the economic benefit of flood risk reduction would be lost at increased costs to communities downstream.

The benefits of ecosystem services hold significant economic value. Ecosystems are the most economically efficient, resilient, and sustainable systems (and in some cases the only systems) capable of producing many goods and services. This can be seen in the case of marketable products such as water or trout. Other benefits may create economically valuable services, such as water filtration. For example, some cities in the United States, including Seattle, New York, and San Francisco, do not require water filtration plants because their upstream forests and wetlands filter water to a quality higher than regulatory requirements. This has saved hundreds of millions of dollars in built capital costs over the last century. Within the Colorado River Basin, the Tonto National Forest was established with a goal of protecting the water supply and quality of the Salt and Verde Rivers in 1905. This has helped secure the water quality of the Theodore Roosevelt Reservoir, a primary water source for the Phoenix metropolitan area. This saves rate-payers capital and maintenance costs for filtration plants. Thus, many ecosystem goods and services can be valued with methodologies similar to valuing traditional built capital benefits that consider the direct market value.[15]

The loss of ecosystem services would decrease economic welfare as measured by a decrease in consumer and/or producer surplus. For example, some economic impacts would be job loss, infrastructure cost, restoration cost, and loss of property due to storm events such as flooding. It is often impractical, generally undesirable, and in some cases absolutely impossible to replace valuable natural systems with more costly and less efficient built capital substitutes. When ecosystems are valued as assets and included in economic decision-making, these cost-effective services are more likely to be retained and save citizens, private companies and government substantial amounts of money.

Ecosystem services can be categorized in different ways. This study follows an approach similar to that developed by the Millennium Ecosystem Assessment and divides 21 ecosystem services into the four functional groups shown below:

PROVISIONING SERVICES

Basic goods including food, water and materials. Forests grow trees that can be used for lumber and paper, wild and cultivated crops provide food, and other plants may be used for medicinal purposes. Rivers provide fresh water for drinking, and fish for food. Coastal waters provide fish, shellfish, and seaweed.

REGULATING SERVICES

Benefits obtained from the natural control of ecosystem processes. Intact ecosystems provide regulation of climate, water, soil, floods, and storms and keep disease organisms in check.

SUPPORTING SERVICES

Provision of refuge and reproduction habitat to wild plants and animals which thereby contribute to the conservation of biological and genetic diversity and evolutionary processes. Local to global nutrient, elemental, water cycles.

INFORMATION SERVICES

Humans' meaningful interaction with nature. These services include recreation, spiritual, aesthetic, historic, educational, scientific, and subsistence values.

These services can be classified and grouped by good or service. They are summarized in Table 5 with a brief description of the economic benefit provided to people.

TABLE 5 21 ECOSYSTEM SERVICES

Provisioning Services

ENERGY AND RAW MATERIALS
Providing fuel, fiber, fertilizer, minerals, and energy

FOOD
Producing crops, fish, game, and fruits

MEDICINAL RESOURCES
Providing traditional medicines, pharmaceuticals, and assay organisms

ORNAMENTAL RESOURCES
Providing resources for clothing, jewelry, handicraft, worship, and decoration

WATER SUPPLY
Provisioning surface and ground water for drinking, irrigation, and industrial use

Information Services

AESTHETIC INFORMATION
Enjoying and appreciating the presence, scenery, sounds, and smells of nature

CULTURAL AND ARTISTIC INSPIRATION
Using nature as motifs in art, film, folklore, books, cultural symbols, architecture, and media

RECREATION AND TOURISM
Experiencing natural ecosystems and enjoying outdoor activities

SCIENCE AND EDUCATION
Using natural systems for education and scientific research

SPIRITUAL AND HISTORICAL
Using nature for religious and spiritual purposes

Regulating Services

AIR QUALITY
Providing clean, breathable air

BIOLOGICAL CONTROL
Providing pest and disease control

CLIMATE STABILITY
Supporting a stable climate through carbon sequestration and other processes

MODERATION OF EXTREME EVENTS
Preventing and mitigating natural hazards such as floods, hurricanes, fires, and droughts

POLLINATION
Pollinating wild and domestic plant species

SOIL FORMATION
Creating soils for agricultural use and ecosystems integrity; maintaining soil fertility

SOIL RETENTION
Retaining arable land, slope stability, and coastal integrity

WASTE TREATMENT
Improving soil, water, and air quality by decomposing human and animal waste and removing pollutants

WATER REGULATION
Providing natural irrigation, drainage, ground water recharge, river flows, and navigation

Supporting Services

GENETIC RESOURCES
Improving crop and livestock resistance to pathogens and pests

HABITAT AND NURSERY
Maintaining genetic and biological diversity, the basis for most other ecosystem functions; promoting growth of commercially harvested species

Adapted from de Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002[ii]

ii A typology for the classification, description, and valuation of ecosystem functions, goods, and services. Ecological Economics 41, 393-408.74 and TEEB, 2009. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the approach, conclusions and recommendations of TEEB.

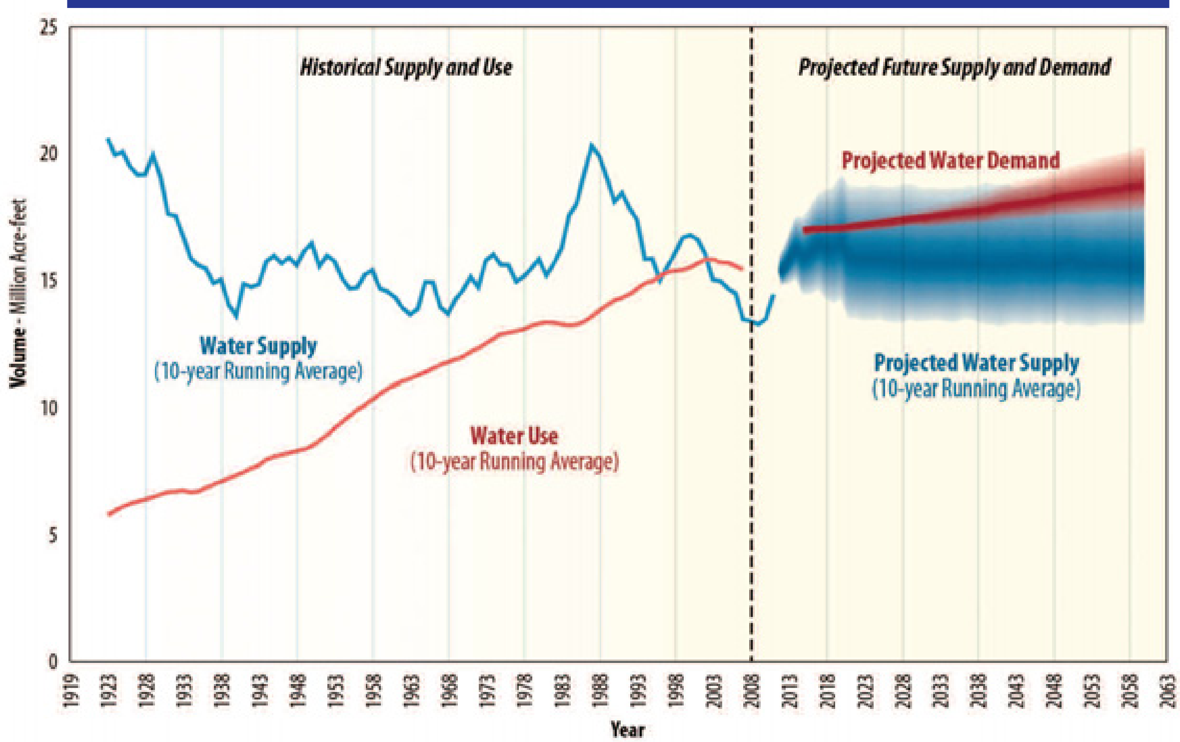
LAND AND WATER: DEPENDENCY ON THE COLORADO RIVER

The Colorado River and its tributaries provide water to nearly 40 million people for municipal use, 5.5 million acres of land for agricultural use, at least 22 federally recognized tribes, 7 National Wildlife Refuges, 4 National Recreation Areas, and 11 National Parks.[16] Within these natural areas, the survival of many plant and animal species rely on direct and consistent supply of fresh water throughout a majority of the year. The fate of the people and habitat reliant on the Basin's water depends heavily on future use of this water supply.

In 2012, the Bureau of Reclamation (Bureau) conducted a study to define current and future imbalances in water supply and demand in the Basin and the adjacent areas of the Basin States that receive Colorado River water over the next 50 years (through 2060). The goal of the study was to develop and analyze adaptation and mitigation strategies to resolve those imbalances. Figure 10 shows projected supply and demand of Colorado River water based on historical trends. Using data provided by the Basin States, tribes, federal agencies, and other water entitlement holders, the Reclamation study detailed four adaptive strategies based on several data projections scenarios. Each strategy was provided in a portfolio of actions, which include the following:

- Portfolio A: Is the least restrictive and contains all options that are in both Portfolio B and Portfolio C.
- Portfolio B: Includes options with high technical feasibility and high long-term reliability; excludes options with high permitting, legal, or policy risks.
- Portfolio C: Includes only options with relatively low energy intensity; includes an option that results in increased instream flows; excludes options that have low feasibility or high permitting risk.
- Portfolio D: Is the most selective and contains only those options that are included in both Portfolio B and Portfolio C.

FIGURE 10 WATER SUPPLY AND DEMAND IN COLORADO RIVER BASIN



Source: US Bureau of Reclamation

The results of the Baseline analysis indicate that, without action, meeting Basin resource needs over the next 50 years will become increasingly difficult. Several factors contribute to this conclusion: Projected development of water supplies, increased consumptive use in the Upper Basin, with potential reductions in future supply which result in reduced volumes of water stored in system reservoirs. With lower water elevations in reservoirs, hydropower and shoreline recreation decline, while water delivery shortages increased. Decreases in flows in key river tributaries have negative implications for flow-dependent resources such as boating, recreation, and river ecology. The study results show that water shortage threats are of grave concern under most scenarios, particularly under scenarios of rapid population growth. Enhanced environmental restoration conditions provide the best water security to 2060. These findings fully support the need to develop and evaluate options and strategies to help resolve the water supply and demand imbalance.

Though the study above did not attempt to consider the effects of climate change, the authors recognized that climate change will further threaten Basin water resources with extended drought periods, stronger heat waves, and more intense storm events.

Without far better water management, the economic viability of agriculture, industry, households, and natural systems in the Colorado Basin are threatened with severe decline. In the following sections, water-dependent sectors are discussed.

Agriculture

A substantial area of the Basin in both the United States and Mexico—roughly 3.5 million acres of land—is dedicated to agriculture, either as cropland or pasture. Over 90 percent of this land relies on irrigation water from the Colorado River for its viability.[17]

Around 2 million acres of that irrigated land is dedicated in some form to livestock, as pasture or forage crops; cattle are the top grossing agricultural product in six out of seven Basin States, with Colorado's output of beef and hides the 5th largest in the nation.[18]

Many other crops are grown throughout the region; Arizona is noteworthy as the nation's 5th largest producer of vegetables,[19] with Yuma County alone producing about 90 percent of the nation's lettuce in winter months.[20] Given Arizona's arid climate—with Yuma Valley one of its most parched regions at less than four inches average annual rainfall[21]—and the water-intensive nature of many of the state's cash crops, vast quantities of irrigation water are required to sustain this desert abundance.

However, in Arizona as in the other lower Basin states and Mexico, the total irrigated acreage has been shrinking, as cities grow and overtake land—and water—that was previously used for agriculture.[22]

Out-of-Basin Agricultural Dependence

Of the nearly 40 million people[23] who rely on water from the Basin, 70 percent reside outside of the Colorado River Basin.[24] A myriad of dams, pipes, pumps, aqueducts, tunnels, and other infrastructure carry the river's water far afield; tunnels beneath the Continental Divide at up to 3,800 feet below ground bolster water supply in the Denver-Fort Collins area,[25] and a maze of canals and aqueducts supplies taps as far west as ocean view apartments in Long Beach, California.[26]

As within the Basin, most of the Colorado River's water exports go to agriculture, irrigating 2.5 million acres of crops outside the Basin's bounds.[27] Nearly 600,000 acres of California land in the Imperial and Coachella Valleys are irrigated via the All-American Canal system.[28] This water allows Imperial Valley to supply roughly two thirds of the vegetables consumed in America during the winter.[29] In northeastern Colorado, Colorado River water is pumped through the Rockies and helps sustain fields in the late summer.[30] And in Mexico, much of Colorado River water received is diverted to sustain agriculture in the Mexicali Valley, where wheat, alfalfa, cotton, and other crops are grown in a climate that, like Yuma Valley, receives less than four inches of rainfall per year.[31]

Municipal

While the urban centers of the Basin compromise only a small fraction of its land use, these Basin cities house most of the region's residents and depend heavily on water from the Colorado River to sustain them; particularly those in Arizona, where over half of the Basin's population resides.[32] Despite this, municipal water use accounts for less than a quarter of total Colorado River water use; however, ongoing urban growth is increasing demand.

Out-of-Basin Municipal Dependence

Many of the Basin states' largest cities—Denver, Salt Lake City, Los Angeles[33]—lie outside the Basin. However, this does not mean that those cities' welfare is not directly tied to the welfare of the Colorado River Basin. The Los Angeles aqueduct conducts Colorado River Water essential to the existence and growth of the city.[34] San Diego residents have recently agreed to foot the bill for water conservation improvements to canals and aqueducts in order to gain access to "extra" Colorado River water.[35] Denver alone uses over a hundred thousand acre-feet per year.[36] And while Salt Lake City does not yet depend on water from the Colorado River, the Central Utah project is slated to pipe Colorado River water to provide up to 12 percent of Salt Lake City's rising water needs by 2020.[37] Table 6 shows the top municipal water users who draw some portion of their supply from the Colorado River.

TABLE 6 2008 ACRE-FEET AND POPULATION BY WATER SERVICE AREA

STATE	SERVICE AREA*	ESTIMATED POPULATION	DELIVERIES (ACRE-FEET)
CA	City of Los Angeles	4,002,071	653,543
CA	San Diego County	3,146,274	648,675
NV	Southern Nevada Water Authority	1,922,069	519,200
CA	Orange County	2,225,192	515,105
AZ	Phoenix	1,566,190	305,577
CA	Central Basin MWD	2,000,000	276,357
CA	Upper San Gabriel Valley	900,000	260,873
CA	West Basin MWD	900,000	239,799
CA	Riverside County MWD	853,000	219,362
CA	Coachella Valley Water Agencies	462,386	208,250
AZ	Tucson MWD	952,670	194,000
CA	Inland Empire Utilities Agency	850,000	175,969
CA	Eastern MWD	660,000	171,341
CO	Denver Water	1,154,000	126,161
CA	Coachella Valley Water District	282,426	125,283
CA	Three Valleys MWD	559,900	117,606
AZ	Mesa	469,989	89,937
AZ	Scottsdale	242,790	83,603
UT	Jordan Valley Water	567,299	83,042
UT	Salt Lake City	322,215	75,843

*Service areas outside of the basin are highlighted in orange, while service areas partly or entirely inside the basin are highlighted in green.

Extractive Industry

Millions of acres of timber lands, particularly in Colorado, support tens of millions of dollars' worth of forestry within the Basin, though harvests and jobs have been declining for some time.[38] Mining, on the other hand, remains a critical industry as well as a significant consumer of water. Arizona's mines produce over two-thirds of US copper, making it the 6th largest copper producing area in the world.[39] Colorado's coal mines, which are mostly located within the Basin,[40] produced nearly 30 million tons of coal in 2012,[41] and the last operating uranium mill in the United States can be found in the Colorado Basin in Utah.[42]

Oil and gas exploration and recovery also consume large quantities of water. Drilling vertically and horizontally requires water. A study in the Wattenberg Field in Colorado showed water extraction with the use of fracking, which requires horizontal drilling, typically consumes over 2 million gallons per well. On a gallons-per-million-BTU-produced basis, fracking can use less water than vertical drilling and recovery. Water consumption per BTU is far higher for corn-based ethanol but highest for biodiesel produced from soy and rapeseed. Enhanced recovery in older oil fields utilizes water pumped down to flush additional oil out, though brackish water from below potable aquifers is usually used. Altogether, mining and fossil fuel extraction within the Basin uses over a hundred million gallons of water each day.[43]

ALTOGETHER, MINING AND FOSSIL FUEL EXTRACTION WITHIN THE BASIN USES OVER A HUNDRED MILLION GALLONS OF WATER EACH DAY.
IN THIS PICTURE: GAS AND OIL WELLS IN SOUTHERN COLORADO AND NORTHERN NEW MEXICO.

Part 2

MEASURING ECOSYSTEM SERVICES ACROSS THE COLORADO RIVER BASIN

QUANTIFICATION OF LAND COVER IN THE COLORADO RIVER BASIN

Ecosystem service valuation assigns a dollar value to goods and services provided by a given ecosystem. This allows for proposed management policies to be considered in terms of their ability to improve ecological processes that produce valuable ecosystem goods and services.

Valuation of ecosystem services in the Basin first requires the use of Geographic Information Systems (GIS) data to assess the acreage of each land cover class within the study region. Examples of land cover classes include coniferous forests, grasslands, shrubs, and wetlands. Land cover classes were chosen based on the ability to derive ecosystem valuation data for that type of class.

GIS data is gathered through aerial and/or satellite photography and can be classified according to several classification systems or "layers." Earth Economics maintains a database of peer-reviewed valuation studies organized by land cover class. For this study, the region was divided into 14 land cover classes by each sub-basin listed in Table 7. Several datasets were compiled for the region's land cover and land use data within the Basin. For details on the GIS data used, see Appendix B.

Land cover types used in the study area are referenced in Table 7, which presents the final land cover classes and acreages that comprise the study area as categorized for this report, and a description of the layer(s). Snapshots of the distribution of these land classes by sub-basin are provided in Figure 11.

Forest types vary widely between sub-basins. Upper Colorado River sub-basins provide much higher water storage and store more carbon than Lower Colorado River sub-basins. Table 8 provides the major forest sub-types that exist within each sub-basin. In the valuation sections of Part 4 this report, the varying forest sub-types of each basin are shown and incorporated in the ecosystem service values.

The spatial distribution of goods and services produced in a region's economy can be mapped across the landscape. Mapping goods and services provided by factories, restaurants, schools, and businesses provides a view of the economy of that region. For example, retail, residential, and industrial areas occur in different parts of the landscape. The economic value of these goods, services, housing areas, and industry areas can also be estimated from market or appraisal values. A map of the Basin by sub-basin is provided in Figure 11.

Land cover types across the sub-basins provide different functions, such as varying amounts of snowpack storage, sediment removal or soil retention or erosion. These processes and functions provide services, such as water supply. Crucial ecosystem functions and process also vary widely within proximity to the Colorado River and its major Basin tributaries. To consider the increased value of habitat, recreation, and other ecosystem services near riverine and other water systems, land cover types within proximity (200 feet) to a major river or lake were considered separately in this report. The acreage of Basin ecosystems within this 200 foot buffer of rivers and

TABLE 7 ACREAGE BY SUB-BASIN LAND COVER TYPE IN THE COLORADO RIVER BASIN

LOWER BASIN				
Land Cover	Gila River Basin	Lake Mead Basin	Lower Colorado River Basin	Middle Colorado River Basin
Lakes and Reservoirs	31,534	109,250	54,416	9,754
Rivers and Streams	22,119	4,409	28,096	11,447
Barren / Desert	481,768	274,648	438,260	420,289
Deciduous Forest	40,227	115,765	8,823	15,596
Coniferous Forest	7,599,052	2,127,525	433,205	5,399,578
Mixed Forest	28,308	7,858	166	346
Shrub / Scrub	27,478,030	9,701,251	9,680,787	14,943,391
Grassland/Herbaceous	1,322,651	637,488	102,803	2,219,230
Pasture / Hay	89,271	31,102	176,572	9,824
Cultivated Crops	989,812	10,190	311,963	5,877
Woody Wetlands	49,508	14,237	12,716	14,315
Riparian	210,130	66,798	98,888	49,536
Herbaceous Wetlands	23,500	14,894	5,442	11,181
Urban Green Space	89,357	15,511	2,457	4,956
Total	***38,455,267***	***13,130,926***	***11,354,594***	***23,115,320***
UPPER BASIN				
Land Cover	San Juan River Basin	Upper Colorado River Basin	Green River Basin	Lake Powell Basin
Lakes and Reservoirs	25,215	40,924	103,980	121,178
Rivers and Streams	6,705	13,540	33,514	22,411
Barren / Desert	233,757	435,873	499,672	2,557,125
Deciduous Forest	470,810	2,144,264	1,701,426	914,949
Coniferous Forest	2,437,254	4,276,440	4,966,669	3,614,753
Mixed Forest	86,415	87,534	99,523	94,613
Shrub / Scrub	6,176,620	3,337,033	18,578,598	10,256,122
Grassland/Herbaceous	1,582,030	960,846	824,669	2,106,539
Pasture / Hay	248,796	363,709	758,322	140,094
Cultivated Crops	196,318	121,542	16,104	22,545
Woody Wetlands	43,121	80,434	109,641	28,818
Riparian	144,738	289,778	424,232	115,231
Herbaceous Wetlands	5,658	11,249	97,761	3,026
Urban Green Space	2,993	7,199	2,015	199
Total	***11,660,430***	***12,170,365***	***28,216,126***	***19,997,603***

TABLE 8 SUB-BASIN FOREST SUB-TYPES

LOWER BASIN				
Dominant Forest Type	**Gila River Basin**	**Lake Mead Basin**	**Lower Colorado River Basin**	**Middle Colorado River Basin**
Dominant Coniferous Forest Types	Piñon-Juniper, Juniper, Ponderosa Pine	Piñon-Juniper, Juniper, Ponderosa Pine, Singleleaf Piñon	Piñon-Juniper, Juniper, Ponderosa Pine	Piñon-Juniper, Juniper, Ponderosa Pine
Dominant Deciduous Forest Types	Mesquite, Evergreen and other Oaks	Evergreen Oak, Mesquite, Mountain Mahogany	Mesquite, Evergreen Oak	Mesquite, Evergreen Oak
UPPER BASIN				
Dominant Forest Type	**San Juan River Basin**	**Upper Colorado River Basin**	**Green River Basin**	**Lake Powell Basin**
Dominant Coniferous Forest Types	Ponderosa Pine, Douglas Fir, Piñon-Juniper, Spruce, Other Pines	Pondersoa Pine, Piñon-Juniper, Spruce, Lodgepole Pine, Other Firs	Piñon-Juniper, Spruce/Fir, Lodgepole Pine, Ponderosa Pine, Other Pine and Firs	Piñon-Juniper, Spruce/Fir, Other Pines
Dominant Deciduous Forest Types	Evergreen Oak, Aspen, Woodland Oaks,	Aspen, Cottonwood	Aspen, Other Woodlands	Aspen, Mountain Mahogany, Gambel Oak

TABLE 9 ACREAGE BY LAND COVER INSIDE OR OUTSIDE 200 FOOT RIVER OR LAKE BUFFER*

LAND COVER	TOTAL ACRES	WITHIN BUFFER	OUTSIDE BUFFER
Barren/Desert	5,341,391	237,663	5,103,727
Lakes and Reservoirs	496,251	496,251	0
River and Streams	142,242	142,242	0
Riparian	1,399,331	1,399,331	0
Deciduous Forest	5,408,448	442,612	4,965,836
Evergreen Forest	30,825,660	2,490,565	28,335,094
Mixed Forest	404,289	21,104	383,184
Shrub/Scrub	100,151,833	9,454,555	90,697,278
Grassland	9,756,256	682,033	9,074,223
Pasture/Hay	1,817,690	303,815	1,513,875
Cultivated Crops	1,674,351	96,166	1,578,185
Woody Wetlands	352,790	156,423	196,368
Emergent Herbaceous Wetlands	172,711	43,466	129,246
Urban Green Space	32,701	32,701	0
Total	***157,975,942***	***15,998,926***	***141,977,016***

*Buffers were calculated using ArcGIS software. A 200ft buffer was drawn on both sides of all major rivers and lakes within the Basin.

lakes is given in Table 9. All ecosystem values in the remainder of this report indicate proximity to a water system. For each ecosystem service there may be one or more methodologies for providing a value to those services.

IDENTIFYING ECOSYSTEM SERVICE VALUE ACROSS THE LANDSCAPE

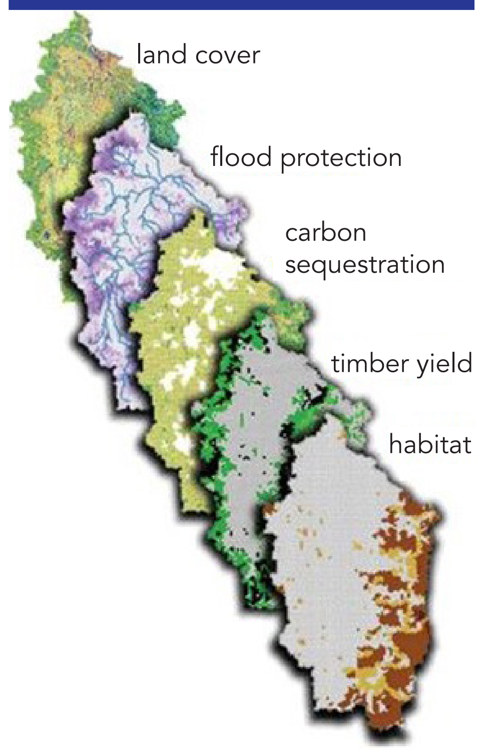
The distribution of ecosystem services within the Colorado River Basin is similar. Each land cover class, from wetland to mature forest to desert shrub, provides a set of economically valuable goods and services. For example, a wetland may provide ecosystem services such as flood risk reduction, biodiversity, climate regulation, and soil formation. Figure 12 illustrates how ecosystem services are "stacked" upon a landscape example. In this figure, the first layer, "land cover," depicts the land cover classes providing ecosystem services. Some land cover classes produce both flood risk reduction and carbon sequestration, while others produce only flood risk reduction.

Ecosystem Service Beneficiaries

Society has historically regarded the environment as a provider of goods and services that produce benefits of value that ultimately affect human well-being.[44] However, unless both environmental and economic (i.e., labor, and capital goods) inputs are

FIGURE 11 MAP OF COLORADO RIVER BASIN BY SUB-BASIN

FIGURE 12 EXAMPLE OF DIFFERENT SUITES OF ECOSYSTEM SERVICES PROVIDED BY VARIOUS LAND COVERS



Source: Erik Nelson (Stanford University, Palo Alto, CA) and Heather Tallis) specified in the general methodologies used to estimate ecosystem service value (i.e., production functions), it becomes difficult to separate the environmental goods and services from human investment to realize the total economic value of those goods and services.

Hydrologic services move through stream networks, carbon sequestration provides emissions offsets or climate stability that can be enjoyed anywhere in the world, and viewshed values are transmitted through lines of sight.[45] When mapping ecosystem services, it is essential to consider the beneficiaries of ecosystem services in order to differentiate between different contexts, such as urban and rural. For example, a forest type in dense urban centers is often both unusual and extremely valuable, assuming use and benefit by city dwellers. This case suggests a much more valuable forest to people than the same type of forest in a rural setting, where it is more common and there are fewer people to benefit from it. Figure 13 demonstrates how benefits of three ecosystem services spread throughout the landscape.

Non-Market Ecosystem Service Valuation

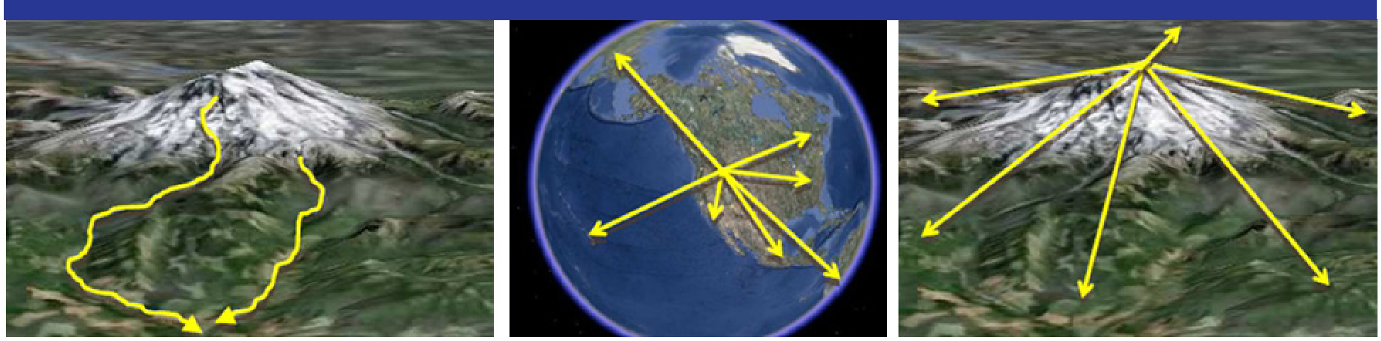
While certain goods are explicitly priced in markets, the services underpinning the production of such goods, and those that are not directly related to goods, are usually absent from market prices. For example, food, fiber, and fuel have been valued in markets for centuries, while pollination and soil retention are not traded in markets, though they have economic value. As a result, many ecosystem services that are not included in the price of goods have no way to be represented in the market signals that influence decision-making.

In absence of these market signals, actions that may damage or destroy basic natural production systems may occur without consideration of the impacts, since these values are "external" to market transactions. Actions may be taken that deteriorate or destroy the underlying ecosystems that support these valuable services. On the other hand, determining the value of ecosystem goods and services is straightforward when they are recognized on the market. Depending on the information available, measuring the value of a specific non-market good or service can be easy, difficult, barely possible, or impossible.

Economists have developed a number of methods for establishing dollar values to measure and assess market and non-market goods and services provided by ecosystems. These can be grouped into three broad categories: 1) direct market valuation approaches such as market-based, cost-based, and production function-based valuations; 2) revealed preference approaches such as travel cost and hedonic pricing methods; and 3) stated preference approaches such as contingent valuation, choice modeling, and group valuation methods.[46]

Direct market valuation methods derive estimates of ecosystem goods and services from related market data. Revealed preference methods estimate economic values for ecosystem goods and services that directly affect the market prices of some related good, and stated preference methods obtain economic values by asking people to make trade-offs among sets of ecosystem services or characteristics.[47]

FIGURE 13 BENEFICIARY MAP OF HYDROLOGIC, CARBON SEQUESTRATION, AND AESTHETIC SERVICES



It should be noted that these valuation methods differ in the value they estimate. Some methods measure the benefits consumers derive from the exchange of goods and services (i.e. consumer surplus), other methods measure the benefits producers derive from the exchange of goods and services (i.e., producer surplus), while others value components of total revenue. This source of heterogeneity in approaches raises the issue of non-comparability between estimated values.[48] Recognizing the need to be cautious in comparing differing concepts of economic value, this study provides a range of values for most ecosystem services being measured (see Appendix A for a more detailed discussion of the strengths and weaknesses of non-market valuation). Table 10 provides descriptions of accepted techniques.

Ideally, a valuation of the ecosystem services of the Colorado Basin would involve detailed ecological and economic studies of each land cover/ecosystem service combination, utilizing one or more of the above primary valuation techniques to estimate a per-acre value. Unfortunately, this would require over 120 separate primary studies. As this is impractical, a benefit transfer approach was used for valuing a range of services in this study.

Benefit transfer as a valuation method involves the application of valuation data from a study site where previous valuation analysis has been conducted to a project site, based on a determination that similar value generation is present. Benefit transfer can be used to evaluate non-market ecosystem services by transferring

TABLE 10 ECOSYSTEM SERVICE VALUATION METHODOLOGIES

VALUATION METHOD	DESCRIPTION	VALUE
Measures		
Market prices	Assigns value equal to the total market revenue of goods/services	Total revenue
Replacement cost	Services can be replaced with man-made systems; for example water quality treatment provided by wetlands can be replaced with costly built treatment systems.	Value larger than the current cost of supply
Avoided cost	Services allow society to avoid costs that would have been incurred in the absence of those services; for example storm protection provided by barrier islands avoids property damages along the coast.	Value larger than the current cost of supply
Production approaches	Services provide for the enhancement of incomes; for example water quality improvements increase commercial fisheries catch and therefore fishing incomes.	Consumer surplus, producer surplus
Revealed Preference Approaches		
Travel cost	Service demands may require travel, which have costs that can reflect the implied value of the service; recreation areas can be valued at least by what visitors are willing to pay to travel to it, including the imputed value of their time.	Consumer surplus
Hedonic pricing	Service demand may be reflected in the prices people will pay for associated goods, for example housing prices along the coastline tend to exceed the prices of inland homes.	Consumer surplus
Stated Preference Approaches		
Contingent valuation	Service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives; for instance, people generally state that they are willing to pay for increased preservation of beaches and shoreline.	Consumer surplus

existing benefit estimates from primary studies already completed for another study area. When using this method, care must be taken to ensure values being transferred exhibit similarities within the specific ecosystem good or service characteristics.

Both primary valuation and transferred studies were used in this report. This combination was necessary due to the lack of primary valuation studies on ecosystem services in the study area. In addition, because ecosystem services are physically different and variably amenable to markets, a variety of different valuation techniques are required. Existing studies were required to meet a set of three criteria to be included in this valuation.

Some benefits are easily transferable; for example, the value of carbon sequestration provides a global benefit, thus the values are global, whereas many recreational benefits are very proximal. Table 11 provides the valuation approach used for each service in this study, the accepted valuation methods, and degree of transferability. For example, waste processing was valued using the benefit transfer approach. When choosing primary studies, only those that followed the appropriate valuation methodology for each ecosystem discussed in Table 11 were included in this study. Appendix A discusses the limitations of benefit transfer method and other methodologies used in this report.

STUDY INCLUSION CRITERIA

1. All primary valuation studies included a peer-review process.
2. For nearly all ecosystem services, primary study locations were restricted to North America. The full list of studies used can be found in Appendix E.
3. Primary studies met methodology recommendations, based upon Farber et al., 2006. See further discussion below.

TABLE II VALUATION METHOD USED BY BENEFIT TYPE

ECOSYSTEM SERVICE	VALUATION METHOD USED IN THIS REPORT	RECOMMENDED VALUATION METHOD	TRANSFERABILITY ACROSS SITES
Aesthetic & Recreational	Primary & Benefit transfer	TC, CV, H, M, P	Low–High
Flood Risk Reduction	Benefit transfer	AC, H, RC	Medium
Carbon Sequestration & Storage	Primary & Benefit transfer	CV, AC, RC	High
Air Quality	Benefit transfer	AC, H, RC	Medium
Habitat Refugium & Nursery	Benefit transfer	CV, P, AC, TC, H	Low-Medium
Energy & Raw Materials	Benefit transfer	M, P	High
Soil Erosion Control	Benefit transfer	AC, RC, H	Medium
Water Quality	Benefit transfer	RC, AC, CV	Medium–High
Water Regulation	Benefit transfer	M, AC, RC, H, P, CV	Medium
Water Supply and Storage	Primary & Benefit transfer	AC, RC, M, TC, CV	Medium
Food Provisioning	Benefit transfer	M, P	High

Note: AC = avoided cost; CV = contingent valuation; H = hedonic pricing; M = market pricing; P = production approach; RC = replacement cost; TC = travel cost. Green = Valuation method added by Earth Economics

Adapted from: Farber, et al., 2006.

Valuation of Ecosystem Services in Colorado River Basin

The full suite of ecosystem services produced by a particular land cover class yields a flow of value (typically $/acre/year) for that land cover class. This report is focused on market and non-market services identified to provide a flow of services. In the case of wetlands, all known non-market ecosystem service values (i.e. water regulation, habitat, recreation, etc.) for which valuation studies have been completed are summed for a total per-acre ecosystem service value. This number can then be multiplied by the number of acres of wetland, for example, in the Basin for a value in $/year.

This study utilizes existing valuation publications across ecological economics literature and other disciplines to derive $/acre/year ecosystem service values. By 'transferring' these values from a database of peer-reviewed academic studies and journal articles, the appraisal of ecosystem service values is accomplished. (For more on benefit transfer, see Appendix A). This approach yields an appraisal, rather than a precise measure, because often the location of the wetland or other land cover is critical to the valuation. For example, one wetland may be crucial for trout rearing, while another may be too far upstream.

This study provides specific references for every value provided for every land cover type. See Appendix E for the list of primary studies applied in this valuation. Each of these primary studies used one of the seven valuation methods shown in Table 10.

Due to limitations in the range of primary valuation studies, for example, the lack of studies conducted for snowpack or desert ecosystem services, not all ecosystem services that were identified on each land cover class in the previous section could be assigned a known value. For example, the land cover class "lakes and reservoirs" has only been valued for three ecosystem services—water supply, water quality, and recreation—though such areas also clearly provide food, genetic resources, water regulation, habitat, spiritual and cultural values, and a number of other important benefits. While primary studies for some services were provided under the scope of this report, resource limitations restricted the ability to carry out other primary valuations to fill valuation gaps.

Table 12 shows a matrix with the ecosystem services stacked vertically and land covers listed horizontally. The table provides colored boxes showing land cover/ecosystem service combinations.

Some land cover types, such as coniferous forest, woody wetlands, and shrubs vary widely in size, type, and ecosystem service capacity throughout the Basin and should not be treated the same. Similarly, ecosystem health and size of habitat corridors also influence ecosystem service value. Due to limited resources for this project, these land cover elements were not considered in this study. However, this study incorporated sub-basin variation across each land cover in order to capture the biophysical differences that influence ecosystem service value. In Part 4 below, sub-basin differences in these land cover types are addressed when transferring economic vales.

A large number of ecosystem services (for each land cover class) have yet to be valued in any primary valuation study. The Colorado Basin is one of the least studied areas for ecosystem services in the United States. This suggests that this valuation significantly understates the true value, because many ecosystem services identified as valuable do not have an associated valuation study, and thus register zero economic value. As further primary valuation studies are conducted and incorporated, the combined known value of ecosystem services in the Colorado River Basin will rise.

TABLE 12 ECOSYSTEM SERVICES VALUED AND/OR IDENTIFIED BY LAND COVER IN THE COLORADO RIVER BASIN

	URBAN GREEN SPACE	DESERT/BARREN	CULTIVATED	PASTURE/HAY	GRASSLANDS/HERBACEOUS	WOODY WETLANDS	EMERGENT HERB WETLANDS	SHRUB/SCRUB	CONIFEROUS FOREST	DECIDUOUS FORESTS	MIXED FORESTS	LAKES AND RESERVOIRS	RIVERS AND STREAMS	RIPARIAN
FOOD			X	X		X			X		X			X
ENERGY AND RAW MATERIALS				X					X	X	X			
WATER SUPPLY												X	X	X
AIR QUALITY	X		X		X				X	X	X			
CARBON SEQUESTRATION AND STORAGE			X	X	X	X	X	X	X	X	X			
FLOOD RISK REDUCTION	X				X	X	X	X			X			X
EROSION CONTROL			X	X	X	X								
WATER QUALITY									X	X	X	X		X
WATER REGULATION	X		X		X						X		X	X
HABITAT AND BIODIVERSITY			X	X	X	X	X	X	X		X		X	X
AESTHETIC INFORMATION	X		X		X	X							X	X
RECREATION AND TOURISM	X	X	X	X	X	X	X	X	X	X	X	X	X	

Several existing ecosystem services such as pollination, biological control, or cultural services, were not considered for this report and were not included in the table above.

KEY	
Ecosystem service produced by land cover and valued in this report	X
Ecosystem service produced by land cover but is not valued in this report	
Ecosystem service not produced by land cover	

Part 3

VALUING THE COLORADO RIVER BASIN

This valuation analysis is organized following the four primary classes of ecosystem services: provisioning, regulating, supporting, and information services. The following sections each describe the subcategories of ecosystem services and goods within each of these four areas. Tables 26 and 27 then provide values across all land cover types for each category. Specific references for each dollar value utilized in this study are provided in Appendix D.

PROVISIONING ECOSYSTEM SERVICES

Provisioning services include a large suite of basic goods including food, water, and materials. Forests grow trees that can be used for lumber and paper, wild and cultivated crops provide food, and other plants may be used for medicinal purposes. Rivers provide fresh water for drinking, and fish for food. The following provisioning ecosystem services were valued in this report.

Water Supply

To date, the Upper Basin States have not used the full apportionment of Colorado River water (7.5 million acre-feet), allowing Lower Basin storage infrastructure to store up to 60 million acre-feet. As a result, all requested deliveries have been met in the Lower Basin, despite experiencing the worst 11-year drought in the last century.[49] However, Basin water authorities face challenges and complexities in ensuring a sustainable water supply to meet future demand in an over-allocated and highly variable system such as the Colorado River.

While the demand for water in the Basin is rising, supply has been static, on average. Within the last decade, water demand has met and in some years exceeded the supply of water provided by the Colorado River annually. Projections of supply under threat from climate change suggest that a gap between supply and demand threatens to widen. Severe water shortages in California, Arizona, and Mexico are resulting in the extraction of groundwater for agricultural and municipal at a rate that far exceeds natural aquifer replenishment. This gap between supply and demand also threatens the 1944 US-Mexico Treaty commitments, which require the United States to deliver 1.5 million acres of treated water to Mexico.

Primary Valuation

A primary valuation was conducted for this report to provide economic values for water supply that are specific to the Colorado River Basin. For the purposes of this section, water supply is defined as the existing flow and stock of water, where flow is provided annually via water flow in the River, and the stock is currently stored in reservoirs along the Colorado River. The following sections provide data sources, methodology, and final calculations of water supply in the Basin.

Methodology. The water supply value was calculated using data estimates for annual water flow provided by the Colorado River, water storage along the river, water extraction per sector dependent on Colorado River water, and water extraction rates per state. Data was collected on average annual water flow and reservoir storage throughout the Colorado River. This data was

AQUIFERS: CRITICAL NATURAL CAPITAL ASSETS AT RISK

Across the Colorado River Basin, aquifers are natural resource stocks that hold tremendous value as water supply sources for current and future generations; shallow riparian aquifers also sustain natural ecosystems that provide additional benefits. However, in many locations, widespread drilling of wells preceded establishment of current active management policies, resulting in a vast number of wells that are exempt from permitting restrictions. Wells that are drilled with permits are often authorized for a standard rate of extraction, which in many cases is not calculated based on recharge rates. For both exempt and approved wells, existing policy controls throughout the Basin are not sufficient to ensure that groundwater extraction does not exceed recharge rates over time, commonly resulting in groundwater overdraw and aquifer depletion.

The issue of aquifer depletion is particularly significant in Lower Basin states such as Arizona, which relies on groundwater sources for more than 40 percent of the state water supply. In the 1970s, conflicts occurred between agricultural users and mining industry water users over groundwater extraction rates. New policies were necessary to resolve three issues central to the conflict: who has the right to extract groundwater, how groundwater overdraft should be avoided, and whether management was the responsibility of local or state government.[50] In 1980, Governor Bruce Babbitt established the Arizona Department of Water Resources and signed the Groundwater Management Act, which required that land developers verify access to a 100-year supply as part of the permitting process. This resolved the short-term conflict and established a medium-term solution, but did not address the long-term issues related to the economics of water resource management. One generation later, continued depletion of groundwater stocks, particularly aquifers, represents a loss of long-term economic value with negative ecological and multi-generational impacts.

These economically valuable groundwater assets cannot be replaced with other sources in any permanent or sustainable manner: surface flows from the Colorado River have decreased due to drought and climate change, and groundwater depletion is widespread throughout the Lower Basin. The risk of this long-term loss of value establishes an imperative for managing aquifers in a way that reduces the overall footprint of consumption beyond recharge, and for protection of aquifers as irreplaceable critical natural capital assets.[51]

Emerging approaches help coordinate surface and groundwater management, but further consistency and alignment of such approaches is needed throughout the Colorado River Basin.[52] Coordinated work at local to inter-state scales is essential to management of critical natural capital assets.

then added with data on water extraction for agricultural, municipal, and industrial use for each state within the Basin. Finally, dollar values were derived with the use of average water rate charges for each industry by state. Several different water use and water charge rates were found in the data collection process, resulting in the use of a data range, where average low and high values reflected regional variability in water per industry and the average amount charged in each state.

Data Sources.
Water Flow: During the creation of the Colorado River Compact, which occurred during a wet period, flow data was collected by the Bureau of Reclamation and used to measure total flow of the Colorado River. These unusually high flows, due to measures occurring over the wet period, led the Bureau to assume that the mean annual average flow of the Colorado River was 16.4 million acre-feet per year.[53] However, additional flow data has been reconstructed based on tree-ring analyses, and clearly shows that the average annual flow is less. A Bureau of Reclamation study provided updated results that reduce the estimated average flow to 15.3 million acre-feet over 2002 to 2011, bringing to light historic miscalculations that have led to water shortages for the river.[54] This recent calculation accounted for water losses due to reservoir evaporation and operational inefficiencies. This Bureau of Reclamation figure was used to estimate water supply flow.

Water Storage: Reservoirs that currently store more than 1,000 acre-feet of water (as of May 5th, 2014) were considered, making up 47 of the largest reservoirs within the Basin, including Flaming Gorge, Lake Powell, and Lake Mead. Groundwater reservoirs (aquifers) were not included in this analysis. Table 13 provides water storage in the Basin.

Water Extraction: According to a study conducted in 2013, approximately 70 percent of the Basin's water is allocated to agricultural lands (not including evaporation or exports).[55] These irrigated lands extend across 6 million acres both inside and outside of the Basin. More than 90 percent of pasture and cropland in the Basin requires supplemental water to make land viable for agriculture. When including exported water, the above study finds that over 80 percent of Basin water is extracted for agricultural purposes. In Table 14 below, water extraction is broken out by state.

Municipal water data accounts for total water deliveries, including diversions from surface streams and extraction from groundwater, but do not account for return flows. The data above was used to determine the amount of Basin water allocated toward agricultural, industrial, and municipal users.

Water Rates: Water rate data was collected from a variety of sources for each Basin state. Agricultural, industrial, and municipal water extraction rates are summarized in Table 15. Industrial and household water users often pay more than 100 times as much as agricultural users due to differing water quality needs, infrastructure, and conveyance standards of these different users.[56] Reference to each water data source is provided in Appendix B.

Value of Water Supply. In this section, the value for annual water flow and storage is calculated separately, using the above data and methodology. The total value of water flow and storage is summarized in Tables 16 and 17. The values below are conservative estimates given that 15.3 million acre-feet of water are provided by the Colorado River every year. The value of this water for agricultural, municipal, and industrial

TABLE 13 WATER STORAGE IN ACRE-FEET

BASIN	NUMBER OF RESERVOIRS CONSIDERED	AVERAGE STORAGE (ACRE-FEET)
Upper Colorado River Basin	44	17,475,719
Lower Colorado River Basin	3[iii]	14,508,582
Total		***31,984,301***

TABLE 14 IRRIGATION AND OTHER WITHDRAWALS FROM THE COLORADO RIVER BASIN BY STATE

STATE	IRRIGATION WITHDRAWAL (ACRE-FEET)*	MUNICIPAL AND INDUSTRIAL (ACRE-FEET)**
Arizona	5,075,271	1,411,675
California	718,536	2,409,367
Colorado	4,675,300	367,326
Nevada	190,178	391,005
New Mexico	554,898	126,792
Utah	928,343	220,357
Wyoming	3,680	86,494
Total	**12,146,205**	**5,013,016**
Grand Total	***17,159,221***	

*Accounts only for Colorado River Water
**Accounts for Basin groundwater and surface water from the Colorado River. Figures also combine municipal and industrial water use and exclude mining and coal production water use.
*** Values changed on 12/15/2015 to reflect updated water use data.

TABLE 15 WATER RATE PER ACRE-FOOT BY STATE (2013 $)

STATE	AGRICULTURE		MUNICIPAL AND INDUSTRIAL	
	Low	High	Low	High
Arizona	$17.02	$25.67	$623.44	$2,357.95
California	$39.84	$41.41	$799.36	$2,675.13
Colorado	$5.28	$12.80	$956.78	$1,309.36
Nevada	$6.47	$9.24	$671.09	$2,100.10
New Mexico	$10.41	$19.99	$814.63	$4,823.46
Utah	$5.27	$13.82	$504.76	$867.09
Wyoming	$3.04	$6.48	$1,005.75	$1,005.75

iii Note: Unlike the Upper Colorado Basin reservoir system, the Lower Colorado Basin does not feature near as many reservoirs. There are some small agricultural diversion dams along the Lower Colorado River, but they do not store an appreciable amount of water. These dams essentially raise the river elevation enough to run pumps for agricultural water diversions). Lake Mead, Lake Mohave, and Lake Havasu are the only dams managed by the Bureau of Reclamation, the source of this data.

TABLE 16 ANNUAL FLOW VALUE OF WATER SUPPLY FROM THE COLORADO RIVER				
	AGRICULTURAL SECTOR		MUNICIPAL AND INDUSTRIAL SECTOR	
STATE	Low	High	Low	High
Arizona	$86,381,120	$130,282,218	$880,094,849	$3,328,659,774
California	$28,626,461	$29,754,562	$1,925,951,565	$6,445,369,807
Colorado	$24,685,581	$59,843,834	$351,450,495	$480,962,415
Nevada	$1,230,449	$1,757,241	$262,399,411	$821,149,180
New Mexico	$5,776,484	$11,092,403	$103,288,460	$611,575,510
Utah	$4,892,370	$12,829,706	$111,227,204	$191,069,016
Wyoming	$11,186	$23,845	$86,991,454	$86,991,454
Total	**$151,603,652**	**$245,583,809**	**$3,721,403,439**	**$11,965,777,157**
Grand Total			***$3,873,007,091***	***$12,211,360,966***

TABLE 17 STORAGE VALUE OF WATER SUPPLY FROM THE COLORADO RIVER				
	AGRICULTURAL SECTOR		MUNICIPAL AND INDUSTRIAL SECTOR	
STATE	Low	High	Low	High
Arizona	$161,011,957	$242,842,358	$1,640,471,824	$6,204,527,361
California	$53,358,911	$55,461,659	$3,589,919,064	$12,013,986,421
Colorado	$46,013,223	$111,547,208	$655,093,749	$896,500,294
Nevada	$2,293,523	$3,275,448	$489,105,056	$1,530,598,771
New Mexico	$10,767,203	$20,675,925	$192,526,759	$1,139,959,396
Utah	$9,119,238	$23,914,207	$207,324,353	$356,147,225
Wyoming	$20,851	$44,446	$162,149,602	$162,149,602
Total	**$282,584,906**	**$457,761,251**	**$6,936,590,408**	**$22,303,869,069**
Grand Total			***$7,219,175,314***	***$22,761,630,320***

* The values in Table 16 and Table 17 changed on 12/15/2015 to reflect updated water use data.

sectors is $16.6 billion to $42.0 billion, which is a flow of value provided to Basin water users annually. Water flow from the Colorado will also continuously feed into reservoir systems, adding to total water storage. In Part 4 of this report, this annual flow is combined with all other ecosystem service values to derive a total value of the Basin ecosystems.

The value of water currently stored in Colorado River Reservoirs is presented in Table 17. This value was not considered in the annual ecosystem service values calculated in Part 4 below, but was considered under the asset value calculation in the same section.

Water currently stored in reservoirs along the Colorado River is worth approximately $34.7 billion to $94.6 billion. This figure was measured as a one-time asset value and reflects the value of water stored in each reservoir since their construction. This calculation reflects the value of water available from storage, a value worth nearly double the amount provided by the river annually.

Both the water flow and storage values are conservative estimates. Future water demand and supply were not considered in the estimate of water storage value under this project scope. Additionally, other demand-specific concepts, such as water scarcity scenarios, were not considered in this assessment, which would otherwise result in a much higher total value. Water storage as an asset value, along with present value of other Basin ecosystem services, is discussed in Part 4 of this report.

Water supply and demand scenarios, in addition to groundwater and water well storage estimates, were not considered in this assessment, thus rendering the water supply value above a conservative estimate. Although evaporation was included in the estimation of water flow from the Colorado River each year, increased rainfall contribution from reservoir evaporation was not assessed in this valuation of water supply.

Discussion. A substantial portion of renewable surface water supplies, such as water from the Colorado River, is extracted for Basin agricultural purposes within and outside the Basin. Water-dependent crops, such as almonds, grapes, cotton, and apricots in California depend on Colorado River water. Elsewhere in the Basin, a billion gallons a day irrigate vast fields of cheaper agriculture goods, such as wheat, alfalfa, cotton, lettuce, cauliflower, and broccoli. Several years of drought have taken their toll, and farmers have resorted to drilling deeper wells and pumping more groundwater to prevent their crops from wilting. A recent survey by the US Geological Survey shows that in California's Tulare Basin, groundwater levels have dropped by as much as 50 feet (15 meters) from 2006 to 2009.[57] Resulting use of the Colorado River has painted a target on farms as urban water managers search for the next bucket of water to meet future demands.

Additionally, larger farms gain the most benefit from Colorado River water in light of outdated and subsidized water rate structures and water rights. A recent study from American Rivers, a leading conservation non-profit, named the Colorado River the most endangered river in the nation largely due to outdated water management.[58] This issue becomes evident when considering the quantity of water piped to California to produce crops that require large amounts of water, like strawberries or almonds. According to one study by the University of California, the average per-acre return of large strawberry farms is approximately $45,144[iv] per year.[59] The study also found that farmers paid approximately $336 per acre-foot of water, a much higher estimate than the rate paid by California farmers from the collection of studies presented above. Riverside County in California produced 327 acres of strawberries in 2010, a $15.2 million dollar return for the county alone, based on the figures above. Using the University study water rates, Riverside County farmers paid only $153,690 for water.

In conclusion, some of the largest Basin farms benefit from the cheapest water rates. Few incentives exist to invest in water conserving infrastructure changes. Those who benefit the most from the dwindling Colorado River water supply also contribute very little to the upstream built and natural infrastructure that provides cleaner and more abundant water throughout the year. Recommendations made at the end of this report propose next steps needed to change incentive structures for all users of the Colorado River water.

Energy and Raw Materials

Raw materials include biological materials used for medicines, fuel, art, and building, as well as materials such as wood or stone used for construction or other purposes. Crude oil, natural gas, and other fossil fuels, as well as mined minerals and quarried rock, are also natural capital assets, but are beyond the scope of this study.

Hydropower facilities along the Colorado River provide more than 4,200 megawatts of generating capacity. That is enough to supply power to 2.6 million households for a year.[v] A series of dams and reservoirs along the Lower Colorado River moderate flows at the cost of the health of natural systems that evolved with a natural flood regime. These dams and reservoirs reduced flooding, which has encouraged building in floodplain areas previously not occupied. The dams control river levels and retain large reservoirs of water (2.5 years of flow) for use in times of drought.

iv Based on 38,760 pounds (4,080 trays) delivered to fresh market and 32% or 18,240 pounds (1,013 trays) delivered to the freezer. Per-pound return of $10.00 per 10-pound tray for fresh market and $6.30 ($0.35 per pound) per 18-pound tray for freezer market.

v Based on average American household use of 14,000 kWh per year.

There are two general types of dams in the Basin: storage dams and diversion dams. Storage dams create large reservoirs that store water for flood control, recreation, hydroelectric power generation, and irrigation. Diversion dams primarily convey water for water supply and irrigation canals.

Nearly every dam along the Colorado River is impaired by sedimentation. Reservoirs reduce the river's gradient and flow velocity upstream of the dam, storing sediment that would be swept downstream by a natural river and dropping it within the reservoir. Sedimentation reduces water storage capacity, flood risk reduction, and hydropower production. All rivers contain sediments: a river can be considered a body of flowing sediments as much as one of flowing water. Lake Powell, the 186-mile-long reservoir on the Colorado River, holds enough sediment to fill approximately 1,400 cargo containers with silt each day.[60] Sedimentation rates in the 1940s were high, and likely tied to overgrazing which, by removing too much vegetative cover, enabled rapid erosion, also reducing cattle carrying capacity. If climate change accelerates with increased high rainfall events causing greater flooding and erosion, sediment accumulation rates may accelerate again. For smaller reservoirs, this is a significant problem. Due to their large size, and the fact that smaller reservoirs catch large volumes of sediment up-stream, indications are that the Glen Canyon and Hoover Dams will not be silted up for some few hundred years, but that day will arrive. When the Bureau of Reclamation was asked about how the sedimentation of these reservoirs would be handled, Reclamation commissioner Floyd Dominy replied, "We will let people in the future worry about it."[61]

WHEN THE BUREAU OF RECLAMATION WAS ASKED ABOUT HOW THE SEDIMENTATION OF THESE RESERVOIRS WOULD BE HANDLED, RECLAMATION COMMISSIONER FLOYD DOMINY REPLIED, "WE WILL LET PEOPLE IN THE FUTURE WORRY ABOUT IT."

Food

Providing food is one of the most important ecosystem functions. Food includes biomass for human consumption, provided by a web of organisms and a functioning ecosystem. Agricultural lands are our primary source of food; farms are considered modified ecosystems, and food is considered an ecosystem good with labor and built capital inputs. Agricultural value is measured by the total market value of crops produced. However, market value is only a portion of the total value generated by agriculture; carbon sequestration, aesthetic value, and other services associated with crop production also add value.

Fishing for trout, striped bass, bass, catfish, crappie, and bluegill is excellent in the river and its canal systems. Several tribes, including the Southern Ute Indian Tribes, depend on wildlife for food and economic gains.[62] Federal laws protect several tribal grounds from outside hunting or fishing activities.

Valuation of Provisioning Services

The value of provisioning ecosystem services was estimated for eight land classes. The studies were drawn from avoided cost, contingent valuation, net factor income, and market price methodologies to value food, energy, and raw materials (see Table 18). The value for water supply was calculated above for the Basin as a whole and so is excluded from this table. However, those water supply values are included in the total values in Part 4. Market values of agricultural goods were also not considered in this report.

TABLE 18 VALUE AND METHODOLOGY OF PROVISIONING SERVICES ACROSS LAND COVERS

LAND COVER	TRANSFERRED VALUATION METHODOLOGIES	VALUES (2013$/ACRE/YEAR)			
		INSIDE 200FT BUFFER		OUTSIDE 200FT BUFFER	
		LOW	HIGH	LOW	HIGH
Food					
Emergent Herbaceous Wetlands	Net Factor Income	$192.58	$10,017.71	$192.58	$192.58
Coniferous Forest	Meta-Analysis	$31.73	$31.73	$31.73	$31.73
Grasslands	Net Factor Income	$36.27	$36.27	$36.27	$36.27
Riparian	Market Price	$17.77	$793.95	N/A*	N/A*
Energy and Raw Materials					
Cultivated	Market Price	$0.01	$144.01	$0.01	$144.01
Deciduous Forest	Market Price	$19.52	$19.52	$19.52	$19.52
Coniferous Forest	Market Price	$3.89	$3.89	$3.89	$3.89
Desert	Market Price	N/A*	N/A*	$29.22	$29.22

*Data that is not available or not applicable (i.e., riverine acreage outside of 200ft buffer) is indicated by "N/A."

REGULATING ECOSYSTEM SERVICES

Regulating services are benefits obtained from the natural control of ecosystem processes. Intact ecosystems provide regulation of climate, water, and soil, and keep disease organisms in check. Degraded ecosystems may not provide effective regulation services, resulting in more volatile and unpredictable fluctuations in climate, water levels, and soil stability, as well as propagation of disease organisms that pose risks to human health. The following regulating ecosystem services were included in the valuation analysis of in this report.

Water Quality

Ecosystems in the Colorado River Basin, including forests, riparian buffers, and wetlands, are natural capital assets that provide valuable water filtration services, improving the quality of water for both human consumption and species reliant on natural habitat. Water filtration services provide environmental benefit and can maintain a level of water quality that is relatively clean, though some natural contaminants do still require mechanical filtration for purification of potable water. These functions are also supported by other natural capital asset functions, such as erosion control and nutrient cycling. Water quality is damaged primarily by human activities that generate water contaminants such as nitrogen, phosphorus, and other soluble pollutants, as well as natural release of minerals such as selenium. Naturally occurring selenium and uranium may contaminate water even in the absence of human disturbance, as occurs in some areas of the Colorado Plateau.[63] However, these elements can be released at much higher levels through activities such as agriculture and mining, causing more widespread problems.[64,65] Additionally, irrigation waters passing through salt-laden sub-soils and draining back into the Colorado generate increased salinity.

A number of federal policies address water quality, putting in place measures to control and measure different types of water quality issues, regulate water suppliers, and set minimum standards for drinking water quality. Water quality issues are a particular concern in the Colorado River Basin, where heavy water re-use and degraded riparian ecosystems can combine to result in water that is highly saline and with agricultural sediment, nutrients, and chemicals. The Colorado River waters have at times been so degraded that international incidents arose with Mexico: the water delivered to Mexico by treaty had such a high salt content as to be unusable for drinking or irrigation, leading to federal legislation in 1974 specifically focusing on salinity control of Colorado River water.

COST OF WATER QUALITY IMPROVEMENT

Nationally, drinking water systems are estimated to have an average cost of $2 per 1,000 gallons of water treated. Only 15 percent of that cost is required for the treatment plant, with the remaining costs funding equipment, distribution systems, labor, general operations, and maintenance. Based on an average consumption of 100 gallons of water per day per capita, this equates to approximately $300 in water bills per household annually.[67]

Water treatment costs can vary depending on the water quality impact and treatment technologies, the initial and target concentrations of contaminants, and the scale of facility required. For example, an EPA study on water treatment for nitrogen and phosphorus removal shows a total lifecycle cost of $157–$324 per million gallons to remove nitrogen, $50-$283 per million gallons to remove phosphorus, and $411–$626 per million gallons to remove both.[68]

The Yuma Desalinization plant was built in 1992 for a cost of $245 million from federal funding, with a potential capacity of 72 million gallons per day, in order to remove high concentrations of salt and address water quality issues in the Lower Colorado Basin.[69] However, the plant runs only when freshwater supplies from the Colorado River are not sufficient and has been in operation only twice. A 2012 study on a pilot run of the facility resulted in the conservation of 30,496 acre-feet of water for deliveries to Mexico as a means to reduce the necessity for releases from Lake Mead to meet international agreements.[70] Desalinization has many costs, including energy consumption, the disposal of salt and other waste products, and intermittent operations. The full costs are not fully captured in the capital and operations costs.

The high cost of water treatment plant construction, operations, and maintenance increases the urgency of exploring natural capital solutions as an alternative to intensive built capital investment. By applying a watershed-scale approach to water quality control, there is a greater opportunity to prevent contamination and pollution, and in some cases a reduced cost to treatment and filtration through reliance on ecosystem services. Protection and restoration of riparian buffers, forested floodplains, wetlands, and other ecosystems are essential elements to a cost-effective approach of water quality management through investment in natural capital. Bioswales, infiltration basins, and other green infrastructure technologies also present opportunities for improving both water supply and quality while reducing the need for costly treatment plant construction. Natural capital solutions will not provide complete solutions in all instances, but can be effectively developed in watershed-scale planning that is coordinated with built capital-investment planning for treatment plant infrastructure.

Fire is another challenge and opportunity for improving water quality management. The Colorado River Basin is dry and has a natural fire regime that was changed as a result of human influence. This has increased fuel loads as well as the risk and severity of wildfires throughout the Basin over time. Catastrophic fires can severely damage water quality and supply, through the release of sediment into waterways and reservoirs. More frequent, less damaging fires that maintain low fuel loads and leave larger trees intact can benefit water supply and quality over the long run by preventing sedimentation from larger wildfires.

vi General information and historical assessments of the Yuma Desalinization Plant are available from the US Department of Interior Bureau of Reclamation at the following link: http://www.usbr.gov/lc/yuma/facilities/ydp/yao_ydp.html

The Upper Colorado Basin region, particularly near the Colorado-Utah border, has thousands of waterways designated under the Clean Water Act as threatened or impaired due to natural deposits resulting in selenium contamination from non-point source contamination, and in some cases disturbance from mining operations. Selenium contamination is at the highest concentrations in areas of the Basin draining into the main stem of the Colorado River from the Gunnison River to the Utah-Colorado border. This has resulted in increased fish and bird mortality, deformities and reproductive problems. Some affected species are protected under the Endangered Species Act.

Impaired waterway designations in Lower Basin regions include issues from pesticides, metals, pathogens, mercury, organic enrichment/oxygen depletion, pH/acidity/caustic conditions, turbidity, ammonia, nutrients, toxic organics, sediment, and chlorine.[66]

Flood Risk Reduction

Ecosystems provide an important buffer against disturbances to the local economy, in particular by reducing the risk of events such as flooding and landslides. Headwater forests, wetlands, and aquifers provide critical water regulation by intercepting heavy rains, and absorbing and storing water, which reduces flood peaks and duration. When natural capital, such as forest cover or riparian ecosystems, are degraded or converted to impervious surfaces, the land's capacity to absorb water is reduced and the velocity of surface runoff increases along with erosion and sediment loading. Development within the Basin, particularly in Nevada, Arizona, and southern California, has steadily increased since the expansion of water and other infrastructure projects. The population of Las Vegas grew by 25 percent between 1999 and 2010. Arizona experienced a population increase from 3.6 million in 1990 to 6.6 million in 2013.[71] The massive expansion has resulted in thousands of acres of land use change including conversion to housing development, agriculture, and green space.

Structures have been built in the floodplains and impermeable surface has expanded, reducing natural flood control and groundwater infiltration. As a result, flooding has become a larger problem. Rain in major cities is no longer captured by vegetation as it moves across the landscape, where it can then recharge groundwater. It is instead channeled, piped, and handled at great cost, picking up dirt, debris, road oil, and other material along the way. This runoff is then piped into streams and rivers more quickly, contributing to higher peak flows, more frequent flood events, and erosion. Major Basin cities have thus spent more to control stormwater runoff. Cities such as Phoenix mostly focus their stormwater management efforts on costly built infrastructure,[72] with attempts to place a greater emphasis on green infrastructure hampered by outdated regulations and a lack of city-wide planning.[73]

Flood damage has increased in the last two decades and has been blamed on the rising number of large storm events. After days of heavy rain in August of 2008, the Redlands Dam located on Havasu Creek in northwestern Arizona burst causing flooding in side canyons which are home to roughly 400 members of the Havasupai tribe. Roughly 300 tribe members and tourists were evacuated by helicopter over the course of ten hours.[74] Additionally, intense monsoon-like conditions combined with development of floodplains resulted in dangerous flash-flood conditions for numerous cities across southern Utah counties in July of 2013. Floods lasted for several days. In some areas, debris flows damaged popular hiking trails and campgrounds, making navigation of these trails and canyons impossible.[75] Another notable event was extremely high rainfall over an extended period of time in September of 2013, which caused tributaries of the Colorado River to overflow and flood nearby towns in northwestern New Mexico. The National Weather Service issued a flash flood watch for much of the area, where heavy rainfall earlier in the week had already severely saturated soils and broke smaller earthen dams, inundating neighborhoods, and leaving behind a muddy mess of debris. The flooding caused millions of dollars in damages.[76]

Soil Erosion Control

Natural erosion, particularly from flood events, can add positive value by providing sand and gravel to streams, creating habitat for fish and other species. Many of these processes have been drastically altered by dam construction over time.[84] Landslides and erosion on a large scale can damage the landscape, including agricultural lands, for decades.[85] Soil erosion control is provided by plant roots, tree cover, and soil crusts.

WILDFIRES: FULL COSTS AND RISK REDUCTION

Wildfires are another frequent disturbance in the Colorado River Basin. For example, in 2011, over 900,000 acres in Arizona burned, including the 535,000 acre Wallow Fire, which destroyed dozens of structures and injured 16 people.[77]

Fire can be beneficial in the maintenance of forested lands, leading to healthier, more diverse forests. Fire can also be ecologically destructive, greatly increasing erosion and runoff. What effects a particular fire may have depend on fire frequency, intensity, weather conditions, and the nature of vegetation communities subject to it. Slower burning understory fires that occur with some regularity can eliminate fuel build-up, liberate fire-activated seeds and do not burn deeply into the soil. High intensity burns, sometimes called "crown fires," consume vegetation from tree crowns to roots, burning deep into the ground and damaging soils. Grazing, logging, and fire suppression practices have led to massive fuel buildup in many areas of the Basin[78] as well as denser forests that increase the probability of these more damaging crown fires.[79] Climate change has contributed to prolonged droughts that exacerbate the problem further.[80]

The link between the health of natural ecosystems and the severity of wildfire can be seen clearly when examining the success of efforts to restore forest ecosystems to their natural state. In the Rodeo-Chedinski fire of 2002, the second largest fire in regional history, the areas of the landscape that had undergone thinning and/or prescribed, managed burns to reduce fuel loads behaved like forests of the region historically would—burning at the surface level, and not the crown level.[79] This also protected downwind patches of untreated forest.[80]

The difference in fire impact from such restoration efforts has not typically been quantified economically, and we do not value fire risk reduction from Basin ecosystems in the scope of this report. However, a recent report in nearby California examined the 2013 Rim Fire, the third largest fire in California's history, and calculated the environmental damages, which is a first step towards placing a value on fire risk reduction in the future. That study estimated the economic value of environmental benefits lost in the Rim Fire at between $100 million to $736 million. This examination also showed the stark differences between Stanislaus National Forest, a catastrophic burn area due to high fuel loads, and the Hetch Hetchy watershed in Yosemite National Park where fires had reduced fuel loads and the Rim Fire became a low-intensity, healthy fire.[81] While the Rim Fire was outside the Basin, these results hold import for the whole American Southwest and beyond. Furthering this research to gain better information about the full costs of fires and the fire mitigation benefits of healthy ecosystems will lead to more sound decisions about forest management.

Erosion control is closely linked with disturbance prevention, including flood risk reduction, storm buffering, and landslide prevention. Sedimentation can be costly. From damage in the headwaters from a large number of landslides, to dredging in irrigation districts, sedimentation can harm riverine habitat, agriculture, energy production, water supplies, and commerce. On the other hand, all agriculture is a product of sedimentation and soil building processes. At the mouth of the Colorado River, sedimentation supported a delta building process, fisheries, and other benefits. Sedimentation in the right places is beneficial, while in the wrong places, it can do great damage.

Forested and vegetated areas naturally provide stability and erosion control, while impermeable built surfaces or deforested areas cannot retain soil well. Human activities may not only affect an area's ability to retain soil, but can also increase the flow of water that may mobilize soil particles. Wildfires can also dramatically compromise the ability of ecosystems to regulate soil erosion, potentially leading to sediment loads many times higher than usual in years after a fire.

FROM CRUST TO DUST: WINDBORNE EROSION AND SOIL CRUSTS

Windborne erosion also has serious impacts in the Colorado River Basin. Dust, when blown from desert areas onto snowpack, darkens the snow surface and promotes more rapid melting, which also results in water losses through evaporation of up to a billion cubic meters of water per year.[86] Additionally, dust in the Basin causes a variety of human health impacts, from asthma to Valley Fever, which was the second most reported disease in Arizona in 2012, with about 150,000 reported cases per year.[87] While many recover, Valley Fever claimed 170 lives between 2007-2012.[88,89]

Dust was not always so prevalent in the Colorado River Basin. Recent studies show that present dust accumulation is five times greater than it was before major human settlement occurred in the region.[90]

Activities such as grazing, mining, and recreation in off-road vehicles can all contribute to greater volumes of dust.[91] This is partly because such activities often damage biological soil crusts, which are composed of moss, lichen, bacteria and algae. These crusts, when intact, slow water runoff, and help capture and percolate water into deeper soils and groundwater.[92] Additionally, they suppress dust.[93]

These crusts therefore hold significant economic value, which has never been directly quantified. Future research on the value provided by biological soil crusts could lead to long term decisions about land use in the Basin that would clear the air, improve water supply, and save lives.

Climate Stability (Carbon Sequestration and Storage)

Carbon sequestration is the removal of carbon dioxide (CO_2) from the atmosphere, thus regulating the atmospheric concentrations of this significant greenhouse gas. This also contributes to the complex and critically valuable service of climate stability. Forests, wetlands, grasslands, and shrub ecosystems all play a role in carbon sequestration; in the Colorado River Basin, carbon sequestration occurs primarily in wetlands, forests, grasslands and urban green spaces. Croplands are also integral to carbon cycles, though the rate of sequestration of carbon depends on the end uses of crops and soil management practices.

Storage of greenhouse gases contributes to the build-up of carbon "stocks." Carbon stocks refer to carbon that is being retained rather than released into the atmosphere. Living plants sequester and store carbon. Non-living biomass, organic matter, sediments, and rocks also store large stocks of carbon. Decaying organic matter releases carbon dioxide back into the atmosphere. Thus, there are flows of carbon to and from the atmosphere through geological and biological stocks of carbon. Both the flow of carbon in sequestration and the stocks of carbon in trees and soils are assessed in this report.

This study determined sequestration rates for land cover classes within the Basin for calculating sequestration values. Different land cover classes, such as grasslands, different forest types, and wetlands, have different carbon sequestration rates and different carbon stocks. The carbon price of $45.32 to $48.30 per metric ton of CO_2 was derived from the two sources: the White House report on the social cost of carbon estimated the emissions cost of one metric ton of carbon at $45.32, and the International Panel on Climate Change Fourth Assessment Report at $48.30. Both dollar figures are the lower, more conservative estimates from these reports; values were converted to 2013 US dollars. Multiple sources were used to estimate carbon sequestration rates and carbon stock values for each land cover type in the Basin. Differences in carbon sequestration and storage values were represent by a value range (See Table 19). To accommodate the difference in carbon storage across forest types in each sub-basin, carbon stock and storage data specific to forest sub-species was collected and used in the final valuations in Part 4 of this report. The studies in this review are listed in Appendix B. Carbon sequestration rates were converted to metric tons of CO_2 per acre per year (mTC/acre/year), multiplied by the social cost per metric ton of carbon, and compared with relevant ecosystem service valuation studies. The rate of carbon sequestered per acre and storage of carbon per acre are shown in Table 19.

TABLE 19 CARBON SEQUESTERED AND STORED PER LAND COVER TYPE

LAND COVER TYPE	CARBON SEQUESTRATION RATE (MTC/ACRE/YEAR)		CARBON STORED 90 TO 100 YEARS (MTC/ACRE)	
	Low	High	Low	High
Cropland	0.01	1.88	4.50	26.10
Pasture	0.01	0.45		
Rangeland	0.28	1.65		
Coniferous forest	0.15	0.82	42.41	127.15
Deciduous forest	0.39	0.82	19.97	94.62
Mixed forest	0.15	0.82	19.97	127.15
Grassland	0.11	0.21	4.72	29.14
Shrub	0.08	0.19	4.27	4.27
Emergent Herbaceous Wetland	0.06	0.29	6.21	48.87
Inland wetland	0.07	0.77		

SOIL CRUSTS: DESERT CARBON

Though not included in this report, desert biological soil crusts play an important role in desert carbon balances. These crusts oxidize methane from the atmosphere, a gas 20 times more powerful than CO2 as a greenhouse gas.

One study estimated methane consumption by microorganisms in desert soils for the San Pedro River and Santa Rita Experimental Range in Arizona.[94] The study found methane consumption to be greatest in open patches, intermediate in mesquite, and lowest in sacaton grasslands.

Water Regulation

Ecosystems absorb water during rains, also regulating water temperature and flow. Forest cover, riparian vegetation and wetlands all contribute to modulating the flow of water from upper portions of the watershed to streams and rivers in the lower watershed. These processes regulate the flow, timing, amount, and temperature of water, which are considered separately from water supply in this report. Built capital, such as dams, levees, and weirs also modulate flows.

The conversion of natural landscapes to less pervious surfaces—clear cutting, loss of forest duff, and overgrazing—can dramatically increase flooding exacerbated by stormwater runoff, which contributes to higher peak flows and turbidity, flash floods, soil loss, streambank erosion, and landslides.[95] This may also reduce the recharge volume to aquifers, as runoff with accelerated velocity due to impervious surfaces does not infiltrate into soil as effectively as in areas covered with forest or other natural ecosystems. The cumulative effects of urban development, land use, and management decisions can create lasting damage to both built and natural capital by reducing the effectiveness of water regulation services.

A wide variety of stream-flow augmentation techniques have been adopted in the Colorado River Basin. In order to balance the demand for commercial water supply with other services such as water regulation and habitat, management must be carefully evaluated for the impact on water flows elsewhere in the watershed. Much of the science behind stream-aquifer relationships and other hydrologic relationships within the watershed is still not fully understood. A greater understanding of stream-aquifer dynamics will improve our ability to protect other ecosystem services while relying on valuable groundwater.

URBAN WATER REGULATION: INVESTING IN GREEN INFRASTRUCTURE

Cities can reap significant economic benefit by following a low impact development strategy of investing in green infrastructure: building, maintaining, or restoring natural assets within urban areas. This investment may be as simple as including strips of grass between traffic lanes, or as extensive as urban stream restoration. Green infrastructure brings economic and environmental benefits by reducing stormwater runoff and flooding, recharging groundwater, improving air quality, and other spillover benefits for city residents. Unlike traditional gray water infrastructure, such as storm pipes and lined ditches, green infrastructure has regenerative capacity and its value can even appreciate over time.[96]

While large cities in the Midwest and Northwest are often motivated to explore green infrastructure approaches by EPA stormwater regulations or water impairment, cities in and around the Basin are starting to recognize a different set of potential long-term benefits, such as water conservation and flood-risk mitigation.[97]

These were some of the reasons that spurred Denver, Colorado and Tucson, Arizona to pursue investments in green infrastructure. Tucson was primarily motivated by water scarcity and the demand for commercial and residential irrigation, while Denver sought to mitigate water impairment and flood risk. Both cities have implemented pilot projects with the support of multiple city stakeholders. Tucson incorporated curb cut-outs, micro-basins, swales, and native planting along Scott Avenue as part of its Downtown Infrastructure Improvement Project.[98] Denver's South Lincoln Redevelopment Project has installed porous landscape detention, grass buffers and swales, porous pavement, rooftop detention, and green roofs.[99] Both cities have made progress in designing green streets and restoring urban streams. Tucson has gone even further in promoting green infrastructure in private development with a city-wide ordinance requiring new commercial development to meet half of its irrigation requirements through rainwater harvesting.[100]

The city of Phoenix, Arizona is an example of a Basin city with unrealized potential for green infrastructure. With even less annual rainfall than Denver and Tucson, Phoenix would benefit from improved rainwater capture. And while nearby Scottsdale's Indian Bend Wash Greenbelt provides an example of a green infrastructure solution to historic flooding problems,[101] Phoenix has historically lacked the local support and policy framework that enables green infrastructure investment. In 2012, however, the EPA provided technical assistance to help Phoenix overcome barriers to green infrastructure.[102] The city may be on its way to realizing the benefits from investing in its natural capital.

Air Quality

Ecosystems help cleanse the atmosphere by filtering pollutants that include tropospheric ozone, ammonia, sulfur dioxide, nitrogen oxide compounds, mercury, carbon monoxide, methane, and particulate matter. In its 2011 annual report, the American Lung Association wrote that in the year prior, Los Angeles had 310,610 cases of underage asthma and 1,030,481 adult cases.[103] This proliferation in respiratory disease is a consequence of air pollution from industrial production and vehicular exhaust. Other cities like Las Vegas or Phoenix face similar issues.

In addition to the air pollution found in these larger cities, coal fired power plants, such as the Navajo Generating Station in Arizona or the San Juan Generating Station in New Mexico, emit thousands of tons of pollutants in more rural areas each year, including hundreds of pounds of mercury, with different but also troubling impacts.[104] For example, haze from the Navajo Generating Station clouds visibility at eleven different national parks and wilderness areas for more than four months out of the year at the most affected sites, which include the Grand Canyon. Far worse, the emissions bring increased health risks for local residents, many of whom are low income members of the Hopi and Navajo tribes.[105] In some cases, partial decommissioning is being looked at as a way of addressing EPA concerns,[106] but in other areas, pollution and pushback continue.[107] All in all, millions of dollars have been spent in the United States to comply with Clean Air Act requirements; and still more has been spent on the health costs associated with air pollution.

As air pollution has become a globally recognized hazard to human health, more studies have valued air pollution reduction by measuring the rate of toxins absorbed by trees. In 2006, one report measured the amount of atmospheric gases removed by forests in the United States. The study concluded that trees in US cities removed approximately 711,000 metric tons of carbon monoxide, nitrogen dioxide, sulfur dioxide, and other particulates that were less than 10 micrometers in diameter.[108] These particulates are the most damaging to human health. Tree cover in urban areas also provides shade to homes, which lowers energy costs, and in turn reduces carbon emissions from local power plants. The study concluded that each acre of forested land located near to cities provided over $230 per year in average value for pollution removal.

Valuation of Regulating Services

The value of regulating ecosystem services was estimated for eleven land classes. The primary valuation studies were transferred from avoided cost, replacement cost, market price, contingent valuation and hedonic pricing methodologies to value water quality, soil erosion control, water regulation, air quality, and flood risk reduction services. These values were applied as low and high values for each land cover with the valuation methodologies noted, through use of benefit transfer (see Table 20). Each individual dollar value is referenced in Appendix D. Carbon sequestration and storage is a primary calculation and is provided separately in Table 21.

TABLE 20 VALUE AND METHODOLOGY OF REGULATING SERVICES ACROSS LAND COVERS

LAND COVER	TRANSFERRED VALUATION METHODOLOGIES	VALUES (2013$/ACRE/YEAR)			
		INSIDE 200FT BUFFER		OUTSIDE 200FT BUFFER	
		LOW	HIGH	LOW	HIGH
Water Quality					
Emergent Herbaceous Wetlands	Avoided Cost	$10.56	$15,661.43	$10.56	$15,661.43
Woody Wetlands	Avoided Cost	$8.21	$5,693.90	$8.09	$5,496.05
Coniferous Forests	Avoided Cost, Replacement Cost	$33.67	$208.90	$33.67	$208.90
Grasslands	Avoided Cost	$6,759.91	$21,934.08	N/A	N/A
Deciduous Forest	Avoided Cost	$286.34	$287.53	N/A	N/A
Lakes	Avoided Cost	$2.30	$1,529.16	N/A	N/A
Flood Risk Reduction					
Emergent Herbaceous Wetlands	Avoided Cost	$16.02	$8,286.26	$10.56	$15,661.43
Woody Wetlands	Avoided Cost, Market Price, Hedonic Pricing	$523.24	$7,869.53	$8.21	$5,693.90
Coniferous Forests	Avoided Cost	$681.00	$681.00	$33.67	$208.90
Grasslands	Avoided Cost	$61.47	$4,151.26	N/A	N/A
Riparian	Avoided Cost	$46.30	$64.01	N/A	N/A
Urban Green Space	Avoided Cost	N/A	N/A	$91.41	$129.11
Soil Erosion Control					
Cultivated	Avoided Cost, Contingent Valuation, Market Price	$2.38	$131.75	$2.38	$131.75
Coniferous Forest	Avoided Cost	$0.82	$0.82	$0.82	$0.82

*Data that is not available or not applicable (i.e., riverine acreage outside of 200ft buffer) is indicated by "N/A."

TABLE 20 VALUE AND METHODOLOGY OF REGULATING SERVICES ACROSS LAND COVERS CONT.

LAND COVER	TRANSFERRED VALUATION METHODOLOGIES	VALUES (2013$/ACRE/YEAR)			
		INSIDE 200FT BUFFER		OUTSIDE 200FT BUFFER	
		LOW	HIGH	LOW	HIGH
Soil Erosion Control					
Grasslands	Avoided Cost, Contingent Valuation	$7.27	$3,393.34	$7.27	$7.27
Pasture/Hay	Avoided Cost	$2.38	$6.22	$2.38	$6.22
Water Regulation					
Cultivated	Replacement Cost, Avoided Cost	$24.78	$49.11	$24.78	$49.11
Emergent Herbaceous Wetlands	Avoided Cost	$101.44	$2,632.77	$101.44	$2,632.77
Coniferous Forest	Avoided Cost	$0.08	$0.08	$0.08	$0.08
Grassland	Avoided Cost	$1.62	$1.62	$1.62	$1.62
Woody Wetlands	Avoided Cost	$342.06	$1,070.30	$690.71	$2,667.57
River	Avoided Cost	$737.68	$2,848.97	N/A	N/A
Urban Green Space	Avoided Cost	N/A	N/A	$9.08	$438.30
Air Quality					
Cultivated	Avoided Cost/Market Price	$0.01	$101.48	$0.01	$101.48
Deciduous Forest	Avoided Cost	$61.43	$271.24	$61.43	$271.24
Coniferous Forest	Avoided Cost	$165.98	$165.98	$165.98	$165.98
Desert	Avoided Cost	$1.12	$1.12	$1.12	$1.12
Urban Green Space	Avoided Cost/Market Price	$31.95	$234.26	$31.95	$234.26

TABLE 21 VALUE OF ANNUAL CARBON SEQUESTRATION AND CARBON STORAGE PER ACRE

LAND COVER TYPE	CARBON SEQUESTRATION ($/ACRE/YEAR)		CARBON STORAGE ($/ACRE)	
	Low	High	Low	High
Cropland	$0.55	$90.61	$203.89	$1,260.81
Pasture	$0.57	$21.50		
Rangeland	$12.84	$79.57		
Coniferous forest	$6.58	$39.82	$1,922.07	$6,141.46
Deciduous forest	$17.72	$39.82	$905.22	$4,570.33
Mixed forest	$6.58	$39.82	$905.22	$6,141.46
Grassland	$4.76	$10.27	$214.01	$1,407.23
Shrub	$3.67	$9.19	$193.67	$206.41
Herb Wetland	$2.93	$13.87		
Inland wetland	$3.09	$37.42	$281.29	$2,360.19

SUPPORTING ECOSYSTEM SERVICES

Supporting services relate to the refuge and reproductive habitat ecosystems provide to wild plants and animals. Intact ecosystems provide commercially harvested species, and the maintenance of biological and genetic diversity. The Colorado River Basin holds a great diversity of fish, wildlife, habitats, and ecosystems. The Lower Colorado River includes wetland areas in southern Nevada, western Arizona, and southeastern California, providing exceptional habitats for waterfowl and passerine bird species.[109] This stretch of the river also is home to four US Fish and Wildlife Service refuges. The following supporting ecosystem services were valued in this report.

Habitat and Nursery

The Basin is home to many endemic species of plants and animals and several of these species are listed as threatened or endangered by the US Fish and Wildlife Service.

A diverse and unique native fish fauna exist within the Basin. However, of the 26 remaining native fish species in the Basin, 16 are listed as threatened or endangered. Four species of endangered fish, including the humpback chub, the bonytail, the Colorado pikeminnow, and the razorback sucker occur in the Upper Colorado River and some of its main tributaries. Several smaller fish species that occur in springs and smaller headwater streams, such as chubs, minnows, dace, and pupfish, are also federally listed. The decline of many of the native fishes is attributed primarily to modifications of flow regimes and water availability (such as dams and pumping of water out of the Colorado River for other uses) and the introduction of more than 70 non-native fishes (many for sport fishing).[110] The majority of revenue generated from fishing results from the harvest of these non-native fish, which often have negative effects on native species. Modification of flow regimes via dams and dewatering has dramatically decreased the quality of habitats of fishes in river systems across the Basin.

The Basin has large populations of harvestable species, including big game (elk, white-tailed and mule deer, and pronghorn antelope), small game (dove, grouse, and quail), upland game (rabbits, squirrels, and wild turkey), waterfowl, and furbearers (martens, beavers, and badgers). There are very limited numbers of hunting permits issued by states in the Basin for bighorn sheep and bears.

The introduction and establishment of non-native, invasive species is just one of many threats to both aquatic and terrestrial species and their habitats across the Basin. Non-native invasive species compete directly with native ones, but they may also lead to modification of fundamental ecological processes, such as natural flood or fire regimes. Other primary threats include urbanization (loss of habitat, need for water), overgrazing (loss of soil productivity, reduced vegetation condition, increased erosion), reduced water availability and ecological flows (competition with agriculture and urban areas, impoundments), and climate change.[111] Many of the Sky Islands and their isolated floras and faunas are likely to be impacted by climate change as suitable habitats will be eliminated from these areas. Due to the Sky Islands' isolated nature, some resident species may be unable to migrate in response to climate change when faced with physical migration barriers of surrounding inhospitable ecosystems and the rapid pace of change.[112] This issue has received considerable recent attention in the conservation community and has prompted new research and potential management options for regional corridors.[113]

THE HUMPBACK CHUB IS AN ENDANGERED SPECIES WHICH LIVES IN THE COLORADO RIVER BASIN. LEFT: YOUNG HUMPBACK CHUB SWIMMING IN SHINUMO CREEK IN THE GRAND CANYON NATIONAL PARK.

Valuation of Supporting Services

The position, pattern (size and shape), and connectivity of habitat elements often determine the quality and number of ecosystem services provided at local to Basin scales. This leads to the conclusion that not all similar habitats provide the same level of ecosystem services.[114] This insight also is important in that environmental managers have limited budgets and must prioritize environmental restoration for a very limited number of areas. Therefore, ecosystem service valuations must consider differential importance of habitat features at local, watershed, and Basin-wide scales across the Basin.

The Department of Interior's Landscape Conservation Cooperatives is a response by the Federal government, states, and universities and institutions to incorporate multi-scaled landscape concepts into natural resource management. The Western Governors Association's wildlife corridor initiative also recognizes the importance of a system of natural land cover corridors to support migration of plants and animals across large areas. This broader landscape perspective is viewed as critical in offsetting some of the impacts of climate change.

The value of supporting ecosystem services was estimated for seven land cover classes. The studies were drawn from used contingent valuation methods that are in some cases combined with avoided cost and market pricing methodologies to value habitat and nursery services (see Table 22). All studies measure non-use value of habitat, often based on a willingness to pay to preservation.

TABLE 22 VALUE AND METHODOLOGY OF SUPPORTING SERVICES ACROSS LAND COVERS

LAND COVER	TRANSFERRED VALUATION METHODOLOGIES	VALUES (2013$/ACRE/YEAR)			
		INSIDE 200FT BUFFER		OUTSIDE 200FT BUFFER	
		LOW	HIGH	LOW	HIGH
Habitat and Nursery					
Cultivated	Factor Income and Contingent Valuation	$0.01	$298.17	$0.01	$298.17
Emergent Herbaceous Wetlands	Contingent Valuation	$13.62	$9,356.54	$13.62	$5,946.53
Woody Wetlands	Contingent Valuation	$2.53	$14,490.32	$2.53	$14,490.32
Coniferous Forests	Avoided Cost and Contingent Valuation	$0.97	$3,844.50	$0.97	$3,844.50
Grasslands	Contingent Valuation	N/A	N/A	$35.29	$35.29
Pasture	Contingent Valuation	$1.94	$4.82	$1.94	$4.82
Riparian	Market Price and Contingent Valuation	$2.26	$4,416.03	$2.26	$4,416.03
Shrub	Contingent Valuation	$0.65	$335.22	$0.65	$335.22

*Data that is not available or not applicable (i.e., riverine acreage outside of 200ft buffer) is indicated by "N/A."

INFORMATION ECOSYSTEM SERVICES

Information services are those that provide humans with meaningful interaction with nature. These services include spiritually significant species and natural areas, natural places for recreation and enjoyment, and scientific and educational opportunities to learn about the planet.

Various species contribute substantially to the Basin's economic vitality and its high quality of life. It is estimated that hunting, fishing, and wildlife viewing contribute more than $10 billion to the economy of the Basin.[115,116] Arizona contributes the largest amount of revenue from these three sources, primarily because 95 percent of the state is within the Basin. The state also has great habitat and ecosystem diversity, including large stands of forests, woodlands, and grasslands. Moreover, Arizona contains all four major North American desert biome types, and a large number of lakes, rivers, streams, riparian areas and wetlands. Terrestrial biodiversity increases greatly as one goes from north to south within the Basin.[117] Pine-oak woodlands and coniferous forests of southern Arizona and southwestern New Mexico (forests in the Sky Islands), which extend northward into the United States from the Sierra Madre Occidental of Mexico, contribute substantially to the diversity of the area's bird, mammal, and reptile fauna.[118] This region provides some of the most exceptional wildlife viewing of any area in the US. This likely contributes to New Mexico's relatively high economic benefit derived from wildlife viewing (third among all of the states in the Basin). Colorado and Utah provide the second and third greatest economic contribution from fishing, hunting, and wildlife viewing. Colorado's mountainous landscapes have numerous streams, rivers, lakes, and forests that provide exception hunting and fishing. Moreover, the Colorado River and its major tributaries and riparian areas provide exceptional habitat for many species of fish and wildlife.

Recreation and Tourism

National parks and recreation areas of the Colorado River Basin include several of the most famous and iconic parks in the world, with millions of visitors annually: Grand Canyon National Park, Arches National Park, Glen Canyon National Recreation Area, and many others.[119] Most of these parks encompass some portion of the Colorado River or one of its tributaries, and derive a significant amount of their inherent beauty from the river itself. Depletion of the river's water or degradation of associated ecosystems risks significantly diminishing the economic value of these areas. Tourism is a major industry in every Basin state, with significant land area and national parks that bring tens of billions of dollars of annual revenue and directly sustains hundreds of thousands of jobs.[120,121,122] The preservation of natural beauty is an economic priority as much as anything else.

In this section, recreation and tourism services are assessed within each Colorado River sub-Basin.

Upper Colorado Basin (UCB)

Rafting within the UCB is a popular activity on several of the tributaries and the main stem Colorado River.[123] However, boating and fishing at the Blue Mesa, the state of Colorado's largest reservoir, is by far the largest recreation activity in the UCB, with about 883,000 annual visits and recreation benefits of $113 million.[124] Following is Ridgeway Reservoir providing approximately $9.5 million.[125] Together these reservoirs account for more than 90 percent of the water-based recreation in the UCB. Commercial rafting values are substantial at $7.6 million, but represents about 6 percent of the overall water-based recreation in the UCB. Data on private rafting and river fishing was not available, so the $130 million in annual economic value understates the total economic value of water-based recreation in the UCB.

Front Range of Colorado. Several reservoirs are at least partially filled by water from diversions of the Colorado River to the urban Front Range of Colorado. The largest reservoir is Pueblo Reservoir. An estimated 25 percent of the water for the reservoir comes from the multiple diversion projects on the west slope of the Colorado (the Upper Colorado River Basin). Pueblo Reservoir State Park has 687,000 visits annually, worth about $64 million in net willingness to pay. Rafting on the State of Colorado's most popular rafting river (the Arkansas River) also receives an estimated 25 percent of its flows from west slope water diversions. Thus 50,000 commercial rafting days would be attributable to Colorado River Basin water, yielding about $2.4 million annually. This is a minimum estimate as these figures reflect only commercial rafting and do not include a sizeable amount of private rafting and kayaking. However, one study on the river showed a 35 percent drop in commercial rafting on the Arkansas River occurred in 2002 with a 75 percent drop in flows, roughly a .5 percent drop in visitation for every 1 percent drop in flows.[126] Though this drop in usage was not incorporated elsewhere, the Arkansas River calculation was discounted to reflect the loss of visits, amounting to a final $1,249,968.

Denver also receives slightly more than half its water from the west slope, and a significant portion of this is stored in Chatfield Reservoir. The estimated proportion of recreation visits to Chatfield Reservoir State Park attributable to Colorado River water is about 25 percent of 257,000 visits annually, worth about $19,878,750 in net willingness to pay. In northern Colorado, the west slope water diversions represent about 17 percent of the water that fills Horsetooth Reservoir County Park and Boyd Lake State Park. Together these parks see approximately 97,000 people attributable to Colorado River water, worth about $9 million a year. The estimated total recreation value on the Front Range associated with Colorado River water is nearly $100 million annually in recreation benefits.

Green River Basin (GRB)

The biggest water resource in the GRB is Flaming Gorge Reservoir in Flaming Gorge National Recreation Area. Its total recreation use value is $43 million annually.[127] The primary activity is boating (74 percent), followed equally by fishing at Flaming Gorge and rafting on the Green and Yampa Rivers. Rafting on some of the rivers would be higher if not for the use limits placed on rafting by the Bureau of Land Management to protect the riverine resources and quality of the recreation experience.[128]

Lake Powell Basin (LPB)

The LPB recreation is dominated by Lake Powell itself, representing most of Glen Canyon National Recreation Area. This massive reservoir provides about 1.86 million visitor days,[129] producing benefits of $241 million annually to visitors. However, there is a significant amount of rafting that takes place as well in the LPB. The largest amount of rafting use is on the Colorado River upstream and downstream of Moab, Utah, for a total of 70,500 days.[130] In total, rafting use is valued at about $8 million a year.

The Middle Colorado Basin (MCB)

This Basin begins just below Lake Powell. The region encompasses the southernmost part of Glen Canyon National Recreation Area (GCNRA) which provides both fishing and rafting. This Basin also include rafting in Grand Canyon National Park, one of the premiere rafting areas in the country, and represents very highly valued recreation experience to users. However, recreational use is also capped in the Grand Canyon, and use has been at this cap for decades. Nonetheless rafting through the Grand Canyon provides about $19 million in benefits. Day use rafting in GCNRA provides about $2 million annually. Rafting represents about 18 percent of the benefits. Fishing below Glen Canyon Dam in Glen Canyon National Recreation Area provides about $4 million in benefits. Fishing values along the Little Colorado River and its tributaries in northern Arizona are $89 million annually, according to angler use statistics from Arizona Fish and Game.[131]

Lake Mead Basin (LMB)

As the name implies this region is dominated by Lake Mead, which is part of Lake Mead National Recreation Area (NRA) managed by the National Park Service. It was estimated that about two-thirds of the total visitation of 7.69 million visits to the Lake Mead NRA were to Lake Mead itself (the remainder is to Lake Mojave in the Lower Colorado River Basin). Boating and fishing are the primary activities. At a value of $93 per day[132] for the intermountain region, NRA recreation (which is predominantly water-based recreation) yields an annual value of $479 million. This is the single most valuable water recreation area in the Colorado River basin. In part this is due to Lake Mead's proximity to the Las Vegas metropolitan area.

Lower Colorado River Basin (LCRB)

The major waters in this Basin are Lake Mojave, Lake Havasu, and the Colorado River forming the border between California and Arizona. Estimated use at Lake Mojave (part of Lake Mead NRA) is 2.5 million visitors. Lake Havasu State Park has 315,500 visits. The BLM administers 8 concessionaires who have developed resorts (hotels, RV parks) along the Colorado River in this Basin.[133] With about half the 2.4 million visits to these concessionaires engaged in water-based recreation (fishing and boating), this amounts to about 1.2 million visits. All of these visits are valued using the estimate of $93 per day[134] based on intermountain NRA's, since Lake Mojave NRA represents more than half the visitation, and all of these sites offer boating and fishing.

Southern California. While southern California receives a significant amount of water from the Colorado River, most of it is directly used for agricultural, municipal, and industrial use. One reservoir at the terminus of the Colorado River Aqueduct (Cajalco Reservoir or Lake Mathews) is not open to recreational use (the reservoir itself is fenced off to the public to safeguard water quality).

San Juan Basin

The major water resource in the San Juan Basin is the San Juan River, and especially Navajo Reservoir in New Mexico. This large reservoir supports about 533,000 visits that are dominated by swimming and boating/fishing.[135] There is also fishing on the San Juan River below Navajo Reservoir. A total of $40 million in annual recreation benefits are provided by the waters of the San Juan Basin.

Gila River Basin

The Gila River Basin is made of up the Gila, Salt, and Verde Rivers along with associated reservoirs. According to Arizona Game and Fish, collectively these receive about 2.2 million angler days. Patagonia State Park and the areas administered by the Tonto National Forest (Saguaro and Canyon Lakes) receive about 140,000 combined boaters and anglers. The fishing is valued at $50 a day[136] and fishing/boating at $93 per day. The total recreation value in this Basin is $139 million.

Aesthetic Information

Aesthetic value, as an ecosystem service, refers to the appreciation of, and attraction to, beautiful natural land.[137] The existence of lakes, federal and state parks, scenic areas, and officially designated scenic roads attest to the social importance of this service. A plethora of research has shown that proximity to and/or views of healthy ecosystems enhance property value.[138] Greater economic value provided by environmental aesthetics is shown by analysis of data on housing markets, wages, and relocation decisions.[139] Similar data show degraded landscapes are associated with lower property values, economic decline, and stagnation.[140]

While most of the land along the Colorado River is in public ownership, some the land around Lake Havasu is private, and houses with views of the lake have an extra value associated with them due to the views. Likewise, in Las Vegas some homes are built around artificial bodies of water (derived from Colorado River Basin water) and they, too, have enhanced value, particularly waterfront homes and view properties.

The economic value of the enhancement in property values is quantified using the hedonic pricing method.[141] While there are no studies of aesthetic value for residences related to the Colorado River, there are examples of this in other similarly dry states such as California.[142] A study by Loomis and Feldman found that a view of a lake added $31,000 to the price of a home, and being on the lakeshore itself increased house prices by $209,000. The $31,000 gain represented a 16 percent gain. The $209,000 essentially doubled the house price compared to an equivalent house without lakefront property.

Cultural Services

The Millennium Ecosystem Assessment (MEA), a globally accepted and standard framework for ecosystem service assessment, defines cultural services to be inclusive of concepts such as spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience.[143] In this report, recreation and aesthetic information were discussed separate from the others listed above due to their ability to be monetarily valued. Other cultural ecosystem services are difficult or impossible to value. Existing ecosystem service frameworks and typologies consider cultural services in a variety of ways. While some frameworks only consider spiritual and religious experiences often related to indigenous peoples, others have defined cultural services to be inclusive of recreation, aesthetic, education, and scientific research.

The concept of social benefits has emerged in limited sociological contexts, offering an alternative approach to the MEA cultural services definition given above. Under the realm of the natural environment, social benefits first emerged in the 1970s under the analyses of benefits derived from tourism and recreation.[144] Social benefits have since included a wide array of things people receive from nature, which are rarely or in limited cases represented in mainstream ecosystem service typologies. In 2011, a case study was conducted on community members of the Deschutes National Forest and forest staff to determine how people benefit from forests. Results showed that the groups identified benefits from the national forest, including stewardship, self-identification, and regulation of urban sprawl, all of which are not benefits identified in the MEA classification scheme.[145]

Cultural services are not valued in this report. The following are considerations in recognition of their importance in the Colorado River Basin.

Indigenous Peoples and a Sense of Place. The natural environment is often associated with the identity of an individual, a community, or a society. It provides experiences shared across generations and offers settings for communal interactions important to cultural relationships. Cultural heritage is usually defined as the legacy of biophysical features, physical artifacts, and intangible attributes of a group or society that are inherited from past generations, maintained in the present, and bestowed for the benefit of future generations. The long-term interaction between nature and human interaction (e.g., property distribution, cultivation, and nature conservation) are characterizations of cultural heritage and their relationship with the landscape.

There are numerous cases where forests, prairies, or deserts, species, or even individual mountains, rivers, plants or animals are strongly associated with cultural identities and place attachments. Relations between ecosystems and religion can center around very material concerns, such as staking claim to land contested by immigrants, invading states, or other government agencies. Nonmarket economic valuation techniques have, in limited cases, been successfully applied to cultural heritage objects. However, valuations of some cultural services, such as regional identity or sense of place, remain elusive and are even impossible to monetize.

Health and Safety in Urban Environments. In recent decades, increased understanding of how trees and green space in urban surroundings benefit people has developed to include social, psychological, and physical domains. In the wake of global climate change and increased population pressure, there is an increased demand for relief from the negative health effects associated with living in densely populated areas. The health consequences of climate change that put people at the highest risk in the United States include mortality from excessive heat, extreme weather, disease, stress, respiratory disease, and air pollution.

Several categories of health benefits from green space can be estimated in dollars, while others are nearly impossible to value. The value of stress relief from a walk in the park, for example, is more difficult to measure than the reduced number of doctor visits per year. Crime reduction, mental illness alleviation, and increased community strength are also missing in the economic valuation literature, but they are recognized as highly valuable in health literature.

Community Benefits. People benefit from positive social interactions, and open spaces encourage greater sense of community with more opportunities for social interactions. Lower-income communities with a larger population of at-risk youth and families are even more likely to benefit from the social interactions made available by shared green space. One study found a positive link between the social integration of the elderly and their exposure to green common spaces.[146]

Before scientific studies established the social, physical, and mental benefits of interaction with natural environments, green spaces and parks were recognized as places where people came together. Today, strong social institutions have formed around local parks, further enhancing their benefits. Community gardeners, educators, and recreational sporting teams are all active users of parks and in many cases are also involved in park upkeep and enhancement.

Once communities become united around their local park, volunteers and donors come together to keep these green spaces alive and thriving. Community efforts to maintain parks increase social capital, or the inventory of organizations, institutions, laws, informal social networks, and relationships of trust that make up or provide for the productive organization of the economy. This increase in social capital creates a stronger sense of community, making the neighborhood safer and stronger, especially in communities that had previously suffered from fear or alienation due to lack of usable public spaces.[147]

Valuation of Information Services

The value of information ecosystem services was estimated for nine land classes. The studies that were drawn from used the avoided cost, replacement cost, factor income, contingent valuation and hedonic pricing methodologies to value aesthetic information and recreation services (see Table 23). Recreation was uniquely considered where river-specific activities were valued using visitation and expenditure data from major park systems. This calculation was broken down by each sub-basin. Non-water-related recreational activities were considered separately across all private and public lands outside the buffer of the major Basin riverine and lake systems.

TABLE 23 VALUE AND METHODOLOGY OF INFORMATION SERVICES ACROSS LAND COVERS

LAND COVER	TRANSFERRED VALUATION METHODOLOGIES	VALUES (2013$/ACRE/YEAR)			
		INSIDE 200FT BUFFER		OUTSIDE 200FT BUFFER	
		LOW	HIGH	LOW	HIGH
Aesthetic Information					
Cultivated	Contingent Valuation	$34.46	$87.83	$34.46	$87.83
Deciduous Forest	Contingent Valuation	$492.80	$492.80	$492.80	$492.80
Emergent Herbaceous Wetlands	Contingent Valuation, Hedonic Pricing	$40.01	$14,924.14	$40.01	$6,299.36
Woody Wetlands	Contingent Valuation	$46.15	$7,158.99	$1,104.85	$7,158.99
Grasslands	Contingent Valuation, Hedonic Pricing	$255.13	$4,882.34	$0.01	$0.01
River	Contingent Valuation, Hedonic Pricing	$8.12	$12,453.45	N/A	N/A
Lake	Hedonic Pricing	$1.81	$247.61	N/A	N/A
Pasture/Hay	Contingent Valuation, Hedonic Pricing, Replacement Cost	$5.20	5.20	$5.20	$5.20
Urban Green Space	Contingent Valuation, Hedonic Pricing, Replacement Cost	N/A	N/A	$135.15	$23,402.96

*Data that is not available or not applicable (i.e., riverine acreage outside of 200ft buffer) is indicated by "N/A."

TABLE 24 NON-RIVER RECREATION ACTIVITIES

LAND COVER	TRANSFERRED VALUATION METHODOLOGIES	VALUES (2013$/ACRE/YEAR)	
		LOW	HIGH
Cultivated	Hunting	$23.62	$27.65
Desert	Hiking, Camping, Wildlife Viewing, Recreational Vehicles, Photography	$0.01	$61.47
Emergent Herbaceous Wetlands	Bird Hunting, Bird Watching, Hiking	$391.00	$5,311.99
Woody Wetlands	Recreation (unspecified)	$102.55	$7,549.10
Coniferous Forests	Recreation (unspecified)	$0.44	$6,445.98

*Data that is not available or not applicable (i.e., riverine acreage outside of 200ft buffer) is indicated by "N/A."

TABLE 25	ANNUAL RIVER RECREATION AND TOURISM VALUE BY SUB-BASIN
UPPER COLORADO BASIN	
Rafting	$8,828,162
Boat/Fish	$177,533,708
Total	***$186,361,870***
LAKE MEAD REGION	
Boat/Fish	$479,315,812
Total	***$479,315,812***
GREEN RIVER BASIN	
Rafting	6,958,684
Boating	$36,348,160
Fishing	$7,004,160
Total	***$50,311,004***
SAN JUAN BASIN	
Swimming	$9,875,491
Boating/Fishing	$28,312,588
River Fishing	$2,201,150
Total	***$40,389,229***
LAKE POWELL BASIN	
Boat/Fish	$241,576,132
Rafting	$8,321,662
Total	***$249,897,794***
LOWER COLORADO BASIN	
Boat/Fish	$391,927,021
Total	***$391,927,021***
MIDDLE COLORADO BASIN	
Rafting	$21,228,388
Fishing	$93,657,250
Total	***$114,885,638***
GILA RIVER BASIN	
Fishing	$109,025,800
Boat/Fish	$29,527,221
Total	***$138,553,021***
Grand Total	***$1,651,641,389***

Summing across the sub-basins of the Colorado River Basin and its tributaries, the area provides 18.9 million days of water-based recreation such as boating (motorized and non-motorized, such as rafting), fishing, and swimming, valued at $1.7 billion annually. This is the net economic value or consumer surplus over and above expenditures.

Table 25 provides the economic value of water-based recreation activities by sub-watershed. This is a conservative estimate and does not include some areas because visitor use data were unavailable. This is also limited to water-based recreation related to the Colorado River and its tributaries.

Part 4

CALCULATING AN ASSET VALUE FOR THE COLORADO RIVER BASIN

Aggregating the dollar values of ecosystem services across ecosystems and land cover types provides a partial estimate of the annual flow of economic value that the Colorado River Basin provides to people. The total value estimated for 11 ecosystem services over 14 land classes ranges from $56.5 billion to $466.5 billion per year. This is a tremendous value by any measure. And as we discussed previously, this is likely an underestimate, since many services lacked valuation data. As more economic valuation studies are done, these combined known values will rise.

Summary results of ecosystem service valuations from each chapter above are provided in Tables 26 and 27. Ecosystem services are valued for each sub-basin across land cover types. The annual value of ecosystem services provided by the Colorado River Basin is shown below. From this flow of value, an asset value can be calculated. The 100 year asset value is calculated for the Colorado River Basin using a discount rate of 4.125 percent and 0 percent.

The low and high values represent the range of the lowest and highest values in the peer-reviewed academic literature. Some primary values were also conducted for this study, for example carbon sequestration values based on the actual forest types in the Colorado Basin, rather than transferring these values from outside the Basin. Though a great deal of research has been completed on ecosystem services in the last 40 years, this is still a new field. Many ecosystem services identified as valuable have no valuation studies. For example, though snowpack is critically important for potable water and flood risk reduction, there are no valuations of snowpack in the Colorado Basin. There are also geographical gaps, where studies may have been conducted in one state but not in others. To base this valuation entirely on original research would require more than 100 studies for an individual study area. That would be cost prohibitive, so a benefit transfer was used to provide a range of values for ecosystem service benefits. This is analogous to a business or house appraisal.

ANNUAL ECOSYSTEM SERVICE VALUATION IN THE COLORADO RIVER BASIN

Tables 26 and 27 present the total annual ecosystem service value across all sub-basins. All values are standardized to 2013 dollars using the Bureau of Labor Statistics Consumer Price Index Inflation Calculator. Each unique forest type from the sub-basins in Table 8 was consolidated for the purpose of these calculations. Ecosystem service values for each land cover and ecosystem service of each sub-basin are provided in Appendix D. These tables provide insight into the annual flow of benefits provided by the ecosystems of the Basin. This represents the annual flow of value for the specific ecosystem services and land cover types examined.

Aggregating the dollar values of ecosystem services across land cover types generates a partial estimate of the total flow of economic value that natural systems in the Colorado River Basin provide to people. Total high and low values are presented in Table 26.

TABLE 26 TOTAL ANNUAL ECOSYSTEM SERVICE VALUE BY LAND COVER

LAND COVER	VALUES (2013$/ACRE/YEAR)			
	INSIDE 200FT BUFFER		OUTSIDE 200FT BUFFER	
	LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	$2,036,416	$881,723,246	N/A*	N/A*
River and Streams	$106,083,375	$2,176,645,462	N/A*	N/A*
Barren/Desert	$267,134	$267,134	$154,938,885	$468,592,897
Deciduous Forest	$388,529,537	$491,593,216	$3,586,568,054	$5,383,500,232
Evergreen Forest	$1,895,927,167	$11,171,343,334	$21,739,619,128	$309,855,507,380
Mixed Forest	$18,927,892	$23,421,611	$341,630,500	$415,413,580
Shrub/Scrub	$40,862,362	$3,256,258,219	$17,722,982,770	$48,067,652,698
Grassland/Herbaceous	$4,882,310,307	$23,468,188,701	$772,053,041	$1,777,583,117
Pasture/Hay	$3,066,494	$29,108,599	$14,471,595	$24,633,942
Cultivated Crops	$7,769,443	$956,505,282	$163,913,346	$15,739,897,235
Woody Wetlands	$144,735,418	$5,681,370,848	$409,122,164	$8,514,363,921
Riparian	$97,134,573	$7,432,431,994	N/A*	N/A*
Emergent Herbaceous Wetlands	$16,393,286	$2,646,769,109	$119,879,582	$5,082,227,909
Urban	N/A*	N/A*	$23,466,559	$791,515,452
Water Supply**	$3,873,007,091	$12,211,360,966	N/A*	N/A*
Total	***$11,442,670,665***	***$70,287,752,768***	***$45,048,645,624***	***$396,120,888,363***

*Data that is not available or not applicable (i.e., riverine acreage outside of 200ft buffer) is indicated by "N/A."
**Water Supply was calculated independent of specific land cover types, although arguably this service could be attributed to a combination of riparian areas, lakes, and rivers. Therefore, water supply was separated from any land cover type to show how the total was derived.

To arrive at total ecosystem service values for the entire basin, we added together all of the values from both inside and outside the 200 foot buffers. Carbon sequestration values were then included, resulting in the grand total annual value across all ecosystem services. The grand total low and high values are provided in Table 28.

When adding the inner and outer buffer ecosystem service values, the Colorado River Basin provides between $56.5 billion and $466.5 billion in benefits for people every year. This includes 12 ecosystem services over 14 land classes. The dollar values for each ecosystem service/land cover type enables the data to be useful for benefit/cost analysis, or rate of return on investment calculations for any activity that enhances or degrades these land covers. FEMA, for example, will accept the appropriate local values in this report in their mitigation benefit/cost tool.

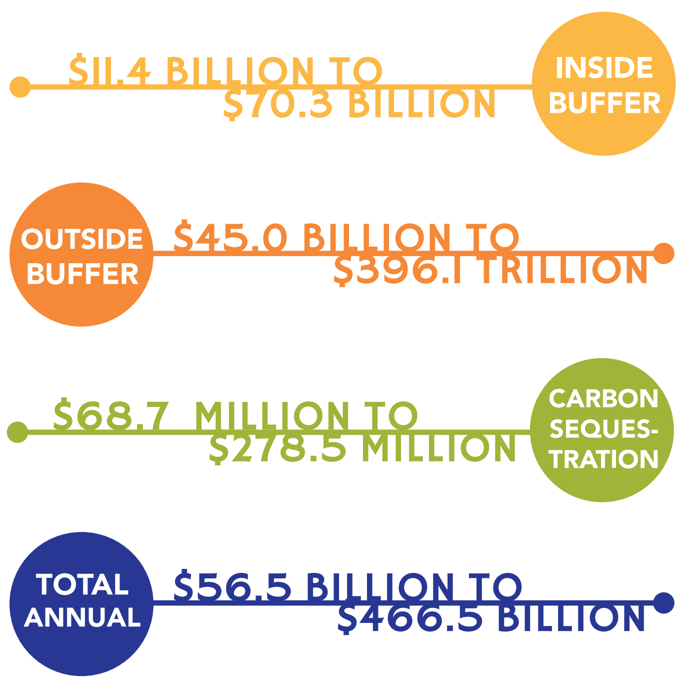


TABLE 27 TOTAL ANNUAL VALUE (MINUS CARBON SEQUESTRATION) BY ECOSYSTEM SERVICE

ECOSYSTEM SERVICE	VALUES (2013$/ACRE/YEAR)			
	INSIDE 200FT BUFFER		OUTSIDE 200FT BUFFER	
	LOW	HIGH	LOW	HIGH
Aesthetic Information	$408,025,731	$7,231,254,334	$2,736,022,915	$5,767,815,232
Air Quality	$444,356,664	$549,201,275	$5,078,640,862	$6,327,626,535
Energy and Raw Materials	$13,145,762	$27,332,115	$302,470,772	$535,863,448
Food	$139,453,736	$2,528,515,735	$1,315,560,734	$15,688,263,499
Habitat and Nursery	$576,581,462	$21,627,309,908	$6,332,028,202	$143,750,439,146
Flood Risk Reduction	$978,258,238	$5,288,017,071	$9,980,682,518	$11,494,555,097
Soil Erosion Control	$29,825,896	$2,330,975,351	$96,943,328	$306,603,969
Water Supply	$3,873,007,091	$12,211,360,966	N/A	N/A
Water Quality	$3,161,848,604	$16,149,028,066	$491,154,398	$6,098,003,397
Water Regulation	$166,526,092	$693,116,558	$136,602,145	$659,162,285
Recreation	$1,651,641,389	$1,651,641,389	$18,544,159,920	$205,353,320,802
Total	***$11,442,670,665***	***$70,287,752,768***	***$45,014,265,794***	***$395,981,653,410***

*Data that is not available or not applicable (i.e., riverine acreage outside of 200ft buffer) is indicated by "N/A."
**Carbon Sequestration was not divided into inner buffer and out buffer assessments and therefore were not included in the table above. Carbon sequestration across all land covers, valued at $68.6 million to $278 million per year, was included in the Grand Total calculations in Table 28 below.

TABLE 28 GRAND TOTAL ANNUAL ECOSYSTEM SERVICE VALUE ACROSS ALL LAND COVERS (2013 $/YEAR)

	LOW	HIGH
Carbon Sequestration	$68,759,661	$278,469,906
Grand Total	***$56,535,696,118***	***$466,547,876,083***

Better information as to the scale of an asset's value helps improve economic decisions. If the natural assets of the Colorado River Basin are conserved or enhanced, they will provide numerous, vast, and long-term benefits to the people of the Basin. Why are these "big numbers" important? The State of Louisiana provides an example of understanding the value of natural assets and investing in those assets at the appropriate scale.

With the deterioration of the Mississippi River Delta (loss of 1.4 million acres of wetlands since 1930), 30 linear miles of buffering wetlands were lost along the path that Hurricane Katrina took before the hurricane struck. With a far larger storm surge due to the absence of coastal wetlands, the Hurricane inflicted $200 billion in damage to built assets within 24 hours. The natural asset value of the Mississippi River Delta was estimated at between $300 billion and $1 trillion, in a 2010 report, "Gaining Ground: Wetlands, Hurricanes and the Economy: The Value of Restoring the Mississippi River Delta". The State of Louisiana, based on solid science, is embarking on a $50 billion restoration investment.[148] This investment will certainly return many times that amount in the form of increased fisheries, reduced hurricane damage, higher food production and rising rather than falling coastal community incomes. This investment also brings jobs, greater productivity and higher wages to rural coastal Louisiana.

While the Mississippi Delta has one of the richest sets of ecosystem service primary valuation studies in the world, the Colorado River Basin, with the notable exception of recreational values, has relatively few studies. Because of this lack of primary literature in the basin, and gaps in the general literature of ecosystem service valuation for certain land covers and ecosystem services, not all ecosystem benefits can be valued. This means that only a portion of the asset value of the Basin's natural capital can be estimated, and implies that the asset values we calculate are likely significant underestimates.

High and low values are provided in this report. This approach provides values that reflect the inherent uncertainty involved in valuation. Every business or house appraisal also has a range of comps that better reflect the uncertainty of valuation than the final choice of a single number. This is the first and most comprehensive overview of natural capital values for the Colorado River Basin, but it is not complete. The authors felt it better to provide the range of values rather than choose a single mean or average.

A healthier Colorado River Basin could provide greater economic benefits from the headwaters in the Rockies to the delta in Baja California. To do so requires an understanding not only of the annual flow of value provided by working and conservation lands within the Basin, but an understanding of the total asset value of that landscape for providing that flow of services. From the annual flow of benefits shown in Table 27, an estimate of asset value can be calculated.

ASSET VALUE

An ecosystem produces a flow of valuable services over time, like a traditional capital asset. This analogy can be extended to calculating the asset value through net present value of the future flows of ecosystem services, just as the asset value of a capital asset (such as a power plant or bridge) can be calculated as the net present value of its expected future benefits.

Like bridges, roads and many other built assets, ecosystems are generally not sold on the market. Thus, this calculation is an estimate of asset value without a potential for sale. However, it is useful for revealing the scope and scale of the economic value that the Colorado River Basin possesses. When the value of natural systems is exposed it shows that investments in restoration and conservation have the capacity to provide good rates of return. Benefit/cost analysis and rate of return calculations were initiated after the 1940s to examine investments in built capital assets which were expected to be productive for a few decades until they required replacement. Natural systems do not depreciate or fall apart like built capital assets. In fact, natural systems can even appreciate in value over time, being comprised of living and growing organisms. Of course, natural systems are only renewable if they are protected against degradation, development, unsustainable extraction, and other impacts. As long as the natural infrastructure of the Basin is not degraded or depleted below its ability to renew itself, this flow of value will likely continue into the future.

Calculating the net present value of an asset implies the use of a discount rate. Discounting can be adjusted for different types of assets and is designed to reflect the following:

- Time preference of money. This is the value that people put on something for use now, as opposed to the value they assign for that use or income at a later date.
- Opportunity cost of investment. A dollar in one year's time has a present value of less than a dollar today, because a dollar today can be invested for a positive return in one year.
- Depreciation. Built assets such as roads, bridges and levees deteriorate and lose value due to wear and tear. Eventually, they must be replaced.

Discounting has limitations that may result in under- or overestimates when applied to natural capital. Using a discount rate assumes that the benefits humans reap in the present are more valuable than the benefits provided to future generations, or even to this generation in just a few years into the future. Natural capital assets should be treated with lower discount rates than built capital assets because they tend to appreciate over time, rather than depreciate. The Colorado River Basin is providing more water, to more people, for a greater total value than it provided 100 years ago. Unlike a factory that is 100 years old, a protected watershed will appreciate in value if it remains mostly intact and experiences an increase in demand for its services. Additionally, most of the benefits that a natural asset such as the Basin provides reside in the distant future, whereas most of the benefits of built capital reside in the near-term, with few or no benefits provided into the distant future. Both types of assets are important to maintain a high quality of life, but each operates on a different time scale. It would be unwise to treat human time preference for a forest like it were a building, or that of a building as if it were a disposable coffee cup. Thus, a low discount rate better reflects the asset value of the Basin.

Asset Value of the Colorado River Basin

The net present value of the Basin was calculated using two discount rates over 100 years: 0 and 4.125 percent. The discount rate of 4.125 percent reflects the fact that human population and future development will degrade Basin ecosystems and reduce their ability to provide ecosystem services if they are not adequately protected. This process is analogous to depreciation of a built capital asset. Federal agencies like the Army Corps of Engineers use a 4.125 percent discount rate for water resource projects.[149]

The cut-off date of 100 years is arbitrary. Clearly, far greater value yet resides for the many generations who should benefit from the watershed well beyond the 100-year point, assuming the watershed is adequately protected. Currently, the value of economic assets is generally not considered beyond 100 years. This study follows that tradition. With no cut-off for value, any renewable resource would register an infinite value. However, the value of watersheds does extend far beyond a 100-year period, and better tools for capturing that value are being developed by economists.

Overall, 12 categories of ecosystem services were valued across the entire Basin. Results show that nature in the Basin generates about $56.5 billion to $466.5 billion (US dollars, 2013) in goods and services every year. These are economic benefits provided to people. From this annual flow of value, a net present value, analogous to an asset value, can be calculated.

The asset values for carbon and water storage are calculated in Part 3 above, and are shown in Table 29. While other ecosystem services like carbon sequestration or recreation are provided every year, carbon and water storage represent the current stock of ecosystem service benefits. These values are added to the 100 year asset value provided by all other ecosystem services. The resulting final asset value is shown in Table 30.

ASSET VALUE, 4.125% — **$1.5 TRILLION TO $11.5 TRILLION**

$5.8 TRILLION TO $46.9 TRILLION — **ASSET VALUE, 0%**

TABLE 29 ASSET VALUES OF CARBON STOCK AND WATER STORAGE (2013 $)

	GRAND TOTAL ASSET VALUE - LOW	GRAND TOTAL ASSET VALUE - HIGH
Carbon Storage	$102,236,520,491	$214,806,321,348
Water Storage	$7,219,175,313	$22,761,630,320

TABLE 30 TOTAL ASSET VALUE OF ALL ECOSYSTEM SERVICES (2013 $)

DISCOUNT RATE: 0%		DISCOUNT RATE: 4.125%	
Low Estimate	High Estimate	Low Estimate	High Estimate
$5,762,025,307,687	*$46,892,355,560,041*	*$1,474,404,089,836*	*$11,503,484,480,331*

Part 5

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE RESEARCH

This report provides an appraisal valuation of ecosystem services in the Colorado River Basin, quantifying the economic value supplied by nature in the watershed every year. By protecting against flooding, assuring a clean water supply, buffering climate instability, supporting fisheries, recreation, and food production, maintaining critical habitat, and providing water quality treatment and other benefits, **Basin ecosystems provide between $56.5 billion and $466.5 billion in economic value every year.** If treated like an asset, the asset value of the **Colorado River Basin ecosystems is between $1.5 trillion and $11.5 trillion at a 4.125 percent discount rate, and between $5.8 trillion to $46.9 trillion at a 0 percent discount rate.**

This initial estimate, which yet excludes many ecosystem services, demonstrates the enormous economic value provided by the Colorado River Basin. The Basin provides these goods and services across long time spans and to people well beyond its boundaries, at little or no cost. The loss of "free" services like flood risk reduction and drinking water quality has real local and regional economic costs. Protecting and restoring the Basin's natural capital is critical to maintaining quality of life, sustainability, equity, and economic progress in the region. Though only a snapshot in time, these appraisal values are defensible and applicable to decision-making at every jurisdictional level. For example, the dollar values provided in this study can be used immediately in local, state, or federal benefit/cost analysis.

In allocating $460 million in federal funding for mitigation after the 2013 Colorado floods, local dollar values derived in this study are better than the FEMA national average values used in the FEMA benefit/cost tool. FEMA recognizes Earth Economics data, and allows it to be substituted by county or state floodplain managers in the FEMA benefit/cost tool to arrive at more accurate flood mitigation values for flood affected businesses, households and local agencies. It also helps allocate mitigation funding more quickly and efficiently.

Because this is a meta-analysis, utilizing many valuation studies, the uncertainty associated with these results is not known. However, both the low and high values established are likely underestimates of the full value of ecosystem services provided within the Basin because values for most ecosystem services have not been estimated. In addition, for those ecosystem services for which value was estimated, most have not been estimated across all vegetation types. Sparse data and omission of existing value are still the greatest hurdles to studies such as this one, and likely the greatest source of uncertainty in this valuation.

While this report provides a valuation of ecosystem services in the Colorado River Basin, it is only a first step in the process of developing policies, measures, and indicators that support discussions about the tradeoffs in investments of public and private money that ultimately shape the regional economy.

NATURAL CAPITAL: AVOIDING NEW TAX DISTRICTS

Policymakers in the Basin could initiate institutional improvements that coordinate ecosystem conservation and restoration to preserve and improve drinking water quality and supply, flood risk reduction, habitat, climate adaptation, recreation, stormwater conveyance and forest stewardship. Adopting an integrated approach saves money and provides greater benefits for Basin residents and regional communities. This approach also reduces "infrastructure conflict," where investments in one location create new costs for taxpayers. The replacement of certain ecosystem services with built infrastructure, such as wetlands with sewage treatment plants, costs money: "lose an ecosystem service, gain a tax district." When an ecosystem service is lost, a tax district is often created to fund costly built capital replacements to the functions once served by natural ecosystems.

Investment in natural capital is essential to the long-term health of the Basin's economy and natural environment. Consider the conservation of the Colorado River Basin ecosystems as a key investment opportunity to generate economic prosperity. This appraisal of value is defensible and applicable to decision-making at every jurisdictional level. For example, in the late 1990s, New York City invested in the nearby Catskill-Delaware watershed as a water supply, when a filtration plant would have cost the city from $8 billion to $10 billion over 10 years. In contrast, the cost of investing in its natural capital was only $1.5 billion over the same amount of time. The watershed program saved the city money and also infused an annual $100 million into the rural economy in the watershed.[150] Subsequently, during Hurricane Sandy, the area affected in New York, which used this gravity-fed, forest-filtered water supply, was completely resilient throughout the storm. People in New York City could turn on the tap and drink the water, though all other services may have failed. In New Jersey, filtration plants and pumps went down and water was either unavailable or it had been contaminated by sewage, which required boiling. The repair costs for the New Jersey water infrastructure will be around $2.6 billion.[151]

A major investment to restore the riverine and other ecosystem processes of the Colorado River Basin is required to maintain and expand the vast value of this natural asset. The movement of water and sediment, and the maintenance and expansion of healthy natural systems underlies the production of many economic benefits, including protection against drought and flood. Without this investment, and with increasing impacts from drought and flood alone, people will be forced to retreat from the Basin, and current economic assets will be degraded. Recommendations of this report are included below.

RECOMMENDATIONS:

- **Invest in natural capital.** The conservation and restoration of natural systems in the Colorado River Basin should be considered investments in a key asset and an opportunity for promoting economic prosperity and sustainability. The Colorado River Basin's natural capital has a large asset value and high rate of return. Investments in natural capital deliver 21 categories of economic benefits to rural and urban communities including water supply, flood risk reduction, recreation, and healthier ecosystems. This appraisal of value is legally defensible and applicable to decision-making at every jurisdictional level.

- **Conduct a more detailed valuation, mapping, and modeling of key ecosystem services.** This study provides a baseline valuation of ecosystem services and identifies key benefits. A more detailed analysis can be used to make more cost-effective investments across the landscape. Expanding on existing attempts to better map and model water supply, flood risk reduction, and more, and integrating economic valuation with those more detailed maps and models, will provide critical information to citizens and businesses.

- **Adapt to water realities.** Continue developing local, state, and federal processes that are flexible and open to adapting to the changing reality of water supply, and the likelihood of future scarcity, rather than assuming a set amount of water will be available. There should be a detailed study of the full stocks and flows of water within the Basin. This would include reservoirs, snowpack, and aquifers. Continuing demand-side actions to better allocate water for maintaining healthy rivers, agriculture, and municipal and industrial uses are essential.

- **Include ecosystem services to advance rural economic development.** By including agriculture, sustainable forestry, water provisioning, flood risk reduction, and access to quality outdoor recreation in economic development planning, long-term and sustainable jobs can be identified, quantified, and secured in the Colorado River Basin. Restoration projects can and should be linked to economic advancement, sustainability, and long-term job creation.

- **Bring ecosystem service valuation into standard accounting and decision-making tools.** Accounting rules currently recognize timber and fossil fuel natural capital values, but need to be improved to include water provisioning. Ecosystem service valuation can provide governments, businesses, and private landowners with a way to calculate the rate of return on conservation and restoration investments. Benefit/cost analysis is a widely used economic decision support tool. Strengthening benefit/cost analyses with ecosystem services will shift investment of public and private funds towards more productive and sustainable projects.

- **Improve incentives for investment.** Water users in Los Angeles pay a portion of the bill for the built capital pipes conveying water from the Colorado Basin. There is nothing on the bill for investing back into the watersheds that actually produce the water. In Denver, by contrast, water users pay a small premium (about $1.65 per year) to support forest management practices that protect water supply and water quality.[152] This program and others like it can bring income into rural areas, reduce conflict, and improve water supply.

- **Improve the management of natural assets.** "Lose an ecosystem service, gain a tax district," states Earth Economics Executive Director David Batker. If natural flood risk reduction is lost, flooding hits and a flood district is created. Pave a city, and the groundwater that used to recharge the aquifer must now be piped and paid for with a storm water district. An ecosystem services framework can solve multiple economic problems while minimizing trade-offs. A systems approach improves natural asset management. Floods can be reduced while groundwater is recharged. Adopting an integrated approach reduces "infrastructure conflict" where one investment destroys another, such as a stormwater system that pushes water more quickly into rivers, increasing flood risk. A systems approach with incentives for landowners saves money and provides greater benefits for Basin residents and regional communities.

- **Apply the dollar values in this report.** This appraisal of value is legally defensible and applicable to decision-making at every jurisdictional level. For example, some values from this report can be used in FEMA's benefit/cost toolkit for post-disaster mitigation.

This study enables better actions, incentives and outcomes for long-term economic prosperity at the local and Basin scales. Understanding the natural capital asset value calculated for the Colorado River Basin shows the vast scale of benefits that it provides. The scale of the asset guides the scale of investment. Annual values provided can be included in microeconomic decisions, such as benefit/cost analysis or rate of return on investment. Integrated into local, county, state, and federal decisions, this analysis can provide long-term benefits to everyone who benefits from the natural capital of the Colorado River Basin.

APPENDIX A
STUDY LIMITATIONS

The results of the first attempt to assign monetary value to the ecosystem services produced by the Colorado River Basin have important and significant implications for the restoration and management of natural capital in the region. Valuation exercises have limitations that must be noted, although these should not detract from the core finding that ecosystems produce a significant economic value to society. A benefit transfer analysis estimates the economic value of a given ecosystem (e.g., wetlands) from prior studies of that ecosystem type. Like any economic analysis, this methodology has strengths and weaknesses. Some arguments against benefit transfer include:

- Every ecosystem is unique; per-acre values derived from another location may be of limited relevance to the ecosystems being studied.
- Even within a single ecosystem, the value per acre depends on the size of the ecosystem; in most cases, as the size decreases, the per-acre value is expected to increase and vice versa. (In technical terms, the marginal cost per acre is generally expected to increase as the quantity supplied decreases; a single average value is not the same as a range of marginal values).
- Gathering all the information needed to estimate the specific value for every ecosystem within the study area is not currently feasible. Therefore, the full value of all of the wetlands, forests, pastureland, et cetera in a large geographic area cannot yet be ascertained. In technical terms, far too few data points are available to construct a realistic demand curve or estimate a demand function.
- To value all, or a large proportion of the ecosystems in a large geographic area is questionable in terms of the standard definition of exchange value. A transaction in which all or most of a large area's ecosystems would be bought and sold cannot be conceived in this case. This emphasizes the point that the value estimates for large areas (as opposed to the unit values per acre) are more comparable to national income account aggregates and not exchange values.[153] These aggregates (i.e. GDP) routinely impute values to public goods for which no conceivable market transaction is possible. The value of ecosystem services of large geographic areas is comparable to these kinds of aggregates (see below).

Proponents of the above arguments recommend an alternative valuation methodology that limits valuation to a single ecosystem in a single location. This method only uses data developed expressly for the unique ecosystem being studied, with no attempt to extrapolate from other ecosystems in other locations. The size and landscape complexity of the Basin makes this approach to valuation extremely difficult and costly. Responses to the above critiques can be summarized as follows:

- While every wetland, forest, or other ecosystem is unique in some way, ecosystems of a given type, by their definition, have many things in common. The use of average values in ecosystem valuation is no more or less justified than their use in other macroeconomic contexts; for instance, the development of economic statistics such as Gross Domestic or Gross State Product. This study's estimate of the aggregate value of the Basin ecosystem services is a valid and useful (albeit imperfect, as are all aggregated economic measures) basis for assessing and comparing these services with conventional economic goods and services.
- As employed here, the prior studies upon which calculations are based encompass a wide variety of time periods, geographic areas, investigators and analytic methods. Many of them provide a range of estimated values rather than single-point estimates. The present study preserves this variance; no studies were removed from the database because their estimated values were deemed to be "too high" or "too low." Also, only limited sensitivity analyses were performed. This approach is similar to determining an asking

price for a piece of land based on the prices of comparable parcels ("comps"): Even though the property being sold is unique, realtors and lenders feel justified in following this procedure to the extent of publicizing a single asking price rather than a price range.

- The objection to the absence of even an imaginary exchange transaction was made in response to the study by Costanza et al. (1997) of the value of all of the world's ecosystems. Even this is not necessary if one recognizes the different purpose of valuation at this scale–a purpose that is more analogous to national income accounting than to estimating exchange values.[154]

This report displays study results in a way that allows one to appreciate the range of values and their distribution. It is clear from inspection of the tables that the final estimates are not precise. However, they are much better estimates than the alternative of assuming that ecosystem services have zero value, or, alternatively, of assuming they have infinite value. Pragmatically, in estimating the value of ecosystem services, it seems better to be approximately right than precisely wrong.

The estimated value of the world's ecosystems presented in Costanza et al. (1997), for example, has been criticized as both (1) a serious underestimate of infinity and (2) impossibly exceeding the entire Gross World Product. These objections seem to be difficult to reconcile, but that may not be so. Just as a human life is priceless so are ecosystems, yet people are paid for the work they do.

Upon some reflection, it should not be surprising that the value ecosystems provide to people exceeds the gross world product. Costanza's estimate of the work that ecosystems do is obviously an underestimate of the "infinite" value of priceless systems, but that is not what he sought to estimate. Consider the value of one ecosystem service, such as photosynthesis, and the ecosystem good it produces: atmospheric oxygen. Neither is valued in Costanza's study. Given the choice between breathable air and possessions, informal surveys have shown the choice of oxygen over material goods is unanimous. This indicates that the value of photosynthesis and atmospheric oxygen to people exceeds the value of the gross world product.

GENERAL LIMITATIONS

- **Static Analysis.** This analysis uses a static, partial equilibrium framework that ignores interdependencies and dynamics, though new dynamic models are being developed. The effect of this omission on valuations is difficult to assess.

- **Increases in Scarcity.** The valuations probably underestimate shifts in the relevant demand curves as the sources of ecosystem services become more limited. The values of many ecological services rapidly increase as they become increasingly scarce.[155] If the Basin ecosystem services are scarcer than assumed here, their value has been underestimated in this study. Such reductions in supply appear likely as land conversion and development proceed; climate change may also adversely affect the ecosystems, although the precise impacts are difficult to predict.

- **Existence Value.** The approach does not fully include the infrastructure or existence value of ecosystems. It is well known that people value the existence of certain ecosystems, even if they never plan to use or benefit from them in any direct way. Estimates of existence value are rare; including this service will obviously increase the total values.

- **Other Non-Economic Values.** Economic and existence values are not the sole decision making criteria. A technique called multi-criteria decision analysis is available to formally incorporate economic values with other social and policy concerns.[156,157] Having economic information on ecosystem services usually helps this process because traditionally, only opportunity costs of forgoing development or exploitation are counted against non-quantified environmental concerns.

GIS LIMITATIONS

- **GIS Data.** Since this valuation approach involves using benefit transfer methods to assign values to land cover types based, in some cases, on the context of their surroundings, one of the most important issues with GIS quality assurance is reliability of the land cover maps used in the benefits transfer, both in terms of categorical precision and accuracy.

- **Accuracy.** The source GIS layers are assumed to be accurate but may contain some minor inaccuracies due to land use changes done after the data was sourced, or classification errors during remote sensing.
- **Ecosystem Health.** There is the potential that ecosystems identified in the GIS analysis are fully functioning to the point where they are delivering higher values than those assumed in the original primary studies, which would result in an underestimate of current value. On the other hand, if ecosystems are less healthy than those in primary studies, this valuation will overestimate current value.
- **Spatial Effects.** This ecosystem service valuation assumes spatial homogeneity of services within ecosystems, i.e. that every acre of forest produces the same ecosystem services. This is clearly not the case. Whether this would increase or decrease valuations depends on the spatial patterns and services involved. Solving this difficulty requires spatial dynamic analysis. More elaborate system dynamic studies of ecosystem services have shown that including interdependencies and dynamics leads to significantly higher values,[158] as changes in ecosystem service levels cascade throughout the economy.

BENEFIT TRANSFER/DATABASE LIMITATIONS

- **Incomplete coverage.** That not all ecosystems have been valued or studied well is perhaps the most serious issue, because it results in a significant underestimate of the value of ecosystem services. More complete coverage would almost certainly increase the values shown in this report, since no known valuation studies have reported estimated values of zero or less for an ecosystem service. Table 12 illustrates which ecosystem services were identified in the Basin for each land cover type, and which of those were valued.
- **Selection Bias.** Bias can be introduced in choosing the valuation studies, as in any appraisal methodology. The use of ranges partially mitigates this problem.
- **Consumer Surplus.** Because the benefit transfer method is based on average rather than marginal cost, it cannot provide estimates of consumer surplus. However, this means that valuations based on averages are more likely to underestimate total value.

PRIMARY STUDY LIMITATIONS

- **Willingness-to-pay Limitations.** Most estimates are based on current willingness to pay or proxies, which are limited by people's perceptions and knowledge base. Improving people's knowledge base about the contributions of ecosystem services to their welfare would almost certainly increase the values based on willingness to pay, as people would realize that ecosystems provided more services than they had previously known.
- **Price Distortions.** Distortions in the current prices used to estimate ecosystem service values are carried through the analysis. These prices do not reflect environmental externalities and are therefore again likely to be underestimates of true values.
- **Non-linear/Threshold Effects.** The valuations assume smooth and/or linear responses to changes in ecosystem quantity with no thresholds or discontinuities. Assuming (as seems likely) that such gaps or jumps in the demand curve would move demand to higher levels than a smooth curve, the presence of thresholds or discontinuities would likely produce higher values for affected services.[159] Further, if a critical threshold is passed, valuation may leave the normal sphere of marginal change as larger-scale social and ethical considerations such as endangered species listings dominate.
- **Sustainable Use Levels.** The value estimates are not necessarily based on sustainable use levels. Limiting use to sustainable levels would imply higher values for ecosystem services as the effective supply of such services is reduced.

If the above problems and limitations were addressed, the result would most likely be a narrower range of values and substantially higher values overall. At this point, however, it is impossible to determine more precisely how much the low and high values would change.

APPENDIX B
GIS AND PRIMARY VALUATION DATA SOURCES

GIS DATA SOURCES

Land cover acreage was calculated from various sources. 2006 NLCD data was used as the baseline data source for land cover calculations, resulting in acreage estimations for all forest, wetland, shrub, grassland, cultivated, barren/desert, and water land types. Other data sources were used to estimate riparian and urban land cover types, as well as the detailed forest land cover types used for carbon sequestration and storage analysis. These alternate data sources are listed below. GIS databases were provided by USGS.

National Land Cover Database (NLCD)

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS 77(9), 858-864.

Riparian Land Covers

USGS National Gap Analysis Program, 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University.

Urban Green Space Boundaries

United States Census Bureau, 2010. Cartographic Boundary Files - Urban Areas. http://www.census.gov/geo/maps-data/data/cbf/cbf_ua.html (Retrieved April, 2014)

CARBON SEQUESTRATION AND STORAGE DATA SOURCES

Social Cost of Carbon Calculation Data Sources

International Panel for Climate Change, 2007. History and present state of aggregate impact estimates. IPCC Fourth Assessment Report: Climate Change 2007. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch20s20-6-1.html (Retrieved April, 2014)

Interagency Working Group on Social Cost of Carbon, 2013. Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12870. http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf (Retrieved April, 2014)

Carbon Sequestration and Storage Data Sources

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APPENDIX C
ADDITIONAL TABLES

Tables 31 – 38 summarize the combined high and low ecosystem service values for each land cover of each sub-basin in the Basin. In the case where high and low values are the same, only one relevant value was found. It is important to note that additional values may increase or decrease the value range presented.

TABLE 31 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF UPPER COLORADO RIVER SUB-BASIN

		TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
LAND COVER TYPE	ACRES	LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	40,924	$167,934	$72,711,731	N/A	N/A
Rivers and Streams	13,540	$10,098,414	$207,201,807	N/A	N/A
Barren/Desert	435,872	$10,720	$10,720	$12,942,678	$39,143,479
Deciduous Forest	2,142,691	$213,993,537	$270,817,676	$1,371,485,242	$2,058,622,897
Coniferous Forest	4,271,528	$394,750,641	$2,121,922,102	$3,532,094,229	$43,769,011,548
Mixed Forest	87,476	$6,028,159	$7,233,130	$74,373,000	$87,774,731
Shrub/Scrub	3,337,033	$1,689,970	$134,671,094	$575,675,194	$1,561,326,084
Grassland/Herbaceous	960,846	$379,033,032	$1,821,928,178	$77,245,693	$177,851,303
Pasture/Hay	363,709	$613,624	$5,824,807	$2,895,646	$4,929,047
Cultivated Crops	121,542	$942,593	$116,043,777	$11,411,837	$1,095,829,896
Woody Wetlands	80,434	$40,628,945	$1,594,828,049	$76,095,789	$1,583,652,265
Riparian	289,778	$20,114,935	$1,539,131,542	N/A	N/A
Emergent Herbaceous Wetlands	11,249	$843,951	$136,259,642	$8,357,976	$354,331,706
Urban Greenspace	6,543	N/A	N/A	$4,695,321	$158,370,863
Total	***12,163,165***	***$1,068,916,455***	***$8,028,584,255***	***$5,747,272,605***	***$50,890,843,819***

TABLE 32 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF GREEN RIVER SUB-BASIN

		TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
LAND COVER TYPE	ACRES	LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	103,980	$426,694	$184,748,821	N/A	N/A
Rivers and Streams	33,514	$24,994,501	$512,843,471	N/A	N/A
Barren/Desert	499,671	$36,997	$36,997	$14,169,779	$42,854,689
Deciduous Forest	1,700,705	$129,737,404	$164,188,053	$1,121,585,885	$1,683,519,673
Coniferous Forest	4,966,371	$404,970,644	$2,176,858,174	$4,160,224,343	$51,552,675,415
Mixed Forest	99,519	$5,548,203	$6,657,235	$85,911,309	$101,392,201
Shrub/Scrub	18,578,599	$7,705,119	$614,008,945	$3,282,039,665	$8,901,432,948
Grassland/Herbaceous	824,668	$467,250,419	$2,245,969,696	$64,610,930	$148,760,892
Pasture/Hay	758,322	$1,565,759	$14,862,915	$5,766,112	$9,815,233
Cultivated Crops	16,104	$99,454	$12,243,926	$1,544,740	$148,334,726
Woody Wetlands	109,641	$46,694,247	$1,832,912,338	$123,290,012	$2,565,825,386
Riparian	424,232	$29,448,053	$2,253,272,374	N/A	N/A
Emergent Herbaceous Wetlands	97,762	$8,750,621	$1,412,826,828	$69,156,659	$2,931,857,953
Urban Greenspace	1,023	N/A	N/A	$734,115	$24,761,332
Total	***28,214,111***	***$1,127,228,115***	***$11,431,429,773***	***$8,929,033,549***	***$68,111,230,448***

TABLE 33 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF LAKE POWELL RIVER SUB-BASIN

		TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
LAND COVER TYPE	ACRES	LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	121,178	$497,264	$215,304,392	N/A	N/A
Rivers and Streams	22,411	$16,714,254	$342,947,281	N/A	N/A
Barren/Desert	2,557,125	$91,472	$91,472	$75,158,636	$227,307,712
Deciduous Forest	914,948	$6,184,196	$7,826,356	$655,731,398	$984,264,088
Coniferous Forest	3,614,754	$75,129,325	$403,846,274	$3,245,908,139	$40,222,650,243
Mixed Forest	94,613	$2,279,424	$2,735,059	$84,648,259	$99,901,553
Shrub/Scrub	10,256,122	$1,388,651	$110,659,442	$1,941,344,691	$5,265,247,029
Grassland/Herbaceous	2,106,539	$274,226,611	$1,318,146,829	$175,969,230	$405,153,423
Pasture/Hay	140,094	$57,956	$550,145	$1,284,311	$2,186,189
Cultivated Crops	22,545	$20,198	$2,486,581	$2,315,603	$222,357,475
Woody Wetlands	28,818	$3,437,322	$134,926,901	$52,300,750	$1,088,446,577
Riparian	115,231	$7,998,763	$612,040,192	N/A	N/A
Emergent Herbaceous Wetlands	3,026	N/A	N/A	$2,806,707	$118,988,763
Urban Greenspace	0	N/A	N/A	N/A	N/A
Total	***19,997,404***	***$388,025,436***	***$3,151,560,924***	***$6,237,467,724***	***$48,636,503,052***

TABLE 34 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF SAN JUAN RIVER SUB-BASIN

LAND COVER TYPE	ACRES	TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
		LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	31,534	$103,474	$44,802,033	N/A	N/A
Rivers and Streams	22,119	$5,000,693	$102,605,481	N/A	N/A
Barren/Desert	481,768	$35,280	$35,280	$6,143,488	$18,580,195
Deciduous Forest	40,227	$30,657,635	$38,798,505	$314,037,894	$471,376,272
Coniferous Forest	7,599,052	$180,152,246	$968,381,033	$2,058,543,405	$25,509,061,822
Mixed Forest	28,308	$3,817,248	$4,580,279	$75,584,610	$89,204,669
Shrub/Scrub	27,478,030	$2,928,584	$233,374,322	$1,074,552,268	$2,914,363,001
Grassland/Herbaceous	1,322,651	$1,297,629,900	$6,237,420,696	$119,179,292	$274,399,667
Pasture/Hay	89,271	$315,742	$2,997,172	$2,079,282	$3,539,410
Cultivated Crops	989,812	$670,439	$82,538,586	$19,528,029	$1,875,193,094
Woody Wetlands	49,508	$22,018,329	$864,296,347	$40,262,598	$837,916,986
Riparian	210,130	$10,046,978	$768,763,162	N/A	N/A
Emergent Herbaceous Wetlands	23,500	$942,840	$152,225,714	$2,929,141	$124,179,284
Urban Greenspace	89,357	N/A	N/A	$1,979,168	$66,756,357
Total	***38,455,267***	***$1,554,319,388***	***$9,500,818,610***	***$3,714,819,175***	***$32,184,570,757***

TABLE 35 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF LAKE MEAD SUB-BASIN

LAND COVER TYPE	ACRES	TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
		LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	31,534	$448,318	$194,111,871	N/A	N/A
Rivers and Streams	22,119	$3,288,212	$67,468,370	N/A	N/A
Barren/Desert	481,768	$36,003	$36,003	$7,365,367	$22,275,613
Deciduous Forest	40,227	$6,975,193	$8,733,606	$77,851,867	$116,856,988
Coniferous Forest	7,599,052	$200,476,457	$1,311,280,706	$1,112,361,868	$18,932,248,620
Mixed Forest	28,308	$369,094	$651,770	$4,232,648	$7,445,648
Shrub/Scrub	27,478,030	$6,385,984	$508,889,123	$1,606,975,638	$4,358,383,003
Grassland/Herbaceous	1,322,651	$725,439,197	$3,487,026,200	$45,616,544	$105,028,015
Pasture/Hay	89,271	$70,542	$669,622	$230,503	$392,369
Cultivated Crops	989,812	$98,000	$12,064,893	$932,369	$89,531,422
Woody Wetlands	49,508	$7,139,459	$280,248,719	$13,586,153	$282,745,494
Riparian	210,130	$4,636,786	$354,792,268	N/A	N/A
Emergent Herbaceous Wetlands	23,500	$1,281,182	$206,852,574	$10,663,816	$452,086,519
Urban Greenspace	89,357	N/A	N/A	$654,460	$22,074,618
Total	***38,455,267***	***$956,644,427***	***$6,432,825,725***	***$2,880,471,233***	***$24,389,068,309***

TABLE 36 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF MIDDLE COLORADO RIVER SUB-BASIN

LAND COVER TYPE	ACRES	TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
		LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	9,754	$40,027	$17,330,592	N/A	N/A
Rivers and Streams	11,447	$8,537,121	$175,166,803	N/A	N/A
Barren/Desert	420,288	$10,614	$10,614	$12,472,433	$37,721,282
Deciduous Forest	15,596	$359,904	$450,633	$10,968,063	$16,463,250
Coniferous Forest	5,385,861	$158,754,687	$1,038,386,055	$3,162,037,130	$53,817,444,521
Mixed Forest	346	$1,245	$2,198	$212,002	$372,933
Shrub/Scrub	14,943,392	$3,965,832	$316,031,035	$2,740,753,952	$7,433,376,808
Grassland/Herbaceous	2,219,230	$1,113,800,429	$5,353,792,979	$175,578,448	$404,253,683
Pasture/Hay	9,823	$18,521	$175,813	$76,360	$129,982
Cultivated Crops	5,877	$77,479	$9,538,526	$510,793	$49,049,296
Woody Wetlands	14,316	$5,415,663	$212,583,690	$17,632,205	$366,949,105
Riparian	49,536	$3,438,543	$263,106,527	N/A	N/A
Emergent Herbaceous Wetlands	11,181	$937,598	$151,379,305	$8,064,876	$341,905,913
Urban Greenspace	13,717	N/A	N/A	$9,843,454	$332,014,845
Total	***23,110,364***	***$1,295,357,663***	***$7,537,954,770***	***$6,138,149,716***	***$62,799,681,618***

TABLE 37 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF LOWER COLORADO RIVER SUB-BASIN

LAND COVER TYPE	ACRES	TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
		LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	54,416	$223,301	$96,684,591	N/A	N/A
Rivers and Streams	28,096	$20,953,870	$429,936,795	N/A	N/A
Barren/Desert	438,260	$10,214	$10,214	$13,028,834	$39,404,047
Deciduous Forest	8,815	$386,238	$483,607	$6,048,830	$9,079,397
Coniferous Forest	433,204	$17,022,586	$111,341,695	$250,122,511	$4,257,051,327
Mixed Forest	160	$28,631	$50,559	$70,257	$123,588
Shrub/Scrub	9,680,787	$4,193,117	$334,143,020	$1,702,122,187	$4,616,436,137
Grassland/Herbaceous	102,803	$64,533,593	$310,198,749	$7,979,671	$18,372,478
Pasture/Hay	176,572	$249,398	$2,367,398	$1,451,704	$2,471,130
Cultivated Crops	311,963	$1,012,155	$124,607,564	$31,099,918	$2,986,392,036
Woody Wetlands	12,716	$2,420,532	$95,014,340	$21,042,807	$437,928,153
Riparian	98,888	$6,864,315	$525,235,753	N/A	N/A
Emergent Herbaceous Wetlands	5,442	$437,872	$70,696,449	$3,970,757	$168,338,035
Urban Greenspace	14	N/A	N/A	$10,047	$338,865
	11,352,136	***$118,335,822***	***$2,100,770,734***	***$2,036,947,523***	***$12,535,935,193***

TABLE 38 TOTAL ECOSYSTEM SERVICE VALUE BY LAND COVER OF GILA RIVER SUB-BASIN

LAND COVER TYPE	ACRES	TOTAL 2013 $/ACRE/YEAR			
		INSIDE 200FT BUFFER		TOTAL $/ACRE/YEAR	
		LOW	HIGH	LOW	HIGH
Lakes and Reservoirs	31,534	$129,404	$56,029,215	N/A	N/A
Rivers and Streams	22,119	$16,496,310	$338,475,454	N/A	N/A
Barren/Desert	481,768	$35,834	$35,834	$13,657,670	$41,305,880
Deciduous Forest	40,225	$235,430	$294,780	$28,858,875	$43,317,667
Coniferous Forest	7,591,320	$464,670,581	$3,039,327,295	$4,218,327,503	$71,795,363,884
Mixed Forest	28,308	$855,888	$1,511,381	$16,598,415	$29,198,257
Shrub/Scrub	27,478,030	$12,605,105	$1,004,481,238	$4,799,519,175	$13,017,087,688
Grassland/Herbaceous	1,322,652	$560,397,126	$2,693,705,374	$105,873,233	$243,763,656
Pasture/Hay	89,271	$174,952	$1,660,727	$687,677	$1,170,582
Cultivated Crops	989,812	$4,849,125	$596,981,429	$96,570,057	$9,273,209,290
Woody Wetlands	49,508	$16,980,921	$666,560,464	$64,911,850	$1,350,899,955
Riparian	210,130	$14,586,200	$1,116,090,176	N/A	N/A
Emergent Herbaceous Wetlands	23,501	$3,199,222	$516,528,597	$13,929,650	$590,539,736
Urban Greenspace	7,734	N/A	N/A	$5,549,994	$187,198,572
	38,365,912	***$1,095,216,098***	***$10,031,681,964***	***$9,364,484,099***	***$96,573,055,167***

APPENDIX D
VALUE TRANSFER STUDIES USED BY LAND COVER

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Cultivated	Food	Faux, J.	$18.62	$233.82
		Piper, S.	$45.68	$45.68
		Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$555.74	$9,133.43
			$405.93	$6,765.51
		Zhou, X., et al.	$21.99	$108.23
	Water Regulation	Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$49.11	$49.11
			$24.78	$24.78
	Habitat and Nursery	Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$0.00	$228.09
				$298.17
			$25.61	$39.63
			$26.10	$35.28
	Soil Erosion Control	Moore, W.B	$4.68	$4.68
		Pimentel, D., et al.	$131.75	$131.75
			$119.66	$119.66
		Wilson, S. J.	$2.38	$2.38
	Aesthetic Information	Bergstrom et al.	$34.46	$87.83
	Nutrient Cycling	Wilson, S. J.	$10.01	$10.01
	Soil Formation	Pimentel, D.	$7.05	$7.05
		Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$0.00	$44.46
			$14.50	$168.65
			$12.56	$205.38
			$0.34	$5.32
			$0.97	$4.35
		Wilson, S. J.	$2.58	$2.58
	Biological Control	Cleveland, C.J., et al.	$14.16	$201.81
		Pimentel, D.	$82.42	$82.42
			$56.74	$56.74
		Pimentel, D., et al.	$30.91	$30.91
		Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$0.00	$48.33
	Energy and Raw Materials	Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$0.00	$108.25
				$144.01

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Cultivated (continuted)	Air Quality	Canadian Urban Institute.	$100.63	$100.63
		Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$0.00	$101.48
	Pollination	Costanza, R., et al.	$2.78	$13.99
		Pimentel, D.	$103.09	$103.09
		Ricketts, T.H., et al.	$196.21	$196.21
		Sandhu, H.S., Wratten, S.D., Cullen, R., Case, B.	$0.00	$211.66
				$219.88
		Winfree et al.	$47.14	$1,956.30
Deciduous Forest	Recreation and Tourism	Prince, R. and Ahmed, E.	$42.70	$54.23
		Shafer, E. L., et al.	$568.94	$568.94
			$3.14	$3.14
			$102.65	$102.65
		Willis	$1.23	$550.23
	Aesthetic Information	Standiford, R., Huntsinger, L.	$492.80	$492.80
	Biological Control	Krieger, D.J.	$10.35	$10.35
		Pimentel, D.	$4.53	$4.53
			$30.14	$30.14
	Energy and Raw Materials	Pimentel, D.	$19.52	$19.52
	Air Quality	Mates. W., Reyes, J.	$61.43	$271.24
Desert	Recreation and Tourism	Richer, J.	$46.95	$61.47
	Air Quality	Delfino, K., et al.	$1.12	$1.12
Emergent Herbaceous Wetland	Food	Allen, J. et al.	$354.89	$354.89
	Water Regulation	Brander, L.M., , et al	$2,632.77	$2,632.77
			$101.44	$101.44
			$1,182.20	$1,182.20
			$677.75	$677.75
	Habitat and Nursery	Everard, M.	$13.62	$13.62
		Gren, I.M. and Soderqvist, T.	$17.93	$17.93
		Loomis, J.	$5,946.53	$5,946.53
		Pearce, D. and Moran, D.	$4,306.57	$4,306.57
			$286.97	$286.97
		Woodward, R., and Wui, Y.	$169.40	$1,749.27
	Recreation and Tourism	Brander, L.M., et al.	$28.60	$857.97

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Emergent Herbaceous Wetland (continued)	Recreation and Tourism	Cooper J. and Loomis, J.	$14.18	$337.50
		Farber and Costanza 1987	$123.97	$259.63
		Gren, I.M. and Soderqvist, T.	$219.89	$219.89
			$241.38	$241.38
			$3,141.22	$3,141.22
		Kreutzwiser, R.	$210.95	$210.95
		Lant, C.A., and Roberts, R.S.	$206.10	$206.10
		Stoll et al. 1989	$620.07	$620.07
		Whitehead	$972.18	$6,299.36
		Willis, K.G.	$35.79	$39.37
			$121.69	$121.69
		Wilson, S. J.	$128.86	$128.86
		Woodward, R., and Wui, Y.	$1.78	$24.96
			$44.58	$351.28
			$941.50	$4,960.71
	Aesthetic Information	Mahan, B. L., et al.	$40.01	$40.01
		(blank)	$972.18	$6,299.36
	Water Quality	Brander, L.M., et al.	$16.02	$4,003.85
		de Groot, D.,	$15,661.43	$15,661.43
		Gosselink et al	$2,519.32	$7,452.98
		Gren, I.M. and Soderqvist, T.	$423.25	$423.25
			$268.71	$268.71
		Grossman, M.	$10.56	$12.41
		Lant, C.A., and Roberts, R.S.	$206.10	$206.10
		Meyerhoff, J., and Dehnhardt, A.	$323.02	$965.35
		Olewiler, N.	$324.46	$911.64
		Wilson, S. J.	$1,329.73	$1,329.73
			$208.90	$208.90
		Woodward, R., and Wui, Y.	$224.68	$2,457.18
	Flood Protection	Brander, L.M., et al.	$16.02	$2,230.72
		Costanza, R., et al.	$2,127.01	$2,127.01
			$2,126.43	$2,126.43

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Emergent Herbaceous Wetland (continued)	Flood Protection (continued)	Gupta, T.R., and Foster, J.H.	$55.73	$445.84
		U.S. Army Corps of Engineers 1971	$460.16	$460.16
		Woodward, R., and Wui, Y.	$158.70	$3,115.16
Evergreen Forest	Food	Lampietti, J.A., and Dixon, J.A.	$31.73	$31.73
	Water Regulation	Adger, W.N., et al.	$0.08	$0.08
	Habitat and Nursery	Brander, L.M., et al.	$1.05	$7.23
			$417.23	$3,844.50
		Costanza, R., et al.	$1.30	$670.45
		Haener, M. K. and Adamowicz, W. L.	$0.97	$6.62
	Recreation and Tourism	Barrick, K., et al.	$6,445.98	$6,445.98
		Boxall, P. C., et al.	$0.22	$0.22
		Costanza, R., et al.	$0.44	$2,662.47
		Haener, M. K. and Adamowicz, W. L.	$0.01	$0.06
		Hanley N.D.	$119.33	$119.33
		Walsh et al. (1978)	$41.80	$41.80
		Wilson, S. J.	$128.75	$128.75
	Soil Erosion Control	Moore, W.B	$0.82	$0.82
	Water Quality	Olewiler, N.	$33.67	$33.67
		Wilson, S. J.	$208.90	$208.90
	Biological Control	Wilson, S. J.	$11.45	$11.45
	Energy and Raw Materials	Haener, M. K. and Adamowicz, W. L.	$3.89	$3.89
	Flood Protection	Wilson, S. J.	$681.00	$681.00
	Air Quality	Wilson, S. J.	$165.98	$165.98
	Pollination	Costanza, R., et al.	$72.79	$326.95
		Wilson, S. J.	$426.51	$426.51
			$236.68	$236.68
Grasslands	Food	US Dept of Comm (1995)	$36.27	$36.27
	Water Regulation	Jones, O.R., et al.	$1.62	$1.62
	Recreation and Tourism	Brookshire, D., et al.	$0.31	$0.31
		Butler, L.D., and Workman, J.P	$4.62	$115.43
		Pearce, D. and Moran, D.	$0.28	$0.28
	Pollination	Wilson, S. J.	$426.51	$426.51

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Shrub	Habitat and Nursery	Costanza, R., et al.	$0.65	$335.22
	Recreation and Tourism	Bennett, R., et. al.	$194.75	$194.75
		Costanza, R., et al.	$16.13	$1,347.13
	Pollination	Costanza, R., et al.	$1.39	$7.00
Woody Wetlands	Water Regulation	Brander, L.M., , et al	$342.06	$342.06
			$1,070.30	$1,070.30
	Habitat and Nursery	Brander, L.M., et al.	$38.89	$1,086.76
		Meyer and Anderson 1987	$14,490.32	$14,490.32
		van Kooten, G. C. and Schmitz, A.	$2.53	$17.36
			$40.03	$40.03
		Wilson, S. J.	$2,569.93	$2,569.93
	Recreation and Tourism	Gupta, T.R., and Foster, J.H.	$195.06	$390.11
		Kozak, J., et al.	$543.62	$543.62
		Whitehead, J. C.	$1,104.85	$7,158.99
	Aesthetic Information	van Vuuren, W. and Roy, P.	$1,440.98	$1,440.98
		Whitehead, J. C.	$1,104.85	$7,158.99
	Water Quality	Grossman, M.	$8.21	$9.65
		Jenkins, W.A., et al.	$546.47	$546.47
			$582.78	$582.78
		Thibodeau, F. R. and Ostro, B. D.	$5,693.90	$5,693.90
	Flood Protection	Brander, L.M., , et al	$3,149.05	$3,149.05
		Leschine, T.M., et al.	$2,000.78	$6,365.32
		Loomis, J. and Elkstrand, E.	$1,619.89	$7,396.61
		Qiu, Z., et al.	$1,880.54	$5,982.79
		Streiner, C., Loomis, J.	$523.24	$523.24
		Wilson, S. J.	$1,779.86	$1,779.86
Pasture/Hay	Habitat and Nursery	Bastian, C.T., et al.	$4.82	$4.82
			$1.94	$1.94
	Recreation and Tourism	Boxall, P. C.	$0.03	$0.03
	Soil Erosion Control	Canadian Urban Institute.	$6.22	$6.22
		Wilson, S. J.	$2.38	$2.38
	Aesthetic Information	Bastian, C.T., et al.	$5.20	$5.20
	Nutrient Cycling	Canadian Urban Institute.	$23.86	$23.86
		Wilson, S. J.	$10.01	$10.01

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Pasture/Hay (continued)	Soil Formation	Canadian Urban Institute.	$6.22	$6.22
		Pimentel, D., et al.	$7.73	$7.73
		Wilson, S. J.	$2.58	$2.58
	Biological Control	Pimentel, D., et al.	$18.55	$18.55
		Wilson, S. J.	$17.52	$17.52
	Pollination	Wilson, S. J.	$426.51	$426.51
Desert	Energy and Raw Materials	Delfino, K., et al.	$29.22	$29.22
Grasslands	Habitat and Nursery	Gascoigne, W.R., et al.	$35.29	$35.29
	Soil Erosion Control	Gascoigne, W.R., et al.	$7.27	$7.27
	Aesthetic Information	Ready, R.C., et al.	$0.01	$0.01
			$0.01	$0.01
Urban	Water Regulation	Birdsey, R.A.	$196.78	$196.78
		McPherson, G.	$9.08	$9.08
			$9.09	$9.09
		Trust for Public Land	$143.26	$194.41
			$438.30	$438.30
	Recreation and Tourism	Bishop, K.	$2,073.88	$2,324.41
		Brander, L.M., et al.	$558.81	$6,567.48
		Breffle, W., et al.	$11,426.81	$11,426.81
		Tyrvainen, L.	$1,452.41	$1,452.41
			$2,144.99	$2,144.99
			$4,257.60	$4,257.60
	Aesthetic Information	Bolitzer and Netusil	$15,545.87	$23,402.96
		McPherson, G.and Simpson	$353.25	$2,208.85
		Nowak, D.J., et al.	$4,370.71	$6,441.04
			$5,179.05	$7,632.26
			$5,626.00	$8,290.95
			$5,896.07	$8,688.95
				$9,285.98
			$6,211.80	$9,154.24
			$7,472.80	$11,012.56
			$12,119.29	$17,860.02
		Opaluch, R.J. et al.	$1,839.52	$3,180.55
		Qiu, Z., et al.	$1,023.78	$1,345.61
		Thompson, R., et al.	$135.15	$11,390.07

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Urban (continued)	Flood Protection	McPherson, G.and Simpson	$91.41	$129.11
	Air Quality	Birdsey, R.A.	$234.26	$234.26
		McPherson, E.G., et al.	$31.95	$31.95
		McPherson, G.	$209.83	$209.83
			$209.96	$209.96
		McPherson, G.and Simpson	$79.83	$172.11
	Climate Stability	McPherson, G.	$1,238.19	$1,238.19
Cultivated	Recreation and Tourism	Costanza, R., et al.	$31.79	$31.79
		Knoche, S. and Lupi, F.	$23.62	$27.65
Deciduous Forest	Recreation and Tourism	Bennett, R., et. al.	$194.75	$194.75
		Maxwell, S.	$141.57	$188.75
	Water Quality	Zhongwei, L.	$286.34	$286.34
			$287.53	$287.53
Emergent Herbaceous Wetland	Food	Woodward, R., and Wui, Y.	$192.58	$10,017.71
	Habitat and Nursery	Meyerhoff, J., and Dehnhardt, A.	$5,680.76	$9,356.54
	Aesthetic Information	Mazzotta, M.	$6,295.74	$14,924.14
		Opaluch, R.J. et al.	$7,436.08	$10,030.98
	Flood Protection	Thibodeau, F. R. and Ostro, B. D.	$7,690.98	$7,690.98
		U.S. Army Corps of Engineers 1976	$8,286.26	$8,286.26
Grasslands	Soil Erosion Control	Rein, F. A.	$3,393.34	$3,393.34
			$39.31	$39.31
			$1,541.00	$1,541.00
			$226.43	$226.43
	Aesthetic Information	Mazzotta, M.	$1,982.11	$3,731.04
		Opaluch, R.J. et al.	$1,839.52	$3,180.55
			$4,882.34	$4,882.34
		Qiu, Z., et al.	$255.13	$1,249.75
	Water Quality	Rein, F. A.	$21,934.08	$21,934.08
		Zhongwei, L.	$6,759.91	$6,759.91
			$11,722.46	$11,722.46
	Biological Control	Rein, F. A.	$24.66	$24.66
			$314.49	$314.49
	Flood Protection	Rein, F. A.	$4,151.26	$4,151.26

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
Grasslands (continued)	Flood Protection	Rein, F.A.	$61.47	$271.42
Lake	Recreation and Tourism	Cordell, H. K. and Bergstrom, J. C.	$1,009.93	$1,987.94
		Costanza, R., et al.	$1.78	$2,016.79
		Ribaudo, Marc , et al	$762.53	$873.29
		Ward, F. A., et al.	$4,754.30	$4,754.30
		Young, C. E. and Shortle, J. S.	$7.00	$7.00
	Aesthetic Information	Berman, M.A., et al.	$247.61	$247.61
		Young, C. E. and Shortle, J. S.	$1.81	$1.81
	Water Quality	Bouwes, N. W. and Scheider, R.	$1,529.16	$1,529.16
		Young, C. E. and Shortle, J. S.	$2.30	$2.30
Riparian	Food	Knowler, D. J. et al.	$793.95	$793.95
		Knowler, D.J., et al.	$17.77	$51.95
	Habitat and Nursery	Amigues, J. P., et al.	$732.84	$732.84
		Berrens, R. P., et al.	$4,416.03	$4,416.03
		Berrens, R.P., et al.	$37.13	$37.13
		Haener, M. K. and Adamowicz, W. L.	$2.26	$15.48
		Wu, J. Skelton-Groth, K.	$141.71	$3,082.63
	Recreation and Tourism	Everard, M.	$15.69	$15.69
		Lant, C. L. and Tobin, G.	$202.13	$2,225.43
	Flood Protection	Zavaleta, E.	$46.30	$64.01
River	Water Regulation	Gibbons, D.C.	$2,848.97	$2,848.97
			$1,214.63	$2,124.01
			$737.68	$737.68
			$2,321.14	$2,321.14
	Recreation and Tourism	Loomis, John B., et al	$18.52	$23.00
			$77.33	$199.10
		Mathews, Leah Greden, et al	$14,481.01	$14,481.01
		Shafer, E. L., et al.	$4,689.06	$4,689.06
			$17,909.56	$17,909.56
	Aesthetic Information	Berman et al.	$507.28	$507.28
		Kulshreshtha, S. N. and Gillies, J. A.	$31.22	$862.15

LAND COVER	ECOSYSTEM SERVICE	AUTHOR(S)	LOW $/ACRE/YEAR	HIGH $/ACRE/YEAR
River (continued)	Aesthetic Information (continued)	Rich, P. R. and Moffitt, L. J.	$8.12	$8.12
		Sanders, L. D., et al.	$12,453.45	$12,453.45
Woody Wetlands	Aesthetic Information	Thibodeau, F. R. and Ostro, B. D.	$46.15	$147.67
	Flood Protection	Leschine, T.M., et al.	$1,723.46	$7,869.53

APPENDIX E
VALUE TRANSFER STUDIES FULL REFERENCES

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