ATTACHMENT 1

(Supplemental Documentation to the: Mogollon Rim Water Resource Management Study Report of Findings)

Hydrogeologic Framework and review of Alternative Water Solutions for the Mogollon Rim Water Resources Management Study Area by HydroSystems, Inc., April, 2008

Hydrogeologic Framework and Review of Alternative Water Supplies for the Mogollon Rim Water Resources Management Study Area

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Mogollon Rim Water Resources Management Study

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1.0 INTRODUCTION

The Mogollon Rim Water Resources Management Study (Study) is a regional assessment of water resources and water use alternatives for the growing communities along the Mogollon Rim in Gila County as shown in ***Figure 1***. The Study region is located within the area bounded by the Colorado Plateau to the north, Fossil Creek and the Verde River to the west, Christopher and Tonto Creeks to the east, and an arbitrary east-west line roughly connecting North Peak in the Mazatzal Wilderness with "Ox-Bow Hill", north of Rye. The Study area is entirely within the central Transition Zone physiographic province and because of its diverse geology and topography climate; it is one of the most complex hydrogeological areas within the State of Arizona.

To meet the needs of the Study, an in-depth evaluation of the region's geology, groundwater chemistry, and isotope geochemistry was commissioned. The hydrogeologic framework presented herein is based heavily on three primary resources. Gaeaorama Inc. developed the geological mapping and much of the geographic data used in this document's figures and plates. Dr. Chris Eastoe of the University of Arizona analyzed significant hydrologic relationships between precipitation and groundwater based on isotopic geochemistry of springs and wells in the area. HydroSystems, Inc. further developed the hydrogeologic relationships of wells and springs in the area using general water chemistry analyses. Additional references include work performed by the Town of Payson, the US Geological Survey (USGS), and data available from the Arizona Department of Water Resources (ADWR). This report is an evaluation of the data and resources developed for this Study and briefly summarize the findings into an information baseline for water resources planning. This report provides a conceptual hydrogeological framework of the Study area and a review of possible alternative water resource solutions as a guide for future water management.

2.0 HYDROGEOLOGICAL FRAMEWORK

The topographic feature known as the Mogollon Rim, along the southern edge of the Colorado Plateau, extends southeast to northwest nearly 200 miles across central Arizona. Exposed along the southern portion of the Rim is a series of Paleozoic sedimentary units nearly 3,000 feet thick. The highest elevations along the Mogollon Rim are in excess of 7,000 feet above mean sea level. The rocks of the Paleozoic sedimentary sequence are composed of interbedded sandstone, shale, and limestone. In many areas, the Paleozoic sequence is capped by Tertiary basalt. Topography along the Rim area is notably rugged, with steep cliffs and hills, covered in most portions of the Study area with thick forest. The topography south of the Mogollon Rim is characteristically rugged, but with less topographic relief. South of the Mogollon Rim, the Paleozoic rock sequence has been eroded away, revealing significant exposures of Precambrian (a.k.a. Proterozoic) rock units. The Proterozoic units consist of granite, diorite, rhyolite, gabbro, and a plethora of metamorphic rocks.

Adding significant complexity to the region are numerous faults and fractures which offset and cross-cut the rock units, leaving a patchwork of geologic discontinuity. Because the Study region is diverse and complex, the area has been broken into four different sub-regions (displayed in ***Figure 2***) for discussion. Each sub-region has generally similar hydrogeologic characteristics and complexities. Because of the size of the Study area, groundwater elevation contours along with flow directions, are presented at this larger (1:24,000) sub-region scale. Upon conclusion of these sub-regional hydrogeologic discussions, the regional groundwater flow system is presented as a composite of the four sub-regions at a smaller 1:45,000 scale.

For additional understanding of the geologic units discussed in this report, ***Figure 3*** displays a generalized/composite stratigraphic cross section across the Study area. This figure shows the presence of the Paleozoic sedimentary sequence, the Proterozoic units beneath, and the numerous younger Tertiary and Quaternary units covering them.

2.1 Sub-Region 1

The Sub-Region 1 encompasses the area south of the Mogollon Rim, along the southern perimeter of the Colorado Plateau, and north of the Diamond Rim Fault. Due to the elongated nature of this sub-region, it is divided and displayed on two plates; ***Plate 1*** (West) and ***Plate 2***

(East). Sub-Region 1 is characterized by the exposure of significant portions of Paleozoic sedimentary rock units of the Colorado Plateau. Although not in the Study area, the Colorado Plateau is extremely influential in regard to both its geology and hydrology.

The Colorado Plateau, just north of the Study area, is the primary recharge zone for the regional groundwater systems that exist both south and north of the Mogollon Rim. Groundwater moving south of the Rim's crest represents the primary groundwater inflow into the Study area. This groundwater recharge represents water from precipitation events infiltrating along the southern fringe of the C aquifer system through the Coconino Sandstone and layers of the Upper Supai Formation down to the Lower Supai Formation (see ***Figure 3***). In this study, the base of the C aquifer is defined as the top of the Lower Supai Formation. The groundwater gradient within the C aquifer south of the Mogollon Rim is steep and groundwater flow is generally southward from the Mogollon Rim.

Numerous springs exist along the south face of the Mogollon Rim. Named springs include: Fossil, Parsnip, Dripping, Red Rock, Pine, Turkey, Bear, Washington, Pieper Hatchery, Fish Hatchery, Horton, and Nappa Springs. The C aquifer's groundwater elevation rises from Fossil Springs in the west part of the sub-region towards the northeast. The discharge from some of the springs displays high variability (Flora, 2004). Some of the larger springs are: Pieper Springs at the headwaters of the East Verde River and the Hatchery and Horton Springs at the headwaters of Tonto Creek in the uppermost northeastern portion of the Study area. These headwater springs discharge groundwater that is relatively young from the C aquifer and consists of the most recently recharged water of the regional C aquifer whereas Fossil Springs discharges groundwater that appears to be much older but has a similar C aquifer source.

The age and source of groundwater is determined based on the isotopic and ionic composition of the water. Isotopes considered as part of the Study's evaluation included stable isotopes of oxygen and hydrogen as well as sulfur, strontium, and tritium (Eastoe, 2006; Flora, 2004). The evaluation of ionic composition incorporates analyses of dissolved materials found within the water and a determination of the rocks and geologic formations, which may have contributed those materials (HSI, 2006).

Fossil Springs are located at the junction of Sub-Region 1 and Sub-Region 2 and are the largest springs in the Study area discharging 32,838 acre-feet per year (afy) or 20,345 gpm (Parker et al, 2005; NAU, 2005). The discharge emanates predominantly along the north side of the Diamond Rim Fault system and issues from between a thick shale and resistant limestone layer in the lower Naco Formation. The majority of the discharge issues from the west side of Fossil Creek Canyon, below a large travertine deposit, itself the result of ancient spring discharge. The occurrence of Fossil Springs is likely due to an interaction of the Diamond Rim Fault system, the Fossil Springs Fault, and the exposure of highly transmissive, fractured limestone at this location. The discharge of groundwater at Fossil Springs is likely a release of significant pressures, as water is confined by the fine-grained units of the Naco Formation.

Groundwater flow in the fine-grained units of this sub-region tends to have a significantly steep vertical gradient (as observed in several wells). The more transmissive units in the area are relatively thin (<10 feet), and wells in the area have calculated transmissivities below 2,000 gallons per day per foot (gpd/ft), low storage coefficients typical of confined systems, and low water production (HWRC, 2005). Wells in the region typically pump less than 30 gpm with specific capacities of less than 1 gallon per minute per foot of drawdown (gpm/ft) (Morrison, 2003).

Although the fine-grained geologic units typically have very low hydraulic conductivities, the fractures and faults through these units appear to be acting locally as sub-vertical conduits and drains for local recharge. This facilitates leakage from the C aquifer, as the structures transmit groundwater from along and beneath the Colorado Plateau into the lower section of Paleozoic strata (through Sub-Region 1) and ultimately into the Precambrian rocks below. Springs along the face of the Mogollon Rim are likely a result of groundwater moving along these fractures and permeable layers of rock as they intercept the land surface. Additionally, fractures appear to promote not only leakage of older C aquifer groundwater but also conduct recent locally recharged groundwater to the springs. This behavior is recognized in water quality data, which indicates mixed water sources in the springs (i.e. Webber Springs). Also, the physical performance of the springs often displays increased flow after precipitation events (Eastoe, 2006).

Our understanding of the nature of fracture and fault systems is mainly derived from their surface expressions and from limited well drilling records. These structures are often presented on geological maps as lineaments, faults, or fracture traces. Water quality sampling has revealed isotopic and chemical differences that indicate these structures act as conduits for leakage of the C aquifer and may act as barriers to lateral flow. Fossil and Hatchery Springs are good examples of this behavior as water is discharged from the regional aquifer in locations where faults cut across low permeability shale sequences.

Finding the location of small-scale transmissive units and understanding their variable connectivity through faults and fractures creates a challenge for developing water resources in many parts of Sub-Region 1. Wells constructed in the dominantly fine-grained sedimentary units in the Pine and Strawberry area (***Plate 1***) display seasonal variation in groundwater elevations and yield. Water levels observed in these well also exhibit a nearly vertical groundwater gradient within the fine-grained units. In the Pine and Strawberry area, there appear to be at least four isolated transmissive units, each possessing different heads (HWRC, 2006a; ERM, 2006). Therefore, the occurrence of water producing zones is highly dependent on depth and local geologic constraints.

A deeper transmissive unit (approaching a depth of 1,000 feet) has not yet been tapped in the Strawberry area except for the 1,870-foot Water Plan Alliance borehole drilled in 2001. However, this interval of the well was sealed with cement grout because of lost circulation during drilling. It is likely that this lower zone is the same transmissive unit that yields groundwater in Pine at a depth between 200 and 300 feet (HWRC, 2006a).

Groundwater moves through the fine-grained layers of the Supai Group and Naco Formation down into the Redwall Limestone and Martin Formation below. The Redwall Limestone and the stratigraphically lower units of this sub-region are also recharged by local precipitation in addition to groundwater inflow from the C aquifer to the north. Isotope and other water chemistry data indicate mixing of recently recharged groundwater with older groundwater coming from the C aquifer, particularly in exposed areas of the Redwall Limestone and Martin Formations. Recharge from precipitation is facilitated by the significant secondary permeability of the limestone and dolomite, with significant fracturing at the surface providing direct infiltration paths to the groundwater system. Significant stream losses coincident with faults and exposures of these units are also observed along segments of Pine Creek, East Verde River, Horton Creek, and Christopher Creek. Spring locations are also affiliated with faults intersecting these units in low-lying exposures.

Secondary permeability (caused by faulting, fracturing, and fluid solution) is the dominant flow mechanism in the Redwall Limestone; whereas there is some primary permeability (interconnected depositional pore spaces) in sandy layers within the Martin Formation, Tapeats Sandstone, and weathered portions of the Precambrian rocks. In many of the Study documents, this portion of the regional aquifer system has been referred to as "RMX" (roughly equivalent to **R**edwall, **M**artin, and Proterozoic units) and includes the relatively thin Cambrian aged Tapeats Sandstone. The Proterozoic units are often labeled on geologic maps using an **X**. These aquifer units are displayed on ***Figure 3***. Although small in comparison to the other units, the Tapeats Sandstone appears to have a significant capacity for groundwater movement. Its higher hydraulic conductivity is likely due to both primary porosity (depositional pore spaces) and enhanced secondary porosity (caused by faulting and fracturing) of the unit. The Tapeats Sandstone can be utilized as an aquifer in areas where the Redwall Limestone or Martin Formations have limited saturation (HWRC, 2005; 2006b).

Just as with groundwater moving from the C aquifer into the lower Paleozoic units, water quality analyses indicate leakage from the Paleozoic units down into the Proterozoic units (Eastoe, 2006). The Proterozoic rock units consist of granite, diorite, gabbro, basalt, and metamorphic rocks of the East Verde River formation that include quartzite, silty quartzite or greywacke, slate and others (Gaearama, 2006). Structural features in the Proterozoic units carry groundwater under semi-confined to confined conditions resulting in some locations having groundwater moving as upward flow in wells within Sub-Region 1 (HWRC, 2005; 2006b).

Unfortunately, there is limited data available on the hydraulic characteristics of the aquifer units, within Sub-Region 1, outside of the Pine and Strawberry area. Data available from a deep well in Pine at Strawberry Hollow, a deep well in central Pine (Milk Ranch LLC.), and another deep well at Ellison Creek Summer homes provides some hydrologic data from the Martin Formation, Tapeats Sandstone, and local Proterozoic units at greater depth. Transmissivity estimates from the Strawberry Hollow and Ellison Creek wells have values approaching 10,000 gpd/ft with relatively high specific capacities; greater than 2 gpm/ft of drawdown (HWRC, 2000; 2005; 2006b). Each of these wells produces significant quantities of very fine sand and silt. This characteristic may be due to the existence of silt and sand in cavernous and fractured areas as well as sandy layers within the dolomite of the Martin Formation and the Tapeats Sandstone units. Anecdotal evidence also indicates that springs discharging from these aquifer units also experience increases in turbidity with precipitation events (Cold, Whispering Pines, Camp Tontozona, and Indian Gardens springs).

2.2 Sub-Region 2

Sub-Region 2 is an area northwest of the East Verde River and south of the Diamond Rim Fault and is displayed in ***Plate 3***. Much of this sub-region is covered by Tertiary basalt units and is sparsely populated. The basalt units covering much of the sub-region range in thickness up to more than 1,500 feet. The basalt, together with the other Tertiary units, overlay some of the same Paleozoic units exposed along the Mogollon Rim, which have been vertically offset by the Diamond Rim Fault as displayed in ***Figure 3***.

Several springs exist within Sub-Region 2, including Indian, Oak, LP, Cane, Whiterock, Walnut, South Walnut, Horse, and Tonto Natural Bridge Springs. Many of these springs exist along the periphery of the large Tertiary basalt units associated with Hardscrabble Mesa and Cane Springs Mountain. As noted previously, Fossil Springs appears roughly at the intersection of the Diamond Rim Fault and Fossil Springs Fault (displayed on ***Plate 1***). Based on water quality data obtained from Fossil Springs; Fossil Springs' discharge is likely a composite of groundwater recharged along the Colorado Plateau and potentially water recharged through the basalt units of Sub-Region 2. It appears that some of the groundwater that flows towards the Diamond Rim Fault is diverted to move along the fault zone. The Diamond Rim Fault provides a conduit for groundwater flow; ushering significant quantities of groundwater towards Fossil Springs where it discharges at a relatively consistent rate.

Groundwater flow in Sub-Region 2 is generally southward from the Diamond Rim Fault. However, there may be significant recharge within the sub-region, as precipitation may quickly infiltrate through the basalts. The fractured and jointed nature of the extensive basalt cap, in addition to its relatively flat topography, provides ideal conditions for groundwater recharge from precipitation. As a result of this recharge, groundwater flow would likely move in a somewhat radial fashion away from the recharge area beneath the basalt covered mesas as displayed on ***Plate 3***. With only 53 registered wells located in Sub-Region 2, most of which are along its periphery, the direction and magnitude of groundwater flow through the sub-region is uncertain. The springs discharging along the outside edge of the basalt are likely an indication of groundwater recharged in the area. However, the basalt also may conceal faults and fractures in the underlying sedimentary units that could transmit unknown quantities of groundwater elsewhere in the Study area.

As water moves southward from Sub-Region 1 into Sub-Region 2, through the Diamond Rim Fault zone, it moves predominantly out of the sedimentary Paleozoic units and down into the Proterozoic igneous rock units. This groundwater enters a tortuous path flowing through systems of fractures, which transmits groundwater southward within the Precambrian rocks that make up the lowermost portion of the regional aquifer system.

2.3 Sub-Region 3

Sub-Region 3 is located in the southeast portion of the Study area, and encompasses the communities of Payson and Star Valley and is displayed in ***Plate 4***. The geology of Sub-Region 3 is predominantly comprised of Proterozoic rock units, except in the northern western portion of the sub-region, where Proterozoic rocks are covered by remnants of the lower Paleozoic sedimentary units. The Proterozoic units, as noted previously, consist primarily of crystalline igneous and metamorphic rocks. Notably, the Payson granite and surrounding igneous rocks have been studied extensively as a result of Payson’s groundwater use and exploration programs.

The groundwater flow through Sub-Region 3 is generally towards the southwest. Water moves into the sub-region along its northeast boundary through the Diamond Rim Fault. The primary groundwater flow paths are inferred to be the faults and fractures. In many areas, the fracturing and weathering of the rock units provide greater interconnection for groundwater flow in shallower intervals. At greater depths, fractures often become more isolated and less transmissive. The age of faults and their associated fractures provide some indication of the potential transmission of groundwater. Many of the older faults in this sub-region have been sealed over time due to mineralization, while many of the fractures associated with more recent Tertiary extensional faulting may have greater open area and interconnectivity.

Groundwater appears to exit the sub-region in a radial fashion towards the east, south, and west; away from the topographic high of the Payson area. The radial movement of groundwater away from the Payson area is likely reflective of significant recharge occurring throughout the Payson area. Most of the wells in the sub-region are relatively shallow and observe significant changes in water levels due to local precipitation variations, which is also indicative of the local recharge to the aquifer. Deeper wells display less water level variability with regard to local recharge, and are more reflective of the larger regional movement of groundwater through the Study area.

Wells constructed in Sub-Region 3 have variable groundwater production capacity. The yield from wells in this sub-region is almost exclusively a factor of fracture size and interconnection near the individual wells. Unlike the Paleozoic sedimentary sequences, the crystalline Proterozoic rock units (characteristic of the RMX aquifer in this sub-region) have almost no primary permeability. Secondary permeability of these units is associated with weathering (chemical and mechanical) and fractures of variable magnitude and interconnection. However, the crystalline rock composition does not promote the formation of solution channels such as those found in many of the limestone units discussed previously. As a result, hydraulic conductivity and storage coefficients determined from wells tested in this sub-region are generally very small. Also, with lower storage capacity, water levels tend to have greater variability in response to local precipitation events.

As the largest community in the Study area, Payson has managed the greatest volume of groundwater use and has observed the most change in water levels over time. Gradual water level declines in excess of 50 feet have been displayed over the last decade in some wells. These negative changes in water levels are a result of a reduction in aquifer storage volumes as well as the decreased recharge associated with regional drought conditions. However, as precipitation and snowfall increases, water levels in some wells have displayed stabilization and rise (Payson, 2006).

Drought conditions are also a cause of some of the spring discharge variability throughout the study area. Springs located in Sub-Region 3 include: Big, Blue, Gilmore, Grapevine, Grimes, Hidden, Lion, Mud, Peach Orchard, Summit, Turkey, Water, and Willow Springs. It is likely that the springs located in this sub-region are discharging both local and distantly recharged groundwater however; no long-term, consistent sampling has been performed on springs discharging from this sub-region to confirm this hypothesis.

Groundwater flow is uncertain in the southeastern portion of Sub-Region 3, which includes Green Valley and the Green Valley Hills. Surface water drainage is into the Tonto Creek however; only 3 registered wells and a single unnamed spring have been identified in this part of Sub-Region 3.

2.4 Sub-Region 4

Sub-Region 4 is located in the southwestern corner of the Study area, south of the East Verde River and is displayed in ***Plate 5***. The sub-region includes a portion of the Mazatzal Wilderness and a portion of the Rye Creek valley along Cypress Thicket. The portion of Rye Creek in the Study area is ephemeral, although it becomes perennial above its confluence with Tonto Creek.

In the eastern portion of the sub-region, groundwater flows west from Sub-Region 3 into Sub-Region 4 and diverges near the Verde River and Tonto Creek watershed divide. Part of the groundwater flow continues moving west along the East Verde River. The other portion of the groundwater moves southwards through the Rye Creek Valley, primarily through the Tertiary sedimentary deposits of the valley; generally following the surface drainage of Rye Creek. Springs discharging along the eastern edge of Sub-Region 4 include: Pig, Larsen, Gould, and Hanging Rock Springs. These springs all appear to be associated with mapped faults and their discharge is likely derived from recharge occurring in Sub-Region 3 as well as more distant sources. However, these springs have not been sampled for any water chemistry confirmation.

Shallow wells constructed in the Rye Creek Valley obtain water from the saturated sedimentary deposits of the basin. The water chemistry of shallow wells sampled in the valley is very similar to the chemistry of local precipitation. However, water quality data from wells screened in deeper intervals, below the Tertiary gravels, indicate a more remote (spatial and/or temporal) water source. The groundwater source may be remotely related to water recharged along the Mogollon Rim and Colorado Plateau but is chemically distinct from water in the Payson area, as the Rye Creek Valley groundwater is higher in sodium, chloride and sulfate (Payson, 2004; HSI, 2006).

The Mazatzal Wilderness in the western portion of Sub-Region 4 (the northernmost end of the Mazatzal Mountains) has very limited hydrogeologic information. The rugged terrain and its classification as a Wilderness Area place tight constraints on any future hydrogeologic data gathering in the area. Only two registered wells exist in the Mazatzal Wilderness, one of which is abandoned. Both wells were drilled into Proterozoic rock units and like much of the Study area, groundwater movement is likely restricted to fractures and faults. Due to the area's higher elevation, it is likely a source of recharge to the surrounding alluvial valleys; including the Rye Creek Valley and Verde River Valley. There may also be some groundwater contribution to streamflow of the East Verde River to the north. Springs discharging from this Mazatzal Wilderness are likely a result of localized recharge in the Mazatzal Mountains. Named springs present in the area include: Cedar Basin, Red Metal, Bullfrog, Old Thicket, Barnett, Pole Hollow, Mineral, Dennis, House Place, and Mine Road Springs along with Fuller and Childers Seeps.

3.0 STUDY AREA GROUNDWATER FLOW

A regional scale compilation of the hydrologic and geologic structural information discussed above is displayed in ***Plate 6.*** This plate is a composite of the groundwater flow maps presented in ***Plates 1*** through ***Plate 5***. The groundwater contours and flow directions appear to represent a complex interconnected regional aquifer system. This section presents the hydrogeology of the Study area as a singular mechanism with its several parts. As discussed in the previous sections, groundwater flow in the Study area is generally from northeast to southwest. Recharge to groundwater occurs throughout the Study area. However, the predominant recharge location is along the Colorado Plateau and the Mogollon Rim through the more permeable sedimentary units of the C aquifer. Recharge contributions are from both regional precipitation and snowmelt during the winter, and more localized precipitation events in the summer, which is typical throughout most of Arizona. As precipitation is a function of elevation, so also is recharge. The higher elevations in the Study area along the Mogollon Rim and northward along the Colorado Plateau tend to have greater rainfall and snow totals. This in turn provides greater volumes of recharge to the regional groundwater systems both north and south of the Mogollon Rim. ***Figure 4*** displays a geologic cross section with water level elevations extending from the Mogollon Rim to the East Verde River, delineated as F to F' on ***Plate 6***.

Recharge capability in some areas is significantly enhanced by faults and fractures. As recharge water reaches the saturated portion of the C aquifer it begins to move with the groundwater gradient. The groundwater gradient north of the Mogollon Rim tends to be shallow through the more conductive Coconino Sandstone and upper Supai sandstone units. Moving south of the Mogollon Rim, the groundwater encounters the fine-grained units of the Lower Supai and Naco Formation; and the gradient becomes very steep as a result of the typically low hydraulic conductivities associated with fine-grained shale and limestone. Near vertical flow through these less permeable units is also promoted by abundant faults and fractures, which provide conduits for groundwater flow.

The locations and discharge rates of springs are regulated by both lithologic and structural controls. Faults and fractures intercepting the ground surface provide conduits to the land surface and result in the formation of springs along the Mogollon Rim. Also, as permeable layers (typically coarse-grained intervals bounded by shale rich layers) intercept the surface; these too may result in the formation of springs. Many of the monitored and sampled springs in the area indicate highly variable discharge rates individually, and have contributions from both local and far removed sources (based on the water's isotopic and ionic composition). In some locations, spring discharge increases substantially after precipitation events, while in other locations, springs show a more tempered response depending upon local hydrogeologic constraints. The increase in discharge may be the result of recharging precipitation increasing head pressures. As recharge occurs at even a great distance, newly recharged groundwater will "push" older groundwater out of the system ahead of the recharge front.

Wells too can display high variability with respect to production capacity and hydraulic characteristics as a result of lithologic and structural controls. Wells developed in the fine-grained units of the Supai and Naco Formations exhibit significant variability in water level elevation and typically, the geologic units supplying water to the screens have very low hydraulic conductivities. As mentioned above, the fine-grained units tend to have very steep downward gradients.

As groundwater moves down through the Naco Formation and into the limestone units of the Redwall and Martin Formation, fractures and solution channels become the dominant mechanism for flow. The surface exposures of these units north of the Diamond Rim fault are recharged by precipitation events as well as by the capture of stream flow (often fed from above by spring discharge along the Mogollon Rim).

The Diamond Rim fault zone potentially represents the most influential structural feature with regard to groundwater flow in the Study area but with limited data in its vicinity, the true relationship between the fault and groundwater flow is uncertain. However, some reasonable inferences can be made. The locality and discharge rate of Fossil Springs appears to be controlled in some great degree by the Diamond Rim fault. Other springs in the Study area appear to be both directly and indirectly related to the presence of this fault. Locally, this fault may act as a barrier or a conduit to groundwater flow; likely a conduit in the case of Fossil Springs.

South of the Diamond Rim fault zone, groundwater exits the Paleozoic sedimentary units and flows down into the Proterozoic igneous and metamorphic units below. The area beneath Hardscrabble Mesa may be an exception to this general statement in that there may be a saturated sequence of Paleozoic sedimentary units (primarily the Redwall Limestone and Martin Formation) preserved below the Tertiary basalt and conglomerate cover.

Groundwater flow through the Proterozoic units (like much of the Paleozoic units) relies primarily upon the secondary porosity and permeability of faults and fractures. The faults and fractures provide avenues for localized precipitation to recharge the aquifer in addition to providing pathways for regional groundwater flow. The uppermost portions of the Proterozoic units tend to have greater hydraulic connections relative to deeper fractured areas. Water levels observed in wells penetrating these units exhibit strong variability associated with localized recharge events. The presence of springs and gaining reaches along the East Verde River and Tonto Creek, along the periphery of Sub-Region 3, appears indicative of groundwater discharging from the regional aquifer system.

The groundwater within the Study area is an interconnected aquifer system flowing through several different geologic units. Continuity of groundwater flow is disrupted by recharge zones, faults, fractures, and by the lithologic variability of the sedimentary units in the area. However, connection between and through these various units is facilitated by the broken and fractured nature of the Study area. Viewing the Study area as a regional groundwater system appears to be supported by water levels observed in wells, spring elevations, and by water chemistry data. This regional aquifer system provides a large canvas upon which the several communities and water resource managers can plan and develop water resources for the area.

4.0 SUSTAINABILITY OF REGIONAL GROUNDWATER RESOURCES

Determination of water needs and availability for sustaining the current and future population within the Study area requires evaluation of the renewable water resources (groundwater recharge and safe yield), water resources in storage (reservoir and aquifer storage), as well as the current and future water demands.

4.1 Groundwater Budget

The conceptual groundwater water budget presented here provides a generalized and simplified account of the groundwater inflow and outflow of the Study area, but does not address the volume of groundwater in storage. In order to evaluate the water budget in any greater depth requires significantly more temporal and spatial hydrologic information for the Study area. Because of the extreme variations in hydrologic and geologic conditions encountered throughout the Study area, analysis of more localized water budgets may vary substantially from the more universal water budget presented here.

The strategy used in developing a groundwater budget for the Study area was adapted from the more expansive USGS report on the Mogollon Highlands (Parker et al, 2005). Although the Mogollon Highlands Study encompasses a larger 4,855 square miles (compared to this Study with 632 square miles) a significant portion of the Mogollon Highlands water budget moves through and is recharged within the Study area. Groundwater inflow includes recharge occurring within the Study area as well as groundwater inflow from the C aquifer north of the Study area. The outflow includes base-flow to streams, spring discharge, as well as groundwater discharging out of the Study area towards the south. ***Figure 5*** provides an overview of the groundwater budget components and the locations of primary springs and stream gages used to estimate groundwater outflow from the Study area.

4.1.1 Groundwater Inflow to the Study Area

The primary contributor to groundwater inflow to the Study area is the C aquifer. The inflow from the C aquifer according to the Mogollon Highlands report was calculated using a precipitation rate of 374,400 acre-feet per year (afy), and allowed for 17% infiltration; thus giving a total inflow of 63,600 afy into the Mogollon Highlands. The current Study area obtains approximately half of that C aquifer inflow (31,500 afy) based on the groundwater flow directions displayed on ***Plate 6*** and in relation to the C aquifer contribution discussed in the Mogollon Highlands report (Parker et al, 2005).

Recharge estimates for the Study area were calculated from areal precipitation totals using Parameter-elevation Regressions on Independent Slopes Model (PRISM) shapefiles. The PRISM shapefiles are contoured annual precipitation rates that have been generated using point data and digital elevation models to simulate the spatial distribution of precipitation (Parker et al, 2005). In order to calculate area-weighted annual precipitation within the Study, PRISM regions denoted as having the same precipitation rate were broken into polygons where the area of each polygon was used to weight the average annual precipitation. The area weighted precipitation for the Study area is 766,703 afy. Factors that inversely influence recharge to the aquifer in the study area include steep sloping areas and typical thin soil horizons overlying low permeability rock units. However, significant areas of exposed karstic limestone units, thick units of weathered granite and Tertiary aged gravel units accept recharge at a much higher rate locally (Payson, 2005; Gookin, 1992; Southwest Ground-water, 1998; Gæaorama Inc., 2003; Clear Creek, 2007). Considering the variability and influence of near surface conditions on groundwater recharge, it is estimated that between 4-5% of precipitation results in recharge (30,700 to 38,300 afy) to the aquifer. These percentages are consistent with the initial estimates discussed in the Mogollon Highlands report (Parker et al, 2005). The groundwater inflows to the Study area are displayed in ***Table 1***.

Table 1. Groundwater Inflow to Study Area

C Aquifer Inflow	31,800
Precipitation	766,703
Percent Infiltration	4 - 5
Total Recharge from Precipitation	30,700 – 38,300
Total Groundwater Inflow	62,500 – 70,100

4.1.2 Groundwater Outflow from the Study Area

Groundwater leaves the Study area directly, as stream base-flow, and as spring discharge. Base-flow leaving the Study area though streams was estimated by using streamflow records obtained from the USGS Surface-Water Data for the Nation website. Tonto Creek, East Verde River, and Fossil Creek provide the primary drainages from the Study area and were used to estimate groundwater outflows. The portion of the Study area not within these drainages (namely the

Mazatzal Wilderness in Sub-Region 4) does not appear to provide significant spring discharge or baseflow to streams leaving the Study area. Although Mazatzal Wilderness in Sub-Region 4 may provide an undefined volume of groundwater flow out of the Study, it is not specifically addressed as part of this conceptual groundwater budget.

Stream gauge data for Tonto Creek was obtained from the USGS gauging station (9499000) located outside the Study area above Gun Creek. Records for this station include approximately 10 years of average daily discharge rates. Stream gauge data for the East Verde River was obtained from near the Study area boundary at the USGS gauging station (9507980) near Childs. This gauging station was selected based on its long-term records of daily stream discharge as well as its convenient location near the Study area boundary. Stream flow within Fossil Creek was gleaned from the Mogollon Highlands report (Parker et al, 2005) as well as Northern Arizona University (2005).

Average annual base-flow for each of the streams was estimated as the median low-flow daily discharge rates for the month of January. This estimate assumes minimal runoff contributions from precipitation as well as no evapotranspiration losses due to low seasonal temperatures. It is also assumed that spring discharge is a component of these average annual base-flow estimates. (In the case of Fossil Creek, it was assumed that base-flow to the stream and discharge from Fossil Springs is equal.) In order to calculate the net base-flow from each stream, the average annual discharge from springs within the watershed were removed from the annual average base-flow. Lastly, the net base-flow from each watershed was reduced based on the percentage of the contributing watershed within the boundary of the Study area. (This assumes that the baseflow contribution for each stream is proportional to the contributing watershed area. Without better understanding of groundwater behavior outside of the Study area, and based on the conceptual nature of the groundwater budget, this seemed a reasonable assumption.) The difference between the annual average base-flow and the average annual discharge for each stream represents the average annual runoff from the watershed. The stream discharge rates and baseflow contributions are displayed in ***Table 2***.

Table 2. Baseflow Calculations for Major Watersheds in the Study Area

Stream Name	USGS Stream Gauge Site No.	Avg. Annual Discharge (cfs)	Avg. Annual Discharge (afy)	Avg. Annual Runoff (afy)	Avg. Annual Baseflow (afy)	Avg. Annual Spring Flow (afy)	Net Baseflow (afy)	Watershed Percentage within Study Area	Net Baseflow from Study Area (afy)
East Verde River	9507980	44.5	32218	17738	14480	5406	9074	94.2%	8548
Tonto Creek	9499000	114.9	83188	46988	36200	4442	31758	46.9%	14895
Fossil Creek	*	62.4	45200	12362	32838	32838	0	47.0%	0
Total (rounded to nearest hundred)		222	145700	70500	77700	42700	35000	87.8%	18000

*(Parker et al, 2005; NAU, 2005)

Table 3. Discharge Rates for Major Springs in the Study Area

Spring Name	Drainage	Spring Discharge (gpm)	Avg. Annual Spring Discharge (afy)
Bear	East Verde River	100	161
Big	East Verde River	138	223
Big	Tonto Creek	175	282
Cold	East Verde River	1060	1711
Fish Hatchery	Tonto Creek	1291	2084
Fossil	Fossil Creek	20345	32838
Geronimo	East Verde River	14	23
Horton	Tonto Creek	1100	1776
Indian Gardens	Tonto Creek	57.5	93
Nappa	Tonto Creek	70	113
Pieper Hatchery	East Verde River	125	202
Spring (Unnamed)	East Verde River	75	121
Tonto Bridge	East Verde River	841	1357
Webber	East Verde River	996	1608
Wildcat	Tonto Creek	58.5	94
Total (rounded to nearest hundred)		26400	42700

Spring discharge removed from the net base-flow noted above included only those springs with an average annual discharge rate in excess of 10 gpm (16 afy). ***Table 3*** lists the springs used in the groundwater budget calculations, their annual discharge rate, and their respective watershed. Each of the springs listed in ***Table 3*** drain into one of three streams (Fossil Creek, Tonto Creek, and the East Verde River). Many of the springs displayed on ***Plate 6*** do not have annual discharge rates due to imprecise measurements and lack of data. The methods used in removing spring discharge from the baseflow of streams are consistent with the Mogollon Highlands report (Parker et al, 2005).

Evapotranspiration as an outflow from groundwater system is assumed to be derived exclusively from shallow groundwater available along active stream channels and near spring discharge locations. Baseflow estimates were made using winter stream discharge in order to more accurately isolate the groundwater component of streams without the influence of significant evaporation or evapotranspiration by riparian vegetation (in addition to avoiding surface runoff from precipitation events). In simple terms, this Study assumes evapotranspiration is a component of the groundwater baseflow estimates and spring discharge from the system.

Direct groundwater outflow was estimated by the amount of groundwater flow through the Proterozoic rocks and the alluvium of the Rye Creek Valley exiting the Study Area towards the south that was not included in the base-flow calculations. The flow of groundwater directly out of the Study area is estimated to be between 1,800 to 9,400 afy. This range of flux out of the Study area represents the water remaining unaccounted for as part of the groundwater budget that is not discharged to streams or springs. The Total Groundwater Outflow is displayed in ***Table 4***.

Table 4. Groundwater Outflow from Study Area

Stream Base-flow	18,000
Spring Discharge	42,700
Direct Groundwater Outflow	1,800 – 9,400
Total Groundwater Outflow	62,500 – 70,100

4.2 Recharge and Watershed Health

The majority of the surface area available for natural recharge to the region’s aquifer system is contained within the public lands of the Tonto National Forest. The relatively small amount of private land in comparison to the size of the region’s watershed and recharge areas, coupled with strict rules governing the use of groundwater from Federal Lands and National Forests, limits the development of groundwater resources and therefore minimizes potential impacts to groundwater in most areas as well as minimizing impacts to stream flow and springs.

One item which may limit recharge to the regional aquifer system is the overgrowth of forest vegetation across the public and private lands of the Study Area. The overgrowth of vegetation is a result of many factors including decades of thwarting the natural effect of wildfire in the Study area. As a result, the overgrowth maintains a higher consumptive use of available water resources. A small increase in vegetation cover over the entire Study area can be a large consumer in terms of the overall water budget. When coupled with growing domestic use, this situation should be evaluated with regard to potential impacts for long-term sustainability of water resources. There is a balance to be maintained in that vegetation slows watershed run-off and controls erosion, but without proper management, the increased vegetation cover may pose a threat for water resources and wildfire management. A large-scale wildfire would be devastating to groundwater recharge as well as uncontrolled watershed run-off and erosion.

The determination and protection of focused groundwater recharge locations is also essential for the long-term viability of the regional aquifer system. This includes land protection for groundwater recharge preservation as well as protection from potential contamination. Just as seasonal precipitation reaches the aquifer system quickly, so too can potential contaminants. Examples of potential contaminants include on-site waste water systems, industrial wastes, or hazardous spills along transportation avenues. Because of the direct interconnection of many fracture networks, a small-scale contamination event could become disastrous as water moves very quickly along some of these pathways. Also, this same scenario should be considered closely in terms of effectiveness of soil-aquifer treatment in managing on-site treatment facilities and the recharge of treated effluent in more populated areas.

4.3 Hydrologic Capture and Safe Yield Estimates for Population Centers

In order to understand the potential long term impacts associated with groundwater use requires a basic understanding of hydrologic capture. In order to understand the concept of capture, we will start by discussing the attributes of an undisturbed natural groundwater system. In an undisturbed natural groundwater system, it is assumed that the groundwater system has come into a long term balance or equilibrium which has been established over thousands of years. This balance requires that the same volume of water added to the groundwater system also leaves the groundwater system. The system acts as a conduit where new water comes in and old water leaves, while the conduit itself maintains the same volume of water. The groundwater budget for the Study area discussed previously assumes this same long-term equilibrium. New water comes into the system through inflow from the C aquifer and recharge from precipitation; old water moves out of the system through direct groundwater outflow, discharge from springs, and base-flow to streams.

When a disruption to the groundwater balance occurs as a result of groundwater pumping, the groundwater system compensates for this disruption by doing one or more of the following: increase inflow, decrease outflow, or change the volume of groundwater in storage. These changes may be observed as increased losses from streams (increased inflow); decreased groundwater outflow, reduced base-flow and spring discharge (decreased outflow); and/or lowering groundwater levels (change in groundwater storage). The volume of water taken as increased inflow, decreased outflow, and change in storage is “captured” from the groundwater system. The effects of these changes may be minor or significant and may be localized or regional depending upon the magnitude of the disruption. However, regardless of magnitude, there are impacts to the groundwater system once groundwater pumping starts.

Historically, the groundwater resource evaluations and impact assessments within the Study area have been developed around the idea of “safe yield.” This concept is based only on the estimates of groundwater recharge for a specific locality. The volume of groundwater deemed “safe” for use in a given year is roughly equal to the average annual volume recharged to the aquifer for that locality. As these estimates relate to the groundwater system locally, it has been observed that many of the springs discharging within the Study area respond rapidly to precipitation. Groundwater elevations in many wells within the Study area also respond rapidly to precipitation. At any given time, local variations in water level elevations and spring discharge may reflect localized variations of recharge. In other words, the groundwater resources in many areas are readily recharged, have relatively low storage capacity, and are highly susceptible to climatic changes (drought sensitive).

Safe yield estimates are calculated from annual average recharge over a 50 to 100 year time frame. Because of this, observed impacts from groundwater pumping in any single year may not appear to behave in an “average” manner. However, using safe yield estimates for groundwater management and development is an attempt to reduce potential long-term impacts associated with groundwater pumping and the removal of groundwater from storage.

Localized calculations developed for the Town of Payson indicate a safe yield of 1,826 afy (Southwest, 1998). Sustainable withdrawal rates have been estimated to be 10-16% of annual precipitation (17-20 inches per year as a conservative estimate) (Gookin, 1992). The calculation methods are believed to be conservative in that much of the groundwater flowing through the Study area was recharged outside of its boundary, and appears to have a groundwater flux in excess of the safe yield calculations.

Applying the same localized assumptions that lead to Payson's estimate of safe yield to the communities of Pine and Strawberry; the deep aquifer accessible below those communities can be estimated to yield no less than 900 afy within a renewable state or "Safe Yield". When used conjunctively with existing shallow resources this number may be as high as 1,200 afy. Utilizing precipitation values, the safe yield of the entire Pine and Strawberry area should range between 1,200 afy to 1,780 afy (Payson, 2005).

The area immediately surrounding Star Valley has recently been evaluated to determine groundwater consumption and safe yield estimates. The estimated safe yield is 4,300 afy, with a current use of approximately 380 afy. As a practical measure, not all of the water is capable of being utilized. So assuming a maximum potential use of 80%, the practical safe yield for Star Valley would be 3,440 afy (Clear Creek, 2007).

In comparison to the groundwater budget components discussed previously, the groundwater available for use by the three major population centers (as derived from Safe Yield estimates) represents 10 to 11% of the total groundwater inflow into the Study area.

4.4 Future Water Demands for the Study Area

In calculating the potential water available for future development, the Study has developed a demand analyses for "build-out" water demand projections from 2002-2040. According to the Study's demand analysis, the 2002 population in the Study area was approximately 21,300. By 2040, the population is projected to increase to approximately 73,200. As population increases, so will the water demands. The current (2002) water demands for the Study area are computed to be nearly 2,600 afy whereas water demands by 2040 are expected to increase to approximately 11,000 afy.

As noted previously, the Town of Payson is currently the largest community in the Study area with a population of approximately 14,500 and by 2040, the population is expected to be within its build out range of 35,000 to 45,000. Thus, Payson is expected to remain the largest community and therefore the largest water consumer in the Study. Using a conservative value of 120 gallons per capita per day, estimated water demands by Payson will be 6,000 afy by 2040. Approximately 1,200 afy will be required to supply the communities of Pine and Strawberry at build-out (by 2040). This estimate was based on a build-out population of 7,259 with a range of demand between 120 and 250 gpcd (gallons per capita day). As a practical matter, actual gpcd values in the region are typically less than 120 gpcd and could be maintained at or below this number via demand-side management.

On a regional scale, it appears that groundwater supplies could easily provide for the expected population increases. However, because of the local variability associated with hydrogeologic conditions or accessibility problems, groundwater may not be the best solution to meet water demands in all communities, if only population demands are factored.

The importation of surface water from C.C. Cragin (formerly Blue Ridge) Reservoir would dramatically offset future demands on the overall groundwater system at the largest population center in the Payson area. Early in its future use, the C.C. Cragin Reservoir water may be used directly, or recharged in the Payson area to offset seasonal demands. Later, the reservoir's water will be used directly, and may require supplemental groundwater pumping to meet peak demands. The addition of a surface water resource will help to eliminate some of the potential impacts associated with localized aquifer pumping. However, the quantity of C.C. Cragin Reservoir water is limited and expensive to distribute, thus many areas throughout the Study area will still rely exclusively on groundwater. The many smaller county island communities do not represent significant groundwater use commitments; therefore, these locations may be able to supplement their growing water demands with limited groundwater from public lands with minimal potential for negative impacts to groundwater and forest resources in the Study area. Nevertheless, it should be noted that the U.S. Forest Service typically requires that all alternative water resource options have been exhausted prior to permitting the installation of wells on Federal lands.

5.0 ALTERNATIVE WATER RESOURCES SOLUTIONS

Developing new water supplies for existing and future developments within the Study area presents many interesting challenges. Matrices of four alternatives have been identified, with each one having its own set of challenges. Each of these alternatives represents a grouping of ideas as possible solutions to finding alternative water supplies. These alternatives are not listed in any specific order but do include the following: 1) surface water and water exchanges, 2) groundwater, 3) reclaimed water (effluent), 4) water conservation including loss reduction.

5.1 Surface Water and Water Exchanges

The surface water and water exchange option could have many components that relate to the use of surface water as one possible water resource solution. Any additional use of surface water will likely require a water exchange agreement involving the Salt River Project (SRP) and possibly a site or several sites having the ability to store the newly acquired surface water supply. By developing a water exchange agreement with the SRP, several options open up whereby additional C.C. Cragin water can be delivered to facilitate a water exchange.

One example of a water exchange would be to acquire (purchase or lease) CAP water rights from the Gila River Indian Tribe, Tonto Apache Indian Tribe and/or from Brooke Utilities. These rights could be exchanged with SRP for C.C. Cragin Reservoir water. Assuming exchange is the means utilized to obtain water (rights) from C.C. Cragin (because direct purchase is found not to be feasible), the keys to this option would be: 1) acquiring the rights to the water, 2) acquiring an exchange agreement with SRP, 3) having a place to store the additional surface water (CAP or C.C. Cragin), and 4) facilitating expansion of proposed distribution infrastructure.

Another possibility might include the capture of storm water runoff within the incorporated boundary of the Town or other development that would otherwise be diverted to local washes and pass through the incorporated area. This could be an additional means of obtaining an intermittent surface water supply during the runoff season. The capturing of this water could be accomplished by stream modification techniques to slow down and store the storm water that would have normally flowed out of the incorporated area and down the watershed. This alternative would require water rights exchanges with downstream appropriators. This alternative could also provide possible recharge sites for excess CAP and C.C. Cragin water. The keys to this option would be: 1) securing water rights, 2) diverting the water, 3) capturing the water and 4) treating and storing the water.

The C.C. Cragin Reservoir presently stores local runoff water from the winter storm season. The reservoir is unlined and likely has a component of leakage that could be recaptured if wells were drilled down gradient within the reservoir's influence. Since this leakage water is presently not accounted for as part of the watershed runoff and it has not been determined where this water ends up, it may therefore be available for use downstream to augment existing water supplies. The keys to this option would be: 1) the rights to this water, 2) the ability to capture the leakage water, 3) the operation of the capture facility and 4) obtaining permits.

5.2 Groundwater

The second option involves the further development of existing groundwater resources on private lands. Currently, most of Gila County is dependent on groundwater supplies as the major source of water. Much of the groundwater comes from fractured rock aquifers, making it difficult to estimate the volume of groundwater in storage. Due to the fractured nature of the rock aquifers, production wells may need to be drilled far from where the water will be used. Therefore, wells need to be located where sufficient fracturing occurs which may be on public lands. The public land sites pose challenges because of the various permits required for water extraction and because of citizens' concerns. Expanding groundwater development programs may require a significant capital expenditure to drill wells and build pipelines to deliver water to where it is needed.

Table 5 below provides a rough estimate regarding construction costs for small-scale domestic wells on privately owned land and the table provides a scalable cost associated with well depth. Significant increases in costs for permitting and NEPA process would be required for wells installed on public lands. Such costs would be project specific and are therefore not included here.

Fortunately, the quality of the groundwater encountered is good and requires little or no treatment other than disinfection and possibly handling localized radon and/or arsenic treatment. The keys to this option would be: 1) finding suitable sites for drilling, 2) acquiring the necessary permits, 3) addressing citizens' concerns, and 4) ensuring continuous access to groundwater resources developed on public lands.

Table 5. Estimated Domestic Well Construction Costs (private lands) (2007)

	Well Construction Costs for Average Well*	Well Construction Costs per Well Foot
Field Drilling and Installation Cost	13,000.00	37.14
Unlisted Items (15%)	1,950.00	5.57
Subtotal	14,950.00	42.71
Contingency (25%)	3,737.50	10.68
Subtotal	18,687.50	53.39
Indirect Costs (25%)	4,671.88	13.35
Subtotal	23,359.38	66.74
Interest During Construction (4.875%)	948.97	2.71
Total	**$24,308.35**	**$69.45**

(*Average well of 350 feet deep, 5-inch PVC casing, without pump)

5.3 Reclaimed Water

The third option involves the further development and use of reclaimed effluent from the treatment of wastewater flows. This alternative could be more challenging for the smaller developments since most of these developments are presently on septic systems and the cost of installing wastewater infrastructure may be prohibitively expensive. However, the use of reclaimed water from the larger developments makes sense because of the larger volume of effluent generated. The use of reclaimed water will also reduce the risk of contamination from septic tank flows migrating downward to the groundwater table. Reclaimed effluent can readily be used on turf areas such as parks, roadways, and golf courses to minimize the additional need for pumping more groundwater. The keys to this option would be: 1) collecting the sewage flows for treatment, 2) constructing and operating a wastewater system and 3) converting irrigated turf to the use of effluent.

5.4 Water Conservation

The fourth option deals with water conservation including loss reduction. This option does not involve the development of a new water supply but involves becoming a better steward of the water that is available. With the recent successes enjoyed by the Town of Payson from its water conservation program, some of the conservation ideas could be applied to the smaller communities outside of the Payson area. Water conservation is such a visible concern that there presently is an Arizona Statute for Water System Planning that deals with the issue.

Part of this option would include evaluating the municipal water distribution system for lost and unaccounted-for-water as another potential water saving strategy. By locating and repairing leaks in the system, waste is reduced which maximizes the efficient use of the supplies available. This option requires metering of most uses within the distribution system, and the metering costs are made up in increased revenue for accurate water deliveries.

This fourth option should be applied even if one or more of the other options are selected. Water conservation and loss reduction programs can be employed by all communities and all people in the State of Arizona no matter their location or source of water used. Water rate-based incentives could be employed to reward those users who conserve. The keys to this option would be: 1) developing a water conservation and loss reduction program that makes sense for each community, 2) educating the community to apply these conservation measures and 3) establishing some level of enforcement or rate-based incentives to ensure communities comply.

6.0 RECOMMENDATIONS

As this Study is a regional assessment of water supplies, this section lists several recommendations to assist in more accurately determining water supplies in the future. As a general statement, given the large Study area, gathering additional data is the first recommendation. Several inferences and subsequent calculations have been made regarding the water resources for the area however; these are based on both temporally and spatially sparse data. The data gathered should encompass both groundwater and surface water supplies.

Groundwater and spring monitoring should include regular water level and discharge measurements and sampling for the entire Study area. As has been discussed in this report, water levels and spring discharge in many areas are seasonally variable. Quantifying the water resources for the study area should include consideration of this variability and how it can be managed. The time frame for collection would be yearly for the most remote areas and quarterly for the well and spring locations nearest the communities. This water level data collection may be promoted in conjunction with the Groundwater Site Inventory (GWSI) water level measurement program of the ADWR. The GWSI consists of field verified data collected by personnel from the ADWR Hydrology Division and/or the U.S. Geological Survey. This information is continually being updated by ongoing field investigations and through a statewide network of water level and water quality monitoring sites.

Stream gauging and water quality sampling for the perennial reaches of streams will provide information regarding the groundwater contribution to these locations. Also provided as part of stream flow monitoring, is an assessment of water volumes recharged into the underlying aquifer unit. Stream gauges also assist in quantifying precipitation distribution during storm events, further enabling the determination of recharge to the groundwater system. Stream gauging in addition to meteorological data also will assist in overall watershed management by the Salt River Project. Stream gauging and water quality sampling stations would be beneficial at multiple locations along Tonto Creek and the East Verde River as well as down gradient of the major spring locations, namely Webber Springs, Cold Springs, Pieper Hatchery Spring, Horton Spring, Tonto (Fish Hatchery) Spring, Tonto Bridge, Big Spring, Indian Gardens Spring, and Wildcat Spring.

The conceptual geology and hydrology developed as part of this Study should be further investigated. Subsurface hydrologic and geologic information should be developed in those critical areas with influence upon future groundwater and surface water resources. It has been speculated within this study that Hardscrabble Mesa in Sub-Region 2 may have significant recharge potential for the regional system, and may contribute water to Fossil Springs. This hypothesis should be confirmed with surface geophysics and the drilling of at least three deep exploration boreholes converted into monitor/piezometer wells on Hardscrabble Mesa. The goals for the drilling and well construction are to confirm groundwater flow direction(s) and water quality components. Further, drilling through Hardscrabble Mesa will provide confirmation of subsurface geology with regard to the presence of Paleozoic rock units below the basalts and their potential transmission of groundwater from recharge on Hardscrabble Mesa or from along the Colorado Plateau.

Additional areas for hydrologic and geologic data gathering through deep drilling exploration include the geologic transition zone between the Paleozoic rock units and the underlying Proterozoic rock units. Understanding this transition is valuable to determining the direction of groundwater flow, the volume of water moving through this transition, as well as for up-gradient groundwater monitoring for the groundwater users in the Study area. Also located along the Paleozoic/Proterozoic unit transition is the Diamond Rim Fault. A determination of groundwater flow across (or along) the fault will aid in understanding the contribution of Colorado Plateau recharge and for long-range management of groundwater supplies. There are eight recommended areas for exploration borehole drilling and monitor/piezometer well construction along the transition zone. These areas are: Buckhead Mesa, near Cedar Mesa, and north of Webber Spring in Sub Region 2; the area south of Milk Ranch Point but north of the Diamond Rim Fault, within Hells Half Acre north of the Diamond Rim fault, and along the control road approximately 2 miles north of the Little Diamond Rim in Sub-Region 1 (West); 2 miles east of Cold Spring near Ellison Creek in Sub-Region 2 (East); north of Houston Mesa just west of Mesa Del Caballo development in Sub-Region 3.

The areas recommended above for additional data gathering represent only a few of the significant spatial gaps in hydrogeological knowledge within the Study area. By gathering information in these areas, much of the conceptual hydrogeologic model presented in this report will be better constrained. This information may then be utilized in creating a numerical groundwater/surface water flow model. The model would allow for the testing and revision of the numerous ideas presented in the Study, including refinement of the overall regional water budget. A numerical model provides a tool for the assessment of potential impacts – temporally and spatially – of the different water resource alternatives presented. The development of a numerical model would also assist in guiding future data collection efforts as well as provide a tool for evaluating and designating wellhead and spring head protection areas. The protection of the groundwater recharge areas is essential for the long-term viability of individual wells and the entire aquifer system. Because many of the areas within the aquifer system are recharged quickly, wells should be protected from potential contamination.

With the observed temporal variation in isotope and Tritium data, quarterly sampling of major springs and a sub-set of wells in the region is also recommended. This effort would help to better understand recharge events, mechanisms, volumes, and local vs. regional groundwater behavior and relationships.

As groundwater is the primary water source for most of the region, the development of additional, reliable groundwater resources would be extremely beneficial. To do this, a groundwater exploratory program in support of the most resource limited communities such as Geronimo Estates, Tonto Village, Wonder Valley / Freedom Acres and Hardscrabble Mesa should be considered. Funding for the investigations may include both public and private components. This program could include a significant surface geophysical survey component as well as an exploratory drilling program with a goal of finding more stable, long-term groundwater supplies. In addition to providing additional supplies, the hydrogeologic information developed as part of the program would likely provide valuable confirmation (or not) of the conceptual hydrogeologic system developed as part of this Study.

The understanding of the fractured nature of the rock units as they relate to groundwater flow in the Study area cannot be overstated. In a study conducted by Maini and Hocking (1977) (as discussed in Marsily, 1986), they relate the characteristics of the flow from a single fracture to flow through a much larger equivalent unit of porous material. The Maini and Hocking study indicated that flow from a single fracture with an aperture less than ¼ inch could yield an equivalent hydraulic conductivity of approximately 283 ft/day. This is equivalent to a transmissivity value of nearly 700,000 gpd/ft in an aquifer 328 feet (100 meters) in thickness. Thus given the capability of a single fracture, determining the location of the fracture networks may be imperative to the development and management of water resources in the Study area. The geologic mapping conducted as part of this Study has indicated several areas where significant faulting is observed at the land surface. A program using surface geophysical methods to identify fractures and faulting at depth (where they intercept groundwater) may be very beneficial for the small outlying communities in the Study area which are in close proximity to mapped faults and fractures.

7.0 CONCLUSIONS

With the information developed in support of and by the Study effort, reasonable solutions to the water resources problems that have historically plagued the communities along the Mogollon Rim have now been identified. The single most important solution appears to be the implementation of the C.C. Cragin surface water project. Implementation of this solution will minimize groundwater use within the study area by importing a renewable surface water source to the primary population center of the region. Thus, groundwater demand then would be limited to only the smaller outlying communities where build-out demand for water should be well within the limits of regional sustainability; given the size of the watershed relative to dispersed demand. Utilization of groundwater in such areas, alongside responsible management strategies, is one way to ensure that the above statement rings true. Ultimately, the “toolbox” of alternative water resource solutions and suggested recommendations can be used as a basis for further study in detail and lead to considerations of feasibility for those wishing to proceed.

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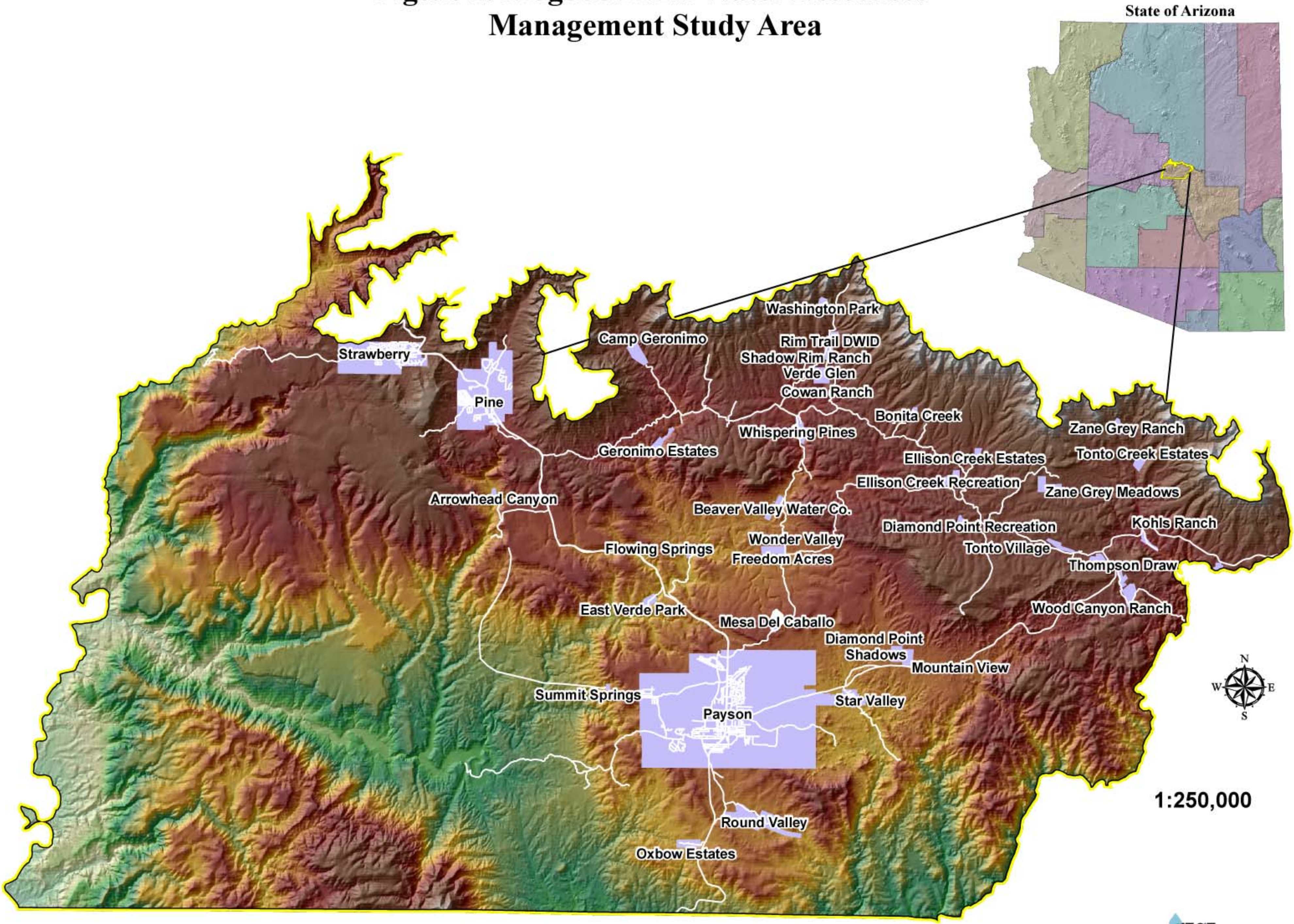
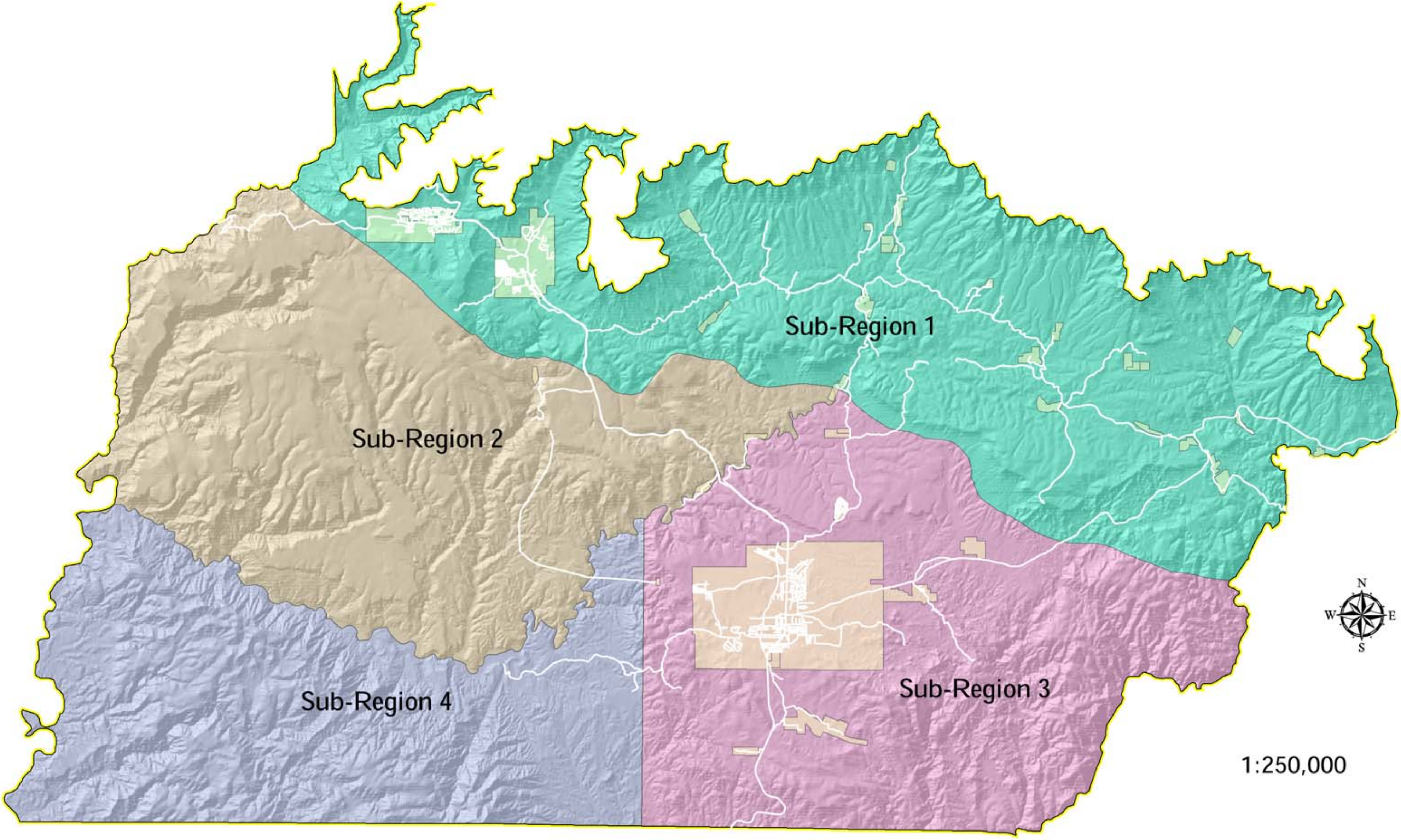
Figure 1. Mogollon Rim Water Resources Management Study Area



HydroSystems Inc.

Figure 2. Sub-Regions of the Mogollon Rim Water Resources Management Study Area



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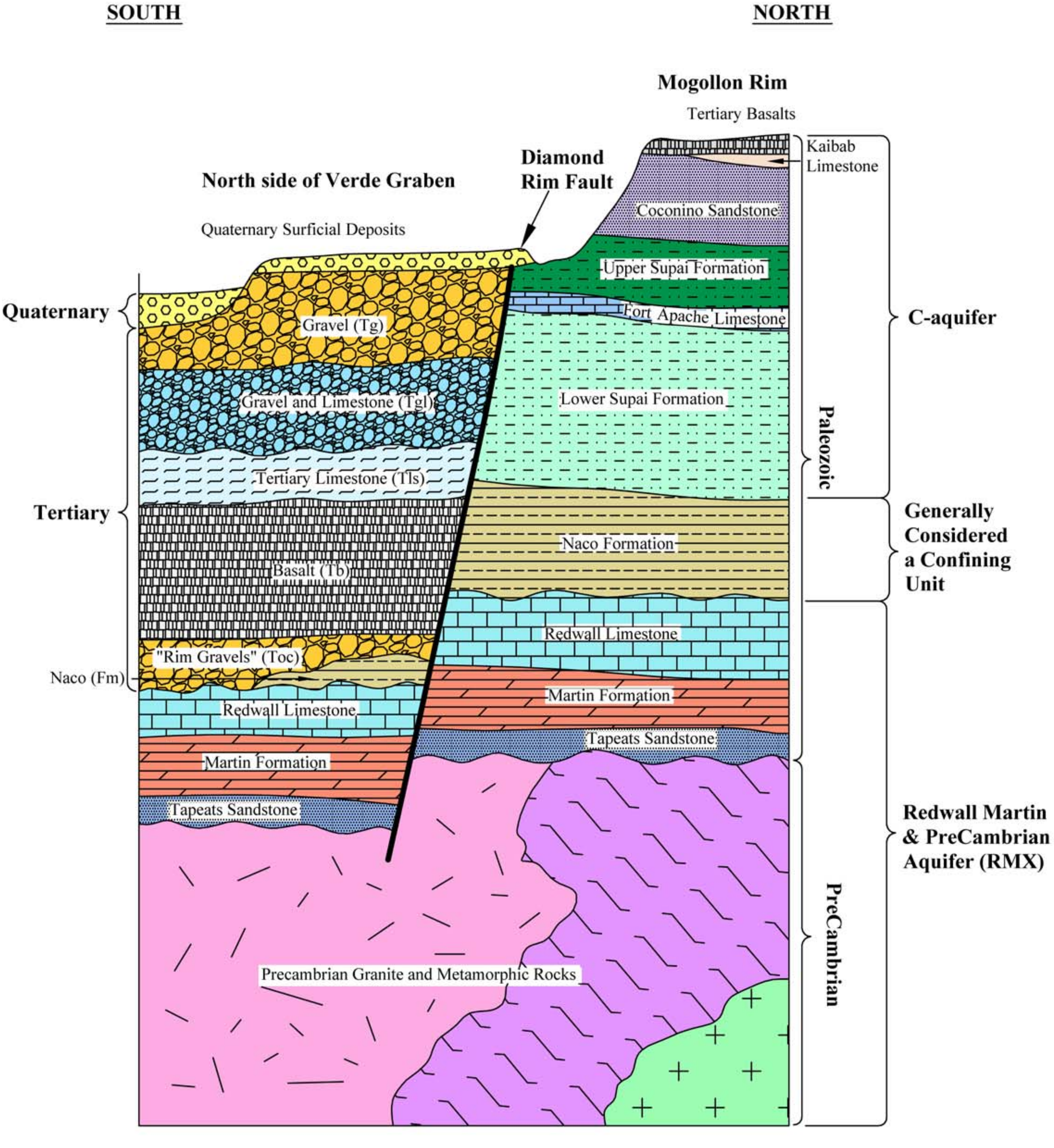

Note: Thicknesses are shown diagramatically and are not exact.

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Composite, Generalized Stratigraphic Section for the Study Area. Looking west along the Diamond Rim fault across the northern part of the Verde Graben, west of Payson

Figure 3