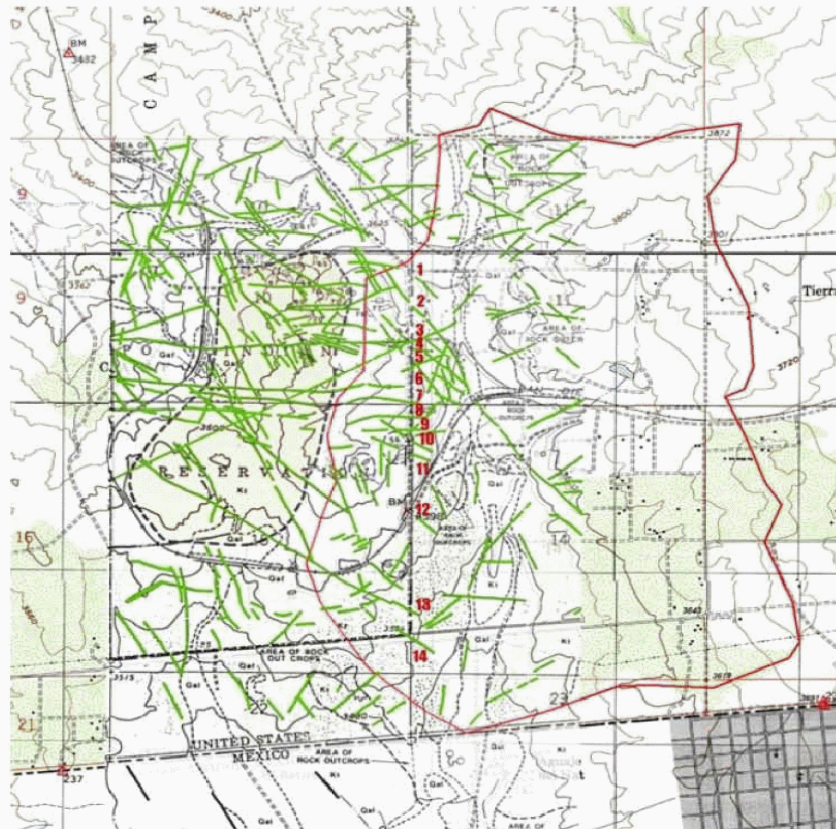


Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 12 of 35



B0002-114 cont.

Fig. 11 Geologic fractures identified on the Campo landfill site and vicinity.⁹

A narrow buffer zone, varying from 212 ft to 688 ft in width, separates the landfill site from the Tierra del Sol watershed. The landfill's footprint has been selected to ensure that drainage should proceed in the northwestern direction, toward Lower Campo Creek, and not in the eastern direction, toward the Tierra del Sol watershed. Limiting the landfill site drainage to the surface drainage assumes that there is no connectivity between surface water and groundwater. However, as Fig. 11 shows, this is most likely not the case.

Many of the identified fracture alignments cross the landfill site in a predominantly west-east direction. At least fourteen (14) fracture alignments cross the boundary between the Campo Indian reservation and privately owned land immediately east of it (Fig. 11).

Advection vs. diffusion. In fluid mechanics, as well as in groundwater flow, the difference between advection and diffusion is largely one of scale. Advection is a first-order process, governed by the advective term in the differential equation of fluid motion; diffusion, on the other hand, is a second-order process, governed by the diffusive term. The terms consist of constant or variable coefficients and partial differential terms; for instance, the advective term $[u \partial u / \partial x]$, in which u is the advective

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 13 of 35

velocity; likewise, the diffusive term [$v \partial u^2 / \partial x^2$], in which v is the diffusivity coefficient.

Flow in fractured-rock aquifers is not typical of groundwater flow. Velocities are higher and travel times shorter than those prevalent in more traditional [diffusive] hydrogeological settings.

In general, an advection-dominated process is much faster than a diffusion-dominated process. This is because the first derivative (the gradient) is much larger than the second derivative (the square of the gradient). While diffusion is the governing process in flow through porous media, advection is the dominant process for flow in open channels (Ponce, 1989). Therefore, flow in fractured-rock aquifers is not typical of groundwater flow. Velocities are higher and travel times shorter than those prevalent in more traditional [diffusive] hydrogeological settings.

Hydraulic conductivity. In hydrogeology, the hydraulic conductivity expresses the ease with which a fluid is transported through a porous medium (Bear, 1979). According to Darcy's law, the hydraulic conductivity is a specific discharge (i.e., a flux, or discharge per unit of area) per unit of hydraulic gradient, with applicable units $L^3 L^{-2} T^{-1}$ (Ponce, 1989). It characterizes the bulk, or macroscopic, velocity ($L T^{-1}$ units) and not the microscopic velocity, which may be real but it is much more elusive.

The hydraulic conductivity is commonly expressed in cm/s, or alternatively, in m/day, where 1 cm/s is equivalent to 864 m/day. In practice, the hydraulic conductivity varies within a very wide range, thirteen (13) orders of magnitude, from 10^2 cm/s for the most pervious cases, to 10^{-11} for the most impervious. In gravel, the variability of hydraulic conductivity is three (3) orders of magnitude, from 10^2 cm/s for coarse gravels to 10^1 for fine gravels; in fractured rock, the variability is four (4) orders of magnitude, from 10^{-2} to 10^{-6} cm/s (Freeze and Cherry, 1979).

In fractured-rock aquifers, porosity is typically much smaller than that of unconsolidated quaternary aquifers. While the porosity of sand and gravel deposits varies in the range 25-50%, that of fractured rock is less than 10% (Freeze and Cherry, 1979). The smaller the porosity, the greater the difference between the matrix velocity and the fracture velocity. This difference is particularly marked if the porosity is less than 2%. In contaminant transport through fractured rock, actual solute velocities, dominated by advection, may be at least two orders of magnitude greater than the values of bulk hydraulic conductivity (Muldoon, 1994). Thus, at the upper limit, values of solute velocities in fractured rock may approach $10^2 - 2 = 10^0$ cm/s, i.e., 1 cm/s, which is roughly equivalent to the hydraulic conductivity of medium-sized gravel.

Variability in well yield. Well yield is a function of hydraulic conductivity. In fractured rock, water-bearing fractures are responsible for most of the yield, with very little of it originating from matrix flow. Thus, well yield is directly related to the number, size, and orientation of existing fractures. To put it concisely, where there is a significant presence of fractures, generally there is ample water; conversely, where there is ample water, its presence may be attributed to a significant number/size of fractures. In general, very little yield could be expected from the rock matrix (Fig. 12).

B0002-114 cont.

Comment Set B0002, cont. Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 14 of 35



Fig. 12 Closeup of matrix structure in rock outcrop at Tierra del Sol.

Well yields in fractured-rock aquifers can vary widely. Well drilling experience in the Tierra del Sol watershed supports this statement, with the variability explained in terms of whether the wells intersect water-bearing fractures or not. Success in well drilling is heavily dependent on the size and orientation of the fractures tapped by the well. One experienced well driller reports wells in the vicinity being as shallow as 5 to 10 ft, and as deep as 600 ft, both yielding water of excellent quality.¹⁰ Another well driller reports yields varying from a few gallons per minute to 400 gpm, with well yield varying drastically between wells that are only a few feet apart.⁷

Several examples attest to the variability in well yield and depth in the Tierra del Sol watershed. In the Morning Star Ranch, the Playhouse well, drilled in 1978 at the end of a severe drought, found water at 4 ft, drilled through rock for 270 ft of its 300-ft depth, and yielded 100 gpm,⁴ a substantial yield by established standards (Davis and DeWiest, 1966; Freeze and Cherry, 1979). This same well (Playhouse well) experienced a substantial cave-in and a significant reduction in yield following a strong earthquake in the 1980s.⁴ The Utz well, also in the Morning Star Ranch, yielded 22 gpm at the depth of 200 ft.⁴ The Madsen well yielded 25 gpm at a depth of 480 ft.⁵ The Jeffries well found water at less than 10 ft below the surface, and yielded 30 gpm at a depth of 140 ft.⁶ The Hucker well found water at a depth of 10 ft, and yielded 14 gpm, with a total well depth of 50 ft.¹¹

• HYDROECOLOGY •

[\[Stream morphology\]](#) [\[Groundwater hydraulics\]](#) [\[Synthesis\]](#) [\[Conclusions\]](#) [\[Summary\]](#)
[\[Endnotes\]](#) [\[References\]](#) [\[Reviewers\]](#) • [\[Top\]](#) [\[Introduction\]](#) [\[Scope\]](#) [\[Hydrology\]](#) [\[Hydrogeology\]](#)

Hydroecology is a relatively new and evolving interdisciplinary science dealing with the structure and function of natural and human-impacted water-dependent habitats and environments. Hydroecology is used here to study selected vegetative species present in the Tierra del Sol watershed in terms of their affinity for water. The aim is to document a potential dependence of the spatial distribution of vegetation on [subsurface] local moisture gradients which may be linked to the rock fractures.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 15 of 35

The chaparral ecosystem. The ecosystem of the Tierra del Sol watershed consists of mediterranean chaparral on gentle slopes and foothills, and is complemented with woody riparian vegetation near springs and watercourses, and certain selected mesophytes. The California chaparral has been studied extensively (Keeley and Keeley, 1988). It is a community of largely taxonomically unrelated shrubs, albeit with similar ecological characteristics. These include a relatively extensive root system, a dense canopy, and sclerophyllous (hard) evergreen leaves (Delgadillo, 1992).

Chamise and red shank. Two closely related chaparral species, chamise (*Adenostoma fasciculatum*) and red shank (*Adenostoma sparsifolium*) are significantly represented in the Tierra del Sol watershed. Notably, these two shrubs are the only species in their genus. Chamise is widely distributed throughout California and Baja California, with a range of nearly 800 miles. In contrast, red shank occurs only in four isolated places in Central California, Southern California, and Baja California as a co-dominant with chamise, with a range of only 300 miles (Marion, 1943; Sampson, 1944; Hanes, 1965).

Although chamise and red shank have overlapping geographical distributions, Beatty (1984) has noted that they do not grow in close association within a given stand. Red shank is commonly found on all aspects of gentle slopes and foothills of inner mountain ranges. Pure stands of red shank can be found in only 3% of the area in which red shank is the dominant species (Marion, 1943).

Chamise and red shank, although congeners, are not at all alike in appearance. Stands of chamise chaparral are dull, of dark-green color and uniform in appearance. The mature chamise plant is a medium-sized shrub 2 to 8 feet tall, with sparse leaf litter. In contrast, stands of red shank are distinctive, spreading above the general level of the chaparral. Red shank is a tall, round-topped arborescent plant 6 to 20 feet high, with thick naked stems and considerable leaf litter, 0.5 to 2 inches in depth (Hanes, 1965).

Red shank dominates over chamise on sites with higher moisture content, organic matter, and nutrient availability.

There is a substantial difference in the rooting habits of the two species. Chamise, even though less than half the average size of red shank shrubs, has a more aggressive root system, possessing stronger roots with greater length and vertical penetration. On the other hand, the roots of red shank are massive, smaller, weaker, and are more likely to spread laterally rather than vertically. Chamise blooms and sets seed best, with low seed viability, following winters of ample rainfall. In contrast, red shank blooms well, with low seed set and viability, regardless of the amount of rainfall the previous winter (Hanes, 1965). Red shank dominates over chamise on sites with higher moisture content, organic matter, and nutrient availability (Beatty, 1984).

Hanes (1965) noted that though both *Adenostoma* species resumed growth in early winter, chamise displayed a sudden flush of growth in the spring, whereas red shank grew more steadily, with continued growth throughout the summer and fall. Chamise flowered in April and May, whereas red shank flowered abundantly in August. While chamise has an apparent enforced dormancy in the fall, red shank has been known to experience substantial autumnal growth, suggesting a sustained moisture source.

It is noted that red shank violates several definitions of sclerophyllous plants. First, it remains physiologically active during summer drought; thus, it is drought tolerant without being drought dormant (Hanes, 1965). Secondly, its root morphology is unique among the chaparral. Its shallow root system suggests that its moisture for summer growth must come from the top layers of the substrate. Red shank seems to be a type of shrub well adapted to drought conditions, but lacking the obvious morphological characteristics suggesting such adaptability (Shreve, 1934). Thus, the water affinities of red shank appear to lie in between those of the xerophytes, which are well adapted to drought, and those of the mesophytes, which habitually require a more sustained moisture source. The spatial distribution of red shank and its possible connection to local moisture gradients associated with rock

B0002-114 cont.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 16 of 35

fractures merits further study.

Blue elderberry. Under moist conditions, such as near the bottom of ravines or small canyons, the chaparral coexists with the small woody winter-deciduous *Sambucus* species and the flowering ash (*Fraxinus dipetala*) (Keeley and Keeley, 1988). One *Sambucus* species, the blue elderberry (*Sambucus mexicana*) is present in the flood plains and other mesic locations of the Tierra del Sol watershed (Fig. 13).

B0002-114 cont.



Fig. 13 Specimen of blue elderberry, Morning Star Ranch, Tierra del Sol watershed.¹²

The water affinities of the blue elderberry and its preeminent role as an indicator of the presence of groundwater have been known for almost one hundred years. Early references to the blue elderberry's moisture habits are scattered throughout the literature. Ball (1907) has stated that in Southwestern Nevada and Eastern California, the elderberry tree is unknown, except in the vicinity of water. Spalding (1909) has noted that the blue elderberry, while being structurally a flood-plain mesophyte, it is nevertheless very limited in its range, growing where there is an ample supply of moisture, such as near irrigation ditches. In the Southwestern United States, particularly in Southern California's inland hillslopes, the blue elderberry may be thought of as a meso-hygrophite, to indicate that while structurally a mesophyte (Meinzer, 1927), its water habits resemble those of a hygrophite, which thrives on wet soil and is more or less restricted to wet sites.

In Southern California's inland hillslopes, the water affinities of the blue elderberry range between those of mesophytes and hygrophytes.

The presence of all the specimens of blue elderberry in a selected portion of the northwestern edge of the Tierra del Sol watershed was mapped with the aid of a global positioning system. The location of forty-three (43) elderberry trees are shown in Fig. 14.¹³ At least three alignments are clearly distinguished from the data, indicating the potential presence of moisture-laden fractures in the underlying rock. The presence of other specimens of blue elderberry elsewhere in the Tierra del Sol watershed point to the existence of sustained moisture sources, possibly fractures, throughout the

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 17 of 35

study area.

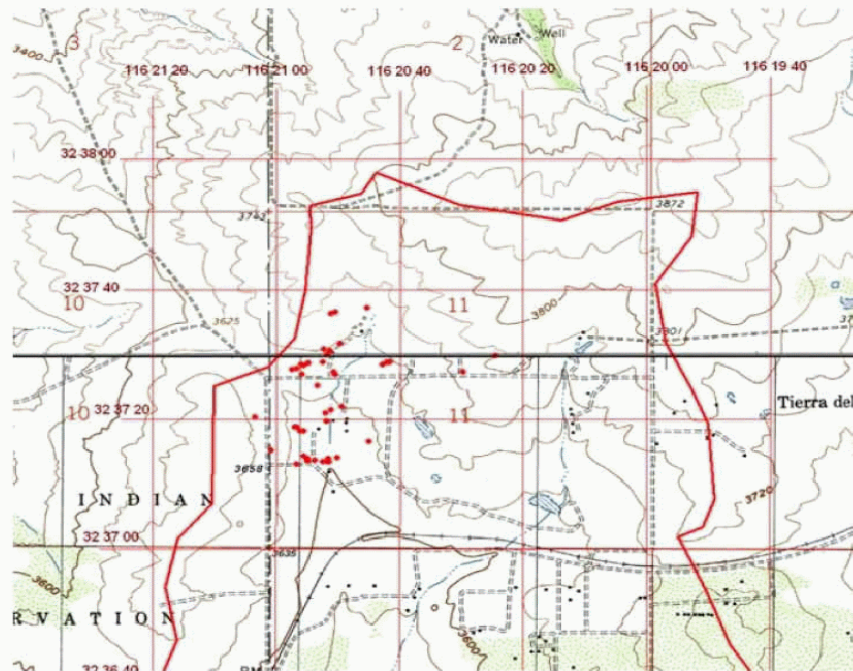


Fig. 14 Presence of blue elderberry (*S. mexicana*) near the northwest edge of the Tierra del Sol watershed.

Remote sensing. Figures 15 to 17 show color images of the proposed landfill site at three different spatial scales, from larger (Fig. 15) to midsize (Fig. 16) to smaller (Fig. 17). These images show the presence of darker spots of approximate longitudinal orientation, referred to as lineaments. They appear as such or are evident due to contrasts in terrain or ground cover on either side. If they are of geological origin, the lineaments are usually traced to faults, joints, or boundaries between stratigraphic formations. When they are related to bedrock features, they are most readily observed in areas where the surficial material is thin (Moore *et al.*, 2002). This is certainly the case in the Tierra del Sol watershed.

B0002-114 cont.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 18 of 35



Source: GIS, Department of Public Works, San Diego County.

Fig. 15 Larger-scale image of the study site.¹⁴

B0002-114 cont.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 19 of 35



Source: GIS, Department of Public Works, San Diego County

Fig. 16 Medium-scale image of the study site.¹⁴

B0002-114 cont.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 20 of 35



Source: GIS, Department of Public Works, San Diego County

Fig. 17 Smaller-scale image of the study site.¹⁴

A substantial number of major lineaments can be observed at all three image scales. Figure 16, in particular, shows a clearly defined lineament located east of Tierra del Sol Creek, close to the bottom right-hand corner of the figure, with a predominant northwest to southeast direction. Field inspection showed that this lineament is constituted by thick stands of red shank (*Adenostoma sparsifolium*), in association with specimens of scrub oak (*Quercus dumosa*), some of which are distinctively large. This observation confirms that red shank prefers a more mesic (i.e., humid) environment than its congener the chamise (Beatty, 1984). Several other red-shank dominated lineaments crossing the boundary between the landfill site to the west and the Tierra del Sol watershed to the east have been observed.

Figure 18 is the same as Fig. 16, but with readily identifiable lineaments, from photo inspection and field verification, highlighted in red. The interpretation of this image is that it is underlain by an extensive system of fractures. There appears to be no other sensible explanation for the presence of the lineaments. Field observations and local experience support this statement.

B0002-114 cont.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 21 of 35



Image source: GIS, Department of Public Works, San Diego County

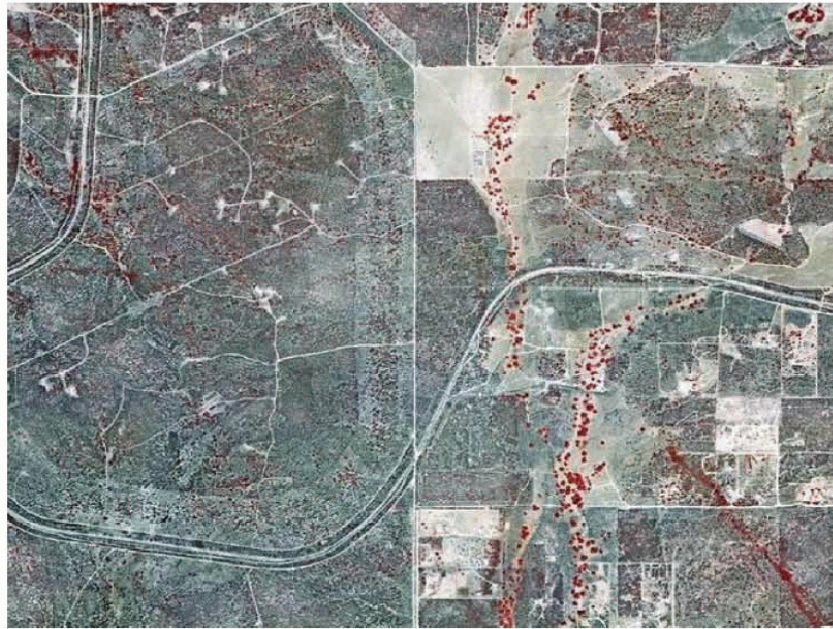
Fig. 18 Readily identifiable lineaments in the Campo landfill-Tierra del Sol site.¹⁴

Figure 19 shows an infrared image covering the same area as Fig. 18. Many of the lineaments highlighted in Fig. 18 can be observed in Fig. 19. Predictably, the major drainage courses (Tierra del Sol Creek and tributaries) feature riparian forests, which draw their moisture from the groundwater (vadose and phreatic zones). The lineament in the bottom right-hand corner is located upland, i.e., it does not follow any clearly defined watercourse. Yet it is seen to consist of large shrubs (red shank) and trees (oak species) with a demonstrated water affinity.

B0002-114 cont.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 22 of 35



Source: Geography Department, San Diego State University.

Fig. 19 Infrared image of the Campo landfill-Tierra del Sol site.¹⁵

Figure 20 shows a digitally enhanced image of the central portion of the Campo landfill-Tierra del Sol site. To obtain this figure, Fig. 19 was processed with the NDVI¹⁶ feature of the ERMapper image-processing software, and cropped to the region of interest. Many of the lineaments depicted in Fig. 18 are clearly visible in Fig. 20.

B0002-114 cont.

Comment Set B0002, cont.
Boulevard Planning Group

Impact of the proposed Campo landfill on the hydrology of the Tierra del Sol watershed Page 23 of 35

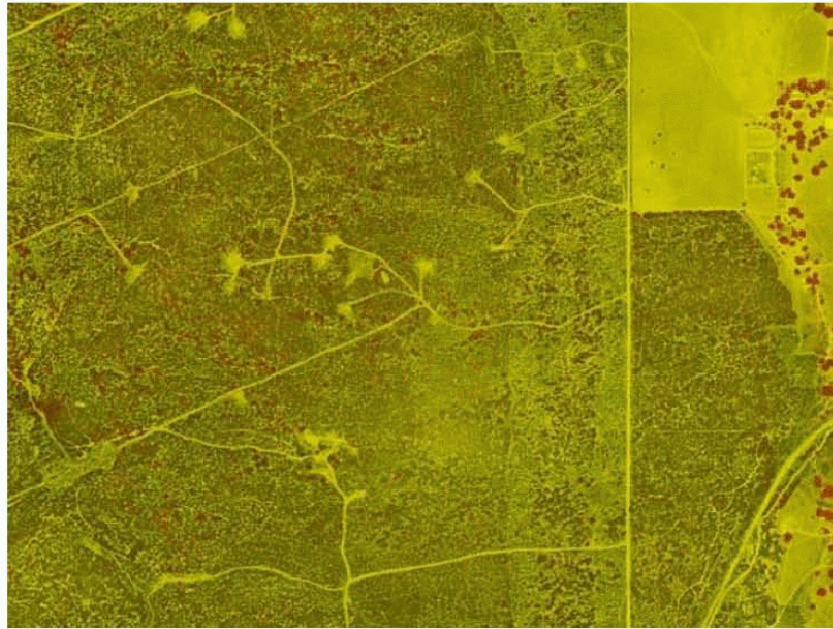


Image processed with ERMapper ©

Fig. 20 Digitally enhanced image of the Campo landfill-Tierra del Sol watershed boundary.¹⁵

B0002-114 cont.

• STREAM MORPHOLOGY •

[Groundwater hydraulics] [Synthesis] [Conclusions] [Summary] [Endnotes] [References]
[Reviewers] • [Top] [Introduction] [Scope] [Hydrology] [Hydrogeology] [Hydroecology]

The existence of springs in upland areas is a reliable indicator of an effective hydraulic connection between groundwater and surface water. The Tierra del Sol watershed is an upland watershed that has its highest point at elevation 3,880 ft, borders with the headwaters of Campo Creek immediately to the north and northwest, and it is within a few miles of the Tecate Divide to the northeast. Its lowest point is at its mouth on the Mexican border, at elevation 3,440 ft. The total watershed relief is 440 ft.

Figure 21 shows the location of eleven (11) springs in the Tierra del Sol watershed. Most of these springs drain northern slopes at elevations above 3,700 ft. The lack of a substantial number of springs along the western boundary of the Tierra del Sol watershed appears to indicate that the local drainage is primarily through the subsurface, from the fractures, downgradient, west to east, to be intercepted by the Tierra del Sol drainage. The latter flows in a predominant north-south direction.