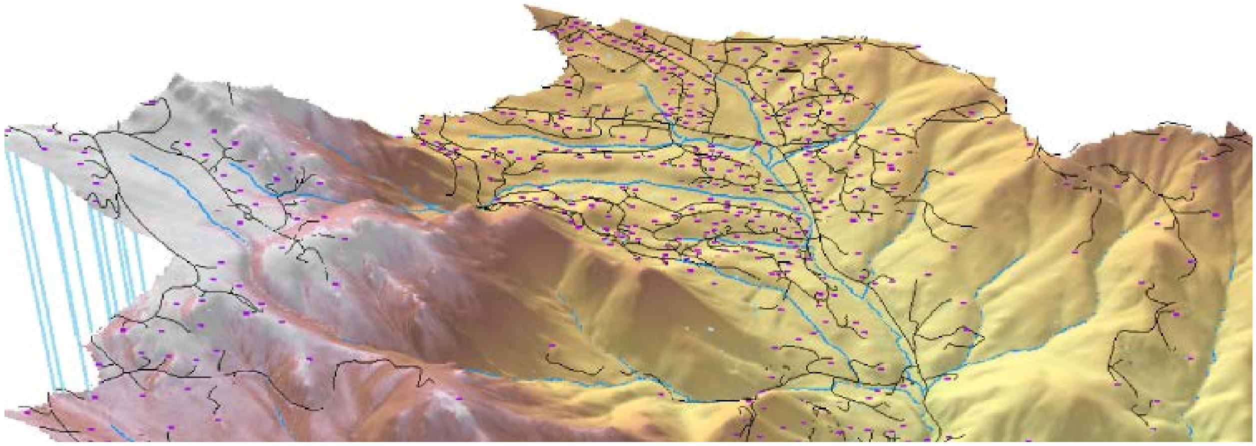

Indian Hills

Groundwater Water Quality Modeling Project

Produced for

Jefferson County Public Health

Produced by

PH Associates, LLC

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Margaret Herzog, PE, PMP, PhD	5.0	4/17/2016	Public-Ready Document w/ clarification Verified prohibition zone list v map + Update, and added Appendices Tables
Margaret Herzog, PE, PMP, PhD	6.0	5/14/2016	Final with Public-Ready Clarification
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Margaret Herzog, PE, PMP, PhD	8.0	6/18/2016	Revised Final for Board Distribution
Roy Laws, PE	8.1	08/04/2016	Address two errors identified by the Indian Hills Water District Board of Directors on page 11 and 12.

Report Acceptance

This Report was developed as the final deliverable of the Indian Hills Groundwater Water Quality Assessment Project conducted from May 19, 2015 through October 31, 2015. If you should have any questions, please contact the PH Associates, LLC (contractor) project manager and lead engineering analyst:

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Thank you for this opportunity to support the county in this critical effort to enhance understanding of potential groundwater water quality concerns and options for improvement.

Roy. S. A. Laws, PE August 4, 2016

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Roy Laws, PE (Project Manager and Reviewer of Report & Deliverables) Date
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JEHS project manager signature above demonstrates receipt and acceptance of this report and all related deliverables that were provided through the JEHS shared document system (BOX) at:
https://jeffersoncountypublichealth.box.com/s/4e2fla73axczm1c9mza5c72a33mkasr8

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Executive Summary

The purpose of this study was to integrate over 40 years of research in the Turkey Creek watershed and Parmalee Gulch sub-basin, conduct advanced geospatial analysis, and review multiple lines of evidence to determine if and how planned and potential development might increase nitrate exceedance risks above 10 mg/L as NO3-N - the EPA standard for drinking water - to Indian Hills private wells and Indian Hills Water District (IHWD) public wells.

Spatial interpolation of NO3-N concentrations from actual maximum well nitrate readings at each well tested in all periods of record throughout the higher-density upper and lower analysis areas were estimated to *average* approximately 8.8 and 8.0 mg/L respectively (Figure 33). However, actual sample concentrations in both public and private wells in some locations, particularly along the valley floor, sometimes already exceed the 10 mg/L standard. Not considering recharge from upslope areas, just the concentrations from recharge and OWTS contributions directly under these zones of analysis results in calculated *average* NO3-N concentrations at current build out of about 10.6 and 10.0 mg/L. Comparing results may indicate that recharge from upslope areas may actually dilute nitrate levels in high-density areas by about 2 mg/L, or that sampling is not completely representative. Although the lower zone would be expected to reflect higher percentages of less contaminated recharge areas upslope, in reality the lower zone did not demonstrate much reduced nitrate concentrations from this potentially greater dilution potential. Development of more parcels in high-density areas in the upper and lower valley areas may reduce groundwater recharge and thus increase pollution concentrations to both IHWD community and private wells. Actual local effects depend on existing OWTS and well number, repair and usage status, horse owner practices, development in the area, and the underlying, porous soils, fractured geology, and complex surface and groundwater flow patterns and interaction.

After verifying by modeling current build out that it reflected approximate actual nitrate levels, the same parcel-level mass balance analysis method was used to estimate potential nitrate increases with development in the Prohibition Area. The Jefferson County Planning and Zoning Department created likely development scenarios to consider - a single owner merging-two-adjacent-parcels or splitting-a-greater-than-2-acre-parcel to create one or more 1-acre parcels for residential development. **Permitting only High Level Treatment (HLT) OWTS (which reduces nitrates more than 50 percent) was estimated to permit NO3-N to increase about 0.5 mg/L under partial, likely development, and near 1 mg/L NO3-N**, if all potential parcels were developed. **If standard OWTS were permitted for new development, the analysis indicates that a more substantial increase of 2-3 mg/L NO3-N may be expected with even moderate increases in OWTS densities**. There is also a greater risks of higher-strength effluent that exits a standard OWTS to preferentially flow from a near surface geologic fracture (or through a damaged well casing often associated with older, unused wells) directly to groundwater used by another area well.

Recommendations include using only HLT systems in all new development in the Prohibition Zone or adjacent areas draining into Parmalee Gulch or tributaries on any lot less than 2 acres, and seeking to keep densities above 2 acres to the extent possible. HLT systems include advanced processes to reduce nitrates, which may also lower a variety of other contaminants, reducing risks to groundwater quality. Due to their complexity, HLT systems require a third party maintenance agreement for required annual maintenance to ensure proper functioning. Studies indicate annual maintenance may assist in catching problems early, reducing both water quality issues and replacement costs. Even greater protection may be accomplished with source separation that eliminates human wastes from entering the groundwater system by using a dual wastewater system or by installing composting, incineration, or other waterless toilets. Further risk reduction measures may include inspecting and permitting the approximately 91 older OWTS that have not been previously inspected as part of point-of-sale requirements or for other reasons in the last ten years. The county may provide incentives to consider replacing standard treatment systems with HLT systems, especially at Point-of-Sale, to further protect area community and private wells. Potentially less effective, poorly sited, older soil treatment areas could also be required to upgrade to newer, dosed, filtered systems that meet improved 2013 regulation standards for soil suitability and updated bed components. A potential method to achieve both objectives could be an incentive program to permit development within the Prohibition Zone on lots of at least 1 acre, if using a HLT system and replacing another, older system with an HLT system in the same year. Denver Water and other downstream water suppliers may be interested in incentivizing improvement, as Denver Water studies also indicate concern with potential OWTS contamination on lower Turkey Creek, citing Indian Hills as an area of probable concern.

Some studies indicate that further development may also reduce yields or dry up existing wells under lower than normal rainfall or higher temperature scenarios, though estimates of definitive impacts would be highly uncertain due to complex geology and recharge patterns. There is somewhat less risk, if new development uses IHWD water because it is partially imported from upstream along Turkey Creek, tested for quality, and IHWD may better ensure long-term delivery, reducing water quality and quantity risks to the entire community. Risks to groundwater supplies are likely to increase over time as climate change scenarios indicate less mountain snowpack, higher rates of evapotranspiration, lower soil moisture, and higher temperatures could increase drought periods significantly.

IHWD should test individual public wells routinely for nitrate, rather than just upper and lower well field water as a unit after treatment before distribution. All residents should be directly warned that nitrates are high at some locations in the upper and lower high-density areas of Parmalee Gulch and **reminded to test their wells yearly**. Residents and business should be encouraged to **share well test results with JEHS and IHWD by choice** to improve overall understanding of groundwater quality degradation or improvement over time. Surface water monitoring at the outflow of Parmalee Gulch for nutrients - and perhaps also chloride and boron, caffeine, paper products, etc. as the most common indicators of OWTS influences - preferably seasonally, but at least annually, could also be a useful indicator of progress. The Bear Creek Watershed Association (BCWA) could likely conduct surface water monitoring at the Paramlee Gulch outfall most effectively as part of their watershed-wide monitoring network.

Commissioning a CDPHE-financed source water protection planning process with potential add-on implementation funding is also recommended. An awareness campaign to promote well head protection, sealing and casing inspections may help ensure that older, unused, or improperly constructed wells are not serving as a direct conduit from adjacent OWTS, horse properties, or other pollutants sources. Wells screened too close to the surface in alluvium may also be contaminating deeper groundwater resources, especially when not being pumped. The 24 Household-Use Only and 97 Domestic well owners in the SEO database that now receive IHWD water supply may be encouraged to properly abandoned unused, older wells or improve maintenance on each of them, since **wells not in use and in disrepair are more likely to draw in contaminants when surrounding wells are pumping.**

Mountain Area Land Trust (MALT) may assist to **protect more open space**, as considered desirable in the most recent Indian Hills Community Plan, which could enhance community connectivity to adjacent Denver Mountain Parks and Jefferson County Open Space. Improving the connectivity, recharge, and **buffering-potential of riparian areas** of Parmalee Gulch and tributaries in high alluvium and colluvium recharge areas could be an important way to increase groundwater recharge, reduce both groundwater and surface water quality issues downstream, while also improving ecological health by reducing sedimentation from the adjacent road network to the stream. The Jefferson Conservation District in collaboration with Jefferson County may assist owners with **small acreage horse properties, pasture and manure management** to reduce the estimated 30-40 mg/L per parcel potentially contributed by a one-acre horse lot or smaller.

1.0 Introduction

1.1 Indian Hills Community within the Parmalee Gulch Subbasin

Parmalee Gulch subbasin is a tributary to the mainstem of Turkey Creek in the Bear Creek Watershed. It covers an area of approximately 5.7 square miles (3,657 acres). Elevations range from 6,726 ft to 8,635 ft above mean sea level (MSL). Approximately 700 onsite wastewater treatment systems (OWTS) serve both residential and commercial structures, mainly along the floor of the gulch and along the rim of the subbasin. The Indian Hills Improvement Association (IHIA) established in 1926, still sponsors annual events and runs the Indian Hills Community Center for private and public meetings. According to the IHIA History page, the area was settled by 1860, which prior had served as a summer campground for Ute Indians. As early as 1918, small lots 50x100 sq. ft. were sold in pairs to create mountain homes. By 1925, five filings had been established to the top of Parmalee Gulch from the entrance as its mouth where building began. In 1922, what would become Geneva Glen Camp was established in the southeast corner of Parmalee Gulch and Messiah Church Camp nearby to the north. The Indian Hills Fire District (IHFD)'s first fire truck was purchased in 1950, followed soon after by establishment of the Indian Hills Water District (IHWD) and the IHIA Community Center.

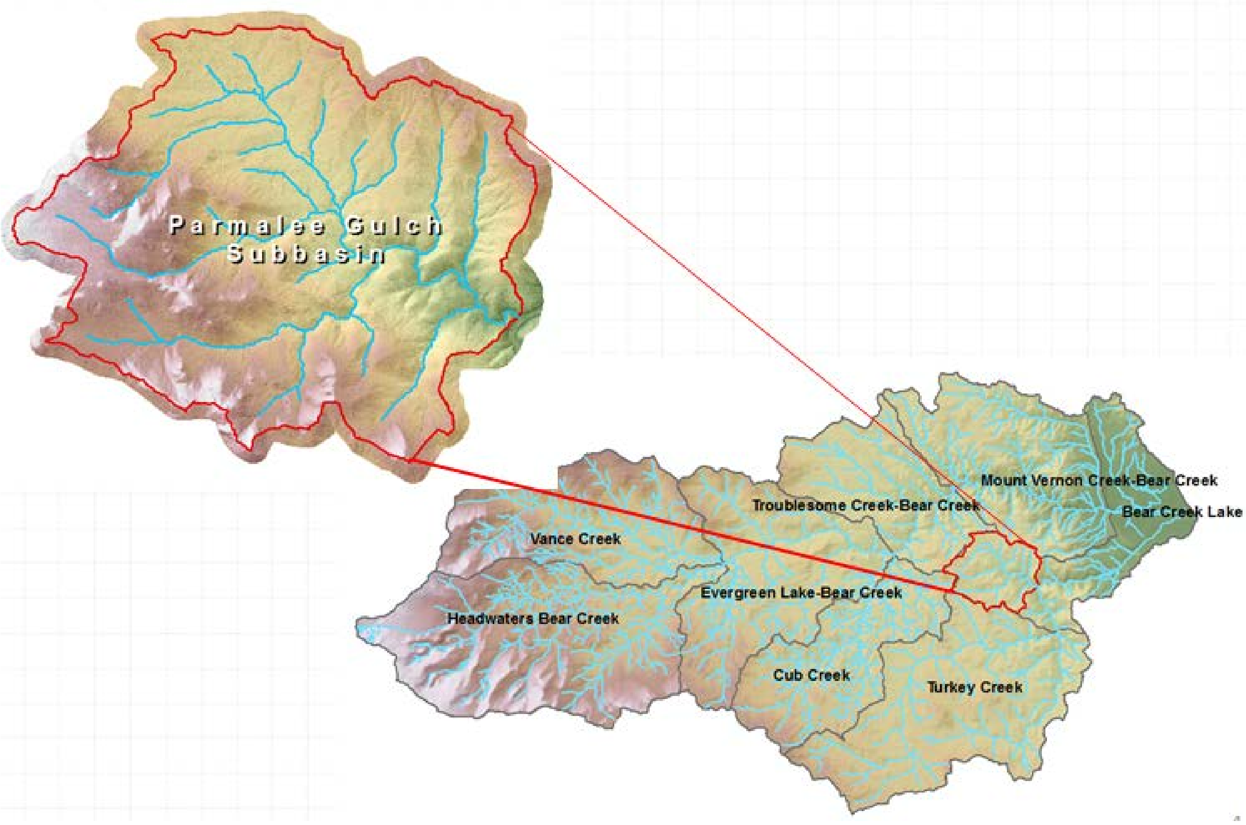


Figure 1. Parmalee Gulch Subbasin: Study Area of Indian Hills

1.2 Indian Hills Water District

The Indian Hills Water District provides water to 400 taps (zone 1 – 97 taps, zone 2 – 162 taps, and zone 3 - 141 for 400 total taps) serving about 57% of the 700 properties with residential or commercial structures. Commercial taps include the Parmalee Elementary School, Geneva Glenn Camp, Indian Hills Improvement Association Community Center (stand-by tap), Sit-N-Bull - a local bar/restaurant, the Turkey Creek Café, one church (two other churches supply their own well water), and the fire and water district offices. The system consists of three pressure zones, each served by a water storage tank above its highest tap to permit pump-up to provide gravity flow service (Figure 3). Storage can supply up to two weeks worth of community water usage. IHWD includes three water treatment plants (WTPs). The WTP behind the post office, WTP01, is only for emergency backup. The main plant, WTP02, is at South Turkey Creek near Tiny Town where the majority of water is taken from a gallery well and Well #11. About half of Zone 3 water supply, which includes Alpine Village at the headwaters of the Parmalee Gulch subbasin (Figure 3), is served by a separate WTP03 in addition to WTP02, using water from the Upper Well Field (UWF), mainly Wells #10 and #5, blended with the water from WTP02. **Due to high nitrate levels in all Upper Well Field Wells exceeding 10 mg/L standards**, WTP03 includes a Nitrate Removal process to remove up to 50% of nitrates as needed. Zone 3 has two tanks of a total 210,000 gallon capacity. A Self Service Water Station located outside of the IHWD office at 4491 Parmalee Gulch Road provides ultra-filtered water with chlorine removal for 25 cents per gallon, which provides an alternate drinking water source for private well users unsure of the nitrate levels or other constituents in their well water. JEHS requests private well users to test a sample for water quality including nitrate levels annually.

Each tap in the district is metered, and customers submit their meter reading by the 20th of the month with their monthly bill or risk a $15 fine. IHWD staff also try to read each meter at least annually to verify and adjust. In late 2015, IHWD began testing 10 water meters that permit remote cellular readings.

Table 1. Indian Hills Raw Water Supply and Nitrate Levels in Upper Well Field (UWF) and Gallery and Well#11

Water Year (Oct-Sep)	Well#5 acre-feet	Well#10 acre-feet	UWF acre-feet	Percent Well#5	LWF acre-feet	Total acre-feet	Tested Zone 3 NO3-N, mg/L	Tested Zone 1 NO3-N, mg/L	Est. UWF NO3-N
2010	11.2932	8.2310	19.5242	57.84	36.4194	55.9436	5.8	0.3	>13
2011	14.0024	1.2247	15.2271	91.96	34.1325	49.3596	8.1	0.2	>16
2012	14.4766	4.1517	18.6283	77.71	30.7404	49.3687	8.2	0.1	>16
2013	7.5823	6.0649	13.6472	55.56	31.1299	44.7771	7.9	0.1	>16
2014	6.9274	4.7014	11.6288	59.57	33.3895	45.0183	7.9	0.1	>16
2015	9.6163	1.2775	10.8939	88.27	36.1362	47.0300	6.6	0.1	>14

Table 1. Notes

- UWF (Upper Well Field) acre-feet is the sum of Well#5 and Well#10 production, LWF (Lower Well Field) acre-feet is the sum of Well#11 and the Gallery Well production, Total is the combined UWF+LWF
- IHWD reports approximately 50% of the water supply for Zone 3 comes from Wells #5 and #10 (UWF wells). The UWF water is blended with LWF - Gallery and Well#11 water before test samples are collected. Nitrate concentrations in Gallery Well and Well#11 lab results are almost too low to be well-measured, so a value of 1 mg/l was used to provide a conservative estimate of nitrates in the UWF by volumetric analysis. Using actual LWF nitrates would result in even higher estimate of unblended nitrates in UWF.
- In 2010, 200 gallons (0.0006 AF) listed as Well #10 were drawn from Well #1
- 2015 figures include an estimated proportion drawn for September and October of 17%, as was in 2014
- No water from Zone 1 or 2 come from the Upper Well Field (UWF) and less than half of Zone 3
- Zone 3 water is treated to reduce up to half of the incoming Nitrate as Nitrogen levels reported, but not sure if before or after the reading is made, so may be even higher if after water treated
- Source: Water Quality Lab data and electronic augmentation records provided by IHWD

IHWD staff test Upper Well Field wells for nitrates using a handheld HACH meter to estimate levels to gauge blending and nitrate removal needs. IHWD has sufficient rights on Bear Creek to meet senior water rights to allow it to extract even more water from wells than it does at present. However, finding an adequate well location of sufficient capacity and quality has proven challenging, so only two additional taps are currently available annually.

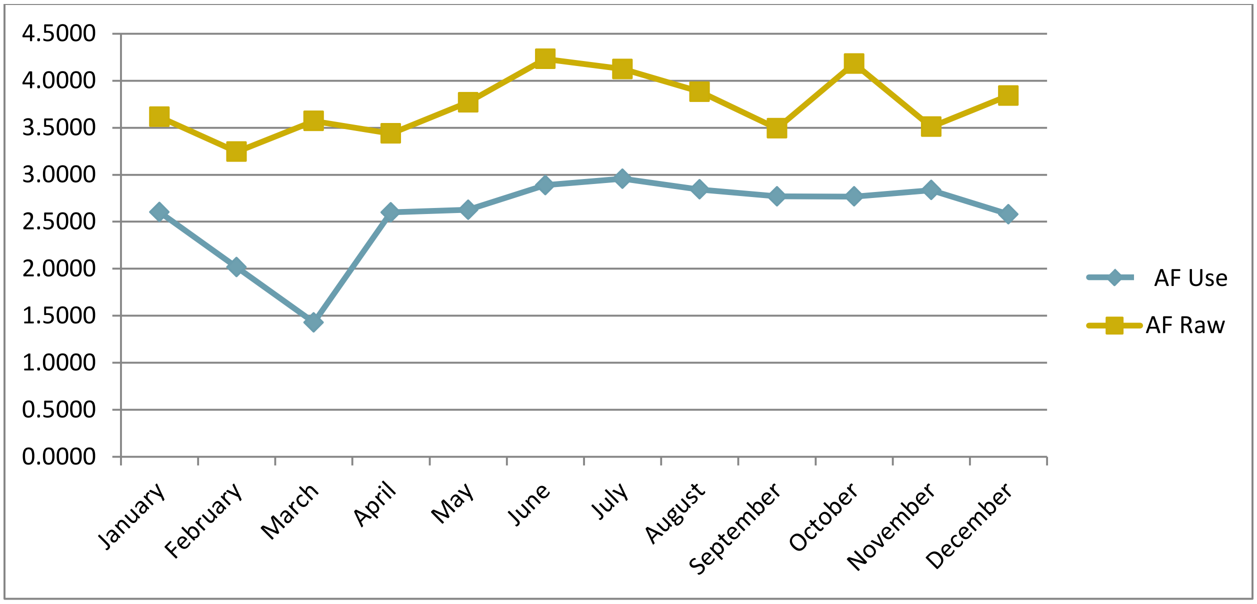


Figure 2. IHWD Actual Reported Usage compared to Raw Water Supply in Acre-Feet (AF)

From 2010-2015, IHWD report pumping 45-56 AFY. For 400 taps, assuming 10% processing and system losses to an average of 48.6 AFY for 43.74 over 400 taps would equate to about 0.11 AF / tap / year or about 98 gpd / tap, which is lower than typical reported usage at actual measured households in Dano, 2004, and Stannard, 2010 of 175-225 gpd / household. However, actual reported usage per zone per tap is only 65 to 82 gpd/tap. Hopefully, improved metering and analysis will help discover if this is simply a paper error rather than actual system losses or unmetered usage.

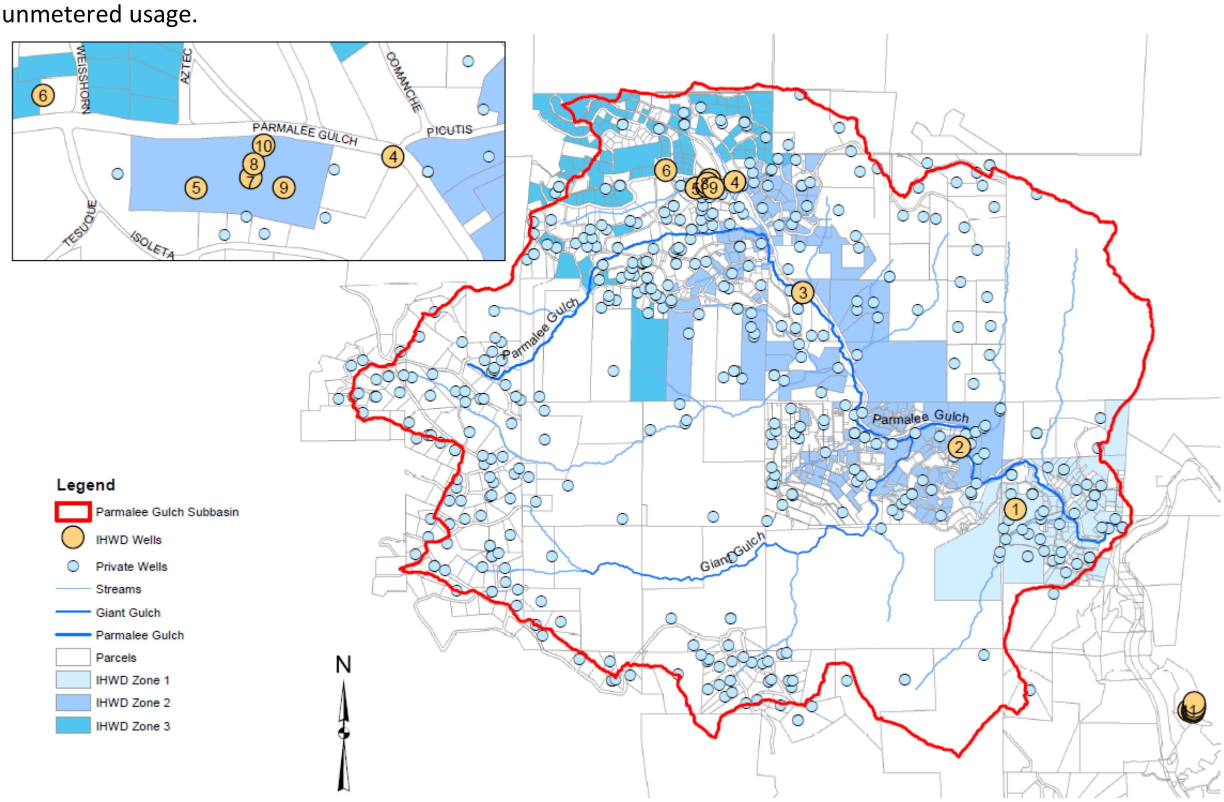


Figure 3. Indian Hills Water Supply Zones and Community and Private Wells

1.3 High-Level Treatment and Commercial Facilities in the Parmalee Gulch Subbasin

New developments adjacent to high-density Prohibition Zone valley areas of less than two acres must install HLT, with about 78 advanced systems currently installed to date. In 2014, the Parmalee Elementary School, at 4460 Parmalee Gulch Road, was upgraded to high level treatment (HLT) using Bio-Microbics MicroFast technology. Despite having over 250 student and faculty, per student use is lower than Jeffco OWTS Regulation estimates for a typical day-school, at less than five gpd on average. The school resides on nearly 12 acres, which at this usage rate represents a significant lower density use than dense residential development on 1 to 2 acre lots. Monitoring could enhance understanding of the benefits of the upgraded system and its impact on adjacent well nitrates. The three churches in the area are not anticipated to be of high use per area. The community center is only used rarely, so its challenge would be to maintain function during sporadic higher usage through consideration of an upgraded storage and dosing system. The Sit-N-Bull bar and restaurant and the Turkey Creek Café adjacent to it near the entrance to Parmalee Gulch both receive a large, variable customer base. Sit-N-Bull can receive especially heavy customer volume, since the patio is heated throughout the year and can expand the sitting area well beyond its listed capacity. Therefore, both lower Paramlee Gulch restaurant OWTS should be inspected more often and reconsidered for adequacy for actual usage and higher contaminant potential. Additional commercial redevelopment adjacent to high-density development should focus on low-impact development to protect or enhance areas of groundwater recharge and to minimize surface water runoff.

1.4 Original Prohibition Zone and 2014 Removal of Four Lots and Later, One Merged Lot

Since the late 1970s, Parmalee Gulch has included a restricted development zone to prevent further degradation in groundwater quality. Although not explicitly stated in the Prohibition Zoning document itself as to how these areas were determined, the **1975 Indian Hill Environmental Resource Inventory: A Citizens Tool for Planning** may provide some clarification through it the wide-ranging, comprehensive criteria that were likely considering in delineating the Prohibition Zone. Most development followed Parmalee Gulch up the valley because of gentler slopes and road access. On page 45, the 1975 community study specifically recorded a desire to preserve wet meadows adjacent to floodplains and recharge areas characterized by alluvium and colluvium near gulches and streams that fed Parmalee Gulch high density usage areas. Adjacent lands to Parmalee Gulch were also found to be direct conduits to the more highly permeable Pikes Peak Granite, thus less suitable for OWTS development due to greater risk to groundwater contamination per the *Septic System Suitability* map and the *Composite Land Suitability* maps included in the 1975 study. In addition to small developed residential lots along the valley floor, the Prohibition Zone originally also included a few larger lots in the upper and lower zones likely due to their steeper slopes and higher recharge potential near streams and tributaries. Currently, several of these commercial properties are under consideration for redevelopment. In 2014, four lots greater than 1 acre were removed from the Prohibition Zone as depicted in Figures 4 and 25. Later, a residential property owner in the Prohibition zone entered into a property merger agreement with county zoning to create a property greater than one acre for additional residential development. JEHS then sought to conduct this study to determine if newer data might inform future decisions determining if these developments and similar development could now be accommodated under revised state and county OWTS regulations that incorporate updated technology and methods to provide improved OWTS performance without compromising the objectives of the original Prohibition Zone.

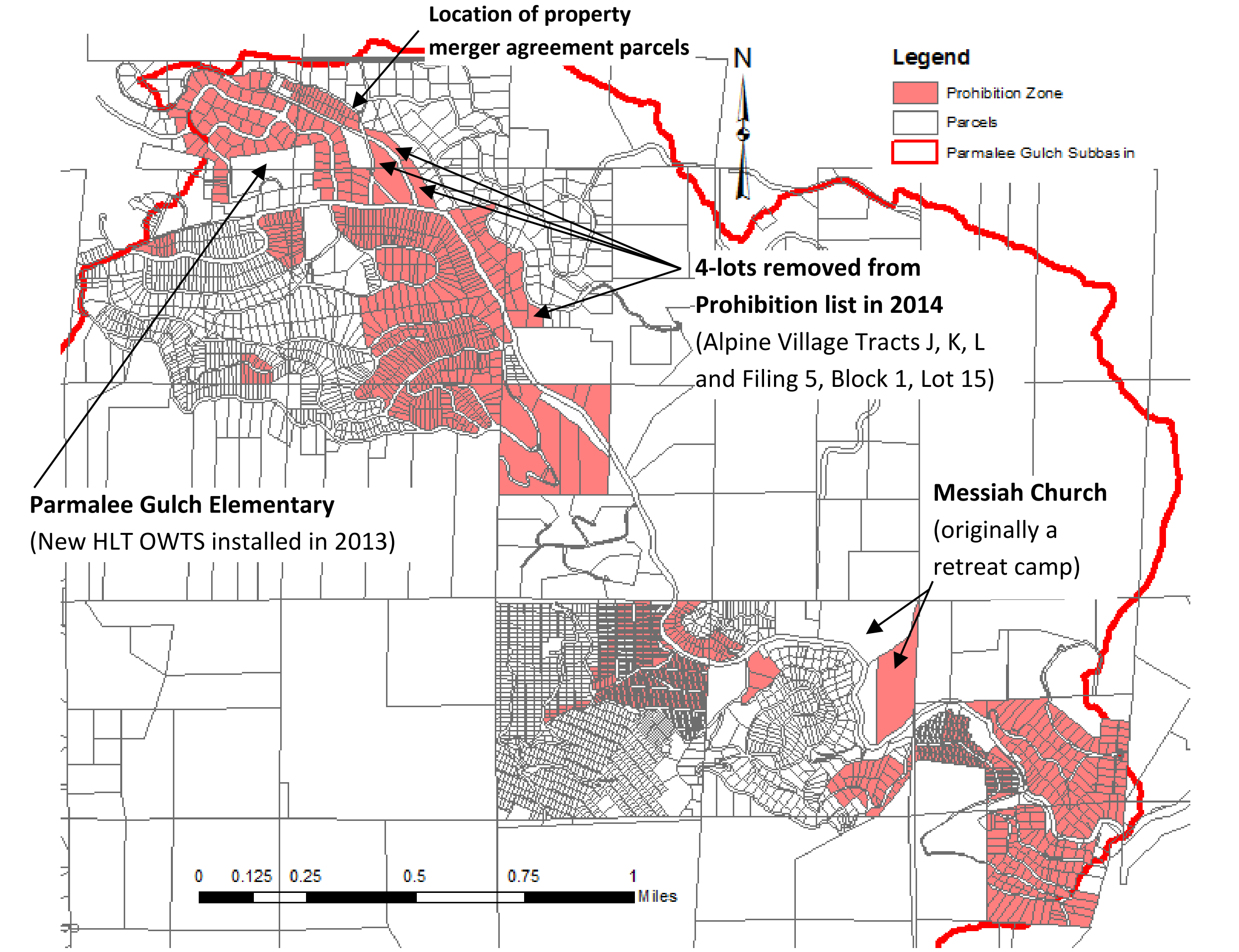


Figure 4. Indian Hills Prohibition Zone by Map (Note that 2014 removed lots are near Parmalee Gulch Channel adjacent to high-density development in principle alluvial groundwater recharge area, which were originally in Prohibition Zone), see Figure 26 showing the adjusted Prohibition Zones in 2014.

1.5 LIDAR Based Digital Elevation Model from which Watershed and Hydrology Developed

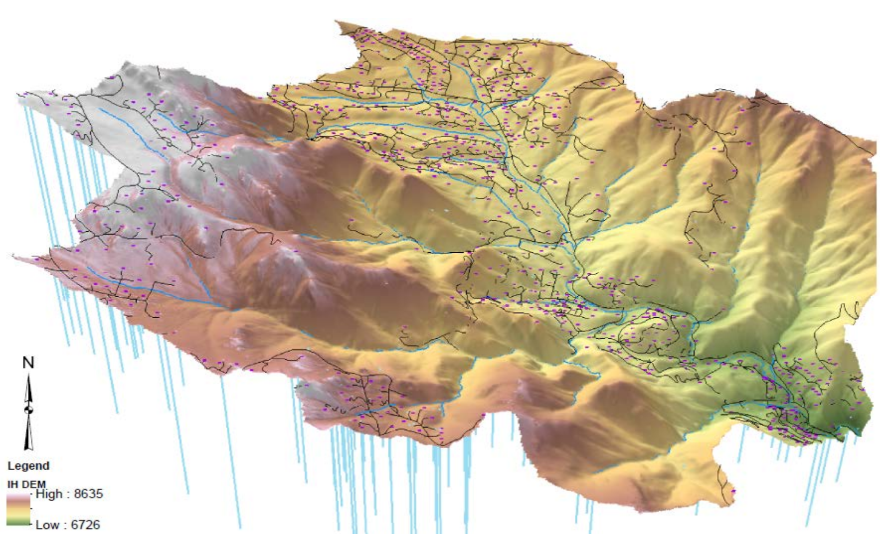


Figure 5. Indian Hills DEM from LIDAR

Elevations in the Parmalee Gulch subbasin range from 6,726 ft up to 8,635 ft above MSL. Development has occurred along the valley floor where roads could more easily be extended and groundwater was found in the alluvium closer to the surface and of more consistent supply as base flow that feeds area streams and tributaries.

1.6 Surface Water and Shallow Groundwater Flow Patterns

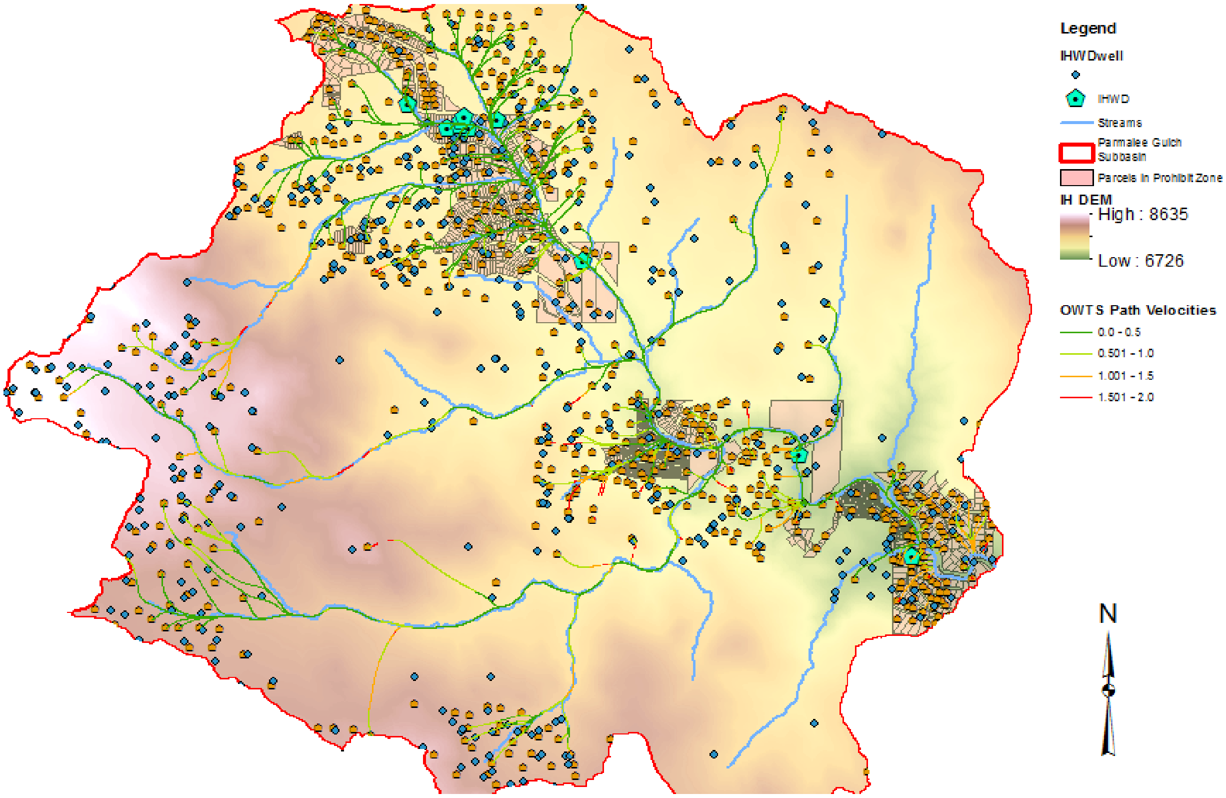


Figure 6. OWTS ArcNLet Tracers showing Relative Velocity of Flow and Path from STA of OWTS to Surface Water

Figure 6 indicates how Soil Treatment Area (STA) effluent discharges to surface water under saturated conditions. The 2011 UMC Aquifer study indicates that only about 52% of (soil treatment area) STA effluent will reach groundwater and of that, a substantial proportion will include the base flow groundwater reservoir, which will discharge to lower elevation perennial streams such as Turkey Creek and Bear Creek downstream of the Parmalee Gulch subbasin. Modelling by both ESRI ArcMap ArcNLet extension by University of Florida and EPA BASINS GWLF-E module indicate that up to 660 pounds of nitrogen a year may reach surface streams. Based on the 52% partitioning estimate from 2011 noted, a similar percentage of the nitrogen may reach the groundwater in Parmalee Gulch each year. Under average recharge conditions, about 1.57 inches of recharge is expected over the 3,657 Acre area of Parmalee Gulch. Without considering the additional contribution to flow from IHWD imported water from upstream gallery area of Turkey Creek and well pumping, this would indicate that at about 300 kg per the volume of recharge (589,284,000 Liters) an average concentration in recharge of 0.5 mg/L nitrate. However, nitrate concentrations have actually been found to be much higher, especially in more densely populated valley areas along Parmalee Gulch and tributaries. There are a number of reasons for localized high nitrate values, in addition to high OWTS densities. Subsequent sections will provide a number of factors that may allow a more direct route for nitrate contamination to reach the groundwater.

1.7 Paved and Unpaved Roads and Driveways

The Basins Model and ArcNlet Model require specific geo-data, which needed to be updated, processed and analyzed to fit input requirements. Data layers include OWTS areas by densities, horse areas by densities, soil areas by porosity type, landuse areas by type, public and private roads, streams, and the Data Elevation Model (DEM) of the Parmalee Gulch Subbasin area of study.

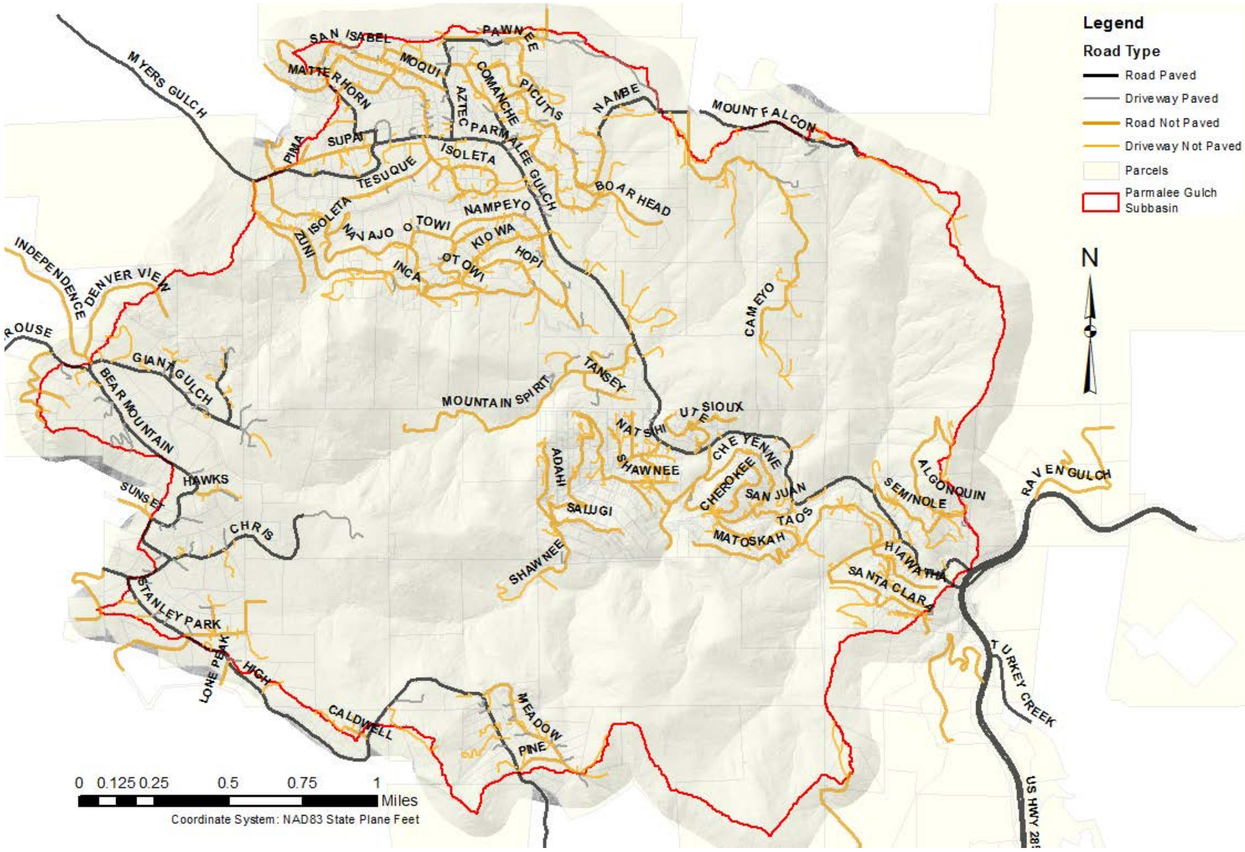


Figure 7. Public and Private Roads Classified by Surface Type

1.8 Landuse Map

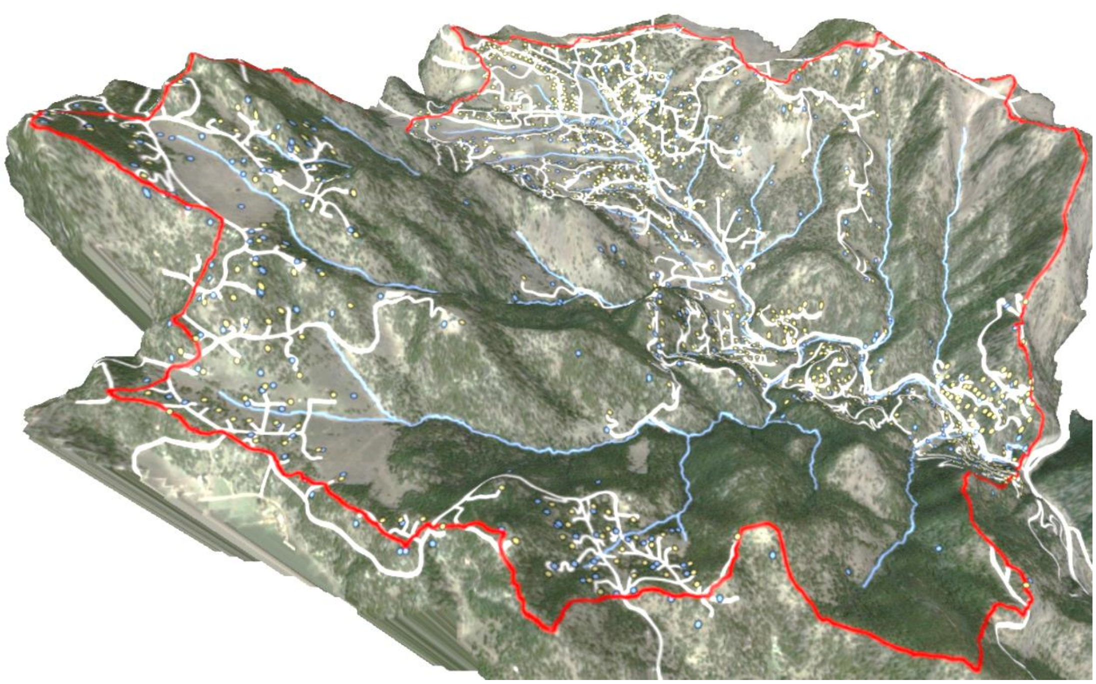


Figure 8. 3-D Visualization of Draped Landscape Features, Roads, OWTS, and Wells

Figure 8 demonstrates actual land cover using a recent satellite image. Unlike the landuse map below, it appears that Figure 9. areas classified as coniferous forest may actually be shown to reflect steep, rocky slopes, which are likely to remain less developed. Much of the rainfall on barren outcrops is not likely to enter fractured bedrock but simply drain off into surface water. Therefore, in addition to the lack of connectivity among fractures in the geological network that could limit supply in localized areas, blanket recharge rates at the subbasin level based on geological type projected over many acres likely overestimate actual recharge in the study area.

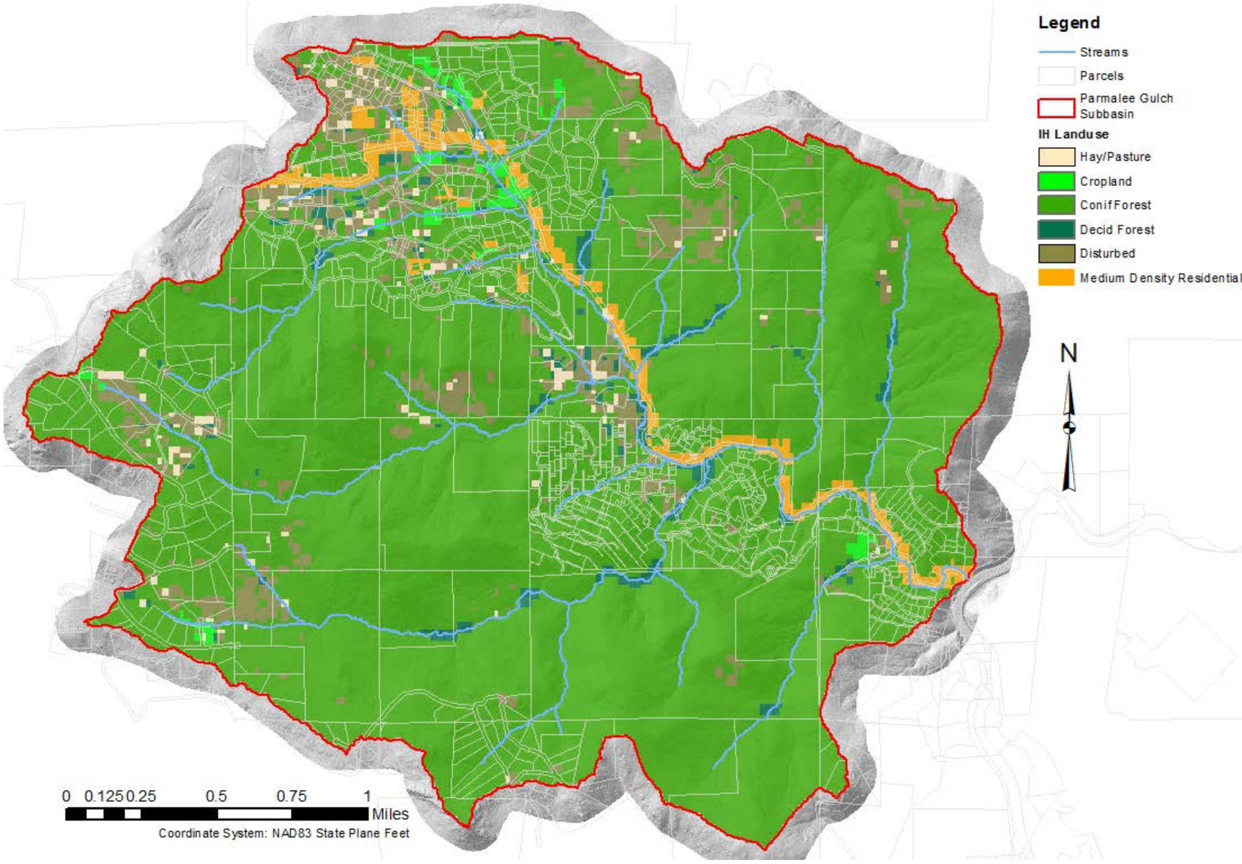


Figure 9. Landuse by Category

Although the national landuse map is somewhat out-of-date and the pasture map shown below in Figure 10 shows slightly larger areas of deforestation, overly dense forests that have not received historic return frequency of natural wildfires for maintenance under increasingly dry conditions expected by mid-century could affect water supply in several ways. Charred ground greatly reduces recharge potential, increases contaminants, and if conditions permit wildfires to burn hotter than normal, it may require centuries to recover what used to usually require only decades to return. Therefore, wildfire hazard reduction at the individual property, neighborhood and Parmalee Gulch Subbasin and surrounding adjacent public and private land areas is another significant concern. This may also be an economic, as well as, a water quality concern, since home prices have been reported by an area real estate agent to remain depressed to a greater magnitude than in areas unaffected by wildfires.

1.9 Horse Properties and Pasture Areas

Horse properties identified by stables from aerial photography and denuded areas of grass within the Parmalee Gulch adjacency area, may represent both surface and groundwater concerns for improperly managed lands, large animals and manure. Each adult horse weighs about 1200 pounds and generates approximately 130 grams (about 0.3 pounds) of Nitrogen per day compared to only 11-14 grams per capita (person) per day. Their heavy bodies

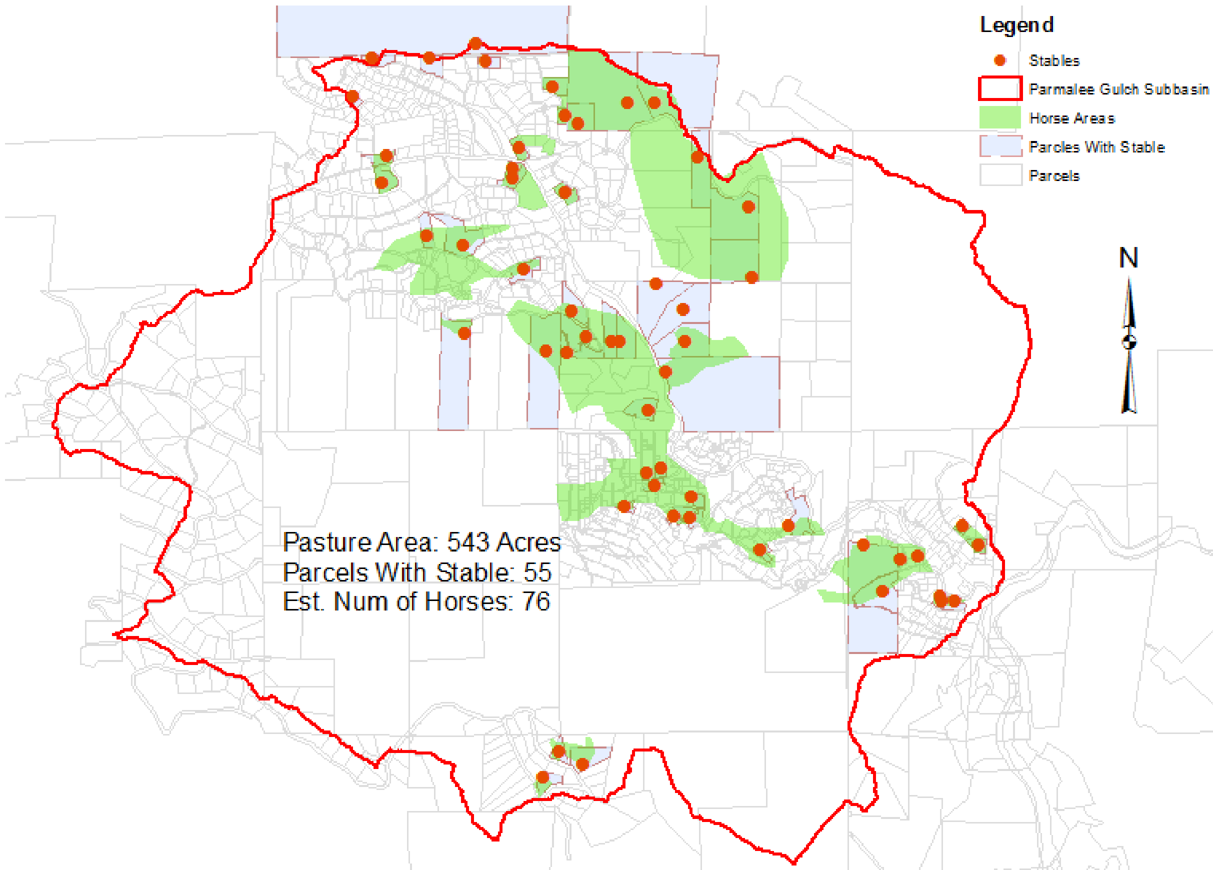


Figure 10. Horse Properties and Pasture Areas Delineated from 2012 Aerial Photography

also lead to ground compaction if left on grazing areas during rainy periods rather than being appropriately moved to a stable indoors and kept off the moist soils in a sacrifice area (gravel or paved) until it dries out. Compaction concentrates wastes in runoff to nearby dry gulches that either recharge groundwater through the porous soils or wash off the waste to surface water. Jefferson Conservation District demonstrated in 2015 that grass kept at least four inches high provides more fodder and stays healthy, and other studies suggest keeping large animals off grazing areas once grass height falls below six inches. An alternate feed source must be used until enough regrowth is available to sustain more grazing. Dividing a property into smaller areas to allow for alternate areas of grazing better ensures even grazing and more rapid recovery for more continuous use. If an owner does not wish a sacrifice area to restrict their large animals to a small area, they can create an outer paved ring around the edge of the property to serve as a continuous circuit for walking or trotting. Fertilizer applications should be kept to no more than thirty pounds per acre and never applied within three days of expected rain. Bedding, wood chips, or another carbon source should be mixed with manure to generate high-quality compost. Manure should always be covered, especially if rain is expected, so a roofed, solid floor enclosure to prevent drainage and leaching is recommended. As noted in Section 2.6 later in the document, nitrates under horse properties in shallow groundwater may exceed OWTS levels by an order of magnitude, just as a horse is 10 times larger than a person and produces 10 times more waste, so proper horse management on the more than fifty horse properties on particularly small acreages should be a management priority, especially near community and private wells, particularly down gradient of the property. It should be noted that IHWD Wells #4 and #6, both too high in nitrates to use regularly, appear to both be downstream of one, or more, smaller than average horse properties. The parcel-based Mass Balance Analysis indicates that horse lots of 1 acre could generate about 39 mg/L NO3-N and overall, upper zone analysis area properties may average about 32 mg/L and lower zone of analysis horse properties about 40 mg/L based on differences in average horse pasture size. Actual nitrate concentrations from any horse property will be determined by several factors including number of horses, parcel size, appropriate manure disposal practices, terrain slopes, vegetation, soil characteristics, and underlying geology.

1.10 Soil Porosity

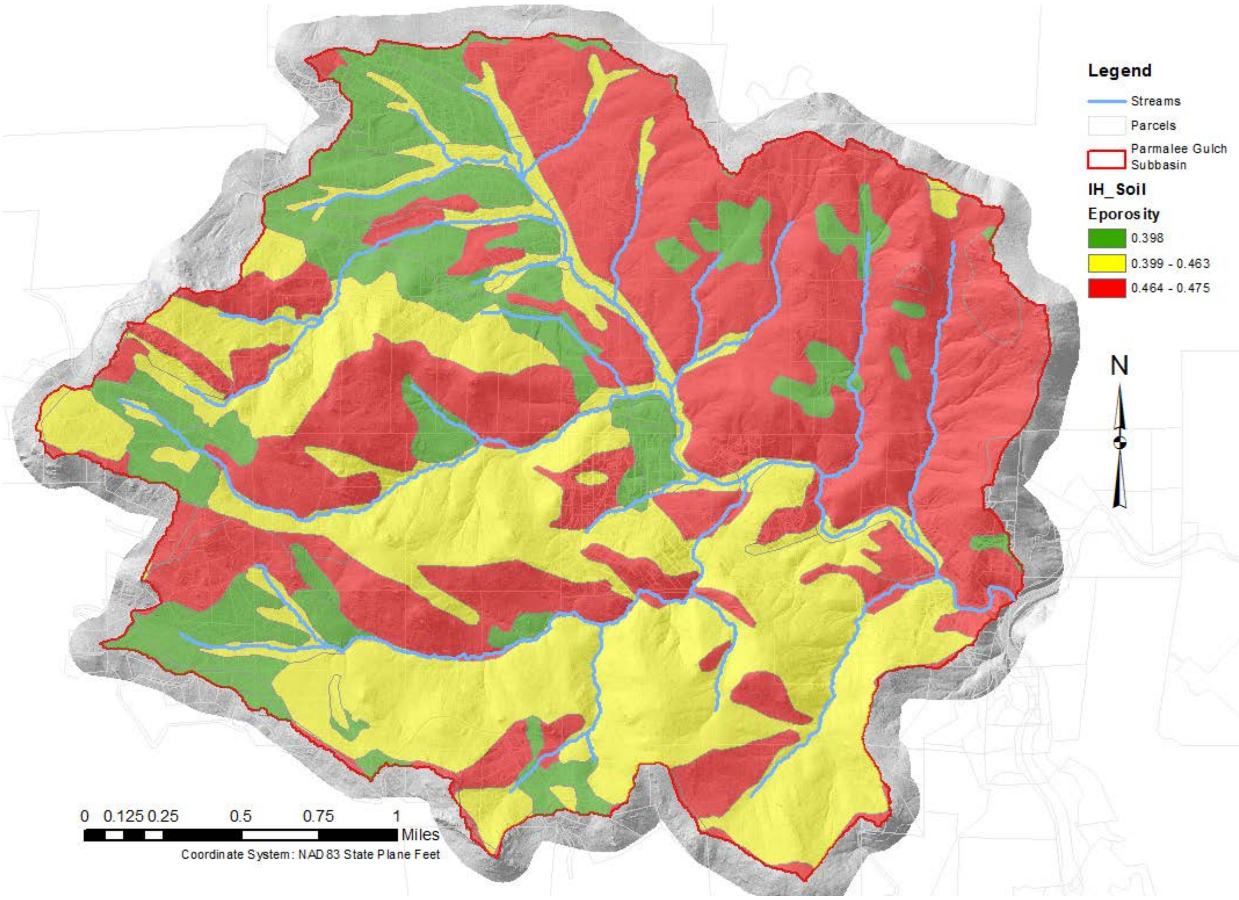


Figure 11. Soil Porosity

Bossong 2003 indicates that soil porosity is high in these mostly coarse soils, so they rapidly drain throughout much of Parmalee Gulch soon after spring runoff as winter snowmelt subsides. Soils remain relatively dry throughout the remainder of the year, which may permit shallow groundwater to be drained through capillary action and deep rooted tree and plant uptake. This reduces flow to subbasin streams and tributaries and leads to Parmalee Gulch streams drying up in dryer years under current well pumping conditions. Citizen scientists monitoring by local residents of tributaries adjacent to their properties may be a low-cost way to monitor where and when streamflow gradually subsides throughout each year to determine if a drying trend with climate change and development is also occurring.

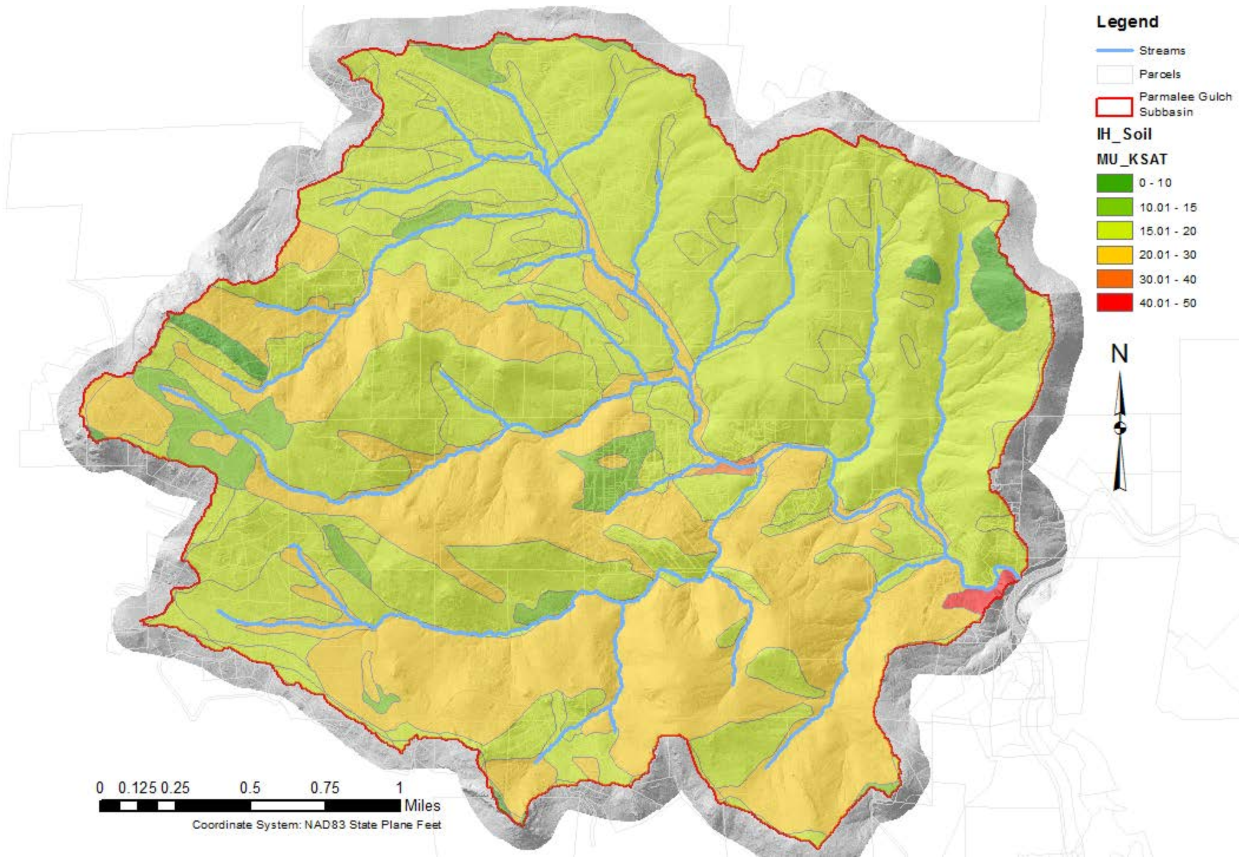


Figure 12. Soil K-sat: Saturated Hydraulic Conductivity (mm/hr)

Soil saturated hydraulic conductivity (ksat) models drainage and movement of solutes in soils, erosion and runoff. It can also be used to determine recommended OWTS loading rates using the formula with Ksat in cm/hr:

$$Loading\ Rate\ (LR)\ =\ 0.22\ Ksat^{0.23}$$

With most soils designated in the sub-basin with Ksat values from 10-30mm/hr, the formula would produce loading rates from 1.3 – 3.9 gpd / sq. ft. that is above the recommended loading rate for STA effluent of less than 1.2 gpd / sq. ft. Soils may actually be more variable than large soil units shown here, but many of the OWTS use only standard treatment and were not under new county regulations in 2013 that base location of the OWTS and loading rate requirements on actual site-specific soil texture. During spring runoff under saturated conditions, Dano 2004 determined that a plume of OWTS could travel over 100 feet though under normal conditions effluent would usually disappear into fractures within about 15 feet. Yesavage, 2008, also found that denitrification was not evident in STA. Denitrification is typically associated with higher clay and organic matter content and slower percolation rates. Therefore, less treatment is likely to occur and more effluent may reach groundwater more quickly than may be predicted. For this reason, instead of only considering 52% effluent reaching groundwater used in the CDM 2011 Aquifer Availability Study, a higher percentage of 75% was also considered in this analysis to determine how this might affect expected dilution levels.

1.11 Aquifers

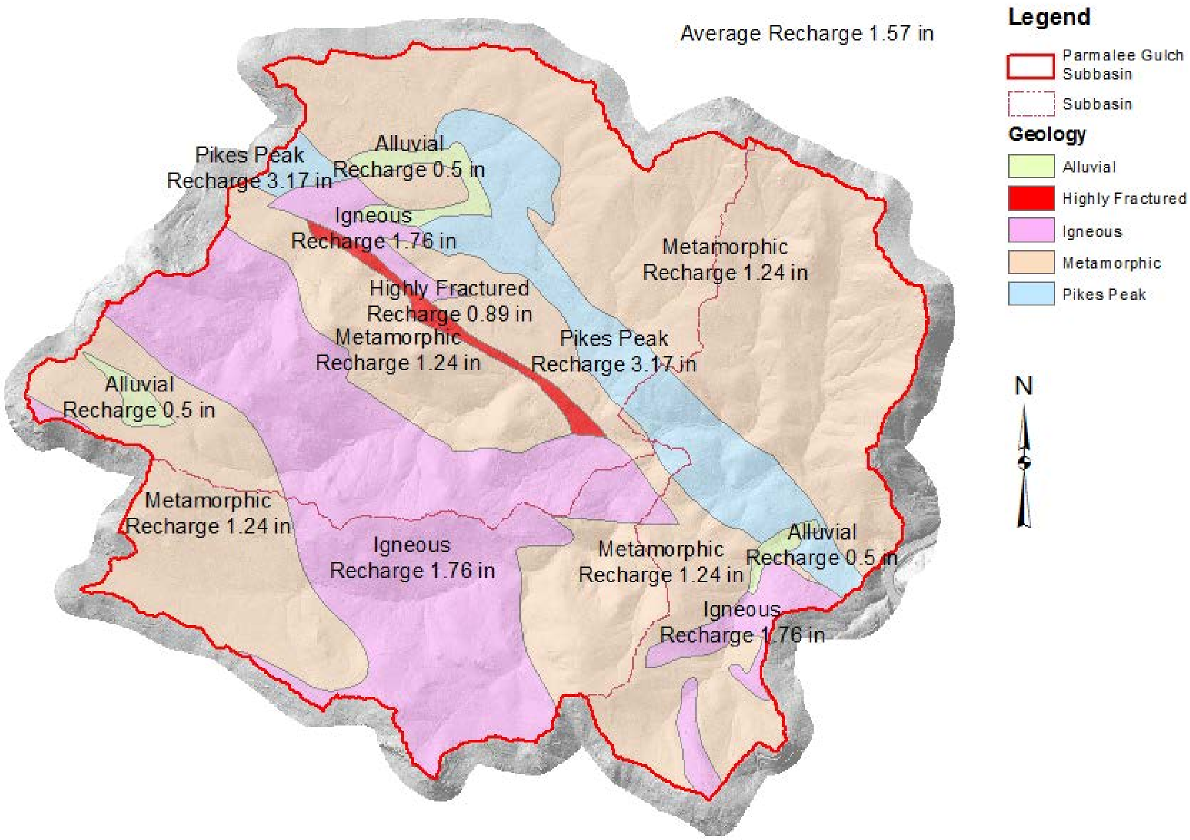


Figure 13. Aquifer Map by Category and Average Annual Recharge

Geological features found in Indian Hills area include alluvial, igneous, metamorphic, Pikes Peak, and highly fractured. The Bossong 2003 study estimated an average recharge for these areas ranging from 0.5 inches per year in alluvial areas to 3.17 inches per year in Pikes Peak areas. CDM 2011 did not consider recharge for alluvial areas, as it considered them to lose all to base flow by late seasons of the year.

Metamorphic and igneous rocks, which cover the majority of the watershed on the steeper side slopes, are less highly fractured than Pikes Peak Granite cutting through the center of the Parmalee Gulch subbasin. These geologies produce only about half as much recharge per year on average. The total area of Parmalee Gulch is approximately 3,657 acres. Buildings account for only about 26 acres and driveways and roads another 52 acres. At 100 gpd / household, residents return about 41 AFY to groundwater and at 175 gpd / household, about 57 AFY might be returned, per calculation methods used in Section 2.3.1.

Bossong 2003 noted that from a risk analysis standpoint, rather than considering average flow years, a low flow year similar to 2002 should be considered, which would reduce recharge to only about 0.1-0.2 inches rather than the average of 1.57 inches per year currently estimated. The average year estimates about 478 AFY of recharge, though much of this may leave the basin in base flow streams, as the apparent seasonal well level fluctuations demonstrate in Section 1.12. Using Bossong's low flow recharge estimates, only about 30-61 AFY would return, which Vanderbeek 2004 also confirms, indicate that highest usage is greater than lowest recharge levels. With climate change predicted to reduce flows and precipitation throughout Colorado by mid-century, conservative, site-specific well yield estimates should be determined, rather than continue to provide blanket SEO permitting.

1.12 Well Information

There are approximately 540 wells in Parmalee Gulch subbasin, though the status of their use is relatively unknown. About 375 of the 400 IHWD taps lie within the in Parmalee Gulch itself, so the balance of the 700 users supply their own groundwater. Not all wells have been permitted, since it is only required at point-of-sale (POS), which unlike OWTS, does not require inspection for well-head protection, and appropriate casing and sealing. Therefore, older, degrading, uncased, existing wells could be of particular concern as a direct conduit of adjacent OWTS effluent to groundwater. About half of wells are designated as Household Use Only (HHUO).

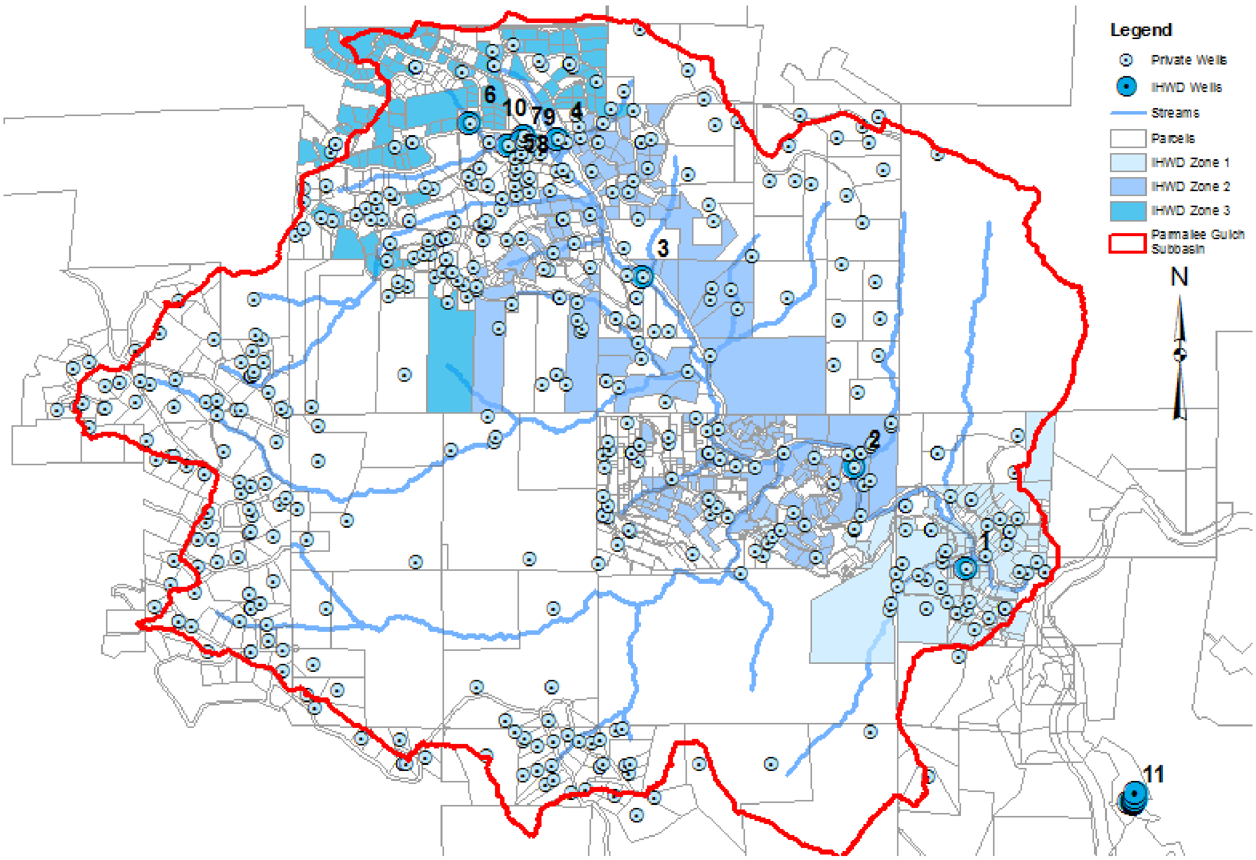


Figure 14. Well Locations With Respect to IHWD Customers

About 97 domestic private well owners and 24 household-use-only well owners are now IHWD clients, so they may no longer use these wells. However, since the State Engineer's Office (SEO) in the Colorado Division of Water Resources (DWR) has no authority to require their abandonment and Jeffco has no ordinance to encourage abandonment, these wells remain and could potentially be in more degraded condition for lack-of-use and awareness of casing, sealing, and well head protection best practices. Unused wells do not provide a positive head potential, so contaminated surface or subsurface water that may enter the borehole could be pumped into other active wells in the vicinity, serving as a more direct conduit to deeper groundwater of pollution from OWTS, horse properties, and other sources. Over 150 residents not using IHWD water do not appear to have a registered well or for which a well could not be matched. To protect their use right and to ensure proper maintenance, all wells should be permitted. Wells should also be more accurately located, inspected, tested, depth assessed, and protected through a formal source water protection process to aid future analysis and water quality improvement.

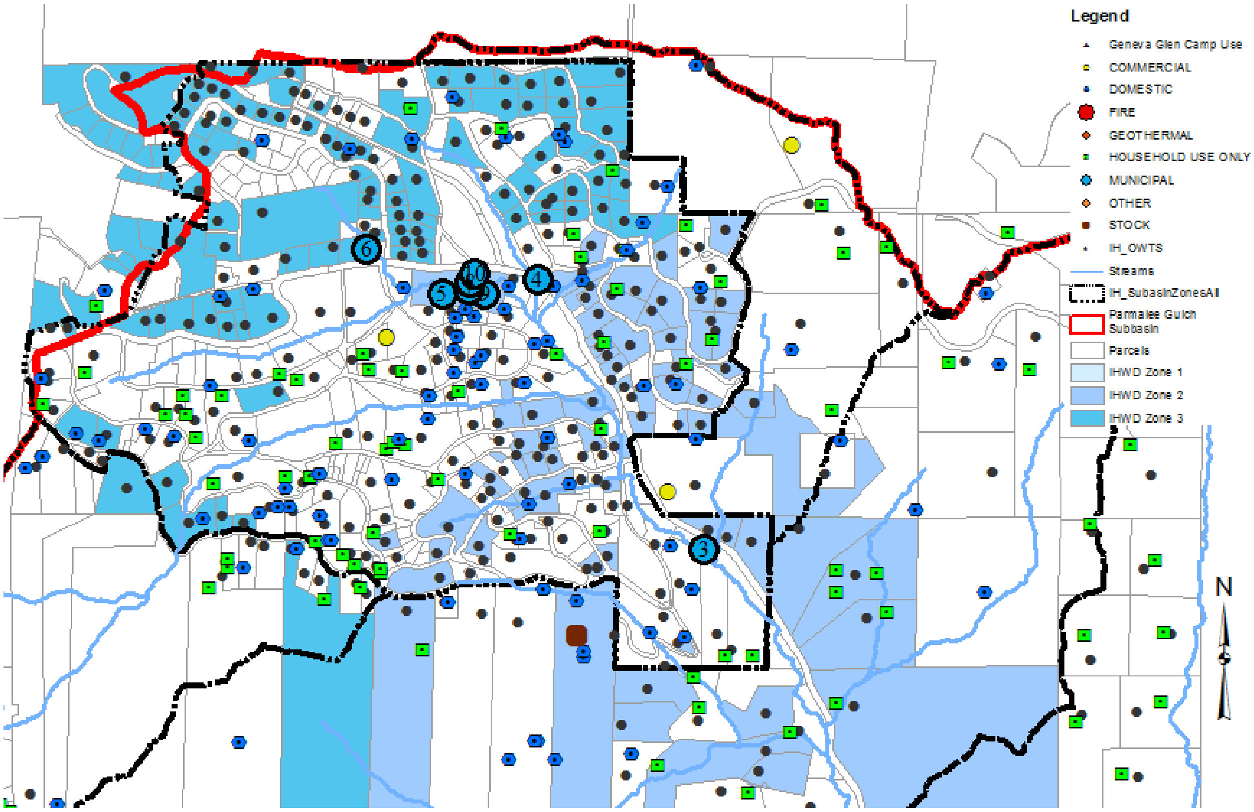


Figure 15. Upper High Density Analysis Area - Wells by Type

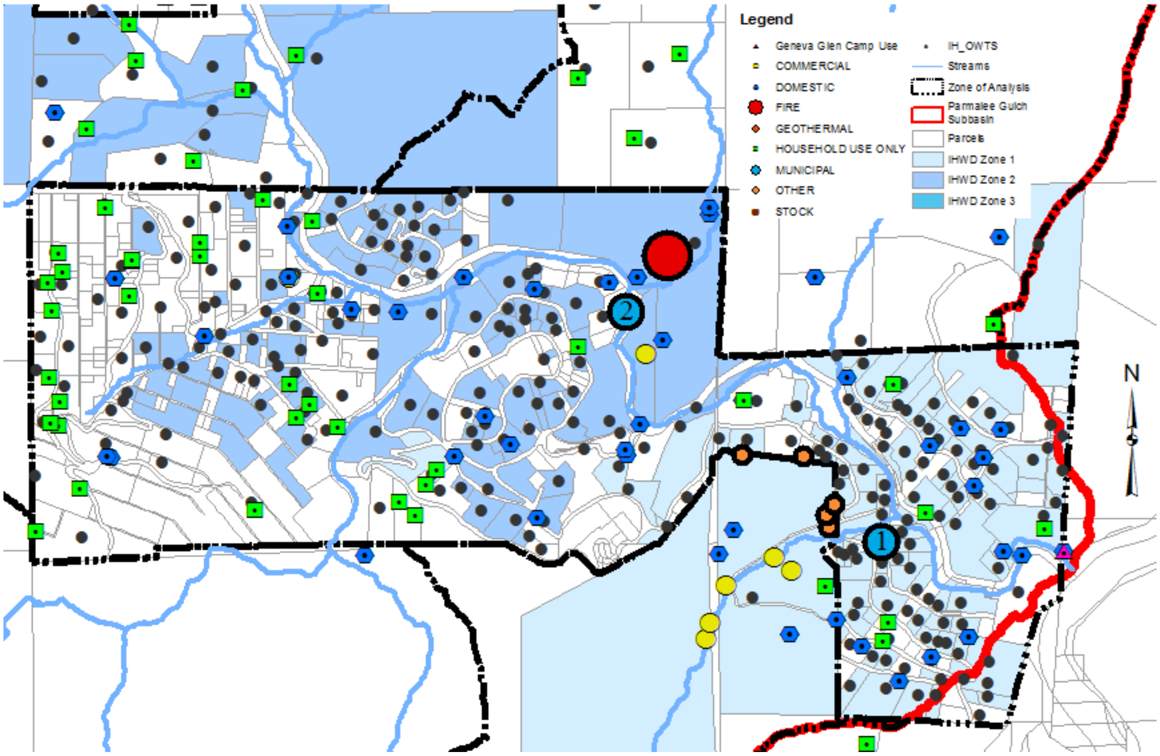


Figure 16. Lower Zone High-Density Analysis Area - Wells by Type

MH1 - http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=393821105161001) is reported by the USGS as being 180 feet below the land surface at an elevation of 7,310 near the top of the aquifer. It is near the top of Parmalee Gulch and demonstrates the seasonality and apparent groundwater mining of about 0.5 feet per year on average reported in Vanderbeek 2004. In an extended drought, under conditions that Bossong 2003 anticipates almost no recharge, water levels would be expected to lower substantially and some wells would likely go dry, which further development would likely exacerbate.

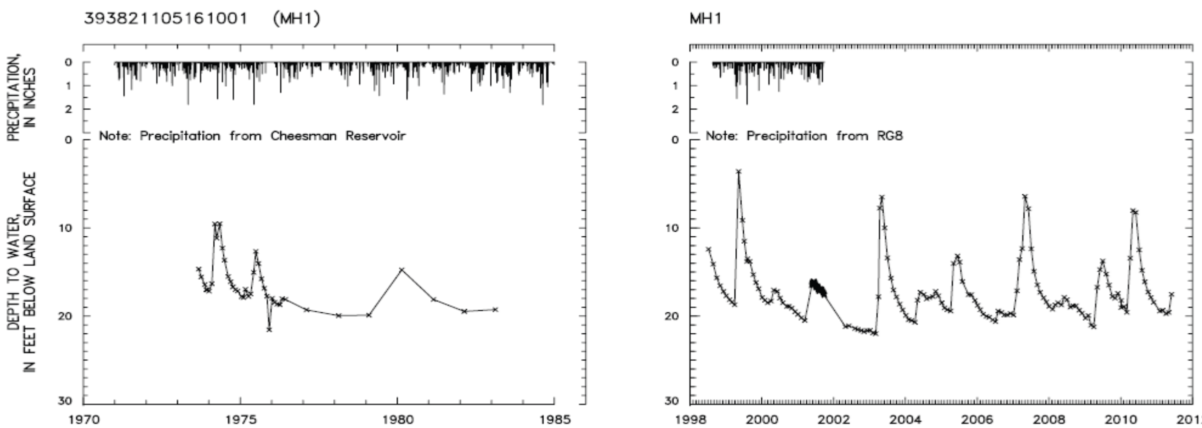


Figure 17. Depth to Water Bossong (GWZPlot)

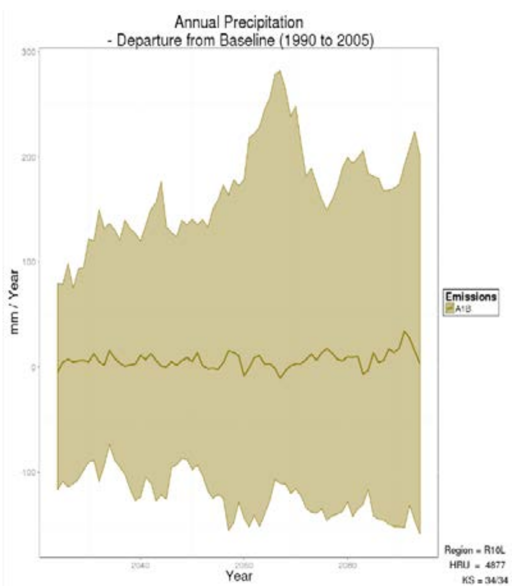


Figure 19. Likely precipitation patterns in Colorado in the future are not clearly understood

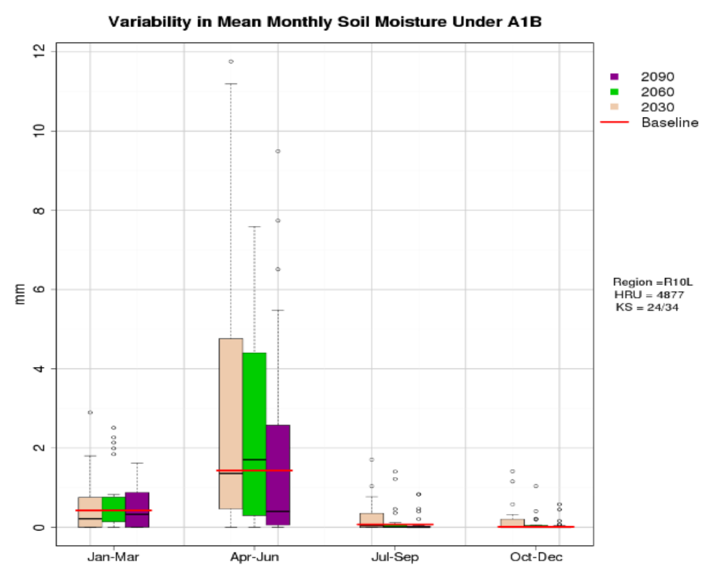


Figure 19. Soil Moisture is predicted to decrease under expected climate change scenarios

Figure 17 indicates a strong seasonality and a possible trend towards groundwater mining from 1998 to 2003 Vanderbeek 2004 had noted (0.5 ft/yr decrease in groundwater levels in Parmalee Gulch) at the headwaters of Parmalee Gulch, and Figure 18 & 19 indicate uncertain precipitation trends, but likely drier soils, which may reduce groundwater recharge from both precipitation and also reduce OTWS STA effluent reaching groundwater, as more may be consumed by deep rooted plants and more upward capillary action trends as soils dry out for longer periods.

1.13 OWTS

Table 2. OWTS by Cluster

Zones	Number of OWTS	Year of Oldest Structure	Average OWTS Density OWTS per Acre (Acres per OWTS)	Structure Gross Area Avg (Square Feet)	Parcel Average Area (Acres)
Prohibition Zone Upper	119	1920	0.5 (2.0)	1531	1.03
Prohibition Zone Lower	149	1875	0.6 (1.7)	1154	0.99
HLT Zone < 5 Ac	360	1900	1.1 (0.9)	1763	1.65
TL1 Zone > 5 Ac	72	1870	0.1 (10)	1860	17.70
	700				

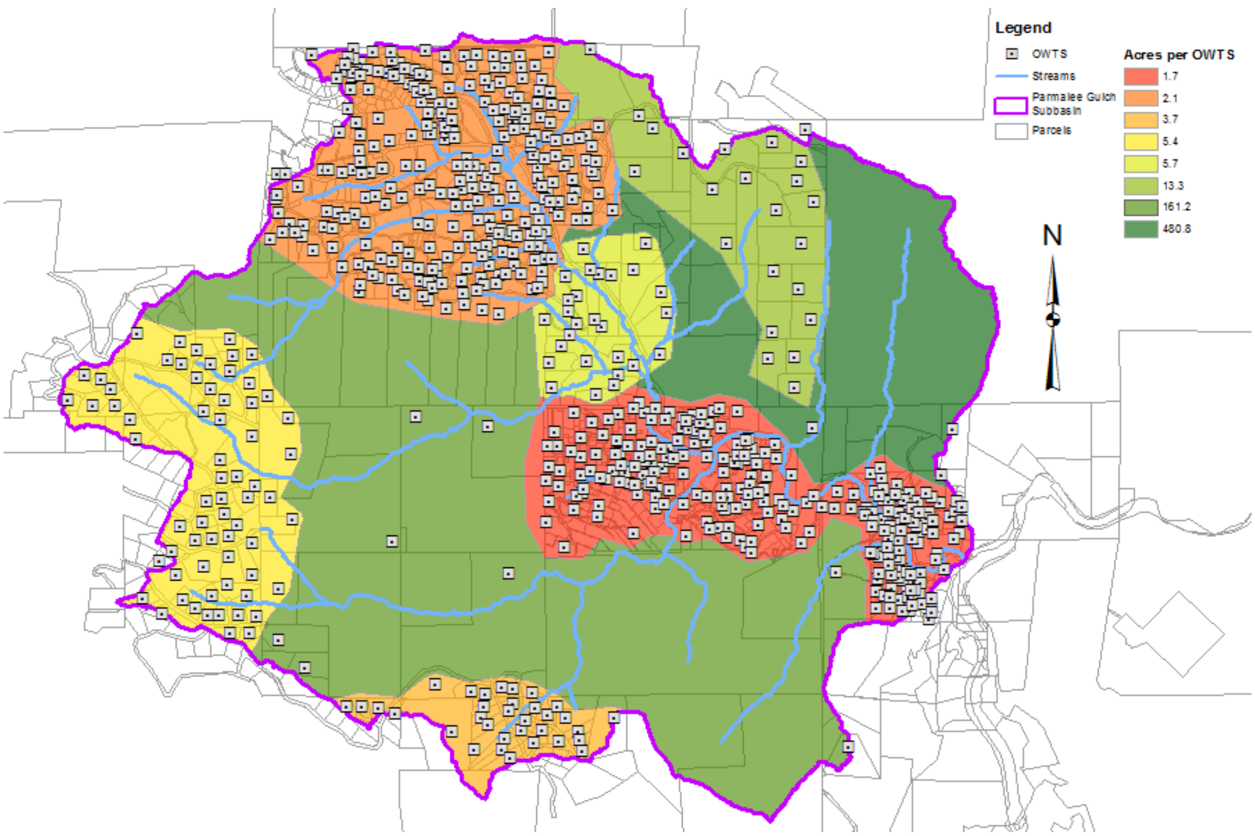


Figure 20. OWTS High Density Delineation

Data layers needed for the GWFL-E model include the OWTS Density Areas, which was generated based on the shapefile data points derived and clipped for the Parmalee Gulch Subbasin from the MTH doctoral thesis ACM DSS As shown in Figure 20, in high-density areas, unless served by IHWD water, wells may be in close proximity to OWTS. This is an endemic problem in high-density development areas, particularly near the upper zone of analysis in the headwaters in the North for two reasons. Well enrichment in nitrates over time may be compounded if older area wells at shallower depths re-use groundwater already contaminated by nearby, older, standard treatment OWTS. OWTS effluent may more directly reach groundwater in Parmalee Gulch through porous soils and geologic fractures to deeper groundwater. With higher well-densities overall, unused wells and older, shallower ones may further provide more direct conveyance of surface and near surface contaminants to groundwater, especially if nearby actively pumping wells draw contaminants in through inactive wells that have not been properly abandoned.

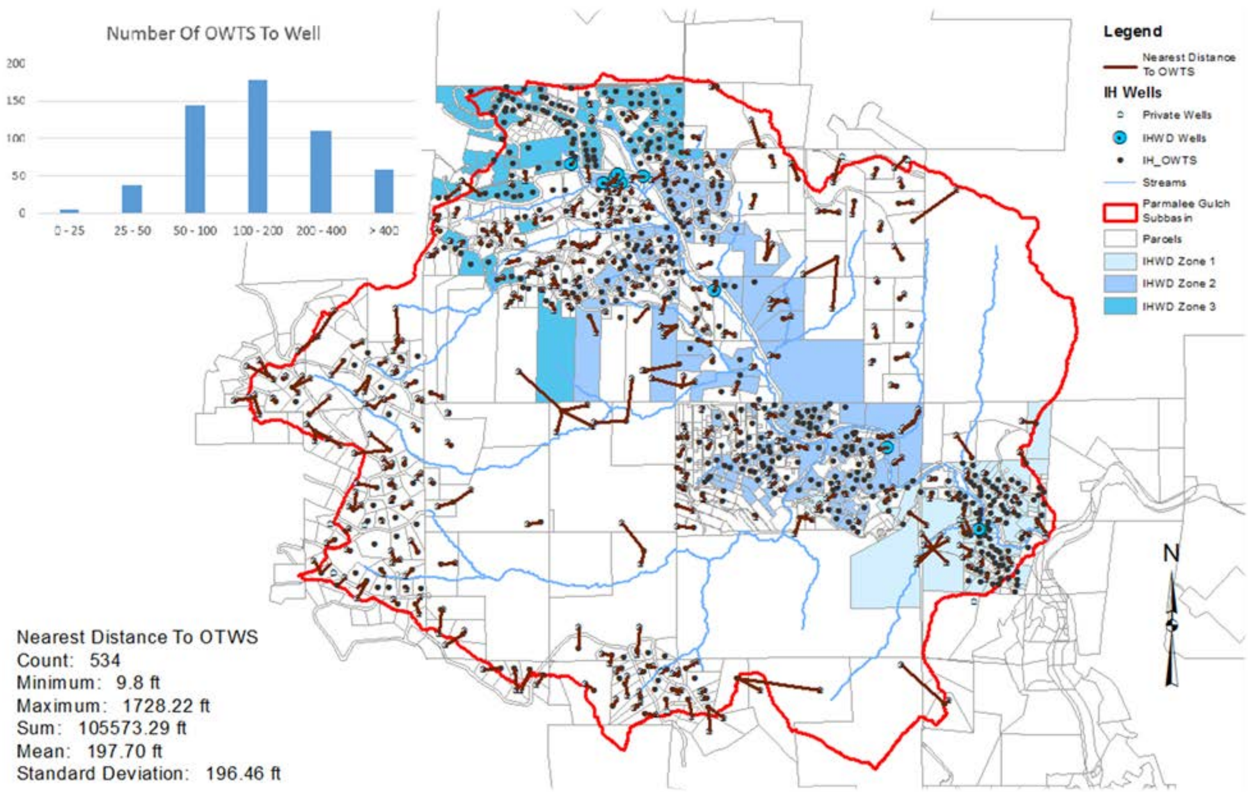


Figure 21. Average Separation between Wells and OWTS in Parmalee Gulch Subbasin

Note: Histogram (upper left corner of Figure 21) depicts Number of OWTS (y-axis) versus Distance to OWTS in feet (x-is)

Figure 21 indicates the approximate distance between each estimated well location and the nearest OWTS. However, SEO data for actual well locations is not always very accurate and the exact location of the STA associated with each OWTS is unknown, so the OWTS point locations are only approximations based on inspection by placing each in a likely open area near the back or side of the structure being served. Nevertheless, in some areas this analysis seems to indicate that particularly older wells may be closer to OWTS than current OWTS regulation would permit. Reviewing this map may help potentially affected homeowner to consider proximity to neighboring OWTS in planning well testing frequency and constituents to test, as well as, the potential desirability to switch to IHWD water supply to provide potentially less risks of water quality concerns should testing indicate contamination.

1.14 Prohibition Zone Delineation from List and Map

The project was unable to obtain a prohibition zone GIS shapefile, so one had to be constructed from paper map and listed lots in the Prohibition Zone. This was time consuming because lots were often re-numbered in later filings for Subdivision 2, 3, 4, to match. The exercise was further complicated by the fact that listed lots did not match the mapped lots shown in the 1979 delineation of the prohibition zone and it was distorted because it was drawn on a USGS topographic map rather than being precisely located at the time.

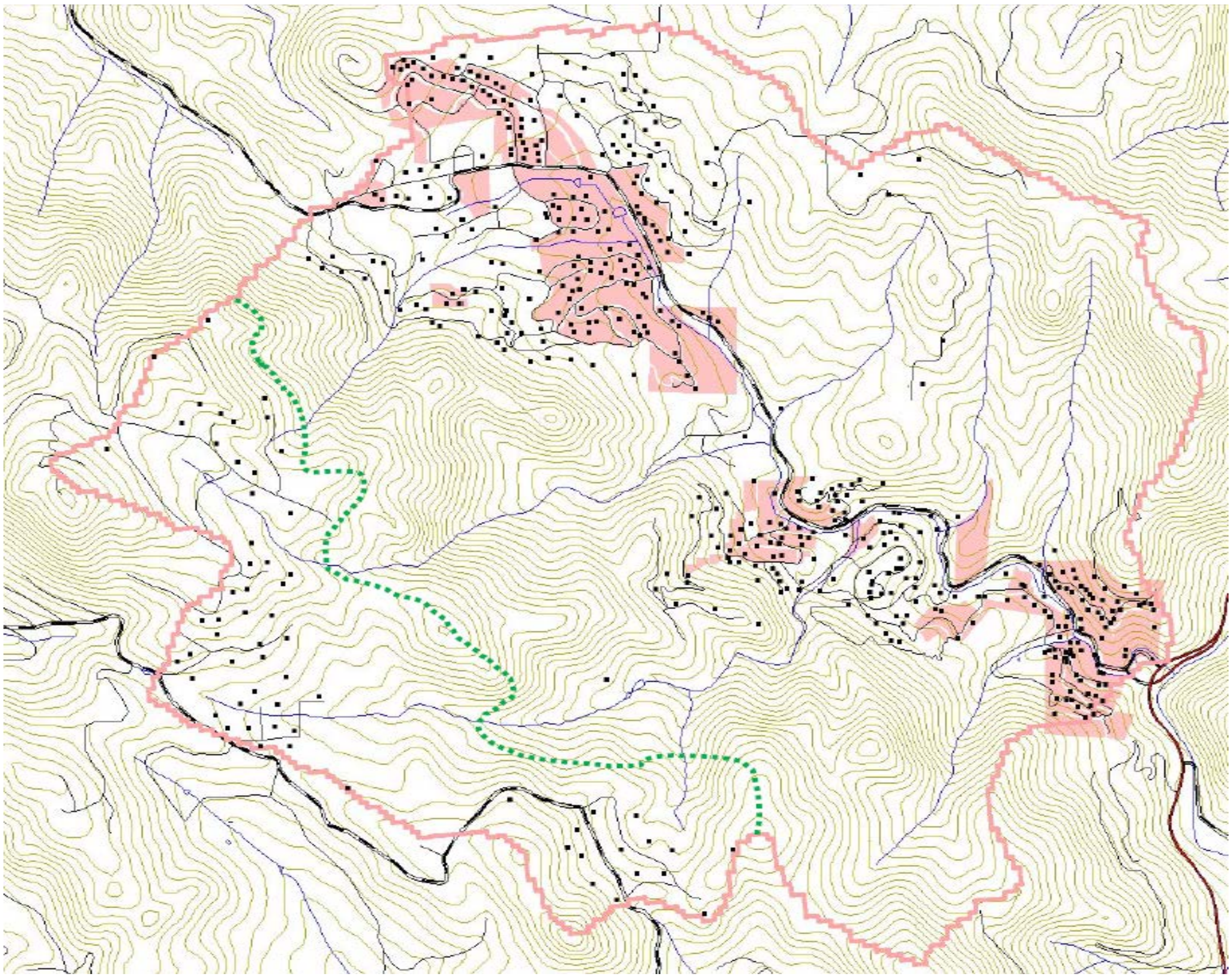


Figure 22. Prohibition Zone Map (circa 2002)

Method 1 (Prohibition map analysis): The document REVISED (2014) Policy for Permitting Requirements for the Indian Hills - Parmalee Gulch Area (2014).pdf was used as the basis for defining the Prohibition Zone. First, the map on page 3 of 5 was used to visually select all lots that appeared to lie in the pink, Prohibition Zone by inspection. This map had *not* been updated to show the four lots removed in 2014 (Alpine Village Tracts J, K and L, and Filing 5, Block 1, Lot 15) and original listing of Filing 5, Block 6, Lots 1-7 which are not shown on the map above.

Method 2 (Prohibition list analysis): Next, a layer of original lots in shapefile transferable format was obtained from Jeffco planning to record-by-record associate the list of Prohibition Zone properties by Filing, Block, and Lot number to the extent possible. One problem was that many of the lots had duplicate lot numbers because the lots were taken from hard copy, so when the numbers were transferred, sometime an entire block appeared to given the same number. There were Prohibition Zone differences as to which lots were included if based on the original map or the list of lots. For example, on closer inspection of the results of method 2, it was evident that some parcels had been picked that did not actually match the map shown. Therefore, both final map and list version of lots is shown below. There were many gaps in the ranges listed as to the actual lots that exist, so the original list, the final list, and the actual list of lots and their associated Parcel Numbers and Owners are included for future reference in a spreadsheet that accompanied the report. Lots are only a subset of a parcel in most cases, so the areal percent of the parcel for each lot is also listed in the spreadsheet analysis.

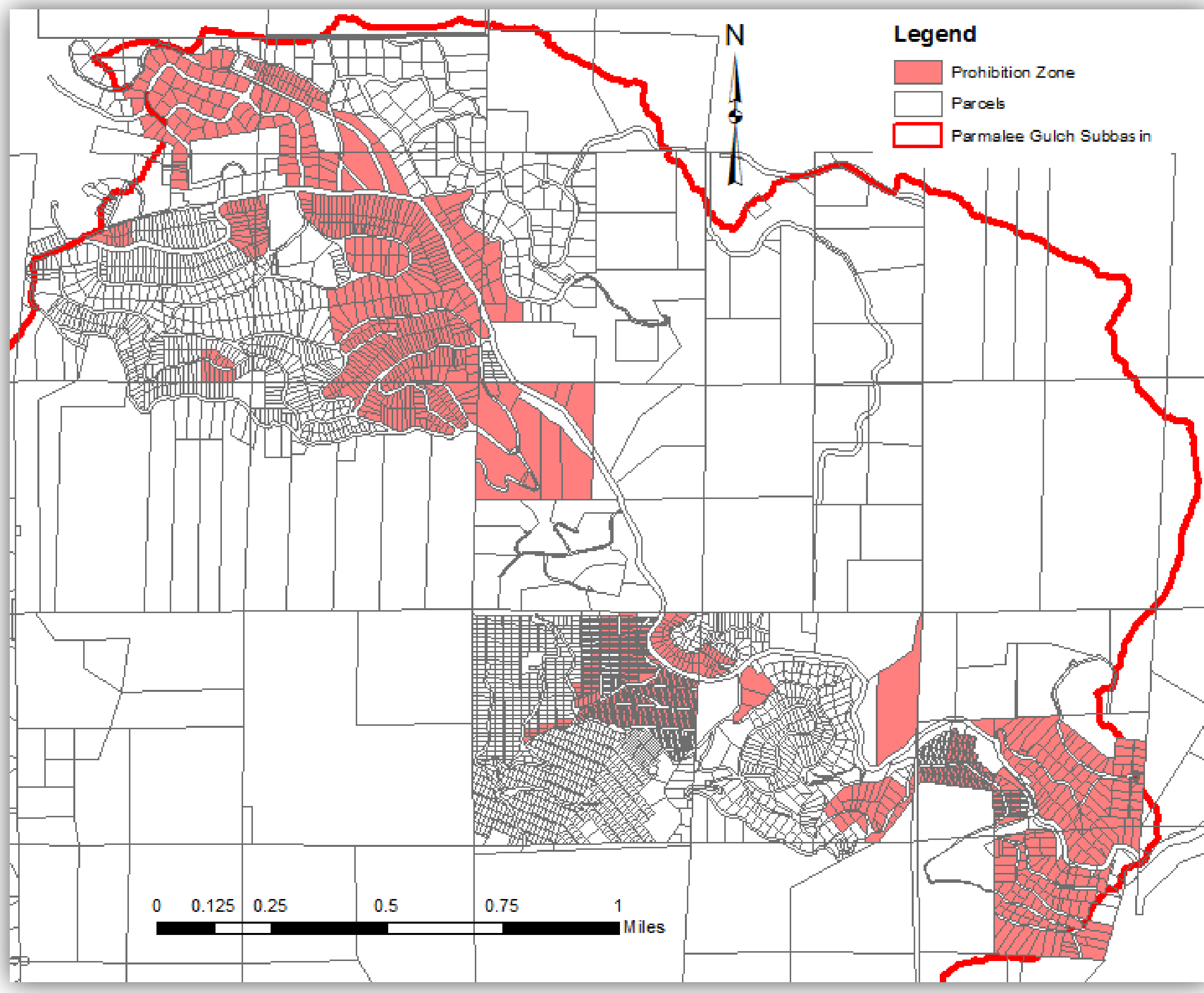


Figure 23. Lots Prohibition Zone by Map - Original 1979

Lot location was matched to reproduce the map included in the original Prohibition Zone restrictions, Figure 22 above.

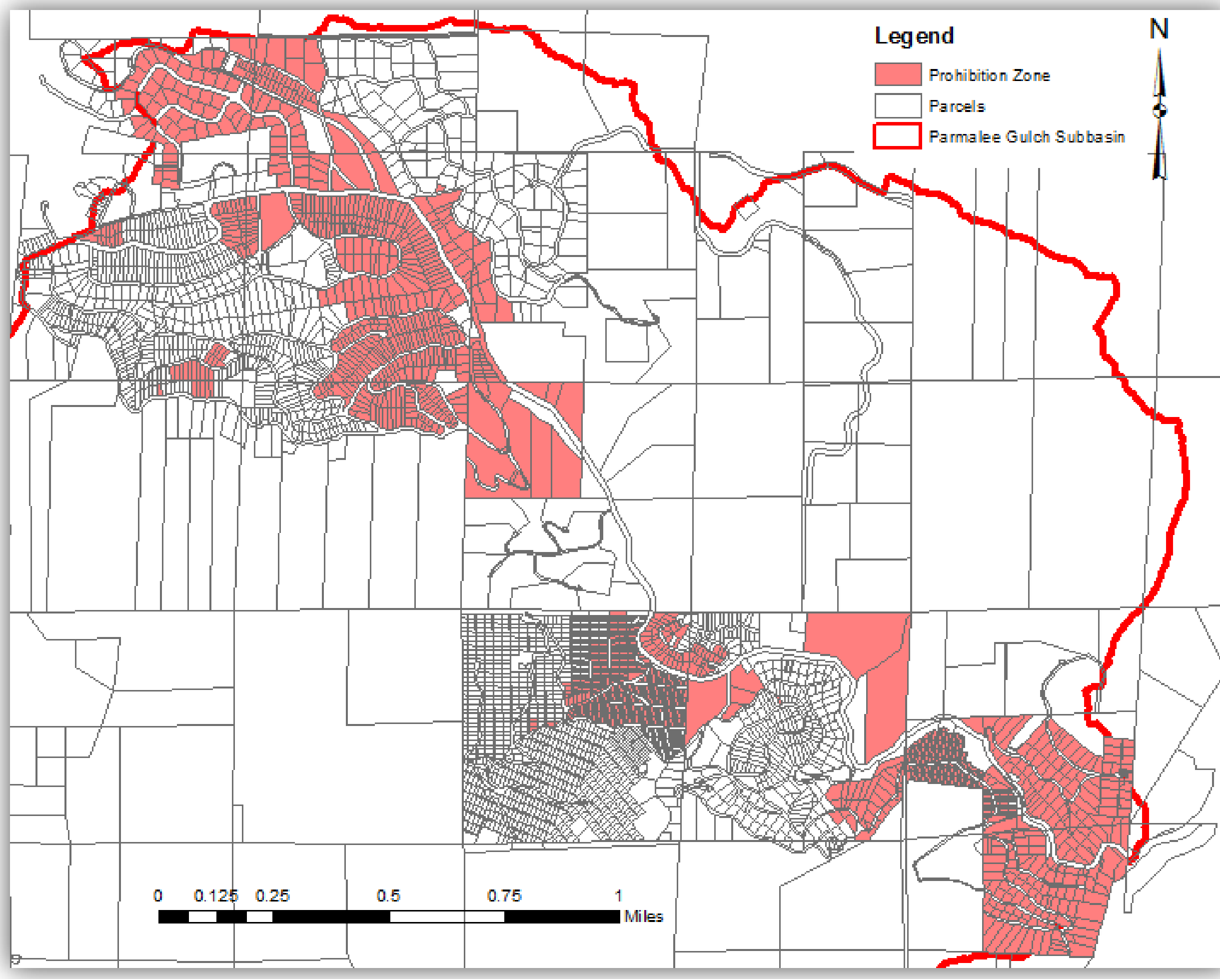


Figure 24. Lots Prohibition Zone by List - Original 1979

For comparison, a spreadsheet analysis accompanies the report, comparing lot-by-lot which parcels included by this original map matching method in Figure 22 and the actual list matching method shown in Figure 23 may not match. Since the upper and lower zone areas of analysis did not focus on weather a lot was in the Prohibition Zone exclusively but included all lots in the upper and lower areas of denser development, the analysis was not affected by slight errors in Prohibition Zone definition. This also permits the analysis to be conservative by including all small parcels in the most desirable areas of existing development as shown in Figures 36 and 37.

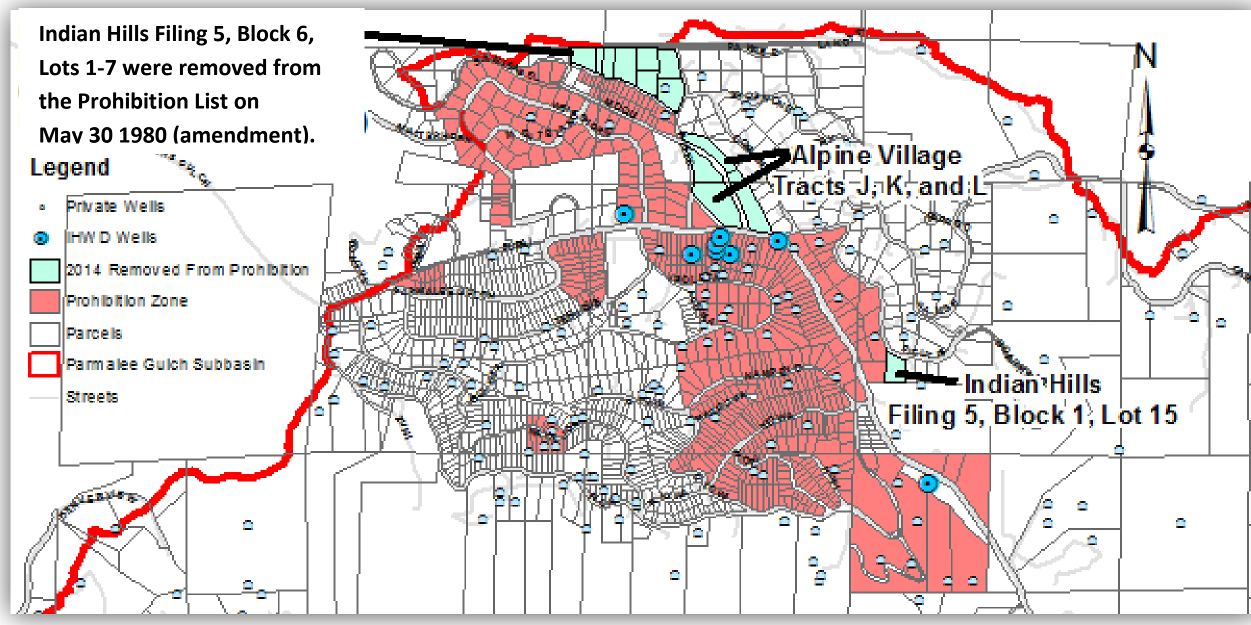


Figure 25. Lots Prohibition Zone by List – 2014 Update Showing Removed Lots

The Prohibition Zone update reflects the Lots by map with removals from "REVISED (2014) Policy for Permitting Requirements for the Indian Hills - Parmalee Gulch Area (2014).pdf" file. A spreadsheet table in related resources for the updated list that removed Alpine Village Tracts J, K, and L, Indian Hills Filing 5, Block 1, Lot 15, and Indian Hills Filing 5, Block 6, Lots 1-7 which were removed from the 1979 Prohibition List on May 30, 1980 by an amendment. The only criteria considered by JEHS in 2014 in the removal was that the four lots exceeded one acre. However, there may have been other criteria in 1979, like the fact that the Filing 5, Block 1, Lot 15 was only slightly greater than an acre and that the Alpine Village Tracts drain into a wet meadow near many of the IHWD public wells in the Upper Well Field, as well as, many downstream private wells, so the community may have included other criteria from their comprehensive analysis of risks conducted through the Indian Hills environmental inventory (McLaughlin and Bevis, 1975) to include originally include these tracts in the Prohibition Zone to prevent their development.

2.0 Groundwater Water Quality Analysis

2.1 Groundwater Nitrate Concentration Interpolation from Actual Well Data

Sampled well data showing nitrate concentrations in higher density development areas were mapped and used to generate interporlated maps for the 70's, 80's, 90's, and 2000's decades and graphed over time. Both in the averages and maximum values listed in Table 3, there seemed to be an upward trend over time from 4 mg/L NO3-N in the early 1970s to 6-7 in later years and maxima below 20 mg/L to maximum readings above 20 mg/L. However, due to the sparsity of data, the change-in-location and seasonality in each dataset, statistical analysis is not possible. In 2007, Yesavage took additional groundwater samples using a HACH meter in Indian Hills at 17 sites or more, which resulted in similar ranges and maxima as the 2004 dataset, so this may further verify the upward trend. Care should be taken to collect synoptic readings at both IHWD and private wells in both spring and fall annually or at least every three years. This would be best accomplished by establishing a data sharing MOU between JEHS and IHWD and developing a mechanism to allow residents to share well test results.

Table 3. NO3-N Well Sampling Statistics from JEHS records (concentrations in mg/L NO3-N)

Year	Sample Count	Avg Of NO3 as N	Min Of NO3 as N	Max Of NO3 as N
1970	20	3.8	0.2	8.8
1971	44	4.1	0.1	7.6
1972	46	4.2	0.2	8.8
1975	10	4.1	0.2	15.8
1976	7	4.6	2.1	7.0
1977	6	4.2	0.9	9.9
1978	27	4.8	0.1	15.0
1979	72	6.0	0.1	17.0
1980	32	5.4	0.9	7.8
1981	31	7.1	0.5	17.1
1984	2	6.4	5.9	6.9
1987	2	5.5	3.6	7.3
1990	1	4.4	4.4	4.4
1992	2	0.2	0.2	0.2
1994	1	1.0	1.0	1.0
1996	48	7.4	0.5	22.0
1997	6	7.5	2.4	11.0
1998	7	7.6	4.2	9.5
1999	1	8.0	8.0	8.0
2001	2	9.8	9.7	9.9
2002	36	5.6	0.2	19.0
2004	26	7.5	0.3	35.0

The analysis sought to demonstrate a clear relationship between nitrate levels and well depth. However, graphed results for all years and only the most recent decade do not show any clear relationships. This is likely because the productive fractures from which a well draws water may occur at any depth, deep wells may still only grout to levels that still permit near surface groundwater in the alluvium to enter, or nearby shallower wells or those grouted to an insufficient depth, may provide a direct conduit permitting nitrate contamination to propagate deeper in the crystalline, bedrock aquifer from which a well pumps.

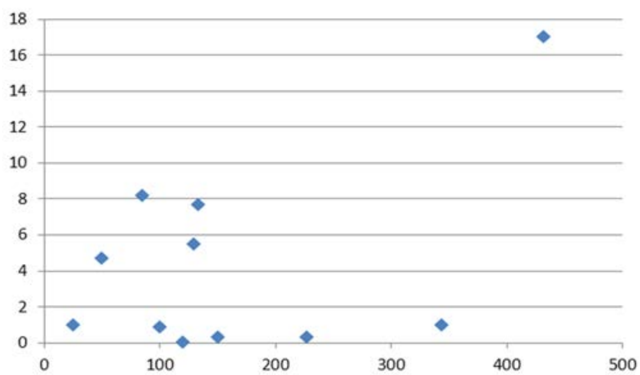


Figure 27. NO3-N mg/L v. Well Depth (2002 and 2004 data only)

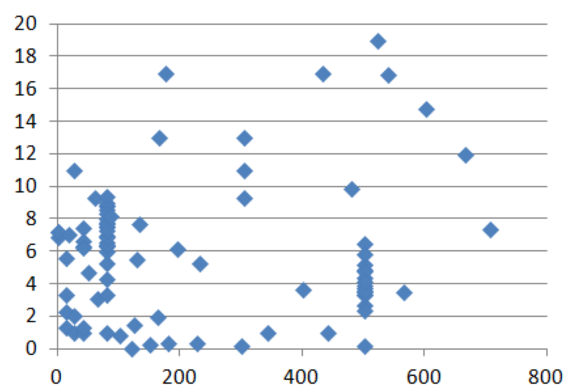


Figure 26. NO3-N mg/L v. Well Depth (All Years)

Considering the data limitations mentioned, time series graphs substantiate the statistical results in Table 3 that nitrate concentrations in high-density development continue to trend upward, as demonstrated in Figure 29.

Figure 28. Time Series of Nitrate (NO3-N) Concentrations in Wells in Parmalee Gulch IHWD and Private Wells (mg/L)

There is no apparent seasonal affect on groundwater Nitrate concentrations during any month, which may indicate that wells are drawing water from more permanent supplies rather than from base flow reservoirs that tend to rise with spring runoff and slowly drain into perennial surface waters. Surface waters do tend to be more diluted in spring runoff per Yesavage 2008, Bossong 2003, and other comparisons of both surface and groundwater data. There also was no apparent pattern related to geologic type, which may also be partially due to the generalized nature of the map, which cannot demonstrate localized complexity of co-mingled rock types (Caine 2003).

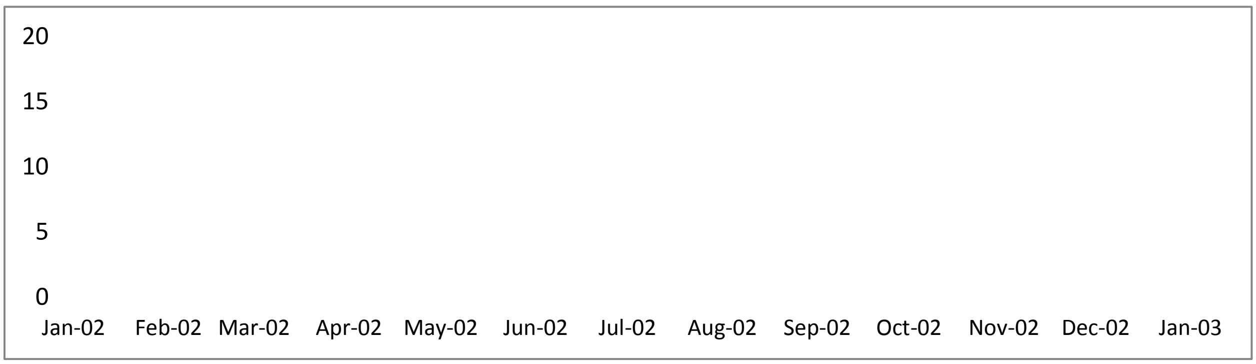


Figure 29. 2002 NO3-N concentrations in wells by month (mg/L)

Only in June 2002 were more than a few different wells tested for nitrates, during an exceptional drought. Although not enough data was taken late in the season to be certain, it does not appear that lack of dilution from limited recharge seemed to increase nitrate levels in groundwater as might have been anticipated. In fact, using only the deeper groundwater sources available after the base flow reservoir was exhausted and less OWTS effluent reaching groundwater appears to have potentially reduced late season year nitrate levels. This would need to be verified by taking more synoptic reading over a larger geographic area in wells of know screening distances below ground surface and well depths at different seasons of the year and in both dry and wet years.

Since data was not consistently collected at the same location over time and since results tended to increase over time, it was determined that to provide the best coverage and most conservative estimate of actual nitrate concentrations in groundwater, all data in all years was used, selecting the maximum value obtained at each location. Locations tested are shown in Figures 31 and 32 and the resulting inverse distance weighted interpolation of values is shown in Figure 33. Figure 33 was masked to eliminate extrapolation beyond 1000 feet from any measured well point to reduce misinterpretation. Results were summarized for the upper and lower high-density analysis areas (Figures 36 & 37) for which the most even and complete sampling coverage was available. The upper zone average nitrate concentration in groundwater was estimated at 8.8 mg/L and the lower zone at 8.0 mg/L. Patterns demonstrated less nitrates on upslope areas in areas of low development and highest nitrate concentrations in close proximity to Parmalee Gulch and higher-density development in flatter valley areas.

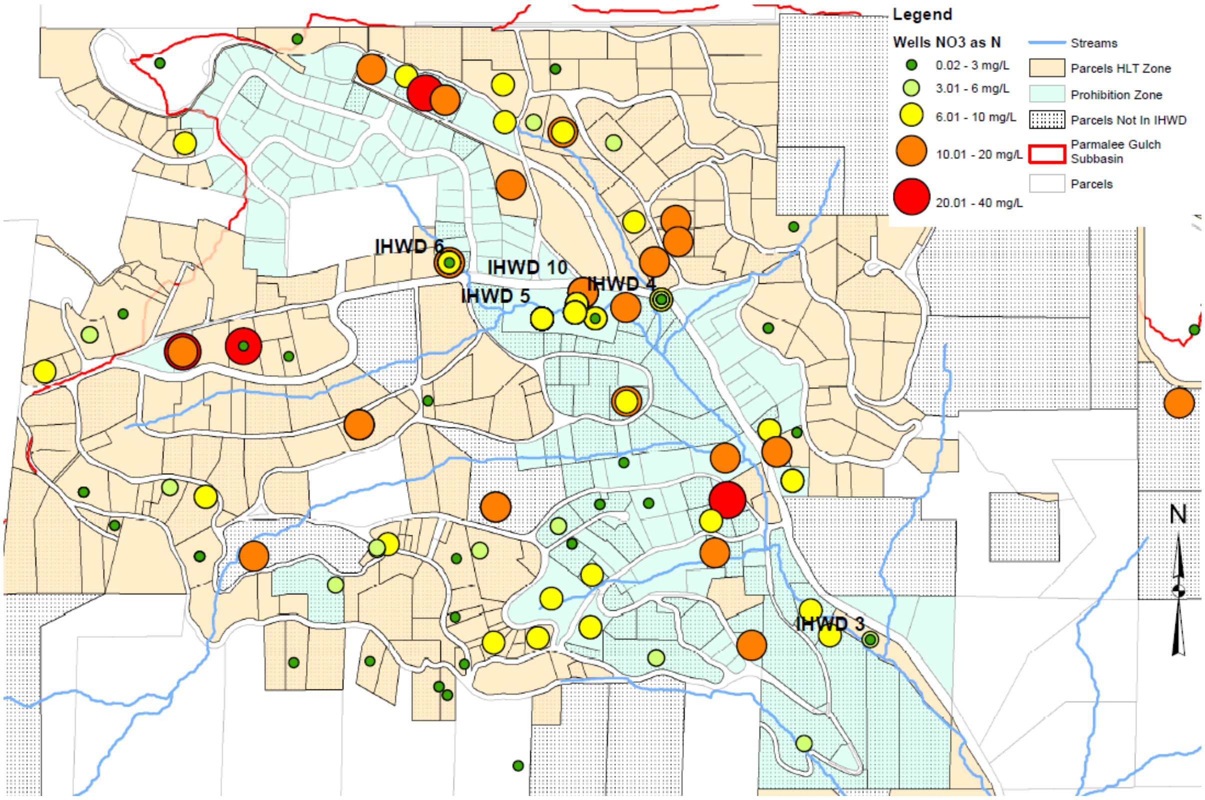


Figure 30. Indian Hills Nitrate Concentrations in Wells All Years (Upper Analysis Zone)

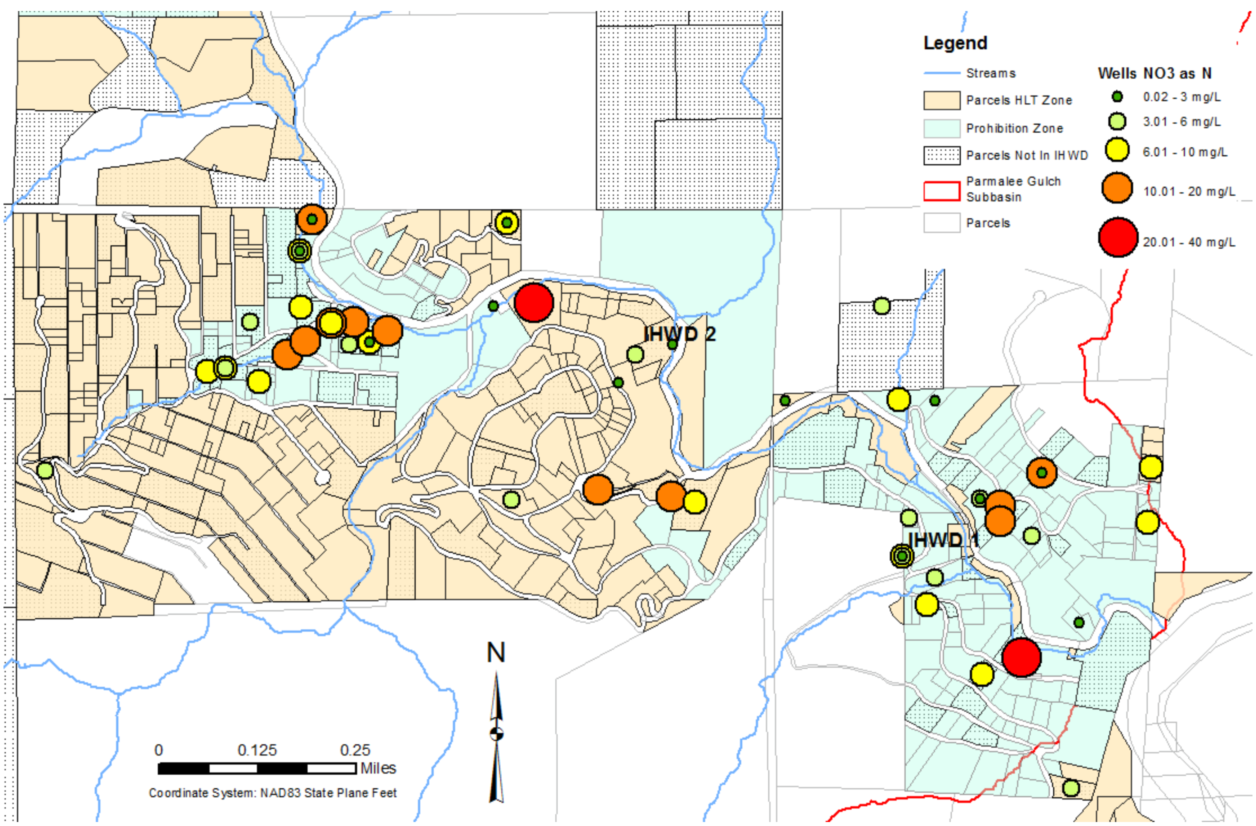


Figure 31. Indian Hills Nitrate Concentrations in Wells All Years (Lower Elevations to the East)

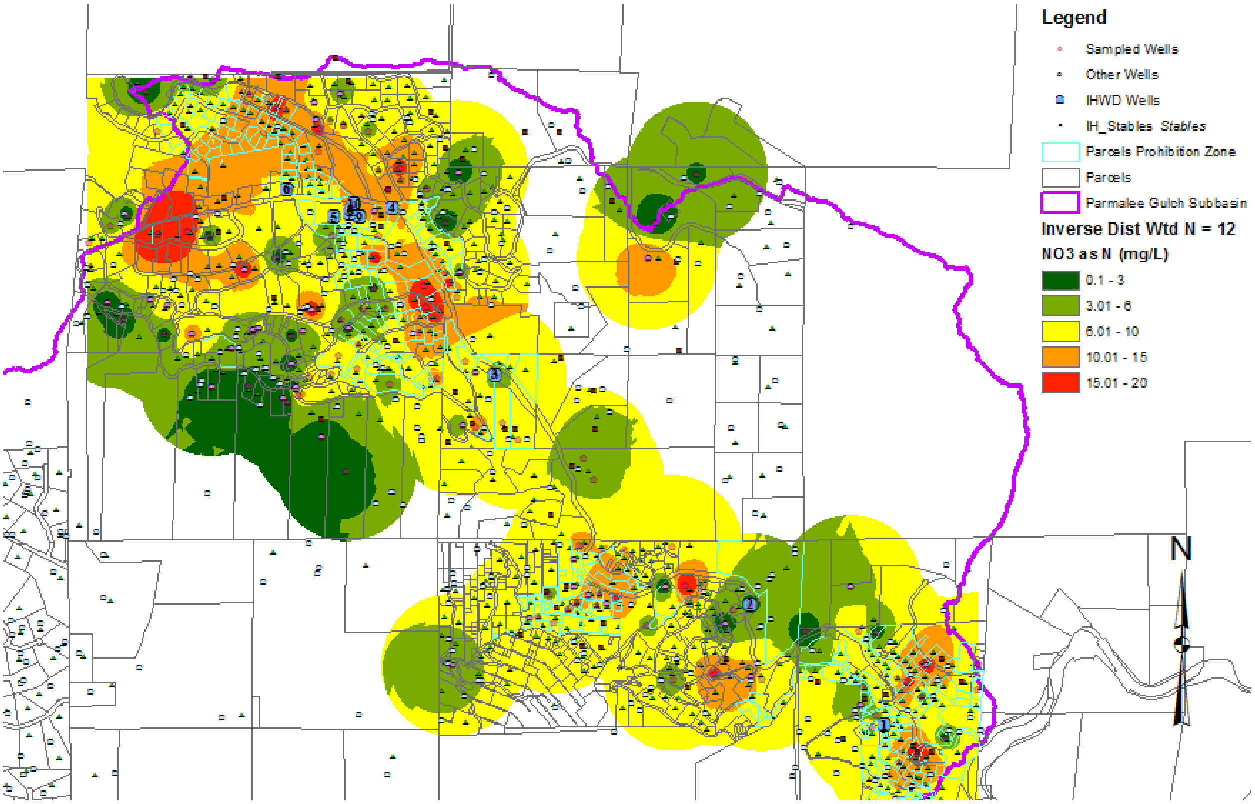


Figure 32. Indian Hills Inverse Distance Weighted Interpolation - All Years (Higher Elevations to the North)

2.2 ArcMap Development Analysis Tool

In the original scope, the objective had been assumed to examine each property for development to recommend a minimum lot size that would be protective of groundwater given the larger parcel conditions on which a subdivision would occur based on the methods of Taylor 2003. To this extent in July 2015, an extension for ArcMap was created to directly incorporate the spreadsheet model this study had developed to recommend lot sizing for any parcel selected. All parameters could be adjusted and an automated map created from the results. Instructions for Use and the ArcMap *.mxd file that includes the Visual Basic extension developed as a new toolbar item are provided in study materials provided. One useful result was a resulting graphing exercise of how any simple mass balance model might demonstrate nitrates to increase with decreasing lot size as shown in Figure 34.

Results indicate that OWTS at normal use rates of 75 gpcd at even 2 acres is not likely to maintain long term steady state nitrates in groundwater levels below 10 mg/L. However, HLT OWTS that can reduce nitrates in half would more likely be able to maintain loading to acceptable rates.

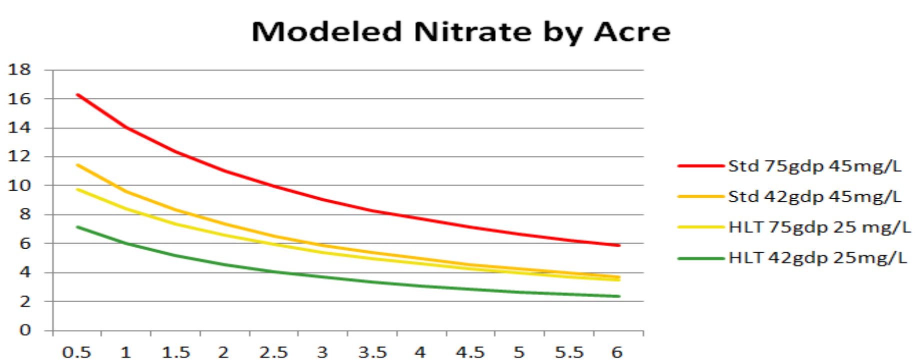
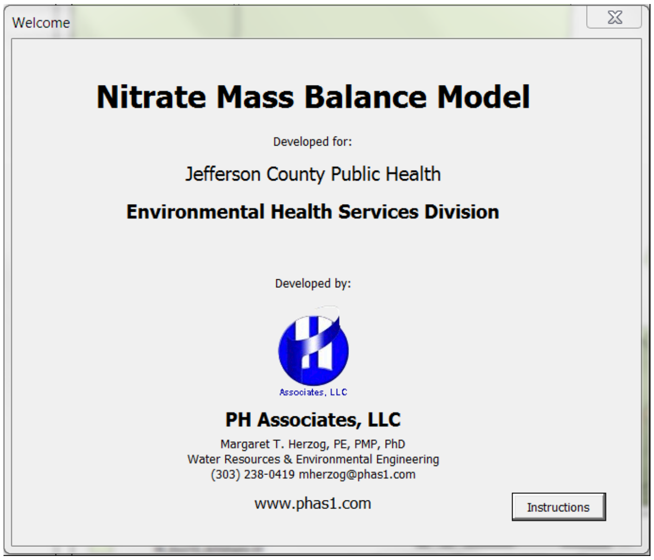
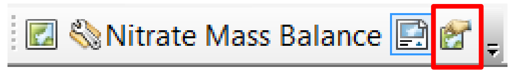


Figure 33. Taylor 2003 Modeled NO3-N (mg/L) Estimated Results by Lot Size in Acres





Although the Nitrate Mass Balance model worked as designed to exactly replicate the Taylor 2003 method to demonstrate potential loading from development of any new larger parcel by subdividing it into smaller lots of a size to prevent nitrate contamination above 10 mg/L, upon demonstration to JEHS staff, they determined this did not answer the overall question of actual impacts of all new development anywhere in the subbasin and in particular effects on area groundwater quality to answer the question if development at 1 acre lots could be permitted.

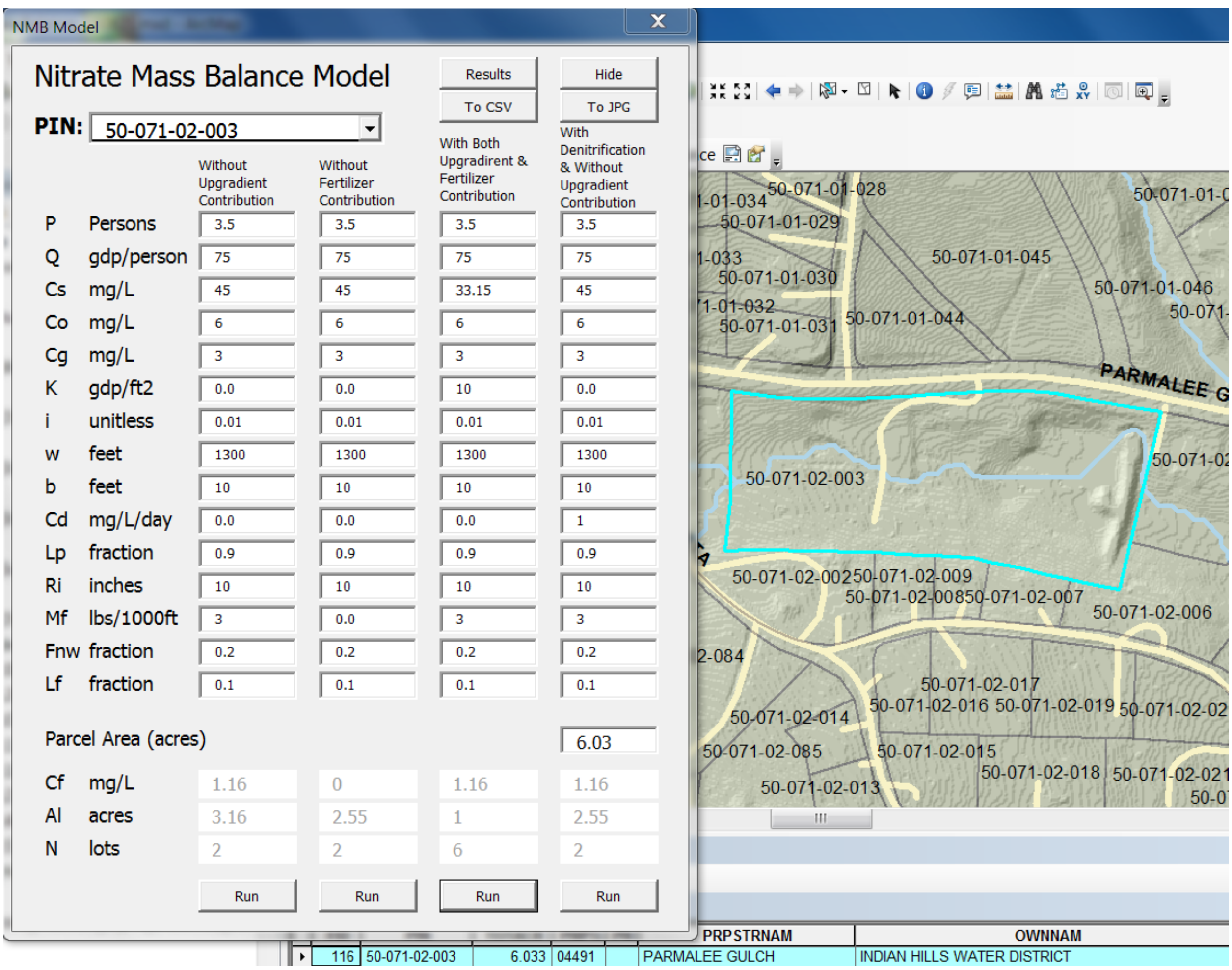


Figure 34. Nitrate Mass Balance Model ArcMap Extension Developed to Replicate Taylor 2003 Method

2.3 Parcel-level Spreadsheet Mass Balance Model Analysis

Therefore, the revised question was determined to be if Parmalee Gulch Subbasin nitrate concentrations would increase if new developments with onsite wastewater treatment (OWTS) are allowed. In order to visualize those increases, a nitrate mass balance model was developed and calibrated to Parmalee Gulch Subbasin specific parameters and types of systems. Based on the original analysis from Taylor 2003 applied in the ArcMap extension developed to determine recommended lot size for any parcel under development consideration, a parcel-based analysis of high-density lower and upper analysis areas, and for the entire Parmalee Gulch subbasin overall, were performed under current build out and under likely development scenarios. For standard OWTS the model was calibrated at 40 mg/L for wastewater nitrate-nitrogen effluent concentration and for high efficiency OWTS the model was calibrated at 20 mg/L. Household usage rates reported under normal conditions by Dano 2004 and Standard 2010 and used in JEHS OWTS regulations of 75 gpcd were adopted, but since IHWD indicated that its users were more likely to use less, 42 gpcd were also considered in sensitivity analysis, but at higher strength of waste of 60 mg/L. The most recent CDM 2011 UMC study was adopted to estimate recharge rates, expected consumptive use, and percent of OWTS effluent reaching groundwater based on previous Turkey Creek Studies, as discussed.

To provide a more conservative and accurate estimate than regional studies had indicated previously, two zones of analysis were developed, representing the Upper Prohibition Zone and Lower Prohibition Zone including high-density upslope parcels as shown in Figures 36 and 37. Jefferson County Planning and Zoning (P&Z) had conducted an analysis of likely development throughout these areas by determining all owners who appeared to own two or more adjacent parcels from which lots could be gathered to form one or more "new" residential parcels without existing development of more than one acre (parcel merge method - gather undeveloped lots from adjacent parcels under common ownership to form a "new" parcel greater than one acre in size – merge undeveloped lots from adjacent parcels to create a new parcel). They also examine all existing parcels greater than two acres from which lots free of existing development could be subdivided to generate additional developable parcels of one acre or more (parcel split method - split an existing parcel into two or more parcels by gathering the adjacent undeveloped lots into a group or groups of lots totaling one or more acres to create "new" parcels). In addition to these likely developments, other large parcels that could be split and smaller parcels that might be merged under less likely conditions were analyzed to estimate potential future full build-out scenarios. Figures 36 and 37 indicate the results of this analysis after the researcher carefully verified from the original P&Z shapefile how many were actually developable to retain at least an acre per parcel. Under current development standards, this exercise would not be valid, but only because the original lots were subdivided before 1972 in Indian Hills, the 2013 JEHS OWTS regulations would not apply, as these lots could be grandfathered in, should the Prohibition Zone be lifted. New regulations provide for more assurance that STA are properly sited and dosed, filtered, and supervised with required cleanouts. New technologies also permit more cost-effective HLT in the tank or even better, source separation of human waste through waterless toilets based on composting or incineration or a growing number of newer technologies, both methods of which nitrates could be substantially reduced or in the latter case, nearly eliminated. Therefore, this study was also to be used to determine how to reduce risks by determining what additional precautions might be needed, if lot sizes of one acre could be permitted under somewhat more restricted circumstances.

In the following sections, details of each calculation employed, the scenarios analyzed, and the sensitivity analysis performed will be detailed. Results should assist in building a case for not only potential development scenarios, but based on the prior analysis of each GIS data layer representing a variety of community factors, other ways that existing OWTS and wells could be improved to reduce nitrates by a variety of judicious, proactive mechanisms. All research conducted in the Turkey Creek subbasin and Indian Hills / Parmalee Gulch and at regional scales were used to inform the parameters chosen in the model (see highlights for each by reference in this document and consolidated in Appendix A). GIS layers and data provided by the various entities included were used to refine results to the parcel-level to the extent possible.

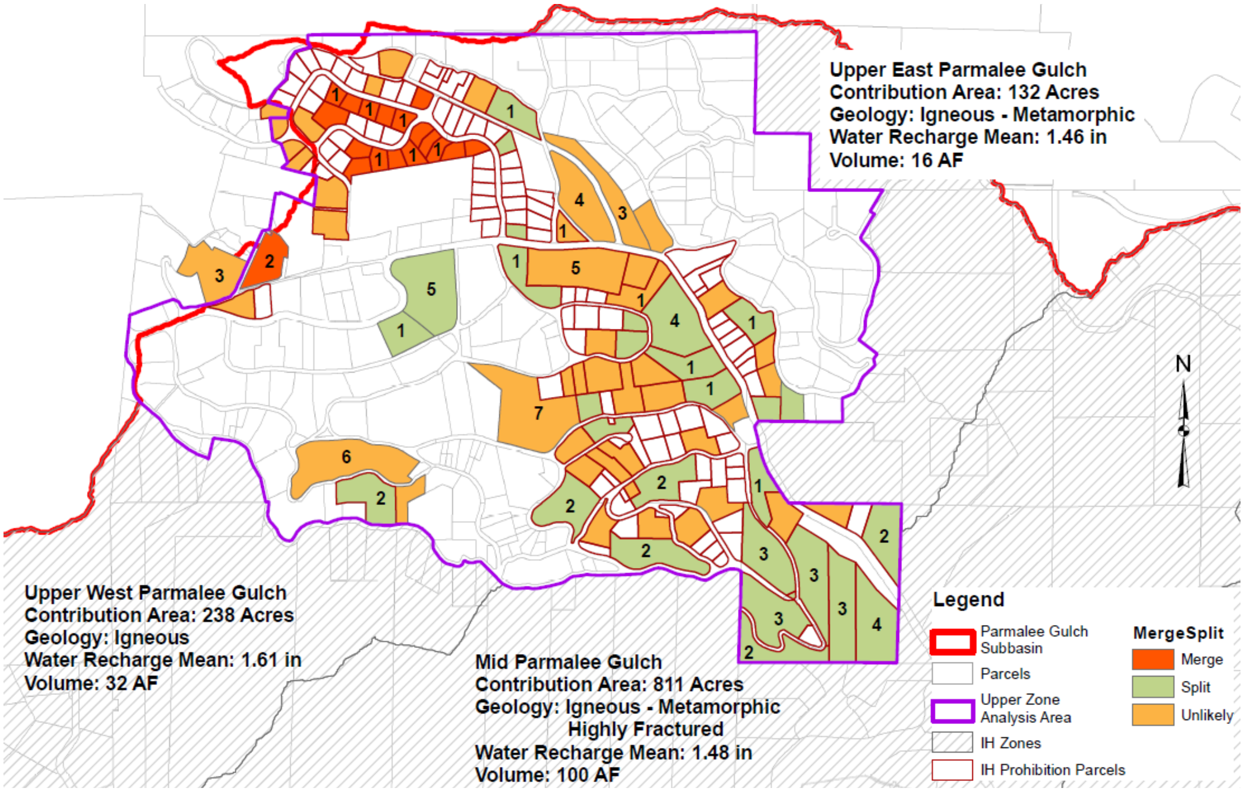


Figure 36. Upper Zone HD Analysis Area with Potential Development and Surrounding Groundwater Contribution Areas

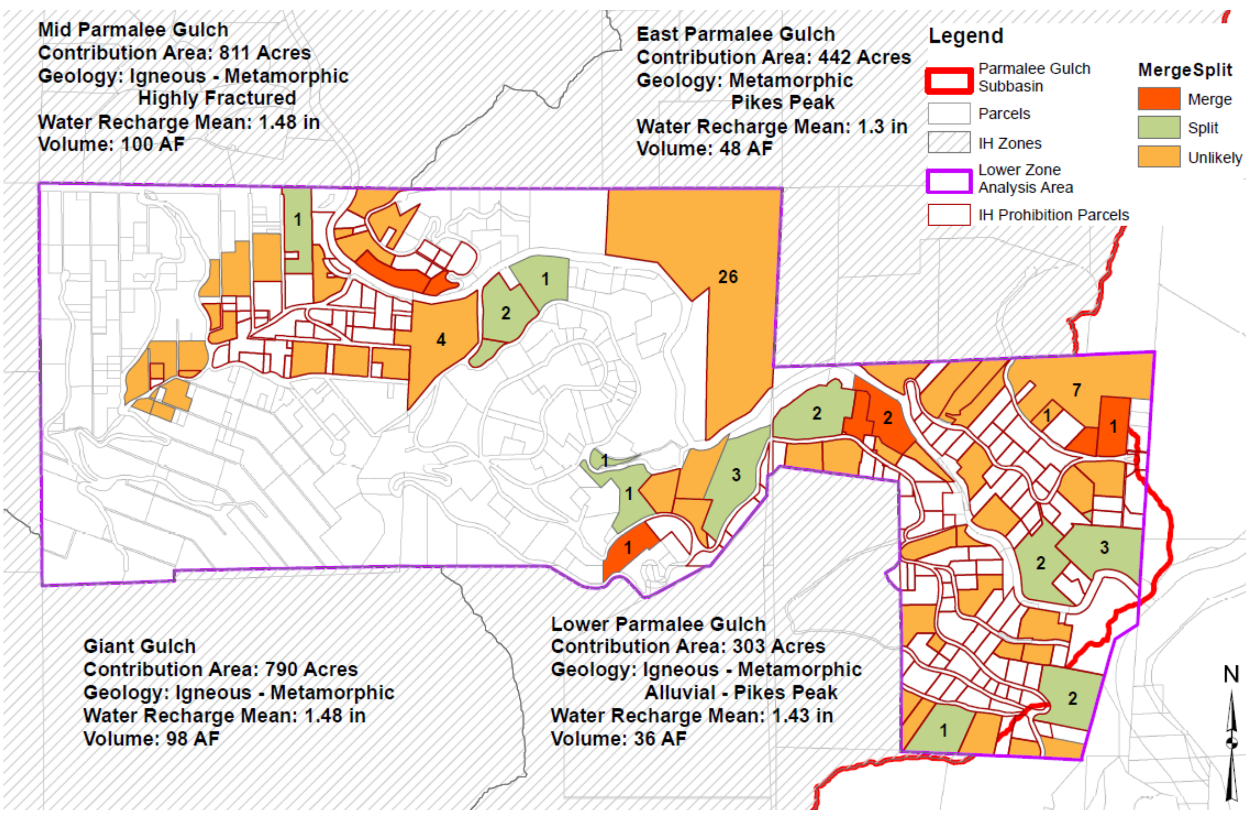


Figure 35. Lower Zone HD Analysis Area with Potential Development and Surrounding Groundwater Contribution Areas

2.3.1 Calculating OWTS Contributions to Groundwater

The volume of OWTS effluent contributed to groundwater and its concentration of nitrates as NO3-N was determined using the following formula based on Taylor, 2003 and CDM, 2011, both based on a compilation of several other prior research and analysis exercises.

First the volumetric contribution of OWTS and Recharge over each parcel were calculated:

$$V_{OWTS} = F_{ncu}\ x\ F_{2gw}\ x\ P_{hh}\ x\ Q_{gpcd}\ x\ CF_{ncu}$$

where:

$V_{OWTS} - Parcel - level\ Volume\ Contribution\ from\ Each\ OWTS\ to\ Groundwater$ (AFY)
$F_{ncu} - Fraction\ non - consumptive\ use - portion\ reaching\ the\ STA$ (0.804 Standard 2010)
$F_{2gw} - Fraction\ reaching\ the\ groundwater$ (0.52 CDM 2011)
$P_{hh} - Population\ per\ Household\ per\ Census\ and\ County\ Indian\ Hills\ Statistics$ (2.33 Census)
$Q_{gpcd} - Volume\ in\ gallons\ per\ day\ per\ capita\ residential\ use$ (75 gpcd avg, 42 gpcd low flow)
$CF_{ncu} - Conversion\ factor\ from\ gpd\ to\ AFY$ (892.72)

$$V_{Recharge} = L_p\ x\ \ A\ \ x\ R_i\ \ x\ \ CF_{i2f}$$

where:

$V_{Recharge} - Parcel - level\ Volume\ Recharge\ to\ Groundwater\ in\ an\ Average\ Year$ (AFY)
$L_p\ - Fraction\ of\ Parcel\ that\ is\ permeable$
$A - Parcel\ Area\ in\ Acres$
$Ri - Average\ Groundwater\ Recharge\ Rate\ in\ inches/yr$
$CF_{i2f}\ - Conversion\ factor\ from\ inches\ to\ feet$

$$L_p = 1 - \frac{A_{dvwy} +\ A_{str}}{A\ x\ CF_{Ac2sf}}$$

where:

$L_p\ - Fraction\ of\ Parcel\ that\ is\ permeable$
$A - Parcel\ Area\ in\ Acres$
$A_{dvwy}\ - Areas\ of\ driveway, ft$
$A_{str}\ - Area\ in\ structure, ft$
$CF_{Ac2sf}\ - Conversion\ factor\ from\ acres\ to\ square\ feet$(43560)

$$C_{gw} = \frac{V_{OWTS}\ \ x\ \ C_{owts} +\ V_{Recharge}\ x\ C_{Recharge}}{V_{OWTS} +\ V_{Recharge}}$$

where:

$C_{gw} - Parcel - level\ Averaged\ Concentration\ of\ NO3 - N\ \ (mg/L)\ to\ groundwater$
$V_{OWTS} - Parcel - level\ Volume\ Contribution\ from\ Each\ OWTS\ to\ Groundwater$ (AFY)
$C_{owts} - Concentration\ of\ NO3 - N\ in\ OWTS\ STA\ effluent\ NO3 - N\ \ (mg/L)$
$V_{Recharge} - Parcel - level\ Volume\ Recharge\ to\ Groundwater\ in\ an\ Average\ Year$
$C_{Recharge} - Concentration\ of\ NO3 - N\ in\ Recharge\ NO3 - N\ \ (mg/L)$

To calculate an average Concentration over the entire upper and lower zones of analysis as well as for Parmalee Gulch as a whole reported in Tables 5 and 6 that summarize results, results of the analysis were summed as:

$$C_{gwTotArea} = \frac{\sum(V_{OWTS}\ x\ C_{owts} + V_{Recharge}\ x\ C_{Recharge})}{\sum(V_{OWTS} + V_{Recharge})}$$

where:

$C_{gwTotArea} - Averaged\ concentration\ of\ NO3 - N\ over\ analysis\ area\ (\frac{mg}{L} NO3 - N)$

$V_{OWTS} - Parcel - level\ Volume\ Contribution\ from\ Each\ OWTS\ to\ Groundwater$ (AFY)

$C_{owts} - Concentration\ of\ NO3 - N\ in\ OWTS\ STA\ effluent\ (\frac{mg}{L} NO3 - N)$

$V_{Recharge} - Parcel - level\ Volume\ Recharge\ to\ Groundwater\ in\ an\ Average\ Year$

$C_{Recharge} - Concentration\ of\ NO3 - N\ in\ Recharge\ (\frac{mg}{L} NO3 - N)$

2.4 Scenario Analysis

Parcel-level mass balance analysis summarized potential nitrate increases in the vicinity of already high-density lower and upper zones of development as designated in Figures 36 and 37 in Section 2.3. Under current build out conditions results of the simple mass balance analysis outlined in Section 2.3 indicate that nitrate levels are estimated at about 10.5 mg/L in the upper analysis zone and about 9.8 mg/L in the lower analysis zone. This analysis does not include potential dilution analysis of either upstream recharge areas, upslope parcels, or potential groundwater inflow upgradient of each parcel in these analysis zones. Nevertheless, actual NO3-N concentrations calculated from zonal statistics averaged over the area from maximum NO3-N readings at each well test location in all years result in average levels in the upper zone of 8.8 mg/L and lower zone of 9.0 mg/L, which are only about 0.8 to 1.7 mg/L lower than estimated by the mass balance analysis. Also IHWD reports that the upper zone nitrates in their wells are actually from 12-20 mg/L, so current levels are probably closer to those estimated through the analysis now than the data from 1970-2002, which did indicate an increasing trend. Synoptic nitrate tests in wells through a coordinated IHWD and community effort as part of a Source Water Protection effort would be the best way to verify these results. Repeating the 1970 and 1990 intensive groundwater and surface water analysis by 2020 as reported in Bossong 2003 would be an even more comprehensive way to determine if the increasing trend in contamination continues.

Permitting only High Level Treatment (HLT) OWTS under likely development (single owner merging-two-adjacent-parcels or splitting-a-greater-than-2-acre-parcel to create another 1-acre parcel for residential development) nitrate increases about 0.5 mg/L NO3-N, and increase near 1 mg/L NO3-N, if the high-density areas were allowed to be more fully developed to include more potential 1 acre lots that would be less likely to develop immediately. Results seem to recommend that standard OWTS should not be permitted, even for replacement, since the analysis indicates a more substantial increase of 2-3 mg/L NO3-N for this type of development in high density area. As the recently updated JEHS OWTS regs indicate in Table 4.1 on page 22, OWTS are no longer permitted on such small unincorporated lots.

Table 4. Jeffco OWTS Regulations, Table 4-1 Minimum Building Site Sizes

SOURCE OF POTABLE WATER	DATE WHEN LOT OR BUILDING SITE WAS CREATED		
	Before Nov. 10, 1973	Between Nov. 10, 1973 and Dec. 5, 1977	After Dec. 5, 1977
Individual wells, potable springs or cisterns	1 acre	2 acres	5 acres (3.5 acres if per Section 4.2.C
Public water system	0.5 acre	1 acre	1 acre

Unfortunately, these newer regulations do not apply to the building sites in question in the Indian Hills Filings that occurred prior to 1973. However, the research presented in this report demonstrates greater risks if effluent from any OWTS, even a new one, preferentially flows from a near surface fracture (or unused well) directly to groundwater used by another area well. There may be more likely impacts of further development on local availability of groundwater supplies in these high-density areas of development along the valley floor, since fracture connectivity and thus overall groundwater volume availability at any specific location is unknown. As also indicated in Table 4, there is somewhat less risk, if, rather than private wells, new development uses Indian Hills Water District (IHWD) water because it is partially imported from upstream along Turkey Creek, tested for quality, and IHWD may better ensure long-term delivery, reducing water quality and quantity risks to the entire community.

In the Table 5 summary of potential development, the results for the Current Build-out, which carefully includes all *existing HLT* systems (79 total). Analysis not shown, but included in the Spreadsheet model folder analysis of scenarios details, without having 42 HLT OWTS in the upper zone and 25 HLT in the lower zone of analysis, current levels of NO3-N under current build-out conditions would have been about 1.0 mg/L or 0.5 mg/L higher respectively, demonstrating how HLT kept these areas from more decidedly crossing the 10 mg/L NO3-N EPA MCL threshold. This analysis does not demonstrate that in reality the impact of HLT would likely be much greater under site-specific monitoring because standard OWTS do not receive annual maintenance to catch problems early and would be affect by difference in soil saturation and temperature throughout the year, as demonstrate by DANO 2004 in which a plume of effluent traveled many meters during spring run off, whereas in-tank pre-treatment would not be as greatly affected by external conditions. HLT further protect groundwater by already reaching levels close to the EPA standard *before* effluent is released to the soil, so if a particular OWTS has more direct connectivity through fractures or direct conduit through improperly maintained or unused wells nearby, it does not need as much dilution to reach safe levels. HLT biological action normally used in the most popular systems today would also reduce a variety of other harmful constituents that could be found in OWTS effluent that are not monitored including household chemicals, medication, hormones, personal care products, and other emerging contaminants.

The potential dilution factor lines in Table 5 are found in the “W Recharge US” tab of the related SS Models. This attempts to factor in potential dilution from upslope areas rather than only considering OWTS contributions and recharge under the high-density analysis areas themselves. These results align well with actual nitrate readings.

Table 5. Summary of Upper and Lower High-Density Development Analysis Affect on NO3-N Levels in Groundwater

Upper Zone of Analysis	Upper High-Density Analysis Area of Parmalee Gulch - Headwaters								
Analysis Zone	In Upper Prohibition Zone			Outside Prohibition Zone					
Dvp Type	merge	split	unlikely	merge	split	unlikely	vacant	Total	Likely
Parcel Count	7	17	3	1	3	4	6	41	28
Num New OWTS	7	36	7	2	8	20	23	**103**	**53**

Lower Zone of Analysis	Area of Parmalee Gulch - Downstream								
Analysis Zone	In Lower Prohibition Zone			Outside Prohibition Zone					
Dvp Type	merge	split	unlikely	merge	split	unlikely	vacant	Totals	Likely
Parcel Count	1	7	2	2	3	1	12	28	13
Num New OWTS	1	13	30	3	5	7	27	**86**	**22**

Outside Analysis Zones	vacant
Parcel Count	24
Num New OWTS	406

Upper Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates

	Current Build Out NO3-N =		10.5 mg/L	from 268 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	103	53	Number new STD OWTS	103	53
NO3-N mg/L	11.4	11.0	NO3-N mg/L	13.2	12.2
Overall Concentration Increase	0.9	0.5	Overall Concentration Increase	2.7	1.7

With Potential Dilution Factor	8.5	mg/L Buildou	9.4 mg/L All HLT Development	0.9	mg/L nitrate increase

Lower Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates

	Current Build Out NO3-N =		9.8 mg/L	from 210 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	86	22	Number new STD OWTS	86	22
NO3-N mg/L	10.6	10.1	NO3-N mg/L	12.1	10.5
Overall Concentration Increase	0.8	0.3	Overall Concentration Increase	2.3	0.7

With Potential Dilution Factor	5.9	mg/L Buildou	6.6 mg/L All HLT Development	0.7	mg/L nitrate increase

2.5 Additional Mass Balance Model Sensitivity Analysis

The first section in Table 6 demonstrates how a Parmalee Gulch wide basin analysis provides non-conservative results that are no longer compatible with actual nitrate concentrations experienced in areas of high density. Using an analysis of all parcels in the subbasin rather than isolating upper and lower high-density analysis areas, nitrates would only reach about 5.6 mg/L on average and likely development would have an almost immeasurable affect. However, even with HLT on all new potential development, including currently vacant land on steeper slopes, nitrates could increase by over 1 mg/L NO3-N overall, though still remain below the 10 mg/L EPA standard.

Additional Sensitivity Analysis was used to determine if lower flow of 42 gpcd (about 98 gpd / household) as reported by IHWD might affect the analysis, though other data from Dano 2004, Stannard 2010, and Jeffco OWTS regulations substantiate the standard 75 gpcd rate used. Since lower flows would likely increase concentration of nitrates, a nitrate concentration of 60 mg/L rather than 40 mg/L was used in the analysis, since human waste and other primary source of nitrates would not diminish, only increase in concentration with lower household dilution. With lower flow and higher concentration, results remained relatively the same as shown in Table 6.

Table 6. Upper and Lower Zone Scenario Sensitivity Analysis

Parmalee Gulch Overall Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates

	Current Build Out NO3-N =		5.6 mg/L	from 740 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	595	75	Number new STD OWTS	595	75
NO3-N mg/L	6.9	5.6	NO3-N mg/L	8.8	5.9
Overall Concentration Increase	1.3	0.0	Overall Concentration Increase	3.2	0.3

This is not a conservative analysis, as it spreads contamination evenly over entire subbasin, rather than in concentrated, high-density areas and includes large, undeveloped recharge areas that contribute 328 AF of dilution to 149 AF recharge in general vicinity of development
This reflects analysis of average recharge; in dry years or under expected climate change, recharge may be less or even in negative some years.

Upper Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates (Low Flow, Higher Conct)*

	Current Build Out NO3-N =		10.1 mg/L	from 268 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	103	53	Number new STD OWTS	103	53
NO3-N mg/L	11.3	10.7	NO3-N mg/L	13.0	11.8
Overall Concentration Increase	1.2	0.6	Overall Concentration Increase	2.9	1.7

Lower Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates (Low Flow, Higher Conct)*

	Current Build Out NO3-N =		9.4 mg/L	from 210 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	86	22	Number new STD OWTS	86	22
NO3-N mg/L	10.4	9.6	NO3-N mg/L	11.9	10.0
Overall Concentration Increase	1.0	0.2	Overall Concentration Increase	2.5	0.6

*This Scenario reduces gpcd from 75 to 42 and increases OWTS discharge concentrations from 40 to 60 mg/L NO3-N
At the census estimated populations used of 2.33 persons per household, usage per OWTS reduces from about 175 gpd to 98 gpd

Upper Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates (75% not 52% to GW)

	Current Build Out NO3-N =		13.2 mg/L	from 268 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	103	53	Number new STD OWTS	103	53
NO3-N mg/L	14.1	13.7	NO3-N mg/L	16.3	15.2
Overall Concentration Increase	0.9	0.5	Overall Concentration Increase	3.1	2.0

Another possibility, especially based on the low levels of nitrates in exiting surface water from Parmalee Gulch despite high groundwater levels, is that a greater than 52% of the OWTS STA effluent is actually reaching the groundwater. Using an alternative of 72% OWTS effluent reaching the groundwater would increase nitrates about 3 mg/L.

Lower Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates (75% not 52% to GW)

	Current Build Out NO3-N =		12.5 mg/L	from 210 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	86	22	Number new STD OWTS	86	22
NO3-N mg/L	13.3	12.7	NO3-N mg/L	15.2	13.3
Overall Concentration Increase	0.8	0.2	Overall Concentration Increase	2.7	0.8

*This Scenario increases leachate percentage reaching groundwater from 52% from UMC 2011 to 75%

Upper Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates (only 0.5 mg/L in Nrecharge)

	Current Build Out NO3-N =		10.1 mg/L	from 268 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	103	53	Number new STD OWTS	103	53
NO3-N mg/L	11.1	10.6	NO3-N mg/L	12.8	11.8
Overall Concentration Increase	1.0	0.5	Overall Concentration Increase	2.7	1.7

Lower Zone of Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates (only 0.5 mg/L in Nrecharge)

	Current Build Out NO3-N =		9.5 mg/L	from 210 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	86	22	Number new STD OWTS	86	22
NO3-N mg/L	10.3	9.7	NO3-N mg/L	11.8	10.1
Overall Concentration Increase	0.8	0.2	Overall Concentration Increase	2.3	0.6

Parmalee Gulch Overall Analysis of Nitrates by Parcel-Based Recharge and OWTS to Groundwater Estimates

	Current Build Out NO3-N =		5.7 mg/L	from 740 existing Built Parcels	
	All Dvpmt	Likely Only		All Dvpmt	Likely Only
Number new HLT OWTS	595	75	Number new STD OWTS	595	75
NO3-N mg/L	7.0	5.7	NO3-N mg/L	8.8	5.9
Overall Concentration Increase	1.3	0.0	Overall Concentration Increase	3.1	0.2

This is not a conservative analysis, as it spreads contamination evenly over entire subbasin, rather than in concentrated, high-density areas and includes large, undeveloped recharge areas that contribute 328 AF of dilution to 149 AF recharge in general vicinity of development
This reflects analysis of average recharge; in dry years or under expected climate change, recharge may be less or even in negative some years.

Although this analysis would indicate a level of nitrates of about 12-13 mg/L NO3-N could occur if a higher percentage of OWTS was indeed reaching groundwater of about 75%, this may indeed be the case, especially in well-fractured areas or where an unused, older unmaintained, or improperly constructed well is providing a more direct conduit from near-surface groundwater to deeper in the fractured bedrock mountain aquifer. The fact that actual nitrate levels on average are between about 8-9 mg/L NO3-N in these high-density upper and lower areas of development might simply demonstrate that expected dilution from upslope areas is occurring in sufficient quantities to reach this dilution level on average. A more complex analysis that attempted to use Caine 2003 potential permeability values derived by geologic inspection did indicate that significant upslope recharge may occur.

However, locally very close to Parmalee Gulch itself, especially in the Upper Well Field, it is known that nitrate levels are actually much higher, approaching the 12 mg/L or more predicted, if more OWTS STA effluent is locally reaching the groundwater, likely due to the proliferation of wells in the area allowing more direct groundwater pollution. Fractures themselves, albeit often representing torturous routes, may also play their role, especially where highly fractured geology exists closer to the mainstem and tributaries or along the prominent wide, long and deeply fractured zones apparent at ground level.

A final scenario considered if NO3-N mg/L concentrations of 1 mg/L estimated for recharge was too high if reducing levels to just 0.5 mg/L would alter the analysis, but it did not as shown in Table 6.

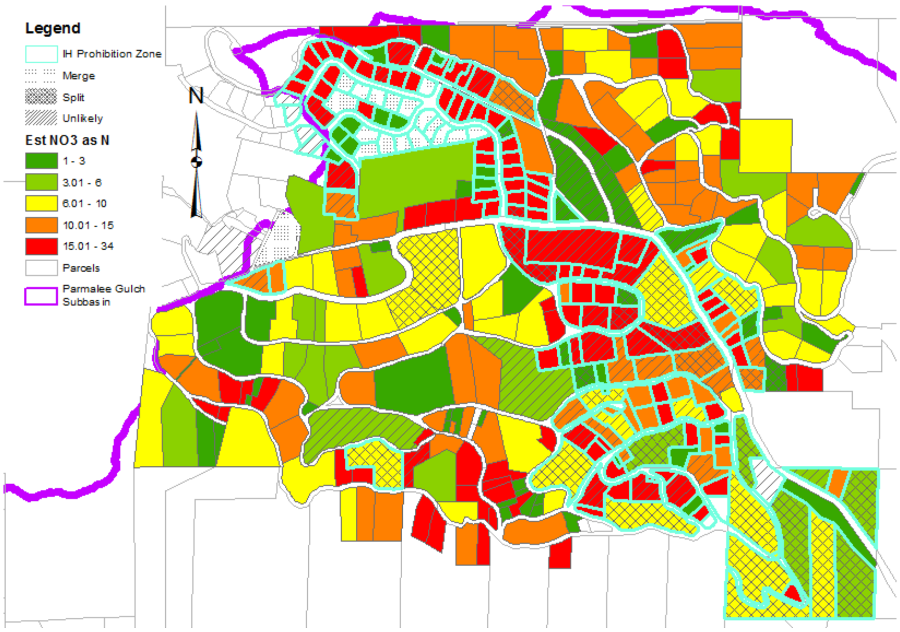


Figure 37. Indian Hills Upper Zone Analysis – Current Build Out

Nitrate concentration levels predicted for the current build out for the Indian Hills Upper Zone of Analysis were classified into a range of five categories from 1 to 3, 3 to 6, 6 to 10, 10 to 15, and over 15 mg/L NO3-N values. The lowest category is represented by the 1 to 3 category and the highest category is represented by 15 and over category. For improved visualization of nitrate concentration levels, a color scheme ranging from dark green to red colors were used. The lowest value represented by color green and color red representing the highest value.

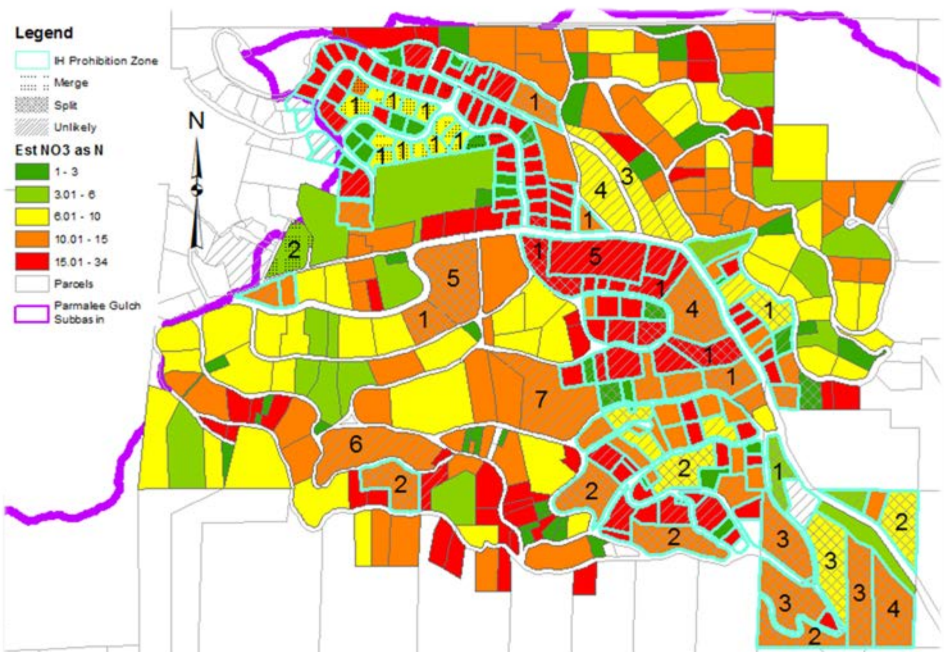


Figure 38. Indian Hills Upper Zone Analysis with HLT OWTS – Probable Future Development (HLT OWTS required)

The above map shows merge, split, and unlikely parcels with probable developable areas as well as the modeled nitrate concentrations requiring HLT systems on all new developable areas.

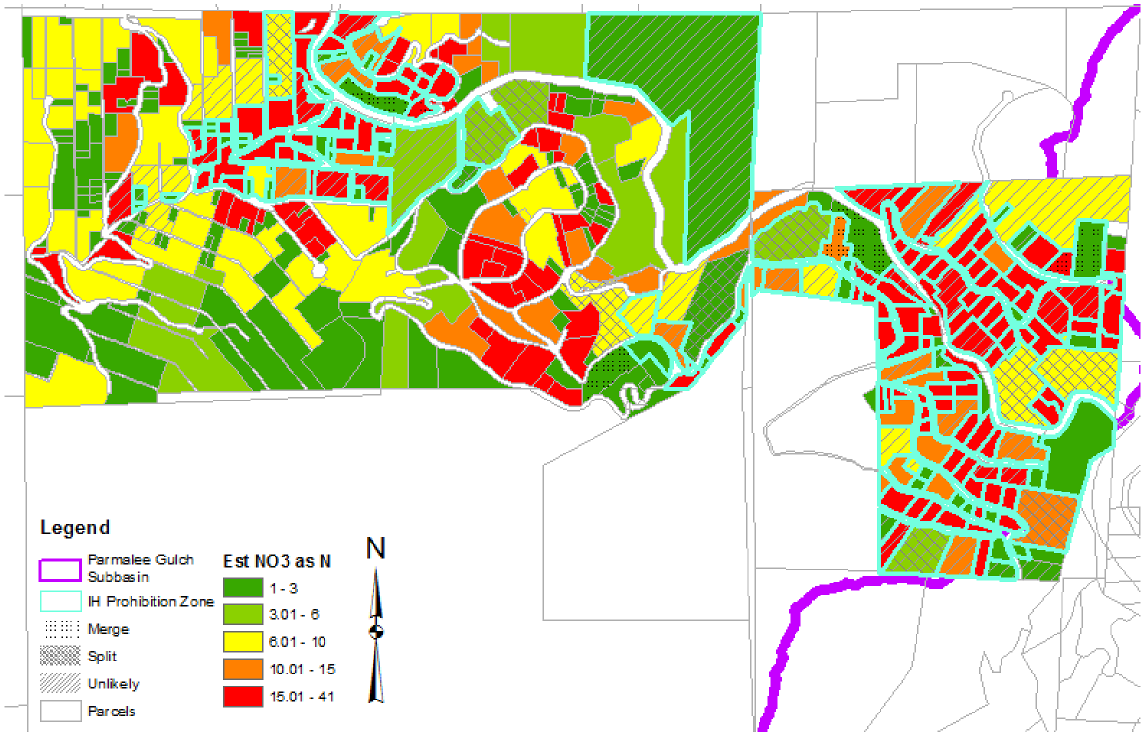


Figure 39. Indian Hills Lower Zone of Analysis – Current Build Out

To have a consistent color scheme and ranges the same color scheme and ranges were used in the modeled nitrate concentrations in the Lower Zone of Analysis.

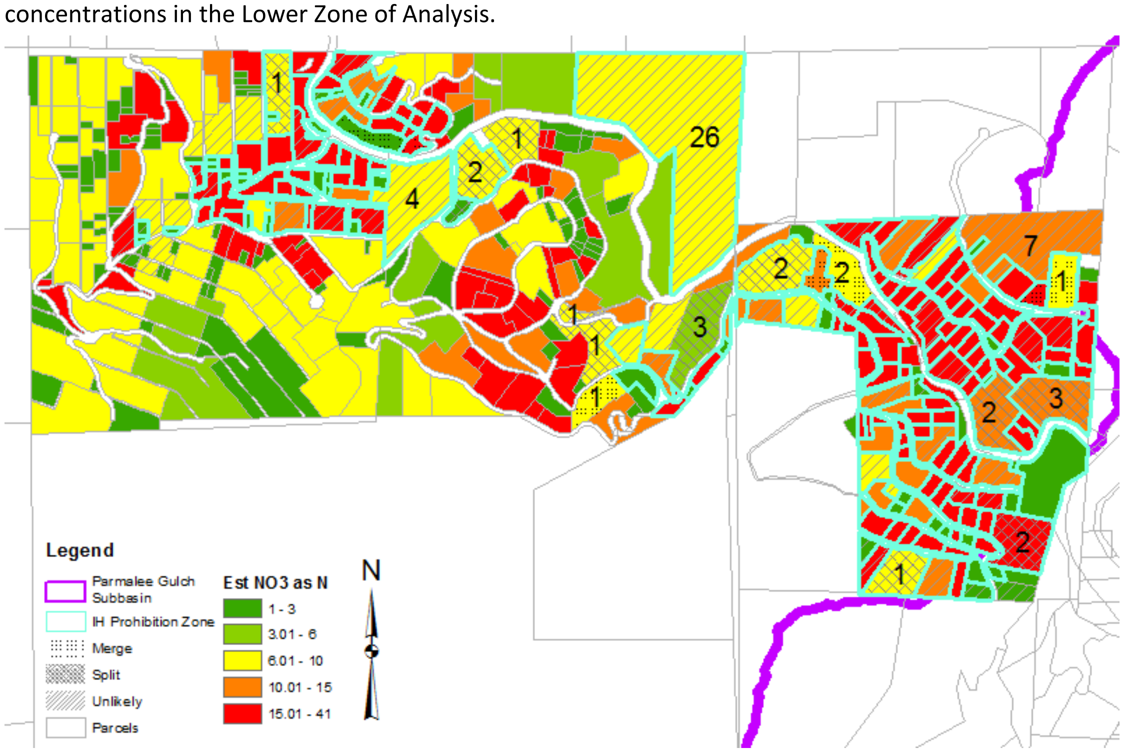


Figure 40. Indian Hills Lower Zone of Analysis – Probable Future Development (HLT OWTS installation required)

2.6 Potential Contribution from Small Acreages that Stable One or More Horses

To estimate the effect of horses and pasture areas, particular within high-density analysis areas, the area of apparent pastures and stable areas was identified from 2012 and 2013 aerial photographs of Parmalee Gulch, as shown in Figure 10 and described in Section 1.9.

Fertilizer contribution were calculated as 10% of the applied recommended fertilizer rate recommended of 30 pounds per acre per year over the apparent lot size in acres plus the discharge rate of a single horse per year, assuming about 10% of each might make it into recharge water over the pasture area, calculated as:

$$C_{ReQPast} = \frac{(A_{past}\ x\ R_i\ \ x\ CF_{i2f})\ x\ F_{2gw}\big(FR\ \ x\ A_{past} + HDR\big)}{V_{ReQpast}}$$

where:

$C_{ReQPast} - Pasture - level\ Averaged\ Concentration\ of\ NO3 - N\ \ (mg/L)\ pasture\ only$
$A_{past} - Pasture\ Area\ in\ Acres$
$CF_{i2f}\ - Conversion\ factor\ from\ inches\ to\ feet$
$F_{2gw}\ - Fraction\ of\ Nitrogen\ from\ Horse\ and\ Pasture\ to\ Groundwater$
$CF_{i2f}\ - Conversion\ factor\ from\ inches\ to\ feet$
$CF_{i2f}\ - Conversion\ factor\ from\ inches\ to\ feet$
$V_{ReQpast} - Pasture - level\ Volume\ Recharge\ to\ Groundwater\ in\ an\ Average\ Year$ (AFY)

$$C_{gwp} = \frac{V_{OWTS}\ \ x\ \ C_{owts} +\ (V_{Recharge} - V_{ReQpast})\ x\ C_{Recharge} +\ V_{ReQpast}\ x\ C_{ReQPast}}{V_{OWTS} +\ V_{Recharge}}$$

where:

$C_{gwp} - Parcel - level\ Averagedc\ Concentration\ of\ NO3 - N\ \ (mg/L)\ with\ pasture$
$V_{OWTS} - Parcel - level\ Volume\ Contribution\ from\ Each\ OWTS\ to\ Groundwater$ (AFY)
$C_{owts} - Concentration\ of\ NO3 - N\ in\ OWTS\ STA\ effluent\ (mg/L)$
$V_{Recharge} - Parcel - level\ Volume\ Recharge\ to\ Groundwater\ in\ an\ Average\ Year$
$C_{Recharge} - Concentration\ of\ NO3 - N\ in\ Recharge\ (mg/L)$
$V_{ReQpast} - Pasture - level\ Volume\ Recharge\ to\ Groundwater\ in\ an\ Average\ Year$ (AFY)
$C_{ReQPast} - Pasture - level\ Averagedc\ Concentration\ of\ NO3 - N\ \ (mg/L)\ pasture\ only$

Results indicate that under a pastures averaging less than 2 acres in the high-density analysis area, a single horse might contribute higher nitrate concentrations in recharge of 32 to 40 mg / L over the pasture area compared to just 1 mg/L used for typical nitrate levels in recharge. Horse contributed estimated nitrate levels translated into a relatively equal effect of its approximately 24 stables with the likely development of 53 likely lots in the upper zone and with just 15 stables to be relatively equivalent to the 26 likely development properties in the lower analysis zone. Therefore, one strategy to essentially offset the potential increase in nitrates likely with development would simply include managing horse properties to maintain grass above four inches across each lot, keeping large animals off wet soils to avoid compaction and runoff to high groundwater recharge areas, and maintaining manure covered and set on a hard surface to avoid leaching nutrients to groundwater and surface water from horse properties, and requiring greater pasture area per horse.

2.7 Dilution Potential from Adjacent Upslope Groundwater

The Scenario Analysis in Section 2.4 demonstrated in Table 5 how areas of recharge surrounding the upper and lower high-density analysis areas in an average year could potentially provide an additional proportion of recharge water to decrease overall nitrate concentrations from upslope areas. The smaller area of recharge for the upper zone of analysis and the lower hydraulic potential in the upper valley near the north edge of the Parmalee Gulch divide to provide upslope recharge is likely why the results of only the high-density area itself still produce a good relative comparison to the actual nitrate well test data, and with recharge added, remained similar in magnitude to the 8.6 mg/L average NO3-N levels calculated. However, although the lower zone has a much greater area of recharge upslope that is relatively undeveloped, either due to the additional contamination from the upper high-density zone comingled with the high potential of less concentrated recharge, it does not reflect a substantially greater nitrate dilution, but instead matches the analysis of the upper zone to be proportionally the same as actual well tests – it was lower in nitrates by about 0.8 NO3-N mg/L both in the well test and the estimated contributions analysis, without showing greater dilution to any significant extent.

Instead of considering only recharge from surrounding parcels and upslope areas, another way to consider groundwater flow is to assume that each parcel is receiving its additional groundwater dilution from incoming groundwater into the parcel from the upslope side. The easiest way to do this is to consider the upslope area to be a square and take the length of one of its side to be the length that groundwater could flow in from the upslope side. The average depth of a well in the upper analysis zone is 272 feet deep and the depth to groundwater from the ground surface is 217 feet deep on average, providing an average saturated thickness of 55 feet. This would estimate an average aquifer thickness of about 55 feet available for wells to draw from. Using the groundwater flow equation:

$$V_{ReQgwus} \;=\; K_{act}\ x\ A_{aq}\ \ x\ i\ x\ CF_{cfd2AFY}$$

where:

$V_{ReQgwus} - Recharge\ from\ upslope\ of\ each\ parcel$ (AFY)
$K_{act} - For\ the\ given\ geology\ per\ Bossong\ 2003, Vanderbeek\ 2004 -\ (ft/d)$
$A_{pastaq} - Lot\ upslope\ width\ x\ average\ aquifer\ thickness\ (ft^2)$
$i\ - Hydraulic\ Gradient\ from\ groundwater\ contour\ map\ (0.04 - 0.08, avg\ 0.06)$
$CF_{cfd2AFT}\ - Conversion\ factor\ from\ cfd\ to\ AFY$

$$C_{gwp} = \frac{V_{OWTS}\ x\ C_{owts} + \ (V_{Recharge} - V_{ReQpast})\ x\ C_{Recharge} +\ V_{ReQgwus}\ x\ C_{gwAvg}}{V_{OWTS} +\ V_{Recharge}\ +\ V_{ReQgwus}}$$

where:

$C_{gwp} - Parcel - level\ Averagedc\ Concentration\ of\ NO3 - N\ \left(\frac{mg}{L}\right)\ with\ groundwater\ inflow$
$V_{OWTS} - Parcel - level\ Volume\ Contribution\ from\ Each\ OWTS\ to\ Groundwater$ (AFY)
$C_{owts} - Concentration\ of\ NO3 - N\ in\ OWTS\ STA\ effluent\ (\frac{mg}{L} NO3 - N)$
$V_{Recharge} - Parcel - level\ Volume\ Recharge\ to\ Groundwater\ in\ an\ Average\ Year$
$C_{Recharge} - Concentration\ of\ NO3 - N\ in\ Recharge\ (\frac{mg}{L} NO3 - N)$
$V_{ReQgwus} - Upslope\ parcel - level\ Volume\ Recharge\ from\ Groundwater$ (AFY)
$C_{gwAvg} - Upslope\ parcel - level\ Averagedc\ Concentration\ of\ NO3 - N\ \ (mg/L)\ groundwater$

Similarly to considering upslope recharge, considering upslope groundwater inflow may reduce nitrates at least 1 mg/L, but since NO3-N levels in surrounding groundwater are high in actual sampling, it does not appear to provide that much dilution potential to local groundwater in the high-density areas, or dilution is being offset by more direct sources of pollutants reaching groundwater with uneven treatment through porous, shallow soils, fractured geology, and unused or poorly maintained wells from nearby high density OWTS, horses, and other surface sources than a the typical model of even-depth, loamy soil and homogenous aquifer system usually considered in OWTS treatment design.

3.0 Surface Water Nitrate Contribution

3.1 EPA BASINS GWLF-E

The EPA BASINS GWLF-E mass balance surface water nutrient loading model requires all spatial data to be in meters, therefore all Indian Hills layers were converted to NAD83 Colorado Central Meters. Layers used for the IH project include Parmalee Gulch subbasin, IH unpaved roads, IH paved roads, OWTS density areas, soils, horse density areas, streams, IH DEM, and vegetation.

The Parmalee Gulch subbasin shapefile was extracted from the IH DEM LIDAR file and a calculated field was added for the area in meters, as well as an ID field. The unpaved roads layer was updated from the 2013 aerial photograph and added the Shap_Leng field calculated in meters. This field was also added and calculated in the paved roads shapefile. OWTS density areas were calculated and included required fields like TRACT for identification of the different density areas, SEW_SEP, SEW_PUB, and SEW_OTHR. In the soils shapefile, the Mu_awc, mu_fk, and muhsg_dom fields were included. The horse density areas shapefile was updated using the 2013 aerial photographs as reference and density areas were calculated. Fields required in this layer include Area calculated in meters, AEU_Acre number of horses per area in acres, and area calculated in acres. The streams layer was extracted from the IH DEM LIDAR and the fields STRMID and Length in meters were added. The land use layer was classified by type of use. After loading all the layers mentioned above and the IH DEM file in EPA BASINS GWLF-E software program and running it a file was generated, which was used in the surface water nitrate calculations.

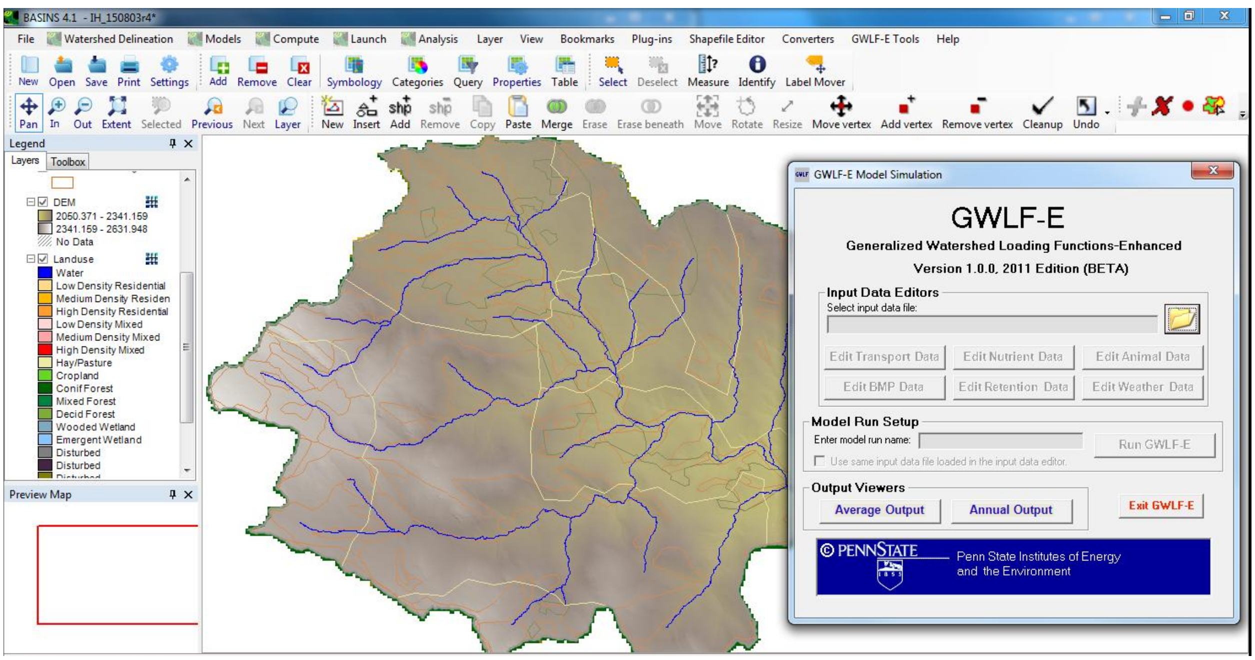


Figure 41. EPA Basins 4.1 GWLF-E Surface Water Nutrient Loading Model

Results indicate that although over 85% of the watershed is forested, forests only represent a small proportion of nitrate loading, since forests recycle nitrogen, increase recharge, and help reduce runoff. Although less than 10% of the overall area is highly developed, residential and disturbed lands account for 20% of the nitrogen. Nitrates in groundwater from previous years and annual additional load from OWTS account for 75% of loading, or about 683 of the 917 kg of nitrate delivered to surface waters from Parmalee Gulch annually. For comparison, Evergreen Metro District, which serves 10x more customers discharges about 6,000 kg directly into Bear Creek, but it does not discharge any nitrogen to groundwater. So Indian Hills overall may provide proportionally more nitrates to surface water, and certainly provides much more nitrogen to groundwater sources that cannot be easily remediated.

GWLF Total Loads for file: g4run1-1 Period of analysis: 13 years from 1997 to 2009

Source	Area (Ha)	Runoff (cm)	Kg X 1000		Total Loads (Kg)			
			Erosion	Sediment	Dissolved N	Total N	Dissolved P	Total P
Hay/Pasture	15	2.8	0.9	0.2	10.4	10.7	1.8	1.9
Cropland	13	5.0	10.6	1.9	16.1	19.9	2.9	3.8
Forest	1298	2.4	5.4	1.0	58.5	60.4	1.9	2.3
Wetland	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Disturbed	111	9.3	3.4	0.6	77.1	78.3	2.1	2.4
Turfgrass	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Open Land	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Rock	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sandy Areas	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unpaved Roads	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LD Mixed	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MD Mixed	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HD Mixed	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LD Residential	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MD Residential	43	6.8	0.0	3.3	14.9	53.3	2.4	6.5
HD Residential	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm Animals						0.0		0.0
Tile Drainage				0.0		0.0		0.0
Stream Bank				22.7		11.0		3.0
Groundwater					350.3	350.3	9.2	9.2
Point Sources					0.0	0.0	0.0	0.0
Septic Systems					332.6	332.6	0.0	0.0
Totals	1480.0	3.00	20.3	29.7	859.8	916.5	20.2	29.1

Go Back | Pathogen Loads | Export to JPEG | Print | Close

Figure 42. GWLF-E Results

ARC-NLET

The Arc-NLet Model was developed by Florida State University and the Florida Dept. of Environmental Protection to estimate nitrate loading to a water body from OWTS in surficial groundwater. In this exercise, the water body was set as stream area in the vicinity of the confluence of Parmalee Gulch and Turkey Creek. It evaluates the groundwater flow directions and magnitudes, determines informative flow paths from each OWTS along which a nitrate plume may travel, estimates contributions from each plume, and calculates potential denitrifications losses taking place to calculate the final nitrate load to target water bodies.

Results indicate that about 578 kg total N should reach the outlet to Parmalee Gulch each year, which is surprising close to the results from the EPA Basins GWLF-E model, which had estimated that 683 kg total N per year could be attributed to OWTS, despite its rougher mass balance estimation techniques. However, ArcNLet also attempted to estimate denitrification and indicated that most of this nitrogen would likely denitrify before reaching the surface waters. Yesavage 2008, however, believed denitrification would be minimal though she could not explain why NO3-N levels in groundwater in Indian Hills could be consistently higher than 7 mg/L, while surface water levels were closer to 1 mg/L. Another explanation could be that the vast majority of undeveloped area on steeper, forested slopes throughout Parmalee Gulch also contributes sufficient dilution base flow to reduce levels.

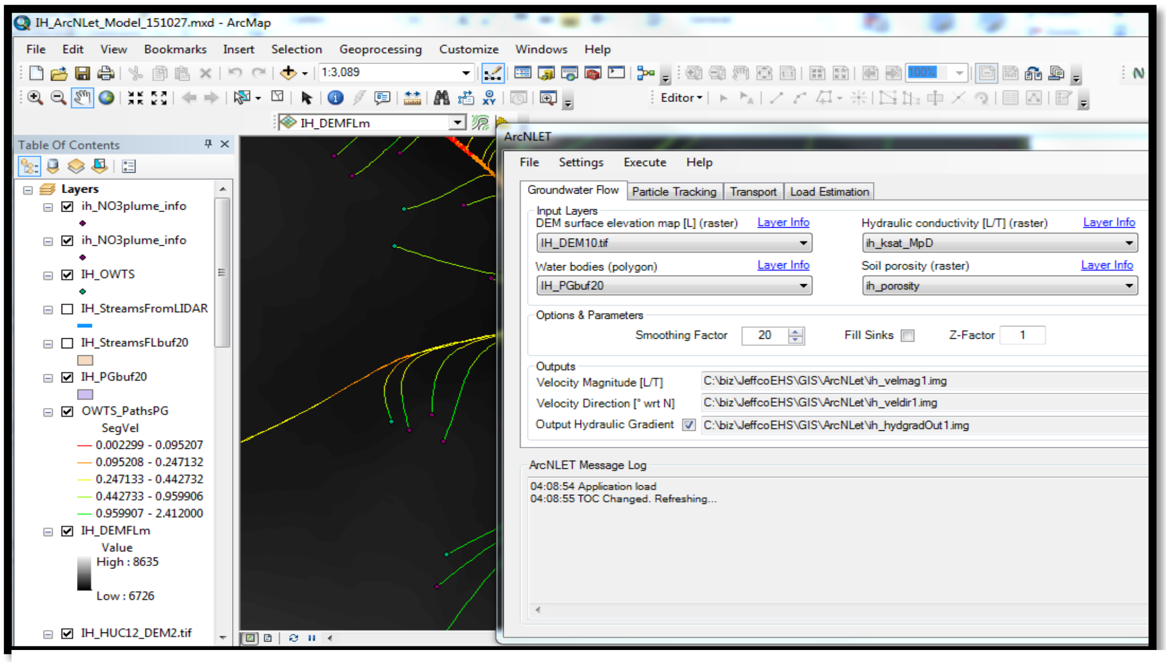


Figure 44. ArcNlet ArcMap Extension Model Input

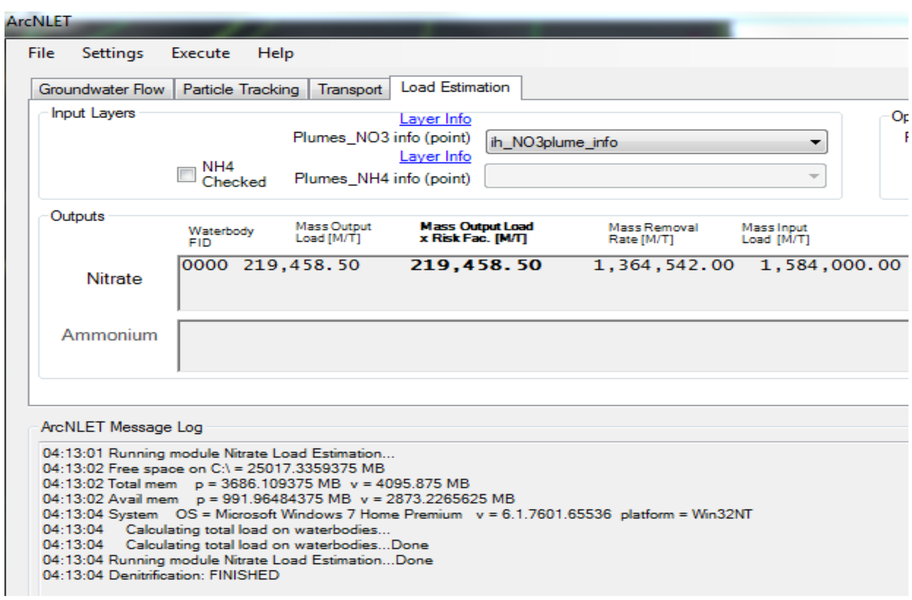


Figure 43. ArcNLet Model Output

Beyond the Results, the automatically-generated intermediate OWTS Tracer Path product can be used for visualization and analysis. Notice how closely packed OWTS and their overlapping plumes are in the Upper and Lower Zones of Analysis, which includes the Prohibition Zone and high-density upslope properties surrounding these restrictions. The green color indicates steepest slopes and highest plume velocities, while OWTS paths transitioning into red indicate slowing of the plume, but also concentrating of multiple plumes in area tributaries.

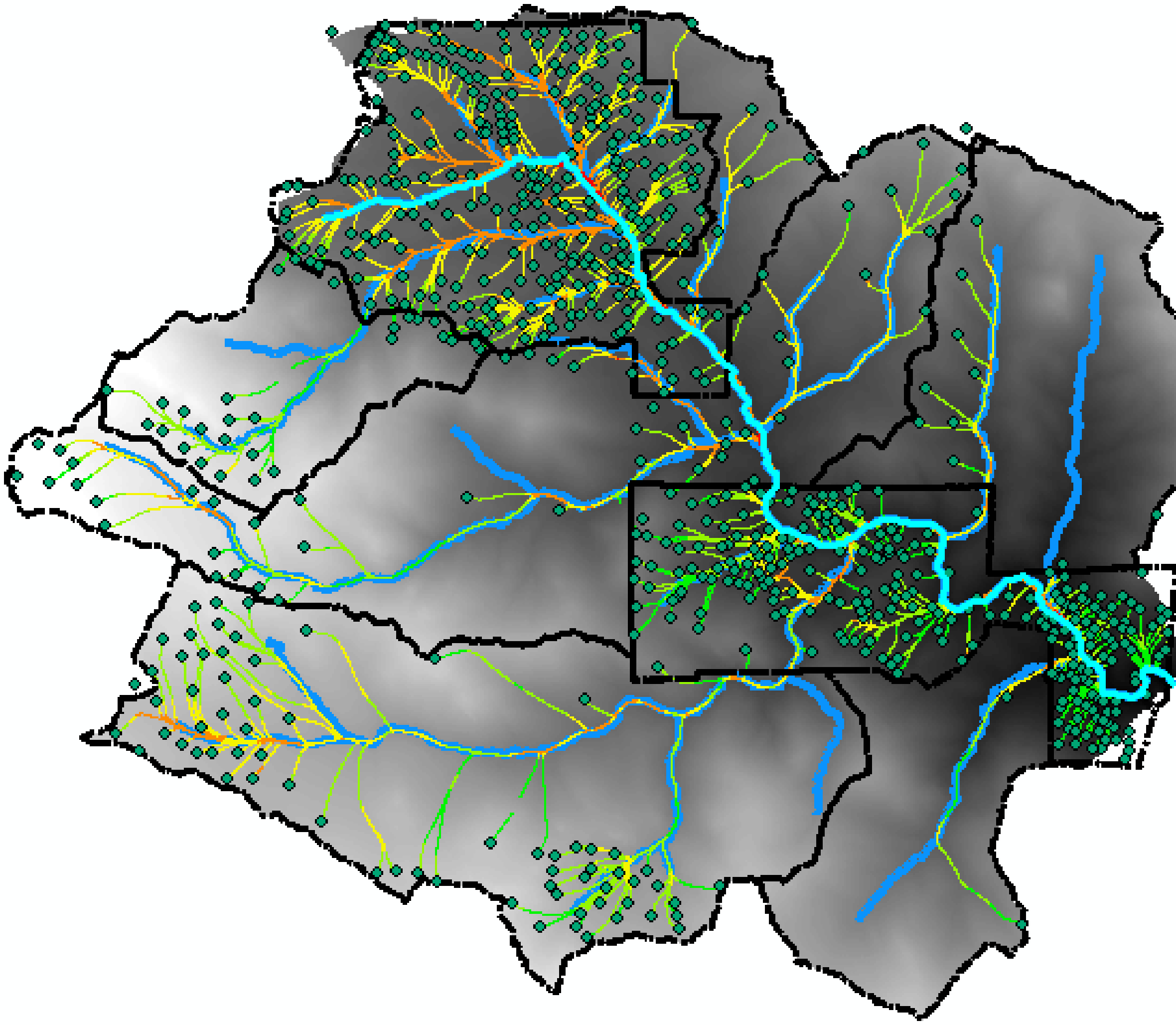


Figure 45. ArcNLet N-Tracer Paths from each OWTS Identified in Parmalee Gulch (red slower to green faster plume travel)

This shallow groundwater does not only reach the stream, but indications are that likely more than half is also reaching deeper groundwater through fractures in the geology, especially in more highly fractured areas below the alluvium (in the vicinity of streams) and colluvium (soils at the bottom of steeper slopes). Shallow wells in these areas that penetrates into the geology may also provide a direct conduit to nitrates from these plumes into deeper groundwater resources. Obviously, HLT is needed on all systems in the two much denser development areas due to high plume overlap and potential direct influence on groundwater quality for both IHWD and private wells in the vicinity of the same upper and lower valley areas. This is also informative in that it demonstrates areas of likely cleaner water that are not in the direct flow path of existing OWTS to which IHWD and private owners might wish to consider moving their groundwater intakes or drilling new test holes.

One might assume that with such large, relatively undeveloped upslope areas, especially contributing to the lower valley near Parmalee Gulch confluence with Turkey Creek that groundwater would be much less contaminated with nitrates due to dilution. However, that has not been found to be the case in groundwater sampling throughout the high-density areas repeatedly over time as demonstrated in Section 2.1. Therefore, the conservative analysis that did not consider dilution potential to estimate the effects of development in these analysis zones provides more close correlation with actual measured nitrate levels in groundwater than expected.

4.0 Recommended Next Steps

4.1 IHWD and JEHS Area Private Wells Joint Source Water Protection Plan

CDPHE WQCD Source Water Protection Program provides matching grants up to $5,000 for Protection Plan Development and Implementation. Both IHWD and Jeffco can apply, IHWD for their community system, and JEHS for the impacts of private wells and OWTS on the community wells and downstream water supply intakes along Turkey Creek. Dr. Herzog could leverage results of this study and the Watershed Online system she developed as noted in APENDIX A 1.12 to facilitate the community process and build on the results of this IH WQ Project. Focus would include working with a variety of other partners to increase community service delivery for protection:

1. Indian Hills Fire District – Formalize the FireWise program and Increase Utilization of Jeffco Slash Collection Programs and State Defensible Space BMPs. Develop a fire hazard mitigation plan.
2. Jefferson Conservation District – Partner with Jennifer Cooke, the state's small acreage coordinator, to promote the covering of manure, well head protection from large animals, creating a sacrifice area to keep large animals off wet soils, and maintaining lands grazed to a height of no less than four inches. Activities could include visits to example BMPS in surroundings, seminars for interested smallholders, etc.
3. Mountain Lands Area Trust – Work with staff to encourage Parmalee Gulch large landowners to put more property under permanent conservation easements and promote high levels of management for riparian areas in particular to create greater water quality buffering capacity.
4. Division of Water Resources – Continue to determine ways to encourage residents to permit their wells and consider properly abandoning wells that are no longer in service, while ensuring proper well-head protection, sealing, and casing through awareness campaigns and professional services arrangements. Also determine if there are change-in-use mechanisms to allow unused wells of sufficient capacity, depth, and water quality to be transferred to IHWD from other entities.
5. Bear Creek Watershed Association – Encourage BCWA to set up a permanent monitoring point for quantity and quality measurements upstream of the confluence of Parmalee Gulch at Turkey Creek and share results with the community through an annual public meeting.
6. Jefferson County EHS – Determine a mechanism by which Indian Hills residents could drop off prior well nitrate level monitoring results at the Post Office and check-off an option to share well testing results with the county moving forward. If successful, this could be expanded county-wide.
7. Watershed Online – If Dr. Herzog is hired to support the process, involve the community in using Watershed Online to report issues throughout the watershed and suggest mitigation projects for discussion on at least a monthly basis at the community center through an expanded Indian Hills Improvement Group [Association] *Sustainable Community* Program.
8. Denver Water – TM1 (2011) indicated that Indian Hills was of particular concern to Turkey Creek intake, so providing a presentation on the Upper South Platte Source Water Protection Plan and similar ways community members could support BMPs to reduce nutrient loading in surface waters.
9. Adjacent County Open Space: Both Denver Mountain Parks and Jefferson County Open Space own large land areas adjacent and within Parmalee Gulch, so both could work with the community to create wildlife and recreational corridor enhancements.
10. Indian Hills Improvement Group and Other Community Groups – Expand this group from its current focus on periodic Community Center Events to form a standing committee open to all residents to participate in Citizen Science and other potential Source Water Protection and Monitoring Programs and Projects to promote sustainability or consider Other Community Groups individually and Parmalee Gulch school.

4.2 Recommended Monitoring Plan and Further Research

Addition Monitoring, Analysis and Research recommendations including obtaining permission to include any opt-in Residential Water Quality Tests in JEHS internal Analysis (Well Test Form: check "YES" to include in the JEHS database for well water quality analysis in time and space). Annual Analysis of Well #6 Near Recently Improved Parmalee Elementary School and at the clean outs below the STA, if water is found in them at any time, such as during saturated conditions in late spring. Also, seek research funding to install a lysimeter below and downstream of this new OWTS for the school.

An Annual Analysis of Static Well Near Actual IHWD Pumped Wells in each Quarter of the Year would help determine groundwater flow patterns to each IHWD community well to better pinpoint areas to focus source water protection efforts.

Larger Water Quality Analysis Effort Involving Area Multi-level Academic Institutions could be accomplished by including Green Mountain High School STEM Program Student interns, Red Rocks Community College Water Quality Mobile Lab and Program Support, and Colorado School of Mines OWTS Monitoring and Groundwater Monitoring Network in a variety of Research Grant Submittals. Proposals could also be written for a variety of masters and doctoral thesis and provided to all state academic institutions water resources and environmental engineering programs to encourage additional, expanded research using all the data compiled through this extensive literature review and GIS compilation, data development, multiple modeling, and accessible spreadsheet analysis.

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6.0 Links

6.1 Indian Hills Commercial Establishments

- Indian Hills Water District - http://www.indianhillswater.com
  (EPA Facility http://echo.epa.gov/detailed-facility-report?fid=110028307017)
- Indian Hills Fire & Rescue District - http://www.indianhillsfirerescue.org/
- Indian Hills Improvement Association (Community Center) - http://www.indianhillscolorado.com/
- Sit-N'-Bull Saloon - https://www.facebook.com/thesitnbull/timeline?ref=page_internal
- Geneva Glen Camp - http://www.genevaglen.org (EPA Facility: http://echo.epa.gov/detailed-facility-report?fid=110011371826)
- Mountain Song Foursquare Church - http://www.foursquare.org/churches/30410
- Messiah Mt. Retreat (ELCA) - 5200 Parmalee Gulch Rd, Indian Hills, CO 80454, (303) 697-8717
- Turkey Creek Café - 5510 Parmalee Gulch Rd, Indian Hills, CO 80465, (720) 583-2169
- Indian Hills Christian Fellowship - http://www.ihcfchurch.org/?page_id=59
- Jim Noble, Inc. (Excavating and Paving Services) - http://www.jimnobleincorporated.com
- Jefferson County Mt. Falcon Park (Open Space) - http://jeffco.us/open-space/parks/mount-falcon-park/
- Note: The Original Coffee Shop and the Equestrian Center are no longer in service

6.2 County and IHWD Documents

- Indian Hills Master Plan - http://jeffco.us/planning-and-zoning/comprehensive-plans/indian-hills/
  BOX: https://jeffersoncountypublichealth.box.com/s/c8i8uza54m4q817kbnmuu0i7w7mlmwg1

- Jeffco OWTS Regs - http://jeffco.us/public-health/water-quality/onsite-wastewater-treatment-systems/
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- Indian Hills 1979 Prohibition
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- Indian Hills Revised Prohibition - http://jeffco.us/public-health/documents/board-of-health-documents/policies-documents/permitting-requirements-for-the-indian-hills-parmalee-gulch-area/
  BOX: https://jeffersoncountypublichealth.box.com/s/hixlmu0xkzdevdfqjnuxsm7sa619v46u

- Indian Hills Data Files
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  BOX: https://jeffersoncountypublichealth.box.com/s/c8i8uza54m4q817kbnmuu0i7w7mlmwg1

6.3 State and Federal Documents

- USGS NWIS GW (Place Name: Indian Hills, GW Inactive Sites - all)-
  http://maps.waterdata.usgs.gov/mapper/

- IHWD EPA ECHO (FRS 110028307017)- http://echo.epa.gov/detailed-facility-report?fid=110028307017

- Geneva Glenn Camp EPA ECHO (FRS 110011371826) - http://echo.epa.gov/detailed-facility-report?fid=110011371826

- DWR IHWD Wells (Division 1, District 9, Structure Name: Indian Hills) Contact: http://water.state.co.us/DivisionsOffices/Pages/SelDistWaterCommissionersDocsAndQLinks.aspx?Div=1&WD=09
  Structures: http://cdss.state.co.us/onlineTools/Pages/StructuresDiversions.aspx
  Well Permits: http://www.dwr.state.co.us/WellPermitSearch/default.aspx
  BOX: https://jeffersoncountypublichealth.box.com/s/3c2611i60ht996l85jzj66jzm8czhdzi

- CDPHE WQCD Source Water Assessment and Protection Program, SWAP Protection Phase
  https://www.colorado.gov/pacific/cdphe/swap-protection-phase

- CDPHE WQCD Nonpoint Source Pollution Management
  https://www.colorado.gov/pacific/cdphe/nonpoint-source-pollution-management

6.4 Modeling Efforts

- ArcNLet Model – ArcMap extensions software, manuals, input GIS layers, and Model Results
  BOX: https://jeffersoncountypublichealth.box.com/s/lknu3u00hzbiqg7rk1cdfhelsd83mj1j

- EPA BASINS GWLF-E – Software, manuals, input GIS layers, and Model Results
  BOX: https://jeffersoncountypublichealth.box.com/s/er020bhebnoycfrn8jaaw1dwn3wou3oi

- Lot-Size Solver Extension – ArcMap extensions created for this study to replicate Taylor 2003 to provide recommend lot size and estimated nitrate loads anticipated for large parcel subdivision development
  BOX: https://jeffersoncountypublichealth.box.com/s/mi84bsxln28xrtq9lyjqotr133x3b165

- SS Model – Parcel-level analysis to estimate high-density area impacts of new development
  BOX: https://jeffersoncountypublichealth.box.com/s/u0t0722xwi6zmid67m4c92xvoe824u5h

6.5 Other Project Folders

- ArcNLet Model – ArcMap extensions software, manuals, input GIS layers, and Model Results
  BOX: https://jeffersoncountypublichealth.box.com/s/lknu3u00hzbiqg7rk1cdfhelsd83mj1j

6.6 Other Community Groups that May Provide Future Support

Jefferson County Open Space - http://jeffco.us/open-space/parks/
Denver Mountain Parks - https://www.denvergov.org/content/denvergov/en/denver-parks-and-recreation/parks/mountain-parks.html
Jefferson Conservation District - http://www.jeffersonconservationdistrict.org/
Mountain Area Land Trust - http://www.savetheland.org/
Bear Creek Watershed Association - http://www.bearcreekwatershed.org/

APPENDIX A: Research Summary

1.0 Prior Indian Hills Studies

1.1 1975 Indian Hills environmental inventory : A citizen's tool for planning

In 1975, with CSU student and faculty support, the community of Indian Hills launched a comprehensive planning effort to understand sources of contamination in groundwater and other community issues. Results recommended zoning controls, which resulted in a prohibition zone by 1978, discussed in Section 1.4.

1.2 2001 Using Low Cost Data for Groundwater Estimates in Fractured Bedrock

Poeter (2001) found fractures to be uniform between 100 and 700 feet below ground surface and recognized the recessional nature of groundwater in fractured crystalline mountain aquifers. She recognized that water levels are declining though OWTS provide significant recharge. In addition to chloride and nitrate increases in groundwater, she also noted that groundwater pH decreases in areas of high population density. As Bossong 2003 also notes, the slow drainage from the tighter bedrock should help sustain low pumping rates through drought periods, though specific yield may decrease with depth, perhaps as fractures size and quantity decrease with overburden weight. This is substantiated by deeper wells not having high capacity found in other types of aquifers. As also noted in Vanderbeek (2004), maximum estimated water use exceeds minimum estimated recharge in dry years.

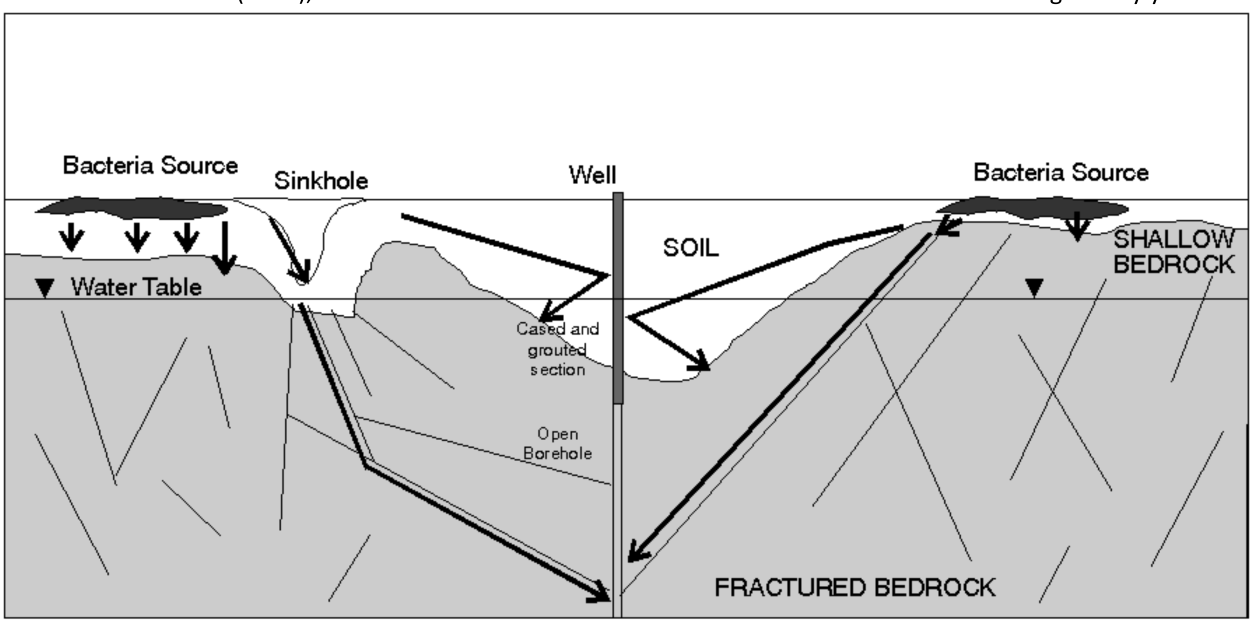

Figure 46. Crystalline Bedrock Aquifers Schematic

Fractured Bedrock aquifers may more susceptible to contamination that others because they do not include a confining layer above them to restrict pollution. A high frequency of wider fractures near the geologic surface overlain with more porous, shallower soils permit more direct avenues to unfiltered point and non-point sources of contamination from surface or subsurface to reach deeper groundwater. Groundwater mixing is less even, so “hot spots” may be prevalent.

1.3 2003 Water Resources Assessment of the Turkey Creek Watershed 1998-2000

In 1999, Jefferson County commissioned USGS to conduct a Phase 1 assessment (Bossong, 2003), which focused on three objectives:

- Understanding groundwater system within the Turkey Creek Watershed
- Developing method for evaluating groundwater quantity in fractured bedrock
- Analyzing water quality changes over 20 years since watershed last sampled

To achieve these goals, the study:

- Collected groundwater quality samples
- Study groundwater characteristics and geology to develop hydraulic response units (HRUs)
- Study fractured bedrock aquifer using Precipitation Runoff Modeling System (PRMS)

Findings indicated that evapotranspiration, ET, was 74.5% of precipitation in 1999 and 97.2% in 2000, 77% on average 1950-2000. 70% of runoff is subsurface flow that discharges into surface water systems, so current withdrawals about equal recharge on average, but withdrawal is deep and return is shallow subsurface. In the past, the aquifer could sustains streamflow during most rainless periods (overall, but Parmalee Gulch was dry in studied period during the summer, Bossong 2003 and Vanderbeek 2004). Since the magnitude of lateral flow is a function of saturation of the vadose zone, as soils dry, less lateral flow and more evaporation may occur. Groundwater levels are affected by drought based on length of rainless period, though no long-term downward trend in water levels over time has been apparent in a well in the Indian Hills area sampled by Jefferson County each month for several years.

Well depth averages 340 feet and yield averages 5.57 gpm. Groundwater is found at 100 to 300 feet down from peak topography and is mostly of recent age. Granite in the southwest and fault zone areas has abundant recharge, though metamorphic and intrusive rock have more poorly sustained stream segments and less domestic supply support. Water quality has significantly degraded since 1970's sampling. Elevated chlorides may be due to OWTS water softening and road salt, but not found elevated in domestic wells sampled. Water quality sampling data found at USGS NWIS for 1970s and 1990 was included through JEHS database nitrate data compilations for this study. Water levels in one Indian Hills well continued to be monitored monthly for several years even after study completion. Water use in the entire Turkey Creek basin was estimated at about 200 gallons per day per household and included about 4900 households, about one per every 6 acres.

Table 7. Comparison of Water Chemistry Data 1970's and 1990's

Surface Water		1975			1999		
Parameter	unit	mean	median	# of samples	mean	median	# of samples
specific conductivity	µS/cm	179	139	25	596	457	78
calcium	mg/L	16	14	24	72	42	56
magnesium	mg/L	4	3	24	16	10	56
sodium	mg/L	8	7	24	36	28	56
potassium	mg/L	2	1	24	3	3	34
alkalinity	mg/L	75	61	28	115	99	58
sulfate	mg/L	8	8	24	71	13	58
chloride	mg/L	9	6	24	79	65	58
fluoride	mg/L	1	0	24	1	0	55
nitrogen (NO3+NO2)	mg/L	0	0	23	1	0	47

Table 1.1 Comparison of water chemistry data from the 1970s (Hofstra and Hall, 1975) and the late 1990s (Bossong et al., 2003).

1.4 2003 Bedrock Geology of the Turkey Creek Drainage Basin

USGS GIS layers and study document indicate that real distribution of hydraulic properties is variable and discrete at the individual to well field scales that may suggest limited storage capacity and permeability (Caine et al, 2003). Surface deposits and weathered bedrock of higher permeability relative to fractured bedrock may allow for interflow of infiltrated water and dissolved constituents or as shallow, near-surface groundwater flow, especially if at high gradients. Recirculating groundwater flow may be limited by compartmentalized pockets at depth, though at 100m, the mean well depth, could be simulated as an equivalent porous medium (EPM) at larger scales. However, distribution of hydraulic properties are actually quite variable and discrete and contaminants travel a likely tortuous path, while low porosity and fracture storage, may locally limit use and be exacerbated during extended periods of drought. Simple averaging may be misleading for understanding fate and transport of contaminants since actual flow paths may be laterally and vertically complex. Adequate modeling may require hydraulic head measurements from denser network of groundwater wells taken over several years to capture temporal variation at the well field or individual scale.

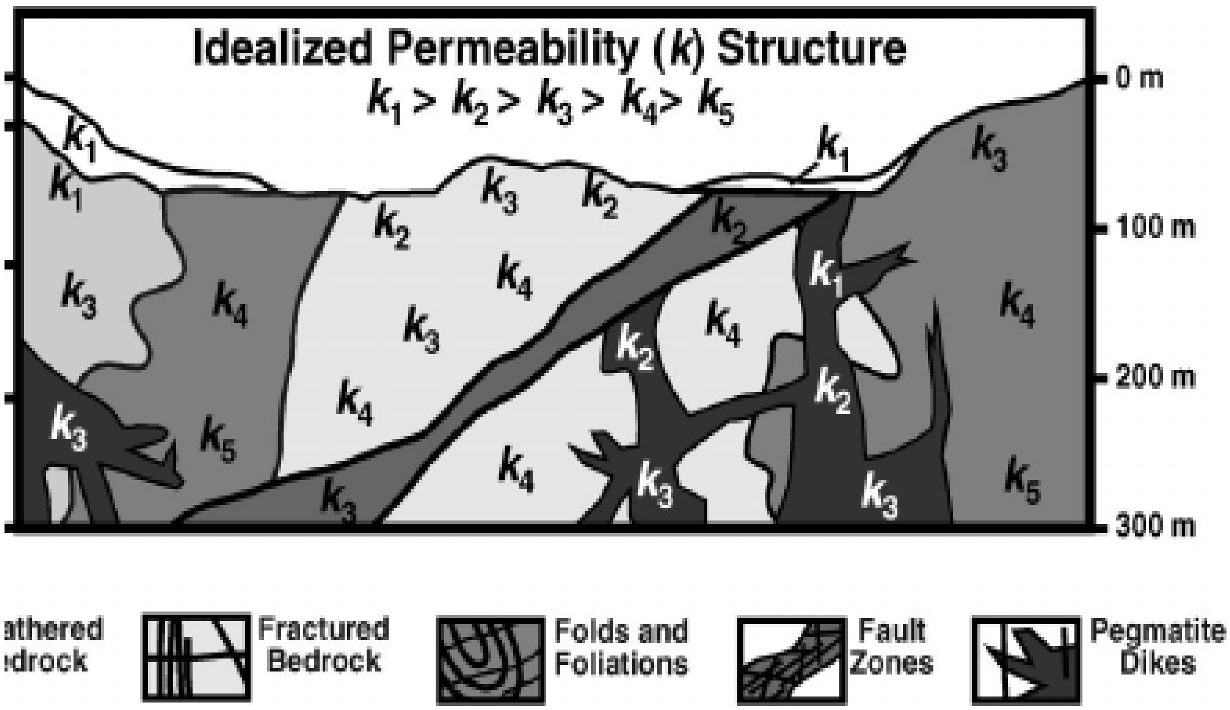

Figure 47. USGS Caine 2003 Conceptualization of Complex Turkey Creek Geology

1.5 2004 Investigation of the fate of individual sewage disposal system effluent in Turkey Creek Basin, Colorado

A single home was studied to measure water level and quality from OWTS (Dano et al, 2004). Pumping was metered at about 170 gpd from which 72% was dosed to the STA. During high spring runoff in a single year the plume migrated 50m to 100m before infiltrating into fractured bedrock, though usually it infiltrated into fractures within 5m. Residence time in regolith may be shorter, though shallow crystalline rock may also not have sufficient sorption sites or metal precipitate reactions. County regulation is 15.2m of separation between OWTS and surface streams, so OWTS near surface water during high spring runoff may allow greater nutrient loads to migrate directly.

1.6 2004 Estimating Recharge and Storage Coefficient in a Fractured Rock Aquifer, Turkey Creek Basin, Jefferson County, CO

Recharge for the Turkey Creek Basin was studied using four different methods: ModFlow, SWAT, Elevation, and Elevation/Aspect model (VanderBeek, 2004). Based on Bossong, Caine, and earlier studies. The Elevation / Aspect model performed better, so this simplified method may be explored to supplement the standard Jeffco Planning and Zoning Water Availability Analysis (WAA). Vanderbeek noted that although his estimates indicate that the rate of groundwater mining in Turkey Creek overall appears to average about one feet drop per year, it only seems to be about ½ foot per year in Parmalee Gulch. His analysis indicated that lowest estimate yields were less than the highest estimated well withdrawals, which could indicate a potential risk to site-specific groundwater supply in drought years.

1.7 2008 Sources and Transformations of Nitrate in the Turkey Creek Basin

Yesavage (2008) discovered that Parmalee Gulch groundwater was higher in nitrates than groundwater in other areas of the basin she collected and analyzed using HACH test methods. Precision was high, so despite lower quality instrumentation, as long as nitrates were high enough to measure accurately, results are expected to be satisfactory for inclusion in analysis. Enrichment of specific nitrate ions did not indicate that denitrification is taking place. Much lower levels of nitrate in surface water (which was also found in 1998, one sample, at Parmalee Gulch Road bridge outlet near Turkey Creek), could not be easily explained. Yesavage considered alternative transformation hypothesis, including high carbon in shallow groundwater and anoxic conditions permitting more denitrification, but the enrichment results did not support either hypothesis. Perhaps high dilution potential from undeveloped areas of Parmalee Gulch in most years, including the growing season of 2007, which she studied, may provide sufficient dilution to surface waters, whereas groundwater contamination may concentrate locally in areas of poorer hydrogeological connectivity. Higher OWTS levels may also be reaching shallow or even deeper groundwater through highly porous soils and larger fractures, as Dano 2004 noted that except during spring runoff when a phosphorus plume could travel longer distances horizontally, typically effluent entered geologic fractures within a few meters distance from the source. Yesavage nitrate levels in wells were somewhat higher than previously reported, as was specific conductivity, usually associated with higher anthropogenic influences, as she concentrated on shallower, denser area wells, but this may also indicated continued concentration of NO3-N levels in groundwater in high-density areas of development.

1.8 2010 OWTS Consumptive Use Study

Stannard, 2010 determined that 19.6% of water pumped equated to consumptive use with about 80.4% returning to the OWTS STA. This was used in calculating the UMC 2011 recharge estimates, as well as, in this study. However, Dano and others have reported as low as 70% of home water use reaches the OWTS STA.

1.9 2010 Watershed-Scale impacts of Nitrogen from OWTS

The watershed analysis risk management framework (WARMF) numerical model used at Dillon was applied to Turkey Creek (Geza 2010). Results indicated that OWTS conversion to WWTPs may actually increase surface water nitrate pollution though WWTP may pollute groundwater less. However, other studies indicate a more direct connection between groundwater recharge of surface water as baseflow, so close OWTS, failing systems, or OWTS in high density areas may have a more direct affect than this study indicates, which did not appear to adequately consider the spatial variability, nor overall conditions of standard, older OWTS in general.

Geza 2010b considered Phosphorus from OWTS. Once again, converting to conventional WWTP increased stream concentrations of P from 1.05 to 1.26. However, if soil adsorption capacity was decreased by 50% then stream TP increased by 1.96. As previously, this did not consider failing systems or the slow but steady migration of TP naturally, which may affect adjacent streams. Significant stormwater events may flush P from binding sites or in saturated soils, again likely those closest to streams, may be less effective at both adsorption and metal precipitate reactions (Dano 2004, others). Geza 2009 also used WARMF to predict affects of development on flows, though low flows were more difficult to predict than increased stormwater runoff due to forest removal and reduced surface permeability of pavements and roofs.

1.10 2011 Upper Mountain Counties Aquifer Sustainability Project

In 2011, CDM conducted an analysis of water supply conditions in the Bear Creek Watershed as part of the Upper Mountain Counties (UMC) Water Needs Consortium. About 52% of pumped water was estimated to enter baseflow or deep groundwater reservoirs, but drawdown in aquifers may decrease hydraulic gradients toward streams, decreasing discharge to streams from the baseflow reservoir zone. Wells located further from baseflow streams may experience water level decline in periods of drought and low recharge. If water from leach field systems that is degraded is not diluted sufficiently by native recharge, well water quality may become affected, though typically OWTS effluent enters upper portion of the aquifer while wells pump from deeper portions. Demands outside service water provider areas are estimated to increase from 9.2 AFY to 21.5 AFY by 2050. Site-specific studies may be required where sustainability issues have been estimated to be likely. Values estimated

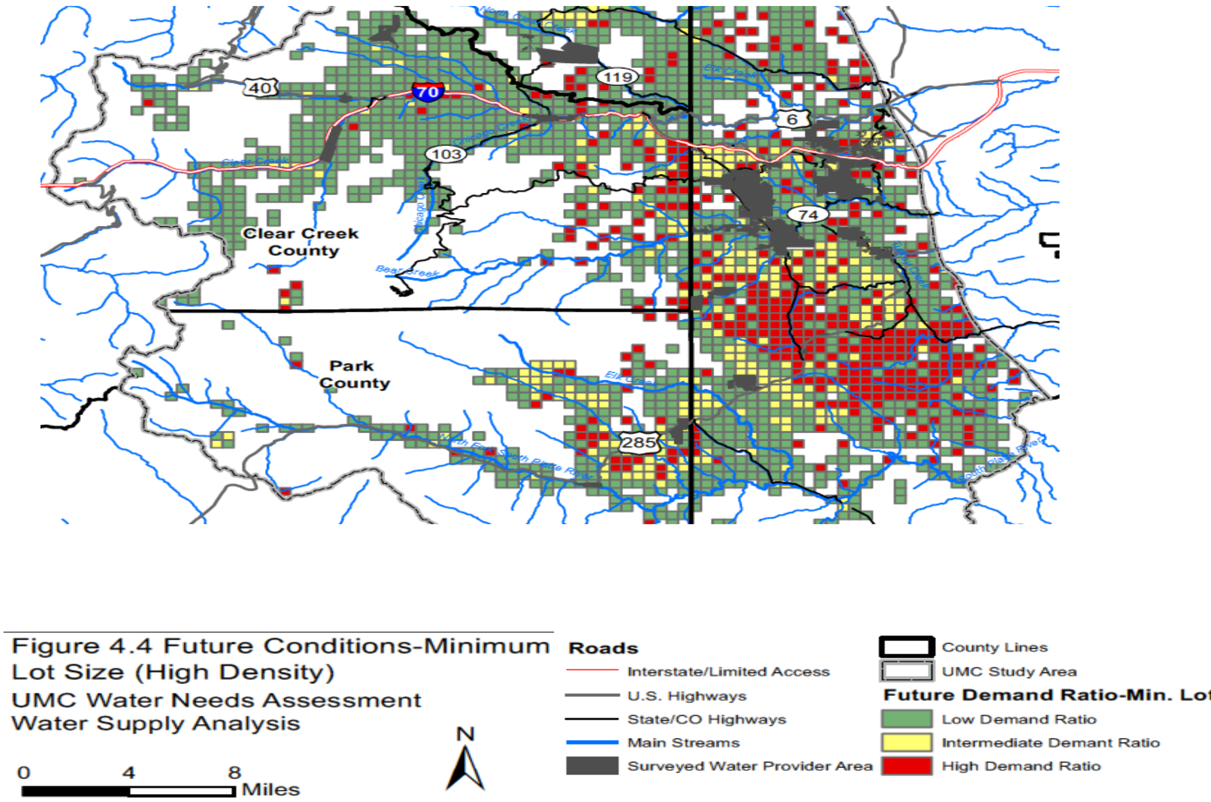

Figure 48. CDM 2011 Aquifer Study Findings

for UMC purposes, were also used in this site-specific Parmalee Gulch analysis, since most were derived from Turkey Creek studies.

1.11 2011 Denver Water Bear Creek / Turkey Creek Watershed Characterization

In 2011, Hydros estimated OWTS by two different methods for determining its potential contribution to Denver Water water quality issues in diversions from Harriman Ditch on Bear Creek and Turkey Creek to Marston Reservoir. Turkey Creek headwaters have over 3,500 OWTS, but relatively low nutrient likely due to the large proportion of undeveloped, forested areas separating upstream development from mid-Turkey Creek reaches. However, their study pinpointed lower Turkey Creek below Parmalee Gulch to have a spike in extreme nitrate concentrations and ammonia at some point. Indian Hills along Parmalee Gulch was considered a particular area of concern with 7.8 mg/L nitrates on average, and 29% of samples over 10mg/L nitrates that they considered in analysis. Indian Hills was platted in 1920 so some OWTS are old, though it is now controlled by stricter Jeffco policies. OWTS in Turkey Creek are estimated to contribute 944 lbs of TP/yr and in Bear Creek are estimated to contribute 2,230 lbs of TP/yr, which is three times the current WWTP discharge, mostly only in Bear Creek. Nitrates were estimated at 14,200 lbs for Turkey Creek (732 pounds for Parmalee Gulch OWTS alone by site-specific GWLF-E model in Sept. 2015) and 32,000 lbs for Bear Creek from OWTS. (USGS and Denver Water have both felt a need for a permanent daily flow gauge on Turkey Creek, which should be promoted, along with more targeted surface and groundwater quality sampling and a watershed-wide groundwater monitoring network). Loading rates from OWTS need to be determined by each high-density area specifically

1.12 2014 Facilitated Process, DSS, and Multi-Method Analysis of Bear Creek Watershed

From September 2011 through December 2014, Margaret Herzog, a CSU student in water resources and environmental engineering, conducted PhD research to assess nutrient contributions to the terminal Bear Creek Reservoir in Bear Creek Lake Park (BCLP). The study included specific analysis of Onsite Wastewater Treatment Systems (OWTS) throughout the watershed, including the Turkey Creek tributary to Bear Creek in which the Parmalee Gulch Subbasin is situated. During this process related analysis included:

1. Flood-related issues including effects on OWTS operation and water quality contamination potential
2. Drought-related issues, including water supply availability, water quality, and wildfire risks
3. Source water protection for Evergreen Lake including OWTS-related contaminant issues
4. Road-related sedimentation and contamination of streams and related habitat effects
5. Innovation clusters to support efforts like development of multi-family OWTS systems

Upon the successful conclusion of the her studies, Dr. Herzog presented study findings and related OWTS management recommendations to staff of the Jefferson County Public Health, Environmental Health Services Division on January 9, 2015. The invitation was in response to a prior presentation on OWTS components of the study presented at the Colorado Professional in Onsite Wastewater Management (CPOW) staff had originally hosted at a session for the CPOW January 2013 Annual Conference.

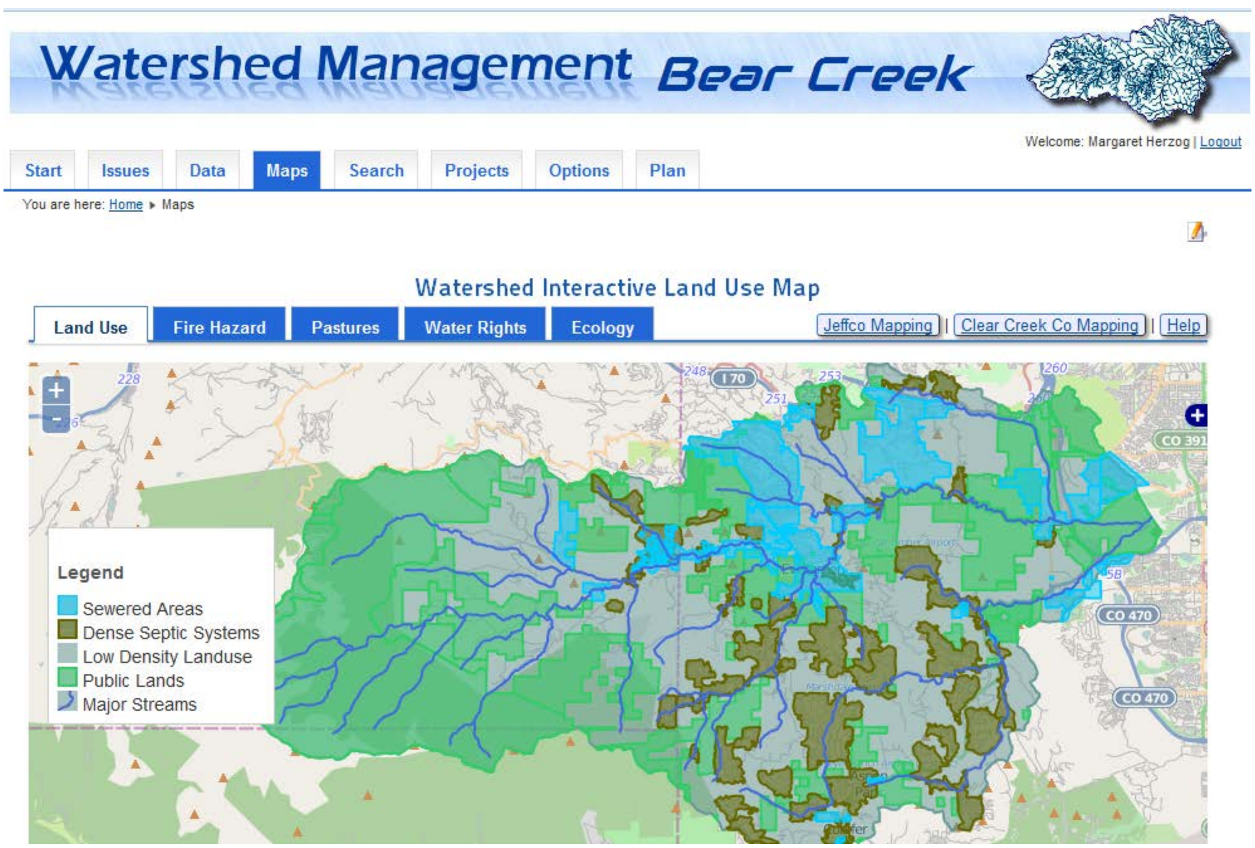

Figure 49. Example Map from BCWA Study demonstrating bifurcation of Water Supply and Sanitation Methods