CLEAR CREEK ASSOCIATES

Estimation of Safe Groundwater Yield
Star Valley, Gila County, Arizona

Submitted To

Town of Payson Water Department
303 North Beeline Highway
Payson, Arizona 85541

Prepared By
Clear Creek Associates, PLC
6155 East Indian School Road, Suite 200
Scottsdale, Arizona 85251

March 23, 2007

REGISTERED GEOLOGIST
CERTIFICATE NO
29376
PAUL R
PLATO
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REGISTERED GEOLOGIST
CERTIFICATE NO
29376
PAUL R
PLATO
Date Signed 3/26/07
ARIZONA U.S.A.

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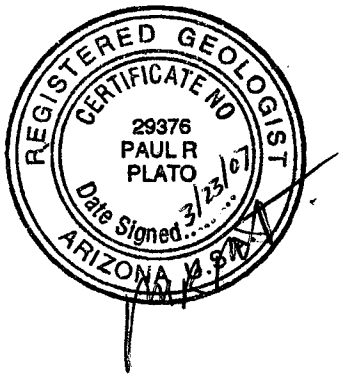

EXECUTIVE SUMMARY

The purpose of this study is to estimate the safe yield of the groundwater system in Star Valley, Arizona. For the purposes of this study, safe yield is defined as the volume of water that could be theoretically pumped without causing long term declines in water levels, by capturing the groundwater outflow from the basin. Clear Creek has assembled available data to assess groundwater flow conditions in the Study Area, and has evaluated the regional groundwater budget. Based on this analysis, the groundwater outflow from the Star Valley area is approximately 4,300 acre-feet, which would represent the safe yield of the aquifer as defined in the scope of work for this project. This estimate is based upon average precipitation of 21.53 inches per year at the Payson station. Safe yield for any particular year may be significantly higher or lower than the estimated 4,300 acre-feet, based on the variations in annual precipitation. During some years, precipitation is not adequate to meet the basic demand from evapotranspiration (vegetation water use). However, in years with above average precipitation, the safe yield value may be higher than 4,300 acre-feet. It should be stressed that this safe yield value is an average value, reflecting long-term precipitation rates (50-100 years). For this reason, shorter term trends in precipitation (such as a drought lasting several years) are not directly addressed by this analysis but should be factored into a management plan for the basin.

Clear Creek has contacted the Gila County Assessors Office to determine the current population to assess current groundwater usage by private wells. Based on data provided (personal communication, Larry Huffer, Gila County Assessor), the approximate population of Star Valley is 2,500 residents. Using 100 gallons per person per day as an estimate of water demand, the annual groundwater demand is approximately 280 acre-feet. Additionally, wells in the Mayfield Canyon area are used as part of the water supply for golf course irrigation at the Chaparral Pines development, and this volume of pumpage is approximately 100 acre-feet per year, yielding a total current demand of 380 acre-feet per year for the Star Valley basin. This current rate is significantly less than the 4,300 acre-feet yield estimate.

Based on this evaluation, it is theoretically possible to capture 4,300 acre-feet of groundwater outflow from the Star Valley area without causing long term declines in water levels. However, in practice it is not realistic to capture the entire outflow from the basin without local effects which may be detrimental or result in localized water level declines. The evaluation presented here does not address the spatial location of pumping from hypothetical or existing wells or shorter term annual variations in precipitation which may cause changes in groundwater conditions. This estimate is intended to assist in developing sound water management practices, by identifying the scale of the available water resources.

Southwest Ground-water Consultants (SGC, 1998) concluded that 80% of the safe yield was a more appropriate value for use in water management decisions for the Town of Payson to allow for uncertainty in the estimates. Using this approach, a practical safe yield value for the Study Area would be 3,440 acre-feet per year, or 80% of the 4,300 acre-feet safe yield estimate.

1.0 INTRODUCTION

1.1 Purpose of Study

Clear Creek Associates, Inc. (Clear Creek) has prepared this report in accordance with our approved scope of work, "*Scope of Work and Cost Estimate for Preliminary Estimation of Sustainable Groundwater Yield, Star Valley, Gila County, Arizona*", dated June 6, 2006.

The Star Valley area (Figure 1-1) is located along Arizona Highway 260, east of the Town of Payson, Arizona. The Town of Star Valley incorporated in late 2005, and is estimated to have a current population of approximately 2,500. In 2005, a property developer considered the potential development of groundwater supplies from Star Valley for use within Payson, completing and testing several wells. Since the incorporation of Star Valley, the Town of Payson commissioned this independent study to evaluate the long-term safe yield of the aquifer in the Star Valley area for use by the Town of Payson and the Town of Star Valley in developing sound, conservative water management practices.

Various methods were employed to estimate the safe yield of the aquifer in Star Valley. Methods that were utilized included: (1) calculating the annual volume of natural recharge derived from the average annual precipitation within the watershed, and (2) calculating recharge based on groundwater flux using a groundwater elevation contour map and the estimated thickness and transmissivity of the aquifer. In addition, previous safe yield estimates commissioned by the Town of Payson and other private parties were evaluated, including an estimate by Gookin Engineers in the early 1990s, and a more recent study by Southwest Groundwater Consultants, Inc. (SGC), in the late 1990s. The results of both studies were reviewed for potential applicability to the Star Valley study.

1.2 Location

The Star Valley area is located adjacent to and east of Payson in Gila County, Arizona (Figure 1-1). Star Valley is located in the northern part of the Tonto Creek Basin within a small watershed that covers an area of approximately 30 square miles. The area is drained by Houston Creek and several tributaries. Groundwater occurs primarily within older, fractured granitic rocks that comprise the local aquifer. The primary source of recharge to the aquifer is natural recharge from precipitation.

1.3 Scope of Work

The scope of work for the Star Valley safe yield evaluation consisted of: (1) attending meetings in Payson, (2) compiling and reviewing available data, (3) electronically scanning documents provided by the Town of Payson, (4) evaluating the data to estimate the safe yield of the aquifer in the Star Valley area, (5) developing a preliminary water budget, and (6) summarizing the results of the evaluation in a report for the Town of Payson. Details are included in the "*Scope of Work and Cost Estimate for Preliminary Estimation of Sustainable Groundwater Yield, Star Valley, Gila County, Arizona*", dated June 6, 2006.

2.0 PHYSICAL SETTING

Star Valley is located in the Transition Zone physiographic province of Arizona, characterized by mountainous terrain. As with the adjacent Town of Payson, Star Valley is located on the flank of an erosionally resistant headland, a remnant high point relative to the surrounding area. Star Valley occupies the eastern portion of the headland, which is cut by several drainages that represent low lying valleys separated by hills. Houston Creek, a tributary of Tonto Creek, is the primary surface water drainage within the Star Valley area. Figure 2-1 illustrates the local physical features near Star Valley, including the major drainages.

2.1 Surface Topography

Surface elevations within the study area vary from 6,380 feet above mean sea level (ft-MSL) at Diamond Point, near the northeast boundary of study area, to approximately 4,420 feet above mean sea level (ft-AMSL) along Houston Creek at the southern boundary of the study area. The primary features within the study area are Diamond Rim in the northern portion, and the Mayfield Canyon/Houston Creek drainage running southward to the southern boundary.

Clear Creek delineated the surface water drainage basin that encompasses the Star Valley area using USGS topographic maps[1]. Figure 2-2 illustrates the topographic conditions in the Star Valley area, and displays the approximate surface watershed boundary for the Star Valley area. This boundary represents the Study Area that was evaluated for this project. For the purposes of this study, it is also assumed that the groundwater basin is similar in configuration to the surface watershed, although an exact match is unlikely.

2.2 Surface Water

Within the defined study area, nearly all of the surface drainages are ephemeral, flowing in response to precipitation events on the watershed. However, the portion of Houston Creek south of the Town of Star Valley is perennial, as illustrated on Figure 2-1. Surface water flow rates in the Houston Creek drainage have not been gaged historically, so no information on annual flow volumes is available.

2.3 Temperature and Precipitation

The Star Valley area is located in a mountainous area generally higher in elevation than the southern portion of the State of Arizona. For this reason, the Star Valley area is characterized by

[1] Topographic Maps included: Payson South, Payson North, Diamond Rim and McDonald Mountain 7.5 Minute Quadrangles.

lower annual temperatures than the lower lying areas in the southern portion of the state. Average maximum temperature is 72.5^{o} F, and average minimum temperature is 38.6^{o} F[2]. Average precipitation is 21.53 inches, with 25.10 inches of snowfall annually.

Arizona generally has two seasons of the year when precipitation is most common, the summer monsoon season (July through September) and the winter season (December through March). Precipitation data for Payson and the Payson Ranger Station are presented in Tables 2-1 and 2-2, respectively.

The summer monsoon season is characterized by an influx of warm moist air from the Gulf of Mexico, which causes the widespread development of convective thunderstorms. The intense summer heating characteristic of Arizona provides the driving force for convection, which leads to development of locally intense thunderstorms. These storms can cause significant, locally heavy precipitation, but generally do not cover extensive areas as those caused by winter precipitation events. For this reason, the intense monsoon precipitation tends to cause rapid increases in surface water runoff, or flash floods. Although the total precipitation is similar during the summer and winter wet seasons, the winter precipitation is believed to be the critical factor in determining the volume of annual natural recharge to the local aquifer.

The winter season is characterized by generally low intensity, regionally extensive precipitation events that consist predominantly of snowfall in the higher elevations. These storms provide a significant source of available recharge for the aquifer as they occur during times of minimal evapotranspiration and have impacts over wider areas.

Clear Creek Associates compiled monthly precipitation records for the nearest precipitation gaging station (Payson), currently located near Green Valley Park in Payson. Additionally, the precipitation data for the Payson Ranger Station was used for years prior to 1949 to augment the available data. Combined precipitation records over the period 1893 to 2006 are presented on Figure 2-3 and in Table 2-3. For the purposes of this analysis, years with incomplete records were eliminated. In addition, each stacked bar illustrates summer months in red (May through October) and winter months in blue (November through April). Trend lines for annual, summer and winter precipitation have been included to display trends over the period of record.

[2]Information presented regarding climate data is derived from *Verde Watershed Study*, Arizona Department of Water Resources (ADWR), April, 2000.

Based on the long term data presented, annual precipitation has increased by approximately 2 inches per year over the period 1893 to 2006, from 20 inches to 22 inches. Clearly, the increases have resulted from higher winter precipitation, as summer precipitation values have remained approximately constant, based on the trend line presented. However, Figure 2-4 presents short term precipitation data for the Payson Station since 1980. This figure illustrates a more recent decline in annual precipitation that is characteristic of drought conditions. The average precipitation over the period 1893 to 2006 is 21.07 inches. For the Payson Station, the average precipitation over the period 1949 to 2006 is 21.53 inches Table 2-1).

3.0 GEOLOGIC FRAMEWORK

The geologic features of the Payson and Star Valley area have been evaluated extensively as part of numerous studies, most recently the ongoing *Mogollon Rim Water Resources Management Study*[3] (USBR, draft data). Additionally, an excellent summary of the regional hydrogeology was presented as part of *Hydrogeology of the Mogollon Highlands, Central Arizona – USGS Scientific Investigations Report 2004-5294* (Parker, et al. 2005). Additionally, some local studies have been conducted by the Town of Payson to evaluate hydrogeology in the area near Payson, Arizona. These studies include, *Structural Geology and Groundwater Potential, Diamond Rim Study Area, Gila County, Arizona* (Gaeaorama, 2003), and *Payson Diamond Rim Project Geophysical Survey* (Zonge, 2004). The following geologic and hydrologic summary is derived from these sources, primarily from *Structural Geology and Groundwater Potential, Diamond Rim Study Area, Gila County, Arizona* (Gaeaorama, 2003).

3.1 Regional Geology

Star Valley is located on the eastern flank of a local topographic high point known as the Payson Headland (SGC, 1998). This headland is locally capped by resistant erosional remnants of overlying Tapeats Sandstone, but is primarily composed of Payson Granite. Figure 3-1 presents a geologic map of the area, which was derived from geologic maps provided as part of the *Mogollon Rim Water Resources Management Study (MRWRMS)*[4] and related geologic mapping conducted and summarized as part of *Structural Geology and Groundwater Potential, Diamond Rim Study Area, Gila County, Arizona* (Gaeaorama, 2003)[5]. Mr. Clay Conway has conducted ongoing geologic mapping for the Town of Payson, the results of which have been presented in several reports, including the Gaeaorama, (2003) report. This mapping has focused on understanding both the regional geology and structural framework for the purpose of identifying favorable locations for groundwater development.

Geologic mapping by Mr. Conway has identified the following generalized summary of the major bedrock geologic units (from oldest to youngest) in the Star Valley Study area:

[3] The report has not been published as final, but GIS data and related reports were available for this study.
[4]Draft GIS data from the MRWRMS, including a regional geologic map were provided by HydroSystems, Inc. These maps integrate previous geologic mapping efforts by Mr. Clay Conway presented as part of Gaeaorama, (2003).

[5]The summary of geology presented in the section is derived from the same report.

- **Gneissic Granitoids** – Xgg - Gneissic rocks underlying northern portion of the Study Area.

- **Gibson Creek Batholith** - Xgc - generally southwest of the Study Area, consists predominantly of golden tan to gray diorite and gabbro.

- **Payson Granite** - Xdp and Xdpg - Red to tan deeply weathered medium to coarse grained granite, which underlies much of the watershed study area.

- **Tapeats Sandstone** - Ct – Dark brown sandstone present as cap rocks on hills and outcrops in the northern portion of the Study Area. Limited groundwater potential due to limited thickness (50 to 80 feet in the Study Area).

- **Martin Formation** – Dm – Dolomite and limestone, present in northern portion of the Study Area, overlying the Tapeats Sandstone; not a significant water resource in the Study Area.

- **Tertiary Gravels** – Toc, Tgl and Tg – Gravels and conglomerate units present in the northeast portion of the Study Area, locally important in groundwater flow.

- **Quaternary Alluvium** - Qal – Alluvial materials are deposited along Houston Creek and other surface drainages. Some shallow wells are completed in the alluvium near Star Valley, but alluvium comprises a limited groundwater source.

3.1.1 Gneissic Granitoids

The gneissic granitoids are comprised of a number of strongly foliated rock types, including granite, gneiss, diorite and metamorphosed igneous and sedimentary rocks. The range of ages for these rocks is 1.78 to 1.73 billion years, with a metamorphic event (which resulted in the strong foliated nature of these rocks) approximately 1.72 billion years ago. Within the Study Area, the gneissic granitoids are deeply weathered and fractured, and underlie the northern third of the Study Area. The unit is characterized by strong foliation, and poor outcrop due to deep weathering. In general, the water production rates from wells drilled into this rock group is unknown, with relatively few wells penetrating the unit. Recent drilling into this unit by the Town of Payson has not resulted in any wells with high production rates. Based on conversations with Mr. Mike Ploughe (Town of Payson), water production rates for this unit are generally poor compared with wells completed in the Payson Granite, based on well drilling results. However, wells drilled in the Mayfield Canyon area north of the Town of Star Valley had good water production rates (several hundred gallons per minute), and are completed in the

Gneissic Granitoids (personal communication with Mr. Mike Ploughe). This suggests that locally the Gneissic Granitoids may have good water production rates.

3.1.2 Gibson Creek Batholith

The Gibson Creek Batholith is a golden to gray diorite and gabbro, found in the areas to the west and south of the Town of Star Valley. The age of the unit has been estimated at approximately 1.73 billion years. The unit intruded by, but structurally overlies, the Payson Granite. The Gibson Creek Batholith is cut by numerous intrusive features, including quartz veins and dikes, which trend north and northwest. This geologic unit is prominent in road cuts south of the Town of Payson, with many visible veins and dikes. The Gibson Creek Batholith is also noted for the presence of gold and silver bearing sulfide mineral deposits associated with the veins, which are mined extensively in the Rye and Gisela areas, south of Payson. The unit is considered to be a very poor water producer, and yields are generally significantly lower than the Payson Granite. This is evident based on a review of water well data from Arizona Department of Water Resources (ADWR) well drilling records, which indicate few wells completed in this unit and low production rates for those wells with reported rates.

3.1.3 Payson Granite

The Payson Granite is a tan to reddish potassium feldspar and quartz-rich granite, approximately 1.70 billion years old (SGC, 1998). The distinctive red color is believed to be the result of alteration at the time of intrusion, not recent weathering. In the area near the Site, the Payson Granite is the primary geologic unit. The Payson Granite is cut by a number of aplitic dikes and fine grained intrusive bodies, many of which are more resistant to weathering than the granite. A clay layer, approximately 10 feet thick, is noted where the Payson Granite is in contact with the overlying Tapeats Sandstone, representing a paleosol from the late Precambrian period, prior to deposition of the Tapeats Sandstone.

3.1.4 Tapeats Sandstone

The Tapeats Sandstone is a Cambrian age, reddish-brown, medium to coarse grained sandstone that unconformably overlies the Gnessic Granitoids in the north portion of the Study Area. Because the unit is 50 to 80 feet thick in the Study Area, it is not a significant aquifer.

3.1.5 Martin Formation

The Martin Formation is a Devonian age dolomite that overlies the Tapeats Sandstone in the far northern portion of the Study Area. In the Study Area, the unit is 150 to 200 feet thick, and does not generally comprise a significant aquifer. However, the Martin Formation is present at depth in the northern portion of the Study Area, and may locally be a productive aquifer.

3.1.6 Tertiary Gravels

The northeast portion of the Study Area includes several gravel and conglomerate units, which appear to be a source of water for wells in the Diamond Point subdivision area. These units are Tertiary in age, and are comprised of red gravel (Toc), gray gravel (Tgl) and late-tectonic gravel (Tg).

- The red-gravel (Toc) consists of reddish to maroon or tan pebbles and cobbles in a sandy to silty matrix. The gravels are poorly consolidated, with limited cementation, and are derived from Payson Granite and quartzite from the Mazatzal Mountains to the southwest. These clasts give the red gravel its reddish color.

- The gray gravel (Tgl) consists of gray pebbles, cobbles and boulders, primarily derived from the Paleozoic limestone and dolomite. The gray gravel is better consolidated than the red gravel, with calcite cementation throughout the unit. Because of the cementation, the unit is thought to have lower permeability than the red gravel.

- The late tectonic gravels (Tg) consist of a mix of coarse gneissic granitoid and Paleozoic carbonate and sandstone cobbles and boulders, related to the faulting along the Diamond Rim Fault. These deposits were formed in response to fault movement, and clast size decreases away from the Diamond Rim Fault.

3.1.7 Quaternary Alluvium

Within the study area, Quaternary Alluvium is found in the Houston Creek/Mayfield Canyon drainage, and is comprised of sands, silts and gravels. Locally, the alluvium includes colluvium and developed soils, but is limited to drainages in the Study Area. The largest area of Quaternary Alluvium is located in the immediate vicinity of the Town of Star Valley, and downstream along Houston Creek.

3.1.8 Other Minor Units

Tertiary basalt flows cap the Houston Mesa area in the northwest part of the Study Area. Additionally, intrusive Tertiary basalt dikes and sills are present, particularly along the Mayfield Canyon area north of the Town of Star Valley. These basalt dikes and sills have been noted in well logs (and in surface exposures) from the Star Valley area, and may strongly influence groundwater flow locally. Because these dikes have not been thoroughly mapped at depth, the local/regional impact on groundwater flow has not been evaluated as part of this report.

3.2 Geologic Structure

As part of the geologic mapping work conducted by Mr. Clay Conway, numerous faults and fractures zones have been identified throughout the Study Area. A detailed discussion of the tectonic history of the area is presented as part of the *Structural Geology and Groundwater Potential, Diamond Rim Study Area, Gila County Arizona* (Gaeaorama, 2003). The summary presented here is derived from this source.

In general, three tectonic periods, or periods of faulting, have been identified in the vicinity of the Study Area: (1) Proterozoic, (2) Tertiary reactivated Proterozoic, and (3) Tertiary. Because the primary aquifer in the Study Area is the Payson Granite, fracturing and faulting plays a significant role in groundwater flow, particularly with regard to well yield. For this reason, Mr. Conway's geologic mapping focused on mapping of faults and fracture sets in the Study Area. The conclusion from this evaluation was that the Proterozoic faults were generally the most likely to be vein-filled, and had the poorest water transmission characteristics. The Tertiary faults, by contrast, were the most open and had good water transmission characteristics.

3.2.1 Proterozoic Faults

The Proterozoic faults in the area include Anderson Tank Fault, Rumsey Park Fault and Stewart Pocket Fault. In general, these faults trend northeast and are of limited interest for hydrologic influence. As noted in *Long Term Management Program of the Town of Payson's Water Resources* (SGC, 1998), the Rumsey Park Fault (western part of Study Area) may be a Tertiary reactivated Proterozoic fault, although evidence is minimal. Limited information is available regarding Anderson Tank Fault (eastern portion of Study Area) and Stewart Pocket Fault (southwest portion of Study Area). The locations of many faults are based on linear features noted on aerial photographs.

3.2.2 Tertiary Faults

The remaining faults in the Study Area are Tertiary age extensional or normal faults, which generally have good water transmission characteristics. These faults have been targeted for well drilling, as the breccia zones and lack of extensive vein filling or mineralization make them excellent for water production. As presented in the *Structural Geology and Groundwater Potential, Diamond Rim Study Area, Gila County Arizona* (Gaeaorama, 2003), much of the mapping effort was focused on identifying these faults.

One of the significant structural features in the north portion of the Study Area is the Lion Spring Graben, which is defined by the Diamond Rim and Mayfield Canyon faults. Geologically, this graben includes the Tertiary gravel units and down dropped blocks of Paleozoic rocks, including Martin Formation (western portion) and Tapeats Sandstone (Figure 3-2). Water level data suggest that the gravels are the primary shallow aquifer in this area.

4.0 HYDROLOGIC AND HYDROGEOLOGIC CONDITIONS

The Payson Granite underlies much of the southern two-thirds of the study area, and for this reason, it is the primary aquifer in the Study Area. The predominant feature of the Payson Granite in the Study Area is the deep weathering and fracturing of the unit. Numerous faults and fracture sets have been mapped throughout the area, and are displayed on Figure 3-1. These faults and fractures enhance and control the flow of groundwater through the Payson Granite, which results in a much more productive aquifer than the Gibson Creek Batholith. In the Diamond Point area, the principal shallow aquifer may be the Tertiary Gravels, particularly the red gravels (Toc – Figure 3-2). Based on reports from local well driller Aero Drilling, which were cited in *Structural Geology and Groundwater Potential, Diamond Rim Study Area, Gila County Arizona* (Gaeaorama, 2003), wells in the Diamond Point area penetrate gravels and Payson Granite. This is likely one of the few areas in the Payson/Star Valley area with a significant quantity of water in storage, as the granites have low porosity (low storage), but locally have high transmissivity.

4.1 Study Area Hydrology

Clear Creek compiled and evaluated a number of hydrographs for wells in the Study Area and observed that wells within the Study Area have generally stable water levels. Figure 4-1 illustrates the location of wells for which hydrographs have been prepared. Figures 4-2 through 4-4 illustrate hydrographs for wells in the Study Area. Although water levels have historically been approximately in stable (or steady state flow conditions) in the area, water levels in wells near the western boundary have shown rises and declines in water levels in response to recharge and pumping. Each hydrograph includes a graph of annual precipitation to illustrate the connection of some wells with varying recharge rates.

Figure 4-2 illustrates water levels in the southwest portion of the Study Area. Well A(10-10)11ACB, has a good period of record and demonstrates a relatively stable water level. Well A(10-10)02DDB1 does illustrate the impact of changes in recharge rates due to varying precipitation, as does well A(10-10)11BBA.

Figure 4-3 illustrates the stability of water levels in the central portion of the Study Area, (wells A(11-10)36ACB and A(11-10)36CAC1), suggesting steady-state conditions. However, wells that are closer to the western boundary (wells A(11-10)34DDC and A(11-10)35CCC) show significant responses to pumping and recharge, as they are closer to the more active pumping in

the Payson area. The water level change in these wells is not indicative of steady state groundwater conditions.

Figure 4-4 illustrates water levels in the south-central portion of the Study Area. These wells are not near the watershed boundary, and demonstrate overall stability of water levels in the Star Valley area. Unfortunately, these wells do not have a long period of recorded data, therefore long term trends cannot be assessed. Additionally, no other wells in the northern, eastern or southern parts of the Study Area have adequate data to compile hydrographs.

Levine-Fricke-Recon (LFR), in conjunction with the Town of Star Valley and the Town of Payson, has installed water level transducers in selected wells in the Town of Star Valley. Figure 4-5 illustrates the locations of five of these wells for which hydrographs are presented on Figure 4-6. These wells have slight trends of generally less than 10 feet of change in water level. The Binney, Willingham, Baker and Sky Run 1 wells show a slight decline in water levels, while the water level in the Sampson well is stable.

4.1.1 Regional Water Levels and Groundwater Flow

Because water level data for the Study Area are scattered over time, constructing a water level map with adequate spatial coverage for a specific timeframe was difficult. To maximize our understanding of the regional groundwater levels, Clear Creek compiled a table of average water levels for wells in the Study Area. It is assumed that groundwater conditions in the Study Area have been at or near steady-state conditions, although this is not the case on the western boundary of the area, based on the hydrographs presented. Figure 4-7 displays a water level contour map of average water levels for the Study Area. Clear Creek prepared this map based on available water level data from the Town of Star Valley, Town of Payson (personal communication, Mr. Mike Ploughe, 2007) and ADWR's GroundWater Site Inventory (GWSI) (ADWR, 2006). Clear Creek included groundwater levels from both wells and springs in the Study Area to develop a regional water level map. This map is a generalized view of aquifer conditions, and it does not address anisotropy and localized conditions which are evident in data from specific wells and aquifer tests.

The groundwater discharge from springs in the Study Area is unknown, although it may be up to 50 to 100 acre-feet per year. Much of the discharged water is transpired by plants, and it is likely that a portion of the spring discharge ultimately recharges to the system. Clear Creek assumes that spring discharge losses are encompassed in the evapotranspiration estimates.

Based on the groundwater contours in Figure 4-7, groundwater flows from north to south across the Study Area, parallel to the Mayfield Canyon/Houston Creek drainages. On the western side of the Study Area, groundwater flows east and southward. Water level elevations vary from 5,878 feet AMSL at Diamond Spring to less than 4,500 feet AMSL along Houston Creek at the southern boundary of the Study Area. It is presumed that groundwater discharges to Houston Creek in the southern portion of the Study Area, and that groundwater exits the Study Area at the southern boundary along Houston Creek. The combined groundwater flux and discharge of groundwater to surface flow in Houston Creek represent the naturally occurring outflow from the basin. Because surface flow gaging records are not available for Houston Creek, base flow rates for Houston Creek are not known. For this reason, the annual volume of surface water that results from discharge of groundwater is unknown.

4.1.2 Impact of Gravel Aquifer on Regional Hydrology

Based on available well and water level data, the gravels (Toc) are locally an important part of the aquifer in the Diamond Point area. Most of the developed wells in both the Payson and Star Valley areas are drilled into, and produce water from, fractured Payson Granite. The Payson Granite is locally very productive, with large well yields and good transmissivity. However, the Payson Granite does not have a large aquifer storage capacity, as wells tend to respond quickly to both pumping and recharge. For this reason, the gravel aquifer in the northeast portion of the Study Area may be one of the few areas in the region with significant groundwater in storage. This may act to stabilize (buffer) water levels over the long term, with groundwater in the gravel aquifer draining into the underlying granites during dry years, and recharging during wet years.

4.2 Aquifer Hydraulic Characteristics

As part of the review of available data for the project, Clear Creek Associates reviewed the following reports that describe aquifer tests conducted on wells in the study area:

1. *Pumping Test Results – CJ Excavating Well, Star Valley, Gila County, Arizona* (Dickens, 2004)

2. *Pumping Test Results – Grimes Deep Test Well, Star Valley, Gila County, Arizona* (Dickens, 2005a)

3. *SkyRun – 5 Acres* (SGC, 2004a)

4. *Hydrologic Investigation, SkyRun 5 Acres, Star Valley, Gila County, Arizon*a (SGC, 2004b)

5. *SkyRun 5 Acres, Phase Three Well Testing* (SGC, 2005)

6. *Pumping Test Results, Well RH-2, Star Valley, Gila County, Arizona* (Dickens, 2005b).

The following sections discuss and summarize the results of these tests.

4.2.1 CJ Excavating Test

In June 2004, Chuck Dickens coordinated a 7-day aquifer test at an average pumping rate of 198.5 gpm (Dickens, 2004) at the CJ Excavating Deep Well. Following pumping, a 24-hour recovery period was monitored. The well penetrates a 10-foot thick basalt layer, but was primarily completed in what appears to be Payson Granite, to a depth of 565 feet. The nearby CJ Excavating Shallow Well (also known as the Floyd Shallow Well) was monitored during testing. A summary of the results is presented below:

Well	Type	Static Depth to Water (feet)	Specific Capacity (gpd/ft)	Transmissivity (gpd/ft)	Test Analysis Method	Well Depth (feet)
CJ Excavating Deep Well	Recovery	50.50	1.35	8,730	Cooper-Jacob	565
CJ Excavating Shallow Well	Pumping	55.04	-	10,275	Cooper-Jacob	90
CJ Excavating Shallow Well	Recovery	55.04	-	14,970	Cooper-Jacob	90

Table 4-1 – Aquifer Test Results for CJ Excavating Well

The CJ Excavating Shallow Well is located 58 feet east of the pumped well. It was estimated that the well would sustain a pumping rate of 200 to 225 gpm, based on the results of the aquifer test.

4.2.2 Grimes Well

The Grimes Well was deepened by Aero Drilling in January 2005, and the well penetrated a 15-foot thick basalt layer, but was primarily completed in what appears to be Payson Granite, to a

depth of 610 feet. In January and February 2005, Chuck Dickens conducted a 7-day aquifer test of the Grimes Well at an average pumping rate of 253 gallon per minute (Dickens, 2005). Following pumping, a 24-hour recovery period was monitored. Three additional nearby wells were monitored during testing: the two wells located at CJ Excavating (also known as the Floyd Shallow and Deep Wells) and a nearby well located at an RV Park.

The completed report presents an analysis of the recovery data for the Grimes Well and recovery data for the CJ Excavating Deep Well, summarized in the following table:

Well	Type	Static Depth to Water (feet)	Specific Capacity (gpd/ft)	Transmissivity (gpd/ft)	Test Analysis Method	Well Depth (feet)
Grimes Deep Well	Recovery	35.0	2.05	3,928	Cooper-Jacob	610
CJ Excavating Well	Recovery	34.9	-	10,773	Cooper-Jacob	565

Table 4-2 – Aquifer Test Results for Grimes Well

The CJ Excavating Deep Well is located about 750 to 800 feet east of the pumped well. The shallow monitoring wells were not analyzed due to lack of observable drawdown. The report estimated that the long-term sustainable pumping rate for the well was 250 gallons per minute (gpm).

As part of the aquifer test analysis, an estimate of the confined storage coefficient was made which was 3.6×10^{-4}. This value was calculated using the data from the CJ Excavating Well.

4.2.3 SkyRun Well PW-1

In March 2004, SGC conducted a 7-day aquifer test on SkyRun Well PW-1 at an average pumping rate of 90 gpm (SGC, 2004a). Following pumping, a 24-hour recovery period was monitored. The well log indicates that this well is completed primarily in what appears to be Payson Granite, to a depth of 300 feet.

Well	Type	Static Depth to Water (feet)	Specific Capacity (gpd/ft)	Transmissivity (gpd/ft)	Test Analysis Method	Well Depth (feet)
PW-1	Pumping	84	4.26	14,060	Cooper-Jacob	300
PW-1	Pumping	84	4.26	13,180	Cooper-Jacob	300
PW-1	Recovery	84	-	14,395	Theis	300

Table 4-3 – Aquifer Test Results for Sky Run (PW-1) Well

Due to uncertainty in the sustainable pumping rate, SGC raised the pumping rate from 30 to 90 gpm over the first hour and a half of the test. The pumping rate was maintained at 90 gpm for the remainder of the test period.

4.2.4 SkyRun Well PW-2

In July 2004, SGC conducted a 7-day aquifer test on SkyRun Well PW-2 at an average pumping rate of 162.5 gpm (SGC, 2004b). Following pumping, a 24-hour recovery period was monitored. Additionally, two nearby wells were monitored: well PW-1 (300 feet deep) and a second well called MW-1 (400 feet deep). The well log indicates that, at that time[6], the borehole was completed primarily in what appears to be Payson Granite, to a depth of 407 feet.

[6] The Well PW-2 was later deepened to 850 feet in March 2005.

Well	Type	Static Depth to Water (feet)	Specific Capacity (gpd/ft)	Transmissivity (gpd/ft)	Test Analysis Method	Well Depth (feet)
PW-2	Pumping	104.1	1.1	3,230	Cooper-Jacob	407
PW-2	Pumping	104.1	-	1,840	Cooper-Jacob	407
PW-2	Recovery	104.1	-	1,920	Theis	407
PW-1	Pumping	84.5	-	13,780	Cooper-Jacob	300
PW-1	Recovery	84.5	-	19,350	Cooper-Jacob	300
MW-1	Pumping	112.6	-	870	Cooper-Jacob	400
MW-1	Recovery	112.6	-	4,560	Cooper-Jacob	400

Table 4-4 – Aquifer Test Results for Sky Run (PW-2) Well

Well PW-1 is located 130 feet northeast of the pumped well, and well MW-1 is located 250 feet southeast of the pumped well. Storage values were not calculated as part of the report. Significant anisotropy was evident in the results, with much greater drawdown evident in MW-1, despite the greater distance from PW-2. This indicates that MW-1 may be located in the same fracture zone.

4.2.5 SkyRun Well PW-2 Deepening

In February 2005, well PW-2 was deepened to a depth of 960 feet, with a new well completed to a depth of 850 feet in the deepened boring. Following the deepening of this well, SGC conducted a 7-day aquifer test at an average pumping rate of 457 gpm (SGC, 2005). Following pumping, a 7-day recovery period was monitored. Additionally, four nearby wells were monitored: well PW-1 (300 feet deep), well MW-1 (400 feet deep), the CJ Excavating (Floyd) Deep Well (565 feet deep) and the RH-1 monitor well (900 feet deep). The well log indicates that this borehole is primarily completed in what appears to be Payson Granite, to a depth of 960 feet, with granodiorite noted from 850 to 960 feet.

Well	Type	Static Depth to Water (feet)	Specific Capacity (gpd/ft)	Transmissivity (gpd/ft)	Test Analysis Method	Well Depth (feet)
PW-2	Pumping	104.1	1.34	1,490	Cooper-Jacob	850
PW-2	Pumping	104.1	1.34	1,220	Cooper-Jacob	850
PW-2	Recovery	104.1	-	3,130	Theis	850
PW-2	Recovery	104.1	-	3,850	Theis	850
PW-1	Pumping	84.5	-	14,420	Cooper-Jacob	300
PW-1	Recovery	84.5	-	13,560	Theis	300
MW-1	Pumping	112.6	-	4,670	Cooper-Jacob	400
MW-1	Recovery	112.6	-	4,200	Theis	400

Table 4-5 – Aquifer Test Results for PW-2 after Deepening

As previously noted, well PW-1 is located 130 feet northeast of the pumped well, while well MW-1 is located 250 feet southeast of the pumped well. Water levels from RH-1 and the CJ Excavating Well were presented, but were not analyzed. Water levels from both of these wells rose during the testing. Storage values were not calculated as part of the report. As before, significant anisotropy was evident in the results, with much greater drawdown evident in MW-1, despite the greater distance from PW-2

An interesting observation regarding the deepening of this well is that the calculated transmissivity values for the deepened well are similar or only slightly higher than the results from the first test. Since the depth of the well (aquifer thickness penetrated) was approximately doubled, the fact that the transmissivity did not double indicates that the aquifer is less transmissive with depth. This is expected in a fracture-dominated aquifer, where fractures tend to close with greater lithostatic pressure (depth).

4.2.6 RH-2 Testing

In April 2005, Chuck Dickens conducted an 8-hour step drawdown and 7-day constant rate aquifer test at well RH-2, at an average pumping rate of 525 gpm (Dickens, April 29, 2005).

Following pumping, a 6 day recovery period was monitored. During pumping, local wells RH-1 and L. Gay were monitored, but responses were not sufficient to permit analysis. The well log indicates that this well is primarily completed in what appears to be Payson Granite, to a depth of 560 feet.

Well	Type	Static Depth to Water (feet)	Specific Capacity (gpd/ft)	Transmissivity (gpd/ft)	Test Analysis Method	Well Depth (feet)
RH-2	Recovery	85.0	3.93	14,215	Cooper-Jacob	560

Table 4-6 – Aquifer Test Results for RH-2 Well

Mr. Dickens concluded that this well may derive its water from east of the Town of Star Valley, as limited responses in wells west and south of RH-2 were noted.

4.3 Aquifer Storage

Clear Creek Associates has generally presumed that aquifer conditions in the Study Area are approximately in steady-state, meaning that there are no long-term changes in the volume of water in storage. In addition, few aquifer tests have been conducted to evaluate specific yield and confined storage coefficients. For this reason, no evaluation of the available water in storage in the aquifer was conducted. Short-term aquifer testing (24 to 72 hours) does not provide accurate estimates of specific yield, which is needed to define the volume of water in storage. Estimates of specific yield for the Payson Granite can vary significantly, and a calibrated groundwater model developed for the Arizona Department of Environmental Quality (ADEQ) Payson PCE Water Quality Assurance Revolving Fund (Payson WQARF) Site incorporated values of specific yield ranging from 0.1 to 0.01 (GeoTrans, 2001). No data are available to evaluate the gravel aquifer in the Diamond Point area. Because the aquifer storage has not been evaluated, the impact of groundwater withdrawals by wells (individually or collectively) on volumes in storage cannot be evaluated from the results presented here.

5.0 EVALUATION OF SAFE YIELD

The concept of managing water use to achieve Safe Yield, in Active Management Areas, as defined in Arizona statutes, is:

> A groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial recharge in the active management area.

This implies that groundwater withdrawals should not exceed available net recharge (natural and artificial). For this reason, the focus of this Study was to evaluate the net recharge to the aquifer. This is presumed to represent the approximate safe yield of the aquifer, although development of groundwater resources may have other potential impacts that need to be considered, such as impacts on surface flows in Houston Creek.

5.1 Basic Assumptions

A number of assumptions were employed in this analysis that defines the conditions upon which this estimate is based. These include:

- The boundaries of the surface watershed and groundwater basin are approximately coincident;
- Overall groundwater flow is approximately equivalent to porous media flow conditions over the entire watershed, with no regional scale anisotropy considered;
- Natural outflow from groundwater basin includes both groundwater underflow exiting the basin and surface water flow;
- The groundwater flow conditions are approximately in a long-term steady state;
- There are no groundwater inflows into the Study Area[7]; and,
- Groundwater conditions are the result of direct net aquifer recharge.

It is assumed that the surface watershed boundaries define the groundwater basin, an assumption which may or may not be appropriate. This assumption is usually more or less valid in many

[7] Based on conversations with Mr. Mike Ploughe (Town of Payson) it is known that groundwater inflows may be occurring in the deep, regional fracture system into the Study Area. Because it is impossible to quantify flow in the regional fracture system, these flows have been ignored for this evaluation.

areas due to the basic connection between surface water and groundwater. Along the western boundary (toward Payson), adequate groundwater level elevation data exist to demonstrate that the boundaries are more or less coincident. However, insufficient data exist to confirm this assumption for the northern and southern boundaries. Water levels east of the eastern boundary also suggest that the boundary is approximately coincident, although flux appears to be leaving the Study Area eastward along State Route 260. It is assumed that no inflow of groundwater occurs at the Study Area boundaries, although underflow is suspected along deep fracture zones that exist in the study area and region.

The conceptual model for this estimate presumes that direct net recharge of precipitation is the only source of inflow to the groundwater system. Precipitation falls on the watershed, with surface runoff, evapotranspiration and residual net recharge being the components of the water budget for the Study Area. Additionally, steady-state conditions are assumed over for the watershed, which implies that there are no long term changes in groundwater in storage within the Study Area.

Although fracture dominated flow and anisotropy are evident from available well yield and aquifer test data, they are difficult to evaluate over the entire watershed due to lack of spatially extensive water level data. For this reason, Clear Creek has assumed for the purposes of developing water level contours, that flow is uniform through the aquifer without significant anisotropy.

5.2 Precipitation Volume

Figure 2-3 and Tables 2-1, 2-2 and 2-3 illustrate the available precipitation data for the Payson and Payson Ranger Station precipitation gages, which are the gages available for the study area. Based on these data, the average annual precipitation using the Payson station records is 21.53 inches over the period of record (1949 to 2005). The average annual precipitation for the Payson Ranger Station is 20.07 inches over the period of record (1893 to 1974, with some missing years). This is consistent with the long term trends illustrated in Figure 2-3, suggesting that precipitation has increased over the period 1893 through 2005. However, as noted in Figure 2-4, short term trends appear to suggest a decline in annual precipitation since 1980.

5.2.1 Adjustment for Elevation

As part of our evaluation of precipitation for the watershed, an effort was made to assess the influence of elevation on precipitation. As a general rule, precipitation increases with elevation, but no direct relationship can be identified without evaluating available gaging station data. To

achieve this, Clear Creek compiled precipitation data for all Arizona stations, including location (converted to UTM) and station elevation. Precipitation is also not uniform over Arizona, because weather patterns impact different parts of the State in different ways, particularly summer monsoon storms. Thus precipitation is a function of both elevation and location. To limit the effect of location, stations were considered that were within 100-miles of Payson. In addition, to limit the influence of significantly different elevation zones, stations were restricted to those within 1,000 feet of the Payson Station elevation. Figure 5-1 illustrates the results of this analysis, displaying average precipitation compared to station elevation. Although the correlation of the trend line is poor (r^2 value of 0.014), the slope of the line was used to adjust precipitation values to correct for altitude variation.

In order to establish elevation zones for the watershed, Clear Creek utilized a GIS based approach. Clear Creek created a set of 100-foot elevation contours for the region using 10 meter Digital Elevation Model (DEM) data from the United States Geological Survey (USGS). These contours were then used to "cut" or "clip" the watershed polygon to generate a set of polygons which represent the area between the contour lines. The elevation of each zone was the 50-foot value between each contour line, so that the polygon between 4,900 and 5,000 feet was assigned an elevation value of 4,950 feet. The result is displayed on Figure 5-2. Using GIS, the area of each of these polygons was calculated, and Table 5-1 displays the precipitation volume for each elevation zone.

Based on the average precipitation of 21.53 inches, an estimate of 38,779 acre-feet of precipitation falls on the Study Area watershed in an average year of precipitation.

5.3 Approach to Evaluating Water Budget

Clear Creek reviewed a variety of approaches for evaluating the water budget for the Study Area, and has presented an analysis of watershed runoff and evapotranspiration using the method outlined in *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995). The Mayfield Canyon study analyzed a portion of the Study Area immediately north of the Town of Star Valley. This study utilized a variety of local and regional approaches to calculating runoff, and a detailed evaluation of evapotranspiration using detailed maps of soil and vegetation for the Study Area. This approach includes a level of detail and local information that is not possible with more generalized methods such as the Maxey-Eakin method (Eakin, 1966), and other methods (Gates, 1963, 1965; Feth and others, 1966) that incorporate runoff and/or evapotranspiration.

As previously noted, the approach to evaluating the water budget for the Study Area assumes that steady state groundwater conditions exist over the long term. This assumption implies that no changes in groundwater storage have occurred over the long term; although individual years may have changes in storage due to dry or wet conditions relative to normal (average precipitation) conditions.

5.3.1 Components of the Water Budget

The water budget presented in this report includes both groundwater and surface water components, as outlined in the following table:

INFLOWS:	
Surface Water	Precipitation Volume
Surface Water	Streamflow into Study Area = 0
Groundwater	Recharge from Percolation
Groundwater	Change in Storage = 0
Groundwater	Inflow = 0
OUTFLOWS:	
Surface Water	Evapotranspiration
Surface Water	Runoff
Surface Water	Recharge from Percolation
Groundwater	Change in Storage = 0
Groundwater	Groundwater Flux at south boundary[a]

Table 5-2: Water Budget Components

a: Groundwater Flux may contribute a portion of the surface flow in Houston Creek

Based on the assumptions previously discussed, recharge from percolation is assumed to be equal to the volume of precipitation minus evapotranspiration and runoff.

5.4 Estimate of Runoff

Because there are no historic surface water gaging records for Houston Creek, no direct measurements of surface runoff are available. For this reason, surface runoff was estimated for this analysis. In *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995), three methods are used to estimate surface runoff:

1. Average annual runoff from hydrologically similar watersheds;

2. Regional regression equation outlined in *Average Annual Runoff from Precipitation and Basin Factors In East Central Arizona* (Hawkins, 1991); and,

3. Annual watershed yield coefficients provided by the Tonto National Forest, derived using *Water Yield Improvement by Vegetation Management Focus On Arizona* (Ffolliott, 1975).

These methods assume that surface runoff exits the watershed at the downstream boundary, and does not account for groundwater discharge to streams, which may be occurring in Houston Creek downstream of Star Valley. Clear Creek used the methods described in *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995) to complete this analysis.

5.4.1 Average Runoff from Similar Watersheds

The average runoff from similar watersheds estimate derived in *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995) estimated that 119 acre-feet of runoff is generated per square mile of watershed for the smaller Mayfield Canyon area. The area of the Study Area watershed is 21,420 acres, or 33.47 square miles. This yields an estimated annual runoff of 3,983 acre-feet.

5.4.2 Regression Equation of Hawkins

Professor Richard H. Hawkins of the Watershed Sciences Program, School of Renewable Natural Resources, University of Arizona, prepared the following regional regression equation for estimating annual runoff from watersheds in east central Arizona (Hawkins, 1991):

$$Q = 0.005724 * P^2 - 0.4563 * (\text{Latitude} - 32^o)$$

Where: Q = Average annual runoff in inches

P = Annual precipitation rate in inches

Latitude = Latitude of Geographic Center of Study Area

The result is adjusted for watershed elevation using the following:

$$R = 1.5863 - 0.000086*(ELEV)$$

Where: R = Ratio multiplier applied to Q

ELEV = Median elevation of watershed

The values to be used here are:

P = 21.53 inches

Latitude = 34.26^{o}

ELEV = 5,047 feet (area weighted average)

Watershed Area = 21,420 acres

The result is an average annual runoff of 1.87 inches per year, which calculates to 3,336 acre-feet per year.

5.4.3 USFS Method

As described in *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995), the United States Forest Service (USFS) has developed a method of estimating average annual runoff based upon yield coefficients for native vegetation types. As presented in *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995), the following coefficients (derived from Ffolliott, 1975) were used:

- Desert (high) 0.24 inches per year;
- Chaparral 1.44 inches per year;
- Oak (assumes Chaparral) 1.44 inches per year;
- Pinyon-Juniper 0.96 inches per year; and,
- Ponderosa Pine 4.44 inches per year.

To apply the procedure, Clear Creek obtained a GIS coverage of the Tonto National Forest soil and vegetation cover through HydroSystems, from the MRWRMS project. This polygon shapefile coverage covers the entire Study Area, with each soil/vegetation zone mapped (Figure 5-3). As part of *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995), each Map Unit ID Zone was generalized into Ecosystem Zones equivalent to the coefficients for zones derived from Ffolliott, 1975 listed above. Table 5-3 summarizes the acreages for each Map Unit ID, listing the relevant Ecosystem Zone.

Table 5-4 displays the calculated runoff for each Ecosystem Zone, based on the runoff coefficients of Ffolliott, 1975. The total runoff is estimated as 3,069 acre-feet annually using this method.

5.4.4 Estimated Runoff Component

Based on the three methods of estimating runoff, the average value of these methods for estimating runoff is 3,462 acre-feet per year. This value was used for evaluating the water budget. This does not include perennial surface flow in Houston Creek, which is not gaged, but is likely a small component.

5.5 Evapotranspiration

Although the GIS coverage outlined the numerically coded soil/vegetation zones, it did not include a breakdown of the vegetation coverage by Map Unit ID. To address this, Clear Creek obtained a copy of the North Tonto Terrestrial Ecosystems Survey (TES) report (USFS, 1985) from the local Tonto National Forest office, which outlines the percentages of different soil and vegetation coverage for each of the soil/vegetation zones. This allowed for an estimation of acreage of different vegetation communities in the Study Area. These acreage estimates were then used to calculate evapotranspiration (ET).

Using the GIS, Clear Creek compiled the total acreage for each of the Map Unit ID (individual vegetation zone in TES), which is included in Table 5-3. This table also displays the percentages that each vegetation community comprises for each Map Unit ID. Taking these percentages, the total acreage of each vegetation type is summarized at the bottom of Table 5-3.

As part of *Mayfield Canyon Water Budget at Mayfield Canyon Ranch, Star Valley, Arizona* (ASL Sierra, 1995), an analysis of ET rates by vegetation community was completed to derive ET demand for the Study Area. Based on that analysis, conservative rates for each vegetation type were established, and using acreages for each community, total ET was calculated (Table 5-5). Details regarding this assessment are presented in *Mayfield Canyon Water Budget at*

Mayfield Canyon Ranch, Star Valley, Arizona (ASL Sierra, 1995). Based on these data, the ET demand for the Study Area is 30,582 acre-feet per year.

5.6 Net Groundwater Recharge

To estimate the water budget for the Study Area, it is assumed that the net recharge to the aquifer is equal to the precipitation volume that falls on the watershed, minus the volume of runoff and minus the volume required for ET. Table 5-6 summarizes the calculated net groundwater recharge:

Component	Volume (acre-feet)
Precipitation	**38370.2**
Runoff	3462.0
ET	30582.1
Net GW Recharge	**4326.1**

Table 5-6 – Estimate of Net Recharge (Acre-feet per year)

Based on the estimated volumes of flow, 4,326 acre-feet is the net recharge under average precipitation conditions.

5.7 Water Budget Estimate

Based on Table 5-6, average precipitation conditions yield approximately 4,300 acre-feet of recharge per year which would be a safe pumping yield, capturing the outflow from the Study Area. This value assumes that the change in storage is zero, or that the groundwater conditions in the Study Area are in a long term steady state. Table 5-7 presents the water budget for the Study Area, based on an average precipitation rate of 21.53 inches per year at the Payson Station.

INFLOWS:		
Surface Water	Precipitation	38,370
Surface Water	Streamflow	0
Groundwater	Recharge to Aquifer	4,326
Groundwater	Change in Storage	0
Groundwater	Inflow as Underflow	0
		42,696
OUTFLOWS:		
Surface Water	Evapotranspiration	-30,582
Surface Water	Runoff	-3,462
Surface Water	Recharge to Groundwater	-4,326
Groundwater	Change in Storage	0
Groundwater	Groundwater Outflow	-4,326
		-42,696

Table 5-7 – Water Budget for Study Area

Notes: Groundwater Outflow includes base flow in Houston Creek, all values acre-feet per year

Because ET demand cannot be calibrated effectively to actual precipitation values, it is difficult to evaluate net recharge under conditions that deviate significantly from "average" conditions. Figure 5-4 displays estimated safe yield based on annual precipitation, assuming a fixed ET value of 30,582 acre-feet. The safe yield value presented on Figure 5-4 is calculated by assuming that groundwater outflow is equal to aquifer recharge, which is equal to volume of precipitation minus runoff and ET. As noted, this analysis also assumes that the change in groundwater storage is zero. Runoff is estimated based on the method presented in Section 5.4.2 (Hawkins, 1991). Negative values of safe yield are years where annual precipitation did not reach 18.11 inches, which calculates to a net recharge of zero, based on the assumptions presented here. This occurred during 14 years over the 57 year period of record (1949 to 2005). The basic ET demand component is equivalent to approximately 17 inches of precipitation, suggesting that during years that have less than 17 inches of precipitation, base ET demand is not met. Over the 57 year period 1949 to 2005 (Payson gage - Table 2-1), 11 years had precipitation lower than 17 inches. The most recent year with precipitation below 17 inches was 2002, which was the lowest value recorded over the period of record (9.56 inches). Clearly, changes in groundwater storage and ET rates are occurring during periods where precipitation is significantly lower or higher than average. Figure 5-4 illustrates the variable nature of net recharge rates, which suggests that safe yield values vary significantly from year to year.

5.8 Aquifer Flux Estimate

As a check on the water budget estimate, Clear Creek completed a groundwater flux estimate. Theoretically, the flux of groundwater in the aquifer should be equivalent to the rate of inflow to the system, or the rate of recharge, since that is the only significant inflow component. Based on Darcy's Law groundwater flux can be calculated based on the following equation:

$$Q = T*I*W$$

Where: Q = Flow in Aquifer (cubic feet per day)

T = Aquifer Transmissivity (cubic feet per foot per day)

I = Gradient (dimensionless)

W = Width of Flow Tube (feet)

Groundwater flux for the Study Area was calculated by drawing flow lines perpendicular to the contours, which are flow tubes for completing a Darcy Strip analysis. These flow tubes are presented on Figure 5-5. Each flow tube was constructed using the groundwater contours (Figure 4-7), with width of each tube and distance between points used for gradient calculations measured using the GIS. Table 5-8 displays the summary of the available aquifer test and specific capacity estimates for each flow tube, with the average or estimated value derived for each. Using these transmissivity values, flux values were estimated and are presented in Table 5-9. No information was available for tubes A or B, but geologic and water level contours suggest that transmissivity values are lower for these areas. Measurements were made at the indicated contour lines. The estimated groundwater flux is 4,784 acre-feet per year. This is close to the estimated groundwater budget value of 4,326 acre-feet, suggesting a good match with observed data.

It should be noted that the groundwater flow map displayed on Figure 4-7 is a generalized and simplified flow map which indicates that flow converges and discharges along Houston Creek. This simplified view does not account for fluxes which may leave the basin via higher permeability fault and fracture zones, particularly along the east and southeastern boundary. Discharges eastward from the Diamond Point subdivision area may also exit the basin along State Route 260, as suggested by the water levels in this area. For this reason, the groundwater

flow directions presented here are approximate, and are intended to provide a general estimate of groundwater flux. Nonetheless these potential "leaks" out of the system as it is defined appear to be quite minor and likely within the error of the study estimate.

5.9 Sensitivity Analysis

In general, the rainfall on the watershed is the "most accurate" parameter because direct measurement of rainfall rates is conducted, and a relatively long period of recorded data is available. Although rainfall varies for any one year spatially over the Study Area, average values should account for the variability over the long period of record. For this reason, the average rainfall values provide a relatively accurate estimate of the long-term average inflow to the Study Area.

Because evapotranspiration is the largest component of outflow, the value of evapotranspiration is a critical component in the water budget for the study area. Unfortunately, evapotranspiration is difficult to measure, and can only be estimated using vegetation information. Additionally, evapotranspiration varies based upon seasonal vegetation water demand and variation in available rainfall. It is clear that evapotranspiration would decline during years with lower precipitation, but these changes are difficult to measure. The analysis presented in this report is intended to estimate the average evapotranspiration based on estimated annual water demand.

Each of the other components of the water budget is smaller in magnitude, and therefore would have less influence on the estimate of safe yield. Runoff from the watershed is ungaged, which implies that surface flows are not accurately known. However, the values presented are relatively consistent, which suggests that runoff values are reasonable. Installing a gaging station to monitor surface runoff in Houston Creek could provide a valuable piece of information to evaluate the estimate presented as part of this report.

5.10 Comparison with Estimate of Safe Yield for Town of Payson

Southwest Ground-water Consultants, Inc. conducted an evaluation of safe yield for the Town of Payson in 1998 (SGC, 1998). This value was derived from a similar water budget approach to that presented in this report. The value estimated was 2,282 acre-feet per year for an area of 12,480 acres that comprise the Town of Payson (SGC, 1998). Since the Star Valley Study Area covers 21,420 acres, a representative estimate for an equivalent safe yield would be 3,900 acre feet per year. This is similar to the estimate of 4,300 acre-feet and supports the general conclusions presented.

6.0 SUMMARY AND CONCLUSION

Clear Creek has assembled available data to assess regional groundwater flow conditions in the Study Area, and has evaluated the regional groundwater budget. Based on this analysis, the net annual recharge is approximately 4,300 acre-feet, which would represent the safe yield of the aquifer as defined in the scope of work for this project. Clear Creek has contacted the Gila County Assessors Office to determine the current population to assess current groundwater usage by private wells. Based on data provided (personal communication, Larry Huffer, Gila County Assessor), the approximate population of Star Valley is 2,500 residents. Using 100 gallons per person per day as an estimate of water demand, the annual groundwater demand is approximately 280 acre-feet, which is significantly less than the 4,300 acre-feet yield estimate.

In addition to the basic water demand by the current population, pumping by wells in Mayfield Canyon may amount to approximately 100 acre-feet per year yielding a current maximum total groundwater withdrawal rate of 380 acre-feet per year. It should be noted that the ADOT well field is operated on a net balance of withdrawal and injection of surface water to replace that groundwater which is pumped. Therefore, groundwater outflow via pumping is not occurring at the ADOT site. However, groundwater outflow may be naturally (or even artificially enhanced by the injection of surface water at the ADOT site) due to the apparent presence of a groundwater divide located in the vicinity of the ADOT well field.

A review of Figure 5-4 shows that safe yield for any particular year may be significantly higher or lower than the estimated 4,300 acre-feet. Since there are insufficient data to evaluate changes in groundwater storage or variability of the ET component, the information presented on Figure 5-4 should be used only as a guide to indicate the variable nature of safe yield in the Study Area.

An issue that should be addressed is the perennial flow in Houston Creek, downstream from Star Valley. This flow appears to be caused by groundwater discharge to the stream, representing a portion of the groundwater outflow from the Study Area. Because these flows have not been gaged, Clear Creek cannot assess the impact of groundwater withdrawal on the flow in Houston Creek. It is also unclear whether the flow in the creek varies on a seasonal basis or is relatively constant.

Southwest Ground-water Consultants (SGC, 1998) concluded that 80% of the safe yield was a more appropriate value for use in water management decisions for the Town of Payson to allow for uncertainty in the estimates. Using this approach, a practical safe yield value for the Study Area would be 3,440 acre-feet per year, or 80% of the 4,300 acre-feet safe yield estimate.

7.0 REFERENCES

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FIGURES

TABLES