Phase III - Water Supply Alternatives
05/09/2013

1.0 Introduction

The purpose of this document is to describe and analyze, at an appraisal level, water supply alternatives to satisfy unmet water demand in the Central Yavapai Highlands Water Resources Management Study (CYHWRMS) Planning Area in 2050. Figure 1.1 shows the location of the study area, and identifies the water planning areas (WPA), groundwater sub-basins, and the Prescott Active Management Area (PRAMA).

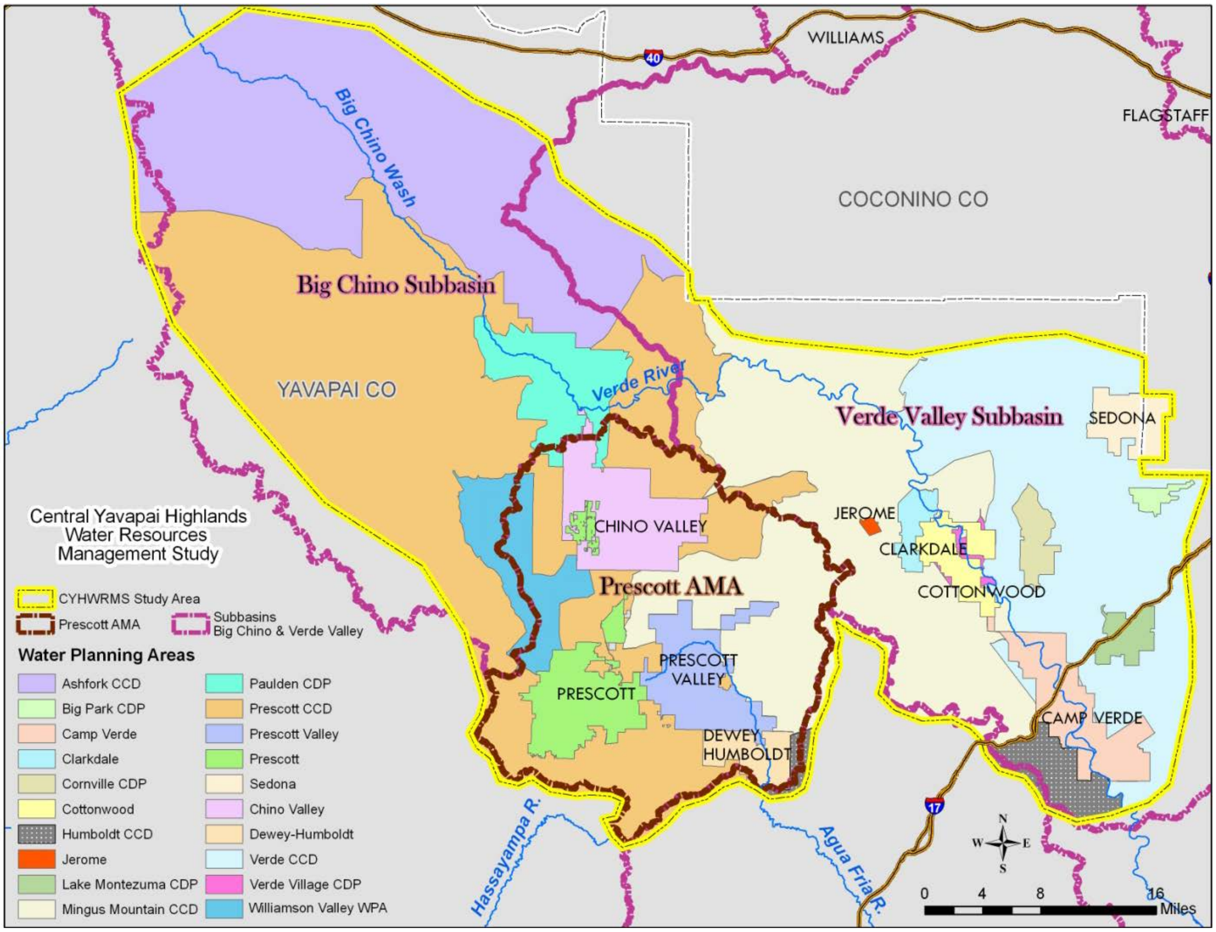


Figure 1.1 Study Area, Water Planning Areas, Sub-basins, and the Prescott Active Management Area

Table 1.1 shows the 2050 water supply excess or deficit for the WPAs; only three WPAs show a supply excess in 2050. It should be noted that the volumes in Table 1.1 are the result of assumptions used in the Phase I Demand Analysis. Specifically, conservation measures and reduction of future agriculture were incorporated into the Phase I methodology. The 2050 water supply excess or deficit was determined by calculating the difference between the 2006 total demand (which is assumed to be the 2006 supply) and the 2050 total demand. The total 2050 water supply deficit is 45,279 AF/yr. All of the alternatives only meet a portion of the total 2050 water supply deficit.

Table 1.1 Water Supply Excesses or Deficits in 2050 from Phase I – Demand Analysis

Water Planning Area	**2050 Water Supply (AF/yr)**	**Water Planning Area**	**2050 Water Supply (AF/yr)**
Camp Verde	1,887	Big Park CDP	-591
Dewey-Humboldt	-456	Cornville CDP	356
Clarkdale	-1,706	Lake Montezuma CDP	-264
Cottonwood	-7,092	Ctn-Verde Village CDP	-1,145
Jerome	-0[1]	Williamson CDP	-1,441
Prescott Valley	-13,869	Verde CCD	-170
Chino Valley	-6,946	Prescott CCD	-712
Prescott	-6,695	Mingus Mountain CCD	-444
Sedona	-1,584	Humboldt CCD	190
Paulden CDP	-590	Ashfork CCD	-4,007

The potential alternative water supplies inside the study area were identified in Phase II and include: groundwater, effluent, flood water[2], and storm water. Surface water[3] and groundwater sources outside the study area were also identified as potential alternative sources of supply.

Through the stakeholder process, 13 potential water supply alternatives were developed. Upon further consideration and investigation, three of the alternatives were removed from the list because, although considered, they will not be evaluated. These alternatives were either a demand side reduction which incorporated conservation measures into the 2050 GPPD (Alt. 9 Implement Conservation) or resulted in increased or restored volumes of surface water flow (Alt.

---

[1] Jerome's 2050 Water Supply Deficit has been updated from 0 in Phase I Demand Analysis to -23 as requested by Jane Moore, Jerome WPA Representative.

[2] From Phase II, "Flood water is generated in tributaries in each of the sub-basins and is available to be developed as an additional supply in the study area. Water supply developed from the collection and storage of unappropriated flood water is dependent on high flow events and will be relatively unreliable from year to year." This water is available because there is little dedicated flood control space in the Verde River system and water from flood events is released when system storage is at capacity. This is typically called a "spill" condition.

[3] The Phase II analysis concluded that existing claims for surface water far exceed available supply within the study area. Therefore, surface water inside the study area was not a potential alternative supply.

12 Weather Modification/Cloud Seeding and Alt. 13 Watershed Management), but they did not have a component for collecting the water supply.

This document provides an assessment of 10 potential water supply alternatives grouped by water supply types (Table 1.2) including the following: a brief summary of the water supply alternative; the WPAs for which the alternative is considered; a description of the alternative including assumptions and volumes of water that will be developed; infrastructure requirements; an alternative cost analysis; and annual and project worth costs. Table 1.3 describes the alternatives that were considered but not evaluated. Additional information regarding those alternatives is presented in section 3.0 of this document.

Table 1.2 Water Supply Alternatives and Description Grouped by Water Supply Type

Water Supply	Alternative	Alternative Description
Groundwater	**1**	Local Groundwater Development within the WPA (Inside and outside PRAMA)
	2	Regional Groundwater Development – Big Chino Pipelines (PRAMA and Verde Valley)
	3	Regional Groundwater Development Outside Study Area - Bill Williams Sub-basin and Big Sandy Sub-basin
Effluent	**4**	Conversion of Existing Systems - Urban
	5	Conversion of Existing Systems - Rural
	6	Additional Effluent from Increased Population
Flood Water	**7**	Capture and Store Unappropriated Verde River or tributary water
Storm Water	**8**	Rainwater Harvesting – Aquifer Storage
Conservation	**9**	Implement Conservation (e.g. low flow toilets, turf restrictions, educational programs, etc.)
Surface Water	**10**	Alamo Lake
	11	Colorado River via (a) Alamo Lake, (b) Diamond Creek, (c) Lake Mead, (d) Lake Havasu, (e) Lake Mohave, and (f) Lake Powell
Other	**12**	Weather Modification – Cloud Seeding
	13	Watershed Management

Table 1.3 Water Supply Alternatives Considered but not Evaluated

Water Supply	Alternative	Alternative Description
Conservation	**9**	Implement Conservation (e.g. low flow toilets, turf restrictions, educational programs, etc.)
Other	**12**	Weather Modification – Cloud Seeding
	13	Watershed Management

The next step after the assessment of the alternatives is to evaluate the alternatives for viability. This document serves as a just one part of the evaluation process and is to describe the alternatives, assumptions and provide costs. Other analyses will be considered during the evaluation of alternatives process. A significant outcome of the evaluation of alternatives is the ability to compare the annual cost per thousand gallons of water for each of the alternatives. At the appraisal study level, it should be noted that all cost estimates for the alternatives are strictly comparative in nature and represent costs only as an order of magnitude. They should not be taken to represent actual construction costs. Refinements would be required for each alternative before an actual cost estimate could be represented which is done at a feasibility level study. Table 1.4 summarizes the costs for each alternative. Alternative number 8 volume and cost information is for 64 acre sample improvements.

Table 1.4 Alternative Annual Cost per Volume

Alt #	Description of Alternative	Volume (AF/yr)	Costs				
			Field Cost ($)	Amortized Annual Cost ($)	Annual O&M Cost ($)	Annual Cost per AF ($/AF)	Annual Cost per Thousand ($/Kgal)
Alternatives Using Groundwater Supplies							
1	Local GW – Inside PRAMA, Non-exempt Wells	1,648	$1,080,713	$51,400	-	$31	$0.10
1	Local GW – Inside PRAMA, Exempt Wells	19,623	$1,570,685,813	$74,687,700	-	$3,806	$11.68
1	Local GW – Outside PRAMA, Non-exempt or Urban Wells	12,178	$8,144,135	$387,300	-	$32	$0.10
1	Local GW – Outside PRAMA, Exempt or Rural Wells	7,592	$607,708,336	$28,897,100	-	$3,806	$11.68
2	Regional GW – Big Chino to PRAMA	12,468	$121,892,305	$5,796,100	$1,868,805	$615	$1.89
2	Regional GW – Big Chino to Verde Valley	12,382	$311,005,854	$14,788,600	$2,643,426	$1,408	$4.32
3	Regional GW Outside Study Area – Big Sandy Sub-basin	42,379	$987,537,108	$46,958,400	$11,595,880	$1,382	$4.24
3	Regional GW Outside Study Area – Bill Williams Sub-basin	42,379	$910,985,979	$43,318,300	$11,124,148	$1,285	$3.94
Alternatives Using Effluent Supplies							
4	Conversion of Existing Systems – Urban	2941	$237,629,700	$11,116,300	$18,702,100	$10,138.85	$31.11
5	Conversion of Existing Systems – Rural	3320	$134,856,500	$6,412,600	$10,788,500	$5,181.06	$15.90
6	New Effluent from New Population – High Volume	34,934	$963,742,300	$45,826,900	$77,099,400	$3518.82	$10.80
6	New Effluent from New Population – Conservative Volume	21,614	$834,349,600	$39,674,100	$66,748,000	$4,923.76	$15.11

Alternatives Using Flood Water[4]							
			Costs				
Alt #	Description of Alternative	Volume (AF/yr)	Field Cost ($)	Amortized Annual Cost ($)	Annual O&M Cost ($)	Annual Cost per AF ($/AF)	Annual Cost per Thousand ($/Kgal)
7	Capture and Store Unappropriated Verde River - Bartlett Dam A	10,000	$166,981,000	$7,940,100	$1,923,800	$986	$3.03
7	Capture and Store Unappropriated Verde River - Bartlett Dam B	25,000	$345,877,000	$16,446,800	$4,888,000	$853	$2.62
7	Capture and Store Unappropriated Verde River - Bartlett Dam C	45,000	$570,108,000	$27,109,200	$8,378,350	$789	$2.42
7	Capture and Store Unappropriated Verde River - Horseshoe Dam A	10,000	$157,956,000	$7,511,000	$1,923,000	$943	$2.90
7	Capture and Store Unappropriated Verde River - Horseshoe Dam B	25,000	$335,785,000	$15,966,900	$4,887,995	$834	$2.56
7	Capture and Store Unappropriated Verde River - Horseshoe Dam C	45,000	$559,746,000	$26,616,500	$8,378,350	$778	$2.39
7	Sullivan Dam	2,240	$48,229,000	$2,293,300	$480,640	$1,238	$3.80
7	Page Springs	2,240	$44,664,000	$2,123,800	$488,040	$1,166	$3.58
Alternatives Using Storm Water							
8	Rainwater Harvesting – Aquifer Storage Scenario 1	18	-	-	-	$4,389	$13.47
8	Rainwater Harvesting – Aquifer Storage Scenario 2	20	-	-	-	$4,805	$14.74
8	Rainwater Harvesting – Aquifer Storage Scenario 3	20	-	-	-	$3,691	$11.33
8	Rainwater Harvesting – Aquifer Storage Scenario 4	20	-	-	-	$3,161	$9.70

---

[4] Alternative 8 field costs and amortized and O&M annual costs are not shown because local and regional costs were not directly additive until presented on a unit area basis. Local and regional field costs are separately presented in Table 2.8.7. Refer to Table 2.8.8 for amortized and O&M annual costs. Alternative 8 volumes are for 64 acre sample improvements.

Alt #	Description of Alternative	Volume (AF/yr)	Costs				
			Field Cost ($)	Amortized Annual Cost ($)	Annual O&M Cost ($)	Annual Cost per AF ($/AF)	Annual Cost per Thousand ($/Kgal)
8	Rainwater Harvesting – Aquifer Storage Scenario 5	14	-	-	-	$4,328	$13.28
8	Rainwater Harvesting – Aquifer Storage Scenario 6	9	-	-	-	$8,370	$25.69
8	Rainwater Harvesting – Aquifer Storage Scenario 7	8	-	-	-	$6,796	$20.77
8	Rainwater Harvesting – Aquifer Storage Scenario 8	26	-	-	-	$5,449	$16.72
8	Rainwater Harvesting – Aquifer Storage Scenario 9	36	-	-	-	$1,746	$5.36
8	Rainwater Harvesting – Aquifer Storage Scenario 10	26	-	-	-	$5,571	$17.10
Alternatives Using Imported Surface Water							
10	Alamo Lake	42,379	$895,515,610	$42,582,700	$11,744,870	$1,282	$3.93
11	Colorado River via Alamo Lake	42,379	$895,515,610	$42,582,700	$11,744,870	$1,282	$3.93
11	Colorado River via Diamond Creek	42,379	$1,028,225,962	$48,893,200	$12,243,356	$1,443	$4.43
11	Colorado River via Lake Mead	42,379	$1,447,553,494	$68,832,600	$14,700,056	$1,971	$6.05
11	Colorado River via Lake Havasu	42,379	$1,397,988,786	$66,475,800	$13,966,410	$1,898	$5.83
11	Colorado River via Lake Mohave	42,379	$1,273,716,646	$60,566,500	$14,709,294	$1,776	$5.45
11	Colorado River via Lake Powell	42,379	$1,161,614,426	$55,235,900	$12,722,029	$1,605	$4.92

2.0 Alternatives

The assessment of alternatives 1 through 13 includes the following elements for evaluation:

Summary
Water Planning Areas Affected
Description
Infrastructure Requirements
Field Costs and Assumptions Analysis
Annual and Project Worth Cost

The alternatives 9, 12 and 13 that did not warrant further evaluation, do not contain all of these elements.

2.1 Alternative 1 – Local Groundwater Development within the WPA (Inside and outside the PRAMA)

A. Summary of Alternative 1

This alternative proposes the continued use and development of groundwater supplies within the WPAs to meet all future water demand. The continued use of local groundwater to meet future demand is perceived to be the most convenient or easiest of the alternatives because it requires the least amount of change as it will continue on the current course of development. However, there may be impacts to the local aquifer that require evaluation and consideration. In areas where unlimited development of groundwater results in overdraft, problems associated with land subsidence, declines in stream flow, and reduction in riparian vegetation may occur. Additionally, the development of groundwater to meet municipal demand inside the Prescott Active Management Area (PRAMA) is limited by the Assured Water Supply regulations.

This alternative relies solely on development of groundwater within the sub-basin to meet the water supply deficit in 2050. For clarity of discussion, this alternative is separated into two components because of regulatory differences with respect to groundwater use within the WPAs. In this alternative, 13 of the WPAs are outside of the PRAMA, consequently, there is little regulation regarding groundwater use within those WPAs. Four of the WPAs are inside the PRAMA and have significant regulatory constraints on development and use of groundwater.

B. Alternative 1 Water Planning Areas

The WPAs considered in this alternative are those that show a 2050 water supply deficit (Table 1.1). Because only part of Williamson Valley, Mingus Mountain CCD and Prescott CCD are within the PRAMA, it has been assumed that they will pump groundwater from outside the PRAMA and are not subject to groundwater restrictions within the AMA.

C. Alternative 1 Description

WPAs inside the PRAMA

The Active Management Areas (AMAs) were created in 1980 in an effort to more effectively manage groundwater use in the highest groundwater use areas of the state through more intense regulation. The goal for the PRAMA is safe yield by 2025. In general, safe yield means that no more groundwater is withdrawn than is naturally and/or artificially replenished. The PRAMA was determined to be out of safe yield in 1999.

The 1999 declaration that the PRAMA was out of safe yield resulted in the implementation of more stringent Assured Water Supply requirements, particularly more stringent limitations on the volume of groundwater that could be utilized by new subdivisions. As a result, new municipal demand that results from the development of new subdivisions must be predominantly met by renewable water supplies. New municipal demand that does not result from the development of new subdivisions may be met with local groundwater.

Prescott WPA

Because the City of Prescott is a designated provider, the Prescott WPA is different from all other WPAs from a regulatory perspective, therefore it was evaluated differently. The method used to determine the manner in which local groundwater could be developed and utilized within the Prescott WPA was guided by the City of Prescott's Modified Designation of Assured Water Supply issued December 30, 2009 - Decision and Order No. 86-401501.0001 (Modified Designation). The Modified Designation mandates the maximum volume of groundwater that may be withdrawn and used by the City of Prescott for 100 years while still meeting the criteria for a designated provider. The City of Prescott has recently developed new wells with sufficient capacity to pump the groundwater allowance in accordance with the Modified Designation. Consequently, it was determined that there is existing well capacity to meet the Prescott WPA 2050 water supply deficit, therefore drafting cost estimates for new wells was determined to be unnecessary for the Prescott WPA

Chino Valley WPA/Dewey Humboldt WPA/Prescott Valley WPA

For these WPAs, Geographic Information System (GIS) was used to query currently platted subdivisions from the Yavapai County parcel database in order to determine the maximum groundwater allowance allowed under currently issued Certificates of Assured Water Supply. The number of subdivision lots was the number of vacant subdivision lots within the WPAs obtained from the Yavapai County parcel database (Table 2.1). For this alternative it was assumed one subdivision lot represented one household. For each subdivision lot, the groundwater volume was calculated by multiplying the WPA's Census Persons per Household (PPH) times 120 gallons per day per person.

The maximum groundwater allowance volume associated with currently undeveloped subdivisions lots was assumed to be met by new non-exempt, municipal wells (Table 2.1.1, column F). Any volume of groundwater in excess of the maximum groundwater allowance, or the 2050 water supply deficit must be met by exempt wells or by an alternative water supply (Table 2.1.1, column H). Private domestic wells are referred to as exempt wells. It was assumed that new non-exempt wells would be operated by water providers pumping an average of 248 gallons per minute for 12 hours per day, or 200 AF/yr. It was assumed that new exempt wells would provide 0.33 AF/yr as identified in the Phase I analysis.

Table 2.1.1. Allowable and not Allowable Groundwater Volume and Number of New Non-exempt and Exempt Wells Required to Supply the Deficit

Water Planning Area	**Subdivision Lots**	**Census PPH**	**Gallons Per Day per Household (GPD)**	**Total Subdivision Allowable GW Use (GPD)**	**Total Subdivision Allowable GW Use (AF/yr)**	**2050 Water Supply Deficit (AF/yr)**	**2050 Water Supply Deficit minus Total Subdivision Allowable GW Use (AF/yr)**	**Number of New Non-exempt Wells**	**Number of New Exempt Wells**
A	B	C	D *(C*120)*	E *(B*D)*	F	G	H *(G-F)*	I *(F/200)*	J *(H/0.33)*
Chino Valley	1,189	2.58	309.6	368,114	412	6,946	6,534	2	19,800
Dewey-Humboldt	685	2.23	267.6	183,306	205	456	251	1	761
Prescott Valley	2,950	2.6	312	920,400	1,031	13,869	12,838	5	38,903
Total	4,824			1,471,820	1,648	21,271	19,623	8	59,464

WPAs Outside the PRAMA

Groundwater use outside the PRAMA is not subject to AMA regulations and beneficial use is the legal limit in these areas. There are four entities outside the PRAMA that have obtained Designations of Adequate Water Supply. There are no volumetric limitations on the volume of groundwater that can be utilized by these entities, however, to maintain an adequate designation, groundwater pumping cannot cause groundwater depths to go below 1,200 feet below land surface. General Statement: It does not appear that groundwater pumping under this alternative would cause groundwater declines of this magnitude, therefore there were no regulatory limitations put upon these WPAs with respect to non-exempt well pumpage.

For these WPAs, an analysis was done to determine what percentage of municipal demand is provided either by a water company or by private domestic wells. It was assumed that groundwater in rural areas is generally accessed by private domestic wells that are referred to as exempt wells. Conversely, it was assumed that urban areas are generally served by water companies of varying sizes by non-exempt wells. The proportion of non-exempt wells and exempt wells reflects an approximation of rural and urban populations in each planning area. It is assumed that the present pattern for rural or urban areas will be similar in future growth. The 2006 Water Use Tables from the Phase I Demand Analysis were analyzed to determine what percentage of municipal water was provided by a water company (urban) and what percentage was provided by private domestic wells (rural) (see Table 2.1.2).

The first step in determining the number of new exempt and non-exempt wells needed to meet demand was calculation of the 2050 urban and rural water supply deficits. This was derived by applying the rural and urban percentages to the 2050 water supply deficit. The number of new non-exempt wells was then calculated by dividing the urban supply deficit by 200 as it was assumed that new non-exempt wells would be operated by water providers pumping an average of 248 gallons per minute for 12 hours per day or 200 AF/yr. The number of new exempt wells was calculated by dividing the rural supply deficit by 0.33 as 0.33 AF/yr (family household usage for private domestic wells identified in the Phase I analysis). The numbers of new non-exempt and exempt wells needed to meet the 2050 water supply deficit are shown in Table 2.1.2.

Table 2.1.2. 2050 Water Supply Deficit and Number of New Non-exempt and Exempt Wells to Withdraw

Water Planning Area	2050 Water Supply Deficit (AF/yr)	Urban %	Rural %	2050 Urban Water Supply Deficit (AF/yr)	2050 Rural Water Supply Deficit (AF/yr)	Number of New Non-exempt Urban Wells	Number of New Exempt Rural Wells
Clarkdale	1,706	100	0	1,706	0	9	0
Cottonwood	7,092	100	0	7,092	0	35	0
Jerome	23	100	0	23	0	0	0
Sedona	1,584	100	0	1,584	0	8	0
Paulden CDP	590	36	64	212	378	1	1,145
Big Park CDP	591	100	0	591	0	3	0
Lake Montezuma CDP	264	56	44	148	116	1	352
Ctn-Verde Village CDP	1,145	0	100	0	1,145	0	3,471
Williamson CDP	1,441	57	43	821	620	4	1,879
Verde CCD	170	0	100	0	170	0	514
Prescott CCD	712	0	100	0	712	0	2,158
Mingus Mtn CCD	444	0	100	0	444	0	1,344
Ashfork CCD	4,007	0	100	0	4,007	0	12,144
Total	19,770			12,178	7,592	61	23,006

D. Infrastructure Requirements

In this alternative, the only infrastructure evaluated is wells. Information regarding well depth, casing diameter and pump capacity was obtained for wells located in the study area from the Arizona Department of Water Resources Well Registry. Initially, this information was intended to be utilized to estimate well construction costs. However, due to the range in well construction costs, it was determined that an average construction cost per well would be more appropriate than determination of a well construction cost based on assumptions regarding depth, casing and pump capacity.

E. Alternative 1 Field Cost Analysis

Exempt Wells

The cost to construct a single exempt well as presented in this document is general in nature and is on a unit cost basis including drilling and casing the well, installing the pump and a volume of on-ground storage. Actual construction costs for wells can vary significantly and are dependent on the well size, depth, and location.

This cost analysis utilizes a construction cost of $17,500 per exempt well. This cost estimate was provided by Nathan White from Northern Arizona Pump Incorporated. Table 2.1.3 summarizes the total cost for all exempt wells within the WPAs included in this alternative. These costs utilize the construction cost plus additional contingencies as appropriate. For additional information regarding cost and contingencies see the Cost Estimate Worksheets in Appendix X.

Non-exempt Wells

The cost to construct a single non-exempt well as presented in this document is general in nature and is on a unit cost basis including drilling and casing the well, installing the pump and a volume of on-ground storage. Actual construction costs for wells can vary significantly and are dependent on the well size, depth, and location.

This cost analysis utilizes three construction costs based on location of the wells. Non-exempt wells in the Big Chino Sub-basin have a construction cost of $46,500, wells in the PRAMA have a construction cost of $89,500 and wells in the Verde Valley Sub-basin have a construction cost of $92,200. These cost estimates were provided by Nathan White from Northern Arizona Pump Incorporated. Table 2.1.4 summarizes the total cost for all non-exempt wells within the WPAs included in this alternative; WPAs within the Big Chino Sub-basin are highlighted in the table and PRAMA WPAs are italicized. For additional information regarding cost and contingencies see the Cost Estimate Worksheets.

Table 2.1.3. Total Construction Cost for Exempt Wells

Water Planning Area	**Number of New Exempt Rural Wells**	**Exempt Well Cost ($)**
Dewey-Humboldt	761	68,109,500
Clarkdale	0	0
Cottonwood	0	0
Jerome	0	0
Prescott Valley	38,903	3,481,818,500
Chino Valley	19,800	346,500,000
Prescott	0	
Sedona	0	0
Paulden CDP	1,145	20,037,500
Big Park CDP	0	0
Lake Montezuma CDP	352	6,160,000
Ctn-Verde Village CDP	3,471	60,742,500
Williamson CDP	1,879	32,882,500
Verde CCD	514	8,995,000
Prescott CCD	2,158	37,765,000
Mingus Mtn CCD	1,344	23,520,000
Ashfork CCD	12,144	212,520,000
Total	82,471	402,622,500

Table 2.1.4. Total Construction Cost for Non-exempt Wells

Water Planning Area	**Number of New Non-exempt Wells**	**New Non-exempt Well Cost ($)**
Dewey-Humboldt	1	89,500
Clarkdale	9	829,800
Cottonwood	35	3,227,000
Jerome	0	0
Prescott Valley	5	447,500
Chino Valley	2	179,000
Prescott	0	
Sedona	8	737600
Paulden CDP	1	46,500
Big Park CDP	3	276,600
Lake Montezuma CDP	1	92,200
Ctn-Verde Village CDP	0	0
Williamson CDP	4	186,000
Verde CCD	0	0
Prescott CCD	0	0
Mingus Mtn CCD	0	0
Ashfork CCD	0	0
Total	69	6,111,700

F. Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual operation and maintenance (O&M) costs divided by the water supply yield. There is no cost inflation for O&M over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 1 variations are shown in Table 2.1.5.

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for the Alternative 1 variations are shown in Table 2.1.6. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.1.5 Annual Project Costs

Alternative Versions	Amortized Annual Const Cost ($)	Annual Cost ($/AF)	Annual Cost ($/ Kgal)
Prescott AMA Non-exempt Wells	$51,400	$31.19	$0.10
Prescott AMA Exempt Wells	$74,687,700	$3,806.13	$11.68
Outside AMA (Big Chino & Verde Valley Sub-basins) Non-exempt or Urban Wells	$387,300	$31.80	$0.10
Outside AMA (Big Chino & Verde Valley Sub-basins) Exempt or Rural Wells	$28,897,100	$3,806.26	$11.68

Table 2.1.6. Present Worth Project Costs

Alternative Versions	Field Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/Kgal)
Prescott AMA Non-exempt Wells	$1,080,713	$655.77	$2.01
Prescott AMA Exempt Wells	$1,570,685,813	$80,043.10	$245.64
Outside AMA (Big Chino & Verde Valley Sub-basins) Non-exempt or Urban Wells	$8,144,135	$668.76	$2.05
Outside AMA (Big Chino & Verde Valley Sub-basins) Exempt or Rural Wells	$607,708,336	$80,045.88	$245.65

2.2 Alternative 2 – Regional Groundwater Development - Big Chino Pipelines (PRAMA & Verde Valley)

A. Summary of Alternative 2

This alternative proposes two versions that rely on development of groundwater supplies from the Big Chino Sub-basin for transportation via pipeline to either specific WPAs within the PRAMA or to specific WPAs within the Verde Valley. This alternative is considered to be regional groundwater development because it requires development of groundwater supply from the Big Chino Water Ranch, within the study area.

It should be noted that Black & Veatch completed a pipeline conceptual design report for the Big Chino Water Ranch including preliminary design work and design and construction cost estimates. The Black and Veatch report has a total project cost estimated at $174,761,600 in 2007 dollars. However, to insure consistency between the alternatives in this document, the Bureau of Reclamation has re-evaluated this alternative at the appraisal level, including costs, and with the assumptions identified within this alternative.

B. Alternative 2 Water Planning Areas

The WPAs considered for this alternative within the PRAMA and the volume of 2050 water supply deficit that will be met are shown in Table 2.2.1. In this alternative, the water supply deficits for Prescott and Prescott Valley WPAs were limited by provisions within the City of Prescott's Modified Designation of Assured Water Supply. The water supply deficit for the Town of Chino Valley to be met by this alternative was determined by the Town of Chino Valley.

Table 2.2.1. Alternative 2 – PRAMA Version WPAs and Volume of 2050 Water Supply Deficit

Water Planning Area	2050 Water Supply (AF/yr)
Prescott Valley	-3,703
Chino Valley	-4,400
Prescott	-4,365
Total	**-12,468**

The WPAs considered in the Verde Valley version of this alternative are: Clarkdale, Cottonwood, Sedona, Big Park CDP, Lake Montezuma CDP and Ctn-Verde Village CDP. This alternative meets the total 2050 water supply deficit of 12,382 AF for these WPAs (Table 1.1). Rural WPAs that are primarily served from private, domestic wells were not included within this alternative.

C. Alternative 2 Description

This alternative is based, in part, on the provisions of A.R.S. §45-555 which authorizes the transportation of groundwater withdrawn in the Big Chino Sub-basin to an initial AMA. Arizona Revised Statutes §45-555(E) permits the City of Prescott to withdraw and transport a total of 8,068 AF of groundwater. The City of Prescott and the Town of Prescott Valley have entered into an agreement to split that volume of water 54%:46% resulting in the volumes listed in Table 2.2.1 for those WPAs. Additionally §45-555(A) authorizes the transportation of groundwater associated with historically irrigated acreage. Transportation of groundwater from the Big Chino for the Chino Valley WPA will likely occur pursuant to this statute.

The transmission line for the PRAMA alternative begins at a conceptualized well field at the Big Chino Water Ranch located approximately 30 miles northwest of Paulden, Arizona. It should be recognized that groundwater transported to the Chino Valley WPA may be withdrawn from a different location. For additional information regarding the transmission facilities (including pumping plant locations, pressure reducing stations, pipeline size and pipeline flows) for this alternative, see Appendix X. The transmission line continues through Paulden south on Highway 89 to the first distribution center located in the Chino Valley WPA. The transmission line continues to Prescott Valley and through the Highway 69 and Highway 89 junction to Prescott.

The transmission line for the Verde Valley alternative also begins at a conceptualized well field at the Big Chino Water Ranch. As stated above, it should be recognized that groundwater transported to the Verde Valley may be withdrawn from a different location. The transmission line continues south through Paulden to the Highway 69 and Highway 89 junction. The transmission line then continues to deliver water west towards each of the water distribution centers from the Highway 69 and Highway 89 junction to Sedona and from the Interstate 17 and Highway 260 junctions to Clarkdale[5].

The location, elevation and profile of pipeline alignments were developed using GIS software and elevation data obtained from the 2004 USGS National Elevation Dataset. Elevations are referenced to the National American Vertical Datum 1988.

D. Infrastructure Requirements and Alternative 2 Field Cost Assumptions and Analysis

The infrastructure requirements and the associated cost component assumptions[6] are presented below. Unit costs were based on the North Central Arizona Water Supply Study (NCAWSS) report and adjusted using the Bureau of Reclamation construction cost indexes. The cost

---

[5] Alternate transmission routes for the Verde Valley version of the alternative were examined that included a pipeline alignment along the Verde River beginning at Sullivan Dam east to Clarkdale. These were not included because of limitations due to topography.

[6] Design data assumptions are based on the North Central Arizona Water Supply Study Report, October 2006 and the Peabody Coal Black Mesa Mine C-aquifer Water Supply Appraisal Study, April 2003.

estimates presented for this alternative do not include non-contract items such as right-of-ways, geological evaluations, public involvement, design costs, contracting, construction management, mitigation, legal, power costs, etc. Additional evaluations not included in these cost estimates are groundwater modeling, well field site selection, and geologic analysis for the well field site. Water storage tanks and pressure reducing stations required by water providers within their distribution system were not included in this cost analysis. For additional information regarding costs and contingencies see the Cost Estimate Worksheets.

Groundwater Wells

Determination of construction costs for groundwater wells is based, in part, on a January 2010 cost estimate for drilling a 600 foot deep well in Manuelito, New Mexico and from published construction rates[7]. In the Big Chino sub-basin near Paulden, existing well data indicates that wells range from seven to 2,800 gallons per minute. It was assumed that the proposed wells will yield 400 gallons per minute. This alternative assumes that 20 wells pumping at 400 gallons per minute will produce approximately 12, 912 AF/yr. The wells are assumed to be 20 inches in diameter and 800 feet deep with a zone of influence of approximately 600 feet. Well construction estimates for this alternative are $301,643 per well installation.

Well Field Gathering System

The well field gathering system quantities were based on wells spaced on-half mile apart. For purposes of these cost estimates, 12 inch PVC pipe was assumed to convey water from the groundwater wells to the transmission pipeline.

Pipelines

Pipe lengths and head classes were determined through GIS analysis of the pipeline alignments. Hydraulic profiles for the pipeline are included in Appendix X. The cost estimate includes the cost for corrosion monitoring and cathodic protection of steel pipelines, where applicable. Construction costs for corrosion monitoring and cathodic protection were assumed to be one percent of the construction cost. Additionally, the cost estimate includes the cost for drainage crossings that includes geologic and site evaluations, design and any additional components or materials for construction. Pipeline drainage crossings were assumed to be two percent of the construction cost.

Appurtenant structures and mechanical equipment associated with the pipeline are covered under "unlisted items" in the Cost Estimate Worksheets. These items include air valves, blowoffs, drains, flowmeters, altitude valves, and sectionalizing valves, etc.

Hydraulics

The Hazen-Williams equation was used to compute the loss due to friction in the pipe laterals. The pipeline design velocity is five feet per second or less and the maximum pumping lift would be approximately 450 feet. Pipe friction losses were limited to about 25 percent of the total dynamic head for the pumps.

---

[7] Rates from RS Means Heavy Construction Cost Data, 2010 edition.

It was assumed that all lateral pipe is mortar lined steel pipe with full inside diameters. A Hazen Williams Coefficient of 140 was used in the head loss calculations. Pipeline capacities were sized based on the 2050 water supply deficit only and a peaking factor was not applied. By limiting the pump lift to about 450 feet of head and adding 30 percent for an upsurge allowance, the pressure class for the pipe was generally limited to 575 feet (250 pounds per square inch). Pressure Reducing valve stations are required when pressures at a maximum exceed 500 feet.

Pressure Reducing Stations

In line pressure reducing stations were assumed to be required to limit the pipe head class to a maximum of 500 feet. The cost is based on a single pressure reducing station.

Excavation and Backfill

Excavation and backfill quantities for pipe earthwork were based on a typical trapezoidal trench section with 1:1 slopes and an average depth of cover of four feet. Excavation was assumed to be 60 percent rock and 40 percent common. This assumption allows for comparison to the NCAWSS Report. It should be noted the excavation cost for rock assumes that the material can be excavated with an excavator or trencher. Excavation that requires blasting or hoe-ramming is not included in this cost estimate because a geology evaluation and testing would be required. Embedment to three inches over the top of the pipeline was assumed to be imported material from nearby borrow areas.

Pumping Plants

The field costs for pumping plants were taken from the NCAWSS Report and adjusted for higher flows. Forebay tanks would be required upstream from each pumping plant to supply water during startup of the pumps. For this appraisal level estimate, all forebay tanks were estimated to be 10 feet in diameter and 20 feet tall. Air chambers will be required downstream and were assumed to be 20-foot-diameter spheres.

The cost estimate includes the cost for a Supervisory Control and Data Acquisition (SCADA) system for the control of the pumping plants. The construction costs for the SCADA system were assumed to be three percent of the construction cost.

Water Treatment

The unit cost of the water treatment for arsenic includes treatment and installation. For the purposes of this study it was assumed to be $1.50 gallons per day (gal/day).

Operation and Maintenance

Annual O&M costs for the pipelines were estimated to be 0.5 percent of the initial pipe costs. For pumping plants, annual O&M costs were estimated at eight percent of the pumping plant costs. Annual (O&M) costs for water treatment were estimated to be eight percent of the water treatment costs.

E. Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual operation and maintenance (O&M) costs divided by the water supply yield. There is no cost inflation for O&M over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 2 variations are shown in Table 2.2.2.

Table 2.2.2. Annual Project Costs

Alternative Versions	Amortized Annual Const Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/ Kgal)
Pipeline from Big Chino to PRAMA	$5,796,100	$1,868,805	$615	$1.89
Pipeline from Big Chino to Verde Valley	$14,788,600	$2,643,426	$1,408	$4.32

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for the Alternative 2 variations are shown in Table 2.2.3. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.2.3. Present Worth Project Costs

Alternative Versions	Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/ Kgal)
Pipeline from Big Chino to PRAMA	$121,892,305	$39,301,071	$12,929	$40.00
Pipeline from Big Chino to Verde Valley	$311,005,854	$55,591,402	$29,607	$91.00

2.3 Alternative 3 – Regional Groundwater Development Outside Study Area - Bill Williams Sub-basin and Big Sandy Sub-basin

A. Summary of Alternative 3

This alternative proposes two options that rely on development of groundwater supplies from either the Bill Williams Sub-basin or the Big Sandy Sub-basin for transportation via pipeline to the WPAs. This alternative is considered regional groundwater development because it is development of groundwater from one localized area outside of the study area. In the Big Sandy version of the alternative, the groundwater is developed near Wikieup, Arizona and in the Bill Williams version the groundwater is developed at Burro Creek.

B. Alternative 3 Water Planning Areas

The WPAs considered in this alternative are those that show a 2050 water supply deficit (Table 1.1) with the exception of rural WPAs that are primarily served from private, domestic wells. The following WPAs were not included within this alternative: Jerome, Verde CCD, Prescott CCD, Mingus Mountain CCD, Humboldt CCD and Ashfork CCD.

C. Alternative 3 Description

In the Big Sandy version of the alternative, the transmission line begins at a conceptualized well field that is assumed to be placed in the river bed alluvium. The transmission line continues southeast along Highway 93 and north along Highway 89 to the first water distribution center located in Prescott, Arizona. The transmission line then continues on to each of the water distribution centers from Prescott to Sedona through the Highway 89 and Highway 69 Junction to Paulden and from the Interstate 17 and Highway 260 junction to Clarkdale.

The Bill Williams transmission line also begins at a conceptual well field and continues heading southeast along Highway 93 towards Congress. The transmission line to the study area from Congress is the same as in the Big Sandy alternative.

For additional information regarding the transmission facilities (including pumping plant locations, pressure reducing stations, pipeline size and pipeline flows) for this alternative, see Appendix X.

The location, elevation and profile of pipeline alignments was developed using GIS software and elevation data obtained from the 2004 USGS National Elevation Dataset. Elevations are referenced to the National American Vertical Datum 1988.

D. Infrastructure Requirements and Alternative 3 Field Cost Assumptions and Analysis

This alternative is very similar to Alternative 2 with respect to infrastructure requirements and field costs assumptions. The infrastructure requirements and the associated cost component assumptions[8] are presented below. Again, unit costs were based on the NCAWSS report and adjusted using the Bureau of Reclamation construction cost indexes. The cost estimates presented for this alternative do not include non-contract items such as right-or-ways, geological evaluations, public involvement, design costs, contracting, construction management, mitigation, legal, power costs, etc. Additional evaluations not included in these cost estimates are groundwater modeling, well field site selection, and geologic analysis for the well field site. Water storage tanks and pressure reducing stations required by water providers within their distribution system were not included in this cost analysis. For additional information regarding costs and contingencies see the Cost Estimate Worksheets.

Groundwater Wells

Determination of construction costs for groundwater wells is based, in part, on a January 2010 cost estimate for drilling a 600 foot deep well in Manuelito, New Mexico and from published construction rates[9].

In the Bill Williams basin where Highway 93 crosses Burro Creek, existing well data indicates that wells range from five to 5,000 gallons per minute. It was assumed that the proposed wells will yield 280 gallons per minute. This version of the alternative assumes that 94 wells pumping an average of 280 gallons per minute will produce approximately 42,482 AF/yr. The wells are assumed to be 20 inches in diameter and 650 feet deep with a zone of influence of approximately 550 feet.

In the Big Sandy groundwater basin near Wikieup, existing well data indicates that wells range from 100 to 2,000 gallons per minute. It was assumed that the proposed wells will yield at least 300 gallons per minutes. This version of the alternative assumes that 88 wells pumping at 300 gallons per minute will produce approximately 42,612 AF/yr. The wells are assumed to be 20 inches in diameter and 700 feet deep with a zone of influence of approximately 600 feet.

Well construction estimates for the Bill Williams version of this alternative is $279,893 per well installation and for the Big Sandy version it is $288,143.

Well Field Gathering System

The well field gathering system quantities were based on wells spaced on-half mile apart. For purposes of these cost estimates, 12 inch PVC pipe was assumed to convey water from the groundwater wells to the transmission pipeline.

Pipelines

Pipe lengths and head classes were determined through GIS analysis of the pipeline alignments. Hydraulic profiles for the pipeline are included in Appendix X. The cost estimate includes the cost for corrosion monitoring and cathodic protection of steel pipelines, where applicable. Construction costs for corrosion monitoring and cathodic protection were assumed to be one percent of the construction cost. Additionally, the cost estimate includes the cost for drainage

---

[8] Design data assumptions are based on the North Central Arizona Water Supply Study Report, October 2006 and the Peabody Coal Black Mesa Mine C-aquifer Water Supply Appraisal Study, April 2003.

[9] Rates from RS Means Heavy Construction Cost Data, 2010 edition.

crossings that includes geologic and site evaluations, design and any additional components or materials for construction. Pipeline drainage crossings were assumed to be two percent of the construction cost.

Appurtenant structures and mechanical equipment associated with the pipeline are covered under “unlisted items” in the Cost Estimate Worksheets. These items include air valves, blowoffs, drains, flowmeters, altitude valves, and sectionalizing valves, etc.

Hydraulics

The Hazen-Williams equation was used to compute the loss due to friction in the pipe laterals. The pipeline design velocity is five feet per second or less and the maximum pumping lift would be approximately 450 feet. Pipe friction losses were limited to about 25 percent of the total dynamic head for the pumps.

It was assumed that all lateral pipe is mortar lined steel pipe with full inside diameters. A Hazen Williams Coefficient of 140 was used in the head loss calculations. Pipeline capacities were sized based on the 2050 water supply deficit only and a peaking factor was not applied. By limiting the pump lift to about 450 feet of head and adding 30 percent for an upsurge allowance, the pressure class for the pipe was generally limited to 575 feet (250 pounds per square inch). Pressure Reducing valve stations are required when pressures at a maximum exceed 500 feet.

Pressure Reducing Stations

In line pressure reducing stations were assumed to be required to limit the pipe head class to a maximum of 500 feet. The cost is based on a single pressure reducing station.

Excavation and Backfill

Excavation and backfill quantities for pipe earthwork were based on a typical trapezoidal trench section with 1:1 slopes and an average depth of cover of four feet. Excavation was assumed to be 60 percent rock and 40 percent common. This assumption allows for comparison to the NCAWSS Report. It should be noted the excavation cost for rock assumes that the material can be excavated with an excavator or trencher. Excavation that requires blasting or hoe-ramming is not included in this cost estimate because a geology evaluation and testing would be required. Embedment to three inches over the top of the pipeline was assumed to be imported material from nearby borrow areas.

Pumping Plants

The field costs for pumping plants were taken from the NCAWSS Report and adjusted for higher flows. Forebay tanks would be required upstream from each pumping plant to supply water during startup of the pumps. For this appraisal level estimate, all forebay tanks were estimated to be 10 feet in diameter and 20 feet tall. Air chambers will be required downstream and were assumed to be 20-foot-diameter spheres.

The cost estimate includes the cost for a Supervisory Control and Data Acquisition (SCADA) system for the control of the pumping plants. The construction costs for the SCADA system were assumed to be three percent of the construction cost.

Water Treatment
The unit cost of the water treatment for arsenic includes treatment and installation. For the purposes of this study it was assumed to be $1.50 gallons per day (gal/day).

Operation and Maintenance
Annual O&M costs for the pipelines were estimated to be 0.5 percent of the initial pipe costs. For pumping plants, annual O&M costs were estimated at eight percent of the pumping plant costs. Annual (O&M) costs for water treatment were estimated to be eight percent of the water treatment costs.

E. Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual O&M costs divided by the water supply yield. There is no cost inflation for O&M over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 3 variations are shown in Table 2.3.1.

Table 2.3.1. Annual Project Costs

Alternative Versions	Amortized Annual Const Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/ Kgal)
Bill Williams Pipeline Alignment	$43,318,300	$11,124,148	$1,285	$3.94
Big Sandy Pipeline Alignment	$46,958,400	$11,595,880	$1,382	$4.24

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for the Alternative 3 variations are shown in Table 2.3.2. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.3.2. Present Worth Project Costs

Alternative Versions	Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/ Kgal)
Bill Williams Pipeline Alignment	$910,985,979	$233,941,457	$27,016	$83.00
Big Sandy Pipeline Alignment	$987,985,108	$243,861,999	$29,057	$89.00

2.4 Alternative 4 - Conversion of Existing Septic Systems - Urban

A. Summary of Alternative 4

Treated effluent is considered to be a renewable water resource that increases as population increases. This renewable water supply has the potential to augment water resources if it replaces use of another water supply. Reuse options include: turf irrigation, groundwater recharge, or industrial use. Costs for reuse options are not developed in this Study. Identification of types and locations of reuse could be part of a feasibility investigation and the associated costs would be developed at that time. This alternative focuses on conversion of urban septic systems to public systems, identifies the potential volume of water that would be available, and develops costs to convey and treat the wastewater.

Septic systems are a source of unutilized or underutilized wastewater. Septic systems may provide a benefit via groundwater recharge, however, recharge volumes are difficult to quantify. Another benefit of converting septic systems to sewer connections is that septic systems may have a negative impact on groundwater quality. The EPA concluded that septic systems are a potential source of water contamination in the United States [1]. Factors that may negatively impact groundwater quality include the density of septic systems, depth to groundwater, and the age of the septic systems. Converting septic systems to sewer systems would minimize the potential for groundwater contamination and provide a new water source to augment water supplies.

This alternative proposes conversion of urban residential septic systems to sewer connections. For the purposes of this study, “urban” refers to a WPA that is serviced by a water provider, sewer provider, or is within the boundary of a Certificates of Convenience and Necessity (CC&N). A CC&N defines an area where an entity holds exclusive rights to supply water or wastewater services within a specified geographic area.

This analysis estimated the number of residential properties in urban areas that use on-site septic systems. Under this alternative, residential septic systems would be converted to connections with sewer conveyance infrastructure. This would involve extending sewer conveyance infrastructure into areas where residences are currently on septic systems.

B. Alternative 4 Water Planning Areas

For Alternative 4, eleven WPA’s are considered urban. They are Camp Verde, Chino Valley, Clarkdale, Cottonwood, Jerome, Prescott, Prescott Valley, Sedona, Big Park CDP, Lake Montezuma CDP and Paulden CDP.

C. Alternative 4 Description

Under this alternative, residential septic systems would be converted to sewer service to increase the availability of effluent for reuse in urban areas. Urban areas typically consist of properties with smaller lot sizes and a higher density of households than rural areas. Septic conversions in higher density developments may be more cost effective than conversions in rural areas because less infrastructure may be required. Resources may already be in place in urban areas, such as right-of-ways, that would facilitate the construction of sewer infrastructure.

In this analysis, infrastructure requirements for each alternative are based on the status of the WWTF's. When average daily flow into a WWTF reaches 80 percent of its rated capacity, it was determined that a WWTF would require expansion. Based on this criteria, the WWTF's are categorized into three groups within each WPA.

Group A – Existing WWTF can accommodate additional wastewater capacity. Expansion of sewer conveyance infrastructure is required.

Group B – Existing WWTF requires expansion to accommodate additional wastewater capacity Expansion of sewer conveyance infrastructure is required.

Group C – Construction of new WWTF and sewer conveyance infrastructure is required.

Each WPA is assessed based on the group that its associated WWTF falls under. WPA's that have WWTF's with the capacity to process increased wastewater flows are within Group A, WPA's that have WWTF's that require expansion to process increased wastewater flows are within Group B, and WPA's that require construction of new WWTF's to process wastewater are within Group C.

Table 2.4.2 segregates the WPA's by WWTF group and shows 2010 wastewater volumes. Wastewater volumes for each WPA were estimated for 2010 using an average wastewater production of 69 gallons per person per day. Average wastewater production could be reduced in the future as implementation of conservation measures further reduces household water use. The number of septic systems located within each urban WPA was estimated using population served by water providers, knowledge of local experts and by calculating the difference between water accounts and sewer accounts.

Table 2.4.2. Grouping of WPAs for Urban Septic Conversion by WWTF Status

Group	Water Planning Area	2010 Septic Wastewater Volume
Group A	Camp Verde	207 AFY (184,798 gal/day)
	Chino Valley	47 AFY (41,959 gal/day)
Group B	Big Park	276 AFY (246,397 gal/day)
	Clarkdale	40 AFY (35,710 gal/day)
	Cottonwood	821 AFY (732,943 gal/day)
	Prescott	751 AFY (670,450 gal/day)
	Prescott Valley	664 AFY (592,782 gal/day)
	Sedona	151 AFY (134,804 gal/day)
Group C	Jerome	10 AFY (8,927 gal/day)
	Lake Montezuma	254 AFY (226,757 gal/day)
	Paulden	146 AFY (130,341 gal/day)

AFY - Acre-feet per year

Although the Jerome WPA is included in Group C (WPA without WWTF) Jerome does have a WWTF. The majority of Jerome's septic systems are located at elevations that are below the existing sewer transmission lines and these septic systems cannot easily be tied into the existing gravity fed sewer system. The Jerome Town Council indicated that a separate WWTF would need to be constructed to serve areas that are located below the elevation of the current WWTF infrastructure.

D. Alternative 4 Infrastructure Requirements

The type and amount of infrastructure required for this alternative depends on the WPA grouping which is based on the status of the associated WWTF.

WWTF's in Group A may require additional infrastructure to expand sewer conveyance systems. Sewer lines, manholes and lift stations would comprise the main components of the expansion. Septic system conversions would require a wastewater pipeline and connection between the residence and the sewer conveyance system.

WWTF's in Group B would include the infrastructure requirements of Group A and in addition, infrastructure to increase the wastewater treatment capacity. Additional infrastructure may include screens, clarifiers, pumps and basins. WWTF expansions would be designed to operate at 80% capacity.

WWTF's in Group C would include the infrastructure requirements of Group A and in addition, construction of a new WWTF. New WWTF's would be designed to operate at 80% capacity and to produce Class A+ effluent.

E. Alternative 4 Field Cost Analysis

General cost estimates are provided for the WPA's based on the WWTF grouping. Cost estimates to construct new sewer conveyance infrastructure, to convert residential septic systems to sewer connections, and to construct additional capacity or new WWTF's are provided in this analysis. Development of detailed cost estimates would require specific information for each WWTF within the WPA's. This level of detail would be completed during a feasibility study and is beyond the scope of an appraisal study.

Group A

Table 2.4.3 shows wastewater volumes and WWTF capacities for WPA's in Group A. If the septic systems in this group were converted to sewer systems, the existing WWTF's would still operate at 80% capacity.

Table 2.4.3. 2010 Wastewater Volumes – Urban Septic Conversion Group A

Water Planning Area	New Wastewater Volume	Current Effluent Generated	Current Plant Capacity
Camp Verde	207 AFY (184,798 gal/day)	195 AFY (174,085 gal/day)	728 AFY (649,917 gal/day)
Chino Valley	47 AFY (41,959 gal/day)	242 AFY (216,044 gal/day)	560 AFY (499,936 gal/day)

AFY - Acre-feet per year

Construction costs for Group A include expansion of the sewer conveyance infrastructure, connection to the sewer system and abandonment of septic systems. Costs to build sewer conveyance infrastructure are shown in Table 2.4.4. Table 2.4.5 shows the unit cost estimate to connect a septic system to a sewer system.

The cost of adding sewer conveyance infrastructure was determined using estimated costs per linear mile of pipeline. To estimate the cost per linear foot to expand sewer conveyance infrastructure, contractor bids for expansion of the City of Prescott sewer system were used. Three project types or sewer system types were identified and bids were averaged for each type: residential ($346 per linear foot), force main residential ($575 per linear foot) and rural ($120 per linear foot). Construction costs may be higher in residential areas due to sidewalks, curbs, gutters, and traffic control features. Costs were indexed to 2011. Urban area sewer infrastructure expansion lengths were determined by taking the square root of the corresponding water service area. Assumptions used to develop costs for urban sewer conveyance expansions include: 1) 80 percent of the line would be residential and, 2) 20 percent would be a force main. Rural sewer infrastructure expansion lengths were assumed to be half of the longest distance across the corresponding WPA.

Costs to connect a septic system to a sewer conveyance pipeline were estimated using an assumed distance of 400 feet from the home to the sewer line, a yard line depth of 18 inches, a 4-inch PVC pipe, and septic system abandonment including emptying the septic tank and filling it with compacted dirt or sand. Costs were indexed to 2011. Permits are required to convert a septic system to a sewer system. Fees associated with septic conversion can be expensive and variable and details regarding specific costs for conversion fees are not provided in this analysis.

Table 2.4.4. Sewer Conveyance Infrastructure Cost Estimate for Urban Area – Group A

Type of System	Linear Foot Estimate	Linear Mile Estimate
Residential Area	$346	$1,826,880
Forced Main in Residential Area	$575	$3,036,000
Rural Area	$120	$633,600

Table 2.4.5. Septic System Conversion Cost Estimate – Group A

Pipe costs including trenching	$10.08/linear foot	$4,032
Backfill and compaction	$35.28cubic yard	$522
Connection to sewer line	$750	$750
Septic System Abandonment	$2,000	$2,000
	TOTAL	$7,304

Group B

Table 2.4.6 shows wastewater volumes for each WPA in Group B. The WWTF's in these WPA's would require construction of additional capacity to process new wastewater from septic conversions and remain at or below the 80% capacity threshold.

Table 2.4.6. 2010 Wastewater Volumes – Urban Septic Conversion Group B

Water Planning Area	New Wastewater Volume	Current Effluent Generated	Current Plant Capacity
Big Park	276 AFY (246,397 gal/day)	365 AFY (325,851 gal/day)	560 AFY (499,936 gal/day)
Clarkdale	40 AFY (35,710 gal/day)	291 AFY (259,788 gal/day)	280 AFY (249,968 gal/day)
Cottonwood	821 AFY (732,943 gal/day)	1,008 AFY (899,886 gal/day)	1,680 AFY (1,499,809 gal/day)
Prescott*	751 AFY (670,450 gal/day)	4,144 AFY (3,700,000 gal/day)	4,704 AFY (4,200,000 gal/day)
Prescott Valley	664 AFY (592,782 gal/day)	2,750 AFY (2,455,045 gal/day)	4,200 AFY (3,749,523 gal/day)
Sedona	151 AFY (134,804 gal/day)	1,410 AFY (1,258,769 gal/day)	1,792 AFY (1,599,797 gal/day)

AFY - Acre-feet per year

*- Current effluent generated and capacity are for Sundog and Airport plants only and obtained from Sundog WWTP and Airport WRF Capacity and Technology Master Plan, October 2010

Table 2.4.7 shows the additional treatment capacity needed for WWTF's in each WPA to process additional wastewater from converted septic systems. The additional capacity is determined using the new effluent volume generated plus a 20 percent increase to account for the extra capacity required for expansion of the WWTF.

Estimated costs for Group B WPA's include construction of sewer conveyance infrastructure, as described for Group A plus the cost to expand the WWTF's to operate at 80% capacity. WWTF expansion costs were estimated using actual costs to expand six WWTF's in Arizona. Based on this, the average cost for a WWTF expansion is $9.42 per gallon per day. Costs were indexed to 2011.

Table 2.4.7. Wastewater Treatment Facility Expansion Volumes – Group B

Planning Area	Additional Plant Capacity	Total New Capacity	Cost of expanding existing facility capacity $9.42/gallon/day
Big Park	209 AFY (186,583 gal/day)	769 AFY (686,519 gal/day)	
Clarkdale	117 AFY (104,450 gal/day)	397 AFY (354,419 gal/day)	
Cottonwood	515 AFY (459,762 gal/day)	2,195 AFY (1,959,570 gal/day)	
Prescott	1,170 AFY (1,044,508 gal/day)	5,874 AFY (5,243,969 gal/day)	
Prescott Valley	103 AFY (91,952 gal/day)	4,303 AFY (3,841,471 gal/day)	
Sedona	81 AFY (72,312 gal/day)	1,873 AFY (1,672,107 gal/day)	

AFY - Acre-feet per year

Group C

Table 2.4.8 shows the wastewater volumes that would be generated in WPA's in Group C if new WWTF's were constructed and residential septic systems were converted to sewer connections.

Table 2.4.8. 2010 Wastewater Volumes – Urban Septic Conversion Group C

Planning Area	New Wastewater Volume	Current Effluent Generated	Current Plant Capacity
Jerome	10 AFY (8,927 gal/day)	N/A	N/A
Lake Montezuma	254 AFY (226,757 gal/day)	N/A	N/A
Paulden	146 AFY (130,340 gal/day)	N/A	N/A

AFY - Acre-feet per year

Table 2.4.9 shows the capacity requirements for new WWTF's for WPA's in Group C. The capacity requirements are based on the new effluent volumes that would be generated plus a 20 percent increase to account for the extra capacity required for a new WWTF to operate at 80 percent capacity. Construction costs include sewer conveyance infrastructure for conversion of septic to sewer as described for Group A and construction of new WWTF's. Costs to construct a new WWTF were estimated using actual costs to construct three new WWTF's located in the City of Peoria, Town of Cave Creek and City of Kingman. These facilities produce Class A+ effluent. The average cost to construct a new WWTF that operates at 80% capacity and produces Class A+ effluent is $13.38 per gallon per day. Costs were indexed to 2011.

Table 2.4.9. New Wastewater Treatment Facility Capacities for WPA's in Group C

Planning Area	**Plant Capacity**	Cost of building new facility
Jerome	12 AFY (10,713 gal/day)	$13.38/gallon/day
Lake Montezuma	305 AFY (272,286 gal/day)	
Paulden	175 AFY (156,230 gal/day)	

AFY - Acre-feet per year

F. Alternative 4 Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual operation and maintenance (O&M) over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 4 groups are shown in Table 2.4.10.

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for each group in Alternative 4 are shown in Table 2.4.11. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.4.10. Annual Costs - Conversion of Existing Septic Systems (Urban)

Group	Amortized Annual Const Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/Kgal)
A	$1,176,800	$1,979,900	$12,427.91	$38.14
B	$8,304,100	$13,970,800	$10,148.02	$31.14
C	$1,635,400	$2,751,400	$8,916.20	$27.36
Total	$11,116,300	$18,702,100	$10138.85	$31.11

Table 2.4.11 Present Worth Costs - Conversion of Existing Septic Systems (Urban)

Group	Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/Kgal)
A	$24,748,600	$41,637,200	$261,361.24	$802.09
B	$174,635,100	$293,806,900	$213,413.20	$654.94
C	$34,392,100	$57,861,400	$187,507.16	$575.44
Total	$237,629,700	$393,305,500	$213,220.42	$654.35

Reuse of Treated Effluent

One of the most efficient tools in the conservation toolbox is reuse or recharge of treated effluent. The appropriate use of treated effluent is an important strategy in every community’s water portfolio. It is important for Cities and towns to use the right water quality for the right use – potable water for potable uses and reclaimed water for non-potable uses. With the advent of new technologies for purifying treated effluent, such as multi-stage membrane bioreactors, the industry is demonstrating that wastewater can be treated to a high degree of quality that may be purer than potable water. When this is the case, it’s logical to consider using treated effluent for potable use rather than non-potable use. The reality is that non-potable demands exist and that matching the water quality to use is a best management practice. Depending upon a community’s water demand portfolio, there can often be a considerable amount of effluent that may be recharged or reused in a beneficial way. Considering a community's water use profile and it's non-potable uses, the demand on groundwater supplies may be reduced if treated effluent is converted to potable water and used as such (Von Gaussig, 2012).

Legal, institutional, and psychological barriers currently prevent direct use of treated effluent for potable use. The psychological barrier and political (institutional) intransigence are the two biggest barriers. Opponents of "direct potable reuse" often tag such use as "toilet to tap," and convince regulators and policymakers that potable reuse is risky to public health and expensive to implement. Current treatment and monitoring practices can essentially eliminate admixture of under-treated water with potable supplies, but the stigma remains. As the public becomes better informed about the quality of treated effluent and the risks and benefits of potable reuse, the stigma will eventually be overcome, and decisions to implement direct or indirect potable reuse projects will gain support. As treatment technologies improve and costs decline, the economics of potable reuse of treated effluent will become more practical. We need to tackle the barriers of psychological resistance and political intransigence by introducing the concept to the public and educating them and our decision makers (Von Gaussig, 2012).

In this analysis, direct use of treated effluent is assumed to be turf irrigation and indirect use is assumed to be basin recharge. The Arizona Department of Environmental Quality (ADEQ) minimum reclaimed water quality standard for turf irrigation is Class B. Class B reclaimed water has undergone secondary treatment and disinfection. The quality of effluent required for basin recharge is dependent on site specific variables including geology, aquifer depth, and groundwater quality. The ADEQ issues an Aquifer Protection Permit for a recharge facility which contains site specific compliance standards for recharge of treated effluent.

Planning Areas Considered for Existing Unused Effluent

To quantify the volume of treated effluent that may be available for reuse, fourteen WPA's were assessed (Table 29).

Table 2.4.12. Water Planning Areas Considered for Existing Unused Effluent

For this alternative, WPAs that have existing unused effluent are considered and they are Camp Verde, Chino Valley, Clarkdale, Cottonwood, Dewey-Humboldt, Jerome, Prescott, Prescott Valley, Sedona, Big Park CPD, Cornville CDP, lake Montezuma CDP, Paulden CDP and Williamson CDP.

Existing Unused Effluent

In this analysis, unused effluent is defined as effluent that is passively disposed of. Effluent that is evaporated or discharged into a wash is not considered used. Effluent that is provided to an area or body of water via a formal agreement is interpreted to be utilized. For example, Big Park Domestic Wastewater Improvement District has an agreement with the Forest Service to discharge a particular volume of effluent down a tributary of Jack's Canyon Wash. Effluent that is discharged to a surface water designated as an effluent dependent water is considered utilized. For example, The Town of Jerome discharges effluent into Bitter Creek which is designated as an effluent dependent water. Table 30 lists WWTF's with unused effluent volumes.

Table 2.4.13. WWTF's with Unused Effluent Volumes

Facility	Planning Area	Volume Generated (Acre-Feet/Year)	Unused Volume
Camp Verde WWTP	Camp Verde	195	195 AFY (174,085 gal/day)
Clarkdale WWTP	Clarkdale	291	291 AFY (259,788 gal/day)
City of Sedona (3 facilities)	Sedona	1,410	1,410 AFY (1,258,769 gal/day)

AFY - Acre-feet per year

Infrastructure Requirements for Reuse

The type and amount of infrastructure required depends on the volume and end use of the effluent. Direct and indirect reuse would require a pressurized system with valves to deliver effluent for turf irrigation or basin recharge. Indirect use would also include costs to construct recharge basins. Indirect use would likely require WWTF upgrades to improve effluent quality for recharge. Infrastructure requirements to upgrade a facility are site specific. Upgrades can include new digesters, clarifiers, ultra-violet disinfection system, and larger drying beds. Details regarding requirements to upgrade a WWTF are not identified in this analysis and would be determined at the feasibility level.

Reuse Analysis

Cost

General unit costs are provided to upgrade facilities and install required infrastructure for direct and indirect reuse. Unit costs were derived from actual WWTF's that were upgraded in the United States.

Reuse Summary

Direct Reuse of Effluent

Construction costs include the installation of a pressurized 8-inch water line with valves to irrigate turf, on-site metering, and connections are shown on Table 31. These costs are based on actual costs to deliver treated effluent to golf courses in Casa Grande. Costs were indexed to 2011 dollars.

Table 2.4.14. Effluent Delivery for Turf Irrigation Cost Estimate

Linear Foot Estimate	Linear Mile Estimate
$131.88	$696,326

Indirect Reuse of Effluent

Construction cost estimates for a basin recharge facility were based on actual costs to construct 4 recharge facilities in Casa Grande and are shown in Table 32. Costs were indexed to 2011. Construction costs include pipeline, pump station, and spreading basins. Information available for the Casa Grande recharge facilities indicates that a total of 76.8 acres would be required to recharge 10 million gallons per day. Based on this information, approximately 130,000 gallons per day can be recharged in a 1 acre basin at an average infiltration rate of 1.2 feet per day. In this analysis, it is assumed that half of the basins would be wetted at any time and that 1.5 times the basin acreage would be needed for berms, roads and buffers for the facility.

Table 2.4.15. Cost Estimate to Construct Basin Recharge Facility

24-inch Pipeline	$272/linear foot
1.5 to 2.0 MGD Pump Station	$1.6 million
Spreading Basin berms roads buffers	$186,600/acre

Upgrade Treatment Facility

Cost estimates to upgrade an existing WWTF were developed based on actual costs to upgrade four existing WWTF's that produce Class A+ effluent. The upgrades consisted solely of improving the quality of the effluent produced at the facility. Three of the upgraded WWTF's were located on the East Coast and one was located on the West Coast. Table 33 shows the total cost and unit cost for the WWTF upgrades. Costs were indexed to 2011. Review of the unit costs indicate cost savings based on an economy of scale. Smaller facilities are much more expensive to upgrade on a unit cost basis.

Table 2.4.16. Total and Unit Costs to Upgrade Effluent Water Quality at Four WWTF's

	Project Cost	Plant Capacity	Unit Cost
San Diego, CA	$92.7 million	25 mgd	$3.71/gallon
Aberdeen, MD	$8 million	4 mgd	$2.00/gallon
Sturbridge, MA	$17 million	.75 mgd	$22.66/gallon
Bowie, MD	$10.5 million	.50 mgd	$21.00/gallon

These unit costs provide general information for effluent reuse and may be used for planning reclaimed water turf irrigation systems and effluent recharge facilities. When locations for turf irrigation and recharge facilities are identified, refined cost estimates can be prepared. This could be a part of a feasibility investigation.

2.5 Alternative 5 - Conversion of Existing Septic Systems - Rural

A. Summary of Alternative 5

Treated effluent is considered to be a renewable water resource that increases as population increases. This renewable water supply has the potential to augment water resources when used to irrigate turf, recharge groundwater, or when used for industrial processes. Costs for reuse options are not developed in this Study. Identification of types and locations of reuse could be part of a feasibility investigation and the associated costs would be developed at that time. This alternative focuses on conversion of rural septic systems to public systems, identifies the potential volume of water that would be available, and develops costs to convey and treat the wastewater.

Septic systems are a source of unutilized or underutilized wastewater. Septic systems may provide a benefit via groundwater recharge, however, recharge volumes are difficult to quantify. Another benefit of converting septic systems to sewer connections is that septic systems may have a negative impact on groundwater quality. The EPA concluded that septic systems are a potential source of water contamination in the United States [1]. Factors that may negatively impact groundwater quality include the density of septic systems, depth to groundwater, and the age of the septic systems. Converting septic systems to sewer systems would minimize the potential for groundwater contamination and provide a new water source to augment water supplies.

This alternative proposes conversion of rural residential septic systems to sewer connections. For the purposes of this study, “rural” refers to areas that are not served by a WPA that is serviced by a water provider, sewer provider, or is within the boundary of a Certificates of Convenience and Necessity (CC&N). A CC&N defines an area where an entity holds exclusive rights to supply water or wastewater services within a specified geographic area.

This analysis estimated the number of residential properties in rural areas that use on-site septic systems. Under this alternative, residential septic systems would be converted to connections with sewer conveyance infrastructure. This would involve extending sewer conveyance infrastructure into areas where residences are currently on septic systems.

B. Alternative 5 Water Planning Areas

All WPA's were considered for this alternative because every WPA contains areas that are not served by a water service area, a wastewater service area, or are designated as a CC&N. Only those planning areas where identifiable wastewater volumes could be documented are assessed.

C. Alternative 5 Description

This alternative involves conversion of residential septic systems to sewer service to increase the availability of effluent for reuse, in rural areas. This assessment considers rural areas to be outside of a water provider service area, a sewer service area or a CC&N. Rural areas tend to have larger lots and lower household density than urban areas. The WPA's are assessed individually.

Rural wastewater volumes were calculated using the number of rural parcels (2007 Yavapai County Geographic Information System), population (US Census 2000), and an average wastewater production of 69 gallons per person per day (Table 2.5.1). Average wastewater production could be reduced in the future as implementation of conservation measures further reduces household water use. Only residential parcels are considered for conversion of septic systems to a sewer system. This process yielded a rural population estimate by planning area.

Table 2.5.1. Conversion of Septic Systems in Rural Areas, Wastewater Volumes Greater than 10 AFY by WPA.

	Rural Population	Volume of Septic Wastewater (acre-feet per year)
Ashfork	470	36
Cornville	2,986	231
Cottonwood	933	72
Humboldt	227	18
Lake Montezuma	863	67
Mingus Mountain	2,170	168
Paulden	2,565	198
Prescott CCD	9,957	770
Prescott Valley	6,250	483
Prescott	4,454	344
Verde	1,056	82
Cottonwood-Verde Village	893	69
Williamson	2,952	228

D. Alternative 5 Infrastructure Requirements

All rural WPA's would require construction of sewer conveyance infrastructure and new WWTF's. The capacity of each WWTF would be specific to each WPA and designed to operate at 80% capacity and produce Class A+ effluent.

E. Alternative 5 Field Cost Analysis

Cost estimates for this appraisal study are general and limited to unit costs. The sewer systems differ in extent and material type. Table 2.5.2 shows the estimated unit cost of constructing a sewer conveyance infrastructure. Table 2.5.3 shows estimated unit costs to connect a septic system to a sewer system. Table 2.5.4 shows the capacity requirements for new WWTF's by WPA. The capacity requirements are determined using the new effluent volume generated plus a 20 percent increase to account for the extra capacity required for the new WWTF's to operate at 80 percent capacity.

The cost of adding sewer conveyance infrastructure was determined using estimated costs per linear mile of pipeline. To estimate the cost per linear foot to expand sewer conveyance infrastructure, contractor bids for expansion of the City of Prescott sewer system were used. Three project types or sewer system types were identified and bids were averaged for each type: residential ($346 per linear foot), force main residential ($575 per linear foot) and rural ($120 per linear foot). Costs were indexed to 2011. Rural area sewer infrastructure expansion lengths were assumed to be half of the longest distance across the corresponding WPA.

Costs to connect a septic system to a sewer conveyance pipeline were estimated using an assumed distance of 400 feet from the home to the sewer line, a yard line depth of 18 inches, 4-inch PVC pipe, and septic system abandonment including emptying the septic tank and filling it with compacted dirt or sand. Costs were indexed to 2011. Permits are required to convert a septic system to a sewer system. Fees associated with septic conversion can be expensive and variable and details regarding specific costs for fees are not provided in this analysis.

Table 2.5.2 Sewer Conveyance Infrastructure Cost Estimate for Rural Area

Type of System	Linear Foot Estimate	Linear Mile Estimate
Rural Area	$120	$633,600

Table 2.5.3 Septic Conversion Cost Estimate per Residence for Rural Area

Pipe costs including trenching	$10.08/linear foot	$4,032
Backfill and compaction	$35.28cubic yard	$522
Connection to sewer line	$750	$750
Septic System Abandonment	$2,000	$2,000
	TOTAL	$7,304

Table 2.5.4 New Wastewater Treatment Facility Capacities for Septic Conversion in Rural Areas

Water Planning Area	Plant Capacity	
Ashfork	43 AFY (38,388 gal/day)	Cost of building new facility $13.38/gallon/day
Cornville	277 AFY (247,289 gal/day)	
Cottonwood	86 AFY (76,776 gal/day)	
Humboldt	22 AFY (19,640 gal/day)	
Lake Montezuma	80 AFY (71,419 gal/day)	
Mingus Mountain	202 AFY (180,334 gal/day)	
Paulden	238 AFY (212,473 gal/day)	
Prescott CCD	924 AFY (824,894 gal/day)	
Prescott Valley	580 AFY (517,791 gal/day)	
Prescott	413 AFY (368,703 gal/day)	
Verde	98 AFY (87,489 gal/day)	
Cottonwood-Verde Village	83 AFY (74,098 gal/day)	
Williamson	274 AFY (244,611 gal/day)	

AFY - Acre-feet per year

F. Alternative 5 Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual operation and maintenance (O&M) over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 5 groups are shown in Table 2.5.6.

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for each group in Alternative 5 are shown in Table 2.5.7. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.5.6. Annual Costs - Conversion of Existing Septic Systems (Rural)

Amortized Annual Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/Kgal)
$6,412,600	$10,788,500	$5,181.06	$15.90

Table 2.5.7. Present Worth Costs - Conversion of Existing Septic Systems-Rural

Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth ($/Kgal)
$134,856,500	$226,883,200	$108,960	$334.38

Reuse of Treated Effluent

Refer to the discussion provided in Alternative 4.

2.6 Alternative 6 - New Effluent from New Population

A. Summary of Alternative 6

Treated effluent is considered to be a renewable water resource that increases as population increases. This renewable water supply has the potential to augment water resources if it replaces use of another water supply. Reuse options include: turf irrigation, groundwater recharge, or industrial use. Costs for reuse options are not developed in this Study. Identification of types and locations of reuse and/or recharge could be part of a feasibility investigation and the associated costs would be developed at that time. This alternative focuses on new wastewater volumes as a result of new population in 2050, identifies the potential volume of water that would be available, and develops costs to convey and treat the wastewater.

This alternative proposes that future effluent volumes will increase based on population increases in each of the WPA's from 2006 to 2050. This alternative assumes that new conveyance infrastructure will be required to connect new locations to sewer connections and that some existing WWTF's will be expanded and new WWTF's will be constructed to accommodate the new wastewater volumes.

B. Alternative 6 Water Planning Areas

Under Alternative 6, all WPA's were considered.

C. Alternative 6 Descriptions

This alternative estimates the volume of treated effluent that would be produced from new population in each of the twenty WPA's from 2006 to 2050. The new population was determined during the Phase I - Demand Analysis conducted for this Study. The new population was multiplied by an average wastewater production of 69 gallons per day per person to estimate the new wastewater volume available in 2050. Average wastewater production could be reduced in the future as implementation of conservation measures further reduces household water use. Table 2.6.1 shows the new population and new wastewater volumes by WPA.

Table 2.6.1. 2050 New Wastewater Volume by Water Planning Area

Planning Area	New Population (2006 to 2050)	New Wastewater Volume
Camp Verde	10,780	833 AFY (743,820 gal/day)
Dewey Humboldt	2,809	217 AFY (193,821 gal/day)
Clarkdale	18,461	1,427 AFY (1,273,809 gal/day)
Cottonwood	57,230	4,423 AFY (3,948,870 gal/day)
Jerome	290	22 AFY (20,010 gal/day)
Prescott Valley	104,390	8,068 AFY (7,202,910 gal/day)
Chino Valley	51,000	3,942 AFY (3,519,000 gal/day)
Prescott	50,928	3,936 AFY (3,514,032 gal/day)
Sedona	5,220	403 AFY (360,180 gal/day)

Planning Area	New Population (2006 to 2050)	New Wastewater Volume
Paulden CDP	8,757	677 AFY (604,233 gal/day)
Big Park CDP	1,079	83 AFY (74,451 gal/day)
Cornville CDP	3,373	261 AFY (232,737 gal/day)
Lake Montezuma CDP	4,071	315 AFY (280,899 gal/day)
Ctn-Verde Village CDP	8,333	644 AFY (574,977 gal/day)
Williamson CDP	6,617	511 AFY (456,573 gal/day)
Verde CCD	2,733	211 AFY (188,577 gal/day)
Prescott CCD	18,300	1,414 AFY (1,262,700 gal/day)
Mingus Mtn CCD	2,825	218 AFY (194,925 gal/day)
Humboldt CCD	382	30 AFY (26,358 gal/day)
Ashfork CCD	35,779	2,765 AFY (2,468,751 gal/day)

Table 2.6.2 shows the volume of effluent generated from new wastewater as a high estimate and a conservative estimate. The high estimate assumes that all new wastewater is captured in a sewer system for treatment, reuse and/or recharge. The conservative estimate takes into account the percentage of population in the region served by WWTF's. In 2002, the NACOG Section 208 Plan estimated that 45% of the population in Yavapai County was served by WWTF's. The conservative estimate uses the percent of the population that is served by a WWTF which may vary for each WPA based on projected land use and wastewater management plans.

Table 2.6.2. 2050 New Effluent High and Conservative Volumes

Planning Area	High Estimate (gallons/day)	% of Population served by WWTF (2050)	Conservative Estimate (gal/day)
Camp Verde	743,820	45%	334,719
Dewey Humboldt	193,821	45%	87,219
Clarkdale	1,273,809	45%	573,214

Planning Area	High Estimate (gallons/day)	% of Population served by WWTF (2050)	Conservative Estimate (gal/day)
Cottonwood	3,948,870	60%	2,369,322
Jerome	20,010	45%	9,005
Prescott Valley	7,202,910	100%	7,202,910
Chino Valley	3,519,000	45%	1,583,550
Prescott	3,514,032	45%	1,581,314
Sedona	360,180	45%	162,081
Paulden CDP	604,233	45%	271,905
Big Park CDP	74,451	45%	33,503
Cornville CDP	232,737	45%	104,732
Lake Montezuma CDP	280,899	45%	126,405
Ctn-Verde Village CDP	574,977	45%	258,740
Williamson CDP	456,573	45%	205,458
Verde CCD	188,577	45%	84,860
Prescott CCD	1,262,700	45%	568,215
Mingus Mtn CCD	194,925	45%	87,716
Humboldt CCD	26,358	45%	11,861
Ashfork CCD	2,468,751	45%	1,110,938

In this analysis, infrastructure requirements for each alternative are based on the status of the WWTF's. When average daily flow into a WWTF reaches 80 percent of its rated capacity, it was determined that a WWTF would require expansion. Based on this criteria, the WWTF's are categorized into three groups within each WPA.

Group A – Existing WWTF can accommodate additional wastewater capacity. Expansion of sewer conveyance infrastructure is required.

Group B – Existing WWTF requires expansion to accommodate additional wastewater capacity Expansion of sewer conveyance infrastructure is required.

Group C – Construction of new WWTF and sewer conveyance infrastructure is required.

Each WPA is assessed based on the group that its associated WWTF falls under. WPA's that have WWTF's with the capacity to process increased wastewater flows are within Group A, WPA's that have WWTF's that require expansion to process increased wastewater flows are within Group B, and WPA's that require construction of new WWTF's to process wastewater are within Group C.

WPA’s were segregated into the WWTF groupings based on the high and conservative wastewater volume estimates and the associated WWTF treatment capacity (Table 2.6.3).

Table 2.6.3. Grouping of WPA’s based on High and Conservative Wastewater Volumes

	High Estimate	**Conservative Estimate**
Group A	Big Park	Big Park
		Camp Verde
Group B	Camp Verde	Chino Valley
	Chino Valley	Clarkdale
	Clarkdale	Cottonwood
	Cottonwood	Prescott
	Prescott	Prescott Valley
	Prescott Valley	Sedona
	Sedona	
Group C	Ashfork CCD	Ashfork CCD
	Cornville CDP	Cornville CDP
	Dewey Humboldt	Dewey Humboldt
	Humboldt CCD	Humboldt CCD
	Jerome	Jerome
	Lake Montezuma	Lake Montezuma
	Mingus Mountain CDP	Mingus Mountain CDP
	Paulden	Paulden
	Prescott CCD	Prescott CCD
	Verde CCD	Verde CCD
	Ctn-Verde Village CDP	Verde Village CDP
	Williamson CDP	Williamson CDP

D. Alternative 6 Infrastructure Requirements

Group A infrastructure requirements include expansion of sewage collection systems.

Group B consists of the requirements from Group A and expansion of existing WWTF's to operate at 80% capacity. Group C includes the requirements from Group A and construction of a new WWTF designed to operate at 80% capacity and to produce Class A+ effluent.

E. Alternative 6 Field Cost Assumptions and Analysis

Cost estimates to construct new sewer conveyance infrastructure, to convert residential septic systems to sewer connections, and to construct additional capacity or new WWTF's are provided in this analysis. Development of detailed cost estimates would require specific information for each WWTF within the WPA's. This level of detail would be completed during a feasibility study and is beyond the scope of an appraisal study.

Total 2050 wastewater volumes calculated for Alternative 6 add effluent that is currently generated to new effluent estimated to be generated in 2050. This alternative does not include effluent volumes generated from conversion of septic to sewer.

Group A

Table 2.6.3 shows the new wastewater volumes associated with WPA's in Group A. The existing WWTF's in these WPA's can treat additional wastewater and operate at 80% capacity. Only the Big Park WWTF has enough capacity to handle both the high and conservative new wastewater volume estimates. The Camp Verde WWTF only has the capacity to treat the conservative wastewater volume estimate.

Table 2.6.3. 2050 Wastewater Volumes – Group A

Planning Area	**Total 2050 Wastewater Volume**		**Current Plant Capacity**
	High	**Conservative**	
Big Park	448 AFY (400,302 gal/day)	402 AFY (359,354 gal/day)	560 AFY (499,936 gal/day)
Camp Verde	N/A	570 AFY (508,804 gal/day)	728 AFY (649,917 gal/day)

AFY - Acre-feet per year

Table 2.6.4 shows the estimated cost to construct sewer conveyance infrastructure for WWTF's in Group A. Costs were indexed to 2011.

Table 2.6.4. 2050 Wastewater Volumes Sewer Conveyance Infrastructure Cost Estimate – Group A

Type of System	**Linear Foot Estimate**	**Linear Mile Estimate**
Residential Area	$346	$1,826,880
Forced Main in Residential Area	$575	$3,036,000
Rural Area	$120	$633,600

Group B

Table 2.6.5 shows the 2050 wastewater volume capacity requirements and deficiencies for WWTF's for each WPA. Deficiencies were determined using 2010 WWTF treatment capacities. Construction costs include conveyance infrastructure as detailed for Group A and the cost to expand WWTF treatment capacities to operate at 80% capacity. The WWTF capacity required to process new effluent volumes in 2050 is determined using current effluent volumes plus new effluent volumes and a 20 percent increase to ensure that expanded WWTF's operate at 80 percent capacity.

Table 2.6.5. 2050 Wastewater Treatment Facility Capacities – High and Conservative Volumes Group B

Planning Area	**High Estimate**		**Conservative Estimate**	
	2050 Capacity Required	Capacity Deficit	2050 Capacity Required	Capacity Deficit
Camp Verde	1,234 AFY (1,101,486 gal/day)	506 AFY (451,569 gal/day)	N/A	N/A
Chino Valley	5,021 AFY (4,482,053 gal/day)	4,461 AFY (3,982,117 gal/day)	2,419 AFY (2,159,513 gal/day)	1,859 AFY (1,659,577 gal/day)
Clarkdale	2,062 AFY (1,840,316 gal/day)	1,782 AFY (1,590,349 gal/day)	1,120 AFY (999,602 gal/day)	840 AFY (749,635 gal/day)

Cottonwood	6,517 AFY (5,818,507 gal/day)	4,837 AFY (4,318,700 gal/day)	3,598 AFY (3,923,050 gal/day)	1918 AFY (2,423,242 gal/day)
Prescott	9,696 AFY (8,656,838 gal/day)	4,992 AFY (4,457,378 gal/day)	7,098 afy (6,337,577 gal/day)	2,394 AFY (2,138,116 gal/day)
Prescott Valley	12,982 AFY (11,589,546 gal/day)	8,782 AFY (7,840,028 gal/day)	12,982 AFY (11,589,546 gal/day)	8,782 AFY (7,840,028 gal/day)
Sedona	2,176 AFY (1,942,739 gal/day)	384 AFY (342,944 gal/day)	1,910 AFY (1,705,020 gal/day)	118 AFY (105,226 gal/day)

AFY - Acre-feet per year

Group C

Table 2.6.6 shows the capacity requirements of new WWTF's, by WPA, to process high and conservative wastewater volumes. Construction costs for this group include those detailed for Group A and the cost to construct a new WWTF to operate at 80% capacity and produce Class A+ effluent. The WWTF capacity required to process new effluent volumes in 2050 is determined using current effluent volumes plus new effluent volumes and a 20 percent increase to ensure that new WWTF's operate at 80 percent capacity.

Table 2.6.6. 2050 Wastewater Treatment Facility Capacities - High and Conservative Volumes – Group C

Planning Area	**Plant Capacity**	
	High Estimate	Conservative Estimate
Ashfork	3,318 AFY (2,962,501 gal/day)	1,493 AFY (1,333,126 gal/day)
Cornville	313 AFY (279,284 gal/day)	141 AFY (125,678 gal/day)
Cottonwood-Verde Village	773 AFY (689,972 gal/day)	348 AFY (310,488 gal/day)
Dewey-Humboldt	260 AFY (232,585 gal/day)	117 AFY (104,663 gal/day)
Humboldt CCD	36 AFY (31,630 gal/day)	16 AFY (14,233 gal/day)
Jerome	26 AFY (24,012 gal/day)	12 AFY (10,806 gal/day)
Lake Montezuma	378 AFY (337,079 gal/day)	170 AFY (151,686 gal/day)

Planning Area	Plant Capacity	
	High Estimate	Conservative Estimate
Mingus Mountain	262 AFY (233,910 gal/day)	118 AFY (105,259 gal/day)
Paulden	812 AFY (725,080 gal/day)	365 AFY (326,286 gal/day)
Prescott CCD	1,697 AFY (1,515,240 gal/day)	764 AFY (681,858 gal/day)
Verde CCD	253 AFY (226,292 gal/day)	114 AFY (101,832 gal/day)
Williamson CDP	613 AFY (547,888 gal/day)	276 AFY (246,550 gal/day)

AFY - Acre-feet per year

F. Alternative 6 Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual operation and maintenance (O&M) over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for Alternative 6 are shown in Tables 2.6.7 and 2.6.9.

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth project costs for each group in Alternative 6 are shown in Tables 2.6.8 and 2.6.10. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.6.7. Annual Costs - New Effluent from New Population in 2050
(High Future Wastewater Volume Estimate)

Group	Amortized Annual Const Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/Kgal)
A	$968,400	$1,629,200	$5,798.30	$17.79
B	$33,325,000	$56,066,200	$3,472.31	$10.66
C	$11,533,500	$19,404,000	$3,538.95	$10.86
Total	$45,826,900	$77,099,400	$3,518.82	$10.80

Table 2.6.8 Present Worth Costs - New Effluent from New Population in 2050 (High Future Wastewater Volume Estimate)

Group	Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/Kgal)
A	$20,365,500	$34,263,000	$121,938.63	$374.22
B	$700,827,200	$1,179,074,800	$73,022.92	$224.10
C	$242,549,600	$408,066,500	$74,424.17	$228.40
Total	$963,742,300	$1,621,404,400	$74,000.88	$227.10

Table 2.6.9 Annual Costs - New Effluent from New Population in 2050 (Conservative Future Wastewater Volume Estimate)

Group	Amortized Annual Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/Kgal)
A	$2,083,000	$3,504,400	$5,748.38	$17.64
B	$28,597,300	$48,112,300	$4,591.19	$14.09
C	$8,993,800	$15,131,300	$6,132.46	$18.82
Total	$39,674,100	$66,748,000	$4,923.76	$15.11

Table 2.6.10 Present Worth Costs - New Effluent from New Population in 2050 (Conservative Future Wastewater Volume Estimate)

Group	Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/Kgal)
A	$43,805,300	$73,698,200	$120,888.41	$370.99
B	$601,403,300	$1,011,803,600	$96,552.96	$296.31
C	$189,140,000	$318,211,700	$128,966.11	$395.78
Total	$834,349,600	$1,403,713,500	$103,546.92	$317.77

Reuse of Treated Effluent

Refer to the discussion provided in Alternative 4.

References

ADEQ, 1978. Bulletin No. 11 Minimum Requirements for Design, Submission of Plans & Specifications of Sewage Works. July 1978.
ADEQ, 2012. Arizona Administrative Code, Title 18 Environmental Quality, Chapters 9 and 11.
Carollo Engineers, 2010. Sundog WWTP and Airport WRF Capacity and Technology Master Plan. October 2010.
EPA, 1984. Evaluation of Septic Tank System Effects on Ground Water Quality. June, 1984.
NACOG, 2002. Section 208 Water Quality Management Plan. June 2002.
Reclaimed Water Quality Standards, Arizona Department of Water Resources, http://www.azwater.gov/azdwr/WaterManagement/documents/ARTICLE3ReclaimedWaterQualityStandards.pdf
Larson and Associates Water Resources Consulting, 2008. Reclaimed Water Use Conceptual Master Plan for the City of Casa Grande and the Arizona Water Company Pinal Valley Planning Area. March 2008.
US Census, 2000.
Yavapai County, 2007. Yavapai County Geographic Information System.
Von Gaussig, D., 2012. Personal communication. June 6, 2012.
City of Casa Grande, 2008. Reclaimed Water Use Master Plan.

2.7 Alternative 7 – Capture and Store Unappropriated Verde River Water – Bartlett Dam, Horseshoe Dam, Sullivan Dam or Page Springs

A. Summary of Alternative 7

This alternative proposes as a source of supply the capture of unappropriated surface water from the Verde River watershed during a spill condition. This volume of floodwater is an intermittent source that is only available when all senior downstream water rights are being satisfied and storage capacity is being exceeded at Salt River Project's (SRP) reservoirs. There are a number of versions of this alternative (see Table 2.7.1) but all include either increasing or creating additional reservoir storage. The increased reservoir storage would result in the ability to store water within the system that would normally be lost during a spill condition. Water supply credits would accrue in the new space and designated for the WPA participants and then debited when the water is used upstream. These alternatives would require appropriate surface water rights and water exchange agreements would likely need to be executed.

In both Alternatives 7.1 and 7.2, the proposed reservoir volume increases are based on the reservoir yield potential concept. The average annual water yield for different variables was determined by conducting a reservoir routing analysis. The proposed reservoir size increases (A through C) shown in Table 2.7.1 reflect the best range of water production reliability versus the historical water yields in the watershed.

Table 2.7.1 Alternative Versions and Volumes

Alternative Version	Description of Alternative Version	Volume of New Supply (AF/yr)
7.1A - Increase Bartlett Dam 3.5 Feet & Conceptualized Upstream Catchment	Captures and stores water behind Bartlett Dam that would normally have spilled. Stored water becomes a source of supply through water exchange. Requires upstream catchment conveyance and treatment facilities.	10,000
7.1 B - Increase Bartlett Dam 8.5 Feet & Conceptualized Upstream Catchment	Captures and stores water behind Bartlett Dam that would normally have spilled. Stored water becomes a source of supply through water exchange. Requires upstream catchment conveyance and treatment facilities.	25,000
7.1C - Increase Bartlett Dam 18.5 Feet & Conceptualized Upstream Catchment	Captures and stores water behind Bartlett Dam that would normally have spilled. Stored water becomes a source of supply through water exchange. Requires upstream catchment conveyance and treatment facilities.	45,000

7.2 A - Increase Horseshoe Dam 3.6 Feet & Conceptualized Upstream Catchment	Captures and stores water behind Horseshoe Dam that would normally have spilled. Stored water becomes a source of supply through water exchange. Requires upstream catchment conveyance and treatment facilities.	10,000
7.2B - Increase Horseshoe Dam 9.5 Feet & Conceptualized Upstream Catchment	Captures and stores water behind Horseshoe Dam that would normally have spilled. Stored water becomes a source of supply through water exchange. Requires upstream catchment conveyance and treatment facilities.	25,000
7.2C - Increase Horseshoe Dam 15.1 Feet & Conceptualized Upstream Catchment	Captures and stores water behind Horseshoe Dam that would normally have spilled. Stored water becomes a source of supply through water exchange. Requires upstream catchment conveyance and treatment facilities.	45,000
7.3 - On-stream Storage at Sullivan Lake	Captures water at Sullivan Dam. Requires modification of the existing dam, extensive excavation, packaged water treatment plant, pump station and waterline.	2,240
7.4 - Off-stream Storage at Page Springs	Captures water near Page Springs on the Oak Creek drainage area. Requires construction of inlet structure, reservoir, packaged water treatment plant, pump station and waterline.	2,240

B. Alternative 7 Water Planning Areas

The WPAs considered in versions 7.1 and 7.2 of this alternative are those that show a 2050 water supply deficit (Table 1.1). The WPAs considered in version 7.3 of this alternative are Dewey-Humboldt and Prescott. The WPAs considered in version 7.4 are Clarkdale and Cottonwood.

C. Alternative 7 Description

All versions of this alternative are based on availability of unappropriated surface water during a specific condition where all senior priority water rights and being met and additional surface water is still available. This condition is commonly referred to as a “spill” condition and it occurs infrequently. Consequently, this alternative will only be available on a sporadic basis.

Versions 7.1 and 7.2 of this alternative require modifications to existing SRP dams in addition to construction of upstream catchments and transmission facilities. Infrastructure requirements for these versions include: increasing dam height, dam spillway modification, dam inlet/outlet modification, access improvements and relocation/reconstruction of ancillary facilities associated with dams, construction of reservoir for off-stream storage, water treatment plant, pump station and waterline. In this evaluation, the catchment locations and transmission facilities are conceptualized and estimated based on the various increased dam heights and water volumes captured. Conceptualized transmission lines are based on eight miles of pipeline; additional transmission lines to WPAs are not estimated. There was no effort in this evaluation to determine the geologic integrity of increasing the height of the dams.

Version 7.3 of this alternative is intake and catchment of water at Sullivan Lake, located about 1.5 miles south of Paulden (Figure 2.7.1). The catchment facility size and location was based on the surrounding topography, existing infrastructure, and proposed water treatment plant. This version assumed a two million gallon per day packaged water treatment plant that yielded the 2,240 AF/yr. At this volume, 2.8 million cubic yards of sediment must be excavated.

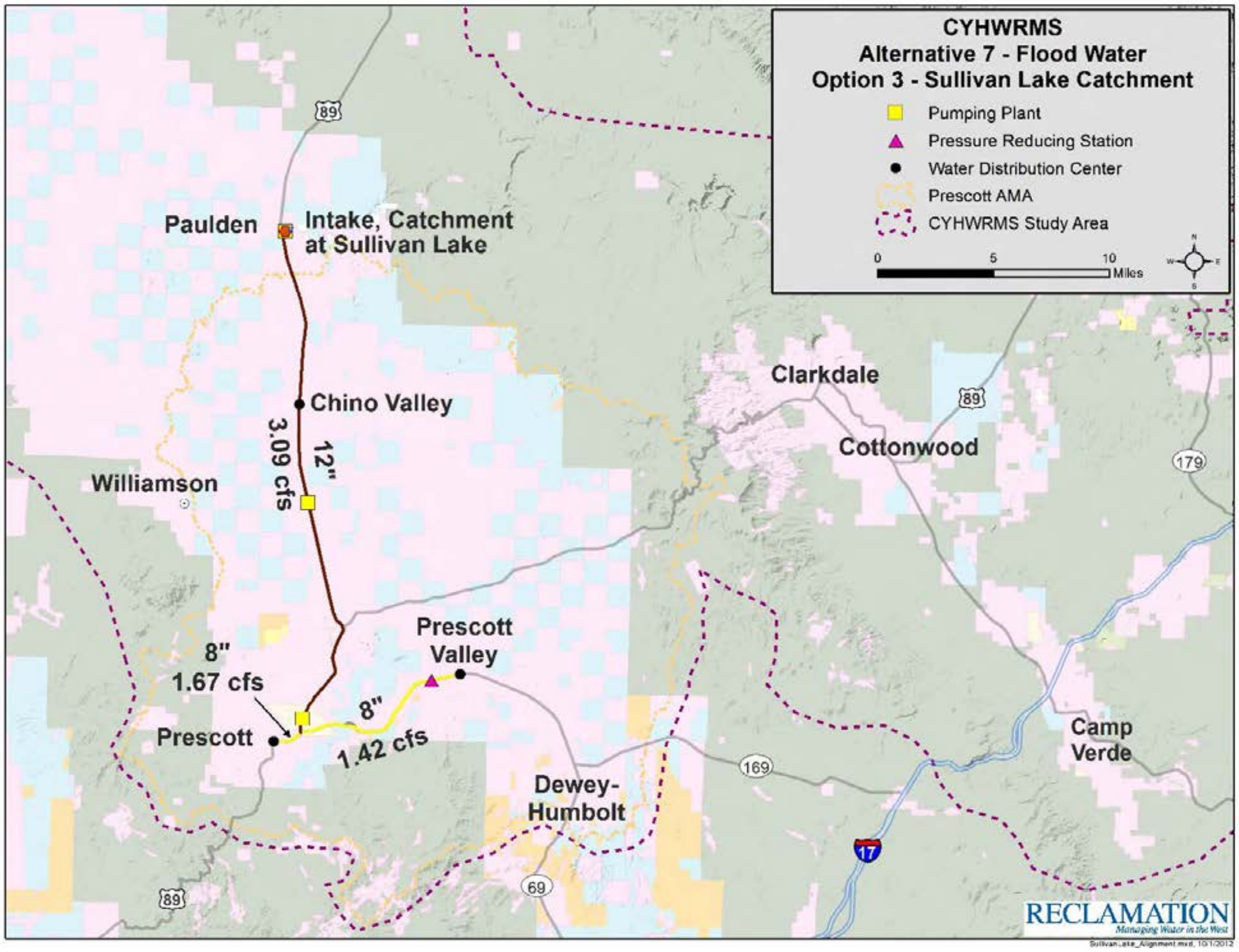


Figure 2.7.1 Depiction of Alternative Version 7.3

Additionally, this version included a 12 inch pipeline running parallel to Arizona Highway 89, south to Chino Valley, Prescott and Prescott Valley. Two pump stations and one pressure reducing station will be required for this alignment.

Version 7.4 of this alternative is catchment of water near Page Springs on the Oak Creek drainage area (Figure 2.7.2). The catchment facility size and location was based on the surrounding topography, existing infrastructure, and proposed water treatment plant. This version assumed a two million gallon per day packaged water treatment plant that yielded the

2,240 AF/yr. Additionally, this version included a 12 inch pipeline running east to a point midway between Clarkdale and Cottonwood. Three pump stations will be required for this alignment.

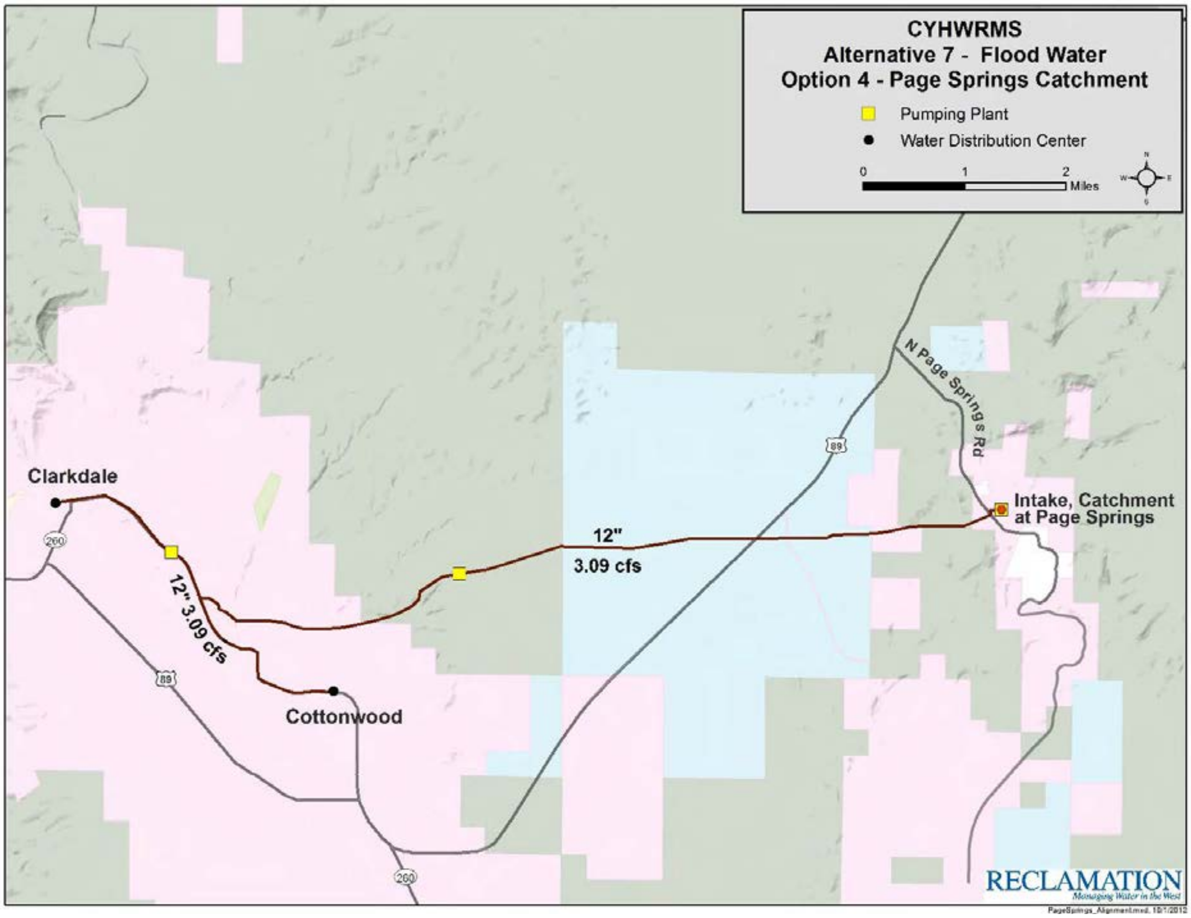


Figure 2.7.2 Depiction of Alternative Version 7.4

For additional information regarding transmission facilities for the versions of this alternative, see the cost estimate worksheets in the appendix.

Dam Spill Probability

An analysis of the probability of Bartlett or Horseshoe Dam spilling during the same time frame that there were high flows on the upper Verde River were conducted using SRP and USGS data. The analysis found that for gage 09503700 near Paulden, there were 15 events where unappropriated surface water could have been diverted during 8 out of 20 yrs. For gage 09504000 near Clarkdale, there were 21 events where unappropriated surface water could have been diverted during 8 out of 20 yrs. The analysis time frame was from 1990 to 2010. Flows that were greater than 75 cfs or more above the median flow were considered high and appeared feasible for extracting water. The long term median flow for 09503700 is 24 cfs and the median flow for 09504000 is 79 cfs. Table 2.7.2 shows the Verde spill timeframes and whether it coincided with high flows on the Verde gages 09503700 and 09504000.

Table 2.7.2 Verde Spill Time Frames and Gage Flows

Verde Spill Timeframes			USGS Gages-Verde Hi Flows	
Start	End	Days	09503700	09504000
3/29/1991	3/31/1991	3	yes	yes
4/2/1991	4/3/1991	2	yes	yes
4/7/1991	4/9/1991	3	**no**	yes
2/13/1992	2/18/1992	6	yes	yes
3/5/1992	3/15/1992	11	**no**	yes
3/25/1992	3/29/1992	5	**no**	yes
8/23/1992	8/25/1992	3	yes	yes
1/3/1993	1/21/1993	19	yes	yes
2/5/1993	2/17/1993	13	yes	yes
2/20/1993	3/1/1993	10	yes	yes
3/4/1993	3/7/1993	4	yes	yes
3/12/1993	3/17/1993	6	**no**	yes
3/31/1993	4/1/1993	2	**no**	yes
2/14/1995	2/21/1995	8	yes	yes
3/5/1995	3/22/1995	18	yes	yes
3/30/1998	4/6/1998	8	yes	yes
4/10/1998	4/15/1998	6	**no**	yes
12/30/2004	3/31/2005	92	yes	yes
1/27/2008	3/23/2008	57	yes	yes
1/21/2010	1/23/2010	3	yes	yes
2/3/2010	5/27/2010	114	yes	yes

D. Infrastructure Requirements and Alternative 7 Field Cost Assumptions and Analysis

Pipelines

Pipe lengths and head classes were determined through GIS analysis of the pipeline alignments. The cost estimate includes the cost for corrosion monitoring and cathodic protection of steel pipelines, where applicable. Construction costs for corrosion monitoring and cathodic protection were assumed to be one percent of the construction cost.

Appurtenant structures and mechanical equipment associated with the pipeline are covered under "unlisted items" in the Cost Estimate Worksheets. These items include air valves, blowoffs, drains, flowmeters, altitude valves, and sectionalizing valves, etc.

Hydraulics

The pipeline conveyance costs include the assumption that the treated water will need to overcome 350 feet of static head loss and 100 feet of dynamic head loss (maximum pumping lift about 450 feet).

It was assumed that all lateral pipe is mortar lined steel pipe with full inside diameters. Pipeline capacities were sized based on Table 2.7.1 **Alternative Versions and Volumes** and a peaking factor was not applied. Pressure Reducing valve stations are required when pressures at a maximum exceed 500 feet.

Pressure Reducing Stations

In line pressure reducing stations were assumed to be required to limit the pipe head class to a maximum of 500 feet. The cost is based on a single pressure reducing station.

Excavation and Backfill

Excavation and backfill quantities for pipe earthwork were based on a typical trapezoidal trench section with 1:1 slopes and an average depth of cover of four feet. This value was chosen because the majority of the pipe alignment is along existing roadways and gradual grades were anticipated. Excavation was assumed to be 70 percent rock and 30 percent common.

Pumping Plants

The field costs for pumping plants were taken from the North Central Arizona Water Supply Study (NCAWSS) Report and adjusted for higher flows. Forebay tanks would be required upstream from each pumping plant to supply water during startup of the pumps. For this appraisal level estimate, all forebay tanks were estimated to be 10 feet in diameter and 20 feet tall. Air chambers will be required downstream and were assumed to be 20-foot-diameter spheres.

The cost estimate includes the cost for a Supervisory Control and Data Acquisition (SCADA) system for the control of the pumping plants. The construction costs for the SCADA system were assumed to be three percent of the construction cost.

Water Treatment
The unit cost of the water treatment plant includes the treatment and installation. For the purposes of this study it was assumed at $2 gallons per day (gal/day).

Operation and Maintenance
Annual O&M costs for the pipelines were estimated to be 0.5 percent of the initial pipe costs. For pumping plants, annual O&M costs were estimated at eight percent of the pumping plant costs. Annual O&M costs for water treatment were estimated to be eight percent of the water treatment costs.

E. Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual O&M costs divided by the water supply yield. There is no cost inflation for O&M over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 7 variations are shown in Table 2.7.2.

Table 2.7.2. Annual Project Costs

Alternative Versions	Amortized Annual Const Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/ Kgal)
7.1A	$7,940,100	$1,926,800	$986.39	$3.03
7.1B	$16,446,800	$4,888,000	$853.39	$2.62
7.1C	$27,109,200	$8,378,350	$788.61	$2.42
7.2A	$7,511,000	$1,923,000	$943.40	$2.90
7.2B	$15,966,900	$4,887,995	$834.20	$2.56
7.2C	$26,615,500	$8,378,350	$777.66	$2.39
7.3	$2,293,300	$480,640	$1,238.00	$3.80
7.4	$2,123,800	$488,040	$1,166.00	$3.58

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for the Alternative 7 variations are shown in Table 2.7.3. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.7.3. Present Worth Project Costs

Alternative Versions	Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/ Kgal)
7.1A	$166,981,000	$40,457,600	$20,744	$63.66
7.1B	$345,877,000	$102,794,800	$17,947	$55.08
7.1C	$570,108,000	$176,197,200	$16,585	$50.90
7.2A	$157,956,000	$40,440,800	$19,840	$60.89
7.2B	$335,785,000	$102,794,800	$17,543	$53.84
7.2C	$559,746,000	$176,197,200	$16,354	$50.19
7.3	$48,229,000	$10,107,900	$26,043	$79.92
7.4	$44,664,000	$10,263,500	$24,521	$75.25

2.8 Alternative 8 – Rainwater Harvesting – Aquifer Storage

A. Summary of Alternative 8

This alternative evaluates a variety of rainwater harvesting methods to capture rainwater that would normally be lost to evaporation and transpiration. The methods evaluated in this alternative are considered large-scale, or macro-rainwater harvesting methods, that capture storm water and re-direct a portion of the rainwater to recharge facilities. It assumes that the water gathered via rainwater harvesting efforts is different from surface water, although that legal distinction does not currently exist. For each alternative, the rainwater that is harvested is gathered at numerous smaller locations (lots) and then transmitted to another location for recharge and recovery.

There were two general categories of rainwater harvesting considered in this alternative. The first is harvesting from developed areas such as existing residential and commercial properties. Harvested water originates from impermeable surfaces such as rooftops, driveways, parking lots, sidewalks and roads. Additionally, there is an opportunity for micro-scale rainwater harvesting from developed areas. When individual micro-scale units reach their full capacity, runoff can overflow into the macro-scale system thus becoming one system. The second is harvesting from undeveloped areas that have land surfaces modified via compaction and re-grading to increase runoff from storm events.

For the purposes of this study, that amount of rainwater that could be harvested and defined as a new water source is estimated by multiplying the horizontal surface area by the annual runoff captured. This assumes the new water source is distinguished from appropriable surface water.

B. Alternative 8 Water Planning Areas

The WPAs evaluated in this alternative are Prescott Valley, Chino Valley, Prescott and Prescott CCD. However, this alternative is applicable to all WPAs.

C. Alternative 8 Description

In this alternative, there were 10 water harvesting scenarios developed for specific lots that differ by lot location, lot size, the amount of development on the lot (pervious versus impervious versus pervious made impervious land surfaces), existing infrastructure and proposed on-site infrastructure improvements (Table 2.8.1). Additionally, each scenario includes the construction of off-site transmission pipelines and recharge and delivery improvements including recharge basins, recovery wells, and water treatment facilities.

Rainwater harvesting scenarios for aquifer storage were evaluated within the Little Chino and Upper Agua Fria groundwater sub basins. Each of the ten scenarios proposed has the potential to be applied in all planning areas associated within the CYHWRMS area.

The intent of rainwater harvesting is to recognize and take advantage of a source of water that is currently available without affecting potential claims for surface water appropriations. Rainwater harvesting in this region is based on the notion of harvesting water that would have been lost to evaporation or transpiration and using it for aquifer storage. Distinguishing surface water from rainwater harvesting (new water source) will still need to be defined.

For each scenario, the horizontal land surface, nature of the land surface, and rainfall records were used to estimate the annual volume of rainwater that could be harvested based on a collective 12 lot sample wherein the lots were physically linked through lateral and collector infrastructure improvements. Table 2.8.5 identifies the volume of rainwater that can be harvested annually for each scenario both for the 12 lot sample size and for a larger 64 acre sample area. The volume from the 12 lot sample was extrapolated to the 64 acre sample area. The 12 lot volumes were used to determine costs for the lateral and collector improvements. The 64 acres sample volumes were used to determine costs for the transmission, recharge and recovery improvements.

The location map for each of the alternative scenarios can be seen in the appendix. A 64 acre sample map of alternative two can be seen in the appendix that includes conceptualized locations for transmission and water development improvements. A basic schematic of the rainwater harvesting system is show on Figure 2.8.1.

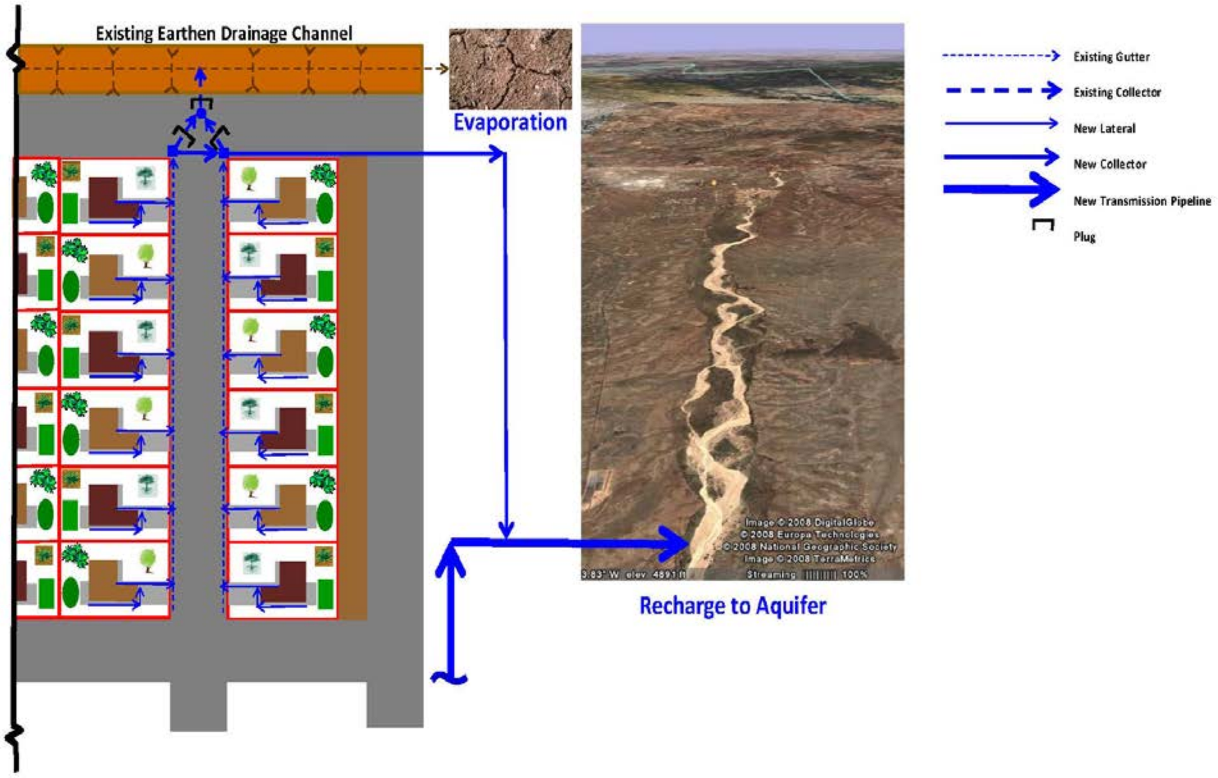


Figure 2.8.1 Schematic reference for Rainwater Harvesting Collection

Table 2.8.1. Alternative Scenario Descriptions

Scenario Number	Scenario Description
1	Located in Chino Valley; residential lots 0.15 acres in size. Existing infrastructure includes paved streets and concrete curbs and gutters. Proposed infrastructure includes lateral and collector pipe improvements, 6 inch and 15 inch corrugated pipe, respectively. Transmission line comprised of 30 inch and 42 inch corrugated pipe.
2	Located in Prescott Valley; residential lots 0.20 acres in size. Existing infrastructure includes paved streets and earthen v-ditches. Proposed infrastructure includes concrete curb and gutters, and lateral and collector pipe improvements, 6 inch and 15 inch corrugated pipe, respectively. Transmission line comprised of 36 inch and 54 inch corrugated pipe.
3	Located in Prescott Valley; residential lots 0.25 acres in size. Existing infrastructure includes paved streets and concrete curbs and gutters. Proposed infrastructure includes lateral and collector pipe improvements, 6 inch and 18 inch corrugated pipe, respectively. Transmission line comprised of 36 inch and 54 inch corrugated pipe.
4	Located in Prescott; residential lots 0.50 acres in size. Existing infrastructure includes paved streets and concrete curbs and gutters. Proposed infrastructure includes lateral and collector pipe improvements, 6 inch and 24 inch corrugated pipe, respectively. Transmission line comprised of 36 inch and 54 inch corrugated pipe.
5	Located in Yavapai County, east of Williamson Valley Road; residential lots 0.80 acres in size. Existing infrastructure includes paved streets and earthen v-ditches. Proposed infrastructure includes concrete curb and gutters, and lateral and collector pipe improvements, 6 inch and 24 inch corrugated pipe, respectively. Transmission line comprised of 36 inch and 48 inch corrugated pipe.
6	Located in Yavapai County, north of Prescott Valley; residential lots 2.0 acres in size. Existing infrastructure includes non-paved streets. Proposed infrastructure includes paved streets, concrete curb and gutters and lateral and collector pipe improvements, 6 inch and 30 inch corrugated pipe, respectively. Transmission line comprised of 30 inch and 42 inch corrugated pipe.
7	Located in Yavapai County, north of Prescott Valley; residential lots 2.0 acres in size. Existing infrastructure includes non-paved streets. Proposed infrastructure includes lined v-ditch parallel to street and lateral and collector pipe improvements, 6 inch and 30 inch corrugated pipe, respectively. Transmission line comprised of 30 inch and 42 inch corrugated pipe.
8	Located in Yavapai County, north of Prescott Valley; residential lots 2.0 acres in size. Existing infrastructure includes non-paved streets. Proposed infrastructure includes lined v-ditch parallel to street, surface compaction and lateral and collector pipe improvements, 6 inch and 42 inch corrugated pipe, respectively. Transmission line comprised of 48 inch and 60 inch corrugated pipe.
9	Located in Prescott Valley; commercial lots 1.5 acres in size. Existing infrastructure includes paved streets and concrete curbs and gutters. Proposed infrastructure includes lateral and collector pipe improvements, 6 inch and 42 inch corrugated pipe, respectively. Transmission line comprised of 48 inch and 60 inch corrugated pipe.
10	No location; conceptual only; open space lots of 2.0 acres Proposed infrastructure includes lined v-ditch parallel to street, surface compaction and collector pipe improvements of 42 inch corrugated pipe. Transmission line comprised of 48 inch and 60 inch corrugated pipe.

Macro Rainwater Harvesting Methodology

As defined in the alternative description, the amount of rainwater that could be harvested and defined as a new water source is estimated by the following:

Annual rainwater harvested = (horizontal surface area) X (annual runoff captured)

The horizontal surface area or land use data for each of the alternative scenarios was determined. Each of the alternative scenarios was divided into three area categories: Impervious, pervious and pervious made impervious. These horizontal surface areas will be used to estimate the amount of annual rainwater harvested based on 12 lots sample.

Table 2.8.2. Land Use Data for 12 Lots Sample

Alternative Scenarios	**Land Use Data Based on 12 lots Sample Area (Acres)**			
	Impervious	*Pervious Made Impervious*	*Pervious*	*Total Area*
1	1.05	0.00	0.93	1.98
2	1.10	0.00	1.48	2.58
3	1.46	0.00	1.88	3.33
4	2.12	0.00	4.33	6.44
5	1.84	0.00	8.28	10.12
6	2.15	0.00	22.84	25.00
7	1.21	0.00	23.78	25.00
8	1.21	22.84	0.94	25.00
9	15.83	0.00	3.66	19.49
10	0.00	24.05	0.00	24.05

To estimate the annual runoff captured, 2005 hourly rainfall records for Chino Valley and Prescott were used to determine the percent captured for each of the alternative area categories. The percent captured was calculated by adding the annual sum of runoff from grouped hourly precipitation storm events and dividing by the annual rainfall amount (∑ Runoff/Annual Rainfall). Runoff was determined using the SCS TR-55 runoff equation with curve numbers associated with the alternative scenario surfaces. Annual Rainfall data was collected from PRISM Data Explorer from PRISM Climate Group, Oregon State University.

The annual runoff captured was then calculated by multiplying the annual rainfall amount by the percent captured for each of the alternative scenarios. See Table 2.8.3. Annual Runoff Captured below:

Table 2.8.3. Annual Rainfall Captured for 12 Lots Sample

Alternative Scenarios	**Annual Rainfall (Inches)**	**Percent Captured (%)**			**Annual Runoff Captured (Inches)**		
		Impervious Area	*Pervious Made Impervious Area*	*Pervious Area*	*Impervious Area*	*Pervious Made Impervious Area*	*Pervious Area*
1	12.62	50.0	0.0	1.0	6.31	0.00	0.13
2	14.34	50.0	0.0	9.0	7.17	0.00	1.29
3	13.97	50.0	0.0	9.0	6.99	0.00	1.26
4	19.65	50.0	0.0	4.0	9.83	0.00	0.79
5	15.81	50.0	0.0	9.0	7.91	0.00	1.42
6	13.74	50.0	0.0	9.0	6.87	0.00	1.24
7	13.74	50.0	0.0	9.0	6.87	0.00	1.24
8	13.74	50.0	35.0	9.0	6.87	4.81	1.24
9	16.13	50.0	0.0	9.0	8.07	0.00	1.45
10	13.74	-	35.0	0.0	0.00	4.81	0.00

The annual rainwater harvested for each of the alternative scenarios was computed from Table 2.8.2 Land Use Data and Table 2.8.3 Annual Runoff Captured for each of the three area categories.

Table 2.8.4. Annual Rainwater Harvested for 12 Lots Sample

Alternative Scenarios	**Annual Rainwater Harvested (Acre-Feet)**			
	Impervious Area	*Pervious Made Impervious Area*	*Pervious Area*	*Total*
1	0.55	0.00	0.01	0.56
2	0.66	0.00	0.16	0.82
3	0.85	0.00	0.20	1.04
4	1.73	0.00	0.28	2.02
5	1.21	0.00	0.98	2.19
6	1.23	0.00	2.35	3.59
7	0.69	0.00	2.45	3.14
8	0.69	9.15	0.10	9.94
9	10.64	0.00	0.44	11.08
10	0.00	9.64	0.00	9.64

To estimate the water supply for the 64 acre sample improvements, the total area from Table 2.8.2 was divided by the total annual rainwater harvested from Table 2.8.4 for each of the alternative scenarios. That ratio was multiplied by 64 acres to determine the 64 acre sample recharge water supply. These values where used to determine the present worth and annual project costs for the transmission improvements.

Table 2.8.5. Annual Water Harvested per Unit Area

Alternative Scenarios	Total Area of 12 Lots (Acres)	Total Annual Rainwater Harvested 12 Lots Sample (AFY)	64 Acre Sample Improvements (AFY)	Ratio AFY/Acre
1	1.98	0.56	17.9	0.28
2	2.58	0.82	20.5	0.32
3	3.33	1.04	19.8	0.31
4	6.44	2.02	19.8	0.31
5	10.12	2.19	14.1	0.22
6	25.00	3.59	9.0	0.14
7	25.00	3.14	8.3	0.13
8	25.00	9.94	25.6	0.40
9	19.49	11.08	36.5	0.57
10	24.05	9.64	25.6	0.40

D. Infrastructure Requirements and Alternative 8 Field Cost Assumptions and Analysis

The infrastructure requirements and the associate cost component assumptions[10] are presented below. Rainwater harvesting improvements were estimated based on lot size and scenario and provided by Doug McMillan (retiree from Civiltec Engineering.) The unlisted items covered in this cost estimate include: regulating structures, additional junctions (manholes), curb inlets, clearing and grubbing and road reconstruction to include paving and base course material for storm drain pipe in developed areas.

Items that are not included but not limited to are the purchase of land, mitigation, and site specific geologic evaluations.

For future consideration, increased runoff associated with land surface treatments should be intercepted and transported to downstream recharge facilities without increasing potential for damage to existing flood control facilities. Runoff from developed areas that are harvested and directed to aquifer storage may be subject to physical and regulatory water quality issues.

---

[10] Unit cost assumptions were based on the North Central Arizona Water Supply Study Report, October 2006 and RS Means Heavy Construction Cost Data, 2010 Edition, and adjusted using Bureau of Reclamation construction cost indexes.

Lateral & Collector Improvements

Lateral improvement estimates include storm drain pipe installation, home/lot connections to lateral storm drain pipe and soil conditioning (compaction). Compaction was estimated on 9 inches of compaction to pervious areas for developed and undeveloped lots. Home/lot connections were estimated on a lump sum price.

Pipe sizing for lateral and collector pipes are based on the rational method one year recurrence interval for each alternative scenario location. For lateral and collector improvements pipe was sized based on land use data for 12-lot samples. NOAA Atlas 14 Precipitation Frequency Data Server was used to determine values for the one year recurrence interval.

The collector improvements incorporated proposed improvements to existing infrastructure including: road improvements (asphalt paving, concrete curb and gutter), collector storm drain pipes and lined v-ditches. Similarly to pipe sizing, the lined v-ditch for collector improvements was sized based on the rational method one year recurrence interval.

Transmission Improvements

Transmission improvements include storm drain pipe installation from runoff collection areas to conceptual recharge facilities. Pipe sizing for transmission pipes used the SCS TR-55 graphical peak discharge method. Transmission improvement pipes were sized on land use data for 64 acre samples.

Improvements Common to All Pipelines (Lateral, Collector and Transmission)

Lateral, collector and transmission pipes were estimated as corrugated HDPE storm drainage pipe Type-S (corrugated outside-smooth inside).

The estimates also include the cost for pipeline utility crossings and relocations in developed areas that include: site evaluations, design, and any additional components or materials for construction. The pipe crossing/relocations were assumed to be 2 percent of the lateral and collector construction costs.

Excavation and backfill quantities for pipe earthwork were based on a typical trapezoidal trench section with 1:1 slopes and an average depth of cover of three feet. Excavation was assumed to be common earth. Lateral improvement pipe excavation is assumed to be minimal and not estimated based on a shallow excavation assumption. Collector pipe earthwork was based on Yavapai Association of Governments standard detail 2-02 trench bedding for underground conduit

Water Development Improvements

Water development improvements include recharge basin excavation, well installation, and water treatment (arsenic). Land use data and quantities for water development improvements were also estimated for 64 acre samples.

The recharge basin excavation was estimated on conceptualized storage volume calculations. The storage volume is estimated as: $V = \frac{CAP_{24}}{12}$

where, V = storage volume estimate, AC-FT
C = Rational Runoff coefficient
A = Contributing drainage area, Acres
P_{24} = One year 24 hour rainfall amount, inches

Each recharge basin will be considered “off-line” in that it only captures non-appropriated water or the amount of rainwater that could be harvested and defined as a new water source. Weighed runoff coefficients were derived from lot coverage for each of the alternative scenarios and the following values where used: impervious C=0.90, pervious C=0.35 and pervious modified C=0.80. The one year-24 hour rainfall amount is based on the NOAA Atlas 14 Precipitation Frequency Data Server, point precipitation frequency estimates with 90% confidence intervals for each alternative scenario. Free board for each recharge basins was added as 10% of the storage volume. Recharge basin excavation estimates for each of the alternative scenarios is provided below in Table 2.8.6.

Determination of construction costs for recovery wells is based, in part, on a January 2010 cost estimate for drilling a 600 foot deep well in Manuelito, New Mexico and from published construction rates[11]. The well construction estimate is $60,100 per well installation. This well installation estimate is based on the following assumptions: proposed wells will yield up to 25 gallons per minute. Groundwater levels are approximately 300 feet below land surface. Wells are assumed to be 10 inches in diameter and 500 feet deep with a zone of influence of 200 feet.

The unit cost of the water treatment for arsenic includes treatment and installation. For the purposes of this study it was assumed at $1.50 gallons per day (gal/day).

---

[11] Rates from RS Means Heavy Construction Cost Data, 2010 edition.

Table 2.8.6. Recharge Basin Excavation

Alternative Scenarios	Area (Acres)	Weighted Runoff Coefficient	Rainfall Amount (P_{24}) (inches)	Storage Volume (AC-FT)	Storage Volume Plus Free Board (AC-FT)	Storage Volume (yds^3)
1	64	0.64	1.36	4.65	5.12	8,258
2	64	0.58	1.59	4.96	5.46	8,802
3	64	0.59	1.54	4.85	5.33	8,605
4	64	0.53	1.87	5.29	5.82	9,388
5	64	0.45	1.63	3.91	4.30	6,944
6	64	0.40	1.51	3.20	3.52	5,678
7	64	0.38	1.51	3.03	3.33	5,380
8	64	0.79	1.51	6.34	6.98	11,258
9	64	0.80	1.66	7.05	7.76	12,516
10	64	0.80	1.51	6.44	7.09	11,434

Operation and Maintenance

The estimated annual O&M cost for each alternative scenario is $15,500. This estimate was based on estimates for biannual scheduled and unscheduled maintenance including fixed rental costs for equipment (including mobilization and demobilization) and daily labor rates. Scheduled maintenance includes sediment and trash removal from the transmission line and mowing, pruning and ripping of the recharge basins to increase infiltration. Unscheduled maintenance includes cleaning of inlets and debris from collector improvements and repairs after flooding to recharge basins. Annual O&M costs for water treatment were estimated to be eight percent of the water treatment costs.

E. Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for the Alternative 8 scenarios are shown in Table 2.8.7. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.8.7. Present Worth Project Costs

Alternative Scenario	Lateral & Collector Improvements		Transmission & Water Development Improvements			Total Present Worth Cost per Acre Foot	Total Present Worth Cost per 1,000 gal
	Field Cost	Present Worth Cost per Acre Foot	Field Cost	Present Worth O&M Cost	Present Worth Cost per Acre Foot		
1	$30,126	$53,797	$344,429	$366,268	$39,704	$93,500	$286.94
2	$47,862	$58,368	$489,265	$372,120	$42,019	$100,387	$308.08
3	$36,246	$34,852	$486,365	$370,545	$43,278	$78,130	$239.77
4	$46,165	$22,854	$492,274	$370,545	$43,577	$66,431	$203.87
5	$78,090	$35,657	$425,809	$357,710	$55,569	$91,226	$279.96
6	$350,965	$97,762	$356,837	$346,228	$78,118	$175,880	$539.76
7	$183,193	$58,342	$353,175	$344,653	$84,076	$142,417	$437.06
8	$750,278	$75,481	$615,779	$383,603	$39,038	$114,519	$351.45
9	$85,272	$7,696	$647,291	$408,145	$1,376	$9,072	$27.84
10	$752,891	$78,101	$617,107	$383,603	$39,090	$117,191	$359.65

The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual O&M costs divided by the water supply yield. There is no cost inflation for O&M over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 8 scenario variations are shown in Table 2.8.8.

Table 2.8.8. Annual Project Costs

Alternative Scenarios	Lateral & Collector Improvements		Transmission & Water Development Improvements			Total Annual Cost per Acre Foot	Total Annual Cost per 1,000 gal
	Amortized Annual Cost	Annual Cost per Acre Foot	Amortized Annual Cost	Annual O&M Cost	Annual Cost per Acre Foot		
1	$1,400	$2,500	$16,400	$17,416	$1,889	$4,389	$13.47
2	$2,300	$2,805	$23,300	$17,695	$2,000	$4,805	$14.74
3	$1,700	$1,635	$23,100	$17,620	$2,057	$3,691	$11.33
4	$2,200	$1,089	$23,400	$17,620	$2,072	$3,161	$9.70
5	$3,700	$1,689	$20,200	$17,009	$2,639	$4,328	$13.28
6	$16,700	$4,652	$17,000	$16,463	$3,718	$8,370	$25.69
7	$8,700	$2,771	$16,800	$16,389	$3,999	$6,769	$20.77
8	$35,700	$3,592	$29,300	$18,241	$1,857	$5,449	$16.72
9	$4,100	$370	$30,800	$19,408	$1,376	$1,746	$5.36
10	$35,800	$3,714	$29,300	$18,241	$1,857	$5,571	$17.10

2.9 Alternatives 10 and 11- Surface Water in Alamo Lake, and Colorado River water via Alamo Lake, Diamond Creek, Lake Mead, Lake Havasu, Lake Mohave or Lake Powell

A. Alternatives 10 and 11 Water Planning Areas

The WPAs considered in this alternative are those that show a 2050 water supply deficit (Table 1.1) with the exception of rural WPAs that are primarily served from private domestic wells. The following WPAs were not included within this alternative: Verde CCD, Prescott CCD, Mingus Mountain CCD, Humboldt CCD and Ashfork CCD.

B. Summary and Description of Alternatives 10 and 11

This alternative proposes use of surface water obtained from outside of the study area in the volume of 42,379 AF/yr. Alternative 10 proposes delivery of water from Alamo Lake via pipeline. The variations of Alternative 11 propose delivery of water from the Colorado River via pipelines from several different locations (Table 2.9.1) Maps of the proposed alternatives, including pipeline alignments, locations of pumping plants and pressure reducing stations and pipeline size and flows are in Appendix X.

Table 2.9.1 Alternative Versions

Alternative Version	Description of Alternative Version
10	Delivers water to WPAs from Alamo Lake Transmission line runs from Alamo Lake Dam to Prescott, Sedona, Paulden and Clarkdale
11A - Alamo	Delivers water to WPAs from Alamo Lake, however the water is Colorado River water obtained via an exchange agreement Infrastructure and alignment same as Alternative Version 10
11B - Havasu	Delivers mainstem Colorado River water to WPAs from Parker Dam Transmission line runs from Parker Dam through Salome and Congress to Prescott and uses same alignment from Prescott as Alternative Version 10
11C - Mohave	Delivers mainstem Colorado River water to WPAs from Davis Dam Transmission line runs from Davis Dam through Kingman and Ashfork to Paulden, then Sedona and Clarkdale and Prescott
11D - Mead	Delivers mainstem Colorado River water to WPAs from Hoover Dam Transmission line runs from Hoover Dam to Kingman; transmission from Kingman same as in Alternative Version 11C

11E – Diamond Creek	Delivers mainstem Colorado River water to WPAs from infiltration gallery in Diamond Creek Transmission line runs from Diamond Creek to Peach Springs then to Ashfork; transmission line from Ashfork same as in Alternative Version 11C
11F - Powell	Delivers mainstem Colorado River water to WPAs as an extension of the Lake Powell pipeline to Flagstaff Transmission line begins in Flagstaff and runs to Lake Montezuma then Paulden and Clarkdale

C. Infrastructure Requirements and Alternative 10 and 11 Field Cost Assumptions and Analysis

Each of the Alternative 10 and 11 versions include the construction of lake intakes, mortar lined steel pipes, pressure reducing stations, pumping plants, power lines and water treatment. Forebay and air chamber tanks are included separately for each pumping plant. An infiltration gallery was only included in the Diamond Creek Alternative. Storage tanks and pressure reducing stations needed by water suppliers were not included.

The infrastructure requirements and associated cost component assumptions are presented below. Design data and unit costs[12] were based on the NCAWSS report and adjusted using the Bureau of Reclamation construction cost indexes.

Infiltration Gallery
The cost of the infiltration gallery was obtained from the Grand Canyon National Park Water Supply Appraisal study from 2002 estimates and factored up for the increase in flow.

Lake Intakes
It was assumed a series of sloping borings with submersible pumps would be used. The inclined bores were assumed to be 30 inches in diameter and 330 feet long, with 18 inch diameter casing and 12 inch diameter carrier pipe. Each 12 inch pipe could deliver approximately eight cubic feet per second. The submersible pumps in each bore were priced at 3600 gallons per minute with a 300 foot lift.

Pipelines
Pipe lengths and head classes were determined through GIS analysis of the pipeline alignments. Hydraulic profiles for the pipeline are included in Appendix X. The cost estimate includes the cost for corrosion monitoring and cathodic protection of steel pipelines, where applicable. Construction costs for corrosion monitoring and cathodic protection were assumed to be one percent of the construction cost. Additionally, the cost estimate includes the cost for drainage crossings that includes geologic and site evaluations, design and any additional components or materials for construction. Pipeline drainage crossings were assumed to be two percent of the construction cost.

---

[12] Design data assumptions are based on the North Central Arizona Water Supply Study Report, October 2006 and the Peabody Coal Black Mesa Mine C-aquifer Water Supply Appraisal Study, April 2003.

Appurtenant structures and mechanical equipment associated with the pipeline are covered under "unlisted items" in the Cost Estimate Worksheets. These items include air valves, blowoffs, drains, flowmeters, altitude valves, and sectionalizing valves, etc.

Hydraulics

The Hazen-Williams equation was used to compute the loss due to friction in the pipe laterals. The pipeline design velocity is five feet per second or less and the maximum pumping lift would be approximately 450 feet. Pipe friction losses were limited to about 25 percent of the total dynamic head for the pumps.

It was assumed that all lateral pipe is mortar lined steel pipe with full inside diameters. A Hazen Williams Coefficient of 140 was used in the head loss calculations. Pipeline capacities were sized based on the 2050 water supply deficit only and a peaking factor was not applied. By limiting the pump lift to about 450 feet of head and adding 30 percent for an upsurge allowance, the pressure class for the pipe was generally limited to 575 feet (250 pounds per square inch). Pressure Reducing valve stations are required when pressures at a maximum exceed 500 feet.

Pressure Reducing Stations

In line pressure reducing stations were assumed to be required to limit the pipe head class to a maximum of 500 feet. The cost is based on a single pressure reducing station.

Excavation and Backfill

Excavation and backfill quantities for pipe earthwork were based on a typical trapezoidal trench section with 1:1 slopes and an average depth of cover of four feet. Excavation was assumed to be 60 percent rock and 40 percent common. This assumption allows for comparison to the NCAWSS Report. It should be noted the excavation cost for rock assumes that the material can be excavated with an excavator or trencher. Excavation that requires blasting or hoe-ramming is not included in this cost estimate because a geology evaluation and testing would be required. Embedment to three inches over the top of the pipeline was assumed to be imported material from nearby borrow areas.

Pumping Plants

The field costs for pumping plants were taken from the NCAWSS Report and adjusted for higher flows. Forebay tanks would be required upstream from each pumping plant to supply water during startup of the pumps. For this appraisal level estimate, all forebay tanks were estimated to be 10 feet in diameter and 20 feet tall. Air chambers will be required downstream and were assumed to be 20 foot diameter spheres.

The cost estimate includes the cost for a SCADA system for the control of the pumping plants. The construction costs for the SCADA system were assumed to be three percent of the construction cost.

Water Treatment

The unit cost of the water treatment for arsenic includes treatment and installation. For the purposes of this study it was assumed at $2 gallons per day (gal/day).

Operation and Maintenance

Annual O&M costs for the pipelines were estimated to be 0.5 percent of the initial pipe costs. For pumping plants, annual O&M costs were estimated at eight percent of the pumping plant costs. Annual O&M costs for water treatment were estimated to be eight percent of the water treatment costs.

D. Annual and Project Worth Costs

There are a number of different costs that are utilized in the process of cost analysis. The field cost includes the construction costs plus any contingencies that must be factored in. The amortized annual construction cost is the annual payment necessary to amortize the field cost over 50 years at the planning interest rate of 4.125%. The annual cost per AF is the amortized annual construction costs plus the annual O&M costs divided by the water supply yield. There is no cost inflation for O&M over the 50 year evaluation period. For additional information regarding the interest rate, see the Cost Estimate Worksheets. The annual costs for the Alternative 10 and 11 variations are shown in Table 2.9.2.

Table 2.9.2. Annual Project Costs

Alternative Versions	Amortized Annual Const Cost ($)	Annual O&M Cost ($)	Annual Cost ($/AF)	Annual Cost ($/ Kgal)
10	$42,582,700	$11,744,870	$1,282	$3.93
11A	$42,582,700	$11,744,870	$1,282	$3.93
11B	$66,475,800	$13,966,410	$1,898	$5.83
11C	$60,566,500	$14,709,294	$1,776	$5.45
11D	$68,832,600	$14,700,056	$1,971	$6.05
11E	$48,893,200	$12,243,356	$1,443	$4.43
11F	$55,235,900	$12,772,029	$1,605	$4.92

The present worth project cost is derived by adding together the field costs plus the present value of 50 years of O&M costs at 4.125% divided by the water supply yield. The present worth projects costs for the Alternative 8 variations are shown in Table 2.8.4. For additional information regarding derivation of these costs, see the Cost Estimate Worksheets.

Table 2.9.3. Present Worth Project Costs

Alternative Versions	Field Cost ($)	Present Worth O&M Cost ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/ Kgal)
10	$895,515,610	$246,995,270	$26,959	$83
11A	$1,397,988,786	$293,714,381	$39,918	$123
11B	$1,273,716,646	$309,337,282	$37,355	$115
11C	$1,447,553,494	$309,142,993	$41,452	$127
11D	$1,028,225,962	$257,478,460	$30,338	$93
11E	$1,161,614,426	$268,596,490	$33,748	$104
11F	$895,515,610	$246,995,270	$26,959	$83

3.0 Alternatives Considered but Not Evaluated

3.1 Alternative 9 – Conservation

This alternative proposes to improve water efficiency which is a simple, effective way to conserve water. Conservation measures such as high efficiency toilets, waterless urinals, hot water recirculation, rainwater harvesting, greywater reuse, xeriscaping, public ordinances for new development and public education are examples of the programs that can be implemented.

This alternative was ultimately not developed further because conservation reduction volumes were included in the Phase I Demand Analysis which allowed WPA's to incorporate their own conservation efforts into their future GPPD. There have been many conservation studies done in the study area and because this is a locally led process, it was left to the individual WPAs to decide. There was no consistent set of criteria to ensure an equal application of conservation for all WPAs, which made it difficult then to go forward with the alternative. Each WPA provided their projected 2050 GPPD for the Demand Analysis and conservation reduction volumes vary for each WPA.

If the Conservation Alternative were developed, it may duplicate conservation reductions already accounted for in the Demand Analysis and could be misinterpreted as double counting the volume of water saved as a result of water use reductions from conservation. However, there could be some potential additional conservation measures that could be pursued and a more in-depth analysis would be done if this alternative moved forward to feasibility.

3.2 Alternative 12 – Weather Modification (Cloud Seeding)

Planning Areas Considered

All planning areas will be considered since this alternative will be done to benefit the study area as a whole. This water supply will not be collected to be delivered to the individual water planning areas but will increase surface water runoff and recharge from precipitation.

Alternative Description

This alternative proposes to look at weather modification, commonly known as cloud seeding for producing additional water. The process enhances a cloud's ability to produce precipitation. There are two primary methods employed to stimulate precipitation. Hygroscopic seeding, affects convective clouds during the warm seasons and enhances rainfall and glaciogenic seeding affects orographic clouds, which are formed over mountains during the cold seasons to augment snow. Either technology can be applied from the surface (ground-based) or from an aircraft. (Website- http://weathermodification.com/cloud-seeding.php)

For this alternative, only cloud seeding during the monsoon season will be considered because most of the rainfall in Arizona occurs during this season and are produced mainly by convective clouds which are conducive to hygroscopic seeding.

Also, there are not many opportunities for glaciogenic seeding in the study area because of specific criteria for the formation or orographic clouds. Because of the criteria, it could be difficult to find places and instances that are favorable for weather modification. However, it was "proposed that the 7,000 foot contour be used to identify potential target areas in Arizona. Part of the rationale for inclusion of this lower elevation area is based upon some earlier field studies conducted by Reclamation indicating potentially favorable seeding conditions in this area (Super et al, 1989)." (*The Potential Use of Winter Cloud Seeding Programs to Augment the Flow of the Colorado River*, Upper Colorado River Commission, March 2006)

The Mogollon Rim and the White Mountains which are both over the 7,000 foot contour and have been identified as offering the greatest potential for in-state weather modification efforts for snow augmentation. "…the Rim forms a barrier that forces flowing air upward to cool, a situation favorable to orographic cloud development." (*Weather Modification: A Water Resource Strategy to be Researched, Tested Before Tried*, Joe Gelt, Arroyo Springs 1992, Volume 6, No. 1) Dr. Rand Decker, Professor at Northern Arizona University, is currently modeling cloud seeding in the White Mountains area which has shown a 10% increase in snow.

Dr. Rand Decker did identify that for the CYHWRMS study area, cloud seeding during the monsoon season for rainfall was more plausible than winter-time cloud seeding for snow since the Mogollon Rim and White Mountains are outside the study area.

Enhancing Rainfall

"The **Arizona Monsoon** is a well-defined meteorological event that occurs during the summer throughout the southwest portion of North America. Monsoon thunderstorms are convective in nature." (Website 2012- http://geoplan.asu.eedu.monsoon.html) Cumulus (convective) clouds are responsible for producing the bulk of rainwater during the summer months. "These towering cloud formations form from strong updrafts of warm, moist air into an atmosphere that is unstable. Intense daytime heating of the near-surface layer of air, or a wedge of cold air moving across the state (as a cold front), usually triggers the formation of convective clouds." (Website 2012- http://www.license.state.tx.us/weather/summary.htm)

"Efforts to increase rainfall during the warm seasons are typically aimed at convective clouds. While it is theoretically possible to seed such clouds using ground-based equipment, targeting from aircraft is much more efficient and accurate. It is usually possible to affect the cloud through releases of a seeding agent in sub-cloud updrafts, or by dropping the seeding agents directly into the upper regions of the clouds."
(Website 2012- http://weathermodification.com/cloud-seeding.php)

"Not all cumulus clouds become rain producers. In fact, only a small percentage of them ever develop the capability to yield an appreciable amount of rainfall. Those convective clouds that do produce rainwater are often inefficient: For all the moisture they incorporate from below, only a tiny fraction of that moisture (as cloud droplets) is ever used to grow large raindrops, which ultimately fall to the ground as rainfall. If done in a timely way and properly, cloud seeding can assist the natural process in clouds by giving them enough "seeds" to make a meaningful number of large raindrops." (Website 2012- http://www.license.state.tx.us/weather/summary.htm)

"The radar data collected after a day of seeding adds to a growing body of evidence that the process works. The data shows seeding can double the amount of moisture in a cloud and the Texas programs boast a 12 percent increase in annual rainfall because of seeding." (*Cloud Seeders Help Make it Rain Over Drought-Stricken Texas*, ABC NightLine, Juju Change, Oct. 6, 2012) Dr. Rand Decker stated that the average yield increase is between 4%-12%.

Infrastructure Requirements

"Current recognized cloud treatment techniques consist of the delivery to a selected cloud volume of (1) silver iodide complexes (Finnegan, et al., 1984) by aircraft or turbulent transport via ground release, and/or (2) dry ice pellets (solid carbon dioxide) by direct injection from aircraft. The selection of a treatment method will depend on terrain features and meteorological conditions in the area of interest. Some situations may require the availability of both ground and airborne nuclei generating systems." (*Feasibility Study on Wintertime Cloud Seeding to Augment Arizona Water Supplies*, Bureau of Reclamation, January 1987)

"While it is theoretically possible to seed such clouds using ground-based equipment, targeting from aircraft is much more efficient and accurate."
(Website- http://weathermodification.com/cloud-seeding.php)

This alternative is for enhancing rainfall yield only and does not include any infrastructure for recovery.

Alternative Analysis

Volume

Volume totals were calculated from the monthly average precipitation increase of 4% and 12% for July, August and September and multiplied by the area to determine increased water yield. This alternative does not include any losses due to evaporation, transpiration, depth-area reduction or surface retention which could be up to a 75% reduction loss. Volume is strictly that amount of precipitation that is possible to enhance. It is not what is available to distribute as a water supply.

Table 1. Volumes from 4% & 12% Increased Rainfall Yield

Water Planning Area	July	August	September	4% July	12% July	4% August	12% August	4% September	12% September	4% Total (July/Aug/Sept)	12% Total (July/Aug/Sept)	Land Area	4% Total Enhanced Rainfall Volume	12% Total Enhanced Rainfall Volume
	monthly avg. inches	monthly avg. inches	monthly avg. inches	monthly avg. inches yield increase	monthly avg. inches yield increase	monthly avg. inches yield increase	monthly avg. inches yield increase	monthly avg. inches yield increase	monthly avg. inches yield increase	3 month avg. inches yield increase	3 month avg. inches yield increase	Acres	Acre Ft./Yr.	Acre Ft./Yr.
Camp Verde	1.81	2.11	1.8	0.07	0.22	0.08	0.25	0.07	0.22	0.23	0.69	29,279.88	558.27	1,674.81
Dewey Humboldt	2.87	3.28	2.07	0.11	0.34	0.13	0.39	0.08	0.25	0.33	0.99	11,998.29	328.75	986.26
Clarkdale	1.7	2.09	1.5	0.07	0.20	0.08	0.25	0.06	0.18	0.21	0.63	6,497.89	114.58	343.74
Cottonwood	1.7	2.09	1.5	0.07	0.20	0.08	0.25	0.06	0.18	0.21	0.63	13,249.68	233.64	700.91
Jerome	2.48	3.03	1.75	0.10	0.30	0.12	0.36	0.07	0.21	0.29	0.87	727.21	17.60	52.80
Prescott Valley	2.07	2.44	1.55	0.08	0.25	0.10	0.29	0.06	0.19	0.24	0.73	30,583.32	617.78	1,853.35
Chino Valley	1.7	2.01	1.59	0.07	0.20	0.08	0.24	0.06	0.19	0.21	0.64	36,887.29	651.68	1,955.03
Prescott	2.97	3.28	2.07	0.12	0.36	0.13	0.39	0.08	0.25	0.33	1.00	32,507.56	901.54	2,704.63
Sedona	1.65	1.9	1.94	0.07	0.20	0.08	0.23	0.08	0.23	0.22	0.66	13,739.40	251.43	754.29
Paulden CDP	1.7	2.01	1.59	0.07	0.20	0.08	0.24	0.06	0.19	0.21	0.64	36,481.64	644.51	1,933.53
Big Park CDP	1.65	1.9	1.94	0.07	0.20	0.08	0.23	0.08	0.23	0.22	0.66	2,989.00	54.70	164.10
Cornville CDP	1.7	2.01	1.59	0.07	0.20	0.08	0.24	0.06	0.19	0.21	0.64	8,535.06	150.79	452.36
Lake Montezuma CDP	1.67	2.15	1.93	0.07	0.20	0.09	0.26	0.08	0.23	0.23	0.69	7,638.16	146.40	439.19
Ctn-Verde Village CDP	1.7	2.09	1.5	0.07	0.20	0.08	0.25	0.06	0.18	0.21	0.63	1,814.31	31.99	95.98
Williamson CDP	1.7	2.01	1.59	0.07	0.20	0.08	0.24	0.06	0.19	0.21	0.64	36,193.14	639.41	1,918.24
Verde CCD	1.65	1.9	1.94	0.07	0.20	0.08	0.23	0.08	0.23	0.22	0.66	199,621.63	3,653.08	10,959.23
Prescott CCD	1.7	2.01	1.59	0.07	0.20	0.08	0.24	0.06	0.19	0.21	0.64	442,958.28	7,825.60	23,476.79
Mingus Mtn CCD	1.7	2.09	1.5	0.07	0.20	0.08	0.25	0.06	0.18	0.21	0.63	261,827.91	4,616.90	13,850.70
Humboldt CCD	1.81	2.11	1.8	0.07	0.22	0.08	0.25	0.07	0.22	0.23	0.69	24,166.52	460.77	1,382.32
Ashfork CCD	1.7	2.01	1.59	0.07	0.20	0.08	0.24	0.06	0.19	0.21	0.64	274,907.95	4,856.71	14,570.12

Precipitation data from website: www.homfacts.com/weather

WPA acreage calculated using GIS and the WPA boundaries

4% is the low average yield estimate and 12% is the high yield estimate for rain
July, August and September are summer months during the monsoon season that produce the highest rainfall
Total enhanced rainfall volumes do not account for losses that maybe up to 75% due to surface retention, infiltration, vegetation, evaporation, depth-area reductions and rainfall outside of WPA.

Cost

"The California DWR (DWR 2005) estimates that an additional 300,000 to 400,000 acre-feet of water could potentially be produced annually by more and improved cloud seeding in California. This increased amount of water would come at a cost of about $19 per acre-foot." *Optimizing Cloud Seeding for Water and Energy in California,* Steven M. Hunter, U.S. Bureau of Reclamation. California Energy Commission**,** March 2007

For cloud seeding projects in Texas, "the cost to produce this additional rainwater was estimated at less than $11 an acre-foot." (Website 2012- http://www.license.state.tx.us/weather/summary.htm)

For this alternative, a conservative price of $19.00 per acre-foot will be calculated for volumes increased for both a 4% and 12% increase in water yield from rainfall. It does not include any costs for infrastructure for recovery.

Table 2. Increase Yield Volumes for 4% & 12%

Water Planning Area	Enhanced Volume 4% Increase Total	Enhanced Volume 12% Increase Total	$11.00 per Acre/Ft. Total Cost for 4% increase	$19.00 per Acre/Ft. Total Cost for 4% increase	$11.00 per Acre/Ft. Total Cost for 12% increase	$19.00 per Acre/Ft. Total Cost for 12% increase
	Acre Ft.	Acre Ft.				
Camp Verde	558.27	1674.81	$6,140.97	$10,607.12	$18,422.90	$31,821.37
Dewey Humboldt	328.75	986.26	$3,616.28	$6,246.31	$10,848.85	$18,738.93
Clarkdale	114.58	343.74	$1,260.37	$2,177.01	$3,781.12	$6,531.03
Cottonwood	233.64	700.91	$2,570.00	$4,439.09	$7,709.99	$13,317.26
Jerome	17.60	52.80	$193.58	$334.37	$580.75	$1,003.11
Prescott Valley	617.78	1853.35	$6,795.61	$11,737.88	$20,386.84	$35,213.64
Chino Valley	651.68	1955.03	$7,168.43	$12,381.83	$21,505.29	$37,145.50
Prescott	901.54	2704.63	$9,916.97	$17,129.31	$29,750.92	$51,387.94
Sedona	251.43	754.29	$2,765.74	$4,777.19	$8,297.22	$14,331.56
Paulden CDP	644.51	1933.53	$7,089.60	$12,245.67	$21,268.79	$36,737.01
Big Park CDP	54.70	164.10	$601.69	$1,039.28	$1,805.06	$3,117.83
Cornville CDP	150.79	452.36	$1,658.65	$2,864.93	$4,975.94	$8,594.80
Lake Montezuma CDP	146.40	439.19	$1,610.38	$2,781.56	$4,831.13	$8,344.69
Ctn-Verde Village CDP	31.99	95.98	$351.92	$607.86	$1,055.75	$1,823.57
Williamson CDP	639.41	1918.24	$7,033.53	$12,148.83	$21,100.60	$36,446.49
Verde CCD	3653.08	10959.23	$40,183.83	$69,408.44	$120,551.50	$208,225.32
Prescott CCD	7825.60	23476.79	$86,081.56	$148,686.33	$258,244.68	$446,058.99
Mingus Mtn CCD	4616.90	13850.70	$50,785.89	$87,721.08	$152,357.66	$263,163.24
Humboldt CCD	460.77	1382.32	$5,068.52	$8,754.72	$15,205.57	$26,264.17
Ashfork CCD	4856.71	14570.12	$53,423.78	$92,277.44	$160,271.34	$276,832.31

Only present worth costs will be estimated because there are no capital improvements and O&M costs associated with cloud seeding. Cloud seeding will have to be repeated annually.

Table 3. Annual Project Costs

Alternative Versions	Amortized Annual Costs ($)	Annual O&M Costs ($)	Annual Cost ($/AF)	Annual Cost ($/Kgal)
Alt.# 12 Cloud Seeding - 4% Avg. Yield Increase	$36,500	$767,315	$146.82	$0.45
Alt.# 12 Cloud Seeding - 12% Avg. Yield Increase	$109,500	$2,301,946	$146.82	$0.45

Table 4. Present Worth Project Costs

Alternative Versions	Field Cost ($)	Present Worth O&M Costs ($)	Present Worth Cost ($/AF)	Present Worth Cost ($/Kgal)
Alt.# 12 Cloud Seeding - 4% Avg. Yield Increase	$767,315	$16,136,684	$3,087.57	$9.48
Alt.# 12 Cloud Seeding - 12% Avg. Yield Increase	$2,301,946	$48,410,052	$3,087.57	$9.48

3.3 Alternative 13 – Watershed Management – Enhanced water yield through ponderosa pine forest restoration treatments

Planning Areas Considered

This study was conducted for the CYHWRMS area as a whole. Volumes were not calculated separately by planning area. The forest restoration treatments analyzed are within the Four Forest Restoration Initiative (4FRI) first EIS analysis project area (figure 1), about half of which drains to the Verde Valley. 4FRI is a collaborative effort to restore forest ecosystems on portions of four national forests - Kaibab, Coconino, Tonto and Apache-Sitgreaves - along the Mogollon Rim in northern Arizona. 4FRI is a landscape-scale initiative designed to restore fire-adapted ecosystems through the use of mechanical forest thinning treatments and prescribed burning. The first analysis area includes the Tusayan and Williams District of the Kaibab National Forest and most of the Coconino National Forest but not the West Clear Creek watershed.

Limitations

The analysis provided below only addresses predicted enhancement to current surface water yield that could be obtained by treating ponderosa pine vegetation within the watershed area. No evaluation was made related to possible increases in aquifer recharge related to watershed management, although a graduate student at Northern Arizona University has revised recharge estimates relative to forest restoration treatments. In the 4FRI analysis area, approximately 90% of precipitation is lost to evaporation and transpiration (Tom Kolb, personal communication). Of the remaining 10% about 6-8% is surface water discharge and 2-4% is groundwater recharge (Pool 2011). In order to fully evaluate this alternative, more information will need to be collected regarding the mechanism of mountain front/mountain block recharge and its relationship to ET by vegetation and ground cover. Any water restored through restoration treatment actions is water that otherwise would have been available under historic forest densities and is therefore already claimed by downstream users with priority dates in the early 20th century or earlier.

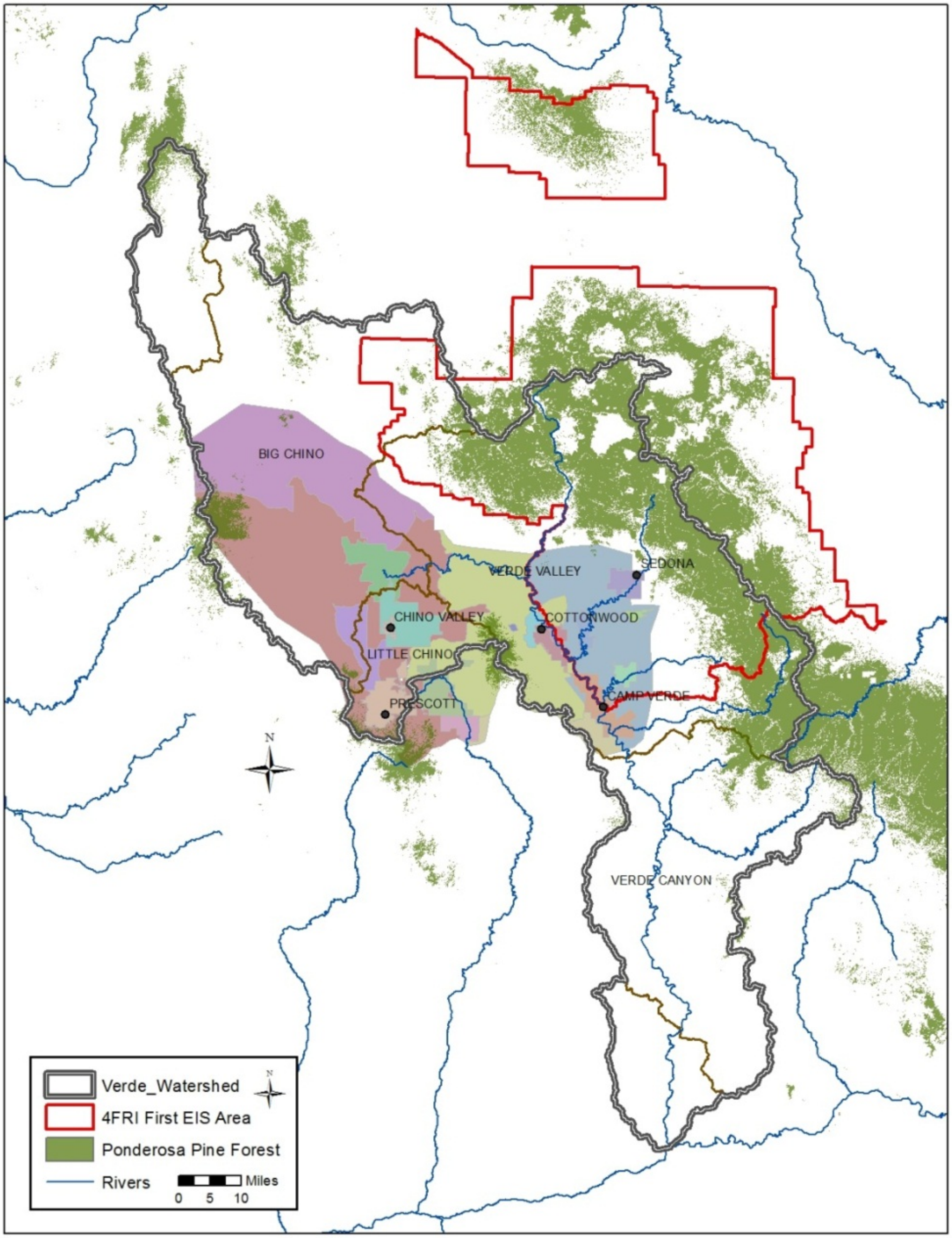
There are several unknowns that could affect water yield response to forest restoration treatments. These unknowns include:

1. When shelf stock treatments will begin. Shelf stock comprises those forest treatment areas for which NEPA evaluation has already been completed or NEPA is in process, so that these areas were not included in the 4FRI NEPA analysis. Initiation of shelf stock treatments is dependent on the contracted mill at Winslow being built,
2. When the 4FRI Environmental Impact Statement (EIS) Record of Decision (ROD) will be issued and whether there will be litigation that slows implementation,
3. To what extent forest restoration treatments effects differ from past forest treatment types,
4. The extent to which follow-up burning treatments can recapture diminished yield due to growth of shrubs and small trees, and
5. How much enhanced water yield may go to groundwater recharge or be lost to evapotranspiration en route from the pine forest to downstream water use areas.

For the purposes of this analysis, the assumption was made that all treatments would happen in a 10-year time frame, with 2 sets of follow-up burning treatments at 7 year intervals from the date of initial mechanical treatment and burning. If this or other assumptions are incorrect (especially if implementation takes longer), the time period for the response would likely be lengthened and the average annual response would be decreased, while the overall cost would probably remain about the same (not accounting for inflation).   Also, a basic assumption is that initial treatments would be paid for by the Forest Service and its contractor (in other words field costs are zero); only follow-up treatment costs are included in the cost of the alternative. Only a portion of the total treated area is “water yield effective”, ie. those treatments that result in at least 30% decrease in basal area are expected to lead to water yield enhancement.

A final limitation is that the actual ‘deliverable’ amount of water is difficult to estimate, because the amount of transmission loss is unknown. Some have estimated that as much as 50% of streamflow is lost between the Mogollon Rim and Phoenix. Perhaps on the order of 20% would be lost on the way to the Verde Valley.

Figure 1. Location map



Alternative Description

National forests were originally reserved with one of their primary purposes to protect water supplies. The Organic Act of 1905, established the National Forest System to "protect the land, secure favorable water flows, and provide a sustainable supply of goods and services". Nationwide 124 million people depend on water from national forests. In the Southwest, streamflow has decreased over the past century as forests have become denser (Covington and Moore 1994). Planned forest restoration treatments are anticipated to restore a portion of this decreased streamflow.

Ponderosa Pine Forests Central AZ
Ponderosa pine grows at elevations of 5,600 and 8,500 feet in the southwest (Schubert 1974). Ponderosa pine forests are a valuable source of water, timber, forage, and recreation (Baker 1999). Although ponderosa pine occupies only about 20% of the Salt-Verde River watershed, nearly 50% of the total water yield in this basin originates from the pine type (Barr 1956). These forests often contain other pine species as well as oak, aspen, or juniper trees (depending on the elevation) with grasses, forbs, and shrubs growing in the understory. A diversity of wildlife uses these forests for cover and food, both seasonally and yearlong. High transpiration rates and soil moisture deficiencies can curtail the growth of plants in ponderosa pine forests, which receive 18 to 30 inches of annual precipitation. High elevation forests tend to have greater frequencies and amounts of precipitation than low elevation forests, although this can be altered by storm patterns and topography. Usually only a small amount of summer rain is converted to streamflow. Winter precipitation is the major source of runoff. Basalt and cinders are the most common parent materials, though sedimentary soils are also found in these forests. Topography is characterized by extensive flat, rolling mesas, intermixed with steeper, mountainous terrain, and a diversity of slope and aspect combinations.

The Four Forest Restoration Initiative (4FRI) is a collaborative effort to restore forest ecosystems on portions of four National Forests - Kaibab, Coconino, Tonto, and Apache-Sitgreaves, - along the Mogollon Rim in northern Arizona. The vision of 4FRI is to restore forest ecosystems that support natural fire regimes, functioning populations of native plants and animals, and forests that pose little threat of destructive wildfire to thriving forest communities, as well as supporting sustainable forest industries that strengthen local economies while conserving natural resources and aesthetic values. A side benefit of the restoration will be enhanced water yield due to decreased evapotranspiration that occurs as a result of forest thinning. Using data from the 4FRI first analysis area, the estimated volume of enhanced (a.k.a. recovered or restored) water yield was calculated. The term "water yield" is used here (as opposed to "runoff" or other terms) because it is the parlance in papers published over 6 decades on which this analysis relies. To be clear, this analysis addresses surface water discharge only, not groundwater recharge which might be considered part of total water yield. Results indicate that enhanced water yield due to initial mechanical thinning combined with burning will range from 693 to 2,947acre-feet per year in the first ten years with an average of 2,166 acre-feet per year. In the absence of additional treatments, the enhanced yield will diminish to non-significance by year 16, because evapotranspiration would likely return to pretreatment rates as available water is captured by shrubs and herbaceous plants or by root invasion by remaining trees (Baker 2003). Follow-up burning treatments at approximately 7-year intervals are expected to extend the effect of initial treatments so that additional enhanced yield due to follow-up burning will range from 173 to 1,863 acre-feet per year over a 44-year period with an average of 1,186 acre-feet per year. Given a treatment cost of $100 per acre for follow-up burning, half of which is anticipated to be paid by the Forest Service, the average annual cost for follow-up burn treatments to sustain enhanced water yield is expected to range from $685 to $6,740 per acre-foot with an average annual cost over 44 years of $1,594 per acre-foot. This analysis was completed at a coarse scale using water yield response to ponderosa pine forest treatment outcomes derived from research in the Beaver Creek Experimental Watershed from the 1950s through the early 1980s (Baker 2003).

Water Yield Opportunities

Watershed management in the form of vegetation manipulation has often been cited as a method to increase water yield in Arizona (Barr 1956, Baker 2003, Fflolliot and Thorud 1977). Water yield improvement with vegetation reduction is based on the premise that streamflow and/or groundwater recharge are increased by an amount equal to the net reduction in evapotranspiration (Hibbert 1979). According to Hibbert, the greatest opportunity to increase water yield by reducing transpiration exists where precipitation exceeds 18 inches and potential evapotranspiration exceeds 15 inches. This kind of climate promotes vigorous growth of vegetation capable of using large amounts of water. Where precipitation is less than about 18 inches and is exceeded by potential evapotranspiration, there is little opportunity to increase water yield by reducing transpiration, because precipitation does not penetrate far into the soil and one cover type is about as efficient as another in using the available water. Because there is a great deal of inter-annual variability in precipitation in Arizona, the potential to increase water yield also varies with moisture conditions, with greater responses in wet years and perhaps no response in drier years.

Ponderosa pine forest stretches almost continuously from the south rim of the Grand Canyon, across the Mogollon Rim, to the White Mountains in eastern Arizona (see Text Box and Figure 1). Prior to European Settlement, the natural fire return interval in Arizona ponderosa pine communities ranged from <5 to 17 years (Dieterich 1980, Fulé et al. 1997). This short fire return interval maintained an open forest with an herbaceous understory (Wright and Bailey 1982, Covington and Moore 1994). An active fire suppression policy as well as land use changes over the past 100 years resulted in a much reduced fire frequency, which is commonly associated with an increase in tree density (Moore and Deiter 1992, Naumberg et al. 2001, Moore et al. 2004), crown closure, and litter depth (Clary et al. 1968). The result is overgrown forests with thin, unhealthy trees and the threat of unnaturally severe wildfire. Since 2010, high intensity fires have burned more than 900,000 acres of Arizona forest lands. The largest in Arizona history, the Wallow Fire in the White Mountains, burned almost 539,000 acres.

The driving force for forest restoration is reducing the risk, and resultant costs, of high-intensity forest fire. The 4FRI is a collaborative effort to address these issues. A draft EIS has been developed that covers forest treatments in the first analysis area, which includes the Kaibab National Forest south of Grand Canyon and much of Coconino National Forest southward (Figure 1).

One of the many expected benefits from forest restoration is enhanced water yield from the current condition. The Forest Service's 4FRI interdisciplinary team has developed specific forest treatment prescriptions that can be expressed in terms of reduced basal area. Basal area is the term used in forest management that defines the area of a given section of land that is occupied by the cross-section of tree trunks and stems measured at breast height. Basal area is generally expressed as ft^2/acre or m^2/ha. The Beaver Creek Experimental Watershed (BCEW) study related water yield of ponderosa pine forests to basal area, with water yield responding to percent reduction in basal area. While the BCEW treatments (clear cut, shelterwood, patch cut, strip cut, etc.) are not the same as restoration treatment types (uneven-aged thinning, intermediate thin, stand improvement thinning, savanna thinning, grassland thinning – see definitions in glossary at end of alternative description), the BCEW findings are the closest approximation available of what we might expect for water yield response to ponderosa pine restoration treatments.

Alternative Analysis

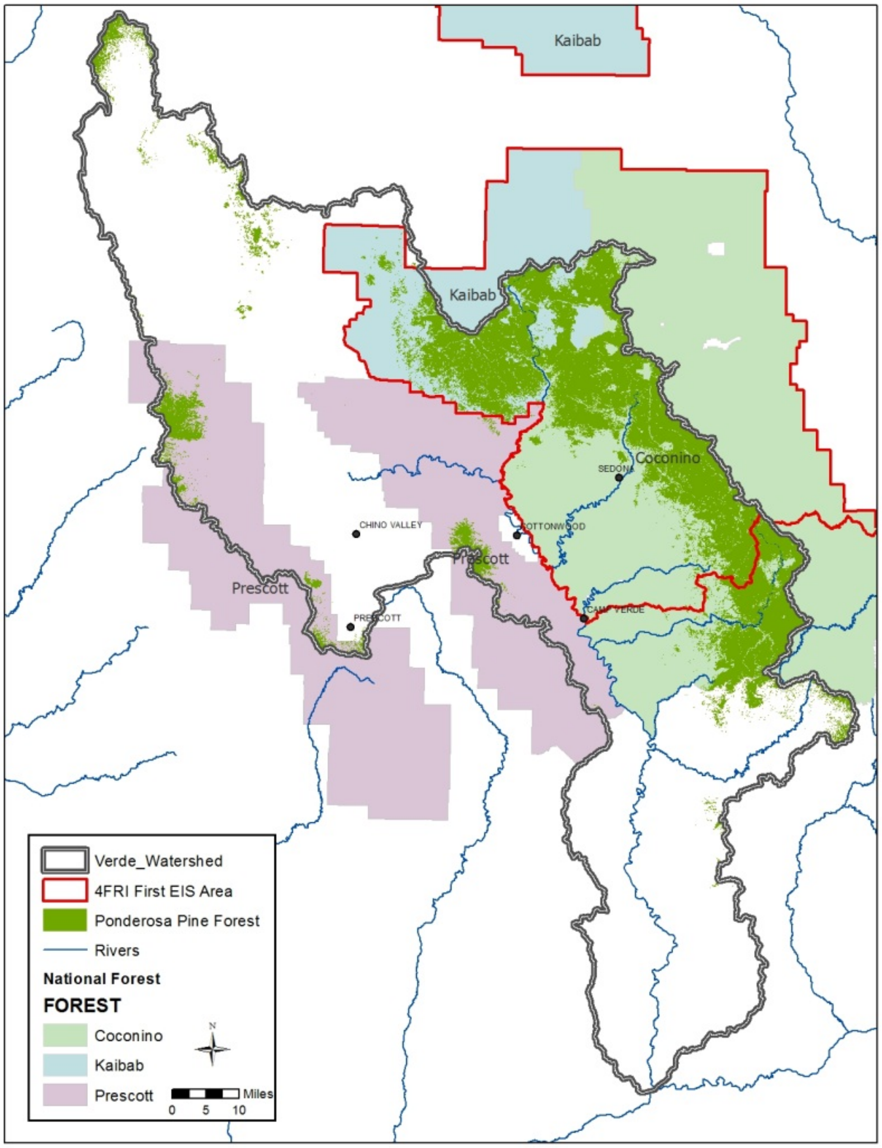
To estimate potential enhancement of water yield from forest treatment in the 4FRI first analysis area (figure 1), the 4FRI Proposed Action (USDA 2011) and GIS data were consulted as well as documents and GIS data for adjacent "shelf stock" project areas. Shelf stock are those forest treatment areas for which NEPA evaluation has already been completed or NEPA is in process, so that these areas were not included in the 4FRI NEPA analysis The shelf stock in many cases will be treated in advance of the 4FRI units, either on individual contracts or as part of the Forest Service's contract for treatment of both shelf stock and 4FRI units. The two together – 4FRI first EIS analysis treatments plus shelf stock treatments – comprise the extent of treatments that are expected in the Ponderosa pine vegetation type that may affect water yield.

The 4FRI and shelf stock GIS files within the 4FRI first analysis area were clipped to the Verde watershed to only consider treatments in areas that drain to the CYHWRMS project area. Note that 4FRI does not include the Prescott National Forest. However, there is limited extent of ponderosa pine vegetation type in the Prescott National Forest within the Verde River basin (table 1, figure 2). For comparison purposes, Table 1 provides acres of ponderosa pine in the Prescott National Forest and the 4FRI first analysis area portions of the Coconino and Kaibab National Forests in the Verde watershed. For the purposes of this analysis "effective" acres are those areas of forest that will experience $\geq$30% reduction in basal area as a result of treatments, from which we would expect to see a response in water yield.

Table 1. Acres of ponderosa pine in the Verde River watershed

Ponderosa Pine in the Verde Watershed	**acres**
entire watershed	718,413
Coconino NF	421,747
Kaibab NF	181,688
Prescott NF	52,069
4FRI first analyis area treatments	276,506
WY-effective 4FRI treatments	159,759
shelf stock treatments	128,202
WY-effective shelf stock treatments	74,075
total effective treatment area	**233,834**

Figure 2. Map showing distribution of ponderosa pine in the Verde River watershed by National Forest



Untreated ponderosa pine forests (known from experimental watersheds1958 to 1983) yield an average of about 0.25 acre-feet/acre of water yield per year (Baker 2003, p. 165). With treatment, average water yield response correlates with percent reduction in the basal area. Baker (2003) reports that initial water yield increase of 15% to 30% results from basal area reductions of 30% to 100%. This relationship can be expressed in the following formula that was used to calculate water yield response to basal area change:

$$\text{if } dBA \geq \text{ to } 30\text{, then}$$

$$WY_e = \left[\frac{(0.3571dBA + 4.2857)}{100}\right] * 0.25$$

where
WY_e = water yield enhancement in acre-feet per acre and
dBA = percent change in basal area.

Using this formula we then multiplied the water yield in acre-feet per acre by the number of acres that will receive treatments that result in each particular percent change in basal area (dBA) to give water yield in acre feet (table 2). Then the water yields for the various dBA are totaled. These numbers apply to sites with shallow, basalt-derived soils, which is the dominant soil type in the area of interest. Baker (1986, p 71) found that water yield increase diminished following the first year of treatment and by year 7 was statistically insignificant on most Beaver Creek watersheds that had no follow-up maintenance treatments such as prescribed burning. Using values generated by the formula above, we adjusted anticipated water yield change to reflect the gradual diminishment of enhanced yields. Using an Excel spreadsheet (table 3), we calculated diminishment for each year of treatment over the course of 6 years at 1/6th diminishment per year. We then added regained water yield for follow-up burning treatments estimated at 7 year return intervals, using the assumption that 25% of lost water yield could be recaptured through these treatments (table 3). It is unknown to what extent follow-up treatments may sustain water yield increases. A paired watershed study is being planned in part to investigate this question. In the meantime, 25% is a “best guess”. The actual percentage could be much more or much less, but we considered this a conservative estimate. Note that detailed data on basal area change at the stand level was available on 4FRI treatments but not all shelf stock treatments; therefore, shelf stock basal area reductions are estimated proportionate to 4FRI treatments.

Table 2. Anticipated water yield change in the Verde River watershed based on basal area change due to 4FRI (Alternative C) and shelf stock restoration treatments over 10 years. Values adjusted for diminishing effect over time are shown in the bottom cell of the table.

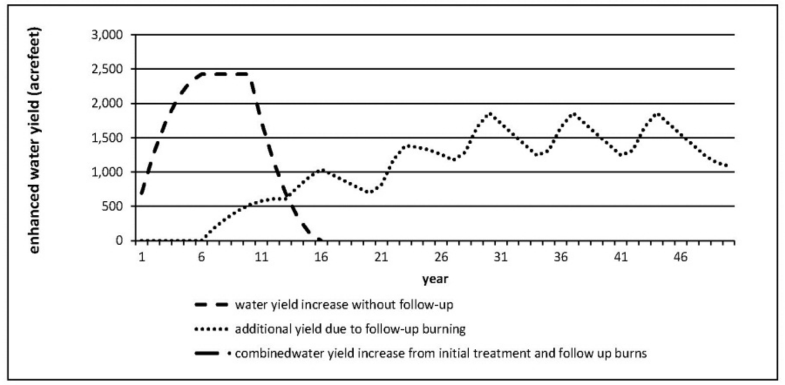
basal area reduction *%*	average effective BA reduction *%*	treatment area *acres*	proportion of total area *%*	proportion of treatments effective or *not effective* *%*	water yield increase w/o diminishment *acft*
4FRI					
Subzero	*0*	*17,810*	*6.44%*		*0*
0-29	*0*	*98,937*	*35.78%*	*42%*	*0*
30-39	34.5	47,011	17.00%		1,951
40-49	44.5	54,056	19.55%		2,727
50-59	55.5	33,720	12.20%		2,032
60-69	65.5	20,089	7.265%		1,390
70-79	75.5	4,807	1.738%		376
80-89	85.5	61	0.022%		5
90-97	93.5	15	0.005%	58%	1
4FRI total acres		276,506			
4FRI effective acres		**159,759**			
4FRI unadjusted water yield change					**8,482**
Shelf Stock					
Subzero	*0*	*8,256*	*6.44%*		*0*
0-29	*0*	*45,871*	*35.78%*	*42%*	*0*
30-39	34.5	21,794	17.00%		905
40-49	44.5	25,063	19.55%		1,264
50-59	55.5	15,641	12.20%		943
60-69	65.5	9,314	7.265%		644
70-79	75.5	2,228	1.738%		174
80-89	85.5	28	0.022%		2
90-97	93.5	6	0.005%	58%	1
S.S. total acres		128,202			
S.S. effective acres		**74,075**			
Shelf stock unadjusted water yield change					**3,933**
Total acres treated		404,708			
Total effective acres		233,834			
weighted average basal area change (%)					47.5
Total unadjusted increase in water yield					12,415
Adjusting for diminishing effects over time					
				unadjusted	**adjusted**
Total increase in water yield				12,415	2,898
current effective area water yield				58,459	58,459
percent change in water yield				21%	5%

Table 3. Diminishing return calculation for increased water yield in the Verde River watershed due to ponderosa pine forest restoration treatments in the 4FRI first analysis area and adjacent shelf stock, taking into account the effects of follow-up burning which may extend treatment effects.

	4FRI	S.S.	Total
total acres treated w/	15	6	21
estimated acres per year			2

	strength of effect by year															
eatment ye	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	0.8333	0.6666	0.5	0.3333	0.1666										
2		1	0.8333	0.6666	0.5	0.3333	0.1666									
3			1	0.8333	0.6666	0.5	0.3333	0.1666								
4				1	0.8333	0.6666	0.5	0.3333	0.1666							
5					1	0.8333	0.6666	0.5	0.3333	0.1666						
6						1	0.8333	0.6666	0.5	0.3333	0.1666					
7							1	0.8333	0.6666	0.5	0.3333	0.1666				
8								1	0.8333	0.6666	0.5	0.3333	0.1666			
9									1	0.8333	0.6666	0.5	0.3333	0.1666		
10										1	0.8333	0.6666	0.5	0.3333	0.1666	
average ef	1	0.91665	0.8333	0.749975	0.66664	0.5833	0.5833	0.5833	0.5833	0.5833	0.49996	0.416625	0.3333	0.24995	0.1666	0
effective a	2	4	6	9	11	13	13	13	13	13	11	9	6	4	2	0
estimated y	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
10-yr avera	**0**															
15-yr avera	**0**															
current yiel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
estimated y	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	0.0%
15-yr avera	**#DIV/0!**															

17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43



Partial recovery of diminished yield due to follow-up burning

llow-up treatment year	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
7	1	0.8333	0.6666	0.5	0.3333	0.1666										
8		1	0.8333	0.6666	0.5	0.3333	0.1666									
9			1	0.8333	0.6666	0.5	0.3333	0.1666								
10				1	0.8333	0.6666	0.5	0.3333	0.1666							
11					1	0.8333	0.6666	0.5	0.3333	0.1666						
12						1	0.8333	0.6666	0.5	0.3333	0.1666					
13							1	0.8333	0.6666	0.5	0.3333	0.1666				
14								1	0.8333	0.6666	0.5	0.3333	0.1666			
15									1	0.8333	0.6666	0.5	0.3333	0.1666		
16										1	0.8333	0.6666	0.5	0.3333	0.1666	
total followup treatment effect	1	0.91665	0.8333	0.749975	0.66664	0.5833	0.5833	0.5833	0.5833	0.5833	0.49996	0.416625	0.3333	0.24995	0.1666	0
prescribed burn or managed wildfire (acres)	2	4	6	9	11	13	13	13	13	13	11	9	6	4	2	0
assumed recovery of diminished water yield (25%)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
estimated yield increase due to followup treatment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

llow-up treatment year	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
14	1	0.8333	0.6666	0.5	0.3333	0.1666									
15		1	0.8333	0.6666	0.5	0.3333	0.1666								
16			1	0.8333	0.6666	0.5	0.3333	0.1666							
17				1	0.8333	0.6666	0.5	0.3333	0.1666						
18					1	0.8333	0.6666	0.5	0.3333	0.1666					
19						1	0.8333	0.6666	0.5	0.3333	0.1666				
20							1	0.8333	0.6666	0.5	0.3333	0.1666			
21								1	0.8333	0.6666	0.5	0.3333	0.1666		
22									1	0.8333	0.6666	0.5	0.3333	0.1666	
23										1	0.8333	0.6666	0.5	0.3333	0.1666
total followup treatment effect	1	0.91665	0.8333	0.749975	0.66664	0.5833	0.5833	0.5833	0.5833	0.5833	0.49996	0.416625	0.3333	0.24995	0.1666
prescribed burn or managed wildfire (acres)	2	4	6	9	11	13	13	13	13	13	11	9	6	4	2
assumed recovery of diminished water yield (25%)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
estimated yield increase due to followup treatment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

llow-up treatment year		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
21		1	0.8333	0.6666	0.5	0.3333	0.1666									
22			1	0.8333	0.6666	0.5	0.3333	0.1666								
23				1	0.8333	0.6666	0.5	0.3333	0.1666							
24					1	0.8333	0.6666	0.5	0.3333	0.1666						
25						1	0.8333	0.6666	0.5	0.3333	0.1666					
26							1	0.8333	0.6666	0.5	0.3333	0.1666				
27								1	0.8333	0.6666	0.5	0.3333	0.1666			
28									1	0.8333	0.6666	0.5	0.3333	0.1666		
29										1	0.8333	0.6666	0.5	0.3333	0.1666	
30											1	0.8333	0.6666	0.5	0.3333	0.1666
prescribed burn or managed wildfire (acres)	total followup treatment effect	1	0.91665	0.8333	0.749975	0.66664	0.5833	0.5833	0.5833	0.5833	0.5833	0.49996	0.416625	0.3333	0.24995	0.1666
assumed recovery of diminished water yield (25%)	prescribed burn or managed wildfire (acres)	2	4	6	9	11	13	13	13	13	13	11	9	6	4	2
	assumed recovery of diminished water yield (25%)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	estimated yield increase due to followup treatment	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Reported in Baker 2003

Initial water yields from ponderosa pine treatments - 15-40% when basal area is reduced 30-100%

Equation for increased water yield from relationship described by Baker is

$(((0.357142857 * \Delta WY_{ave.})+4.2875)/100)*(TA*E_{ave}*WY_0)$

where

0.357142857 is the slope of the line connecting the low high end of percent water yeild change as a function of percent basal area change

$\Delta WY_{ave.}$ is the weighted average of the percent change in water yield across all basal area changes equal to or greater than 30%.

4.2875 is the y-intercept in the slope formula for (40-15)/(100-30)

TA is effective treatment area (acres) [acres with $\geq$30% decrease in basal area]

E_{ave} is the average effect due to diminishment

WY_0 is the original water yield before treatments

0.25 acre-feet per acre = longterm water yield in ponderosa pine forest without treatments (acre-feet/acre)

Table 3. Continued. Diminishing return calculation for increased water yield in the Verde River watershed due to ponderosa pine forest restoration treatments in the 4FRI first analysis area and adjacent shelf stock, taking into account the effects of follow-up burning which may extend treatment effects.

4th round follow-up treatment year																																																	
28																											1	0.8333	0.6666	0.5	0.3333	0.1666																
29																												1	0.8333	0.6666	0.5	0.3333	0.1666															
30																													1	0.8333	0.6666	0.5	0.3333	0.1666														
31																														1	0.8333	0.6666	0.5	0.3333	0.1666													
32																															1	0.8333	0.6666	0.5	0.3333	0.1666												
33																																1	0.8333	0.6666	0.5	0.3333	0.1666											
34																																	1	0.8333	0.6666	0.5	0.3333	0.1666										
35																																		1	0.8333	0.6666	0.5	0.3333	0.1666									
36																																			1	0.8333	0.6666	0.5	0.3333	0.1666								
37																																				1	0.8333	0.6666	0.5	0.3333	0.1666							
total followup treatment effect																											1	0.91665	0.8333	0.749975	0.66664	0.5833	0.5833	0.5833	0.5833	0.5833	0.49996	0.416625	0.3333	0.24995	0.1666							
prescribed burn or managed wildfire (acres)																											23,383	46,767	70,150	93,534	116,917	140,300	140,300	140,300	140,300	140,300	116,917	93,534	70,150	46,767	23,383							
assumed recovery of diminished water yield (25%)																											0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25							
estimated yield increase due to followup treatment																											**173**	**569**	**776**	**932**	**1,035**	**1,087**	**1,087**	**1,087**	**1,087**	**1,087**	**776**	**517**	**310**	**155**	**52**							
5th round follow-up treatment year																																																	
35																																		1	0.8333	0.6666	0.5	0.3333	0.1666									
36																																			1	0.8333	0.6666	0.5	0.3333	0.1666								
37																																				1	0.8333	0.6666	0.5	0.3333	0.1666							
38																																					1	0.8333	0.6666	0.5	0.3333	0.1666						
39																																						1	0.8333	0.6666	0.5	0.3333	0.1666					
40																																							1	0.8333	0.6666	0.5	0.3333	0.1666				
41																																								1	0.8333	0.6666	0.5	0.3333	0.1666			
42																																									1	0.8333	0.6666	0.5	0.3333	0.1666		
43																																										1	0.8333	0.6666	0.5	0.3333	0.1666	
44																																											1	0.8333	0.6666	0.5	0.3333	0.1666	
total followup treatment effect																																		1	0.91665	0.8333	0.749975	0.66664	0.5833	0.5833	0.5833	0.5833	0.5833	0.49996	0.416625	0.3333	0.24995	0.1666	
prescribed burn or managed wildfire (acres)																																		23,383	46,767	70,150	93,534	116,917	140,300	140,300	140,300	140,300	140,300	116,917	93,534	70,150	46,767	23,383	
assumed recovery of diminished water yield (25%)																																		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
estimated yield increase due to followup treatment																																		**173**	**569**	**776**	**932**	**1,035**	**1,087**	**1,087**	**1,087**	**1,087**	**1,087**	**776**	**517**	**310**	**155**	**52**	
6th round follow-up treatment year																																																	
42																																									1	0.8333	0.6666	0.5	0.3333	0.1666		
43																																										1	0.8333	0.6666	0.5	0.3333	0.1666	
44																																											1	0.8333	0.6666	0.5	0.3333	0.1666	
45																																												1	0.8333	0.6666	0.5	0.3333	0.1666
46																																													1	0.8333	0.6666	0.5	0.3333
47																																														1	0.8333	0.6666	0.5
48																																															1	0.8333	0.6666
49																																																1	0.8333
50																																																	1
total followup treatment effect																																									1	0.91665	0.8333	0.749975	0.66664	0.5833	0.5833	0.5833	0.5833
prescribed burn or managed wildfire (acres)																																									23,383	46,767	70,150	93,534	116,917	140,300	140,300	140,300	140,300
assumed recovery of diminished water yield (25%)																																									0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
estimated yield increase due to followup treatment																																									**173**	**569**	**776**	**932**	**1,035**	**1,087**	**1,087**	**1,087**	**1,087**
Total Water Yield Increase (acft)	**693**	**1,271**	**1,733**	**2,080**	**2,311**	**2,426**	**2,600**	**2,744**	**2,860**	**2,947**	**2,311**	**1,762**	**1,300**	**1,127**	**1,041**	**1,041**	**954**	**867**	**781**	**694**	**809**	**1,176**	**1,383**	**1,365**	**1,324**	**1,260**	**1,173**	1,289	1,656	1,863	1,708	1,552	1,397	1,242	1,312	1,656	1,863	1,708	1,552	1,397	1,242	1,312	1,656	1,863	1,708	1,552	1,397	1,242	1,138	1,087
Initial 10-year average yield increase	**2,166**																																																
50-yr average annual yield increase (acft)	**1,529**																																																
current yield of effective acres	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459	58,459
estimated yield increase (%)	1.2%	2.2%	3.0%	3.6%	4.0%	4.2%	4.4%	4.7%	4.9%	5.0%	4.0%	3.0%	2.2%	1.9%	1.8%	1.8%	1.6%	1.5%	1.3%	1.2%	1.4%	2.0%	2.4%	2.3%	2.3%	2.2%	2.0%	2.2%	2.8%	3.2%	2.9%	2.7%	2.4%	2.1%	2.2%	2.8%	3.2%	2.9%	2.7%	2.4%	2.1%	2.2%	2.8%	3.2%	2.9%	2.7%	2.4%	2.1%	1.9%	1.9%
10-yr average yield increase (%)	**3.7%**																																																
50-yr average yield increase (%)	**2.6%**																																																
add'n yield due to follow-up (acft)	**0**	**0**	**0**	**0**	**0**	**0**	**173**	**318**	**434**	**520**	**578**	**607**	**607**	**781**	**925**	**1,041**	**954**	**867**	**781**	**694**	**809**	**1,176**	**1,383**	**1,365**	**1,324**	**1,260**	**1,173**	**1,289**	**1,656**	**1,863**	**1,708**	**1,552**	**1,397**	**1,242**	**1,312**	**1,656**	**1,863**	**1,708**	**1,552**	**1,397**	**1,242**	**1,312**	**1,656**	**1,863**	**1,708**	**1,552**	**1,397**	**1,242**	**1,138**	**1,087**

Potential Amount of Water and Cost

In summary, it is estimated that restoration treatments on 4FRI first analysis acres plus shelf stock acres in the Verde River watershed have the potential to enhance water yield in the range from 310 to 5,279 acre-feet per year over 25 years with a long-term average of 2,600 acre-feet per year when diminishing returns are considered. The cost for initial treatment, which is typically quoted at $800 per acre, will be borne by the U.S. Forest Service and its contractor who will implement the treatments and use resulting fiber to manufacture diversified products and bioenergy. To maintain water yield benefits, retreatment (maintenance burning) must be conducted within seven years following initial treatment. In reality, the interval between initial treatment and follow-up burn(s) will vary, depending on available resources and opportunities to use managed wildfire rather than prescribed burns. To the extent that planned prescribed burns are used, it is assumed that the downstream water users will pay half the cost of these follow-up treatments that will provide renewed enhancement of water yield. The Forest Service will pay for the other half of the cost, because there are other benefits from burning (forest health, wildlife & livestock forage, reduced wildfire hazard, etc).

For cost estimation purposes, it is assumed that treatment of the 233,834 acres with potential for water yield enhancement in the Verde River watershed will occur over a period of 10 years, with 23,383 acres being treated each year. A matrix was built to estimate the number of acres that must be treated each year, and a maintenance treatment cost of $100/acre was applied. Resulting treatment costs and water yield enhancement are shown in table 4. Cost summary per USBR method is provided in table 5. Field costs are zero because the initial treatment costs will be paid for by the US Forest Service and its contractor. Operation and Maintenance costs (O&M) are the retreatment (maintenance) costs, which are estimated in the range of $2.3 to $4.7 million total cost per year, half of which would be paid by the Forest Service. Estimated total annual cost ranges from $646 to $3,765 per acre-foot of enhanced yield. In a 44-year period from when follow-up treatments start the overall average annual cost per acre-foot would be $1,594.

Table 4. Cost for follow-up burning treatments to sustain enhanced water yield due to forest restoration initial mechanical treatment and prescribed burning.

	round 1	round 2	round 3	round 4	round 5	round 6	total	price	total cost	Forest Service	Other	improved yield	cost	ave. cost
year	acres	acres					acres	per acre		funding	funding	acft	per acft	per acft
7	23,383						23,383	100	$2,338,341	$1,169,171	$1,169,171	173	$6,740	**$1,594**
8	23,383						23,383	100	$2,338,341	$1,169,171	$1,169,171	318	$3,677	
9	23,383						23,383	100	$2,338,341	$1,169,171	$1,169,171	434	$2,696	
10	23,383						23,383	100	$2,338,341	$1,169,171	$1,169,171	520	$2,247	
11	23,383						23,383	100	$2,338,341	$1,169,171	$1,169,171	578	$2,022	
12	23,383						23,383	100	$2,338,341	$1,169,171	$1,169,171	607	$1,926	
13	23,383						23,383	100	$2,338,341	$1,169,171	$1,169,171	607	$1,926	
14	23,383	23,383					46,767	100	$4,676,682	$2,338,341	$2,338,341	781	$2,996	
15	23,383	23,383					46,767	100	$4,676,682	$2,338,341	$2,338,341	925	$2,528	
16	23,383	23,383					46,767	100	$4,676,682	$2,338,341	$2,338,341	1,041	$2,247	
17		23,383					23,383	100	$2,338,341	$1,169,171	$1,169,171	954	$1,226	
18		23,383					23,383	100	$2,338,341	$1,169,171	$1,169,171	867	$1,348	
19		23,383					23,383	100	$2,338,341	$1,169,171	$1,169,171	781	$1,498	
20		23,383					23,383	100	$2,338,341	$1,169,171	$1,169,171	694	$1,685	
21		23,383	23,383				46,767	100	$4,676,682	$2,338,341	$2,338,341	809	$2,889	
22		23,383	23,383				46,767	100	$4,676,682	$2,338,341	$2,338,341	1,176	$1,988	
23		23,383	23,383				46,767	100	$4,676,682	$2,338,341	$2,338,341	1,383	$1,690	
24			23,383				23,383	100	$2,338,341	$1,169,171	$1,169,171	1,365	$856	
25			23,383				23,383	100	$2,338,341	$1,169,171	$1,169,171	1,324	$883	
26			23,383				23,383	100	$2,338,341	$1,169,171	$1,169,171	1,260	$928	
27			23,383				23,383	100	$2,338,341	$1,169,171	$1,169,171	1,173	$996	
28			23,383	23,383			46,767	100	$4,676,682	$2,338,341	$2,338,341	1,289	$1,814	
29			23,383	23,383			46,767	100	$4,676,682	$2,338,341	$2,338,341	1,656	$1,412	
30			23,383	23,383			46,767	100	$4,676,682	$2,338,341	$2,338,341	1,863	$1,255	
31				23,383			23,383	100	$2,338,341	$1,169,171	$1,169,171	1,708	$685	
32				23,383			23,383	100	$2,338,341	$1,169,171	$1,169,171	1,552	$753	
33				23,383			23,383	100	$2,338,341	$1,169,171	$1,169,171	1,397	$837	
34				23,383			23,383	100	$2,338,341	$1,169,171	$1,169,171	1,242	$941	
35				23,383	23,383		46,767	100	$4,676,682	$2,338,341	$2,338,341	1,312	$1,783	
36				23,383	23,383		46,767	100	$4,676,682	$2,338,341	$2,338,341	1,656	$1,412	
37				23,383	23,383		46,767	100	$4,676,682	$2,338,341	$2,338,341	1,863	$1,255	
38					23,383		23,383	100	$2,338,341	$1,169,171	$1,169,171	1,708	$685	
39					23,383		23,383	100	$2,338,341	$1,169,171	$1,169,171	1,552	$753	
40					23,383		23,383	100	$2,338,341	$1,169,171	$1,169,171	1,397	$837	
41					23,383		23,383	100	$2,338,341	$1,169,171	$1,169,171	1,242	$941	
42					23,383	23,383	46,767	100	$4,676,682	$2,338,341	$2,338,341	1,312	$1,783	
43					23,383	23,383	46,767	100	$4,676,682	$2,338,341	$2,338,341	1,656	$1,412	
44					23,383	23,383	46,767	100	$4,676,682	$2,338,341	$2,338,341	1,863	$1,255	
45						23,383	23,383	100	$2,338,341	$1,169,171	$1,169,171	1,708	$685	
46						23,383	23,383	100	$2,338,341	$1,169,171	$1,169,171	1,552	$753	
47						23,383	23,383	100	$2,338,341	$1,169,171	$1,169,171	1,397	$837	
48						23,383	23,383	100	$2,338,341	$1,169,171	$1,169,171	1,242	$941	
49						23,383	23,383	100	$2,338,341	$1,169,171	$1,169,171	1,138	$1,027	
50						23,383	23,383	100	$2,338,341	$1,169,171	$1,169,171	1,087	$1,076	
TOTAL	233,834	233,834	233,834	233,834	233,834	210,451	1,379,621		$49,105,164	$24,552,582	$68,981,064			
										Average	**$1,567,751**	**1,186**		

Table 5. Costs per USBR method.

Field costs	$0
Water Supply AF/YR (average)	1,035
Annual Costs	
Amortized Annual Cost (50 yrs @4.125%)	$0
Annual Operations & Maintenance Cost (average)	$1,113,496
Total Annual Cost	
Annual Cost per Acre Foot	$1,076
Annual Cost per 1,000 gallons	$3
Present Worth Project Costs	
Present Worth O&M Cost (50 yrs @ 4.125%)	$85,408,625
Present Worth Cost per acre foot	$42,204
Present Worth Cost per 1,000 gallons	$130

Infrastructure Requirements

There are no infrastructure requirements as this alternative description considers enhanced availability of water as a consequence of improved snowpack retention and reduced ET and assumes that the water will be delivered to the users via natural waterways.

Future Items for Evaluation

This analysis was completed at a coarse project level scale with regards to the shelf stock, whereas additional spatial data made available by the USFS for 4FRI allowed more detailed analysis, down to the stand level in the 4FRI area. If more detailed information is made available for the shelf stock areas, such as accurate accounting of existing basal area and desired future basal area, then a more precise estimate of water yield changes could be generated. Also, as the sequencing of treatments becomes known, the volume and timing of water yield enhancements can be more accurately predicted. As 4FRI monitoring is implemented, estimates of water yield increase per basal area reduction percent could be refined for the soils in the project area. A surface water model could be developed to route the enhanced yield to and through stream channels and account for transmission losses due to groundwater recharge along the channel bottom and uptake by riparian plants. A coupled groundwater model could be developed to estimate recharge.

Legal, Institutional, and Environmental

Because NEPA is being conducted (4FRI first analysis area EIS and some of the shelf stock) or has been conducted (most of the shelf stock) by the USFS, there are few legal, institutional, or environmental considerations for the treatment. The timeline for the EIS, as of December 5, 2012 is that the draft will be released in early 2013, there will be a 60-day comment period, and a record of decision is anticipated in mid-2013. If a payment for watershed services system were to be developed to support follow-up treatments to maintain water yields, roles and responsibilities of participating organizations would need to be defined through agreements preferably during the early years of treatment so that a pool of funding could be collected and available for follow-up treatments starting in year 7.

In consideration of water rights, none of the water users in this study who have an increased projected demand in 2050 have the legal right to use the water from enhanced yield nor the infrastructure to take, divert, or treat the water. Because reduction in water yield due to thickening forest density has been occurring since the time of the earliest water right priority dates, and because water rights in the basin have been generally over allocated for a very long time, it is assumed that water made available through forest treatments is already claimed water.

Adaptive management was incorporated into the 4FRI process to provide flexibility to account for inaccurate initial assumptions, to adapt to changes in environmental conditions, and/ or to respond to subsequent monitoring information that indicates that desired conditions are not being met. As hydrologic data are obtained from implementation of 4FRI treatment in paired watershed studies, there may be potential to affect treatment implementation for enhanced water yield response. However, there are currently some procedural unknowns with adaptive management.

Conclusion

Water yield enhancement in the Verde River watershed is anticipated due to mechanical thinning and burning treatments that are part of the landscape-scale Four Forest Restoration Initiative. While the initial cost of treatments will be paid by the U.S. Forest Service and their contractor implementing the treatments, the Forest Service's current budget projections are that there will be a 50% funding need for follow-up burning treatments. The follow-up burning treatments, along with providing other forest health benefits, are expected to help extend the period of time in which water yields are enhanced post treatment, through reduced evapotranspiration by shrubs and small trees. Interested parties wishing to participate in payment for follow-up treatments could be called on to provide an average of $1,594 per acre-foot for an average of 1,186 acre-feet per year of enhanced water yield in years 7 through 27 following the start of mechanical treatments. These costs do not take into account the enhanced water yield due to initial mechanical treatments (1,618 acft/yr average) that will occur in the first 15 years. The cost and water volume estimates also do not account for possible transmission losses due to groundwater recharge or riparian water use between the forested areas yielding the water and the downstream water use areas. Estimates also do not include the cost of conveying the water by means other than stream channels.

Glossary

Grassland Thinning – This type of treatment involves tree removal to restore grasslands that have been encroached upon.

Intermediate Thinning (IT) – This type of thinning would be used to: (1) thin stands that are moderately to heavily infected with dwarf mistletoe to improve growth and vigor, (2) retain the best dominant and co-dominant trees with the least amount of mistletoe, and, (3) establish interspaces between residual tree groups and clumps. Improved growth and vigor of the best trees rather than sanitation is a primary objective.

Savanna Thinning - This type of treatment is specific to areas where soils developed under an open tree canopy and a robust herbaceous (grass/forb) understory. Thinning would be used to: (1) focus removal on those trees that have become established post-settlement using pre-settlement tree evidence as guidance, and, (2) attain the desired amount of interspaces between tree groups or individuals that range from 70 to 90 percent

Shelf stock – These are forest treatment areas for which NEPA analysis has already been completed or is in process at the national forest district level. They are, therefore, not included in the 4FRI NEPA analysis. Shelf stock in many cases will be treated in advance of the 4FRI treatment units. Treatment types for shelf stock are very similar to 4FRI treatment types.

Shelterwood Cut – Removing trees on the harvest area in a series of two or more cuttings so new seedlings can grow from the seed of older trees. This method produces an even-aged forest.

Stand Improvement Thinning (SI) – This type of thinning would be used to: (1) thin and improve the growth and vigor of young, even age plantations or stands dominated by trees <8.5" dbh; (2) begin the conversion to uneven age condition, and (3) establish interspaces between residual tree groups and clumps

Uneven-aged Thinning (UEA) – The objectives of this type of thinning is to: (1) establish interspaces between residual tree groups and clumps, (2) establish regeneration openings where seedling/sapling size class trees are under-represented, (3) establish interspaces between individual trees and clumps of trees within a group, (4) enhance growing space for younger age classes to become free to grow with limited competition, and, (5) meet Tusayan, Williams, and Flagstaff community wildfire protection plan (CWPP) desired conditions in the wildland urban interface (WUI).

References

Baker, M.B.. 1986. Effects of ponderosa pine treatments on water yield in Arizona. Water Resources Research, 22 (1) 67-73.

Baker, M.B. 1999. History of watershed research in the central Arizona highlands. USDA U.S. Forest Service Rocky Mountain Research Station, Research Paper RMRS-GTR-29.

Baker, M.B.. 2003. Hydrology. Chapter 10 *in* Ecological Restoration of Southwestern Ponderosa Pine Forests, Peter Friederici ed. Island Press, Washington, D.C. p. 161-174.

Barr, G.W. 1956. Recovering rainfall. Technical report. Tucson: Department of Agricultural Economics, University of Arizona.

Clary,W.P., Ffolliott, P.F., Jameson, D.A., 1968. Relationship of different forest floor layers to herbage production. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-123.

Cooper, C.F., 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecol. Monogr. 30, 129–164.

Covington,W.W., Moore, M.M., 1994. Southwestern ponderosa forest structure changes since Euro-American settlement. J. Forestry 92, 39–47.

Dieterich, J.H., 1980. Chimney Spring forest fire history. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Paper RM-220.

Ffolliott, Peter F. and David B. Thorud. 1977. Water yield improvement by vegetation management. Journal of the American Water Resources Association, 13 (3) 563-572.

Fulé, P.Z., Covington, W.W., Moore, M.M., 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecol. Appl. 7, 895–908.

Hibbert, Alden R. 1979. Managing vegetation to increase flow in the Colorado River Basin. Gen. Tech. I'ap. RM-66. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky l\fountain Forest and Range Experime.nt Station. 27 p.

Mast, J.N., Fulé, P.Z., Moore, M.M., Covington, W.W., Waltz, A.E.M., 1999. Restoration of presettlement age structure of an Arizona ponderosa pine forest. Ecol. Appl. 9, 228–239.

Moore, M.M., Huffman, D., Fule´, P.Z., Covington, W.W., Crouse, J.E., 2004. Comparison of historical and contemporary forest structure and composition on permanent plots in southwestern ponderosa pine forests. For. Sci. 50. 162–176.

Moore, M.M., Deiter, D.A., 1992. Stand density index as a predictor of forage production in northern Arizona pine forest. J. Range Manage. 45, 267–271

Naumberg, E., DeWald, L.E., Kolb, T.E., 2001. Shade responses of five grasses native to southwestern U.S. Pinus ponderosa forest. Can. J. Bot. 79, 1001–1009.

Pool, D.R., K.W. Blasch, J.B.Callegary, S.A. Leake and L.F. Graser. 2011. Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010-5180, 101 p.Schubert, Gilbert H. 1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. Res. Pap. RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 71 p.

Wright, H.A., Bailey, A.W., 1982. Fire Ecology: United States and Southern Canada. John Wiley and Sons, New York, NY

USDA 2011. Proposed Action for Four-Forest Restoration Initiative, Coconino and Kaibab National Forest, Coconino County, Arizona. United States Department of Agriculture Forest Service Southwestern Region.