Estimating Monetized Benefits of Groundwater Recharge from Stormwater Retention Practices

Prepared for

United States Environmental Protection Agency

Nonpoint Source Control Branch (4503T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460
Contract Number: EP-C-11-009

Prepared by

TETRA TECH

10306 Eaton Place, Suite 340
Fairfax, VA 22030

April 2016

(This page is intentionally left blank.)

Contents

Figures

Tables

1 Introduction

Stormwater impacts from development have been documented extensively in peer-reviewed literature and summarized in the National Research Council's report titled Urban Stormwater Management in the United States (National Research Council, 2009). To address these impacts, the U.S. Environmental Protection Agency (EPA) Office of Water (OW) evaluated several potential scenarios for managing stormwater from new development and redevelopment using small stormwater retention practices. The objective of these practices is to reduce runoff volume to simulate pre-development hydrology and protect water quality. These practices are often designed to infiltrate the retained water, which can provide groundwater recharge to help maintain predevelopment groundwater levels. For the purposes of this study, infiltration was assumed, whereas in practice capture-and-use or other methods also may be applied.

Many communities throughout the U.S. are currently planning for alternative water supplies to supplement limited local groundwater resources. Florida, Texas and California are examples of states with decreasing groundwater reserves. In addition to addressing groundwater supply needs, maintaining groundwater levels could help prevent land subsidence, protect aquatic habitats and commercial fisheries, prevent saltwater intrusion in some coastal areas, and help maintain water supply and generation of hydroelectric power in dry periods through increases in baseflow. These direct benefits contribute to further indirect benefits to communities and ecosystems.

Studies on the monetization and valuation of groundwater recharge and related benefits have been conducted by others (Appendix A). While it is difficult to assign a dollar value to a unit of water, water is valuable to the U.S. economy, and can be protected, in part, through groundwater recharge.

Water supply uses are only a portion of the total economic value of groundwater recharge. However, the water supply value of maintaining groundwater levels in developed areas could be significant. EPA commissioned this study to explore methods for estimating the consumptive direct use value of groundwater recharge achieved through stormwater retention practices designed to simulate predevelopment hydrology.

1.1 PURPOSE AND SCOPE

The purpose of the study is to inform valuation of groundwater recharge from stormwater retention in areas projected for new development and redevelopment. Retention practices can prevent the loss of natural recharge that may occur on a developed site without these practices. This study examined a simplified methodology for estimating recharge volume and used observed prices of water for monetary valuation.

Groundwater recharge is just one benefit within the larger context of the costs and benefits of stormwater retention practices. The full range of potential benefits were not addressed in this study, but the full suite of benefits should be considered when comparing to an estimated cost of implementation. Costs of implementing retention practices in areas of new and redevelopment also were not addressed in this study.

The estimates represent the groundwater recharge volume and value that would result if stormwater retention practices were implemented in areas within the contiguous U.S. not currently requiring stormwater retention. The stormwater retention practices were assumed to capture a specified depth of runoff, in the range of 0.5 to 2 inches (i.e. not large storm attenuation) with a goal of reducing runoff volumes to levels similar to those for pre-developed landscape conditions. This approach is commonly referred to as "green infrastructure" for stormwater management or low impact development (LID). While small storm retention that approximates predevelopment runoff could also be achieved with cisterns in those areas where infiltration is not desired or is not feasible, the option of cistern capture was not evaluated in this study. The timeframe selected for the purpose of the predictive study was the 20-year period of 2021 through 2040.

1.2 MAJOR ASSUMPTIONS

Because of the national scale of this analysis, broad assumptions were necessary for both the recharge volume and groundwater value estimates. The scope did not allow for a direct estimate of the marginal value of the groundwater recharge; instead, water supply price data were used to approximate the potential value. When approximating the volume of groundwater recharge on a national basis, a number of assumptions were necessary regarding the variability of groundwater recharge in terms of geology, climate, and other factors.

The retention scenarios presented in this study are expressed as percentile rainfall events. For example, the 95th percentile rainfall event represents a precipitation depth for which 95 percent of all rainfall events in the period of record do not exceed. In more technical terms, the 95th percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the 95th percentile rainfall depth based on the range of all daily rainfall event occurrences during this period.

The major assumptions are listed below, separated by monetized unit value and recharge volume methods. Additional assumptions and sources of uncertainty are presented in Section 4.

- **Monetized Unit Value Assumptions**
    - The marginal value for recharged groundwater is assumed to be equivalent to the price for extracted raw, high quality water as represented by western water rights transactions, retail utility water rates, and wholesale bulk water purchases. For retail utility water rates and wholesale purchases, the value was adjusted to reflect raw water prices.
    - A single price per acre-foot of groundwater recharge was assumed across each state. Where possible, volume-weighted means were used to estimate this value.
    - Each unit of groundwater has a constant value within each 5-year period which escalates between each 5-year period.
    - Prices would not change as the volume of groundwater recharge changed.
    - Groundwater value is achieved upon infiltration, i.e. there is no delay caused by the water reaching an accessible aquifer.
    - Infrastructure to extract groundwater is in place. The geographic area was selected, in part, based on counties that have used groundwater as a significant water source in the past. Related infrastructure and pumping costs were omitted from the monetization analysis.
- **Stormwater and Recharge Volume Assumptions**
    - Small stormwater retention practices can recharge, on average, the designed retention depth at the natural recharge rate. The natural recharge rate is approximated at the county-scale. With the exception of counties with low recharge (assumed to be less than 3 inches per year) and/or low precipitation (assumed to be less than 15 inches per year), it was assumed that the retention practices would not increase groundwater recharge beyond what was capable within the subject land area during pre-development.

  - Published recharge rates of existing aquifers provided estimates of natural recharge rates at the county level. Where published natural recharge rate data were not available, the Horsley method was used as a simplified approach to estimate recharge taking into account varying climatic and other geographic conditions, on average, nationwide.
  - The use of small scale stormwater retention practices sized to retain a percentile rainfall event depth (such as the 90th percentile rainfall event depth) is approximately equivalent to retention of that percentile of annual stormwater runoff volume (such as 90 percent of annual stormwater runoff volume) which would under natural/background conditions (i.e. undeveloped) recharge to groundwater. This assumption may not be accurate in areas with extreme weather conditions.
  - All small stormwater retention practices are implemented correctly and continue to function as intended with proper operation and maintenance.
  - The volume of stormwater runoff was estimated using the Simple Method (Schueler 1987), an empirical method intended to represent a wide range of storms as a function of watershed area and imperviousness. A single reduction factor for precipitation loss was used nationwide when applying the Simple Method.

While a number of uncertainties are associated with these broad assumptions, the study findings provide general insight into the groundwater recharge benefits of small stormwater retention practices and are useful in understanding the potential scale of these benefits. In particular, the study recognizes the uncertainty and potential bias inherent in assuming that water supply prices are equivalent to the marginal economic value of groundwater. The study's monetary value estimates provide an exploration of the potential economic value of groundwater recharge while recognizing that these values are based on prices alone and that additional analysis would be required to approximate the true economic value.

To limit the overestimation of benefits, the study assessed benefits only on locations where the likelihood of achieving benefits from groundwater recharge exists. Therefore, the study area is limited to areas that have been identified to be water stressed now or in the future, rely to a significant extent on groundwater resources, and do not already have stormwater retention standards that exceed those being evaluated. More detailed information about the study's limitations, factors that might tend to result in overestimated or underestimated values, and recommendations for future study efforts are provided in Sections 4 and 5.

1.3 REPORT ORGANIZATION

This report documents the source data, methods, results, and uncertainties and limitations of the groundwater recharge volume and monetary benefit estimates. In addition, recommendations are provided to support future analysis at the national or regional scale.

Section 2 documents the detailed methods and assumptions used. Section 2.1 explains how the geographic area was selected for the analysis. Section 2.2 documents the methods for estimating the monetary value of groundwater. Section 2.3 discusses the methodology used to estimate the recharge volume.

Section 3 presents the results of the monetary value and volume estimation. Tables organize the results by scenarios, and charts are provided to illustrate variation across states.

Section 4 discusses the strengths and weaknesses of the study and lists uncertainties and limitations related to the results. Section 5 outlines recommendations for future refinements to the study methods as well as more detailed approaches that could be applied at a regional level.

Appendix A reviews relevant literature on groundwater benefits valuation. Appendix B shows the geographical variation in monetized value of groundwater recharge. Appendices C and D respectively, contain detailed methodologies used in generating annualized values and escalating those values over time. Appendix E describes the methods used to estimate development area and impervious surface.

2 Methods

This section describes the three main aspects of the study methodology for estimating the value of groundwater recharge that would be achieved through small storm retention practices for new development and redevelopment nationwide:

- *Geographic area of focus*
- *Monetized unit value*
- *Recharge volume approximation*

2.1 GEOGRAPHIC AREA OF FOCUS

The geographic area was limited to communities that would be expected to place a value on groundwater. The area was defined by the intersection of communities within the contiguous U.S. that 1) rely on significant groundwater use to meet current water supply demands and 2) are projected to experience water shortages in the future. The selected data sources discussed below report this information principally at the county level; therefore the analysis was conducted using the county as the unit of evaluation. The geographic area of focus represents those counties that are actively using groundwater, are likely to have the infrastructure to extract additional groundwater, and are projected to experience demand for additional groundwater – all major factors indicating that these counties would value groundwater recharge.

2.1.1 Significant Groundwater Use Areas

A value for the groundwater recharge that would be maintained by using green infrastructure practices during development and redevelopment is more likely to be present if a demand for groundwater supply already exists and a community possesses the infrastructure to extract it. The 2005 U.S. Geological Survey (USGS) Groundwater Use Data can be used to identify counties where significant groundwater use exists. The USGS 2005 data were useful in determining likelihood of demand and availability of infrastructure; evaluation of water scarcity is discussed in Section 2.1.2.

USGS conducts water use surveys every five years and reports data by county and type of water use (USGS, 2009). At the time of this analysis, the most recent available data were collected in 2005. As an estimate of counties that would realize value in maintaining groundwater recharge, Tetra Tech selected counties with relatively high annual groundwater use volumes. Counties were considered to have relatively high use if groundwater use volume was measured at or above selected thresholds, relative to all other counties in the contiguous U.S., in any one of the five major groundwater use categories (fresh water only): public supply, domestic self-supplied, industrial self-supplied, irrigation-crop, and livestock (categories for mining and thermoelectric uses were excluded because they tend to be focused in specific areas and may not be representative of water use countywide).

The selection of use categories was purposefully broad to include both urban and agricultural uses. While this valuation of groundwater recharge focuses on the value of groundwater used for potable water, the initial selection of counties considered all uses in the USGS water use data set for the purposes of identifying counties with any type of groundwater demand and availability of infrastructure. Later in the analysis (Section 2.3.2), the geographic area is further narrowed to new development and redevelopment within these counties. It was assumed that potable water would be in demand within counties with new development and redevelopment regardless of the groundwater use breakdown for urban versus agricultural uses.

Two thresholds were established to provide a means to determine sensitivity of the analysis to level of groundwater use: 1) counties in the "upper 25th percentile use" category; and 2) counties in the "upper 50th percentile use" category.

- A county that meets or exceeds the "upper 25th percentile use" threshold has an annual volume of groundwater use in any one of the five groundwater use categories above the upper quartile volume of groundwater use for all counties in the contiguous U.S. The volume is based on total volume, not by percentage of total local water use. To be included in this group, a county needed to meet the criteria in any one of the five use categories. Twenty-five percent of counties in the U.S. meet this criteria for each use category. Some counties meet the criteria in all five categories while others meet the criteria in four or fewer categories. As a result, the total number of counties identified as meeting or exceeding the "upper 25th percentile use" threshold exceeds 25 percent of all counties considered for the analysis.
- A county that meets or exceeds the "upper 50th percentile use" threshold has an annual volume of groundwater use in any one of the five groundwater use categories above the median volume use for all counties in the contiguous U.S. For reasons similar to those for the upper 25th percentile, the total number of counties identified as meeting this threshold exceeds 50 percent of all counties considered for the analysis.

Both thresholds are considered conservative estimates because for many counties that fall below the thresholds on a percentage basis, overall water use is relatively low, but groundwater still represents the majority of the county's water consumption. For example a county may rely exclusively on groundwater withdrawal for public supply water yet fall below the threshold due to a relatively low water volume demand relative to all other counties nationwide. This scenario applies primarily to counties of a very small area, low population, and limited industrial and agricultural water demand. Therefore, where new development and redevelopment are projected, additional counties that are not selected may realize monetary benefits from maintaining groundwater recharge. The number of counties selected from each use category is summarized in Table 2-1.

Table 2-1 Summary of County Selection by Groundwater Use Category

Groundwater Use Category	Upper 25th Percentile Use Threshold		Upper 50th Percentile Use Threshold	
	Number[1]	Percent of Total	Number[1]	Percent of Total
Public Supply	799	25%	1,598	50%
Domestic Self Supplied	795	25%	1,595	50%
Industrial Self-Supplied	796	25%	1,541	48%
Irrigation Crop	404	13%	800	25%
Livestock	800	25%	1,602	50%
Total that meet the threshold for at least one category	**1,938**	**61%**	**2,804**	**88%**

[1] There are 3,191 counties and county equivalents in the contiguous U.S. dataset of groundwater use. The number of water-stressed counties is provided in Table 2-2.

Figure 2-1 shows counties selected for significant groundwater use that met or exceeded the upper 25th percentile and the upper 50th percentile thresholds. By definition, all counties that met the upper 25th percentile use threshold also met the upper 50th percentile use threshold. The upper 25th percentile use threshold provides a more conservative groundwater recharge valuation because fewer counties were included. Counties that met these thresholds were considered to be "significant" in this analysis. Those counties that did not meet the thresholds tended to have either very low water use overall, a high ratio of surface water to groundwater use, or both. For example, in most Kentucky counties, surface water represented a very high percentage of water use in 2005 and, as a result, groundwater use volume was so low in these counties that they did not meet either use threshold.

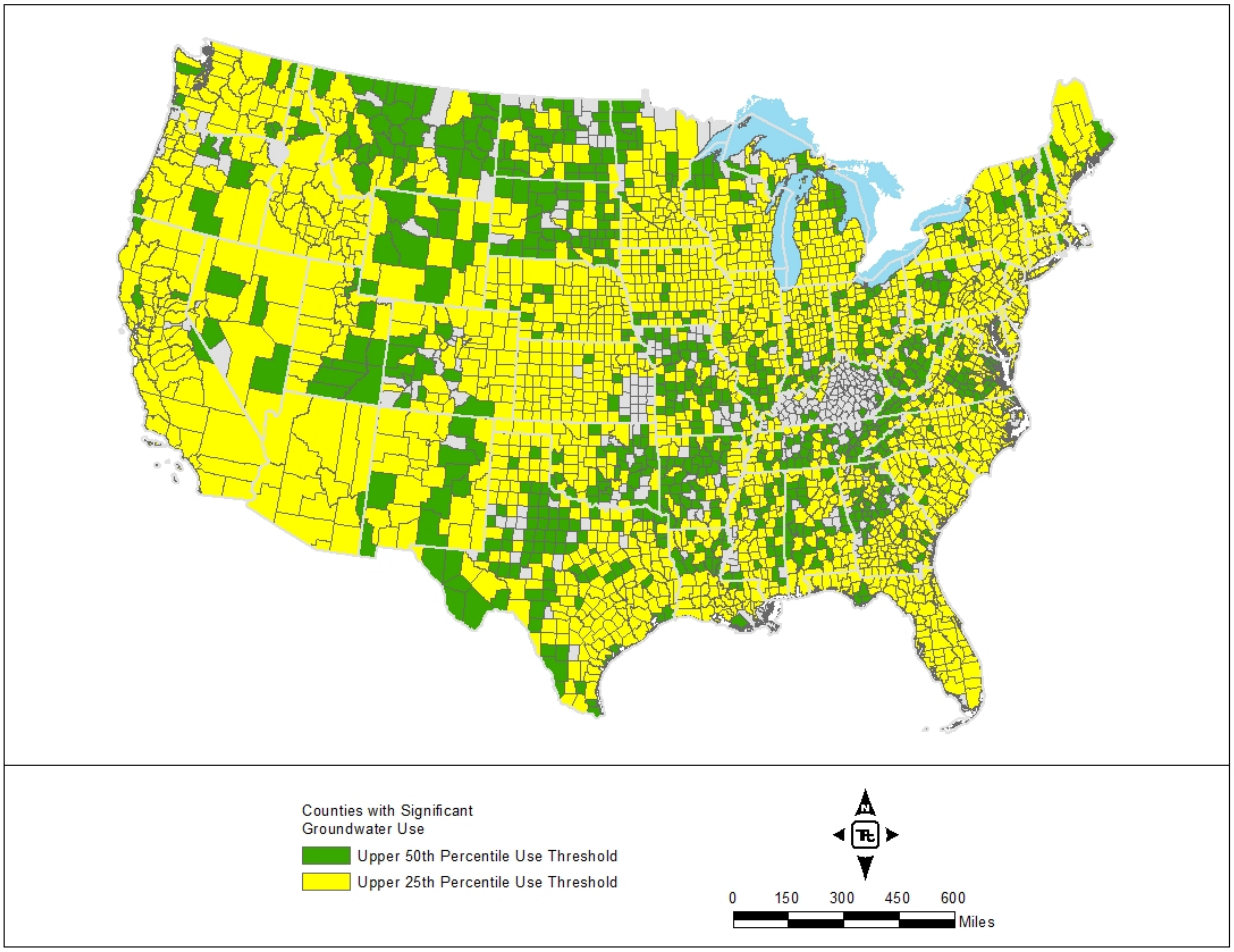


Figure 2-1 Counties within the Contiguous U.S. with Significant Groundwater Use.

2.1.2 Water Shortage Areas

The Water Supply Sustainability Index (WSI; Tetra Tech, 2011) provided an estimate of where the greatest water shortages are likely to occur in the future, under a range of climate change scenarios. Climate change projections in the WSI study were derived from statistically down-scaled results from an ensemble of 16 global climate models. Tetra Tech (2011) used the model output that represented the AB1 gas emission scenario, which is a midrange scenario as documented in Nakicenovic et al. (2000) that represents emissions of 1100-1800 gigatons of carbon dioxide. As stated in Tetra Tech (2011), the choice of emissions scenario did not have a strong effect on the WSI since variability among the scenarios is low for years 2059 or earlier.

The WSI is based on five criteria and ranks the sustainability of water supplies for each county in the U.S. The risk to water sustainability for counties meeting two of the criteria are classified as “moderate,” those meeting three of the criteria are classified as “high,” and those meeting four or more are classified as “extreme.” Counties meeting fewer than two criteria are considered to have low risk to water sustainability. The following criteria were used to develop the WSI (Roy et. al, 2012):

1. Extent of development of local renewable water supply: Greater than 25 percent of available precipitation is used. The larger the fraction of available precipitation that is used to meet human needs, the greater the risk to supply when available precipitation decreases. High percentages of withdrawals are also indicative of impacts not related to water quantity, specifically water quality and ecological impacts.
2. Susceptibility to drought: Summer deficit, as defined in Roy et al., is greater than 10 inches, and this water requirement must be met through stored surface water, groundwater withdrawals, or transfers from other basins. If the precipitation is lower than average, as is typical under drought conditions, the water requirements will increase, or some demands will not be met.
3. Growth in water withdrawal: The increase of total freshwater withdrawal between 2005 and 2050 is more than 20 percent. Growth in water demand is driven largely by population growth and the need for new thermoelectric generation.
4. Increased need for storage: summer deficit increases more than 1 inch from 2005 to 2050. As noted in item 2 above, the summer deficit is met through stored surface water, groundwater, or transfers from other basins. An increase in the summer deficit means that additional supply must be generated in the dry months through new storage or other means.
5. Groundwater use: The ratio of groundwater withdrawal to total withdrawal (groundwater and surface water) is greater than 25 percent (based on current groundwater withdrawal). Withdrawals below this percentage are indicative of regions in proximity to large surface water resources and less likely to be influenced by changes in local precipitation.

A summary of the number and percent of counties within the contiguous U.S. included in each WSI category is provided in Table 2-2.

Table 2-2 Summary of Counties by Category in the WSI for Contiguous U.S. at Year 2050 with a "Midrange" Climate Change

Water Sustainability Index	Number of Counties[1]	Percentage of Total Counties
Extreme	415	13%
High	611	20%
Moderate	1196	39%
Low	857	28%
Total	3079	100%

[1] There are 3,079 counties in the contiguous U.S. WSI dataset. As noted above the groundwater use data is reported for an additional 112 county equivalents. A WSI category was assigned to each county equivalent based on the WSI reported for its encompassing county. These areas are not included in Table 2-2 but are incorporated into the final area selection detailed in Section 2.1.3.

Figure 2-2 shows the year 2050 WSI dataset by county, with WSI categories shown for each county. Counties with high and extreme WSI values for the year 2050 with midrange climate change projections were used to distinguish those areas in the contiguous U.S. that are more likely to experience water shortages and realize a value from the marginal relative increase in groundwater recharge obtained by using green infrastructure practices during development and redevelopment compared to the loss of recharge that may otherwise occur. Although extreme and high WSI values were calculated throughout the contiguous U.S., these values are generally more concentrated in the southwestern states.

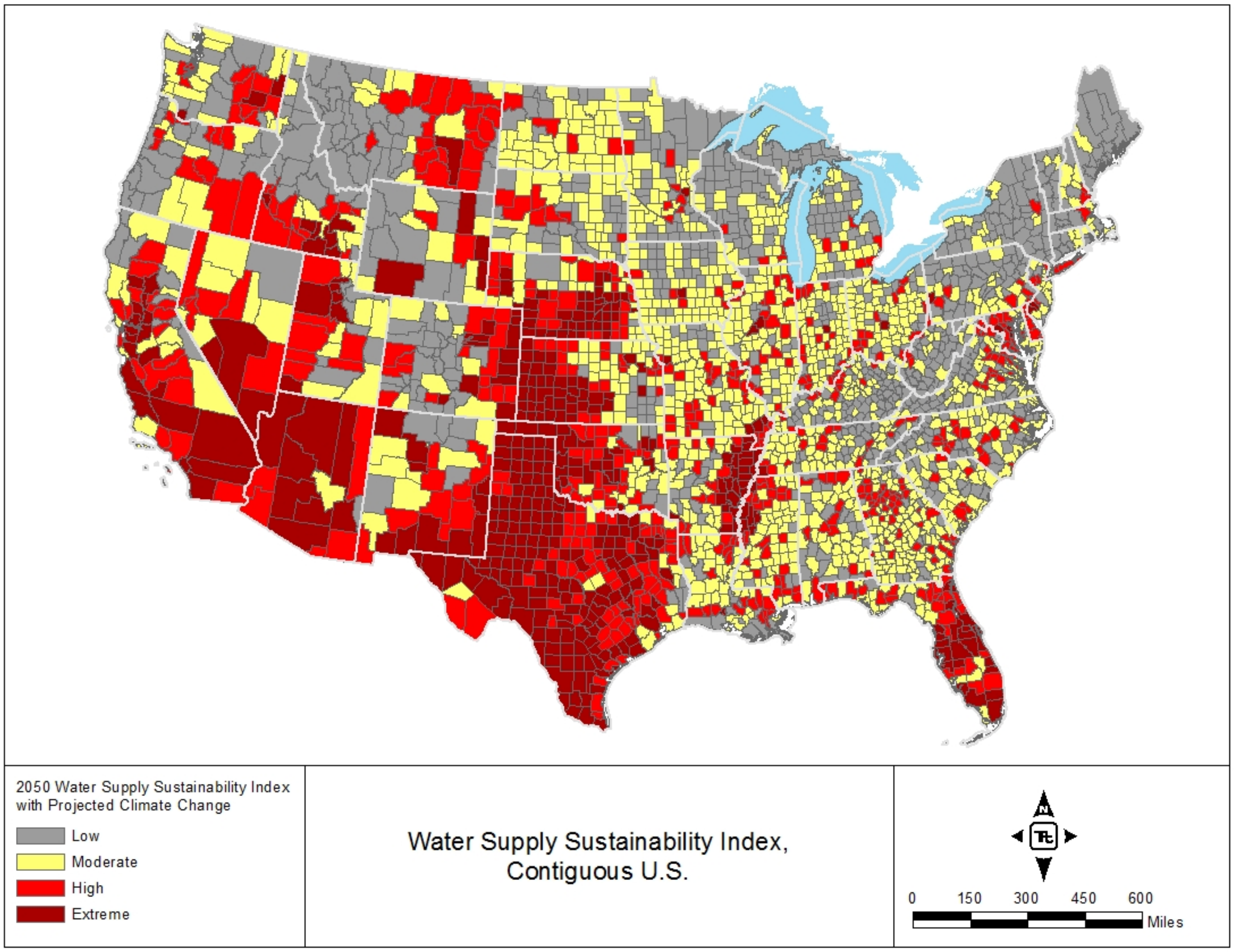


Figure 2-2 Water Supply Sustainability Index (WSI) for the Contiguous U.S. (Tetra Tech, 2011)

2.1.3 Final Area Selection

To approximate the areas with the greatest potential to realize groundwater recharge benefits, the counties identified as having "significant" groundwater use (Figure 2-1) were intersected with the high and extreme WSI layers (Figure 2-2). This intersection eliminated Connecticut, Maine, Rhode Island, and Vermont from the analysis since none of the counties in those states met both the WSI and groundwater use criteria. Results of this intersection are shown in Figure 2-3 for both the upper 25th percentile and upper 50th percentile groundwater use threshold. The groundwater benefit valuation was conducted for each of these thresholds to provide an upper and lower limit of the anticipated benefit. The number of counties included in these two thresholds is provided in Table 2-3.

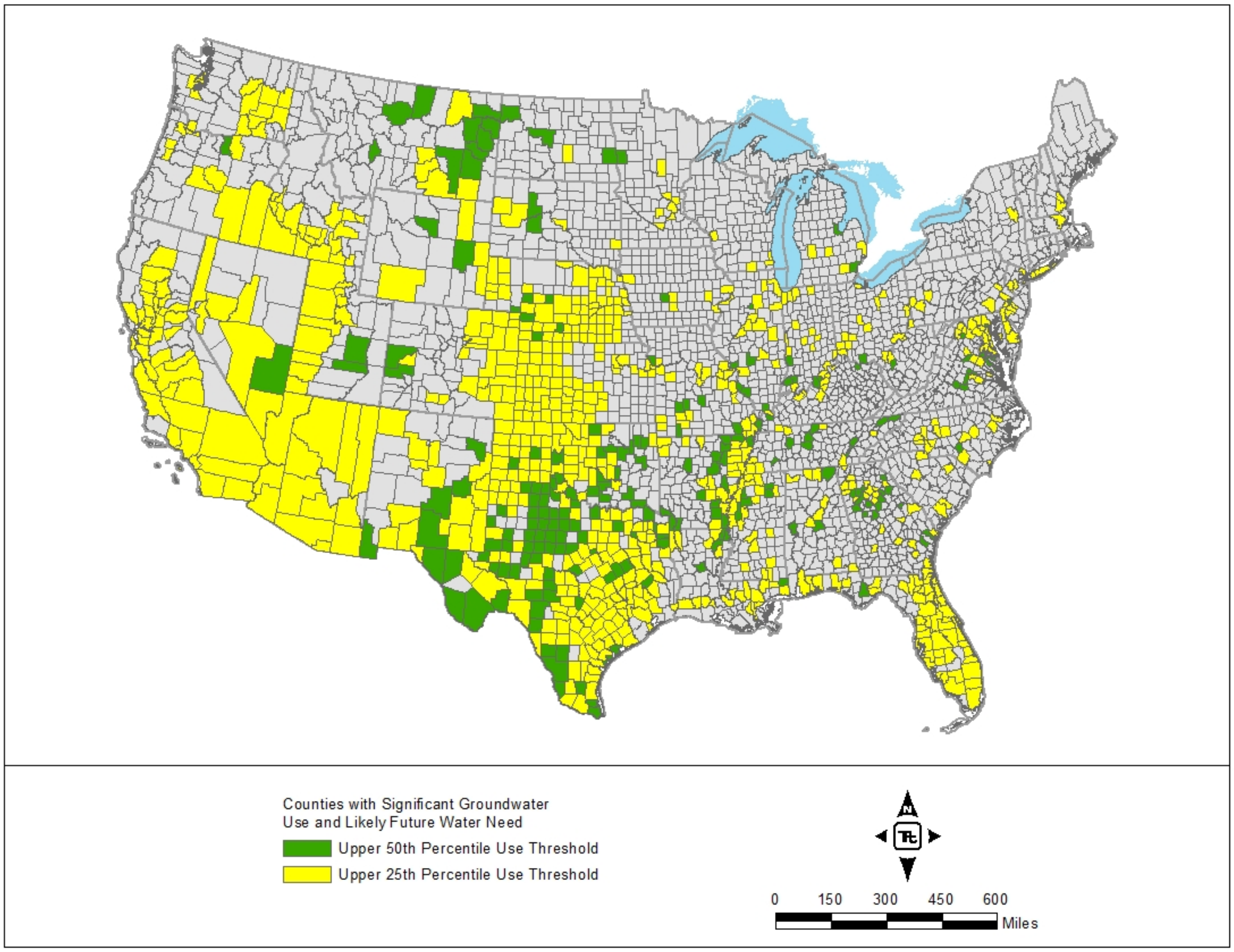


Figure 2-3 Counties within the Contiguous U.S. with Significant Groundwater Use and Likely Future Water Need through 2050 Based on the WSI.

Table 2-3 Summary of Counties Included in Geographic Area of Interest

Groundwater Use Threshold	Number of Counties in each WSI Category		Total
	High	Extreme	
Upper 50th percentile	580	399	979
Upper 25th percentile	435	322	757

2.2 MONETIZED UNIT VALUE

The purpose of this study was to provide a nationwide estimate of the potential monetary benefit that could be assigned to groundwater recharge volumes achieved through small stormwater retention practices. The valuation was designed to produce a conservative benefit estimate by focusing solely on the consumptive use benefit of groundwater and employing conservative assumptions throughout the analysis. This section outlines the methods used to select state-specific monetary values, per unit volume, for groundwater recharge volumes that would be maintained after development.

2.2.1 Data Sources and Data Summaries

A number of data sources were considered to estimate the dollar value of groundwater recharge. The values within this section are conservative benefit estimates. Available data on the costs of water conservation, water reuse programs, aquifer storage and recovery, and desalinization were reviewed, but none of these datasets provided sufficient data on a nationwide basis to establish a dollar value for water. However, relatively large datasets of permanent western water rights transfer prices, bulk sales rates, and water utility retail rates were available and provided the best means for a representative benefit estimate.

Permanent water rights transfers arguably provided the most representative estimate for the marginal value of groundwater. Generally, water rights transfers should reflect the price users are willing to pay for an additional unit of water beyond their current supply. The transfer volumes reflect both surface water and groundwater transfers. Given that water prices vary considerably throughout the U.S., western water data were not considered representative for prices in other, non-western states. Therefore, permanent transfer data were limited to select western states. For non-western states, state-specific bulk and retail rates were used to represent the marginal price although they are more reflective of the average price of water.

The benefit estimates were developed using the following datasets:

1. Donohew and Libecap (2010) Permanent Western Water Rights Transfers dataset, which represents the prices paid for the rights to raw, or untreated, water in perpetuity.
2. The American Water Works Association's (AWWA, 2011) water rate survey wholesale/bulk purchase values dataset, which represents sales prices of treated water.
3. Drinking water utility retail rates from local municipalities (excluding sewer charges), which represent sales prices of treated water.

Data processing was conducted only for those counties selected within the Geographic Area of Focus, as described in Section 2.1. Each dataset required unique processing steps to derive representative values for each state, and these steps are described in the following sections.

2.2.1.1 Permanent Western Water Rights Transfers

Donohew and Libecap (2010) provides a dataset of publically-available permanent water right transactions in the western U.S. drawn from water transactions reported in monthly trade journals from 1987 through 2009. Each observation in the dataset either represents a single water transaction or a bundle of transactions. Some observations represent two or more water transactions made by a single entity or occurring in a single location, such as a state or water basin. The dataset contains records for 11 western states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, and Washington. These data represent prices paid for rights to raw, or untreated, surface water or groundwater in perpetuity (Donohew and Libecap, 2010).

Prior to using the dataset, faulty survey responses and missing data were removed. In addition, two observations with costs per acre-foot of \$0.30 and \$0.37 were removed because they were extremely low (1 percent of next highest value of \$28 per acre-foot) and appeared to reflect unusual transactions not representative of the dataset as a whole. The dataset was further filtered to represent the years 1999 or later and agriculture-to-urban or urban-to-urban transfers only. Data were converted into 2011 dollars (using the Bureau of Economic Analysis (BEA) GDP deflator; (BEA, 2013)).

Water rights transfer prices are well-suited to establishing a value for the water itself, as the price represents the rights to the water only, not the supporting infrastructure (in most cases). However, these data present the following limitations:

1. Many private buyers and sellers do not release sales information, making the database incomplete;
2. The price paid may be a function of that purchase's individual characteristics, such as seasonal availability, a "junior" right (subject to availability after more senior rights have been met), proximity to the buyer, or other characteristics not mentioned in the database; and
3. Water market activity and price are geographically variable, reflecting the particular physical, legal, administrative, and economic characteristics of individual water markets, making comparisons between states difficult (Brown, 2006).

These limitations were acknowledged as a portion of the overall uncertainty of the estimates. Despite these limitations, the transfer value data represented the largest single water price dataset that was publically-available (689 records following data screening), and weighted averages based on this dataset are likely to be the best available estimate given the scale of the study.

Donohew and Libecap (2010) reports the data as a contract price that represents the cost of water used in perpetuity. In order to apply these data towards the valuation, it was necessary to estimate annualized values from these contract prices. Appendix C outlines the methods used to annualize these data for use in the valuation. An annuity formula is used to calculate the annual price; therefore the calculated annual price will vary based on the discount rate assumed.

To obtain a representative value for each state, a volume-weighted mean was generated by multiplying the unit price by the volume of water transferred and then dividing by the total volume transferred within each state. Montana and Oregon had only one data point and were assigned that value in place of a weighted mean.

2.2.1.2 Bulk Rates

The AWWA Water and Wastewater Rate Survey is conducted every two years. At the time of this analysis, the most recent survey had been conducted in 2010. The survey was sent to more than 1,100 utilities within the U.S., and about 300 utilities responded. The resulting data provide a means for studying trends in utilities rates on a national basis. The survey included questions on how much utilities charge individual consumers and wholesale customers (bulk rates) for treated water (AWWA, 2011).

Several steps were taken to process the data for use. The AWWA survey data include seller name but not location. To determine the relevant county, responses were grouped by the seller's name and assigned county affiliations based on an internet search of the seller's name. Faulty survey responses and missing data were removed. In addition, 10 observations were removed that reflected rates ranging from about \$4,300 to \$1,400,000 per acre-foot, which were much higher than the next lowest value of about \$1900 per acre-foot and were suspected to be either reporting errors or unusual circumstances that did not reflect representative rates. Data were converted into 2011 dollars using the BEA GDP deflator (BEA, 2013).

Following the data screening, bulk value data were available for 27 states. In most cases, only a few utilities were surveyed per state. Within the screened bulk rate dataset, about 50 percent of the utilities used groundwater for at least a portion of their water supply (total water supply, not specific to bulk or retail sales), ranging from 2.5 to 100 percent, with an average of 60 percent; the remaining utilities obtained 100 percent of their supply from surface water or by purchasing from another entity. The number of bulk water customers per state ranged from 1 to 200 with an average of 10.

Volume data were available for each utility, and volume-weighted means were calculated using the same approach used for the transfer prices dataset. The state-wide volume-weighted mean bulk rate data was used as the representative value for each state. Ten states had only one AWWA bulk rate record and were assigned that value in place of a weighted mean.

To convert the survey responses from treated to untreated (raw) water prices, a multiplier was developed. For states represented in both datasets, the western water rights transfer volume-weighted mean value for raw water was compared to the corresponding bulk volume-weighted mean value for treated water. Then, the percentage of treated water represented by raw water was calculated for each state. Colorado had a higher value for western water rights transfer mean price than the bulk mean price, which generated a change of 128 percent, the highest ratio observed. The average across all states was 34 percent. The comparisons are shown in Table 2-4.

Table 2-4 Comparison of Permanent Water Rights Transfer Average Price to Bulk Water Average Price

States with Water Rights Transfer and AWWA Bulk Data	Permanent Water Rights Transfer Price Weighted Average ($/acre-ft)	AWWA Bulk Water Rates Weighted Average ($/acre-ft)	Comparison Multiplier for Water Rights Price vs. Bulk Price
AZ	$41.28	$718.84	6%
CA	$58.48	$487.35	11%
CO	$276.95	$216.32	128%
MT	$219.24	$409.34	54%
OR	$16.01	$266.24	6%
TX	$15.04	$751.53	2%
Average Water Rights Price/Bulk Price with CO			34%
Average Water Rights Price/Bulk Price without CO			16%
Percentage selected for use in analysis			20%

It is clear that the Colorado water rights price biases the average ratio across the states. In Table 2-4 , the average percent difference for all states excluding Colorado is 16 percent and including Colorado is 34 percent. To ensure the results of this analysis were not biased (up or down), a multiplier of 20 percent was selected. The bulk volume-weighted means were multiplied by 20 percent to convert these values from treated to untreated prices. This assumes that untreated water represents, on average, approximately 20 percent of the value of treated water bulk rate.

It is important to note how the assumptions in this analysis affect the groundwater recharge value estimated in states like Florida with relatively high estimates of recharge volume. During the final selection of the price used for each state, if water transfer prices were not available, the lowest of the available estimates was selected (a percentage of bulk value, or a percentage of retail value) as explained in Section 2.2.2. An estimate based on a percentage of bulk value was selected in 12 of the 48 states. One of these states was Florida, which also was among the states with the highest volume of groundwater recharge calculated. One of the recommendations for any future study is to more closely examine the value of water in Florida as well as other states with significant volumes.

2.2.1.3 Retail Rates

Values for either western water rights transfer or bulk rate data were not available for several states. Of the 44 states in the geographic area of focus, 12 states either were not included in the western water rights transfers or AWWA bulk water rates survey datasets, or had their data removed during screening for potential errors. Additionally, several other states had only one or two data points in both the bulk rates and water rights transfer datasets. To provide a basis for the benefit estimate in these states, a dataset of retail water rates was developed.

The retail water rates were gathered from local municipalities and water supply company websites. To ensure that the rates were representative, retail rates were used if they were from one of the 10 largest counties, by population, in the state. To facilitate immediate data collection, retail rates were obtained if the utility rate schedule was available online. The retail rates represent the price charged for water and do not include the cost of municipal sewer services. Data were converted into 2011 dollars (using the BEA GDP deflator; BEA, 2013).

When multiple retail rates were reported by a utility, a representative rate was selected to achieve an average value. A few water utilities varied their retail rates depending on the season, with higher rates occurring in the summer and lower rates in the winter. When utilities listed seasonal rates, winter rates (lower rates) were used in this analysis.

Furthermore, many utility sources have a tiered rate structure for volume of water used. When such scales existed, the middle volume usage (or medium use, assumed to be representative of the average household) was used to represent an "average" utility rate. The use of a medium volume may avoid the influence of subsidies for lower volume tiers and price hikes as deterrents for high volume tiers. Figure 2-4 provides an example of a tiered rates structure from Huston County, AL. For this analysis, the Medium-High Usage value was used.

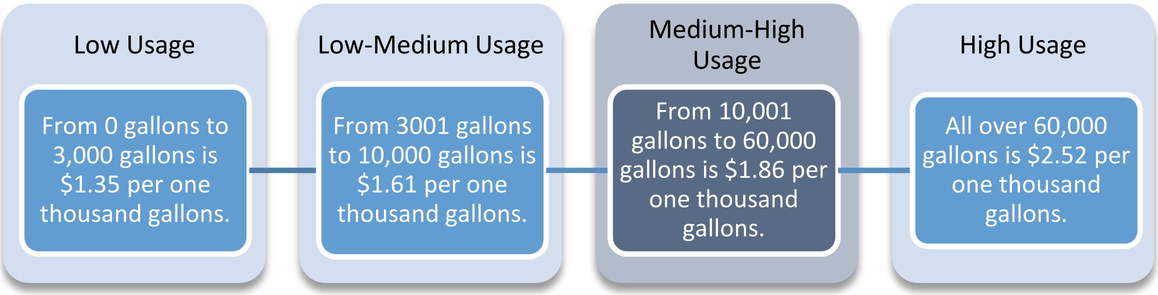


Figure 2-4 Example of Tiered Rates Structure, Huston County, AL

For counties with only two tiers the higher value was used with the exception of Santa Fe, New Mexico. The city's non-summer utility volume rates were $5.60 per 1,000 gallons for the first 7,000 gallons and $20.07 per 1,000 gallons for all use above 7,000 gallons. Considering that the other retail rates within the compiled dataset ranged from $0.28 to $9.1 per 1,000 gallons, the $20.07 rate was considered not representative and the lower Santa Fe tier was used. For other counties, the higher rate was selected, in general, on an assumption that the lower rate might be subsidized to ensure low cost water to households.

Insufficient data were available (volume, number of customers, etc.) to perform a weighted average consistently across the retail rate data. For each state, an arithmetic mean was calculated using at least two retail rates collected from separate utilities.

Using a similar approach as outlined above for the bulk values, a multiplier was developed to convert the retail values from treated to untreated water prices. Using a comparison between the Western Water Rights Transfer prices and the retail prices, the ratio was calculated for each state and averaged across all states (9.42 percent). For simplicity, a 10 percent multiplier was used to convert the treated retail rates to untreated prices. The calculations are shown in Table 2-5.

Table 2-5 Percent of Treated Price that is Represented by the Raw Price

States with Water Rights Transfer and Retail Rate Data	Permanent Water Rights Transfer Price Average ($/acre-ft)	Retail Rates Average ($/acre-ft)	Comparison Multiplier for Water Rights Price vs. Retail Rate
AZ	$ 41.28	$ 1,058.00	4%
CA	$ 58.48	$ 1,357.37	4%
CO	$ 276.95	$ 1,425.92	19%
ID	$ 6.85	$ 488.53	1%
MT	$ 219.24	$ 791.66	28%
NM	$ 137.78	$ 1,128.02	12%
NV	$ 208.76	$ 1,016.24	21%
OR	$ 16.01	$ 1,132.27	1%
TX	$ 15.04	$ 723.08	2%
UT	$ 38.02	$ 464.70	8%
WA	$ 19.20	$ 792.70	2%
			Average Percentage Difference: 9.42%

2.2.2 Final Unit Value Selection

Water rights transfer prices and water utility rates (bulk and retail) were used to estimate a representative unit value for groundwater for each state. The final value selection provides a conservative estimate of groundwater values through the following process:

- A volume-weighted mean was used for the water rights transfers and bulk rates datasets.
- When several retail values were presented, an approach was chosen that was believed to represent a more accurate routine valuation. For example, when retail rates were reported for both summer and winter, the lower winter values were used for the retail means. When only two retail rates were used by a utility, the higher rate was selected, as the lower rate might represent a subsidized price for households.
- When a state had data from the bulk rate and retail rates dataset (and not the water rights transfer dataset), the lower value was chosen.

Section 2.2.2.1 explains the process used to select the final representative unit value for each state, and Section 2.2.2.2 displays the results. A comparison to literature values and other sources of price data by state is also included to provide other context to the final value selection.

2.2.2.1 Selection Process

As outlined above in Section 2.2.1, representative values were compiled by state from each major dataset, resulting in up to three representative values per state. A step-by-step review of these data was conducted to select a final unit value for each state to be applied to the monetary benefit estimate. The selection was intended to best represent the marginal value of raw, high-quality groundwater independent of treatment, distribution, and utility management costs. The selection involved the following major elements:

1) Water Rights Transfer Value Preferred: The water rights transfer value was selected if available with the exception of three states in which it was considered biased. The water rights transfer value was much lower than expected for Oregon and Texas, and in these cases, the lower of the

raw bulk rates and raw retail rates were used). For Nevada, the weighted average was considered to be biased upward due to several outliers, and the raw retail rate, which was within the lower range of the transfer value data, was used for this state (bulk rate were not available for this state).

2) Where water rights transfer values were not available, the lower of either raw bulk-based or raw retail-based rates was selected (in order to be conservative), with the exception of Michigan which was considered an outlier, and the next highest value in same climatic region (see explanation below; USEPA, 2013) was used.
3) If only a retail rate was available, then the raw retail rate was selected, with the exception of Massachusetts which was considered an outlier and the next highest value in climatic region was used (see explanation below; USEPA, 2013).

A cursory analysis was performed on the final values of each state to observe how the water price value might vary between regions of the county. Each state was assigned to a section of the country using EPA's climate region map, which divides the contiguous U.S. into Pacific Northwest, Southwest, Great Plains, Midwest, Southeast, and Northeast Climate Regions. For the purposes of this analysis, these regions were consolidated into four categories: Northeast, Midwest, Southeast, and West. All states with water rights transfer values were compiled into the West category. The Great Plains and the Midwest should ideally be distinct regions but were considered in the Midwest category for simplicity. The Southeast and Northeast states were used in accordance with the EPA's Climate Region map (USEPA, 2013), except West Virginia, which was moved into the Southeast rather than Northeast region. Appendix B provides a graphical display of these results.

2.2.2.2 Selection Results

The final selected values for each state are listed in Table 2-6 along with the data source and rationale descriptions. For states with water rights transfer data, the assumed discount rate (used in the annuity formula as detailed in Appendix C) determines the calculated price. The maximum selected value was $650 for Colorado (at a 7% discount rate and $280 at a 3% discount rate) and the minimum value was $20 (at 7% and $10 at 3%) for Idaho. Values selected for Montana ($520, at 7%) and New Mexico ($330, at 7%) were also relatively high compared to other states. Figure 2-5 compares the values across the 44 states included in the analysis.

Table 2-6 Final Selected Unit Values in dollars per acre-foot [1]

State	Bulk times 20% factor	Water Rights Transfer Weighted Average		Retail times 10% factor	Final Value		Category selected	Number of Data Points		
		3% discount	7% discount		Selected at 3% discount	Selected at 7% discount		Bulk Values	Transfer Values	Retail Values
AL	-	-	-	$80	$80	$80	10% of retail value, no other data available.	0	0	4
AR	$110	-	-	$120	$110	$110	20% of bulk rate	2	0	3
AZ	$140	$50	$100	$110	$50	$100	Water transfer	2	57	3
CA	$110	$60	$140	$140	$60	$140	Water transfer	5	23	3
CO	$50	$280	$650	$150	$280	$650	Water transfer	1	521	3
CT	-	-	-	-	-	-	-	0	0	0
DE	$390	-	-	$150	$150	$150	10% of retail value	1	0	3
FL	$130	-	-	$170	$130	$130	20% of bulk rate	9	0	3
GA	$160	-	-	$130	$130	$130	10% of retail value	4	0	3
IA	$70	-	-	$130	$70	$70	20% of bulk rate	2	0	3
ID	-	$10	$20	$50	$10	$20	Water transfer (two data points)	0	2	3
IL	$50	-	-	$100	$50	$50	20% of bulk rate	2	0	3
IN	$90	-	-	$100	$90	$90	20% of bulk rate, similar value to retail, bulk is more reliable	1	0	3
KS	$180	-	-	$120	$120	$120	10% of retail value	3	0	3
KY	$90	-	-	$110	$90	$90	20% of the bulk rate	3	0	3
LA	$100	-	-	$80	$80	$80	10% of retail value	2	0	3
MA	-	-	-	$260	$180	$180	Outlier, adjusted to the next highest value in their respective climatic region (NJ).	0	0	3
MD	$100	-	-	$170	$100	$100	20% of bulk rate; bulk volume sold was zero for 2010	2	0	3
ME	-	-	-	-	-	-	-	0	0	0
MI	$150	-	-	$180	$120	$120	Outlier, adjusted to the next highest value in their respective climatic region (NE).	2	0	3
MN	$130	-	-	$100	$100	$100	10% of retail value	1	0	3

State	**Bulk times 20% factor**	**Water Rights Transfer Weighted Average**		**Retail times 10% factor**	**Final Value**		**Category selected**	**Number of Data Points**		
		3% discount	7% discount		Selected at 3% discount	Selected at 7% discount		Bulk Values	Transfer Values	Retail Values
MO	-	-	-	$100	$100	$100	10% of retail value, no other data available.	0	0	3
MS	$70	-	-	$80	$70	$70	20% of bulk rate	1	0	3
MT	$90	$220	$520	$80	$220	$520	Water transfer	1	1	2
NC	$180	-	-	$140	$140	$140	10% of retail value	1	0	3
ND	-	-	-	$110	$110	$110	10% of retail value, no other data available.	0	0	3
NV	-	$210	$490	$110	$110	$110	10% of retail value; transfer weighted average was biased by multiple outliers; retail rate was within lower range of transfer values.	0	26	3
NE	-	-	-	$120	$120	$120	10% of retail value, no other data available.	0	0	3
NH	-	-	-	$160	$160	$160	10% of retail value, no other data available.	0	0	4
NJ	-	-	-	$180	$180	$180	10% of retail value, no other data available.	0	0	3
NM	-	$140	$330	$120	$140	$330	Water transfer	0	15	4
NY	-	-	-	$130	$130	$130	10% of retail value, no other data available.	0	0	3
OH	$120	-	-	$120	$120	$120	10% of retail value	2	0	3
OK	$310	-	-	$100	$100	$100	10% of retail value	1	0	3
OR	$60	$20	$40	$120	$60	$60	20% of bulk value; because water rights had just 1 data point that was very low	1	1	3
PA	$110	-	-	$230	$110	$110	20% of bulk rate	4	0	3
RI	-	-	-	-	-	-	-	0	0	0
SC	-	-	-	$80	$80	$80	10% of retail value, no other data available.	0	0	3
SD	-	-	-	$90	$90	$90	10% of retail value, no other data available.	0	0	4

State	**Bulk times 20% factor**	**Water Rights Transfer Weighted Average**		**Retail times 10% factor**	**Final Value**		**Category selected**	**Number of Data Points**		
		3% discount	7% discount		Selected at 3% discount	Selected at 7% discount		Bulk Values	Transfer Values	Retail Values
TN	$130	-	-	$120	$120	$120	10% of retail value	2	0	3
TX	$150	$20	$40	$80	$80	$80	10% of retail value, water transfer data appeared low (see Table 2-7)	13	21	3
UT	-	$40	$90	$50	$40	$90	Water transfer	0	16	3
VA	$60	-	-	$130	$60	$60	20% of bulk rate	3	0	3
VT	-	-	-	-	-	-	-	0	0	0
WA	-	$20	$50	$80	$20	$50	Water transfer	0	6	4
WI	$40	-	-	$60	$40	$40	20% of bulk rate	1	0	0
WV	-	-	-	$160	$160	$160	10% of retail value, no other data available.	0	0	3
WY	-	-	-	$80	$80	$80	10% of retail value, no other data available.	0	0	3

[1] Unit values were rounded up to the nearest $10/acre-foot for display purposes. The original values, prior to rounding, were used to calculate the total present values.

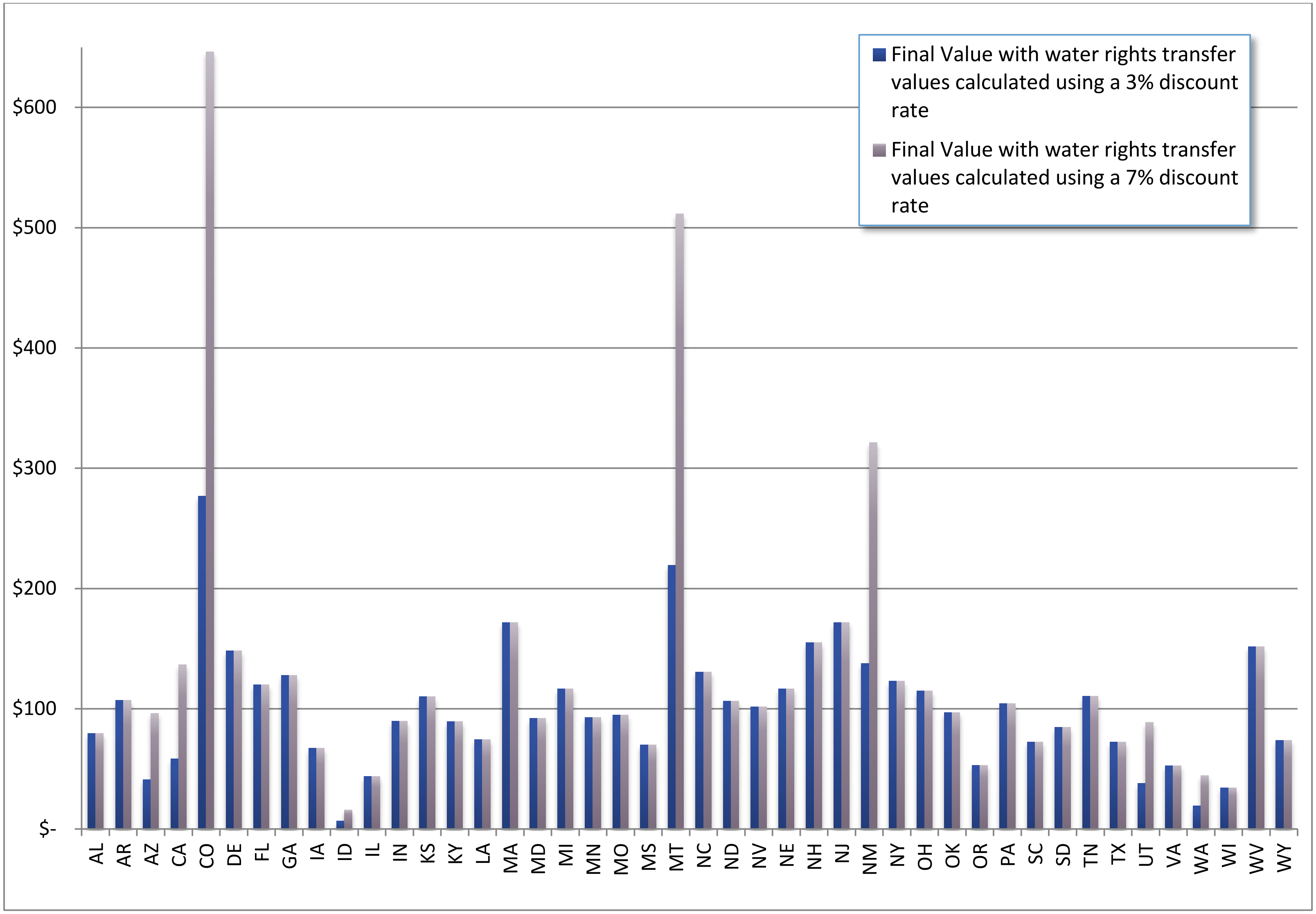


Figure 2-5 State-Specific Final Value Estimates for Unit Price of Groundwater,$/acre-ft (Where the water rights transfer values were selected, differing values reflect annualization based on discount rates of either 3 or 7 percent.)

The selected values compare favorably to literature values for water prices and other measures of water value nationwide (Table 2-7). Literature values range from as low as $17 per acre-foot for irrigation water to over $3,000 per acre-foot, an estimated cost to treat stormwater runoff in California. The final selected values from this analysis exhibit a similar range.

Table 2-7 Literature References for Water Values

State	Source	Date of Values	Type of Value Estimate	Value ($/ac-ft)	Final Value Selected for this Study[1]
CA	Fermanian Business & Economic Institute (2010)	2010	Marginal cost of groundwater	$375 to $1,100	$60/$140
	Cutter (2007); Los Angeles and San Gabriel Rivers Watershed Council. 2010	2010	Value of a stored supply of groundwater	$757 to $943	
	Los Angeles and San Gabriel Rivers Watershed Council. 2010.	2010	Cost of the current water supply and of imports that would avoided if local supplies were available	$811	
	Davis (2011)	2011	Stormwater infiltration; based on replenishment costs	$500	
	Devinny et al. (2005)	2005	Stormwater infiltration	$800	
	Barringer, New York Times (2012)	2012	Orange County's reclaimed water cost when regional water subsidies are factored in. Article notes it is similar to cost to import water	$586	
CO	The Associated Press as reported in SummitDaily.com (2012)	2012	Price paid to Town of Windsor, CO, for water for hydraulic fracturing (8.4 MG)	$659	$280/$650
		2011	Price paid to Town of Greeley, CO, for water for hydraulic fracturing (491 MG)	$1,064	
FL	Tampa Bay Water, wholesaler of raw groundwater, surface water, and desalinated water (2011)	2011	Price charged for raw groundwater (when available)	$315	$130
			Price charged for raw surface water (when available)	$522	
			Price charged for desalinated water	$933	
	City of Tampa	2011	Rate for residential potable water, medium volume user	$1,770	
IL	Center for Neighborhood Technology (2007)	2007	Groundwater recharge; based on the costs of water supply	$40 to $300	$50
LA	Martin (2011)	2011	Price of untreated water	$49	$80
MA	National Research Council (1997)	1997	Cost of an alternative water supply	$218	$180
MO	Mercer (2012)	2012	Rates projected by US Army Corps of Engineers for new allocation agreements for use of surplus reservoir water (draft proposal, withdrawn)	$17 to $175	$100
NJ	NJDEP (2012)	2012	Groundwater protection from contamination; based on fees charged for contamination	$280 to $3,128	$180

State	Source	Date of Values	Type of Value Estimate	Value ($/ac-ft)	Final Value Selected for this Study[1]
TX	Texas Water Development Board (2012)	2012	Water supply conveyance capital cost (i.e., the cost to construct pipelines or other methods for transferring water supply long distances)	$938	$80
	Galbraith, The Texas Tribune (2011)	2011	Reclaimed water from the Fort Worth treatment plant for use as golf course water costs about 40% less than potable water [Ft. Worth retail water is approximately $1,000/acre-ft]	$400	
	El Paso Public Water Service Utilities Board (2013)	2013	Rate for reclaimed water for sale as posted on public website	$416	
	San Antonio Water System (2013)	2013	Rate for reclaimed water for sale as posted on public website. Price shown does not include the monthly fee for having the service available.	$311	
	Midland County Fresh Water Supply District No.1 (Larson et al., 2013)	2013	The “not-to-exceed” wholesale rate in the first 3 years of a contract with the City of Midland for 10 mgd of groundwater, representing high-demand in a drought region. The City already owns the land and water rights; this rate compensates the District for well development, water delivery and chlorination.	$900	
WY	Jordan et al., 1998	1998	Cost of irrigation water	$80 to $158	$80

[1]Unit values were rounded up to the nearest $10/acre-foot for display purposes. The original values, prior to rounding, were used to calculate the total present values. Values presented as $X/$Y represent contract price for western water rights calculated at 3% and at 7% discount rates.

2.2.3 Discounting and Escalation Methods

For the purposes of this study, the total present value of groundwater recharge was estimated for the time period of 2021 through 2040 and reported as 2011 dollars. The values were escalated using factors documented in Appendix D to account for increases in groundwater recharge values over time that are independent of inflationary changes. The year 2011 was assumed to be year 0, and the values occurring in years 2021 through 2040 were discounted and escalated in relation to that year. After the present value was calculated for each year, the resulting unit values were averaged for each 5-year period, to align with the recharge volume estimates (See Section 2.3). In summary, the average per unit present value is calculated as follows for each state and 5-year period:

$$\overline{PV} = \frac{\sum \frac{(B_d)(1+r)^t}{(1+i)^t}}{5}$$

Where:

$\overline{PV}$ = Average per unit present value of groundwater recharge benefit ($/acre-foot) for each 5-year period

t = Number of years since 2011 (2011-2040, in first year t=0)

B_d = Raw benefit value (from Table 2-6)

r = Escalation rate (see Appendix D for specific rates used, varying by location)

i = Annual discount rate (0, 3, or 7 percent)

These data (in $/acre-foot) were then multiplied by the recharge volume approximated for each county (See Section 2.3) for the associated 5-year period and summed across the 20-year period to calculate the total present value of groundwater recharge for each county. The total present value estimates were then annualized for each county. The following equation summarizes this process:

$$AV = \sum V_{Net} \times \overline{PV} \times \left(\frac{i \times (1+i)^n}{(1+i)^n - 1} \right)$$

Where:

AV = Annualized value

V_{Net} = Volume of annual recharge attributable to the retention scenario (See Section 2.3)

n = Number of periods for annualization (20 years for this benefits analysis)

Finally, the annualized values by county were summed to calculate a national annualized value across the 20-year period.

2.3 RECHARGE VOLUME APPROXIMATION

The estimation of recharge volume resulting from the retention scenarios evaluated in the study required basic assumptions on the processes by which recharge occurs. Given the scope of the analysis, these assumptions were necessarily applied with data resolution at the county level. Because such a broad scale is used for a characteristic that can be highly variable, this analysis provides a conceptual-level estimate while recognizing that the connection between infiltration and aquifer recharge is being broadly assumed in order to generate a national scale estimate within this scope of this study. The methods combine established approaches, literature, expert input, and nationwide spatial data. The process involved two major steps:

1. Natural surficial recharge rates were estimated on the county level using either USGS recommended rates, literature values, or methodology from Horsley (1996).
2. The natural surficial recharge rates were then used to approximate the recharge volume achievable through stormwater retention using assumptions relating to runoff, new development and redevelopment, and existing retention standards.

This process required assumptions relating to runoff, new development and redevelopment area, and existing retention standards. The recharge volume estimate was specified using the relationship:

Retention Scenario × Natural Recharge Fraction × Runoff Volume = Recharge Volume

Each component of this relationship is described in more detail below. For those components described by an equation, variables, definitions and units are provided.

Retention Scenario is the fractional retention of stormwater runoff potentially required by additional stormwater retention practices evaluated in this study.

S_{Ret} = Retention Scenario[1]

The three retention scenarios evaluated are presented in Table 2-8:

Table 2-8 Retention Scenarios Expressed as Percentile Rainfall Depth

Retention Scenario	New Development	Redevelopment
High	0.95	0.90
Medium	0.90	0.85
Low	0.85	0.80

---

[1] For example, the 95th percentile rainfall event represents a precipitation amount which 95 percent of all rainfall events for the period of record do not exceed. An assumption for this analysis is that retention of a percentile rainfall event depth is approximately equivalent to retention of that percentile of annual stormwater runoff which would recharge under natural/undeveloped conditions.

Natural Recharge Fraction is the fraction of precipitation that is recharged to groundwater under undeveloped conditions:

$$R_f = \frac{R_n}{P}$$

Where:

R_f = Natural Recharge Fraction, unitless

R_n= Natural Surficial recharge, inches/year

P= Precipitation, inches/year

Runoff Volume may be determined using the 'Simple Method'

[1] described by Schueler (1987):

$$V_r = \frac{\left[(P)(R_c)(A)(P_j)\right]}{12}$$

Where:

V_r = Annual Runoff Volume, acre-feet/year

P = Precipitation, inches/year

R_c = Runoff Coefficient (Schueler, 1987),
= 0.05+ 0.009(I),
Where I = Estimated percent impervious area (whole number),

A = Area of interest (acres); this area includes both new development and redevelopment areas, calculated separately because different retention standards are assumed to apply to each

P_j = A reduction factor, i.e., a value of 0.9 was used, which assumes 10 percent of rainfall events do not result in runoff because of small rainfall amount, low intensity rainfall filling only depression storage, and other potential losses. The reduction factor is highly dependent on many variables but further investigation of site-specific loss analyses were beyond the scope of this study.

12 = A conversion factor to convert acre-inches to acre-feet

The expression of annual recharge volume described at the beginning of this section can be simplified to the following form by combining the component expressions for retention standard (S_{ret}), natural recharge fraction (R_f) and runoff volume (V_r):

---

[1] The Simple method was developed empirically as a means to estimate the volume of stormwater runoff for a wide range of storms as a function of watershed area and imperviousness. It was developed using data from the National Urban Runoff Program utilizing monitoring sites from urban settings across the country.

$$V = \frac{[(R_n)(R_c)(A)(S_{Ret})(P_j)]}{12}$$

Where:

V = Annual Recharge Volume, ac-ft

This equation assumes that runoff from new and redevelopment areas would be retained using stormwater facilities and infiltrated at natural surficial groundwater recharge rates to achieve predevelopment land use conditions. To account for existing retention standards, the annual recharge volume was calculated to represent 1) existing state retention standards and 2) additional stormwater retention practices. The net recharge volume attributable to additional stormwater practices was calculated as follows:

$$V_{Net} = V_2 - V_1$$

Where:

V_{Net} = Volume of annual recharge attributable to additional stormwater water retention practices
V_1 = Volume of annual recharge assuming existing state retention standards
V_2 = Volume of annual recharge assuming additional retention practices

Using this method for annual estimates, net recharge volume was calculated in five-year increments during the time period of 2021 through 2040.

The recharge calculations outlined above determine the estimated change in recharge compared to existing retention standards. Because routing cannot be determined at this scale, the runoff volume is assumed to be routed to infiltration systems that are adequately sized to contain and infiltrate the entire volume required by the scenarios evaluated. This methodology does not expressly consider land use and land cover changes (e.g., single family, multi-family, mixed, industrial, or commercial land uses) or topography (slope) and likely oversimplifies evapotranspiration. The analysis does include projections of the amount, type, and imperviousness of development area during the period of interest. The intent was to develop a simplified approach; as such, the inclusion of these factors was beyond the scope of this effort.

Sections 2.3.1 and 2.3.2 describe the methods and assumptions used to develop the input parameters discussed above. Section 2.3.3 provides an example calculation of recharge volume for a single county. Section 2.3.4 outlines the sensitivity analyses conducted to test the methods and assumptions.

2.3.1 Natural Surficial Recharge

The term “natural” refers to recharge occurring on undisturbed landscapes, which does not include agriculture, development, or other land that has been altered from its natural state. In addition, natural recharge rates are assumed to occur through natural infiltration processes without engineered soil or drainage. Surficial recharge was defined as the amount of precipitation that reaches aquifers that are directly connected to the soil and bedrock layers by infiltrating through the overlying soil.

The natural rate of groundwater recharge depends on many factors including climate, vegetation, soils, and topography. Similarly, recharge rates for diffuse recharge (recharge occurring fairly uniformly over large areas from precipitation or irrigation) can be quite different from focused or concentrated recharge in natural or designed systems such as streams, lakes, playas (depressed areas in which ephemeral lakes form during wet periods) or water infiltration facilities. In addition, many uncertainties in hydraulic conductivity can lead to order-of-magnitude uncertainties in recharge estimates. Recognizing these uncertainties, the natural recharge rate estimates were based on high-quality, readily-available data and estimates were made using simplified approaches that could be applied at the national scale.

For each eligible county, natural surficial annual recharge rates were estimated by first assigning literature values and seeking verification of these values through regional experts from USGS. If appropriate literature values were not available, then the simplified method described by Horsley (1996) was used to calculate and approximate annual recharge values. The following sections explain the assignment of natural recharge rates and recharge calculations in more detail.

2.3.1.1 USGS and Literature References

Counties were assigned recharge rates based on available literature, and USGS reports comprised the majority of literature used. Other literature sources included peer reviewed papers and scientific studies conducted by government agencies or institutions. Each county was assigned to a principal aquifer, as defined by USGS, and the available literature was reviewed for recharge rates associated with each principal aquifer (USGS 2012). Many counties (264 out of 976) were underlain by unnamed principal aquifers categorized as “Other Rocks” by USGS, which vary in composition across the U.S. The exact properties of these rocks were unknown, and further investigation was beyond the scope of this analysis. However, many literature and USGS reports reported recharge rates without reference to principal aquifers, relying rather on other geographic reference information. These sources were consulted for approximate recharge rates relevant to the location of counties underlain by unnamed principal aquifers.

These recharge rates obtained from literature sources were submitted for verification or comment to individual state USGS Water Science Centers, via the USGS Program Coordinator, within the 44 states containing counties of interest. Twenty of the USGS Water Science Centers responded and provided updated recharge estimates, additional literature references or verification that submitted recharge rates were appropriate.

Literature values for recharge that exceeded the historical precipitation rate for each county, described further in Section 2.3.1.2.2, were not used, representing less than 2 percent of recharge values originally compiled (this might be observed, for example, if recharge was occurring because of irrigation instead of natural infiltration). None of the data provided or approved by USGS Water Science Centers fell into this category, which provided confidence in their reporting efforts. A summary of the sources of county level recharge values selected is provided in Table 2-9.

Table 2-9 Summary of Sources Selected for Natural Recharge Rate

Source of Natural Recharge Value	Number of Counties for which these Data were Available	Percentage of Total Counties in Study Using this Source
Literature	251	26%
USGS Water Science Centers	371	38%
Horsley	354	36%

2.3.1.2 Horsley Method

Where literature and/or USGS-approved recharge estimates were not available, the natural recharge calculation described by Horsley (1996) was used. This simplified method primarily uses the infiltration properties of hydrologic soil groups (HSGs) to estimate annual recharge from precipitation rates. This technique was derived on a limited scale for temperate climates in the northeast U.S. and may not be representative of climates in other regions. Other methods such as Wolock (2003), as described in the recommendation section, may provide better field-verified approaches and be more widely applicable. The Horsley method is currently used in stormwater programs in several states including Maryland, Massachusetts, Minnesota, Vermont, and Virginia. The method is described by the following equation:

$$R_n = (S_{HSG})(P)$$

Where:

R_n = Annual natural recharge rate (inches per year)

S_{HSG} = unitless soil-specific recharge factor (from HSG), i.e., area-weighted percent of annual rainfall that may infiltrate

P = Area-weighted Mean Annual Rainfall for each county (inches-calculated from square kilometer raster data; described in Section 2.3.1.2.2)

And:

$$\sum R_n = [S_{HSGa} * (T_{HSGa}/M)] + [S_{HSGb} * (T_{HSGb}/M)] + [S_{HSGc} * (T_{HSGc}/M)] + [S_{HSGd} * (T_{HSGd}/M)]$$

Where:

S_{HSGx} = Unitless soil-specific recharge factor (For HSG-specific categories)

T_{HSGx} = HSG area

M = County area

HSGa = Hydrologic Soil Group A (HSG A specific recharge = 0.55)

HSGb = Hydrologic Soil Group B (HSG B specific recharge = 0.36)

HSGc = Hydrologic Soil Group C (HSG C specific recharge = 0.18)

HSGd = Hydrologic Soil Group D (HSG D specific recharge = 0.09)

The following sections explain how the variables S_{HSG} and P were derived for each county. The resulting recharge rates were used for counties where literature and/or USGS-approved recharge estimates were not available.

2.3.1.2.1 Hydrologic Soil Groups

The U.S. Department of Agriculture hydrologic soil groups (HSGs) define the hydraulic properties of soils. Within the four primary HSGs, Group A represents the greatest rate of annual recharge with properties closer to sand, and Group D represents the lowest rate of recharge with properties closer to clay. Estimates of annual recharge for each HSG are shown in Table 2-10.

Table 2-10 Estimated Properties of USDA Defined Hydrologic Soil Groups (Horsley, 1996, revised per personal communication, 2012)

Hydrologic Soil Group (HSG)	Estimate of Annual Recharge (percent of annual precipitation)	Estimate of Annual Recharge for Humid Climates Receiving 44 inches/year (inches/year of recharge)
A	55%	24
B	36%	16
C	18%	8
D	9%	4

HSG areas were determined by county based on the USDA dataset STATSGO2 (USDA, 2006). S_{HSG} was area-weighted based on the proportion of county area within each HSG. For HSG designations like A/D, the more conservative HSG was applied, which would be Group D in this example. STATSGO2 data are accurate at relatively large spatial scales and generally represent existing soil conditions. Some HSG designations may not reflect localized soil compaction and other alterations that would affect soil infiltration rates.

2.3.1.2.2 Precipitation Data

Area weighted means[1] of physical and climatic conditions are commonly used and have been shown to be positively correlated with mean annual precipitation (MAP) (Keese et al. 2005). The precipitation data used in this study were obtained from the PRISM Climate Group and reported in inches per year of annual rainfall at a one square kilometer resolution (PRISM, 2011). These data were used to calculate the MAP for each county using an area-weighted mean for the period 1981-2010.

On a county by county basis, precipitation data were not necessary when natural recharge rates from literature or USGS reports were available (see previous equation for natural recharge volume (V)). When literature or USGS values were not available, and the Horsley method was used, then precipitation data were necessary to calculate the natural recharge rates for a particular county.

2.3.1.3 Annual Recharge Rate Summary

The natural surficial recharge rates were obtained using the sources and methods detailed in Sections 2.3.1.1 and 2.3.1.2. Of the 976 eligible counties, 622 (about 64 percent) have literature-reported and/or USGS-approved estimates. USGS staff noted that providing a single value for estimating "average" county recharge was a rough approximation, but more detailed sub-county estimations for this national estimate were beyond the scope of this study.

2.3.2 Other factors

The following sections describe the methods and assumptions used for imperviousness, developed areas, and state retention standards.

2.3.2.1 Imperviousness

To derive the runoff coefficient (R_C), the estimated percent impervious area (I) is required, as indicated in the equation in Section 2.3. For this analysis, "I" represents the impervious area percentage projected for the new and redevelopment area that was applied to the recharge calculation. The estimate of impervious area percentage for new and redevelopment area for each county within the geographic area of interest was provided by EPA. The EPA's methodology for the estimate is provided in Appendix E. Imperviousness was provided in 5-yr increments with a single value representing areas of both new and redevelopment for each county. The imperviousness values are summarized in Table 2-11.

Table 2-11 Summary of County Imperviousness Values Assumed for Each 5-Year Period

	2021-2025	2026-2030	2031-2035	2036-2040
Median	21.8%	23.0%	23.3%	23.3%
Maximum	75.7%	90.9%	75.2%	88.4%

2.3.2.2 Area

New and redevelopment area for the time period of 2021 through 2040 was projected and summarized by county in five-year increments. The EPA's methodology for these projections is provided in Appendix E. The resulting areas represent the cumulative new and redevelopment predicted to occur, starting in January 2021, and existing during each five-year period. New and redevelopment projections for 23 counties that were eligible for the analysis (eligibility based on WSI and groundwater use) indicated no

---

[1] An area weighted mean, at the county scale, is the proportional value based on area of characteristic present compared to total county area.

development or redevelopment during the study period; for this reason, these 23 counties were excluded from the analysis. The development areas are summarized in Table 2-12 and Table 2-13.

Table 2-12 Summary of County Percent Area in New Development for Each 5-Year Period

	2021-2025	2026-2030	2031-2035	2036-2040
Median	4.5%	4.1%	4.3%	3.6%
Maximum	6.0%	6.3%	5.1%	10.0%

Table 2-13 Summary of County Percent Area in Redevelopment for Each 5-Year Period

	2021-2025	2026-2030	2031-2035	2036-2040
Median	3.6%	2.8%	2.8%	2.9%
Maximum	4.9%	6.0%	5.6%	15.1%

2.3.2.3 Existing State Retention Standards

As stated above, the recharge calculation for existing conditions accounted for any state retention standards currently in place. The retention scenario percentile storm event (S_{Ret}) that is currently set as regulatory standards for each state (or applicable jurisdictions in a state) was identified by EPA, as of 2012. Where the state retention standard was reported in the applicable regulation in terms or units other than a percentile storm event, a review was conducted of supporting documentation or available NPDES permits to determine the appropriate standard expressed in terms of the percentile stormwater depth, assumed in this study to be equivalent to the fractional retention of annual runoff. Table 2-14 lists the states under each category and the associated value for S_{Ret}. Two states, Delaware and Maryland, have existing retention standards that meet or exceed the retention scenarios evaluated in this study. These states were omitted from analysis because the scenarios evaluated would not result in additional groundwater recharge benefits in these areas.

Where a statewide standard exists, the associated S_{ret} value was used for each county in the state. Where a state standard applied only to municipal separate storm sewer systems (MS4s), the associated S_{ret} value was used for those counties where an MS4 exists and was multiplied by the ratio of the county area within the MS4 boundary to the total county area. States with no existing regulatory standard (all states not shown in Table 2-14) were given a value of 0.05 to account for recharge from stormwater infiltration devices implemented through voluntary efforts or required at the local level. The S_{ret} value of 0.05 was also applied to counties without MS4s in states with MS4-only retention standards. The value of 0.05 was based on best professional judgment but is supported by literature indicating low adoption rates for voluntary stormwater practices (Taylor and Wong, 2002).

Table 2-14 States with Existing Retention Standards[1]

Retention Standards which apply Statewide		Retention Standards which apply to MS4 areas Only	
CA	0.85	MA	0.90
NJ	0.90	MT	0.87
NY	0.90	NH	0.90
PA	0.95	TN	0.85
WI	0.90	WV	0.90

[1] Maryland and Delaware have standards exceeding the scenarios here; therefore no benefits are assumed.

For the stormwater retention scenario recharge calculation, S_{Ret} was defined separately for new and redevelopment. The three retention scenarios were presented in Table 2-8 and are provided in Table 2-15 for convenience.

Table 2-15 Retention Scenarios Expressed as Percentile Storm Depths[1]

Retention Scenario	New Development	Redevelopment
High	0.95	0.90
Medium	0.90	0.85
Low	0.85	0.80

[1] For example, the 95th percentile rainfall event represents a precipitation amount which 95 percent of all rainfall events for the period of record do not exceed. An assumption for this analysis is that retention of a percentile storm event depth is approximately equivalent to retention of that percentile volume of annual stormwater runoff.

2.3.3 Example Calculation

The example calculations shown below in Figure 2-6 and Figure 2-7 detail the input values and results for new development in Loudoun County, VA for the period 2021 through 2025. In the larger analysis, these calculations are performed across the entire period of 2021 through 2040 and summed to provide an estimate of total groundwater recharge volume maintained by implementing stormwater retention practices for new development and redevelopment in those states are areas that do not currently have existing retention standards that meet or exceed the scenario values.

Scenario: Time Period 2021-2025, Retention scenario: medium (0.90 for new development)

$$V = \left[\frac{[(R_n)(R_v)(A)(S_{Ret})(P_j)]}{12}\right] * 5\ year\ period$$

Where:

R_n= 12.35 in/yr natural background recharge (from literature)

$R_v = 0.05 + 0.009 * 22.56$ (22.56% impervious)

A =5,813 acres[1] of new development for 2021-2025

P_j= 0.9

Existing Retention Standards

$S_{Ret} = 0.05$ (no existing retention standard in Virginia)

V_1= 341 acre-feet

Stormwater Retention Scenario

$S_{Ret} = 0.90$

V_2 = 6,131 acre-feet

$V_{\text{Net new}} = V_2 - V_1$

= 5,790 acre-feet

[1]This area is ½ of the new development projected to be implemented through the 2021-2025 period and represents the average new development implemented during this period. The use of the full development area would overestimate the recharge volume, as this area is only present, in full, at the end of the period. For subsequent periods (2026-2030 for instance) the full developed area from 2021-2025 is cumulatively added to ½ the reported development area for the period of interest to obtain the net recharge.

Figure 2-6 Example Calculation of Net Volume of Recharge Maintained by Implementing Stormwater Retention Practices for New Development in Loudoun County, VA, During the Years 2021-2025

Scenario: Time Period 2021-2025, Retention scenario: medium (0.85 for redevelopment)

$$V = \left[\frac{\left[(R_n)(R_v)(A)(S_{Ret})(P_j)\right]}{12}\right] * 5\ year\ period$$

Where:

R_n= 12.35 in/yr natural background recharge (from literature)

R_v = 0.05 + 0.009 *22.56 (22.56% impervious)

A =3,932 acres[1] of redevelopment for 2021-2025

P_j= 0.9

Existing Retention Standards

S_{Ret} = 0.05 (no existing retention standard in Virginia)

V_1= 230 acre-feet

Additional Stormwater Retention Practices

S_{Ret} = 0.85 (medium retention scenario for redevelopment)

V_2 = 3,916 acre-feet

$V_{\text{Net redevelopment}} = V_2 - V_1$

= 3,686 acre-feet

[1] This area is ½ of the redevelopment projected to be implemented through the 2021-2025 period and represents the average redevelopment implemented during period. The use of the full development area would overestimate the recharge volume, as this area is only present, in full, at the end of the period. For subsequent periods (2026-2030 for instance) the full developed area from 2021-2025 is cumulatively added to ½ the reported development area for the period of interest to obtain the net recharge.

Figure 2-7 Example Calculation of Net Volume of Recharge Maintained by Implementing Stormwater Retention Practices for Redevelopment in Loudoun County, VA, During the Years 2021-2025

2.3.4 Effect of Adjustments to Input Values

The following adjustments to input values were made in the above methods for comparison in order to test the sensitivity to changes in the underlying assumptions:

- **Groundwater Use Criteria:** Use of the upper 50th percentile groundwater use threshold as criteria for selecting the geographic area of focus compared to the more restrictive upper 25th percentile use threshold. The upper 50th percentile threshold results in more total counties being selected for inclusion in the analysis than by using the more restrictive upper 25th percentile threshold.
- **Low Recharge:** For all annual natural recharge rates less than 3 inches per year, increase the natural recharge rate by a factor of 1.5 with a cap equal to the precipitation rate.
- **Low Precipitation:** For counties with annual precipitation of less than 15 inches per year, increase the natural recharge rate by a factor of 50 with a cap equal to the precipitation rate.

The effect of these adjustments on the calculation inputs are discussed in the following sections.

2.3.4.1 Groundwater Use Criteria

As described in Section 2.1.1, the geographic area of interest was partially defined by those areas currently utilizing groundwater. To explore the sensitivity of the analysis to this criteria, the threshold was calculated using areas that exceeded the 50th percentile for groundwater use in any of the five categories, and for areas that exceeded the upper 25th percentile for groundwater use, a more restrictive criteria resulting in fewer counties being included in the analysis. Expanding the geographic area of interest resulted in the inclusion of 189 additional counties.

2.3.4.2 Low Recharge Adjustment

The USGS review of available natural recharge rates indicated that some recharge rates appeared low compared to precipitation data. This sensitivity analysis evaluates whether the recharge rates may be underrepresenting natural recharge. Natural recharge rates, as determined using the methods described in Sections 2.3.1.1 and 2.3.1.2, were below 3 inches/year for 282 counties included in the analysis. Recharge rates for these counties were increased by a factor of 1.5 to explore the sensitivity of the recharge valuation approach to underestimated natural recharge. The revised annual recharge rates for these counties were limited to a maximum value equal to the annual precipitation rate for each respective county.

2.3.4.3 Low Precipitation Adjustment

The review of literature regarding groundwater recharge in arid environments revealed the observation of a net increase of recharge as a result of stormwater basins of up to 50 times the recharge observed where no stormwater retention basins were used (Stephens, 2012). This phenomenon may result from reduction of evaporative losses from concentrated volumes of water routed to stormwater basins from impervious surfaces when compared to the distributed soil/water interaction that occurs in undeveloped areas. A precipitation of 15 inches/year was selected to represent the threshold between arid and semi-arid environments based on best professional judgment. To evaluate the impact of potential increases of recharge within arid environments, the natural recharge rates for counties in which precipitation was less than 15 inches/year were increased by a factor of 50 with an upper threshold equal to the precipitation rate. Annual precipitation rates were less than 15 inches/year for 92 counties, representing about 10 percent of counties within the study area.

3 Results

To obtain an estimate of the present value of groundwater recharge potentially provided by stormwater retention practices that would approximately maintain the natural recharge rate, the monetized unit values (averaged across each 5-year period) were multiplied by corresponding 5-year recharge volume estimates and then summed across the entire 20-year period. A number of variations on the input values used for the retention scenarios were generated that reflect differences in methods for both the recharge volume and monetary value quantification. The variations in the input values were based on the following assumptions:

- Unadjusted or adjusted groundwater recharge rates:
    - Unadjusted rates reflect the use of methods prior to any input adjustments (Section 2.3.4).
    - Adjusted rates reflect that both the Low Precipitation and Low Recharge adjustments were applied (Section 2.3.4.2 and Section 2.3.4.3, respectively). If a county was eligible for both adjustments, then the maximum resulting recharge was applied.
- County-level groundwater use criteria: upper 50th versus upper 25th percentile (documented in Section 2.1.1)
- Differing escalation rate scenarios (to account for the escalation of groundwater recharge values over time, independent from inflationary changes, as documented in Appendix D):
    - For states where monetized unit values were based on the permanent water rights transfer prices: 0.0%, 5.5%, and 10.0% were used for Low, Medium, and High, respectively.
    - For all other states: 0.0%, 2.0%, and 4.0% were used for Low, Medium, and High, respectively.
- Differing discount rates (0%, 3%, and 7%)

The following tables present the results by retention scenario and with variations on input values. Table 3-1 provides the estimated cumulative volumes for the period 2021-2040 that could result from stormwater retention practices maintaining infiltration and recharge to approximate the natural recharge rate. Table 3-2 provides the results of the estimated annualized monetary benefits in 2011 dollars. Table 3-3 provides the estimated cumulative monetary benefits for the period 2021-2040, in present value 2011 dollars, for the recharge volume estimates. All values shown have been rounded, at a minimum, to the nearest 10,000th.

While these estimates are not intended to represent exact values, they are based on available data to approximate the value that could be realized from expanding practices for maintaining recharge rates for new development and restoring recharge in redevelopment in those states where existing regulatory standards do not already meet or exceed the retention scenario evaluated. Across the scenarios, the estimated cumulative volumes range from 6.8 million to 10.8 million acre-feet. The monetary values range from about $16 to $225 million, annualized, and $0.2 to $4.5 billion in cumulative, present value benefits.

Table 3-1 Cumulative Groundwater Recharge Volume (acre-feet), Estimated as Achievable through Additional Small Storm Retention for 2021-2040

Retention Scenario	Unadjusted[1]		Adjusted[2]	
	Upper 50% Groundwater Use	Upper 25% Groundwater Use	Upper 50% Groundwater Use	Upper 25% Groundwater Use
High	8,650,000	7,870,000	10,800,000	9,980,000
Medium	8,070,000	7,340,000	10,000,000	9,260,000
Low	7,530,000	6,840,000	9,320,000	8,610,000

1"Unadjusted" refers to recharge rates derived from Literature, USGS provided or Horsley method annual recharge rates.
2"Adjusted" refers to recharge rates adjusted upward where the rate is less than 3 inches per year and in arid areas.

Table 3-2 Groundwater Recharge Present Value, Annualized (2011 dollars per year), Estimated as Achievable through Additional Small Storm Retention for 2021-2040

Escalation/ Discount[3]	Unadjusted[1]		Adjusted[2]	
	Upper 50% Groundwater Use	**Upper 25% Groundwater Use**	**Upper 50% Groundwater Use**	**Upper 25% Groundwater Use**
	Retention Scenario: High			
L/0[4]	$40,900,000	$36,900,000	$48,300,000	$44,000,000
L/3	$28,400,000	$25,600,000	$33,500,000	$30,600,000
L/7	$19,800,000	$18,000,000	$25,800,000	$23,900,000
M/0[4]	$79,100,000	$72,000,000	$104,000,000	$96,300,000
M/3	$53,800,000	$48,900,000	$70,600,000	$65,200,000
M/7	$39,200,000	$36,100,000	$58,400,000	$54,700,000
H/0[4]	$156,000,000	$143,000,000	$225,000,000	$209,000,000
H/3	$104,000,000	$95,400,000	$149,000,000	$139,000,000
H/7	$78,400,000	$72,800,000	$128,000,000	$121,000,000
	Retention Scenario: Medium			
L/0[4]	$38,200,000	$34,400,000	$45,000,000	$41,000,000
L/3	$26,600,000	$23,900,000	$31,200,000	$28,500,000
L/7	$18,400,000	$16,700,000	$23,900,000	$22,000,000
M/0[4]	$73,800,000	$67,000,000	$96,600,000	$89,200,000
M/3	$50,200,000	$45,600,000	$65,500,000	$60,400,000
M/7	$36,300,000	$33,300,000	$53,700,000	$50,200,000
H/0[4]	$145,000,000	$133,000,000	$208,000,000	$193,000,000
H/3	$96,800,000	$88,500,000	$138,000,000	$128,000,000
H/7	$72,200,000	$67,000,000	$117,000,000	$111,000,000
	Retention Scenario: Low			
L/0[4]	$35,700,000	$32,200,000	$41,900,000	$38,200,000
L/3	$24,800,000	$22,300,000	$29,100,000	$26,500,000
L/7	$17,100,000	$15,500,000	$22,200,000	$20,400,000
M/0[4]	$68,800,000	$62,400,000	$89,800,000	$82,800,000
M/3	$46,800,000	$42,500,000	$60,900,000	$56,100,000
M/7	$33,600,000	$30,900,000	$49,600,000	$46,300,000
H/0[4]	$135,000,000	$124,000,000	$192,000,000	$179,000,000
H/3	$90,000,000	$82,300,000	$128,000,000	$119,000,000
H/7	$66,800,000	$61,900,000	$108,000,000	$102,000,000

[1] "Unadjusted" refers to recharge rates derived from literature, USGS provided or Horsley method annual recharge rates.

[2] "Adjusted" refers to recharge rates adjusted upward where the rate is less than 3 inches per year and in arid areas.

[3] Monetary value scenarios are coded as follows: A / B

A = Escalation scenario: Western Water Rights Transfers States/ Other States

Low	0.0% / 0.0%
Medium	5.5% / 2.0%
High	10.0% / 4.0%

B = Discount rate used for present value calculation (0%, 3%, or 7%). The water rights transfer value was calculated using the rate in the present value calculation, except for the 0% scenarios.

[4] While discount rates of 0%, 3%, and 7% are used to generate three different present value estimates, the formula for developing an annual price for a water transfer cannot be performed using a 0% discount rate (0.00 multiplied by anything will equal 0). Therefore, all 0% discount rate calculations for water rights transfer volumes were annualized using a 3% discount rate.

Table 3-3 Cumulative Groundwater Recharge Present Value (2011 dollars), Estimated as Achievable through Additional Small Storm Retention for 2021-2040

	Unadjusted[1]		Adjusted[2]	
Escalation/ Discount[3]	**Upper 50% Groundwater Use**	**Upper 25% Groundwater Use**	**Upper 50% Groundwater Use**	**Upper 25% Groundwater Use**
	Retention Scenario: High			
L/0[4]	$818,000,000	$737,000,000	$965,000,000	$881,000,000
L/3	$423,000,000	$381,000,000	$499,000,000	$455,000,000
L/7	$209,000,000	$190,000,000	$274,000,000	$253,000,000
M/0[4]	$1,580,000,000	$1,440,000,000	$2,080,000,000	$1,930,000,000
M/3	$801,000,000	$728,000,000	$1,050,000,000	$970,000,000
M/7	$415,000,000	$382,000,000	$619,000,000	$579,000,000
H/0[4]	$3,130,000,000	$2,860,000,000	$4,490,000,000	$4,190,000,000
H/3	$1,550,000,000	$1,420,000,000	$2,210,000,000	$2,060,000,000
H/7	$831,000,000	$772,000,000	$1,360,000,000	$1,280,000,000
	Retention Scenario: Medium			
L/0[4]	$765,000,000	$689,000,000	$900,000,000	$820,000,000
L/3	$395,000,000	$356,000,000	$465,000,000	$424,000,000
L/7	$195,000,000	$177,000,000	$253,000,000	$234,000,000
M/0[4]	$1,480,000,000	$1,340,000,000	$1,930,000,000	$1,780,000,000
M/3	$746,000,000	$678,000,000	$974,000,000	$899,000,000
M/7	$384,000,000	$353,000,000	$569,000,000	$532,000,000
H/0[4]	$2,900,000,000	$2,660,000,000	$4,150,000,000	$3,870,000,000
H/3	$1,440,000,000	$1,320,000,000	$2,050,000,000	$1,910,000,000
H/7	$765,000,000	$710,000,000	$1,240,000,000	$1,170,000,000
	Retention Scenario: Low			
L/0[4]	$715,000,000	$644,000,000	$839,000,000	$764,000,000
L/3	$369,000,000	$332,000,000	$433,000,000	$395,000,000
L/7	$181,000,000	$165,000,000	$235,000,000	$216,000,000
M/0[4]	$1,380,000,000	$1,250,000,000	$1,800,000,000	$1,660,000,000
M/3	$696,000,000	$632,000,000	$905,000,000	$835,000,000
M/7	$356,000,000	$327,000,000	$525,000,000	$490,000,000
H/0[4]	$2,700,000,000	$2,470,000,000	$3,850,000,000	$3,580,000,000
H/3	$1,340,000,000	$1,220,000,000	$1,900,000,000	$1,770,000,000
H/7	$708,000,000	$655,000,000	$1,140,000,000	$1,080,000,000

[1] "Unadjusted" refers to recharge rates derived from Literature, USGS provided and Horsley method annual recharge rates.

[2] "Adjusted" refers to recharge rates adjusted upward where the rate is less than 3 inches per year and in arid areas.

[3] Monetary value scenarios are coded as follows: A / B

A = Escalation scenario: Western Transfers States / Other States

Low	0.0% / 0.0%
Medium	5.5% / 2.0%
High	10.0% / 4.0%

B = Discount rate used for present value calculation (0%, 3%, or 7%). The water rights transfer value was calculated using the rate in the present value calculation, except for the 0% scenarios.

[4] While discount rates of 0%, 3%, and 7% are used to generate three different scenarios, the formula for developing an annual price for a water transfer cannot be performed using a 0% discount rate (0.00 multiplied by anything will equal 0). Therefore, all 0% discount rate calculations for water rights transfers were annualized using a 3% discount rate.

A comparison between value and volume estimates by states provides insight into the sensitivity of the national estimate to individual state methods and assumptions. The influence that a particular state has on the total nationwide value depends, in part, on the state's relative volume of groundwater recharge. The following set of assumptions provides a representative comparison: high retention scenario, medium escalation rate, 3% discount rate, unadjusted recharge, and counties in the upper 25th percentile for groundwater use. The greatest recharge volume for this scenario is estimated for Florida, where the cumulative groundwater recharge (maintained or restored by retention practices) estimated during 2021-2040 is about 1.5 million acre-feet (Figure 3-1). Texas represents the second highest at about 0.7 million acre-feet. Accordingly, Florida and Texas have the second and third highest value estimates, which dwarf most of the other states (Figure 3-2). The national value estimates, therefore, are expected to be sensitive to the methods and assumptions used for these states. While Colorado's recharge volume estimates fall below the state average, Colorado stands out as having the highest value estimate of $77 million. Therefore, the high unit value selected in this analysis places Colorado as substantial influence on the national estimate of groundwater recharge values among the states evaluated (states with existing stormwater retention regulations that met or exceeded the retention scenarios in this study were not evaluated, such as California).

The results of this analysis demonstrate that stormwater retention practices for new development and redevelopment could maintain or restore a sizeable volume of recharge if these practices were implemented in states where existing retention standards are not in place. The estimates of monetary value for this volume of recharge varied widely depending on the assumptions used, and the results were sensitive to specific states (Florida, Texas, and Colorado) with the highest monetary value estimates associated with large volumes. Considering that a number of broad assumptions and simplified methods were applied, the results provide an approximate estimate of the potential value range that could be realized from groundwater recharge as an ancillary benefit of additional stormwater retention practices.

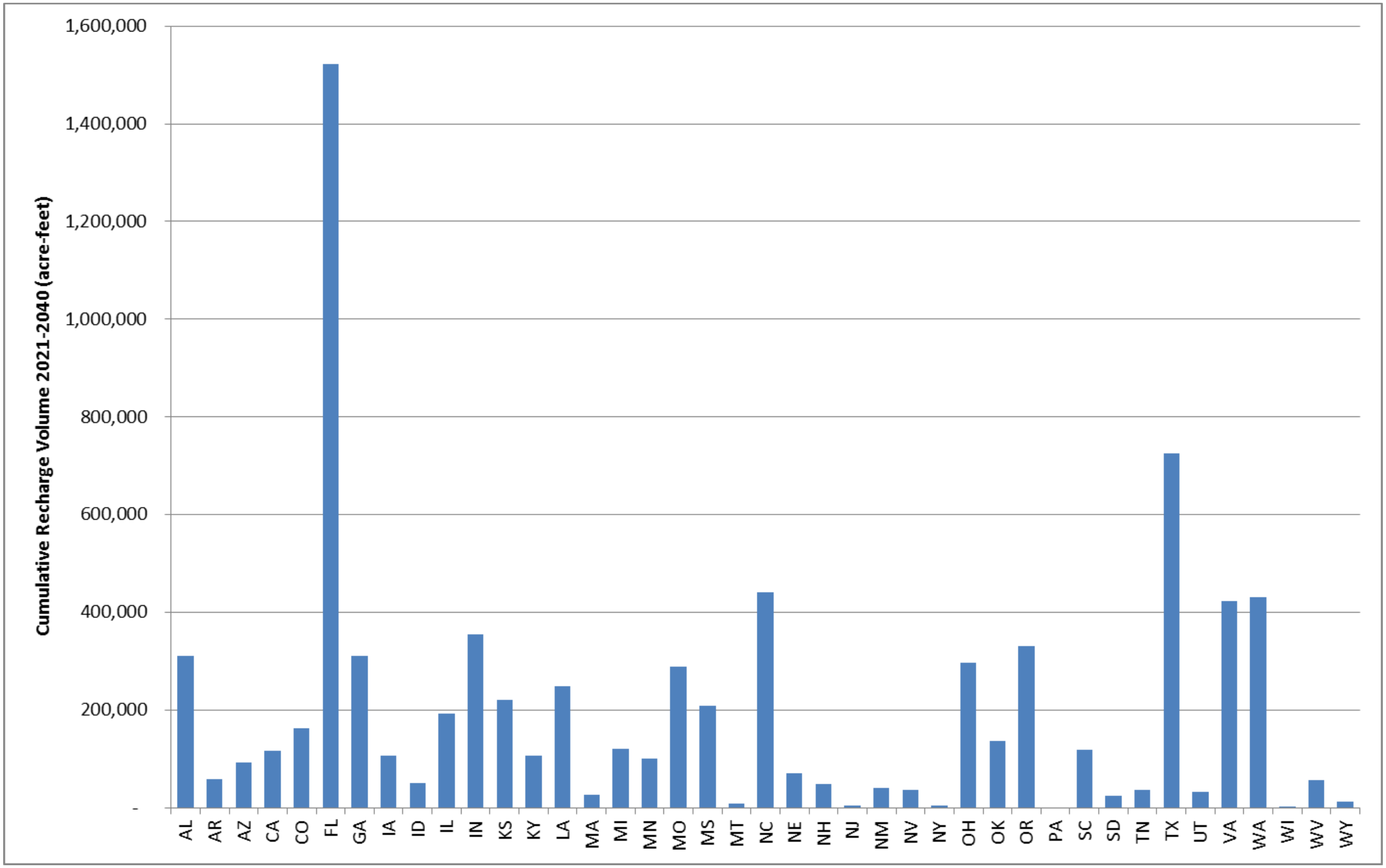


Figure 3-1 State-Specific Cumulative Volume of Recharge 2021-2040, High Retention Scenario, Medium Escalation Rate, 3% Discount Rate, Unadjusted Recharge, and Counties in the Upper 25% for Groundwater Use, for States without Existing Retention Standards or with Standards Lower than the "High" Retention Scenario.

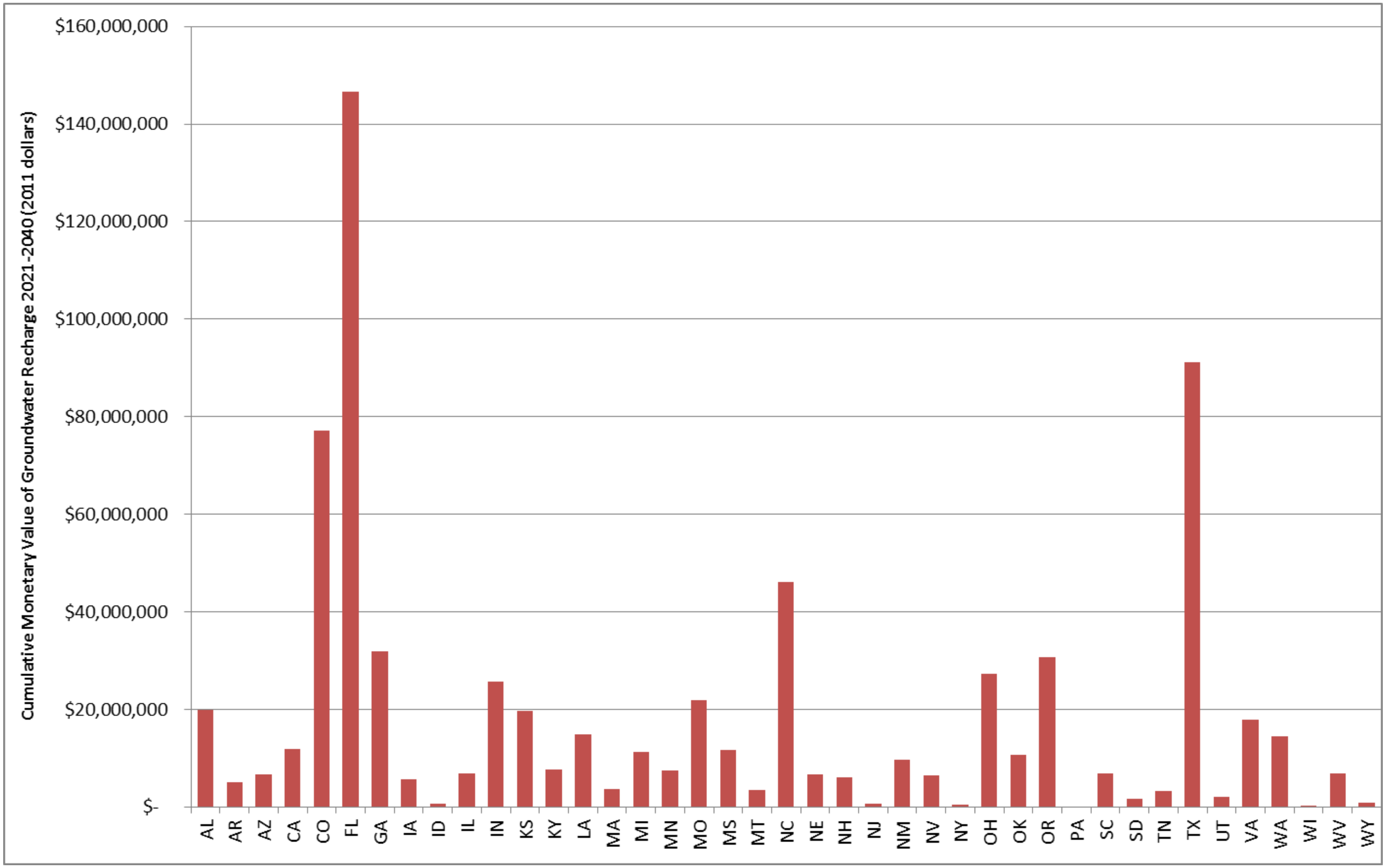


Figure 3-2 State-Specific Cumulative Value of Recharge 2021-2040, 2011 Dollars, High Retention Scenario, Medium Escalation Rate, 3% Discount rate, Unadjusted Recharge, and Counties in the Upper 25% for Groundwater Use, for States without Existing Retention Standards or with Standards Lower than the "High" Retention Scenario.

4 Uncertainty and Limitations

The results of this study can inform future valuation of groundwater recharge from stormwater retention. The study used high quality national datasets where available, a detailed documentation of methods and assumptions, and input from peer reviewers to help guide the study plan and suggest recommendations for improvements. Due the national scale of this analysis, it was necessary to make broad assumptions for both the recharge volume and value estimates. The major assumptions are documented in Section 1 and in more detail in Section 2. In addition, the researchers also identified the major limitations of the study, most of which derived from the national scale of the modeling effort, the modeling methods used, and data selected. Table 4-1includes a description of the uncertainty and limitations inherent in the study methodology for the estimation of the benefits of groundwater recharge that may accrue from stormwater retention practices.

Table 4-1 Uncertainty and Limitations of the Groundwater Recharge Methodology

Uncertainty/ Assumption	Notes
Use of the Water Supply Sustainability Index (WSI)	The WSI does not account for the stream base flow buffering effect that groundwater provides when surface water supplies are highly variable. If this value could be estimated, it is anticipated that it would present an additional and greater value to replenished groundwater recharge.
Use of a constant unit value over time	Other than adjustments due to discounting and escalation using constant rates, a constant monetized unit value was assumed for the entire period. This assumption does not account for variability in the value of groundwater over time caused by drought, wet years, or other supply variations.
Partitioning of Recharge	It was assumed that all recharge would benefit human consumers. The selection of counties helped ensure that the study area included those areas that were currently using groundwater as a water supply and, therefore, had the infrastructure and geology to access groundwater. This study was designed to estimate the value of that recharged groundwater and not necessarily its extracted value. The study did not account for site-specific factors that may prevent the full recharge volume from being available for consumption. If these factors could be accounted for in future analysis, this may result in a decrease in the groundwater recharge volume estimated and the corresponding benefit value would be lower.
Energy costs	As noted above, the results of the study present an estimate of the value of recharged groundwater and not necessarily the net benefit of extracted groundwater. The energy cost to pump the replenished groundwater for human consumption was not accounted for in this study. If energy related costs were included in the analysis, the estimated monetary values may be less than are currently reported.
Estimating the value of groundwater using water rights	Water markets are more complex than markets for other resources, such as land. In this analysis water rights were used to approximate that value of groundwater. Property rights to water are less complete due to the mobile and uncertain nature of water supplies, the incomplete adjudication of water rights in many watersheds, and the fact that individuals have legal rights subject to state oversight (Brewer et al., 2007). In addition, the quantified water right can differ from the expected utilization. The expected utilization of a water right can never exceed 100 percent; however it is common for the utilization of a water right to be less than 100 percent. Therefore, the expected value of an annual water utilization value can only be greater than the expected value of an annual water right valuation (Chesnutt and Pekelney, 2013).

Uncertainty/ Assumption	Notes
Estimating the value of groundwater using bulk rates	The values used from the AWWA bulk rates survey relate to treated water. To account for the extra costs of treating water, a multiplier was developed to convert the values from the survey to approximate the value of raw water. The multiplier was generated using existing data from the bulk rate and transfer value datasets that contain a limited number of data points. In addition, bulk rates tend to reflect the average cost, rather than the marginal cost, of water supply.
Estimating the value of groundwater using retail rates	The values used from utility companies relate to treated water. To account for the extra costs of treating water, a multiplier was developed to convert the values from utilities to approximate the value of the raw water. The multiplier was generated using existing data from the retail rate (with only 2-3 data points per state) and water rights transfer value datasets. In addition, retail rates tend to reflect the average cost, rather than the marginal cost, of water supply.
Generating an average water value for one state	The assumption was made that all groundwater recharge achieved is valued equally across a state. Although water market activity offers important information about the value of water, it is important to understand that water values are highly variable both geographically and over time and are commonly affected by factors that interfere with competitive pricing. As a check on the reasonableness of the final selected monetary value for each state, a comparison was made to recent reported or literature values for water reflective of the raw water value in several states.
Changes in the value of water into the future	This benefits analysis uses a 0%, 3%, and 7% discount rate to generate three different scenarios for the future value of water. These different discount rates attempt to account for varying conditions in the future, which cannot be predicted accurately today. Three different escalation scenarios for the future value of water were also considered to address this uncertainty.
Infiltration practices are implemented correctly	The correct design and placement of stormwater infiltration practices is essential to realizing their benefits and avoiding unintended costs. This analysis assumes all practices installed on new development and redevelopment parcels are sited and designed to maximize recharge, are implemented correctly, and continue to function as intended with proper operation and maintenance.
Estimating recharge rate	The natural rate of groundwater recharge depends on many factors including climate, vegetation, soils, and topography. Similarly, recharge rates for diffuse recharge can be quite different from focused or concentrated recharge in natural or designed systems such as streams, lakes, playas or water infiltration facilities. In addition, there are many uncertainties in hydraulic conductivity that can lead to order-of-magnitude uncertainties in recharge estimates. Recognizing these uncertainties, the natural recharge rate estimates were based on the best available data that could be applied at the county scale using methods applied nationally. Conservative assumptions were used in cases where a mixed soil type was present, such as C/D, where the lower recharge rate was used. Several variations to input parameters were assessed to determine the effect of different recharge rate assumptions on the final monetary estimate. The Horsley method is a simplified approach and other methods such as Wolock (2003) or site-specific studies can provide a more field-verified approach.
Estimating recharge volume	The recharge calculations outlined above determine the estimated change in recharge compared to existing practices and retention regulations currently in place. Because routing cannot be determined at this scale of analysis, the future runoff volume is assumed to be routed to infiltration systems that are adequately sized to contain and infiltrate the entire volume of the retention scenario evaluated. This methodology does not expressly consider land use and land cover changes (e.g., single family, multi-family, mixed, industrial, or commercial land uses) or topography (slope) and likely oversimplifies evapotranspiration. The analysis does include projections of the amount of imperviousness of development area during the period of interest. The intent was to develop a simplified approach; as such, the inclusion of these factors was beyond the scope of this effort.

5 Recommendations for Future Study

The following refinements are recommended if further studies are undertaken:

- Investigate the effect of the cost to pump groundwater in the selection of unit value.
- Select data sources for monetized unit values by county instead of by state where data are available. Focus resources on states or counties shown to have a more significant contribution to total valuation.
- Conduct more sensitivity analysis on valuation and volume as a whole.
- Refine annualization of permanent water rights transfers so that the assumed discount rate is more consistent with private industry rates or the return inherent in permanent water transfer payments. Alternatively, use lease prices of water rights transfers to avoid the need for annualization.
- Estimate direct use values of water based on water rights transfer leases rather than on purchases in perpetuity.

Although this study was conducted at a national scale, more accurate values and volumes of recharge might be estimated by conducting more detailed recharge studies at a regional or local scale. The following recommendations pertain to future studies at these smaller scales where more comprehensive data are available:

- Consider differences in value between counties whose primary water supply is groundwater and counties that rely more on surface water.
- Consider mining and thermoelectric water use; at smaller scales, representativeness could be verified. Value may vary depending on localized demand for these use categories.
- Develop a regression model with explanatory variables for year, drought condition, assumed variables for location, etc. Use the model to predict the variability of the monetized unit value. This approach may be hindered in some locations where other drivers dictate water pricing.
- Conduct a meta-analysis of available valuation studies and then use the results to drive estimates of recharge values in the study area.
- Evaluate cost of the best alternative water supply as avoided cost.
- Instead of the Simple Method, use a runoff estimation approach which uses regional or locally applicable data sources and methods such as TR-55 or EPA's Storm Water Management Model (SWMM). Compare approaches as an order-of-magnitude check.
- In areas with modified soils and hydrology, or soils that infiltrate slowly, consider the use of engineered practices to facilitate enhanced infiltration.

For counties where estimates of natural recharge rates were not available, the Wolock (2003) method could be used instead of the Horsley method. Wolock (2003) provides a spatial dataset based on PRISM precipitation and USGS stream-gage data and might provide more accurate estimates of recharge in arid areas. If this method were used, a cursory analysis indicates the recharge volume estimates would likely be reduced by about 30 to 35 percent. It is recommended that this method be considered in future estimates.

The following references are among those recommended by peer reviewers for consideration in future studies:

Eden, S., Efrein, M., and Radonic, L., 2014, What is the value of water? A complex question, *Arroyo*, University of Arizona Water Resources Research Center, Tucson, AZ, *v. 119,* no.1, p. 1-19.

Endreny, T. & Collins, V. 2009: Implications of bioretention basin spatial arrangements on stormwater recharge and groundwater mounding. Ecological Engineering 35, 670–677.

Gee, G.W. and Hillel, D., 1988, Groundwater recharge in arid regions: review and critique of estimation methods, *Hydrological Processes, v.2* , p. 255-266.

Gobel, P. et al. 2004: Near-natural stormwater management and its effects on the water budget and groundwater surface in urban areas taking account of the hydrogeological conditions, *Journal of Hydrology,* 299, 267–283

Healy, Richard W., 2010, *Estimating Groundwater Recharge*. Cambridge University Press. ISBN 978-0-521-86294-4 Hardback.

Newcomer, M.E., Gurdak, J.J., Sklar, L.S., and Nanus, L., 2014, Urban recharge beneath low impact development and effects of climate variability and change, *Water Resources Research*, v. 50, no. 2, p. 1716-1734, doi:10.1002/2013WR014282.

Leila Talebi and Robert Pitt. 2011. Stormwater Non-Potable Beneficial Uses: Modeling Groundwater Recharge at a Stormwater Drywell Installation, *World Environmental and Water Resources Congress 2011*, pp. 3509-3518. doi: 10.1061/41173(414)368.

Randall, M.T., Troldborg, L., Refsgaard, J.C., & Kidmose, J.B. 2013. Assessing urban groundwater table response to climate change and increased stormwater infiltration. *GEUS Geological Survey of Denmark and Greenland Bulletin 28*, 33–36. http://www.geus.dk/UK/publications/geol-survey-dk-gl-bull/Pages/default.aspx

Scanlon, B.R., Keese, K.E. Flint, A.L. Gaye, C.B., Edumnds, W.M., and Simmers, I., 2006, Global synthesis of groundwater recharge in semiarid and arid regions, *Hydrological Processes, v.20* , no. 15, p.3335-3370, doi: 10.1002/hyp.6335.

Thompson, A., Nimmer, M. & Misra, D. 2010: Effects of variations in hydrogeological parameters on water-table mounding in sandy loam and loamy sand soils beneath stormwater infiltration basins, *Hydrogeology Journal*, 18, 501–508.

6 References

AWWA. 2011. *2010 Water and Wastewater Rate Survey*. American Water Works Association. Denver, CO.

Barringer, F. 2012. As 'Yuck Factor' Subsides, Treated Wastewater Flows From Taps. *The New York Times*, February 9, 2012. Accessed February 2012. http://www.nytimes.com/2012/02/10/science/earth/despite-yuck-factor-treated-wastewater-used-for-drinking.html.

Berrens, R.P., P. Ganderton, and C.L. Silva. 1996. Valuing the Protection of Minimum Instream Flows in New Mexico. *Journal of Agricultural and Resource Economics* 21(2):294-309.

Brewer, J., R. Glennon, A. Ker, and G. D. Libecap. 2007. *Water Markets in the West: Prices, Trading, and Contractual Forms*. National Bureau of Economic Research (NBER), NBER Working Paper Series, Cambridge, MA. March 2007.

Brown, T.C. 2004. *The Marginal Economic Value of Streamflow from National Forests*. Rocky Mountain Research Station, U.S. Forest Service, December 2004.

Brown, T.C. 2006. *Trends in water market activity and price in the western United States*. Rocky Mountain Research Station, U.S. Forest Service, September 2006.

Brown, T., and J. Duffield. 1995. Testing Part-Whole Valuation Effects in Contingent Valuation of Instream Flow Protection. *Water Resources Research* 31(1995):2341-351.

Bureau of Economic Analysis (BEA). 2013. Table 1.1.9. *Implicit Price Deflators for Gross Domestic Product, Seasonally Adjusted.* Accessed March 2013. http://www.bea.gov/iTable/iTable.cfm?ReqID=13&step=1#reqid=13&step=3&isuri=1&1301=I&1303=13.

Center for Neighborhood Technology. 2007. *Green Values Stormwater Management Calculator Benefits Sheet*. Center for Neighborhood Technology. Accessed December 2011. http://greenvalues.cnt.org/national/benefits_detail.php#groundwater-recharge.

Chesnutt, T.W., and D.M. Pekeiney. 2013. Review of Methods for using Western Water Transfer Data. Technical Memorandum to Tetra Tech, A & N Technical Services, Inc.

City of Tampa. 2011. Schedule of Rates. City of Tampa Water Department Accessed June 2013. http://www.tampagov.net/sites/default/files/water/files/schedule-of-rates-oct-2011.pdf

City of San Diego Water Department. 2007. *San Pasqual Basin Groundwater Management Plan*. Adopted November 2007.

Cutter, B.W., 2007. Valuing groundwater recharge in an urban context. *Land Economics* 83(2):234-252.

Cianfrani, C.M., W.C. Hession, and D.M. Rizzo. 2006. Watershed imperviousness impacts on stream channel condition in southeastern Pennsylvania. *Journal of the American Water Resources Association* 42:941-956.

CUWA. 1994. The Value of Water Supply Reliability: Results of a Contingent Valuation Survey of Residential Customers. Prepared for California Urban Water Agencies by Barakat & Chamberlain, Inc., August 1994.

Davis, M. 2011. Stormwater Systems Technologies for Effective Resource Management: A View from the Water/Wastewater Industry. 2011 VERDEXCHANGE Green Marketers Conference.

Devinny, J.S., S. Kamieniecki, and M. Stenstrom. 2005. *Alternative Approaches to Stormwater Quality Control*. Center for Sustainable Cities, University of Southern California, Los Angeles, CA.

Donohew, Z., and G. Libecap. 2010. *Water Transfer Level Dataset*. University of California Center for Water Resources Grant WR1023 and National Science Foundation Grant 0317275. Accessed June 2012. http://www.bren.ucsb.edu/news/water_transfers.htm.

Duffield, J.W., C.J. Neher, T.C. Brown. 1992. Recreation benefits of instream flow: application to Montana's Big Hole and Bitterroot Rivers. *Water Resources Research* 28(9):2169-2181.

El Paso Public Water Service Utilities Board. 2013. *Reclaimed Water Rates*. Accessed May 2013. http://www.epwu.org/reclaimed_water/reclaimed_rates.html.

Frederick, K.D., T. VandenBerg, and J. Hanson. 1996. *Economic Values of Freshwater in the United States*. Resources for the Future, Washington, DC.

Fermanian Business & Economic Institute. 2010. *San Diego's Water Sources: Assessing the Options*. Sponsored and published by the Equinox Center. Researched and produced by the Fermanian Business & Economic Institute. Accessed June 2012. http://www.equinoxcenter.org/assets/files/pdf/AssessingtheOptionsfinal.pdf.

Galbraith, K. 2011. Draft Water Plan Says Texas "Will Not Have Enough." *The Texas Tribune*. Accessed December 2012. http://www.texastribune.org/texas-environmental-news/water-supply/draft-water-plan-says-texas-will-not-have-enough/.

Gilmer, E.M. 2011. Determined Florida City Digs Deep to Expand Supplies. *Energy and Environment News*. September 22, 2011. Accessed December 2011. http://www.eenews.net/public/Greenwire/2011/09/22/1?page_type=print.

Horsley, S. 1996. Methods for Calculating Pre and Post Development Recharge Rates. Memorandum prepared for State of Massachusetts Stormwater Technical Advisory Group. Dated July 10, 1996.

Howe, C., and M. Smith. 1994. The value of water supply reliability in urban water systems. *Journal of Environmental Economics and Management* 26:19-30.

Jordan, J.L., J.B. Blackburn, and G.L. Callaway. 1998. *Trans-Texas Water Program Southeast Area Planning Memoranda: Equity Issues Related to Water Transfers Southeast Area*. Trans-Texas Water Program. Accessed September 2011. http://www.sra.dst.tx.us/srwmp/ttwp/br-docs/final/EQUITY_REPORT.pdf.

Keese K.E., B.R. Scanlon, and R.C. Reedy. 2005. Assessing controls on diffuse groundwater recharge using unsaturated flow modeling. *Water Resources Research* 41:W06010.

Larson, T., J. Edwards, D. Cherry, R. Eads, and M. High. 2013. Fast track to quench thirst in Midland, Texas. *Water Environment and Technology* 5(25):38-41.

Loomis, J.B. 1998. Estimating the Public's Values for Instream Flow: Economic Techniques and Dollar Values. Journal of the American Water Resources Association. 34:5(1007-1014).

Los Angeles and San Gabriel Rivers Watershed Council. 2010. Water Augmentation Study: Research, Strategy and Implementation Report. Accessed September 2011.

Maimone, M., D.E. O'Rourke, J.O. Knighton, and C.P. Thomas. 2011. Potential impacts of extensive stormwater infiltration in Philadelphia. *Environmental Engineer: Applied Research and Practice* 14:2-12.

Martin, S. 2011. Water for sale: the Sabine has it; Texas needs it. *Louisiana Life*, July-August 2011. Accessed September 2011. http://www.myneworleans.com/Louisiana-Life/July-August-2011/Water-for-Sale.

McCormick, B., R. Clement, D. Fischer, M. Lindsay, and R. Watson. 2011. *Measuring the Economic Benefits of America's Everglades Restoration*. Prepared for The Everglades Foundation by Mather Economics.

Mercer, Bob. 2012. 'Surplus water' plan to include fee for Missouri water, *Aberdeen American News*; September 1, 2013. Accessed September 2013. http://articles.aberdeennews.com/2012-09-01/news/33540101_1_missouri-river-lake-sakakawea-corps

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T. Yong Jung, T. Kram, E. Lebre La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H.-H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, and Z. Dadi. 2000. Special report on emissions scenarios, Summary for Policymakers, 20 pp., Cambridge U. Press, Cambridge, UK.

National Research Council. 1997. *Valuing Ground Water: Economic Concepts and Approaches*. Committee on Valuing Ground Water, Water Science and Technology Board Commission on Geosciences, Environment, and Resources, National Research Council. National Academy Press, Washington D.C. Accessed January 2013. http://www.nap.edu/catalog.php?record_id=5498.

National Research Council. 2009. *Urban Stormwater Management in the United States*. National Academy of Sciences, Washington, D.C. 610 pp.

Newcomer, M. E., J. J. Gurdak, L. S. Sklar, and L. Nanus. 2014. Urban recharge beneath low impact development and effects of climate variability and change. Water Resources Research, 50:1–16.

NJDEP. 2012. Natural Resource Injury (NRI) Assessment. Accessed June 2012. http://www.nj.gov/dep/nrr/nri/nri_gw.htm.

Paul, M. and J. Meyer. 2001. Streams in the urban landscape. *Annual Review of Ecology and Systematics* 32:333-365.

Powell Consortium. 1995. *Severe Sustained Drought: Managing the Colorado River System in Times of Water Shortage*. The Powell Consortium, Arizona Water Resources Center, University of Arizona, Tucson, AZ.

PRISM. 2011. Annual Rainfall. PRISM Climate Group, Oregon State University. Accessed 2011. Available online at http://www.prism.oregonstate.edu/.

Roy, S.B. L. Chen, E.H. Girvetz, E.P. Maurer, W.B. Mills, and T.M. Grieb. 2012. Projecting water withdrawal and supply for future decades in the U.S. under climate change scenarios. *Environmental Science and Technology* 46(5):2545-2556.

San Antonio Water System. 2013. Recycled Water Service. Accessed May 2013. http://www.saws.org/service/rates/recycled.cfm.

Sanders, L., R. Walsh, and J. McKean. 1994. Comparable estimates of river recreational values. *Water Resources Research* 27(1990):1387-1394.

Schueler, T.R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Metropolitan Washington Council of Governments, Washington, DC.

Shuster, W.D., R. Gehring, and J. Gerken, 2007. Prospects for enhanced groundwater recharge via infiltration of urban storm water runoff: A case study. *Journal of Soil and Water Conservation* 62(3):129-137.

State of Florida. 2008. *Protecting Florida's Springs: An Implementation Guidebook*. Florida Department of Community Affairs, Tallahassee, FL. *Accessed January 2012.* https://www.dep.state.fl.us/springs/reports/files/springsimplementguide.pdf.

Stephens, D.B., M. Miller, S.J. Moore, T. Umstot, and D.J. Salvat. 2012. Decentralized groundwater recharge systems using roofwater and stormwater runoff. *Journal of the American Water Resources Association* 48(1):134-144.

SummitDaily.com. 2012. Some Colo. cities sell water for use in fracking. Accessed June 2013. http://www.summitdaily.com/article/20120311/NEWS/120319976

Tampa Bay Water. 2011. *Schedule of Rates: Rates for Tampa Bay Residents are Tiered to Encourage Conservation*. Accessed May 2013. http://www.tampagov.net/sites/default/files/water/files/water_scheduleofrates_residential_0.pdf.

Taylor, A. and T.H.F. Wong. 2002. Non-structural Stormwater Quality Best Management Practices—A Literature Review of their Value and Life-cycle Costs. Cooperative Research Centre for Catchment Hydrology. Technical Report 02/13, Monash University, Melbourne. http://www.clearwater.asn.au/user-data/resource-files/CRC-Life-Cycle-Costing-2002.pdf. Accessed May, 02, 2014.

Tellinghuisen, S. 2011. *Every Drop Counts: Valuing the Water Used to Generate Electricity*. Western Resource Advocates, Boulder, CO. Accessed June 2013. http://www.westernresourceadvocates.org/water/value/EveryDropCounts.pdf.

Tetra Tech. 2011. *Evaluating Sustainability of Projected Water Demands on Future Climate Change Scenarios*. Prepared for Natural Resources Defense Council by Tetra Tech, Inc. Accessed September 2011. http://rd.tetratech.com/climatechange/projects/doc/Tetra_Tech_Climate_Report_2010_lowres.pdf

Texas Water Development Board. 2012. *2012 Draft State Water Plan*. Texas Water Development Board, Austin, TX. Accessed January 2013. https://www.twdb.texas.gov/waterplanning/swp/2012/.

USDA. 2006. U.S. General Soil Map (STATSGO2). Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Accessed 2011. Available online at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053629.

USEPA. 1995. Interim Economic Guidance for Water Quality Standards. EPA-823-B-95-002. Accessed December 2014. http://water.epa.gov/scitech/swguidance/standards/upload/2007_06_18_standards_econworkbook_complete.pdf

USEPA. 2013. EPA Climate Region Map. United States Environmental Protection Agency, Climate Change and Water website. Accessed April 2013. Available online at http://water.epa.gov/scitech/climatechange/index.cfm.

USGS. 2008. Consumptive Water Use in the Great Lakes Basin. Fact Sheet 2008–3032. Accessed December 2014. http://pubs.usgs.gov/fs/2008/3032/pdf/fs2008-3032.pdf

USGS. 2009. *Estimated Use of Water in the United States County-Level Data for 2005*. U.S. Geological Survey. Circular 1344. Accessed September 2011. http://water.usgs.gov/watuse/data/2005/index.html.

USGS. 2012. *Principal Aquifers of the 48 Conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands*. U.S. Geological Survey. Accessed July 2012. http://nationalatlas.gov/mld/aquifrp.html.

USGS. 2013. *Groundwater Depletion in the United States (1900–2008).* U.S. Geological Survey Scientific Investigations Report 2013 – 5079. Accessed May 2013. http://pubs.usgs.gov/sir/2013/5079/.

Wright, T., J. Tomlinson, T. Schueler, K. Cappiella, A. Kitchell, and D. Hirschman. 2006. *Direct and Indirect Impacts of Urbanization on Wetland Quality*. Center for Watershed Protection, Ellicott City, MD. Accessed June 2013. http://www.northinlet.sc.edu/training/media/resources/Article1Impact%20Urbanization%20Wetland%20Quality.pdf.

Winter, T.C. 2007. *The Role of Ground Water in Generating Stream flow in Headwater Areas and in Maintaining Base Flow*. JAWRA Journal of the American Water Resources Association 43(1):15-25.

Wolock, D.M., 2003, Estimated mean annual natural ground-water recharge in the conterminous United States: *U.S. Geological Survey Open-File Report 03-311*, http://water.usgs.gov/lookup/getspatial?rech48grd

(This page is intentionally left blank.)

7 Appendices

APPENDIX A ADDITIONAL VALUATION LITERATURE

Background

Relevant literature on groundwater recharge benefits, stormwater infiltration, and benefit valuation provides a useful context for the analysis. This section reviews the relevant literature and explains some of the approaches used by others in benefits estimation. This section discusses the total economic value of groundwater recharge and the full suite of potential direct and indirect benefits from groundwater recharge to provide context for this study. As explained below, this study focuses on a subset of these values, and the specific valuation methods used for this study are explained in Section 2.2.

Benefits of Maintaining or Restoring Groundwater

As an integral part of the water cycle, groundwater provides many uses and functional benefits. The U.S. relies on groundwater as a major source of drinking and irrigation water (USGS, 2013). Groundwater serves important geological functions, and the maintenance of relatively stable groundwater levels can also help prevent land subsidence and saltwater intrusion. Groundwater also contributes to baseflow for streams and wetlands (Winter, 2007; Wright et al. 2006), which is an important source of water during low-flow conditions, and provides habitat for fish and other aquatic life (Cianfrani, 2006). While urban stream baseflow is a function of many inputs and outputs (irrigation, septic drainage, interbasin transfers, and WWTP effluent), reduced groundwater recharge can decrease baseflow discharge in urban streams (Paul and Meyer, 2001).

The benefits of groundwater recharge warrant investigation as many communities throughout the U.S. are currently facing water shortages and the need to plan for alternative water supplies. Declining groundwater levels in Florida provide one example. The Floridian aquifer is thought to be one of the most productive aquifers in the world, and the Upper Floridian aquifer produces over 90 percent of the water used in Florida. However, recent low lake and stream levels indicate that use of the Upper Floridian aquifer is reaching an unsustainable limit, and communities are exploring alternative sources, including drilling into the deeper portion of the Floridian Aquifer (Gilmer, 2011). Stormwater infiltration for the purpose of recharging these aquifers is recommended by the State of Florida (State of Florida, 2008). Areas such as Tampa Bay have resorted to desalination to meet water demand during dry periods (Personal communication with Lynda Vatter, Budget Administrator, Tampa Bay Water, 2013).

The State of Texas provides another example of shrinking water supplies. The draft 2012 State Water Plan for Texas (the Plan) outlines a number of new and expanded water sources and estimated infrastructure costs of over $50 billion. The Plan projects droughts that could lead to economic losses, including billions of dollars of lost income (Galbraith, 2011). Groundwater is a significant source of water supply throughout the state and groundwater depletion has continued to increase over the past decade in all regions of the state except the central part of the Texas Gulf Coastal Plain aquifer system (USGS, 2013). While surface impoundments provide a major means for retaining water in drinking water reservoirs, these surface impoundments are subject to very high evaporation rates, land availability issues, and environmental impact issues.

Many communities, states, and regions are dealing with similar issues and are needing to plan and protect alternative water sources. Some areas, such as San Diego, CA, require leases of public land to follow best management practices to protect surface and groundwater quality in the basin (City of San Diego Water Department, 2007). While efforts like southern California's are focused in the arid western U.S., water supply shortages and groundwater depletion occur at many locations in the country. Saltwater intrusion, exacerbated by freshwater withdrawals, is a concern along the eastern and gulf coasts. Rising sea levels are exacerbating the intrusion problem, making it even more important to infiltrate fresh water (Dr. Frederick Bloetscher, Florida Atlantic University, personal communication 2013).

The use of stormwater management practices to promote infiltration is currently practiced in many U.S. states and is becoming more common. A number of recent studies have documented the effect of stormwater infiltration on groundwater. Newcomer et al. (2014) evaluated simulated and measured recharge below an infiltration trench finding that recharge efficiency ranged from 58%-79%. These recharge rates were an order of magnitude higher than the recharge rates resulting from irrigated lawn. Through modeling and verification in semi-arid New Mexico, Stephens et al. (2012) found that unlined retention ponds can significantly increase groundwater recharge above naturally-occurring infiltration rates by capturing runoff from an impervious area. Shuster et al. (2007) showed that infiltration of stormwater into the vadose zone and recharging shallow groundwater can support necessary ecological functions such as longer durations of baseflow. Other studies have shown that the application of stormwater management practices promoting infiltration can create enhanced recharge locations in highly urban settings that can even surpass recharge rates found in grassy or wooded open space (Maimone et al., 2011).

Maintaining and restoring groundwater recharge would help address water supply needs while providing an array of other functional benefits. Benefits of groundwater recharge include, but may not be limited to, the following:

- Maintenance of water supplies (residential, commercial, agricultural, and industrial)
- Prevention of saltwater intrusion and land subsidence
- Preservation of wetland habitats
- Protection of aquatic habitat through baseflow
- Replenishment of surface water supply in dry periods through baseflow
- Generation of hydroelectric power in dry periods through baseflow
- Provision of stream flow-dependent recreational opportunities, including boating and fishing
- Protection of commercial fisheries in dry periods through baseflow.

All of the above benefits would lead to further indirect benefits to communities and ecosystems. Increased water supply provides economic benefits to human populations. Habitat protection can lead to more resilient ecological communities and protection of endangered and threatened species. Recreational opportunities provide economic as well as health benefits to human populations. The protection of fisheries contributes both economic and ecological benefits. Overall, groundwater plays an integral role in both the economy and ecology of the U.S. This study does not count the additional direct and indirect benefits of groundwater recharge.

Valuation Literature

For the purpose of this study, background on groundwater valuations is provided here to demonstrate the complexity of this topic. These valuation methods demonstrate that while groundwater has economic benefits for services other than drinking water supply, assigning dollar values to those benefits is both a science and an art that is still in development and does not produce definitive values. Refer to Section 2.2 for the approach selected to estimate water value for this study.

The total economic value of groundwater recharge can be divided into two major categories: use and non-use values. These primary categories and their respective subcategories are shown in Figure 7-1.

Use values pertain to either direct uses of groundwater, such as water supply, or indirect uses, such as protection of fisheries. Direct use values can be further divided into consumptive and non-consumptive use values depending on whether groundwater is consumed during its use. Consumptive uses generally exclude other uses of the same resource. For example, water is consumed when it is diverted from a waterbody for irrigation purposes. With non-consumptive uses, like swimming for example, the resource base remains unaltered after use (USEPA, 1995). As a consumptive use, water supply is also often considered to have market benefit since a market exists for the resource or its use (e.g. industrial water supply, domestic water supply, irrigation). For example, USGS (2008) analyzed water use in the Great Lakes Basin and defined consumptive water use "…as water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from an immediate water environment."

The second major category, non-use values, recognizes that the resource provides a value regardless of whether it is used. Option value is a non-use value in which an individual recognizes the option to enjoy future recreational opportunities. Alternatively, existence value can be realized when an individual gains satisfaction from protecting the habitat for an endangered species regardless of whether he or she will have an existing or future use for the species.

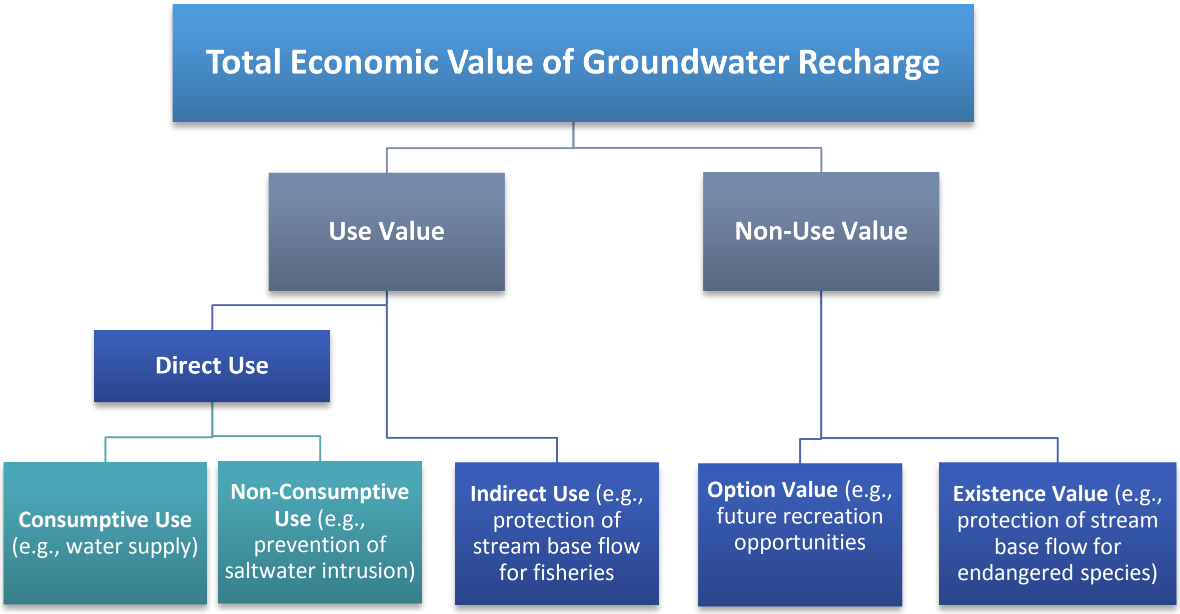


Figure 7-1 Categories of Economic Value of Groundwater Recharge

Having a more reliable water supply is, by itself, of value. Stated preference studies have provided estimates of the value to consumers for avoiding risk of water shortages. CUWA (1994) found that California residents are willing to pay an additional $12 to $17 on monthly household water bills to avoid water shortages of varying degrees, which summed to an estimated cumulative $1 billion in 1994. In a similar Colorado study, Howe and Smith (1994) found that residents were willing to pay a base payment of about $18 to avoid any water shortages, and this amount increased with shortage duration and probability of occurrence.

Consumptive Use Value

This study derived a dollar value based on price observations to represent the consumptive use value of groundwater recharge. Available literature relating to this value category is discussed below; some of these values are presented in Table 2.7 to compare to the dollar values selected in the study. Literature relating to the other value categories is listed in the next section. Pertaining to the consumptive use value category, groundwater recharge is expected to have the greatest value in areas where it is currently a major water source. Within this subset, communities whose groundwater supplies are considered scarce or are projected to be scarce in the future are expected to have a higher value for groundwater and therefore would realize the greatest benefit from replenishing groundwater sources. To estimate this value, common methods include the use of avoided costs and stated preference studies.

Groundwater valuation studies have applied the "avoided cost" method throughout the U.S. The "avoided cost" method places a value on the groundwater equal to that of the infrastructure cost, or other cost, that would alternatively be incurred to provide a similar quantity and quality of water. Davis (2011) estimates that the value of lost stormwater infiltration in the Santa Ana watershed in California is $20 million per year, based on replenishment costs of $500 per acre-foot. Devinny et al. (2005) estimate the value of stormwater infiltration is roughly $800 per acre-foot when valuing water for urban centers in Southern California. The Everglades Foundation reports that groundwater purification provided by ecosystem restoration in the everglades is worth a net present value of over $13 billion based on the avoided operation costs of groundwater desalination (McCormick et al, 2011). Areas that are often considered to have more plentiful groundwater supplies have also realized significant benefits of groundwater recharge as well. The Center for Neighborhood Technology (2007) estimates the value of groundwater recharge to range from $40 to $300 per acre-foot infiltrated based on the costs of water supply in northeastern Illinois.

The "avoided cost" approach has also been used to estimate the value of groundwater supply lost to contamination. The New Jersey Department of Environmental Protection uses water rates and simple volume calculations to derive monetary damage to groundwater supply caused by contamination. The rates used to calculate damages range from $280 to $3,128 per acre-foot of groundwater recharge depending on the planning area where the contamination occurs (NJDEP, 2012).

For the purposes of valuation, water rates can function as another type of "avoided cost." One example of "avoided cost" is the difference between the prices for raw groundwater, raw surface water, and desalinated water that are calculated by Florida's Tampa Bay Water, a regional water supplier. Historically, groundwater was used but as supplies became strained surface water was used more frequently. As the supply of surface water is now also limited in dry periods, desalination is used to meet peak demands in dry periods. The costs of supplying groundwater, surface water and desalinated water are $315, $522, and $932/acre-ft, respectively, allowing a perspective on the value of an adequate local groundwater supply (David Bracciano, Tampa Bay Water, personal communication).

At a local level, water rates depend on a number of factors, including, but not limited to, the type of industry, the political climate, financial status of a government or utility, the need for subsidized supply, and goals of the water rate structure (e.g., conservation). In addition to these factors, some water rate structures are based on recovering historical costs of infrastructure but do not account for future water supply needs. These conditions may lead to relatively low water rates in an area of scarce water supply. For example, AWWA (2011) reported that wholesale water rates in California, a state known for widespread water scarcity, ranged from $238 to $552 per acre-foot. Wholesale water rates reported for Michigan, a state with plentiful freshwater supplies, were within a similar and slightly higher range of $349 to $991 per acre-foot (AWWA, 2011).

Additional Valuation Literature

While this study used estimates of the consumptive use value of water, other studies have investigated the other value categories of non-consumptive use, indirect use, and non-use values. These studies are discussed briefly below.

Electric power generation is a major non-consumptive use. A number of studies have quantified the value of water for this use. The values reported range from $1 to $1,292 per acre-foot (Frederick et al., 1996; Powell Consortium, 1995; Brown, 2004; Tellinghuisen, 2011)

Commercial fisheries, commercial navigation, recreation and tourism, are all areas where indirect use and non-use water provides value that cannot be replaced by any other substance. It is challenging to place a dollar value on non-consumptive uses of water and as such, there is limited data sets from which to develop a nationwide monetization estimate. These non-consumptive uses are of significant value to the US economy.

Relating to indirect use and nonuse values of groundwater recharge, a number of studies have estimated the value for protecting or restoring stream flow. Duffield et al (1992) estimated the willingness to pay (WTP) per day or per trip. In addition, a number of papers have reported annual WTP per household for the restoration and protection of stream flow for aquatic life. Based on both use and non-use values, annual WTP per household for stream flow protection/restoration ranged from $2 to over $500 in these studies. Table 7-1 displays these annual WTP values and sources.

Table 7-1 Annual Willingness to Pay per Household for Protecting or Restoring Stream Flow.

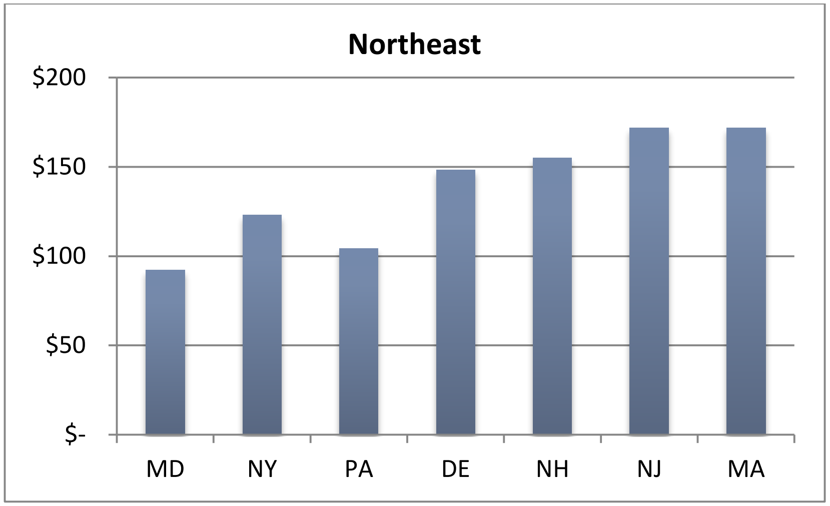
Location	Type	Value (2011 dollars)	Source
New Mexico	Non-use; endangered species protection	$45 to $140	Berrens et al. 1996
Montana	Non-use; multiple benefits	$2 to $3	Brown and Duffield 1995
Montana	Use; multiple uses	$8 to $14	Brown and Duffield 1995
Western States	Non-use; endangered species protection	$68 to $136	Berrens et al. 1996
Colorado	Use; recreation	$41	Sanders et al. 1994
Colorado	Use; option value for future recreation	$34	Sanders et al. 1994
Colorado	Non-use; multiple benefits	$62	Sanders et al. 1994
Colorado	Non-use; multiple benefits for future generations	$78	Sanders et al. 1994
AZ, CO, NM, UT, and rest of U.S.	Non-use; endangered species protection	$508	Loomis 1998

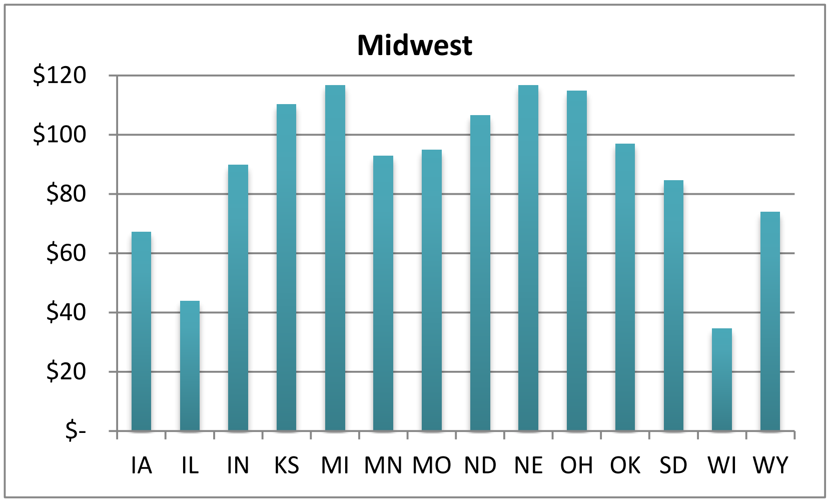
Selected Valuation Focus

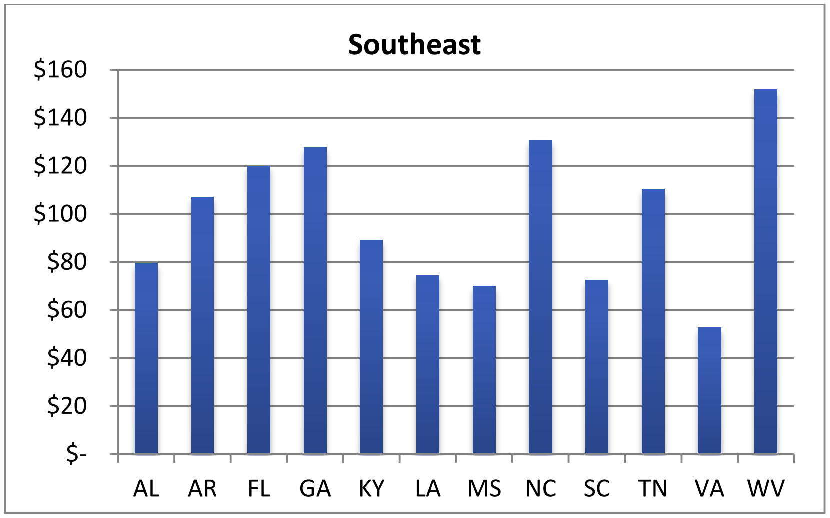
The above review of groundwater recharge benefits and their monetary valuation suggests groundwater recharge provides a significant economic value to many areas of the U.S. An accurate national estimate of the total economic value for groundwater recharge would require extensive data collection beyond the research that is currently available. This analysis focused on developing a conservative estimate based solely on the consumptive use value of water supply observed in water prices. The resulting valuation, therefore, reflects a partial valuation of the multiple benefits provided by groundwater recharge.

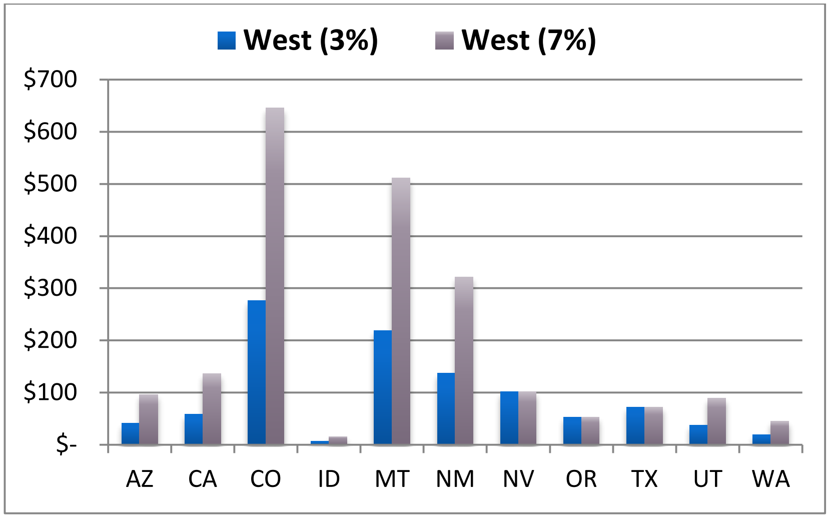
(This page is intentionally left blank.)

APPENDIX B GRAPHICAL DISPLAY OF VARIANCE WITHIN CLIMATE REGIONS ($/ACRE-FT)









(This page is intentionally left blank.)

APPENDIX C METHODOLOGY FOR ANNUALIZATION

Method for Annualizing the Contract Price Paid for Western Water Transfer Rights in Perpetuity

Referenced as Donohew and Libecap (2010) in the main document of this report, the permanent Western Water Rights Transfers data set was compiled by the University of California, Santa Barbara (UCSB) Bren School of Environmental Science & Management and is referred to as the Water Transfer Level Data Set. The School's website notes that this Water Transfer Data Set is the only comprehensive accounting of water trading between 1987 and 2008. The report reflects publically-available permanent transfers that occur in the western United States as reported in monthly trade journals. At the time of this evaluation, the database contained data up to 2009.

This appendix describes the methods for developing an annualized value from the UCSB Bren School's Water Transfer Level Data Set. This appendix outlines the methods of arriving at annualized values for the water rights transfer prices so that a representative value per acre-foot can be calculated using the reported estimates of average annual transfer volumes.

As described in Section 2.2.1.1, EPA used a subset of data extracted from the Bren School's data set, with the following manipulations:

- Filtered to years 1999 to present (up to year 2009 available in the dataset).
- Filtered to Agriculture to Urban transfers or Urban to Urban transfers only.
- Filtered to Sales only (not leases).
- Adjusted for inflation to represent Year 2011 values using the Bureau of Labor Statistics GDP deflator.
- Ten observations were removed that reflected rates ranging from about \$4,300 to \$1,400,000 per acre-foot, which were much higher than the next lowest value of about \$1900 per acre-foot and were suspected to be either reporting errors or unusual circumstances that did not reflect representative rates. Individual contract transactions were not researched.

The annualization approach taken by the Bren School is described below as is explained on the data set's website. The authors created a volumetric variable, called the committed variable, to capture the fact that more water is transferred than just in the first year of a sale. The committed variable discounts the flow of water over time relative to the year the water was first transferred using a 5% discount rate. For permanent transfers of water rights, the committed amount of water is determined the same way as finding the present value of a perpetual bond—by dividing the annual flow of water by the discount rate.

The purpose of the committed variable is to estimate the amount of water provided by the sale in perpetuity for the purpose of estimating value per acre-foot in perpetuity. While this approach is used in the water transfer field, it is difficult to justify the "discounting" of water volume to a broad, interdisciplinary audience. Therefore, the following method was developed for deriving a value per acre-foot that is independent of a discounted volume.

Application of the present value concept to monetary value is much more broadly understood than its application directly to water volume, as was the Bren School's approach. A more straightforward, intuitive approach would be to apply the total price paid for the water in perpetuity to an annuity formula. Once the annual payment for water is estimated, this can be divided by the average volume estimated for the first year after purchase. The standard annuity formula is:

$$A_{pt} = \frac{PV_{pt}}{[1-(1+r)^{-n}]/r}$$

Where:

A_{pt} = annualized price of permanent transfers

PV_{pt} = present value = price paid for permanent transfer

r = discount rate

n = number of years over which the water will be available

Note that if $n = \infty$, the equation simplifies to:

$$A_{pt} = PV_{pt}\ x\ r$$

Since the purchased water right extends into perpetuity, the correct formula multiplies the constant dollar upfront purchase price by the real discount rate to compute the annual annuity that, if paid each year into perpetuity, would exactly equal the net present value of the upfront contract purchase price. To complete the calculation, the annualized price was divided by the annual estimate of water purchased in the Bren School dataset as follows:

$$B_{pt} = \frac{A_{pt}}{V_{pt}}$$

Where:

B_{pt} = benefit value ($/acre-foot) based on permanent transfers

V_{pt} = annual volume purchased in acre-feet ("Average Annual Acre-Feet" variable in Bren School dataset)

The annualization of the water transfers values were determined with respect to a 3% and 7% discount rates. Figure 7-2 presents a comparison of the two annualization scenarios. For the 0% discount rate analysis variation presented in the study, 3% was used to derive the water rights price.

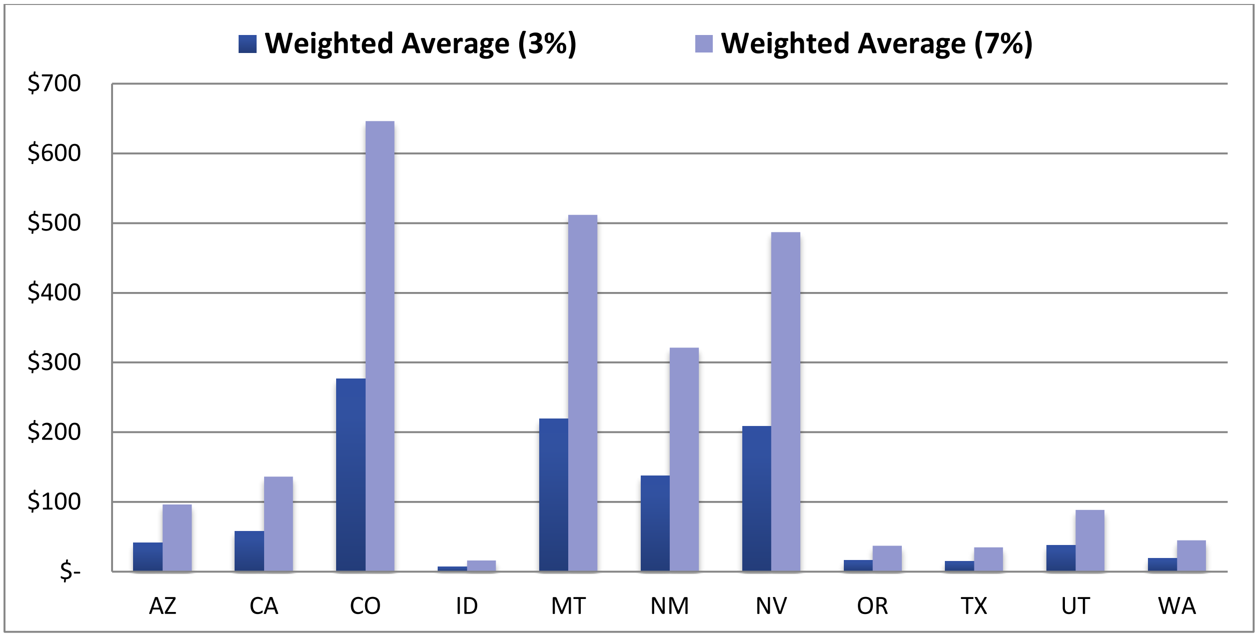


Figure 7-2 Comparison of Annual Payments for Western Water Rights Transfers Using a 3% and 7% Discount Rate

(This page is intentionally left blank.)

APPENDIX D METHOD FOR ESCALATION OF 2011 VALUES

This appendix outlines the multipliers used to account for the escalation of groundwater recharge values over time (independent from inflationary changes). The escalating annual values for groundwater benefits were recommended by a technical consultant specializing in western water pricing. The approach involved selecting a range of real annual escalation rates for the future value of water as displayed in Table 7-2.

Table 7-2 Recommended Real Annual Escalation Rates for the Future Value of Water

Application	Lower Bound	Likely Range	Upper Bound
Overall – Water and Wastewater Service	0%	2%	4%
Bulk Water Rates	0%	1-3%	4%
Retail Water Rates	0%	2-4%	6%
Water Transfers	0%	5-6%	10%

Three escalation scenarios were then developed to account for the range of factors that will affect water prices in the future. Table 7-3 below displays these three scenarios.

Table 7-3 Escalation Scenarios

Scenario	Escalation Rate	
	Western Transfers	Other States
Low	0.0%	0.0%
Medium	5.5%	2.0%
High	10.0%	4.0%

Commonly, escalation rates will vary across cost components of water and wastewater systems. The range and level of retail water rate escalation can be reasonably expected to be greater than that of bulk (wholesale) water rates because retail rates incorporate treatment and distribution which have stronger cost escalation drivers than other cost factors. The range and level of cost escalation of permanent water transfers is expected to be higher than either bulk water or retail water rates because of the tendency for transfers to be made in market tightening conditions where lower cost supply sources are no longer available. Additionally, western states have historically and will most likely continue to experience greater increases in water prices than other parts of the nation. For these reasons, the values from the Western Water Rights Transfers database were escalated using 0.0% (lower bound) for the low scenario, 5.5% for the medium scenario (mean of the likely range), and 10.0% for the high scenario (upper bound). Water values based on bulk rates or retail water rates were escalated using 0.0% (lower bound) for the low scenario, 2.0% for the medium scenario (within the likely range), and 4.0% for the high scenario (upper bound).

(This page is intentionally left blank.)

APPENDIX E EPA'S PROJECT PREDICTION MODEL

Overview of the EPA's Project Prediction Model for Estimating Future Development and Impervious Surface

EPA separately developed the impervious area projections that were used in this study. To predict future development, EPA combined forecasts of population growth and construction value with distributions of observed project characteristics to estimate a *baseline forecast of new and redevelopment projects* covering the period 2016 – 2040. [In the groundwater recharge study, the time period of study 2021 to 2040, and the value of construction was not required for use in the analysis.]

A forecasting model referred to as the Project Prediction Model (PPM) was developed. The forecast was made at 5-year increments, predicting individual projects – each with detailed project characteristics – at the Hydrologic Unit Code 12 watershed level (HUC-12). Characteristics included construction type (single-family residential, multi-family residential, commercial and institutional, industrial), development density class (rural, exurban, suburban, urban) and development type (new development, redevelopment). The next section of this appendix provides detail on the accounting methodology for impervious area in the forecasting process. The principal components of the PPM forecasting process include:

- *Estimating the baseline level of development and impervious cover in the year 2010.* The baseline estimate of existing development includes assessments of developed area and impervious surface cover (IS), and accounts for land area available for future development. The baseline was estimated according to algorithms that integrate:
    - Population density data obtained from the GIS-based Integrated Climate and Land Use Scenarios (ICLUS, v1.5);
    - Data on commercial and industrial IS from the 2006 National Land Use Cover Database (NLCD);
    - Ratios of historical industrial and commercial development based on IHS-Global Insight construction value data; and,
    - Data describing individual project characteristics that is derived from
        - RSMeans (Reed Construction), and
        - State-level Notice of Intent (NOI) databases for Maryland, New York, and California.

  By combining these datasets, an integrated picture of baseline development, including developed area, IS area, population density, and undeveloped land was established for the year 2015 at the HUC-12 scale nationwide.

- *Estimating aggregate development value constraints.* The PPM methodology was designed to ensure that the profile of forecasted projects matches future expectations about the quantity, type, and location of development across the United States. These constraints were developed based on estimates of population growth from the US Census Bureau, IHS Global Insight construction value forecasts, and the ratio of new to redevelopment projects (occurring across construction types and population density categories) estimated from Maryland, New York and California NOI data.

- *Generating a project database for each State-MSA region.* The second component of the PPM converts the aforementioned measures of construction activity into individual projects. EPA uses distributions and ratios describing key project characteristics obtained from the RSMeans and the NOI databases. Project level values were randomly drawn, within constraints, to forecast future construction occurring in State-MSA regions over 5-year increments between 2016 and 2040. Each project was then probabilistically assigned a suitable project size (acres), IS cover (acres) and a dollar value.

- *Spatially allocating forecasted projects to HUC-12 watersheds within State and MSA regions.* Projects forecast for a given MSA/Non-MSA region were allocated to HUC-12 watershed polygons in that region according to patterns of growth projected by the ICLUS model. If allocation of new projects was not possible (because of insufficient land area available to new development), the fraction of redevelopment projects was increased, projects re-generated, and spatial allocation attempted once again. This process was repeated until either i) new projects were successfully assigned, or ii) all construction value was assigned to redevelopment projects.
- *Assigning additional project characteristics.* Once assigned to HUC-12s, projects were assigned additional characteristics appropriate to location, density- and construction-type, including soil characteristics (according to the US General Soil Map - STATSGO2), state (for MSAs crossing state boundaries), representative climate station, and existing stormwater regulations. Project characteristics assigned into individual HUC-12s were tracked such that total IS (and marginal changes to IS occurring with redevelopment) can be calculated through time, and land available to new construction decreases. Notably, as population densities increase (and available land decreases), the fraction of total construction value occurring in redevelopment projects increases.
- *Aggregation to the county level.* The county level aggregations are based on an intersection between the HUC12 project prediction model results and the census block GIS data overlay. The block-level data included information on the percentage of each census block that overlapped different HUC12 watersheds (for example, a census block might overlap 3 different HUC12s, in which case the percentage of block area in each of those three HUC12s was available). Using this intersection of HUC12s and Blocks, the PPM HUC12 results were parsed to the block-level based on the percentage of block area in each HUC12. Then census blocks were aggregated to counties.

Using Project Prediction Model Results to Predict IS at the County Level

The Project Prediction Model was designed to predict projects at the MSA/HUC-12 watershed scale. This geographic scale was considered to be sufficiently detailed to address climate and demographic patterns relevant for regional and national scale analyses, while also being large enough to accommodate the prediction of construction projects that can range in size from one to several hundred acres.

The prediction of individual development projects, rather than only developed acres, was necessary to support the economic and engineering analyses, as these analyses must account for the frequency of occurrence for project level attributes. However, modeling at the HUC-12 watershed scale did not align with the county-scale data for the groundwater recharge analysis, so a methodology was developed to allocate HUC-12 scale estimates of development and IS areas to 1-hectare pixels located within the watershed. What follows is an overview of the methodology used to 'push' aggregate development estimates to a finer resolution, first for baseline development, then for future new and redevelopment.

A basic approach was used to allocate the predicted development area and IS area for each HUC-12. First, baseline (i.e., 2015) development and IS estimates were allocated. New and redevelopment estimates for each of the five subsequent 5-year time steps were then allocated in turn. ICLUS model output and NLCD data were available at the hectare scale, and were used to estimate hectare-scale baseline development and undeveloped land areas. Output from ICLUS provided pixel-level residential IS estimates, while NLCD data provided pixel-level IS estimates for non-residential development. Using ratios of average total developed area to IS from state NOI data, EPA was able to estimate residential land area and non-residential land area.

Baseline Development and Impervious Surface Allocation

For each hectare pixel within a HUC-12, the amount of potentially developable land was estimated by subtracting all of the residential development estimated by ICLUS and nonresidential development estimated by NLCD[4]:

Developable Area = Total Area – Residential Area – Commercial/Institutional Area – Industrial Area

Note that ICLUS residential IS output and NLCD non-residential IS data were derived independently of one another. Consequently for this analysis, development area estimates were extrapolated from both of these data sets using average ratios of IS to developed area derived from NOI data. As a result, the sum of residential and nonresidential land exceeded the area (1 hectare) of some pixels. When this occurred this excess developed area was reallocated to other pixels within the same HUC-12.

Before the excess developed area was reallocated, it was first aggregated across the HUC-12 and then divided into smaller units one tenth of a hectare in size. These smaller units were then assigned to pixels with developable space, starting with the pixels with the most developable area. This was done until all of the excess developed area had been reallocated.

Once all developed area was allocated to individual pixels and re-allocated as necessary within the same HUC-12, these pixels were checked for excessive IS. Pixels with excessive IS arise because ICLUS/NLCD estimates of IS sometimes exceeded the maximum imperviousness of projects observed in NOI databases. To ensure the sum of pixel-level estimates of IS were consistent with those used in the project prediction model, reallocation of this excess IS was required. For each pixel, IS% was compared against the maximum percent IS (Max IS %) observed in NOI data. For all pixels with IS greater than the Max IS %, pixel IS was capped at Max IS % and the excess was aggregated for the HUC-12. This process followed the same approach for reallocating excess developed area, where excess IS was divided into one tenth of a hectare units and reallocated to pixels with developed area below Max IS %, with probabilities of reallocation highest in pixels with the lowest IS %.

New Development and Impervious Surface Allocation

For each time step, each new project greater than one hectare was split into blocks of one hectare. These blocks were then allocated to pixels with developable area equal to one hectare within the same HUC-12. Maintaining project integrity was not necessary for the groundwater recharge analysis, would have been extremely computationally intensive, and for many HUC-12's likely infeasible. Consequently, each block was allocated independently, and there was no effort to allocate blocks to contiguous pixels. These hectare blocks were allocated until either all of the project's blocks were allocated or there were no more pixels with a hectare of developable land remaining in the HUC. When this occurred, remaining project area was divided into progressively smaller blocks (e.g., 0.5, 0.1, 0.05, 0.01 hectares) and the allocation process was repeated as needed until each project's area had been fully allocated. A check was made to ensure that no pixel contains more than a hectare of development; if any excess development was found, it was aggregated, divided into tenths of a hectare, and reallocated using the same approach as with baseline development above.

Project IS was divided up into the new project blocks equally (i.e., if the initial project had 40% IS, all subsequent blocks were assigned 40% IS). After all project developed area had been allocated, a check was made to ensure that no pixel contains more than the maximum IS observed in NOI data. If any excess IS was found, it was aggregated and reallocated using the same approach as with baseline IS, described above.

---

[4] The ICLUS model screens out pixels containing areas considered undevelopable, including: water features, parkland, and agricultural zones. No development was allocated to pixels identified as being undevelopable.

Redevelopment and Impervious Surface Allocation

For a given time step and HUC-12, redevelopment projects were allocated after all new development projects. Each redevelopment project was split into blocks and allocated, using a process similar to that used to allocate new development. However, only pixels with existing development were assigned redevelopment projects, and then only to the previously developed area within each pixel.

After all redevelopment projects were allocated, the net change in IS was calculated for each pixel assigned redevelopment. Similar to the check made with new development IS, net redevelopment IS for each pixel was compared to the maximum IS observed in the NOI data, and all excess IS was reallocated to other pixels containing redevelopment area. Once the redevelopment process was complete, new project area was allocated for the next time step. This process continued until all projects predicted within the analytical time frame and relevant HUC-12s were allocated.