Maintaining and Protecting Nevada's Aquifers from SNWA Pipeline Extraction

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Summary

This report is in response to the Southern Nevada Water Authority's (SNWA) proposed 287 mile pipeline moving 41 billion gallons of extracted groundwater every year from the Snake and Spring Valley aquifer system in White Pine County towards the Las Vegas Valley region. Evidence will show that the ecological repercussions of excessive groundwater extractions as planned by the SNWA pipeline will likely be land subsidence, fracturing, fissuring, aquifer cavern collapse, seeps and springs drying out and causing extinctions of endemic species such as spring snails. The SNWA pipeline is another example of a continuing pattern of groundwater overdraft of aquifers in southern Nevada resulting from perpetual sprawling suburban development in the greater Las Vegas Valley. The purpose of this report is to demonstrate the overall negative ecological and hydrological effects from the SNWA's over dependency on aquifer water and introduces probable financial motives by SNWA officials and certain developers in pushing the people of Nevada to believe that the pipeline from the distant Snake and Spring Valley aquifer system is even needed.

Introduction

Recent protests throughout Nevada and neighboring Utah pertain to the proposal by SNWA to remove 41 billions of gallons of groundwater yearly from the Spring and Snake Valley aquifer system by constructing an approximately 287 mile long pipeline. The Spring and Snake Valley aquifer system is found throughout a network of solution carbonate karst caverns found along a strata layer of slightly metamorphosed limestone of various degrees of strength. The Snake and Spring Valley aquifer is one continuous underground body of water that slowly flows through carbonate or karst caverns located below unconsolidated sedimentary basin fill stretching across the Snake Valley, Snake Range and Spring Valley. The recharge points for these aquifers are the Schell Creek Range and the northern and southern Snake Ranges that receive above average yearly precipitation due to their high elevation above the surrounding valleys. The rainwater then percolates down through sediment strata layers into the carbonate limestone layer where aquifer caverns enlarged by dissolution store rainwater as groundwater. This groundwater eventually discharges as surface springs, seeps and local wells that provide life to the aquifer dependent ecosystems and humans of the Snake and Spring Valleys. However, the aquifer cavern roofs far below ground that store the aquifer water constantly depend on the buoyant upwards directional support of the water itself to prevent the heavy layers of basin sediment fill from eventually collapsing the cave's roof inwards. This process of aquifer cavern collapse is related to land subsidence and has been documented to occur regularly in similar limestone aquifers found elsewhere as a result of aquifer overdraft. In addition, aquifer overdraft almost immediately drops the groundwater table to levels below their prior discharge points at seeps and springs. Species such as spring snails are endemic to these seeps and springs, meaning they are only found in these specific habitats and no place else on Earth. If the springs dry out from a drop in groundwater level, the endemic spring snails will become extinct. This is not new, as the Las Vegas region developed more desert land with lawns and golf courses, groundwater withdrawals from nearby aquifers became the leading factor responsible for the extinction of the Vegas Valley Leopard Frog and the Vegas dace that were both endemic to those specific springs that dried up following overdraft.

Pattern of Aquifer Overdrafts and Land Subsidence in Las Vegas Valley

This latest aquifer draining quest by SNWA officials will result in the same eventual depletion of the Snake and Spring Valley's groundwater, followed by land subsidence, dried out springs, endemic species extinctions and dust storms as with many other aquifers tapped dry by the developers of the Las Vegas Valley in the prior decades. The regional aquifers around Las Vegas Valley were overdrafted decades ago, causing land around the Las Vegas Valley to subside by several feet in many regions, more in some places than others. This overdraft mostly occurred during the recent decades of Las Vegas Valley's rapid development when many newcomers were somewhat unaware of the sensitive dynamics of the region's underground water storage. Over-abstraction, overdraft or excessive lowering of groundwater is one of the leading causes of subsidence and is documented to regularly occur in all nations around the globe. Parts of the Las Vegas valley have subsided over 1.5 meters as a result of over-abstraction with rainfall averages of only 100 mm/year (worldwaterday.org).

Indigenous people of the Las Vegas Valley were able to live for at least several hundreds of years in this extreme desert environment without overdrafting the region's aquifers and drying out surface springs. Unfortunately modern day developers in the Las Vegas Valley have managed to overdraft aquifers and dry up the region's springs in just a few decades due to carelessness and ignorance. The chronology of aquifer withdrawal and subsidence in Las Vegas Valley shows that an ancient aquifer such as the Snake and Spring Valley karst system that required centuries of percolating rainwater to form caverns full of filtered groundwater can be drained dry in mere decades. In the Snake and Spring Valley aquifer system the rate of recharge from precipitation is measured in centuries while the rate of discharge from extractions and spring outflow is measured in mere months. The scales are balanced much more in favor of rapid emptying of the aquifer than the aquifer becoming refilled in the event of overdraft. Though the material substrate in the Las Vegas aquifer is sedimentary while the Snake and Spring Valley aquifer is slightly metamorphosed limestone of varied grades of strength, general rules of physics apply to conditions such as overdraft and subsidence in all aquifers.

The influence of gravity on dewatered aquifer caverns or lowered groundwater levels is nearly identical, the absence of water in either the pore spaces of sedimentary groundwater or the aquifer cavern in carbonate karst systems results in a loss of upward directional buoyant pressure and the eventual lowering of the ground to fill in the spaces emptied of water.

Since 1925 fissures were documented as appearing in the Las Vegas Valley, many forming as small tension cracks in sediment above the water table and are believed to enlarge from mechanical piping. The fissure continues to grow until it is visible after breaking through the sedimentary cover bridging the pipe, sometimes causing lines of small potholes to form on the surface (Bell).

In Las Vegas Valley land began subsiding around 1935, documented during studies related to Hoover Dam's construction. Regional monitoring programs since 1935 have documented a widespread shallow sinking of land along Boulder Canyon around 19 km north of Hoover Dam, showing a southeastward tilt of 10-12 cm resulting from loading of stored water (Bell).

The Las Vegas Valley's hydrologic basin is mostly hundreds of meters of sedimentary alluvial deposits, with coarser grains around the margins and fine grained in the middle. The aquifers are confined and semi-confined at 200-300 meter depths. Decreases in sediment volume from groundwater removal result in subsiding of land. The increase in effective stress on silts and clays force permanent rearrangement of fine grained particles. Fine grained sediments show greater tendency to compact than coarse grained deposits (Bell).

Many residents from the Windsor Park section of North Las Vegas were forced to relocate following years of repairing twisted homes, schools, roads and other infrastructure deformations. The homes in Windsor Park are being destroyed by subsidence related slow movement and rupture of the ground below them. One effect of long term subsidence is a change in locations of frequently flooded areas (Helm).

In 1946 annual groundwater withdrawals from the Vegas Valley were greater than annual recharge, and have consistently exceeded recharge by two to three times the amount. The long term effect of constant overdraft is witnessed in some locations where water levels have declined by more than 90 meters (Bell).

From elevation benchmarks at various locations around the Valley a map of cumulative subsidence was formed in 1963. The '63-'87 subsidence map shows depths of greater than five feet occurred near Craig Rd. and Ranch Dr. in the northwest Valley . From 1963-80 the cumulative subsidence map was published in Nevada Geology's summer '89 issue (no.3), though since recent development has destroyed elevation benchmarks future maps cannot use the original base data. Two geodetic surveys (GPS) were run in 1990-91 to try to establish new base data (Helm).

Nevada Bureau of Mines and Geology (NBMG) scientists John Bell and Jon Price have collected earlier data until 1980 and updated this with new data that ended in 1989. The annual rate of subsidence since 1980 has remained close to what it was prior to 1980. This leveling off could reflect common sense decisions to manage the groundwater differently, instead of overdrafting the aquifers year round they were finally reinjected with runoff during the wetter winter season (Helm).

According to Nevada Geology (No. 3, Summer 1989) the cause of Las Vegas Valley's subsidence is caused by groundwater withdrawal as pumping from aquifers has exceeded the natural recharge rates by 25-35 k acre-feet per year since the mid-1940s. In 1968 the region's groundwater withdrawal had reached a maximum yearly rate of 88k acre feet, though in the years after decreased to 68k acre-feet per year after imports from Lake Mead began. Then in 1987 the Las Vegas Valley Water District began an artificial recharge program during times of lower usage, from 10-20k ac.-ft./yr. (Helm).

The effects of groundwater overdraft are continuous declines of water levels and the reduced artesian spring pressure throughout the greater Las Vegas Valley basin. Reduction of upwards pressure from the groundwater below allows the effective stress to increase at depths. This occurs because the percentage of the overburden's weight supported by contact between the grains increases while the percentage supported by interstitial water inside of the pore spaces decreases. An increase in effective stress throughout the sediment source material of withdrawal causes pore structures to yield to gravitational pressure and compress. The cumulative effects of individual pore space compression results in land subsidence as the gradually increasing density of grains at depths moves upwards (Helm).

In 1963 scientists documented the center of the valley had subsided by 1 meter and by 1980 by 1.5 meter. One broad subsiding bowl covers the central portion of the valley, while three smaller subsiding bowls cover downtown, the southern strip and the northwestern region (Bell).

Near fault lines subsidence causes uneven tilting as rates differ on opposite sides across the fault. There is documented evidence of steep gradient of differential subsidence near the Eglington fault with a 2 ft. contour line in close proximity to a five ft. contour line (Helm).

Several linear and curvilinear north to northeast faults cross the valley, raising scarps by 50 meters in some places. Studies have shown that the faults are preferred sites for local, subsidence created vertical movements (Bell).

Between 1978-91 data for four contour lines across three separate fault zones show constant rates of movement. Along the northeast trending Eglington scarp between 1978-85, the data on elevation shows subsiding on the upthrown northwest was subsiding at 5 cm/yr. Along all four contour lines the most extreme differences in elevation occur either along the central portion of the scarp or begin their differential readings at the scarp. All four lines show and antithetic movement opposing the original geologic displacement (Bell).

“Areas within the valley that have been heavily pumped and show large water-level declines have also been the sites of major elevation change, surface deformation, and damage” (Bell).

Subsidence fissures are a result of long narrow cracks from depths migrating upwards to meet the surface. When erosion transports sediments into the fissure it forms a line of potholes and gullies at the surface. Subsidence fissures from horizontal aquifer movements at depths are different from desiccation cracks from drying of near surfaces clays. Most fissures are near already existing faults throughout Las Vegas Valley, 45% percent of fissure lengths are within 500 ft. of the nearest fault and 82 % are within 1,200 feet of the nearest fault (Helm). Throughout the eight zones of fissuring show close relations with geological faults, a result of the fault’s tensile strains being the ideal sites for fissuring (Bell).

The reason for cracks at depths along already existing faults is from downwards aquifer movement being lowered by groundwater withdrawals. Geological heterogeneities and aquifer hydraulics are closely interdependent regarding subsurface fissuring (Helm).

If groundwater discharge center is located on the upthrown side of a fault, the upthrown side moves downwards at greater distance when compared to the downthrown side, opposing the prior geological direction of motion. Geological structure seems to determine the locations of fissures while groundwater hydraulics determines the direction, magnitude and timing of subsidence related fissuring (Helm).

Based upon their dedicated research, the scientists at NBMG reached certain conclusions to mitigate subsidence hazards in Las Vegas Valley;

1) Reduce net annual groundwater withdrawal to level of net annual recharge by reducing dependency on groundwater withdrawals and increasing aquifer injection recharge.
2) Continue to recognize hazards zones based upon location of faults or existing subsidence related fissures.
3) In regions prone to fissuring encourage drought tolerant native landscaping to prevent needless withdrawals from sensitive underlying groundwater.
4) Establish a Las Vegas Valley Subsidence District to be responsible for water policy related to subsidence.
5) Monitor and track locations with subsidence and fissuring. Even if future reductions in withdrawals equal levels of annual recharge subsidence would continue for 5-10 years and fissures would increase from erosion. This would help noticing changes in runoff and erosion patterns.
6) Continue research in geological causes of horizontal movements, and subsidence related cracks at depths and fissuring. Network and compare research with other places experiencing fissuring (Helm).

Despite improvements in future rates of subsidence, the winter aquifer injections were not able to recover the subsidence prior to 1986-87 when the recharge program began. Near Las Vegas downtown Post Office six inches of subsidence occurred prior to 1950. These regions then were measured at a steady rate of subsidence until 1987 (Helm).

The lessons learned from the excessive groundwater withdrawal and resulting subsidence in the Las Vegas Valley seem to be ignored by the current establishment of the SNWA. The recommendations from the NBMG include lowering dependency on groundwater, to recharge aquifers at greater rates than those of discharge and withdrawals. This advisory from the NBMG is not because the scientists "don't want to see Las Vegas grow" as the SNWA public relations machine would have people believe. The NBMG scientists' sage advice is solely for the reason of protecting and maintaining Nevada's aquifers for the future generations of people, plants, animals and entire ecosystems that depend upon the aquifers remaining full for their survival. The greater rates of aquifer recharge recommendations from the NBMG scientists also apply to the limestone based karst carbonate aquifers found far to the north of the Las Vegas Valley.

Hydrogeology of Basin and Range Carbonate Karst Aquifer System

The Snake and Spring Valley carbonate karst aquifer system is part of the greater Basin and Range province geology with rising mountain ranges running parallel at length with falling valleys. The source of current recharge is the surrounding Schell Creek Range and northern and southern Snake Range. The aquifer stretches between the two valleys and beneath the Snake Range. Aquifers in the Basin and Range Province that formed and filled in much wetter climates than that of our modern deserts experience far greater potential yearly losses from discharge and extraction than they gain from precipitation. During the wet prehistoric climate the aquifer gained water, while in the modern desert climate the aquifer suffers a net loss. This climactic inconsistency results in the Basin and Range aquifers at spring and seep level being very sensitive to overdraft of the groundwater. At the extraction rates proposed by SNWA to the tune of billions of gallons per year, expected results from the proposed pipeline would be excessive losses from the aquifer with minimal ability to recharge under modern climactic conditions. As the groundwater drops below levels where inadequate recharge raises the levels, the seeps and springs can go permanently dry. Having this understanding of climactic influences on geology is causing those scientists with ethics to experience grave concerns about the outcome of the proposed SNWA pipeline.

Most desert basins such as Snake and Spring Valley have land sloping from rising mountain blocks towards a central depression with a central drainage that is usually dry. Some valleys have playas that are remnants of seasonally sporadic lakes, many containing alkaline water with large amounts of dissolved salts and minerals (USGS Atlas).

Three main types of aquifers in Basin and Range Province are volcanic rock, carbonate rock and basin fill aquifers. The carbonate rocks under Snake and Spring Valley are dolomites and metamorphosed limestone mostly from the Mesozoic and Paleozoic ages. Drill test results show intervals of carbonate caverns exist from 5,000 to 15,000 feet in depths (USGS Atlas).

Many of Nevada's eastern carbonate rocks have minerals such as quartzite, shale, siltstone and limestone deposited from earlier eras lying beneath them, with their minimal permeability forming a lower limit to the carbonate rocks. Carbonate rock aquifers exhibit two parts; the upper plate rocks from Late Triassic to the Early Mississippian age that are mainly limestone with smaller amounts of dolomite and interbedded with shale and sandstone and lower plate rocks of limestone and dolomite from Middle Devonian to Middle Cambrian age with hardly any amounts of clastic material (USGS, Atlas).

The primary strata that is a source of aquifer caverns in the Snake and Spring Valley is Cambrian Pole Canyon Limestone, usually found above a layer of Pioche Shale and below the Lincoln Peak Limestone and Dunderberg Shale strata layers. Shale is notorious for being fragile, flaky and crumbly. By sandwiching two different grades of metamorphosed limestone between two layers of shale, the aquifer bearing strata is seated on some rather crumbly bread slices.

There are great variations in thickness of carbonates from deep erosion and structural deformation, saturated up until 10,000 feet and with total depth in some locations as great as 15,000 feet. The thickness and position of the carbonates generally allows the saturated zone of an individual aquifer to begin at several thousand feet throughout most of the areal extent of the aquifer system. This type of aquifer is completely unsaturated only in the vicinity of the outcrop and is found everywhere except atop buried structural highs (USGS, Atlas).

These carbonates are very fractured and locally brecciated, with rocks consisting of angular clastic fragments. Clastic fragments found in monomictic breccias have the same composition, while polymictic breccias contain clastic fragments of varied compositions. Gravel size in sedimentary breccias are more than 30% of fragments at (>2mm) and angular clasts are produced by either physical weathering or brittle deformation of surrounding rocks. The angular shape of the clastic fragments indicates near distance transport. Sedimentary breccias form at the foot of slopes with talus or nearby active faults. Karst breccias result from erosion, dissolution and collapse of limestone. Pressure solution from high local stresses at points of contact between angular limestone fragments, marble, or chert can result in interpenetration of clastic fragments (enotes.com).

Specific outcrops found within the aquifer system can have three or more sets of joints, one or more high angle faults and one or more brecciated zones. Near the Nevada Test Site north of Las Vegas the joints and most of the faults in carbonate rocks are fractures with steep angles. Brecciation usually happens along faults showing only a few feet of displacement and does not automatically indicate displacement from larger magnitude quakes. Joint density correlates with type of rock, with fine grained carbonates having the greatest joint density. The fine grained joints usually divide rocks into blocks from one inch to a few inches on each side. The medium grained carbonates are separated into blocks from a few inches to one foot per side. Coarse grained carbonate rock blocks range from 6 inches to two feet on each side (USGS, Atlas).

The outcrops usually contain secondary openings locally along the bedding planes, some from subaerial weathering and some from dissolution of the rock. Dissolution results in smooth tabular openings, while weathering alone would have tightly closed bedding and joint planes (USGS, Atlas).

Most Basin and Range groundwater flow systems are either in individual basins or two or more hydraulically connected basins where groundwater flows into a final discharge point or collects in a sink. Except for Colorado River drainage, the water does not leave the Great Basin and is used by desert plants. Basin and Range aquifer boundaries are the impermeable rocks of mountain ranges, with most water traveling through the basin fill deposits towards the carbonate caverns beneath. Basin fill groundwater is replenished from snowmelt entering fractures in bedrock channels and working down through alluvial fans. Water from summer thunderstorms usually is soaked up by dry soil and does not percolate far down enough to resupply groundwater. The mountains with carbonate rocks usually lack runoff as most water enters the permeable carbonate aquifer system (USGS Atlas).

There are four types of aquifer classificatons; undrained closed basins, partly drained closed basins, drained closed basins and the terminal sink basin. The undrained closed basins are simple single valleys surrounded by underlying impermeable bedrock with no interbasin flow and a central discharge point into a playa or sink. The partly drained closed basins are surrounded by moderately permeable bedrock with some flow out of the basin at the downgradient site and some playa evaporation on the upgradient site. The drained closed basins have deep aquifers that discourage evapotranspiration though are surrounded by highly permeable bedrock that enables all recharge to leave the basin. The terminal sink basin is surrounded by highly permeable bedrock to enable flow from several connected basins to enter the basin and collect in a playa (USGS Atlas).

Partly drained closed basins have permeable bedrock below them and are often hydraulically connected systems spanning across several valleys. In some cases, stream courses can connect several basins that are not closed. However, the Snake and Spring Valley aquifer is not connected by surface streams, though is connected below ground by interbasin flow between the two valleys beneath the Snake Range. This would classify the Snake and Spring Valley aquifer as a partly drained closed basin, though with deeper groundwater storage capacity that discourages upgradient evapotranspiration. With the exception that the aquifer is deep below ground, the similarities are close enough to consider the aquifer as a partly drained closed basin (USGS Atlas).

Pahrump Valley Subsidence from Extractions of a Partly Drained Closed Basin Aquifer

Many aquifers throughout Nevada exhibit similar characteristics of a partly drained closed basin. One example is the Pahrump Valley, covering around 1,050 square miles between Inyo and San Bernardino Counties in CA and Nye and Clark Counties in NV. The water source for this aquifer complex is the Spring Mountains (not the same Spring Mountains neighboring the Snake Range) on the northeastern border of the basin. On the southwest slope of the mountains, large alluvial fans drain the canyons descending from Charleston Peak, called the Pahrump and Manse Fans (USGS Atlas).

The intervalley groundwater flow of Pahrump Valley heads southwest to low elevations bordering the Amargosa River. The downgradient discharge point is between the towns of Tecopa and Shoshone, between 10-15 miles southwest of the Pahrump Valley's topographic boundary. Thrust faults exposed in these mountains also displaced low permeability clastic rocks nearby the water storing permeable carbonate rocks, thus restricting aquifer flow. This is evidenced above ground by stands of mesquite and springs along the northwestern side of the fault, showing the barrier causes groundwater to move parallel along the barriers until it emerges at the surface. Throughout the fault, there are sections of broken rock and fractures where some permeability allows escape of water from the fault zone (USGS Atlas).

Similar to the Snake and Spring Valley aquifer, the Pahrump aquifer consists of two distinct segments; the carbonate rock karst caverns found beneath the valley, and the top layer of sedimentary basin fill, consisting of accumulated unconsolidated deposits of debris that fill the structural elongated bowl of the valley floor. Other similarities include the lifting mountain ranges that capture recharge and the falling valley basins that collect the groundwater in karst caverns under sediment fill, discharging in seeps and springs. In the Pahrump Valley, the groundwater is transported to the nearby Chicago and Amargosa River Valley southwest of the source. Due to the depth of the fill, the wells are drilled to extract water from the basin-fill aquifer (USGS Atlas). In the Pahrump Valley, the carbonate aquifer is at such a great depth that drilling it would be nearly impossible, and as a result all water is withdrawn from the basin fill layer of sediments (USGS Atlas).

Since there are no wells in the Pahrump Valley's carbonate karst aquifer, this makes it an excellent example of how an aquifer is supposed to replenish from precipitation and discharge into springs and streams at a reliable rate. The carbonate rocks of the Pahrump Valley aquifer system are of Triassic to Cambrian age and appear as outcrops in the Spring Mountains and also underneath the basin fill of the valley. From the Spring Mountains the aquifer extends southwestwards through the Nopah and Resting Springs Range into the California and Chicago Valleys. Localized solution openings and interconnected fractures allow the groundwater to move through the rocks.

The estimated transmissivity measured at 10 wells outside the valley was from 130 to 120,000 feet squared per day. The greater the transmissivity, the more water the aquifer will yield. The wide range in transmissivity numbers for the Pahrump Valley may be a result of variations resulting from faulting and the number and size of solution openings (USGS, Atlas).

Transmissivity (T) is equal to the volume of water that flows through a randomly selected cross section of an aquifer measuring 1 ft. x aquifer thickness (b) under a hydraulic gradient of 1 ft./1 ft. over a selected time frame such as 24 hours. Transmissivity is written as ft2/day because if T = Kb, then T = (ft./day)(ft./1). The measure of (T) is also equal to hydraulic conductivity (K) times aquifer thickness (b), or expressed as T = Kb (NC water). This indicates that subsidence would bear a direct effect on the lowering of transmissivity values by decreasing the thickness of the aquifer. The transmissivity values reflect on the amount of water stored in the aquifer (NCwater).

Similar to the Snake and Spring Valley, the Pahrump Valley basin fill aquifer is composed of unconsolidated alluvial and lacrustine deposits that partly fill the valley. Coarser grained material is found on the sides, while fine grained material occurs in the valley center. The 650 square mile areal extent of the aquifer is two thirds of the entire valley floor. To the northeast, northwest and southwest, the aquifer boundaries are the consolidated rocks of the Spring, Resting Springs, Nopah and Kingston Mountains. The southeastern boundary is a topographic high that separates the Pahrump and Mesquite Valleys (USGS, Atlas). The Spring Mountains mentioned in this section refers to a different mountain found in Clark County and is not connected to the Spring Valley aquifer other than the same first name.

The wells drilled into the Pahrump's basin fill aquifer are from 50 feet to over 1,000 feet deep; none penetrating the basin fill except a few at the margins. The estimation of basin fill width was from geophysical measurements with maximum thickness of 4,800 feet in the valley center, with the thickest accumulations in the axis parallel to the valley length with some variations in the south end attributable to faulting (USGS, Atlas).

There are often extreme differences in transmissivities between different aquifers. In North Carolina's coastal plain karst aquifers, some Cretaceous age aquifers have transmissivities from 100 to 1,000 ft2/day while Eocene age Castle Hayne Limestone can be as high as 50,000 ft2/day (NCwater.org).

Virtually all the Pahrump Valley's aquifer water comes from precipitation, with ground water recharge percolating from the mountains down through bedrock fractures to zones of saturation, and the remainder on upper slopes of alluvial fans percolating into basin fill until reaching saturation. The flow is from recharge areas near the Spring Mountains southwestwards across the valley towards the Nopah Range. Evapotranspiration occurred in areas of shallow groundwater and additional water loss from subsurface outflow beneath the Nopah Range. The 2,600 foot contour lines on maps indicate the hydraulic gradient if the northwestern section of the valley is towards the Ash Meadows discharge site in the Amargosa desert north and west of Pahrump Valley. Instead, the majority of the groundwater flow is discharged along an area of the Amargosa River between the towns of Shoshone and Tecopa to the southwest of the Pahrump Valley (USGS, Atlas).

The Pahrump Valley's agriculture depended upon two large springs for many years. In the late 1800's, Bennetts Spring discharged nearly 7.5 cubic ft. per sec. (5,430 ac. ft./yr.) and Manse Springs nearly 6 cubic ft. /sec. (4,340 ac. ft./yr.) until 1913 when groundwater withdrawals began. Soon thereafter the springflow decreased drastically until Bennetts Spring ceased flow in 1959 and not one drop coming out of Manse Spring during the 1975 irrigation season. By this time, 9,800 ac.ft./yr. of spring discharge was diverted as groundwater withdrawals (USGS, Atlas).

The Pahrump Valley's first well was drilled in 1910 and by 1916 there were 28 operational wells, with 15 of them flowing. Wells and withdrawals increased thereafter until the mid '40s when the first large capacity wells were drilled. These newly installed wells increased aquifer water discharge from wells from 4,000 to 28,000 ac. ft./yr. (USGS, Atlas).

Additional residential growth increased aquifer withdrawals throughout the '60s and '70s, resulting in noticeable effects as springs ceased to discharge and ground water levels began to decline. Differences between annual rates of decline depend upon the distribution of the withdrawal and the hydraulic properties of basin fill and well depth. The regions nearest the greatest concentration of wells showed groundwater level drops of 100 feet, while those with less concentrated wells showed less decline (USGS, Atlas). Other factors are variations within the aquifer itself, both rate of extraction and aquifer topography can effect the rate of the aquifer's transmissivity.

Tranmissivity estimates only represent the top 1,000 feet of the aquifer, and some variations occur from deposition of coarser material and the water table's positioning. Transmissivity values are shown to increase from the mountain's edge where saturated materials are thin towards the center where the water table rises to meet the flattening land surface. The increasing thickness of the coarse materials saturated by groundwater give the greatest transmissivity values of 4,000 feet squared per day in the Pahrump and Manse Fans. Transmissivity values then decrease in almost parallel bands across the valley to less than 1,000 feet squared per day as the sediment layer's saturated thickness decreases towards the mountain's edge (USGS, Atlas).

Though citing the Pahrump Valley's groundwater level dropping and causing subsidence in a sedimentary basin fill aquifer could be invalidated with contrasting the differences of the Snake and Spring Valley aquifer's limestone carbonate karst aquifer system, the common theme in terms of physics of groundwater removal resulting in a lack of countergravitational buoyancy applies to both. The differences are primarily of scale; the sedimentary basin fill aquifer's groundwater is stored in billions of almost microscopic and nearly equally sized and spaced pore spaces found between near equally sized and spaced sediment grains and the limestone carbonate aquifer water is stored in much smaller numbered yet much larger and also unequally sized and spaced karst caverns. In the Snake and Spring Valley aquifer system, the layer most responsible for forming aquifer caverns is Cambrian Pole Canyon Limestone (PCL). Surrounding the PCL layer are strata layers of Pioche Shale, Dunderberg Shale, Lincoln Peak Limestone and other limestone strata of varying strength. The limestone caverns could be thought of as a vertically thin and widespread extended layer of a water storing "pore space" sandwiched between much thicker strata layers of "sediment grains" incapable of storing water. Generally speaking the "sediment grain" below the limestone layer is Pioche Shale and the other "sediment grain" layer directly above the limestone is Lincoln Peak Limestone and Dunderberg Shale. Removing water from the pore spaces of sedimentary fill aquifers causes gravity to force the sediment grain formerly found above each now dewatered pore space downwards to fill and replace the empty pore space until it touches the sediment grain formerly found below the pore space.

Another difference would be in the rates of timing of land subsidence, overdraft of a sedimentary basin fill aquifer will result in an immediate yet gradual subsidence as small pores spaces empty of water and sediment grains slowly move downwards to fill the pore space emptied of water. When a carbonate aquifer cavern roof loses support from countergravitational buoyant groundwater, the collapse of the large empty cavern can take a much longer time yet be a sudden dramatic incident once the fracture occurs and weakens the cavern's structural integrity. The reason is the extreme size variations of the two aquifer's water containing cavities, the billions of micro-sized pore spaces in sediment basin fill aquifers will begin emptying gradually immediately after groundwater level drops, moving sediment grains downwards along with the groundwater level movement. The limestone karst aquifer caverns are house sized and relatively solid, so an initial groundwater drop can partially empty a karst cavern over months or even years before the cavern's roof stability becomes compromised and suddenly collapses. Immediately following groundwater overdraft, the falling groundwater levels will not show any subsidence on the surface for as long as the karst aquifer cavern remains stable. Metamorphosed limestone aquifer caverns as those found in the Snake and Spring Valley aquifer system are able to maintain their structural integrity for years and suddenly collapse several meters in seconds without warning. After enough time of being dewatered the weight of the overburden will fracture the roof along stress points of the karst aquifer cavern roof and result in a sudden collapse and subsidence after the overburden's pressure from gravity overwhelms the karst cavern's unsupported roof.

A similarity between the Pahrump sedimentary aquifer and the Snake and Spring Valley carbonate aquifer is in overall reduction of transmissivity following overdraft. Transmissivity is effected on both sides of the equation ($T = Kb$), with $K = (\text{ft./day})$ and $b = (\text{ft./1})$. The hydraulic conductivity (K) is measured as the amount of water flowing through a 1 foot square of a cross section of the aquifer over one 24 hour day. The height of the aquifer (b) is measured as one foot width times however many feet in vertical height the aquifer reaches. The effect of overdraft is reducing the amount of water and the height of the aquifer by cavern collapse and subsidence.

Carbonate Aquifers Collapse Potential Visible in Lehman Caves Talus Room

Although the Snake and Spring Valley aquifer system's variations of different degrees of strength of metamorphosed limestone carbonate aquifer may endure greater overall overburden stress for a longer duration than the Pahrump and Las Vegas Valley's sedimentary basin and fill aquifer, the same concept of overburden stress applies to karst cavern collapse and land subsidence. Removal of groundwater ends the upwards directional countergravitational buoyant pressure on the cavern's roof, causing gravity to move the roof downwards to lower elevation positions in the cavern now emptied of the water's prior support. Once an aquifer cavern becomes strained from gravity by unsupported overburden and collapses, the cavern can never be restored to the original capacity. The aquifer cavern's roof lowers and moves closer to the floor, resulting in less empty space to store groundwater. One would hope that SNWA officials would reach the conclusion that groundwater in an undisturbed aquifer cavern that has not yet subsided from climactic dewatering is more desirable than an overdrafted aquifer cavern that has collapsed and is no longer capable of maintaining artesian springs or the aquifer cavern's original storage capacity.

Limestone based karst aquifers like the caverns found beneath Snake and Spring Valley are eventually vulnerable to the same forces of gravitational collapse that caused the subsidence in Pahrump and Las Vegas Valley. Limestone cavern subsidence is not a result of pore spaces between grains growing smaller, it occurs as large hollowed out caverns deep beneath the Earth can no longer support the overburden following drops in groundwater level. One example of an earlier limestone karst cavern roof lowering collapse can be witnessed firsthand by a visit to Lehman Caves at Great Basin National Park. In this situation Lehman Cave's Talus Room shows the results of a prehistoric karst cavern collapse caused by a climatic influenced lowering of groundwater tables. As the groundwater level dropped inside of the Talus Room's caverns, the overburden's gravitational pressure without any upwards buoyant support pressure from groundwater caused stress fractures in the metamorphosed limestone and caused the karst cavern's roof to move downwards as a sudden collapse.

The great number and large sizes of intact Lehman Cave mineral formations indicates that very little shifting occurred except in the Talus Room. The numerous rockfalls in the Talus Room were likely a result of water draining out of the cave following climate change to drier conditions and removing buoyant support from the ceiling's weight. The original strength of the bedrock itself was not weakened by the lowering water table. However, the original strength of the bedrock alone may never have been able to support the cavern's roof without the additional countergravitational support of the groundwater. The process of the Talus Rooms's ceiling collapse began when the water drained out of the cave and has not yet reached a stable point due to the room's large size and is possibly enhanced by nearby faults. It is probable that several old cave passages are buried beneath the Talus Room's layers of rubble (NPS).

The Snake and Spring Valley aquifer system did not fill up over just a few years of rainfall. These aquifer caverns consist of metamorphosed limestone that filled after corrosion of the limestone by slightly acidic carbonic acid from downward percolating rainwater. The duration of time that was needed for this aquifer to fill completely to the point of having artesian springs was several thousands of years. The climate during the time of formation was also much wetter with greater precipitation rates than current times.

Above the aquifer caverns lies the overburden of eroded sediment from the surrounding mountains. The Basin and Range geology of the Snake and Spring Valleys is lifting the mountains and lowering the valleys. The aquifer caverns are buried underneath the overburden in the valley. The water in the aquifer cavern is responsible for supporting the tremendous weight of the overburden. Removal of the aquifer water would result in the weight of the overburden resting solely on the limestone cavern's roof itself. Both the caverns of Lehman Caves Talus Room and the modern day aquifers under the Snake and Spring Valley are considered solution caves, formed by carbon dioxide dissolved in rainwater and acting as an acid on the karst bedrock.

Pole Canyon Limestone Members Form Solution Caves of Varying Grades of Strength

The geological materials that form karst solution caves such as Lehman Cave's Talus Room are limestone, dolomite, gypsum, salt and marble, and all are dissolved over time by contact with slightly acidic rainwater. The material of Lehman Caves and the Snake and Spring Valley aquifers is a type of metamorphosed limestone that became low grade marble, named Pole Canyon limestone for Pole Canyon on the west side of the southern Snake Range's Mount Washington. Pole Canyon limestone conformably overlies the Pioche Shale and unconformably (thrust faulted) underlies the new Lincoln Peak Limestone. The age is Middle Cambrian, determined by the presence of trilobite fossils (ngmdb.usgs.gov).

Pole Canyon limestone is composed of massive gray and white limestone and is divided into five members (ascending);

1) Member A; 415 ft thick; composed of massive dark gray crystalline limestone; locally white calcite blebs, veinlets, and Girvanella type forms produce mottled texture; at 30 and 85 ft above base, two yellowish gray quartzite units 3-5 ft thick are present

2) Member B; 630 ft thick; massive, moderately coarse-grained, light gray limestone

3) Member C; 160-320 ft thick; similar to Member A

4) Member D; 220-380 ft thick; massive light gray limestone similar to Member B

5) Member E; about 340 ft thick; light to medium gray limestone with pale red to yellow-brown argillaceous partings, and much varicolored shale near the top. Overall thickness is about 2000 ft.

According to the above categories, there is considerable variation in the types of limestone and the height of each strata layer. One question relevant to the proposed SNWA pipeline is;

"Are certain members of Pole Canyon Limestone more vulnerable to fracture than others?"

To find an answer to the above question an understanding of the chemistry of limestone formation and dissolution is needed. The karst material of Pole Canyon limestone formed the many interconnected solution caverns of Lehman Caves. The Pole Canyon Limestone formed as an ancient shallow sea deposited calcium carbonate ($CaCO_3$) or calcite on the sea floor in thick layers over 500 mya (NPS). Over time the limestone went through various stages of metamorphism, though as is clearly shown in the different strata layers each member is unique.

Solution karst caves form by chemical dissolution of bedrock by carbonic acid in percolating rainwater. Calcite in limestone can dissolve in weakly acidic rainwater. Carbonic acid is the most common form of acid rain as near atmospheric CO_2 reacts with rainwater according to the following reaction;

$H_2O + CO_2 \rightarrow H_2CO_3$ (carbonic acid)

This same reaction occurs in soil air at higher rates as CO_2 levels in soil can be 300 times higher than the 10% levels of CO_2 in the air. When carbonic acid contacts limestone, the reaction dissolves calcite into liquid solution as follows;

$CaCO_3 + H_2CO_3 \rightarrow Ca^{+2} + 2(HCO_3^-)$ (calcium bicarbonate solution)

Limestone dissolution occurs in the vadose zone where initial contact with acid occurs, located in the aerated zone beneath the soil zone. Cave formation does not occur here, the rock dissolves from the top down (NPS).

Limestone dissolution and cavern formation occurs mostly at or slightly below the surface of the water table for three main reasons;

1) The water in the saturated (phreatic) zone moves slower than water percolating down and is in contact with the rock for a longer dissolving time.

2) The top of the saturated zone (groundwater level) receives acidic water from above, being closer to the source causing more dissolution to occur near the top than deeper.

3) Mixing two different water chemistries causes dissolution even if both were saturated with calcite, this occurs when surface water chemically mixes with CO_2 rich groundwater.

These three factors combined create strong tendencies for cavern development at or slightly below the existing water table at time of formation. This can be observed as Lehman Cave's plane is level, despite being inclined from later uplift and tilting (NPS).

Several varieties of mineral formations show characteristics of the cavern's material. Lehman Caves have over 300 shield formations, an unusually large concentration of these two oval parallel plates that contain a thin crack between them. The theory for shield formation is when water under pressure moves through thin fractures in limestone it deposits calcite on either side of the crack, building calcite plates with thin water filled cracks in between the plates. Shield formations often form in caves with highly fractured limestone like Lehman Caves (NPS).

The great number and large sizes of intact Lehman Cave mineral formations indicates that very little shifting occurred except in the Talus Room. The numerous rockfalls in the Talus Room were likely a result of water draining out of the cave following climate change to drier conditions and removing buoyant support from the ceiling's weight. The original strength of the bedrock itself was not weakened by the lowering water table. However, the original strength of the bedrock alone may never have been able to support the cavern's roof without the additional countergravitational support of the groundwater. The process of the Talus Rooms's ceiling collapse began when the water drained out of the cave and has not yet reached a stable point due to the room's large size and is possibly enhanced by nearby faults. It is probable that several old cave passages are buried beneath the Talus Room's layers of rubble (NPS).

In the case of the Talus Room cavern collapse the lowering water table was a result of a changing prehistoric climate. If this is compared to the proposed SNWA pipeline it becomes clear that lowering groundwater levels for any reason would be directly correlated to collapse of an aquifer cavern's roof. However, the future collapse of Snake and Spring Valley aquifer system would be a result of human induced lowering of the water table, not a result of a changing climate.

Temperature and airflow in caves are less variable than on the surface, creating near constant conditions. Mineral formations develop at timescales much longer than human observation can observe in the present day. This results in changes caused by humans exceeding that which may be anticipated by extrapolating data based upon surface conditions and expectations, possibly causing impacts that last for centuries (NPS). There are also examples of modern day karst aquifer contamination resulting from overdraft of groundwater.

Other regions with similar karst aquifers have witnessed the effects of groundwater overdraft. The Great Swamp of NY between Putnam and Dutchess Counties occupies a valley worn into exposed carbonate rocks such as dolomitic marble, semi-pure marble and carbonate sandstones covered by glacial fill. Wells pumping out of this carbonate aquifer reversed normal groundwater discharge and caused contaminants to be drawn down into the aquifer system (Mead).

Similar to Lehman Caves and Snake/Spring Valley aquifer caves, the Great Swamp carbonate aquifer formation are fractured caves of various grades of marble below sedimentary glacial fill. The carbonate bedrock lies directly beneath the glacial sediments, creating a permeable path for downwards groundwater infiltration (Mead). In the Snake and Spring Valley aquifer system the sedimentary basin fill derived from erosion of mountains reacts the same way to infiltration.

In another study done in Western Ukrainian's gypsum karst caves, it was demonstrated that loss of buoyant support of the cavern's roof due to lowered groundwater was one of the most important factors in triggering a breakdown collapse. This loss of buoyancy occurred as the Miocene aquifer lost its' prior state of confinement due to geological factors. The loss of buoyant support can disrupt the previously metastable state of the cavern's roof at points where other geological and speleogenetic factors have already brought the roof's resistance to failure, or bridging capacity, close to critical levels. This process is shown to happen repeatedly in quarries where massive groundwater withdrawal from the Miocene aquifer resulted in sudden drops of the potentiometric surfaces and intensifications of collapse and subsidence formations near the quarries (Klimchouk). Though gypsum is a much more fragile type of karst cavern than is low grade marble or even limestone, it may just be another difference in time until the eventual collapse of the Pole Canyon limestone cavern's roof occurs.

Metamorphic Core Complex of Northern Snake Range Decollement (NSRD) Show Strata Instability, Excessive Faulting and Multiple Variations in Marble Grade

Part I – Boudinage and Mylonitic Marble in the Spring Mountain Quadrangle (SMQ)

The northern Snake Range decollement (NSRD) is part of the 150 km long north trending Snake Range that is considered a classic example of a Cenozoic metamorphic core complex. The NSRD is a low angle fault adjacent to an upper plate of complexly normal faulted Paleozoic and Tertiary strata against a lower plate of ductiley attenuated metasedimentary and igneous rocks. The NSRD is exceptional in that it consists of a north trending arched dome that has near 5,000 feet of strata structure within the dome (Gans, Miller, Lee pg; 1).

Beneath the NSRD lie strata layers of Precambrian and Permian miogeoclinal shelf strata. Other miogeoclinal strata is found exposed in the footwall of the NSRD and is aged from late Precambrian to Ordovician. The geohistory of these rocks is one of ductile deformation, metamorphism and intrusion. The NSRD's upper plate is a hanging wall of Middle Cambrian to Permian miogeoclinal rocks including Tertiary sedimentary and volcanic rocks. This plate contrasts extremely with the lower plate rocks that show intense faulting, are tilted by several generations of normal faults and have very few metamorphic rocks. (Gans, Miller, Lee pg; 5).

Within the Spring Mountain Quadrangle (SMQ) of the northern Snake Range decollement (NSRD) are isolated remnants (klippen) of the NSRD's upper plate and a small section of the lower plate. Here the rocks show similar recordings of the many phased deformational and metamorphic history of rocks found elsewhere throughout the NSRD. In the upper plate are at least two generations of normal faults, and the lower plate has both Cretaceous and Tertiary metamorphism and ductile deformation (Gans, Miller, Lee; pg. 7).

In the lower plate rocks of the NSRD exposures of Middle and Upper Cambrian rocks are found at lower elevations in the western portion of the quadrangle. These lower plate rocks include calcite marble, dolomitic marble and calc-schist. Some metamorphic minerals found there are high Mg biotite + phlogopite + muscovite + quartz + calcite + dolomite +/- plagioclase +/- tremolite/actinolite +/-

clinozoisite +/- sphene. Common minerals found in the calc-schists include phlogopite or biotite with possible (+/-) muscovite, quartz, clinozoisite, plagioclase and calcite (Gans, Miller, Lee; pg. 8))

The units of the lower plate are usually in the correct order though are very deformed tectonite with mostly eastward dipping mylonitic foliation and a well formed ESE trending mineral elongation lineation. The force from the penetration has thinned the stratigraphic portion to a much smaller segment of the original thickness One example is found in the Dunderberg shale, where the original thickness was 60-100 meters to their current thickness of only a few meters. Other sections along the eastern flank of the Snake Range entire portions of the lower plate can be thinned to only 10% of their original thickness. The incredible complexity of this region of the NSRD is a result of polyphase history and heterogeneous strain. The lower plate marble commonly shows variations of intraformational folding that stretches from mere centimeters to hundreds of meters. The intraformational folds are mostly isoclinal recumbent folds that have hinge lines paralleling the mineral elongation lineation, though other variations are also found (Gans, Miller, Lee; pg. 8).

The more resistant layers such as mafic sills, dolomitic marble, calc-schist and diorite show boudinage on scales from centimeters to hundreds of meters. On canyon walls of the lower plate boudinage can be observed as low strain lozenges of dolomitic marble, calc-schist and diorite are inlayed in a streaky pattern inside a foundation of blue and white calcite marble mylonite (Gans, Miller, Lee; pg. 8).

Boudinage is found after deformation of rock layers by tectonic forces such as faulting. Forces fold and squeeze hard rock layers and stretch them until the break into chunks and the softer rocks flow around them and take up the empty space between the breaks. The word boudin is Belgian for sausage and refers to the process of erosion inside a larger body of schist causing rocks such as quartzite to appear in the outcrop as cross sections of broken ribbons resembling sausages.

Complex lower plate features such as variations in fold geometery and orientation, multiple foliations and conflicting shear sense indicators seems to be a result of heterogeneous strain and quasiturbulent flow field around the blocks that show more durability. One example of this is when shear bands, trains of asymmetric folds and multiple transposition foliations found in the streaked marble mylonites are best formed on the flanks of lenticular bodies of dolomite and calc-schist between 10 to 100 meters, usually moving towards opposing directions on either side of the same boudin (Gans, Miller, Lee; pg. 8).

The Spring Mountain Quadrangle (SMQ) contains fragmented hills and ridges of unmetamorphosed Middle Cambrian to Pennsylvanian sedimentary rocks and Tertiarty volcanic rocks that rise over the older layers of alluvium pediment surface. These isolated rocks are termed "inselbergs" and lay above a subsurface projection of this fault and show normal structure for this type of plate rock throughout the NSRD. Upper plate rocks are exposed in the NW, NE, and SW sections of the SMQ. The Middle Cambrian to Ordovician units in the NW section touch the lower plate rocks along the NSRD and begin the southern point of a ridge of bedrock that continues north with the eastern Kern Mountains. These rocks are dipping mostly westwards and are cut by older subtly dipping westwards faults and younger, more moderate to high angle eastwards dipping faults (Gans, Miller, Lee; pg. 9).

Beneath Spring Mountain (aka Gandy Peak) are Middle Cambrian to Lower Ordovician units dipping mostly eastwards and are cut by four moderate displacement normal faults, the two older ones dip northeastward at a small angle relative to their bedding plane and omit only a small amount of their section, and the two younger ones dip westward at high angles relative to their bedding planes (Gans, Miller, Lee; pg. 9).

Brecciated rocks from Upper Devonian, Mississippian, and Pennsylvanian Rocks are exposed in the lower hills in the range's eastern flank of the south end of the SMQ. These rocks are pervasively faulted on a small scale, have erratic westwardly dipping bedding attitudes and contacts between units are either hidden or perceptibly faulted. There are occasional fragments of slightly tilted Miocene aged marl and conglomerate in the washes that are carved deeper into the Quaternary pediment surface. There is a chance that this Paleozoic and Tertiary aged unit of rocks represents a type of composite slide block into the Miocene sedimentary rocks now found tilted. These sorts of relationships have already been documented at the Sacramento Pass site further south and could apply to the entire bedrock region of the NSRD (Gans, Miller, Lee; pg. 9).

The deep canyons cut into an eastward dipping pediment surface of Pleistocene pre-glacial times that was reworked by ancient Lake Bonneville levels as terraces and back beach lagoons. This carving into the pediment surface is most likely a result of the gradual shrinkage of the lakeshore and the eventual position of the water table to the current position at the Snake Valley playa lake (Gans, Miller, Lee; pg. 9).

The name Spring Mountain is derived from a 65-70 degree spring at the base of the mountain's southern tip. The water comes out of caves from the Middle Cambrian aged limestone at the contact site with the older alluvial sediments. The warm temperature indicates that the water's origin is shallow groundwater drainage from a vast low region between the northern Snake Range and the Kern Mountains, flowing along the base of the older alluvial sediments until being forced to the surface by Spring Mountain's bedrock barricade (Gans, Miller, Lee; pg. 9).

Before Cenozoic faulting, the SMQ's Paleozoic strata developed as part of a set of miogeoclinal strata that was deposited on North America's subsiding western continental shelf. The SMQ's upper plate Paleozoic rocks show complex faulting and are not complete in most sections. The SMQ's lower plate Middle and Upper Cambrian rocks are very metamorphically deformed, with their current thickness many percentages smaller than their original depth (Gans, Miller, Lee; pg. 9).

Part II – Ductile and Brittle Faulting Found at the Pole Canyon Limestone Upper and Lower Plate Boundary in Miller Basin

Large regions of penetratively stretched Upper Precambrian to Lower Cambrian metasedimentary rocks and yet undated granitic plutons are exposed in the NSRD. Lithologic contacts and foliation within the lower plate rocks are structurally concordant with the NSRD's slightly sloped dome that proceeds alongside the top portions of Lower Cambrian Pioche Shale. This stands in direct contrast with the upper plate's Middle Cambrian to Permian and Tertiary layers broken and tilted by imbricate normal faults that do not cut into the NSRD (Miller, Gans, Garing; pg. 242).

The structural sections that "young to the west" are repeated to the east along eastward dipping faults. These sections contain westward dipping older faults that usually are missing some units. The younger faults space apart from one km, dip 10-20 degrees to the east, and eventually merge with though do not offset the NSRD. The older faults are spaced apart at less than one km, dip 10-30 degrees to the west and are ended by either younger faults or the NSRD (Miller, Gans, Garing; pg. 243).

The upper plate shows a variety of bedding attitudes. Though most strata layers strike N10E to N45E and dip NW, the tilting amounts can range from 0-90 degrees and beyond, to the point of being overturned. Nearby faults or in incompetent units bedding plane tilts are usually low, though becoming steeper moving away from fault planes, with the steepest west facing dips found in the more massive limestone units located between faults spaced widely apart. These steepest dips are the only ones that reveal the total amount of rotation towards the west and the initial angle of bedding plane to relative to fault (Miller, Gans, Garing; pg. 243).

The Miller Basin region shows a more complex faulting where domains of conjugate, down to the west faults and SE tilting happen and also domains of down to the east faults. Strike-slip fault zones with high angles separate the domains of opposite tilting. To the south of Miller Basin, the faults become more distant from another while there is a sudden decrease in the total amount of extension (Miller, Gans, Garing; pg. 243).

Within the lower plate the metasedimentary rocks are of amphibolite grade and the metamorphism increases both with depth and towards the north. There is a younger penetrative subhorizontal foliation and lineation rising in intensity moving both upwards and eastwards towards the decollement overlaid on all lower plate metamorphic and igneous rocks. The farthest west exposure of the lower plate's Prospect Mountain Quartzite the foliation and lineation are poorly formed, while the NSRD's eastern flank strata units that were once 3 km thick have been ductiley thinned to less than 0.5 km thick. Both the basal section of Pole Canyon Limestone and very attenuated and mylonitic parts of Pioche Shale are found throughout the decollement as extremely thin layers. Though lower plate strain decreases further away from the decollement, it doesn't stop within the current exposure levels. The original thickness and strain of the McCoy Creek Group rocks are not known, the distance down to the Precambrian crystalline basement rock is also unknown (Miller, Gans, Garing; pg. 248).

The NSRD has a very sudden fault break between brittlely and ductilely deformed rocks. Pole Canyon Limestone is present both above and below this fault nearly everywhere throughout the NSRD. The NSRD gives an example of an exhumed mid-Tertiary ductile-brittle transition zone provided that the stretching of the lower plate was synchronous with faulting of the upper plate. Intermittent sections of ductile deformation and recrystallization found in the lower sections of the upper plate fault slices (ex. Pole Canyon Limestone) show a relatively dispersed evolution. The extension proceeded with the transition becoming quickly localized inside a tapered (<100m) space. The NSRD most likely evolved into a brittle fault based upon the localized shattering and brecciation of lower plate mylonitic rocks (Miller, Gans, Garing; pg. 250).

The mylonitic marble Cambrian Pole Canyon Limestone of the NSRD is rated at a sample normative density value of 2.64 g/cm3 as opposed to the average density of 2.66 g/cm3. This compares with the Quaternary Valley fill at a density of 2.1 – 2.4 g/cm3 and Hornblende diorite at 2.895-2.925 g/cm3 (Miller, Gans, Garing; pg. 254).

The Yelland Well #1 in Spring Valley went down through 1650 m of Quaternary and Tertiary deposits and another 150 m of Paleozoic rocks before stopping at the quartzite section at 1800 m. Along the eastern flank of the Schell Creek Range a thick strata of 30-45 degree west dipping Precambrian McCoy Creek Group and Prospect Mountain Quartzite is exposed. Here the rocks are not ductilely extended as are their lower plate matches, and many are conformably covered by Pioche Shale and Pole Canyon Limestone. In the Connor's Pass region lower angle younger on older faults in the middle Cambrian strata were mapped between Cambrian and Ordovician strata. Another low-angle fault within the Pole Canyon Limestone strata was mapped to the north. These faults could show a westward continuation of the NSRD, though would alter the NSRD's character of juxtaposing brittlely and ductilely deformed rocks. Another explanation could be that the faults are not basal detachments and instead represent rotated upper plate faults that dragged bedding planes to be parallel with fault planes. The McCoy Creek Group strata shows down to the southeast normal faulting with steep 50 degree westerly tilting, indicating that this strata is positioned above a deeper detachment fault. It seems that the NSRD ends underneath Spring Valley while a deeper mid-Tertiary ductile-brittle transition is located under the Schell Creek Range (Miller, Gans, Garing; pg. 255-6).

The northern regions of the NSRD show younger marbles from the Middle Cambrian in the lower plate. Here the NSRD dips less than 5 degrees to the north under faulted Paleozoic strata and runs until the Kern Mountains. The southern flank of the NSRD show Precambrian and Cambrian strata in both the upper and lower plates. Units of the upper plate do not have ductile deformation and eventually enter the lower plate of another decollement further south. This southern Snake Range decollement (SSRD) does not separate the ductile deformed rocks from the brittle deformed rocks and thus cannot be considered part of the NSRD pattern. Since both McCoy Creek Group and Prospect Mountain Quartzite strata are involved in upper plate faulting in the northern section of the SSRD, it follows that if the NSRD continues south from Sacramento Pass it must carve into deeper structural levels (Miller, Gans, Garing; pg. 256-9).

Since the position for the NSRD's boundary between Pioche Shale and Pole Canyon Limestone is consistent, it can be reasoned that it began at 6-7 km deep and was initially subhorizontal. There are no offset markers and this prevents the precise amount of directional motion of the upper plate with relation to the lower plate from being straightforward. As is the case with many other core complex detachment faults, the NSRD juxtaposes rocks from extremely different structural levels and deformational styles. This juxtaposition is a result of normal faults that thin the upper plate and collapse of isograds from ductile thinning in the lower plate. There does not need to be a lot of offset on the

NSRD since the amount of extension of both upper and lower rocks is nearly identical. This could show that the upper plate's extension from normal faulting may have been accommodated on site by penetrative stretching and magmatism of the lower plate (Miller, Gans, Garing; pg. 259).

However, a contrasting view indicates that there could be some movement on the NSRD. One reason for this is that the metamorphic grade of the youngest strata layers found in the lower plate may locally be higher than that of older strata layers found in the upper plate. In addition the upper plate's extension is slightly higher than the lower plate's extension. Furthermore the irregularity of lower plate deformation and the preferential development of down to the east normal faults match with the upper plate's movement towards the east in relationship with the lower plate. This means that a portion of the upper plate along the range's western flank and beneath Spring Valley may be embedded further east where the greatest amount of plate strain occurs. Finally the observed strain gradient directed towards the decollement shows that lower plate deformation could have included an aspect of simple shear. If this holds true, then upper plate rocks would be progressively more allochthonous with regards to the increasingly deeper strata layers found in the lower plate. Another alternative theory is that the gradient in penetrative stretching may show a growing dilation by plutons found at greater depths (Miller, Gans, Garing; pg. 259).

Part III – NSRD Metamorphic Core Complex Upper and Lower Plate Relations as Rolling Hinge Model of Fault Movement

The northern Snake Range contains a metamorphic core complex that is also called a decollement (NSRD). The term metamorphic core complex was used for the past two decades to describe uplifted and often domed exposures of metamorphic rocks occurring in highly extended terranes. These complexes are found throughout the North American Cordillera in regions where crustal thickening has happened, such as behind the Sevier thrust belt. These core complexes formed as metamorphic uplifts isolated from one another and extending along a belt from Mexico to Canada. They have a subhorizontal to gently dipping or domed detachment fault that divides unmetamorphosed and complexly faulted upper plate rocks that underwent brittle deformation from metamorphosed lower plate rocks that were ductilely deformed during their extension (Johnston, CalPoly pg; 2).

Lower plate rocks ranging from slightly metamorphosed breccias to protomylonites through mylonites and metamorphic tectonites are formed when grain size is reduced and plastic flow of quartz and other minerals which deform ductilely at 300 degrees C occurs. Tectonic uplift and deformation are closely linked processes, as shown by preservation of mylonitic rock fabrics in the lower plate requiring fast cooling as deformation continues simultaneously (Johnston, CalPoly pg; 2).

A thesis study done by S.C. Johnston at Cal Poly noted that earlier models used relations in lower plate rocks beneath the decollement instead of a detailed study of upper plate stratigraphy and faulting. This additional information would have shown how low angle detachment faults form. The study shows that earlier models for upper plate faulting failed to note the amount of rotation needed to rotate faults to their current location is not consistent with the dips of the rock units involved with faulting and the increasing amounts of Cambrian Pole Canyon limestone at the upper plate's base from west to east. The study suggests a new model for the decollement more like a rolling hinge concept as described by Buck et.al. where first generation faults represent a complicated web of faults and fault splays in relationship with the originally high angle master fault that soled listrically into brittle ductile transition at depth. Isostatically induced back-rotation of top portions of the master fault result in the forming of a set of second generation faults that soled into the steeper sections of the master fault and enabled ongoing uplifting of the lower plate rocks parallel to the master fault. This new model explains the increasing amounts of Cambrian Pole Canyon Limestone from west to east as it is compatible with the tilts observed on fault planes and in stratigraphic units (Johnston, CalPoly pg; 1).

In the NSRD upper plate rocks are exposed, showing the relationship between upper plate faulting and core complex detachment faults. Some recent mapping of the Sacramento Pass quadrangle map by Johnston et. al. shows the transition zone between the highly extended northern Snake Range and the lesser extended southern Snake Range along with a set of NW – SE striking faults and fault zones with what appears to be a strike-slip offset that could help alleviate differential strain between the northern and southern Snake Ranges (Johnston, CalPoly pg; 8).

The northern Snake Range's stratigraphy begins with a surface layer of uniformly 15 km thick miogeoclinal sediment sequence from upper Precambrian siliciclastic rocks through Cambrian and Triassic carbonate dominated rocks with shale and quartzite mixed in. In the late Mesozoic, compression and crustal thickening occurred and were coeval with emplacement of plutons in Jurassic and late Cretaceous. The peak metamorphism and deformation of lower plate rocks that occurred during the Late Cretaceous also resulted in intrusion of two-mica granite plutons, metamorphic assemblages upwards through to the staurolite zone and penetrative west dipping cleavages The direction of the cleavages combined with the plutons shows that the crust here was most likely thickened while an easterly divergent simple shear similar to the Sevier thrust belt was occurring (Johnston, CalPoly pg; 10).

The NSRD is part of a larger fault system that reaches 150 km along a strike from the Deep Creek Range to the north and into the southern Snake Range. Out of the Deep Creek, southern and northern Snake Range the northern range exhibits the greatest deformity with estimated extension up to 330-500% and is the only range with large exposures of mylonitized rocks in the lower plate or footwall position when compared to the overall NSRD. The NSRD reaches underneath the Snake Valley to the east and ends under the Confusion Range, and is also seismically imaged underneath the Spring Valley to the west where it stops at the Schell Creek Fault (Johnston, CalPoly pg; 11).

The first extensional event of the NSRD began in the late Eocene until the early Oligocene, shown by a slow movement of fault activity from west to east. The second event began suddenly around 17 Ma and caused between 12-15 km of a rapid fault slip along the NSRD on the northern range's eastern front. The second event is also coeval with ongoing arching and doming of the NSRD's western section resulting from reverse drag along the Schell Creek Fault, including down to the west faulting and folding that uplifted the northern Snake Range's western front relative to the adjoining valleys (Johnston, CalPoly pg; 11).

In the northern Snake Range's southern half the lower plate of the NSRD are mostly Precambrian through Cambrian siliciclastic rocks underneath Cambrian Pioche Shale containing sporadic fragments of marble blocks from Cambrian Pole Canyon Limestone that is located above the Pioche Shale layer. The upper plate's extensional deformation contains several generations of very complex NE-SW to N-S trending normal faults that deform and cut Paleozoic rocks down through to the Cambrian Pole Canyon Limestone. However, the faults don't cut into the Cambrian Pioche Shale or any of the Precambrian to Cambrian siliciclastics beneath the shale layer. Lower Paleozoic strata and Cambrian Pole Canyon Limestone is found exposed more often moving from west to east. Over time the faults rotated and tilted the upper Paleozoic strata to their present position of dipping between 0 and 90 degrees to the W to NW. The oldest faults are spaced close together and most likely are originally east trending normal faults that have moved to their existing angle dipping 10 to 30 degrees to the W to NW. Younger faults are spaced more widely apart and dip from 20 to 30 degrees eastwards and suddenly sole into the NSRD, in the process displacing older fault generations and upper plate rocks to the east. There are estimates of calculations of faulting showing between a 450 and 500% extension of upper plate rocks in the northern Snake Range (Johnston, CalPoly pg. 13).

A detailed description of Sacramento Pass and the Six Mile Quadrangle located in the southwestern flank of the northern Snake Range shows the furthest west exposures of the Tertiary Sacramento Pass Basin succession are exposed in the southeast section of the Sacramento Pass Quadrangle (SPQ). The SPQ at this location shows Middle Miocene and younger conglomerate, lacrustine deposits and intermittent volcanic rocks lying disconformably above upper Paleozoic rocks. This can be witnessed along Weaver Creek in the southern region of the Old Mans Canyon Quadrangle (OMCQ), where the Tertiary section contains huge sheets of various Paleozoic breccias deposited by landslides from nearby mountains. The Tertiary section was tilted from 30 to 60 degrees to the northwest and repeats this pattern along a series of rotated low-angle normal faults that sole into the NSRD and is responsible for at least a 200% extension of the basin (Johnston, CalPoly pg. 13).

The more resistant upper plate Paleozoic carbonates and shales form a set of rough ridges throughout the area as topography rises to the north from the lower places that lie beneath Sacramento Pass Basin sediments. There is excellent preservation of upper plate rocks and their fault relationships as a result of a west dipping high angle normal fault extending along the SPQ's eastern side and extending into the OMCQ. This fault may have become localized along the huge Jurassic granite pluton's western margin that could have experienced more rigid deformation than their neighboring Precambrian to Cambrian quartzite country rocks. The fault's offset slowly ceases along a strike to the northeast and also cuts and offsets the NSRD, where it displaces upper plate rocks at least 300 meters down to the west. This shows that the fault is responsible for the final doming and arching of the NSRD and contributes to the uplifting and forming of the current mountain range. At least two older generations of top to the southeast normal faults that repeat section and combined tilt bedding from 30 to 70 degrees to the northwest cut into upper plate rocks in the SPQ and the Sixmile Canyon Quadrangle (Johnston, CalPoly, pg. 14).

The second generation faults displace upper plate rocks down to the east, range from 2-11 km in length and are spaced apart by at least 1 km between faults. Exposures of second generation faults are found along Six Mile Canyon and show that these faults sole precipitously into the NSRD at depth. In this Canyon it is common to find truncated first generation faults touching the NSRD, indicating that a slip along second generation faults is correlated to another component of slip along the NSRD. Given the regular spacing between second generation faults, the sudden intersections between these faults and the NSRD, and simultaneous slip along these faults and the NSRD, it is likely that these faults began as a west to east forming set of faults similar to a rolling hinge. The rolling hinge model of faulting consists of originally high-angle second generation faults soled into a briefly tilting NSRD, then rotated to their modern position of shallow dips resulting from a negative isostatic load applied with increasing offset and uplift along the NSRD (Johnston, CalPoly pg; 18-9).

The first generation faults show shallow dips to the northwest. Since the northwesterly dips of bedding planes are much steeper than the faults, it was surmised by Gans (1983) that the first generation faults were initially down to the southeast normal faults that were later cut and rotated through horizontal by younger faults. The first generation faults are spaced much closer, in some cases only tens of meters apart. These faults transect and splay off one another along the western ridges of the NSRD region. Since first generation faults do not form an exact match with second generation faults, it follows that the older faults geometry with abundant splays is complex along strike and remained active even after being cut by the younger faults. The first generation faults have low fault to bedding plane angles from 10-30 degrees, to some extent the outcome of powerful normal drag that rotated bedding planes between closely spaced faults into almost parallel positions with the faults. This could also mean that first generation faults could have cut through upper plate strata at less than 60 degree angles. Several first generation faults in Plate II B show intersections where Permian Ely Limestone is placed above Cambrian Notch Peak Limestone and also bracket the maximum offset along these faults between 6-3.5 km with 30 to 60 degree fault to bedding plane angles, respectively. The southern part of Sixmile Canyon Quadrangle (SCQ) has exposed first generation faults that can be traced from the westside of the SCQ to the NW corner of Old Mans Canyon Quadrangle. Here these faults are positioned below an intact part of 3 km thick upper plate rock of Upper Ordovician to Permian age. This wide spacing without any faulting shows that usually close spaced first generation faults were not penetrative and were instead a result of zones of shearing creating more widely spaced fault splays (Johnston, CalPoly pg; 20).

Lower level first generation faults are often obscured in the thick Cambrian limestone section. For example, just south of Miller Basin a left-lateral, dip-slip accommodation fault extends along the NE corner that caused strata contacts and strikes and dips of bedding to fold and bend far from their initial positions. This region has a set of rotated, top to the east normal faults dipping from 10-40 degrees westwards that repeat intact section that strikes nearly east-west within fault slivers. While these faults rotated another set of faults with much less offset formed in the shale of the Ordovician Pogonip Group and Cambrian Lincoln Peak Formation above and below the more resilient Cambrian Notch Peak Limestone. The smaller faults were important in relieving problems with spacing on either side of the unyielding Cambrian Notch Peak Limestone as offset along the greater faults increased (Johnston, CalPoly pg; 22).

This sort of faulting pattern can also be found along the south side of Sixmile Creek. Here the lowest first generation fault of the structure dips 25 degrees NW, exposing an intact portion of the upper Cambrian Notch Peak Limestone (Cl) and the Ordovician Pogonip Group (Op) that dips SW and was downdropped onto lower strata portions of the Cambrian Notch Peak Limestone. This is different from the Miller Basin region where no smaller displacement faults observed within the Op or Cl. Here a set of faults with offsets on a meter long scale formed within the more durable beds in the Cambrian Lincoln Peak Formation, indicating that problems with spacing were solved with a collection of microfaults on the scale of less than one meter. Directly on top of this fault there are three additional tightly spaced first generation faults as recorded by klippen of Ordovician Eureka Quartzite and Ordovician Silurian Dolomite on top of the Ordovician Pogonip Group. Here two closely spaced folds in the Ordovician Pogonip Group show fold axes that strike at 199 and 232 degrees nearly parallel to the first generation fault's strike. The deformation found here indicates that the initial bedding relations were not protected from shear and normal drag between the tight spaced first generation faults. Though the specific character of the first generation faults are not yet explained, the more detailed maps underscore their incredible geometric complexity (Johnston, CalPoly pg; 22).

Both the first and second generation faults are joined and acted upon by a third set of faults that strike NW – SE and show strike-slip displacement. These faults accommodate the upper plates' variations in extension rates and are located in positions where first generation normal faults cease and begin to splay off into opposing directions. Strata units and structures found in the vicinity of these accommodation faults are usually bent and dragged into forced parallel positions with the accommodation faults zones. In the middle of the Sacramento Pass Quadrangle (SPQ) two accommodation faults are recorded that juxtapose units so that it seems there is left lateral offset and down to the SW sense of slip. In the northern section first generation faults position Permian strata against middle Cambrian strata, though the wider spaced fault splays in the southern section position Permian rocks against Devonian rocks showing an offset under 2 km. Over time the fault system formed second generation faults that splayed off of the southern accommodation faults, rotating the entire system to a left lateral displacement found today (Johnston, CalPoly pg; 27).

The furthest south of the two accommodation faults of the SPQ expose large sections of glowing red jasperoid along the length of the fault. The lineations on the jasperoid generally trend NE- SW with high plunge numbers, indicating the shear was down to the SW and normal. The SPQ's eastern side has another accommodation zone striking NW – SE and suggesting left lateral and down to the south offset. This fault runs across into the south side of Old Mans Canyon Quadrangle (OMCQ) as a key strike slip fault contrasting upper and lower plate rocks. This fault becomes the northern boundary of Sacramento Pass Basin (SPB) and the end point for major faults that carve through the SPB and slowly come together into this strike slip zone. This evidence of faults carving into the SPB combining with accommodation faults shows that both fault systems were acting together and that at depth the NSRD stayed active south of the accommodation fault while to the north of this fault all extension activity either slowed or stopped. When this fault reaches into the SPQ, it contrasts mylonitized lower plate rocks to the north against unmylonitized Cambrian Prospect Mountain Quartzite in the south. Since the Cambrian Prospect

Mountain Quartzite usually is located with the lower plate rocks, this indicates that the fault carved into the NSRD and shows substantial strike slip offset. To the west the fault's offset lessens and is probably shifted to the accommodation fault set, indicating that these third set of faults also carved into the NSRD. Since the region west of the younger normal fault is underneath upper plate rocks, the nature and location of the boundary between mylonitized and unmylonitized rocks is yet unexplained. The furthest south of this series of accommodation faults is hidden beneath Tertiary alluvium along U.S. 50. This fault is understood to exist by Cambrian carbonates north of Sacramento Pass strike into strata of a nearly identical striking Precambrian siliciclastic rocks found south of Sac Pass. The rotation of strata boundaries and bedding shows this fault has right lateral offset. The evidence of these faults developing parallel to the direction of maximum stretching show their relations to differential amounts of extension connected with the transition zone between the Snake Range's greatly extended northern region and the barely extended southern region (Johnston, CalPoly pg; 28-9).

Earlier models of the NSRD's upper plate faulting have oversimplified complex sets of upper plate faults by detailing them as two generations of planar, rotating, domino-type faults that soled into brittle ductile boundary at depth. They showed a tight spaced series of first generation faults beginning at high angles of 60 degrees, and then rotating 30-40 degrees prior to being sliced by another wider spaced series of second generation faults that completed another 30-40 degrees of rotation after moving. Both series of faults combined created the severe thinning found in the upper plate and then gave total extension values between 450 and 500%. Since both sets of faults cut into though no deeper than the strata of Pole Canyon Limestone, the researchers concluded that on site stretching or a pure shear model was a satisfactory explanation for the formation of the NSRD (Johnston, CalPoly pg; 29).

Johnston's thesis paper provided several explanations for why this oversimplified model of the NSRD's formation is not adequate;

1) When 30-40 degree rotation between normal fault generations is recorded in the Singatse, Wassuck and Egan Ranges nearby, the second generation faults are usually younger, steeper and spaced wider apart and first generation faults were not rotated through horizontal. This means that two series of tight spaced normal faults as detailed in the earlier models are not often found.

2) Since first generation faults dip between 10-40 degrees westwards, the early model needs first generation faults to have rotated between 70-100 degrees. However, reduced dips in rock strata included in faulting indicate that strata did not rotate anywhere near the expected numbers. Though this difference was explained in early models by high amounts of normal drag along first generation faults straining strata to become parallel with tight spaced first generation faults and causing low fault to bedding plane angles, even the upper plate strata's mostly maintained and durable strata with the lowest amount of faulting recorded in the OMCQ's NW corner only show rotation between 60-70 degrees.

3) The faults found within individual fault series need to be tightly spaced and synchronous through the width of the uplifted zone so that the crustal column can be thinned and the flat brittle ductile transition zone can be uplifted. Thermochronological and geochronological data from the northern Snake Range shows an asymmetric uplift history with fault activity slowly moving from west to the east. Even though first generation faults are tight spaced, there is not any direct proof that they were prevalent across as wide of an area as the modern day exposures of the NSRD. Palinspastic reconstructions of the NSRD's upper plate show first generation faults initially stretched only 1.7 km horizontally.

4) All upper plate faults are guessed to carve down through the Cambrian Pole Canyon Limestone immediately on top of the brittle ductile transition zone, the early model does not show why the Cambrian Pole Canyon Limestone exposures increase from westwards to eastwards.

5) Rigid fault block rotation above a flat detachment fault creates severe space problems in locations where faults contact the detachment. The base of wide spaced second generation faults would have the most prominent space problems of the NSRD. The early models propose that less durable strata being warped and folded, and that first generation faults were reactivated as fault splays off of the second generation faults. The thesis claims that this would be unlikely as it would need the first generation faults to remain active as normal splays even as they moved into thrust position. Furthermore, neither first generation faults nor deformation is consistently noticed in the immediate hanging wall of second generation faults.

The thesis suggests a new model for the upper plate faulting in the NSRD based upon the rolling hinge, suggesting the NSRD's origin is a master fault (MF) that began at high angles relative to bedding planes. The master fault then soled in a listric way into a decoupling zone along a subhorizontal brittle-ductile transition. Following an increase in movement along the MF a complicated system of related faults and fault splays developed synthetically to it, then soled in a listric way into the basal brittle-ductile transition. This alleviated spacing problems created at depth (Johnston, CalPoly pg; 32-3).

Between the tight spaced faults normal drag deformed and bent strata units to create low fault to bedding angles. Thinning and extension of the upper plate continued east of the MF and formed a negative isostatic weight onto the footwall rocks, resulting in a slow uplift and backrotation of the furthest west and highest elevations of the MF. Over time as this portion of the fault kept rotating, it got to a point that was unlikely to slip, then the first of a set of younger second generation faults formed and soled into a deeper portion of the MF that stayed steep. While displacement along the younger fault grew, upward truncations of first generation splays slid down on top of the deeper sections of the MF and the upper portion of the original MF and related faults and splays were tilted into the footwall of the second generation fault and continued to rotate horizontal. Similar to the original MF, the first second generation fault was slowly back rotated by negative isostatic pressure applied to the footwall, and a younger second generation fault was formed at high angles soling into a steeper incline of the MF. This process was repeated many times, every time carving through the first generation faults with a slip happening along new second generation faults with the lower section of the initial MF and along the base of the brittle-ductile transition. The new model needs to have mylonitized lower plate rocks be placed into contact with upper plate rocks in the footwall of the MF with increased slip along the fault system. As the MF rotates horizontal it is gradually exposed as the NSRD and upper and lower plate rocks become separated. To conserve strata unit volume in the footwall of the MF or NSRD, the rocks are thinned and a set of listric normal faults are formed that tilt brittle rock units that move westwards from the east. The youngest listric normal fault is the Schell Creek Fault that carves through the NSRD's western section (Johnston, CalPoly pg; 35).

The results of these three in depth reports on the NSRD show that there is a great deal more variation in geology than what the SNWA claims. The public relation team of the SNWA attempts to oversimplify the Snake and Spring Valley karst aquifer system as either "metamorphosed limestone" or marble, thus implying it is very durable and can withstand excessive extractions without fracturing the aquifer cavern roofs. However, the above studies make it clear that there are only thin slices of aquifer holding metamorphosed limestone found between layers of Pioche Shale, Lincoln Peak Limestone and other marbles of much lower grade of strength. The study featured in Part I showed the boudinage and mylonitic marbles of different grades located and interfolded with one another, showing instability and increased stress points once the caverns are dewatered. The presence of Pioche Shale near Cambrian Pole Canyon Limestone indicates that points of contact between the two different strata units could be vulnerable to fracture and instability as shale is a less durable rock than is limestone.

Another factor influencing the stability of the karst aquifer is the location of Pole Canyon Limestone at the boundary between upper and lower plate rocks of the NSRD. This means that if the NSRD is moving as suggested by Gans et. al. there will be greater strain at the boundary between the upper and lower plate. This additional strain would be compounded by SNWA groundwater extractions as the Pole Canyon Limestone contains the aquifer and is also located along the boundary

The thickness of potential aquifer holding strata is less than most other layers and only consists of one layer of Pole Canyon Limestone (PCL) of varying degrees of strength. All other surrounding layers including Pioche Shale are not capable of bearing aquifer holding caverns as is the karst layer of PCL. By dewatering aquifer caverns and reducing upwards buoyant pressure on the cavern's roof the reduction of the limestone aquifer holding strata will become even thinner as the cavern's roof collapses and lowers the height of the ceiling.

The thin strata layer of PCL also indicates that there is a specific time limit before dewatering occurs if the rate proposed by the SNWA is put into action. The thin strata layer would only supply about a decade's worth of water before aquifer cavern collapse would occur as the caverns are dewatered underground one at a time directionally based upon the slope of the limestone strata layer itself. Considering the boudinage and swirling in the PCL and other karst layers, it should be considered that the weakest or lowest grade marble of the strata would be most vulnerable to collapse if it remains undissolved by the water in the cavern.

The thesis by Johnston shows that the early models that oversimplified the NSRD's separation boundary are not correct and should instead be replaced by the rolling hinge model. The rolling hinge shows repeating faults moving from west to east and pointing downwards. The rolling hinge concept includes the spiderwork fracture networks as the faults "roll" away from their point of origin. The rolling hinges of faults enable water to percolate downwards and enter the karst aquifer system. The fracturing along the rolling hinge faults shows that instability is the normal factor in the NSRD and that this unique system of aquifer caverns is more vulnerable because each rolling hinge fault fracture zone includes multiple points of weakness that could enable larger fractures or collapses of a strata section into a dewatered aquifer cavern in the strata layer below. These internal collapses of falling shale debris will take up space within the aquifer cavern and reduce future aquifer storage capacity.

The rolling hinge model proposed in Johnston's thesis differs from the earlier domino model that showed faults lined up next to one another though not touching or interconnecting. The domino model faults "fell" from west to east instead of connecting out as several first generation fault splays from an originally high angled master fault that soled listrically at depth. The second generation faults that soled into steep sections of the master fault allowed continued uplift of the lower plate rocks parallel to the master fault. This rolling hinge model explains why Cambrian PCL increases from west to east in relation to strata and tilts.

Learning from Overdraft Caused Limestone Aquifer Cavern Collapse in Florida

The Las Vegas Valley, Houston, Long Beach and many other places worldwide are experiencing land subsidence due to their excessive withdrawals of groundwater (Helm). In other regions limestone aquifer collapses occurred soon after overdraft. At times limestone aquifer cavern collapse can cause sinkholes or large potholes to form suddenly. Whereas sedimentary aquifer subsidence is usually gradual as every little pore space grows smaller, limestone aquifer collapse can occur without warning as the huge cavern's roof falls several feet in mere seconds.

We have plenty of chances to learn from the mistakes of others. Similar reactions already were documented in Florida's karst limestone aquifer system after an increase in sinkholes followed excessive groundwater withdrawals. Though the karst limestone of Florida's aquifers is not metamorphosed as is Snake and Spring Valley's Pole Canyon limestone, when filled with water it is capable of maintaining large aquifer caverns that emerge at surface elevations as large springs that form Florida's rivers. The excessive removal of groundwater shifts the balance away from upwards directed force of groundwater fluid pressure and towards the downward directed force of gravity acting on the overburden. This shift out of balance increases load at the surface and can cause structural failure in caverns or sinkholes to form (Sinkholes.org).

It was determined by Newton in 1986 and Sinclair in 1982 that induced sinkholes are either a result of construction and development practices or groundwater pumping. Construction related sinkholes result from drainage modifications or increases in load bearing from runoff. Newton determined that excessive pumping can cause rapid formation of sinkholes by abruptly lowering groundwater levels. The sudden decline in water causes decrease of fluid pressure support combined with additional weight on soils and rocks stretching across the underlying cavity. These stresses can cause the cavern to collapse and fill in with overburden material (Sinkholes.org).

Before the lowered groundwater level, incipient sinkholes are in relative stress equilibrium with groundwater supporting the cavern ceiling and increasing cohesion of sediments. Once the water table is lowered, the unconsolidated sediments can dry out and coarse grained sediments can move into empty spaces. When overburden is thicker with greater clay content, cover-collapse sinkholes may form in only a few hours as the cavern moves upwards while the roof increasingly collapses. When overburden sediments are permeable with greater sand content, cover-subsidence sinkholes form gradually as overburden sediments settle into spaces now emptied of water. This process of infilling sediments is termed "piping". (Sinkholes.org)

Despite Florida's 50 inches yearly rainfall, karst limestone aquifers in Pasco County were overdrafted in a few decades to such an extent that several lakes became dried up mudflats. Residents discovered that as the regional utility had pumped water out from well fields it caused the water beneath them to empty out of the lakes. The utility engineers then tried to refill the lakes by pumping 375,000 gallons of groundwater into the lakes, though without the initial water support the lakes could not retain water (Glennon).

When Steve and Kathy Monsees retired in Florida they lived near a lake. Over time the lake grew smaller and eventually became a mudflat. After realizing that the well fields being pumped out by the utility were draining the water out from beneath the lake, the Monsees and their neighbors embarked on a letter writing campaign. Following public protests, the utility attempted to fix the problem by refilling the lake. However, the subsidence and absence of water in the aquifer had already collapsed the cavern. The lake was not able to refill and remained a mudflat. Instead of admitting to their errors, the utility engineers denied that they made any mistakes. When Robert Glennon's book "Water Follies" came out and exposed these errors in detail, the chief engineer of the utility sent a 12 page letter to the publishers at Island Press demanding that the book be taken off the shelves, defending their practice of refilling subsided aquifers as sound (Glennon).

These examples of aquifer collapse and subsidence from groundwater overdraft in Florida's karst caverns serve to teach society that aquifers have their finite limits and cannot be used in excess without severe consequences. Another lesson from Florida's Pasco County is that once the overdraft causes subsidence, it is nearly impossible to repair the damage and restore the aquifer to the original condition. As was the case with the Monsees, only mitigation lawsuits for financial compensation can attempt to make up for the loss of the aquifer and lake's previous condition. Ranchers and residents of the Snake and Spring Valley may soon find themselves in the position of Pasco County's Monsees as their wells run dry and they lose their cattle to dehydration while SNWA bureaucrats deny any responsibility for overdraft as did the Pasco County utility officials in Florida. In addition to drying out the wells of ranchers and human residents, one of the results of groundwater overdraft lowering the water table is the loss of springs and seeps.

Prior Species Extinctions from Loss of Seeps and Springs Following Overdraft

Many of the Snake and Spring Valley's natural springs and seeps are located at a specific elevation level where the groundwater reaches the surface. This is dependent on the groundwater remaining at this elevation where the aquifer's opening to the surface exists. If the groundwater table is lowered from overdraft, the elevation of the water will not be high enough to reach the surface where it previously emerged as either a spring or seep. One of the verifiable risks of dried out springs and seeps is the increasing probability of endemic species extinction following the overdraft of Snake and Spring Valley aquifer water. Even if the metamorphosed limestone of the Snake and Spring Valley's dewatered aquifer caverns can withstand the weight of the overburden for a few years following groundwater level drops without subsidence or collapse, the lowering water table will decrease pressure on artesian springs and seeps. Dependent upon these aquifer springs are unique species endemic to that ecosystem, occurring only there in the entire world. Documented evidence of species extinctions from loss of artesian springs and seep springs is found in the Las Vegas region's tragic loss of the endemic Las Vegas dace and the Vegas Valley Leopard Frog.

The loss of Las Vegas springs began soon after 1829 when upon discovery artesian springs gushed with such pressure that a human could be suspended above the ground. These springs once supported an oasis of wildflowers, grasses and wetlands that supported the now extinct Las Vegas dace (*Rhinichthys deaconi*). The extinction of the Vegas dace occurred in 1957 when the main spring that fed the creek where the dace lived dried up following decades of withdrawals soon after the spring's initial discovery. Until then the Vegas dace survived for thousands of years in the same spring fed oasis surrounded by miles of hostile dry desert, having adapted over many generations from ancestors who lived in large ancient glacial meltwater lakes (Williams). Many of the dace and small fish found in springs and seeps throughout Nevada are endemic species specifically adapted to the unique chemistry and temperatures of the groundwater being discharged at that particular spring or seep.

The Vegas Valley Leopard Frog (*Lithobates fisheri*) has recently been considered a valid genus unique from the originally named *Rana fisheri* genus (Maas). The Vegas Valley Leopard Frog was about 2-3 inches from nose to rear, olive green dorsal and yellow hind legs (Maas). It was different from other leopard frogs as it lacked the usual white jaw stripe (Maas).

The Vegas Valley Leopard Frog's habitat was in the headwaters of Las Vegas Creek and other artesian springs around the valley between 370-760 meters elevation. The most concentrated populations were at three large springs at the western edge of the city that forms the headwaters of Las Vegas Creek (Maas). This frog was dependent on springs, seeps and riparian habitat with willows, tules and cottonwoods where they ate insects, spiders and other invertebrates (Maas).

Originally the Vegas Valley Leopard Frog was abundant in their range, as 99 were taken in two days during 1913 (Maas). As increasing urbanization in Las Vegas overdrafted groundwater and capped springs, their decline began (Maas). On January 13, 1942 researcher A. Vanderhorst collected the last ten recorded specimens of the Vegas Valley Leopard Frog from Tule Springs, now stored in the

University of Michigan's Museum of Comparative Zoology. No other species have been located in any searches thereafter, and the Vegas Valley Leopard Frog is considered extinct (Maas).

The causes of extinction of the Vegas Valley Leopard Frog are from spring capture and lowering groundwater from extraction by outwards expanding urban growth of Las Vegas, and compounded by the invasion of the eastern Bullfrog (*Lithobates catesbeianus*). The loss of springs from groundwater overdraft caused habitat loss and the invasive Bullfrog then competed intensely for food in the remaining dwindling habitat (Maas).

The needless extinction of the Vegas Valley Leopard Frog could have been prevented if the aquifers had not been overdrafted and dried up their home seeps and springs. This knowledge of cause and effect of overdraft may not have been as readily available during those years, though today we can no longer claim ignorance of the consequences of our actions, nor the actions taken by water agencies like SNWA. We need to prevent further species extinctions by repeating the same mistakes made by earlier generations. Today we have enough information to demonstrate the serious risks posed to the endemic species of the seeps and springs of the Snake and Spring Valley by the SNWA's proposed pipeline withdrawals of billions of gallons yearly.

A safer choice would be to install protections specific to each regional aquifer's geological characteristics by closely monitoring groundwater levels and if needed limiting withdrawals from the region, and ensuring that all groundwater withdrawals from the basin remain in the same watershed from where it was extracted. This will enable the runoff to percolate downwards and refilter through the sedimentary basin fill layer until finally reentering the same aquifer system it was initially removed from, thus contributing to raising the groundwater level. These protections of Nevada's remaining aquifers may be needed to ensure the survival of the endemic spring snail of the Snake and Spring Valley aquifer's riparian ecosystem.

Protecting Aquifer Dependent Seep and Spring Habitats for Endemic Spring Snails

Throughout the springs and seeps of the Snake and Spring Valley reside several endemic species of spring snails. Similar to the dace and pupfish that reside in springs, these spring snails ancestors were inhabitants of ancient Lake Bonneville. After the Lake dried out some smaller components remained and eventually only the springs were the source of life giving water. These spring snails evolved to the thermal and chemical conditions of each specific spring, and significant genetic variations may exist between related species from spring to spring. In most cases the spring snail is dependent upon their home spring, and if that spring dries up they are left without a home or habitat. Though spring snails may have evolved some resistance to short term droughts, the long term loss of the region's springs from excessive withdrawals as proposed by the SNWA would make their survival difficult if not impossible.

The spring snails depend entirely on the near yearly emergence of water from the springs of the Snake and Spring Valley aquifer system. The springs and seeps fed by the aquifer system emerge regularly based upon subsurface storage, not yearly precipitation. Without water available, the plants the spring snails need for food will no longer grow, nor the water that they require for egg laying and reproduction. These spring snails also form a base layer of the region's food pyramid, providing nutrition to top predators like lizards, snakes, birds, other insects, fish and small rodents among many others. Removing the water dependent plants would erode the spring's stability and make restoration of the original structure impossible, resulting in permanently dry spring beds and any remaining spring snail's eggs being unable to hatch. Once this happens the extinction of a species of spring snail is nearly certain.

Most spring snails belong to the Genus *Pyrgulopsis* and are subtly diverse in their mitochondrial DNA. Their life cycle is entirely aquatic and they cannot move about between habitats on their own. This indicates that the genetic diversity amongst the spring snail varies on a geographic scale (Hsui-Ping Lui, Rocky Mountain Center).

The spring snails are found in Clark, Lincoln, Nye, and White Pine counties in Nevada and Beaver and Millard counties in Utah. One single spring location is home to 14 of the 42 snail species, and 39 are found at fewer than 10 locations. None of the 42 species are currently protected by state or federal laws (CBD). According to CBD's Rob Mrowaka; "Without protection under the Endangered Species Act, these spring snails will be lost forever. Groundwater withdrawal, spring diversion, livestock grazing, and an array of other threats severely threaten these 42 spring snail species along with the other species that depend on desert springs." (CBD)

It is difficult to understand the claims made by SNWA's public relations team that "Las Vegas cannot grow without the pipeline" in light of the serious risks of extinction to endemic spring snail species of the Snake and Spring Valley's aquifer dependent seeps and springs. The spring snails would be at real risk of extinction from groundwater extractions for the entire duration of the SNWA pipeline. For the last decade, the SNWA has pursued the pipeline from the Snake and Spring Valley by hyping up risks of drought and making claims of necessity without providing any actual evidence besides amped up rhetoric. However, as many investigative journalists have often discovered, when politicians and high ranking bureaucrats engage in seemingly illogical behavior there is usually some potential financial gain involved for them personally that would explain their skewed logic and misguided reasoning.

Additional Probable Financial Beneficiaries of the SNWA Pipeline Revealed by Location Choices and Contribution History

Following their statement of "the pipeline will bring more jobs to Las Vegas" the SNWA public relations propaganda machine has enrolled the President of the AFL-CIO to be their spokesperson. Despite the fact that a great percentage of the easily swayed labor union President's constituency will be paying for the pipeline out of their own pockets, the official union support for the pipeline continues. The suburban sprawl developers are certainly in favor of promises of more "unlimited" water by SNWA officials, every drop can be used as allocated water for future sprawl development far outside city limits. There seems to be some behind the scenes cohesion between the AFL-CIO union leadership and the developers when both become adamant supporters of the pipeline. Given enough bribery and arm twisting from politicians with great clout, the union leadership can be coerced to support decisions that go against the general interest of the rank and file workers that they claim to represent. For the average working people of Las Vegas who are also the primary ratepayers of utility bills, the SNWA pipeline will be a tremendous economic burden with a very short shelf life. Once the Snake and Spring Valley aquifer system is depleted from excessive withdrawals, the ratepayers themselves will bear the burden of the cost while reaping little of the benefits. The benefits of water were already available through the Lake Mead storage of Colorado River water without any additional costs. However, the geographic location of the proposed SNWA pipeline may benefit certain developers with convenient access to water in an otherwise dry and isolated location.

When examining the geographic details of the SNWA's proposed pipeline, their maps show that it would pass within less than twenty miles of the Coyote Springs development designed by Harvey Whittemore and located at the intersection of Nevada's 168 and the U.S. 93. His future plans for Coyote Springs include building 159,000 homes and 16 golf courses at this site some 50 miles north of the city of Las Vegas. It also happens that Mr. Whittemore has previously donated large sums of money to the SNWA and has verbally supported their pipeline project's proposal several years ago. When the initial purchase was made, it was known by Mr. Whittemore that the Coyote Springs region had inadequate groundwater supplies to support that large a development and that to proceed with his grandiose vision of a desert oasis water would need to be imported from somewhere else. After the initial land purchase he sold part of the former Aerojet's property to the SNWA for 25 million (Williams). It would not be logical for Mr. Whittemore to invest in the construction of these homes without the reassurance from the SNWA that he would be able to cash in on the pipeline's "blue gold" coming out of the aquifer to his north. Since Mr. Whittemore has already built around 50,000 homes, the remaining 100,000 homes selling at least with a beginning price of 200,000 dollars each would net between 20-30 billion dollars. That seems like enough incentive to produce a professed "need" for the SNWA pipeline to run close to the Coyote Springs development site. Certainly there will be plenty gifts from Harvey "Santa Claus" Whittemore waiting under the tree of the compliant SNWA officials who delivered the blue gold to his doorstep.

In addition, since 2000 Nevada's Senator Harry Reid's son has been employed as legal counsel for Mr. Whittemore. Mr. Whittemore also makes regular campaign contributions to Sen. Reid (Williams). It could be claimed that it is more than coincidence that Sen. Reid has given the green light to the SNWA's pipeline despite serious risks of ecological damages to the Snake and Spring Valley from this pipeline project. It is the responsibility of a state senator to look out for the interests of the entire state, not just the interests of his campaign contributors.

In 2006 the SNWA altered their proposal to allow Whittemore's Coyote Springs development the legal access to tap into their proposed pipeline (Williams). On Jan 27, 2006 the U.S. Fish and Wildlife Service gave the SNWA senior water rights intended for the survival of the Moapa dace to enable Whittemore's development of Coyote Springs. By trading the water rights of an endangered species in favor of suburban sprawl development the U.S. Fish and Wildlife officials violated the National Environmental Policy Act, the National Wildlife Refuge Administrative Act, and the Endangered Species Act (Williams).

Based upon the rates of extraction planned by SNWA for the Snake and Spring Valley aquifer pipeline, there is a specific time limit on availability of aquifer water before overdraft occurs. This pipeline is a short term plan that will only result in another aquifer overdraft and Las Vegas residents believing their water needs are dependent on the same pattern of conquest of ever more distant aquifers. The eventual drawdown of these aquifers with limited yearly recharge and yearly increases in billions of gallons of withdrawals is probable after a decade or two, leaving a long term drought for the Snake and Spring Valley and 300 miles of useless pipeline infrastructure buried and corroding below ground. Urban ratepayers of Las Vegas would be bearing the burden of the financial costs of the Snake and Spring Valley pipeline while wealthy suburban developers like Harvey Whittemore would reap the short term benefits of free water siphoned off the SNWA's pipeline for his Coyote Springs development. From Mr. Whittemore's perspective, the duration of the aquifer system is irrelevant, as once his 159,000 homes and 16 golf courses are built and sold based upon promised SNWA pipeline water he doesn't need to worry about the long term duration of the aquifer's water. He and his publically funded SNWA support team can retire wealthy from their profits and leave the stranded homeowners of Coyote Springs and the overpaying urban ratepayers in Las Vegas to fend for themselves in the desert for future water supplies. Once the aquifers dry out and the lawsuits begin, the proponents and beneficiaries of the great pipeline water heist will be old enough to be safe from any legal recourse or responsibility.

Even if Harvey Whittemore is cut out of any SNWA pipeline water to save face, the general developers interested in pushing north out of Las Vegas are also focused on promises of more water, regardless of how long this water will last in reality. It may not even be Harvey Whittemore in the lead to get first access to the Snake and Spring Valley's aquifer water; maybe other developers are awaiting the promise of future gallons of aquifer water brought from distant locations to make them some money. The point is that regardless of who the beneficiary of the pipeline will be, there are entire ecosystems and lives that will be destroyed with the water removed for some developers benefit. People need to be aware that jobs for the sake of jobs is not progress if those jobs result in the destruction of ecosystems and other already existing jobs such as ranching. Jobs are not bones to be thrown and we the people are not dogs who should jump at any bone thrown in our direction. We can also freely choose jobs for ourselves, such as sustainable free range ranching in rural regions and industrial manufacturing of high tech rainwater harvesting devices to enable urban areas to be more efficient with limited water resources. It would be far more logical for labor unions to endorse the construction of a manufacturing center that enables Las Vegas to become a leader in rainwater harvesting technology instead of destroying lives of rural residents by collapsing their regional aquifer with the SNWA pipeline.

The current choice made by the AFL-CIO President to support the SNWA pipeline supports the long term financial interests of some powerful politicians and developers. It is very unfortunate that the AFL-CIO President has chosen to abandon the welfare of their members in favor of chasing some temporary bones thrown to them by wealthy developers such as Harvey Whittemore. By choosing the short term profit of suburban sprawl development in desert regions made possible by the SNWA pipeline over the long term investment in manufacture of rainwater harvesting technology the AFL-CIO President is failing to consider the lives of the working people of Las Vegas that will foot the bill yet receive little benefits.

Exposing Myths of SNWA Public Relations Propaganda

The SNWA public relations officials have attempted to paint the Snake and Spring Valley's regional opposition to their pipeline as a few spoiled ranchers who don't want to share their infinite supply of groundwater. Some myths from the SNWA public relations team include one about the Snake and Spring Valley aquifer system being an eternally limitless supply of water for Las Vegas. This SNWA myth could only be physically tested in reality if we accept that collapsing aquifer caverns, groundwater lowering, dried up springs and land surfaces subsiding by several feet yearly would be a desirable outcome of this test. In mathematical theory this SNWA myth would be proven false simply by comparing the number of gallons of SNWA's proposed future extractions to the number of gallons of yearly discharge and current extractions and then compare both to the current rate of recharge and expected recharge in the next few decades. From these numbers a graph would likely show a steady decline over two decades with milestones of seep and spring dry ups along the way down as groundwater slowly falls. Maybe the hydrologist whose graph comes closest to predicting the year of the eventual point of reaching 'bottom level' of aquifer drawdown can win some sort of an award. The SNWA myth of limitless supply could only be proven false in physical reality once the aquifer becomes overdrafted, though by then the proof of their deceptive public relations becomes a widespread ecological nightmare. In reality even the ranchers of the Snake and Spring Valley need to be cautious about how much groundwater they remove each year, as rates of recharge will never be greater than rates of discharge in the current dry climate.

The SNWA proposed pipeline would remove 180,000 acre feet of groundwater yearly from nearly 300 miles away from a site where 20 federally listed endangered or threatened species and 137 wetlands dependent species that are extremely limited in their distributions reside. The SNWA calls their take "perennial yield", referring to any unallocated perennial yield as "unused water". The SNWA adheres to this claim despite the fact that this unallocated "unused" water emerging as seeps and springs is the very source of life needed for the survival of endemic spring snails. According to UNLV's desert biologist James Deacon, if all perennial yield is taken, "all spring discharge and evapotranspiration will cease, there will be no underflow to other basins, and all plants that rely on groundwater will die." (Williams)

Though some basins are unallocated, others are over allocated by as much as 600 percent, "The aquifers interconnect," says Deacon, "and even without additional pumping the combined current allocation for the entire 78-basin area is 102 percent." (Williams)

The SNWA claimed at a public hearing in 2006 that it was unable to run computer models to determine the projected effects of groundwater withdrawal, though a hydrologist from the NPS ran the model the results showed a 150 foot drop over 75 years. The SNWA claimed that if they did not access this water, Las Vegas would stop growing, though 4 of every 5 witnesses who testified on their behalf were developers and their politician supporters attempting to justify their needs for water for procedural reasons (Williams).

Once people examine aquifer hydrology they will discover that the SNWA's claims of "infinite aquifers" dries up. The SNWA officials are making the public promises of future water supplies that they know they are unable to keep, though if they can manage to fool enough people to support the pipeline they would be safe in retirement once their deceptions become apparent. The future generations will shoulder the burden of dried up springs, extinct endemic species, abandoned ranches and dust bowl conditions.

Restoring Hydrological Sanity by Maintaining and Protecting Aquifers from Overdraft

Based upon the documented evidence of endemic species extinctions such as the Vegas dace and the Vegas Valley Leopard Frog resulting from lowered groundwater levels, measured land subsidence, collapse sinkholes and dried up springs it becomes apparent that the pattern of aquifer overdraft is pathological behavior. Insanity is best described as making the nearly the same identical choices and each time expecting different results. If our society has repeatedly overdrafted aquifers and as a result has caused land subsidence, dried up springs and endemic species extinctions for the last several decades why do we believe that this time we can remove large amounts of water each year from another aquifer without the same outcome eventually occurring? The most reasonable approach to achieving a saner desert living would be the protection and maintenance of aquifers at their highest groundwater levels possible. Maintaining groundwater at or slightly above spring and seep emergence levels would ensure healthy habitats for endemics such as spring snails and long term survival of the aquifer caverns to their greatest potential storage capacity. As greater demand for water creates an economic market where groundwater flows to the highest bidder, long term protections will be needed to maintain and protect regional aquifers. Included in protection of our shared aquifers is a greater understanding through education of the public, developers and scientists by conducting further research into the complex hydrogeology and ecology of karst aquifer systems from point of recharge in the mountains to point of discharge from seeps and springs flowing into riparian habitats as streams.

Several scientists have proposed more accurate classification systems for the different types of karst aquifers. Carbonate or karst aquifers are various types of limestones with varying degrees of strength. Within the Snake and Spring Valley aquifer's limestone caverns there are two variants found on the boundary between the upper and lower plate rocks; Lincoln Peak Notch (2.57-2.76 g/cm3) on the upper plate and Cambrian Pole Canyon Limestone (2.59 – 2.85 g/cm3) on the lower plate. These differences may seem slight, though when compared to the least organized Quaternary Valley Fill (2.1 – 2.4 g/cm3) and the most compressed Cambrian Prospect Mountain Quartzite (2.615 – 2.66 g/cm3) the overall range is not that far apart and slight differences in density can determine fracture potential.

Understanding the types of karst aquifers and their probable reactions to changing conditions of temperature, groundwater levels and other human influenced hydrological changes is crucial to protecting the karst aquifers themselves and the springs and seeps that depend upon steady groundwater elevations to remain active.

Karst morphology is infinitely complex pattern of fissures and voids carved into the limestone rock substrate, occurring on exposed outcrops, at the rockheads under the surface soil and deep below in underground fractures. The five categories of features found in karst systems are surface microfeatures, surface macro-features, subsoil features, caves and sinkholes. Karst caverns such as those of the Snake and Spring Valley aquifers are best formed in competent, fractured rocks with unconfined compressive strength between 30-100 MPa. The weaker limestones such as chalk and unlithified carbonate sediments do not have enough stability to create caverns with large spans (Waltham).

The type of karst of the Snake and Spring Valley aquifer would be considered buried paleokarst. Since most karst is formed in wet tropical environments as water with dissolved carbon dioxide is needed to dissolve limestone into caverns, the past climate is the reason that this karst aquifer exists in an otherwise arid region. The process of dissolving limestone with slightly acidic CO2 saturated rainwater takes time. The retreat of walls in fissures and lowering of the cave's surface are ordinarily not greater than a few millimeters per 100 years (Waltham).

Caves and caverns form in soluble limestone provided there is enough water flowing through the fractures. The rate of cave enlargement depends upon the flow rate and the degree of the water's chemical undersaturation. The origins of caverns are bedding planes and tectonic fractures, which enlarge to networks of open fissures and eventually favorable flowpaths form caves. Caves can be filled partially or totally with either clastic sediment or calcite stalagmite. Cavern collapse can occur from dimensions with unstable roof spans. Progressive roof collapse and cavity stoping that advances upwards can create a pile of fallen rock debris in a breccia pipe within the greater limestone matrix. An example of progressive bed failure of a cavern passage roof was witnessed in the Agen Allwedd Cave found in South Wales. The breakdown process caused the void to migrate upwards over an increasing pile of rock debris. This process occurred over 100,000 years and moved the cave's roof 12 above the dissolution cave's original position (Waltham).

The process of stoping in the Snake and Spring Valley aquifer system causes intrusions of igneous rocks such as hornblende diorite (2.89 – 2.92 g/cm3), biotite granite (2.62 – 2.66 g/cm3) and other assorted volcanic rocks (2.3 – 2.4 g/cm3) to enter the strata layer of Cambrian Pole Canyon Limestone from below. As in the example from the South Wales cavern, stoping in the Snake and Spring Valley aquifer caverns result in brecciation and rock debris filling the cavern space.

Cavern dimensions are influences by temperature, caves formed in temperate regions are usually less than 10 meters in diameter, whiles caves formed in wet tropical climates are usually around 30 meters diameter. All voids in a block of limestone such as narrow fissures, wide river passages and large caverns are interconnected as they were formed by the through drainage of water. However, the distribution of caverns and their openings cannot be predicted (Waltham).

An informal guideline of cavern's roof stability is that stability is achieved if the thickness of the rock is equal to or greater than the cavern's span. Typical limestone karst with Class III quality, rated Q = 4-10 on the Barton classification scheme and RMR = 40-60 on Bieniawski's rock mass rating scale. Cover thickness of intact rock that is 70% of the cave width would be considered stable under foundation loads that do not exceed 2MPa, or half the Safe Bearing Pressure needed for sound limestone (Waltham).

The guide for roof thickness only covers limestone with a normal fracture density and bedding planes.

Roof integrity can be weakened by localized zones of heavy fissuring. Simple beam failures can occur as caves naturally form arched roofs with partial support from cantilevered rocks around the sides of the cavern (Waltham).

Sinkholes are formed when a closed depression develops over a point where the ground surface has been eroded around an internal drainage point into the underlying limestone. There are six different types of sinkhole classifications; dissolution, collapse and caprock sinkholes that occur in rock. Dipping limestone is shown to have more complex structures, cave patterns and sinkhole profiles than in horizontal limestone (Waltham).

Dissolution sinkholes form slowly as the limestone rockhead is dissolved and lowers. Collapse sinkholes occur suddenly after failure of the limestone roof above a large cavern or several smaller connected caves. Large collapse sinkholes are rare, as intact limestone is usually strong enough to support the surface. There is a continuum between dissolution sinkholes and small scale collapse sinkholes. Caprock sinkholes are similar to collapse sinkholes, except for the undermining and collapse of insoluble caprock above the limestone karst cavern. Caprock sinkholes are found only in paleokarst or interstratal karst with large limestone caverns in subterranean limestone (Waltham).

Dropout, suffusion and buried sinkholes occur in soil cover and do not apply to limestone caverns. However, these sinkholes can occur as a result of rainwater washing surface soils into fissures and caverns of the limestone caverns. Dropout sinkholes are formed in cohesive soils such as clays, while suffusion sinkholes are formed in non-cohesive soils such as sand. There is also a continuum between dropout and suffusion sinkholes, with variations dependent upon rainfall, flow and soil type. Dropout and suffusion sinkholes are also called subsidence sinkholes forming slowly as the soil slumps and settles into the top layers while the lower layers are washed away into the limestone caverns beneath. Buried sinkholes are dissolution or collapse sinkholes that became filled with soil, debris or sediment following environmental changes. Most sinkholes form as a result of human engineering errors and not from natural processes (Waltham).

Sinkholes can create hazards, especially the instant dropout sinkholes. Sinkholes can occur in soils from 30-50 meters thick. Many sinkholes form when karst limestone aquifers have their water removed from beneath the soil and fill covering the cavern's roof. When the water table is lowered beneath the rockhead, downward vadose drainage can transport sediments into the limestone cavern's void previously filled with water. However, collapsing sinkholes can be avoided if people do not disturb the natural processes of limestone aquifers (Waltham).

Rockhead in karst may be irregular in karstic bedrock, along inclined and vertical joints and dipping bedding planes where they meet the exposed or buried surfaces and let rainwater into the limestone rocks there are enlarged fissures based upon the water's preferred pathway. This process of erosion occurs fastest nearest the rock surface, causing the upper rockhead to become more fissured and eventually causing isolated blocks to separate from their neighbors, forming pinnacles of limestone supported by the surrounding loose soil. The spaces between the rockhead pinnacles often become fissures that enable downward percolation of water into caves below (Waltham).

The amount of instability of rockheads are a result of geology and climate, usually larger rockheads are a result of formation during times of wet tropical climates. The location of the karst effects the formation of rockheads, with valley floor creating more complex corrosion as soil water and shale run off increases acidity (Waltham).

Civil engineers use a classification system to describe the rockhead variability, frequency and locations of sinkholes and sizes of underground caverns. Although rockhead relief can be easily identified and quantified, the propagation location of sinkholes and caverns is very unpredictable. Karst located under a soil or sediment cover will be more difficult to predict subsidence events because caverns are obscured. In addition, covered karst will also have a greater frequency of subsidence events, an indication of a higher karst class. Recent sinkholes in the soil cover above the karst are a result of short term water movement at the rockhead, which could result in variations of sinkhole frequencies across otherwise uniform karst class and rock morphology (Waltham).

The karst aquifer classification system proposed by Waltham and Fookes has five general karst classes with specific recommendations to avoid geohazards. The criteria for each karst class category includes; rate of new sinkhole formation (NSH), measured per km2 per year, the type of climate it was formed in, rates of fissuring, permeability, and type of carbonate.

Here are the five karst classes as proposed by Waltham and Fookes;

1) kI Juvenile – NSH <0.001 Found only in deserts and periglacial zones, or on impure carbonates. Frequency; Rare; Rockhead almost uniform, minor fissures are minimal, low secondary permeability rare and small, some isolated relict features, conventional.

2) kII Youthful – NSH 0.001-0.05 The minimum climate needed for formation is in temperate regions. Small suffusion or dropout sinkholes with open stream sinks are common. Many small fissures are widespread in the few meters nearest the surface. Many small caves, most are <3m across. Mainly conventional; Probe rock to 3 m, check fissures in rockhead, grout open fissures and control drainage.

3) kIII Mature – NSH 0.05 - 1.0 Common in temperate regions, the minimum climate needed for formation is in the wet tropics. Rockhead has many suffosion and dropout sinkholes, large dissolution sinkholes and small collapse and buried sinkholes. It also has extensive fissuring relief of <5m with loose blocks in cover soil and extensive secondary opening of most fissures, many that are <5m across at multiple levels. Probe to rockhead, probe rock to 4m, and microgravity survey rafts or ground beams, consider geogrids, driven piles to rockhead and control drainage.

4) kIV Complex – NSH 0.5 – 2.0 Formed only localized in temperate regions, normally formed in tropical regions. Has many large dissolution sinkholes, numerous subsidence sinkholes,

scattered collapse and & buried sinkholes. Rockheads are pinnacled, with relief of 5-20m, loose pillars, extensive large dissolutional openings, on and away from major fissures, many are >5m across at multiple levels. Probe to rockhead, prove rock to 5m with splayed probes, microgravity survey bored piles to rockhead or cap grouting at rockhead, control drainage and abstraction.

5) kV Extreme – NSH >>1 Formed only in the wet tropics. Has very large sinkholes of all types, remnant arches, soil compaction in buried sinkholes. Rockhead has tall pinnacles with relief of >20m, loose pillars are undercut between deep soil fissures with abundant and very complex dissolution cavities, numerous complex 3-D cave systems with galleries and chambers >15m across. Make individual ground investigation for every pile site, bear in soils with geogrid, load on proven pinnacles, or on deep bored piles, control all drainage and abstraction.

They also point out that a desert class 'kl Juvenile' karst may have almost no contemporary dissolutional development, though it may have large unseen caves left over from earlier climates that were wet and tropical (Waltham). This needs to be included in the karst class, described as k1 Juvenile containing pockets of kV Extreme. In the Snake and Spring Valley, this occurs nearly across the entire aquifer system. Most of the large karst caverns from Lehman caves to the aquifers beneath the valleys were not formed during desert conditions as the climate during formation was wetter and warmer, between temperate and tropical. The combination of warm temperatures and greater amounts of precipitation bringing acidic carbonic acid rainwater into contact with the ancient karst rockhead of the Snake and Spring Valley aquifers resulted in the current large caverns that are capable of storing large quantities of groundwater.

Waltham and Fookes state in their recommendations for karst classes kIV – kV that control of abstraction is needed to maintain the karst system's structural integrity (ie., prevent subsidence, collapse, etc...). Engineers in Florida recognize a potential and probable geohazard when new sinkhole failure rate is greater than 0.1 per km2 per year. However, sinkhole frequency is not a dependable reference for karst classification as the rate increases in places of either thin soil cover or groundwater lowering (Waltham).

Karst classification should include karst class, sinkhole density, cavern size, rockhead relief and whether the material is limestone or gypsum. Sinkhole density should include number per unit area and their size in diameter. The rate of new sinkholes (NSH) is measured per km2 per year. The NSH rate will be higher in karst regions with thin soil cover and can also be temporarily raised by engineering activities (Waltham).

It is difficult for geologists to find underground caverns who often depend on closely spaced probes to find any. Usually a density of 2,500 probes per hectare is required to have a 90% chance of discovering a cave at least 2.5 meters diameter. Probing beneath every column base and pile foot usually is more reliable and often needed for mature karst. Probe depth should be similar to expected cave size. For karst classes kI – kIII, caves greater than 5 m wide are not often found, so a 3.5 m probe should be adequate. In karst class kIV caves are usually near 10 m wide, needing a probe of 7 meters. The largest caves are often found in karst class kV (Waltham).

To prevent sinkhole failures from occurring, it is important to control water flows and abstraction. At Florida's Disney World, wells are monitored so that pumping is switched whenever a lowering of local groundwater levels is noticed (Waltham). The common factor between over-abstraction or excessive removal of groundwater in either limestone or low grade marble karst aquifer systems is eventual subsidence of land and loss of aquifer capacity. Karst caverns are enlarged only if they are filled with acidic carbonic acid rainwater, they do not enlarge from removal of water. The removal of water from karst caverns results in lowering of cavern roof towards cavern floor and overall loss of future water storage space.

The same process of aquifer overdraft will happen in the Snake and Spring Valley aquifer system if the SNWA gets their way and builds this proposed pipeline. The karst classes are like grades of marble, each one varies in strength and ability to withstand fracturing at stress points. Two different types of karst layers with two varying strengths can exacerbate this instability by causing the more fragile shale rock to collapse into the limestone strata below.

More Reasonable Water Acquisition Methods for Las Vegas Valley than the Snake/Spring Valley Pipeline

The most reliable source of water for the Las Vegas Valley remains the Colorado River at Lake Mead. The concerns positioned by the SNWA about Las Vegas "running out" of water because Lake's levels are lower than average are overly exaggerated and possibly a feeble excuse to build massive infrastructure projects like the SNWA pipeline from Snake/Spring Valley aquifer system for the sole benefit of suburban sprawl developments like Coyote Springs. The amount of profit from building over 100,000 houses is enough incentive for SNWA beneficiaries to endorse an otherwise cumbersome, expensive and overall unreliable source of water for their ratepayers.

The concerns expressed by SNWA are that the lake levels are too far below the intake valves where water enters the system for purification. However, there is a much simpler method of overcoming this obstacle than building an expensive pipeline that would eventually be unusable. Designing a simple flexible tube similar to a bending straw that can be extended from the intake valve, curved 90 degrees and then lowered to the lake level where an electric powered vacuum pump would lift the water up would be more effective and cost SNWA ratepayers far less. It is highly improbable that Lake Mead would ever dry out entirely as there will always be some amount of inflow from the Colorado River even in the driest season. If the least likely scenario of dam failure were to occur, there would still be time to rebuild a temporary dam and harness any Colorado River water that passes through the steep canyon underneath the intake valve hoses that could be lowered as far as needed until water level is reached. This lowering curved straw tube would be an enhancement to the current system of intake valves that depend upon the Lake remaining at a certain level. The lowering curved straw intake tubes prevent crisis from occurring during a several year drought period when the Colorado River watershed receives less than expected precipitation for several years duration.

It should be stated that there is no current crisis as a season of heavy above average precipitation has restored Lake Mead's levels from the recent drought of several years. It is not ironic that the SNWA public relations team has played up this recent drought as a reason the pipeline was so desperately needed even though only one season of above average precipitation has ended a drought of several years. The existence of Las Vegas has relied nearly entirely upon Lake Mead's water for several decades without any threat of or actual interruption of access. Over the last few decades the water usage per person has declined, so why the sudden urgency for this pipeline in the last decade?

It seems apparent that there is no real need for the pipeline from the Snake and Spring Valley and there is some unethical activity afoot behind the scenes at the SNWA boardroom where their authority is being wielded unjustly against the residents and ecosystems residing above the two targeted aquifers. It is unfortunate that developers are making short term choices that effect the ecosystems that depend upon the aquifers. Excessive groundwater withdrawal for golf courses, lawns and other lifestyle choices transplanted from regions with greater amounts of rainfall can compact sediments, reactivate old faults, and cause surface fissuring (Bell).

The main beneficiaries of the SNWA's proposed pipeline include developers like Harvey Whittemore who would benefit from promises of future water along the nearby pipeline. Developers who cash in now and sell their homes to unsuspecting owners can cash in early and retire rich before the aquifer is depleted and the pipeline rendered useless. However, for the sake of argument, if there were a longer drought what are some additional ways that Las Vegas Valley can be more efficient with their limited water supply?

Other options for accumulation of water during summer rainstorms would benefit Las Vegas Valley residents in two different ways. Rainwater can be collected from rooftops with rainwater harvesting systems and filtration following collection. Any extra rainstorm surplus stored belowground would benefit the local aquifers that were left overdrafted for years. The additional side benefit of rainwater harvesting is that during summer rainstorm events when the majority of the region's precipitation falls, the rainwater collected from rooftops would be less runoff water that leads to flash flood events.

Las Vegas Valley is notorious for their summer rainstorms dumping nearly the full year's amount of rainfall in just a few hours storm. Several inches of water in under an hour all running off into the streets often causes severe flash flooding events that causes loss of human and animal life along with property damage. This sort of rainfall pattern is normal in summer months for the desert climate may become more intense from global warming sea temperature rising (Haro).

During the summer storms the torrents of rain often drop from 35 – 75% of the total 4.13 average annual rainfall from 60-90 minutes. During a storm on July, 8 1999 a heavy downpours overwhelmed the flood basins, killing two people and caused over 20 million dollars property damage. The location of the Las Vegas Valley between the Sheep and Spring Mountains combined with the impermeable nature of the caliche (Calcium Carbonate) soils make the Las Vegas Basin prone to flash flooding. Urban development and roadways above former alluvial fans only worsen the severity of the flooding events (Haro).

The runoff from rainstorms either settles into puddles on hardpan where it evaporates or enters the Las Vegas Wash that enters Lake Mead. Although it seems there is no net loss, the transport of water through the Las Vegas Wash still loses a percentage to infiltration into the sands of the wash channel and extra losses from evapotranspiration by the mesh of water loving trees that line the wash channel. The trees of Las Vegas Wash were not there in such large numbers until after there was yearly water flowing through the channel that was previously a dry wash for most of the season. By intercepting the summer rainstorms with rainwater harvesting technology, the net loss of water from evapotranspiration through the Las Vegas Wash and losses from hardpan puddle evaporation can be eliminated and every drop of stormwater will be stored in cisterns beneath the ground.

Instead of depriving Northern Nevada's ranchers of their livelihoods by taking out their aquifers one by one like a water thirsty serial killer, the SNWA could instead help provide the Las Vegas Valley with sustainable green jobs by being innovators of new and exciting rainwater harvesting systems designed for personal home use and also large industrial buildings and casinos. There are rainwater harvesting systems designed specifically for large buildings with greater rooftop surface area for capturing rainfall. For larger rooftop areas, the filtration system needs to accommodate for excess flow. System can be designed by building three circular chambers where the outer chamber is filled with sand, the middle one with coarser gravel aggregate and the inner-most layer with pebbles. This would increase filtration area for the sand, with relation to the coarser aggregates and large pebbles. Rainwater eventually reaching the central chamber would be collected in the sump and finally treated with chlorine and ready for safe drinking. (Rainwater Harvesting, R Jeyakumar)

In Alex Steffen's book titled "Worldchanging" he discusses the benefits of rainwater harvesting and storage in underground cisterns was used for thousands of years. Considering the book's foreward is written by Al Gore one would think a learned Democrat like Sen. Harry Reid would follow the advice of his peer and encourage sustainability by promoting rainwater harvesting instead of looking the other way when the SNWA promotes treating aquifers as if they were disposable plastic cups with their pipeline (Manaugh).

The book also discusses options to transport water from regions with surplus supplies such as the Midwest, especially along the flood prone Mississippi. This is heading in a logical direction as these are often regions with surplus water and large scale river flooding events, whereas the Snake and Spring Valley aquifer output is never in surplus and is often below what it should be. Recharging aquifers with flood surplus water is the way to shore up reserves for potential drought years.

In a hypothetical future Midwestern flood event the use of setback levees and settling ponds along river floodplains could be used to store excess flood water. Setback levees are further away from the riverbed and enable larger volumes of water to spread out and thus reduce pressure on the levees. Sacrificing some portion of land to set the levees further back and give the river more room to roam in a flood event would save everyone from a catastrophic flood. During these flood events the water stored in settling ponds could be transferred by tanker trucks to rail cars and then taken to Las Vegas to be injected into the aquifer for storage.

Conclusion

The SNWA's proposal to extract 41 billion gallons per year from the Snake and Spring Valley aquifer system would show a probable result of eventual groundwater overdraft, land subsidence, dried out springs and eventual extinction of spring dependent endemic species such as spring snails. This can be determined by comparing the rate of aquifer recharge from a wetter prehistoric climate with far more yearly precipitation to the current rate of recharge in the modern desert climate to the SNWA's proposed rates of extraction by the pipeline. The numbers do not ever balance out, the current rate of recharge is nothing near the initial rate of recharge during the far wetter climate and the proposed rate of extraction will overwhelm the stored reserves in mere decades.

The subsidence in the Pahrump Valley and around Las Vegas Valley from extractions begun decades ago shows this dysfunctional habit of taking from aquifers until they are overdrafted to a point beyond repair. The evidence shown from previous aquifer drawdowns and resulting species extinctions of spring dependent endemics such as the Las Vegas dace and the Vegas Valley Leopard Frog is that the pattern of overdrafting groundwater is pathological for a society that is otherwise able to learn from their mistakes. Earlier mistakes that caused extinctions by drying up springs may have been out of ignorance, though today the SNWA no longer has this excuse. The pattern of aquifer overdraft based upon perpetual suburban sprawl development in desert regions is pathological behavior and needs to cease for the greater good of the ecosystem. In this situation the pathology is not gambling or other so-called "vices" that the Las Vegas Valley is known for, but the overconsumption of groundwater needed by the encroachment of poorly planned suburban sprawl developments, golf courses and other needless luxuries demanding ever greater inputs of water than the surrounding desert ecosystem is able to provide.

This report has shown evidence of the earlier extractions from aquifers near Las Vegas and the Pahrump Valley resulting in land subsidence and also loss of springs and seeps. The loss of the groundwater's surface exit through springs and seeps at specific elevations caused endemic species such as the Vegas dace and the Vegas Valley Leopard Frog to become extinct. These extinctions could have been prevented had groundwater levels been maintained at their highest possible levels so that the seeps and springs were always guaranteed to remain viable habitat for endemic species that depend upon the water for their very survival.

Further details from the sediment fill aquifer in Pahrump Valley and limestone aquifers in Florida show common repeating patterns of overdraft, subsidence and sinkholes as the final result. These and other examples of aquifer overdraft throughout the U.S. show that the problems of groundwater overdraft are not limited to Nevada. This common trend of overdrafting aquifers and the resulting effects of subsidence and loss of springs occur regardless of the type of aquifer substrate as the same force of gravity pushes down on the overburden and forces the land formerly above the aquifer to a lower position. Without any upward directional buoyant support from the groundwater there is nothing else to prevent the force of gravity from pushing the material above down into the aquifer space below that was previously occupied by groundwater.

The three detailed studies of the northern Snake Range decollement (NSRD) highlighted in this report show the incredible complexity of strata with faulting at many different angles, brecciation and boudinage. The studies show strata of upper and lower plate rocks interacting along the boundary between Lincoln Peak Limestone (LPL) and Cambrian Pole Canyon Limestone (PCL). The position of the LPL and PCL strata is along the boundary between the upper and lower plate rocks, effectively cutting the aquifer holding strata layers into two components that operate independent of one another with respect to movement. This already existing geological instability would be worsened by the caverns being dewatered by SNWA pipeline extractions as less counter-gravitational support from water can cause more fracture prone stress points vulnerable to collapse during any future movements along the plate boundary.

In comparison with other layers the PCL karst strata primarily responsible for forming aquifer caverns is relatively thin and cannot be expected to last for long at the SNWA's proposed rate of 41 billion gallons per year for more than two decades. Even at far lower rates of extraction than those proposed by the SNWA the aquifer would not be capable of lasting longer than three decades due to significantly lower rates of recharge when compared to precipitation amounts during the time of formation. Even the current extractions by local ranchers are having a detrimental effect on the aquifer, indicating that there is not a drop of water to spare. The most effective way to protect the Snake and Spring Valley aquifer system is to limit extractions to where water can be returned to the same aquifer drainage basin from where it was initially removed from.

Removing groundwater from the Snake and Spring Valley aquifer system and transporting it 300 miles away will cause irreparable harm to the caverns by suddenly dewatering them. The long term result of the SNWA pipeline extracting groundwater from the Snake and Spring Valley aquifer system will be land subsidence, reduction of aquifer capacity, loss of springs causing extinction of endemic species and finally a useless 300 mile long pipeline paid for by the working people of urban Las Vegas.

When examining the NSRD strata layers and their neighbors, it appears that several types of limestone, dolostone, shale and marble of various grades of strength all share nearly the same level and interact with one another often. Since the aquifer system is not confined to one basin, the removal of large amounts of water as proposed by the SNWA would effect every part of the aquifer and not just be confined to the location of drilling. If one region of the aquifer is dewatered, it will effect other locations also. The outcome of lowering groundwater levels in this aquifer system is uncertain, based upon the instability and fracture potential of different grades of marble, limestone, dolostone and shale all located nearby one another.

The thesis paper by Cal Poly student Johnston examined the nature of faulting throughout the NSRD and concluded a "rolling hinge" model of faulting is the most appropriate description model for the process. The new model differs from earlier "falling domino" models by showing a spiderweb network of faults originating from a central axis point of a main fault pushing from west to east. The network of faults displaces tension between the faults by stretching the rocks out along the rolling hinge. However, the rolling hinge of fault networks also would create more stress points vulnerable to fracture if there is removal of counter-gravitational support from the groundwater below. Many of these rolling hinge faults cut into the Pole Canyon Limestone where the aquifer caverns are located. With the complex network of faults connecting to and splaying out from the axis of the rolling hinge there are infinite stress points vulnerable to fracture if there is removal of counter-gravitational support once supplied by the groundwater.

Research highlighted the importance of protecting and maintaining aquifers and groundwater levels to their fullest potential. The facts show that removing excessive water from aquifers not only dries up seeps and springs that provide crucial habitat for endemics such as spring snails, it also can reduce the future capacity of the aquifer to hold groundwater by lowering the elevation of the cavern ceilings following land subsidence. By keeping aquifers at their fullest potential, the storage capacity will be increased as the pressure of the groundwater will be in all directions, causing the fissures and fractures to expand from dissolution. This reflects the ongoing pattern of karst cavern formation from contact with pressurized groundwater.

The political and financial aspirations of Harvey Whittemore's Coyote Springs development with the additional 100,000 homes planned and their relationship to the pipeline should be investigated. The potential for making between 20-30 billion dollars from the planned homes would be enough incentive for the SNWA to work with Mr. Whittemore behind the scenes to make the pipeline a reality. However, this plan would only benefit the few developers and SNWA bureaucrats who would profit the most from the pipeline while the working people of urban Las Vegas will shoulder the financial burden as ratepayers and the spring ecosystem endemic snails will suffer the penalty of extinction. It could be reasonably estimated that the Snake and Spring Valley aquifer will be overdrafted beyond repair in only a few decades if the SNWA's proposed extraction amounts occur. This would result in the abandonment of the pipeline for only a few decades worth of water. However, it would be ample time for the developers at Coyote Springs to provide their 100,000 new homeowners with promises of pipeline water until their retirement.

Alternative means of harnessing water such as rooftop rainwater harvesting, additional conservation, landscaping with drought tolerant plants and a "bending straw" extension with a pump attached to the intake valves at Lake Mead should be able to provide enough water for all even in the worst drought years. Rooftop rainwater harvesting would also provide additional benefits of flood control by removing an amount of stormwater based on the rooftop's area size from the overall net runoff stream and diverting it to underground cisterns for future uses. This report shows that these options are far more cost effective, reliable and safer for ecosystems than is extracting groundwater from distant aquifers that do not contain enough water to last for more than a few decades.

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