ESTIMATING QUANTITY
AND QUALITY OF GROUND WATER
IN DRY REGIONS USING AIRPHOTOS

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ABSTRACT

Under certain circumstances it is possible to determine from airphotos alone
where water may be obtained in arid and semi-arid regions, the minimum amount
that is perennially available, and whether the water is of good chemical quality. The
interpretation is based on the simple premise that water of good quality which is
forced to the surface in dry regions will have been pre-empted by phreatophytes,
and that the amount of water available will depend upon the size of that vegetated
area. Some familiarity with the general region and the plant types may be necessary
to interpret with maximum effectiveness. The geologic condition attending the
appearance of the water at the surface may be evident on the airphoto. A fault acting
as a conduit will show springs where it intersects the axes of the valleys. A small spring
produces a spot of phreatophytes, whereas a larger spring will show a line of
phreatophytes extending downstream. A fault acting as a barrier is shown by a patch
of phreatophytes sharply limited by the fault on the downslope side, and commonly
a strip of dense vegetation marking the overflow. Areas of constriction in dry alluvial
channels are often marked by large quantities of rising water. In closed desert basins
with no groundwater outlet, the two areas of alluvial fans discharge large quantities
of water; a concentric strip of phreatophytes is replaced downslope by halophytes
where salinity has been increased by a high evaporation rate.

Although the examples discussed are in western United States, the same approach
may be applicable in other dry regions.

INTRODUCTION

Since 1950, various members of the Department of Geology, University of
Southern California have been directing their major research efforts toward problems
of desert geology, with particular emphasis on eastern and southeastern California.
One of the important problems investigated has been the availability of potable water
supplies; the purpose of this paper is to outline briefly the preliminary results of the
continuing study of the use of airphotos in the location and evaluation of water
supplies in desert areas.

The chief basis for interpreting the airphotos is an understanding of the
significance of the various plant patterns. Desert surfaces characteristically appear
pale on airphotos, whereas the plants are almost always dark gray to black. On the
unvegetated surfaces the plants can not grow because of lack of soil, excessive sali-


Unvegetated Surfaces

In the California deserts, surfaces devoid of vegetation constitute but a few per cent of the total arid area. Several distinct types may be recognized.

Bare-rock Surfaces. On bare-rock surfaces, where slopes are too steep to permit the development of a soil mantle, plants are scarce. Although no shallow waters may be present, the detection of a line of xerophytes developed on a soil marking the position of fault gouge may be a guide to deeper waters trapped along or behind this fault. Even if not accentuated by vegetation, well developed joint planes in plutonic rocks may offer excellent objectives in prospecting for deeper water.

Dry-type playas. Playas underlain by low water tables are shown on airphotos by pale unvegetated areas of uniform tone. Dry-type playas are probably confined to ground-water basins in which there is discharge by subsurface flow but none by evapotranspiration. The absence of vegetation may be the result of impermeable soil, excessive salinity, or both. The xerophyte pattern of the adjoining alluvial fans ends abruptly at the edge of the playa; there are no intermediate bands or strips of differing vegetation. The absence of vegetation bands, coupled with the uniform pale color tone, serves to differentiate the dry-type playas from the moist-type playas.

Dunes. Large areas of sand dunes generally have no perennial plants except near the edges. Water may be available beneath dunes, either as perched water in the base of the dune sand, or as a shallow water table entirely beneath the dune sand in the underlying deposits. Near the central parts of the large dune areas the water table is usually more than 50 feet deep, and beyond the reach of phreatophytes. The plants which suddenly grow on desert dunes following heavy rains are small, pale-colored, and would only rarely be detected on airphotos.

Xerophyte Patterns

Most plants which grow in desert regions are independent of perennial water supplies. These xerophytes have a wide spacing and an extensive shallow root system

Fig. 1 — Tracing of airphoto showing contrast between dry-wash xerophyte pattern (A) and sheet-wash xerophyte pattern (B).
to utilize effectively the sparse and infrequent rainfall. Between rains the plants become dormant. That lack of water is a controlling factor is shown by the vigor with which these xerophytes grow when favorably situated, as along roads and flood control ditches.

Sheet-wash xerophyte pattern. On alluvial fans the xerophytes benefit from direct rainfall and also from small volumes of semi-channeled flow. This shotgun-type pattern can be discerned on airphotos with a scale of 1:20,000, but can be studied better on the larger scales (fig. 1). Most alluvial fans will show remnants of a darker surface a few feet higher than the abundant anastomosing channels. The xerophytes are smaller and sparser on this higher surface than in the lower, paler washes.

Desert-flat xerophyte pattern. On the flattest alluvial surfaces, where there is little runoff, the xerophytes are smaller than on the alluvial fans. These plants are stunted because they must subsist on direct rainfall only, and on clayey soils much of this rainfall is evaporated directly. On the sandier portions of the desert flats, the xerophytes are more vigorous, perhaps reflecting that more of the rainfall can be utilized by the plants.

Dry-wash xerophyte pattern. The more or less diffuse runoff on the alluvial fans is eventually channeled into broad sandy washes, where the larger intermittent supplies of water are reflected as larger xerophytes. On airphotos, dry washes are usually of a paler color than the remainder of the alluvial fan. The size of the dry-wash trees is a rough index of the thickness of the clean alluvium in the wash and of the amount of water available to the plants. For a short while following floods potable water may be obtained at shallow depths in these washes. However, the thalweg usually has a steep gradient and the water rather quickly drains downslope. The dry-wash xerophytes become dormant as soon as they have depleted the water films on the sand grains.

Linear xerophyte patterns. Superimposed on the random xerophyte patterns on alluvial surfaces or on hills of older materials may be seen prominent linear trends of xerophytes following the outcrops of faults. A tracing of an airphoto showing such an occurrence is presented in fig. 2. The faults are in a hill of cemented alluvial deposits a few miles northeast of the well-known San Andreas Fault zone and are related to it in trend. The plants are not phreatophytes but are vigorous xerophytes thriving in gouge soil.

Fig. 2 — Tracing of airphoto showing faults delineated by xerophytes.
SURFACES UNDERLAIN BY SHALLOW SALINE WATERS

The most obvious areas of shallow saline waters in the California deserts are the bottoms of closed topographic basins occupied by moist-type playas. It is likely that the subsurface basins are also closed and that discharge of water from the basin is primarily by evapotranspiration. In sharp contrast to the uniform color tone of the dry-type, the moist-type playa on airphotos shows a splotchy pattern of numerous shades of gray from very pale to very dark. On some moist-type playas a well-developed polygonal pattern may be evident. In the central parts of moist-type playas there is no vegetation, but on the edges there is usually a strip of halophytes marking a transition zone between the brines of the playa and the fresher waters at the toes of the alluvial fans (fig. 3). The banded pattern flanking the splotchy playa surface is highly diagnostic of a basin in which the shallow ground waters have been made highly saline by excessive evaporation.

Fig. 3 — Tracing of airphoto showing moist-type playa (A), halophyte strip (B), and alluvial fan (C).

SURFACES WHICH MAY BE UNDERLAIN BY SHALLOW POTABLE WATERS

Direct evidence of effluent groundwater or shallow water tables is to be looked for in plant patterns other than those of the xerophytes. The appearance of phreatophytes on airphotos is usually as dark gray to black spots, often arranged in a somewhat systematic manner. The coarser-textured phreatophyte patterns can be clearly discerned on airphotos with a scale of 1:62,500, about the smallest scale commonly flown commercially. It is axiomatic to the present study that phreatophytes will have pre-empted all the water of tolerable salinity that is within a few feet of the ground surface, and some of the water from greater depths. It was established some time ago by Meinzer (1927) that most phreatophytes are able to utilize water within a few feet of the ground surface and that some, such as mesquite (Prosopis) tap water tables which are 50 feet or more below the ground surface. The amount of water being used by the phreatophytes (which can be considered the minimum amount that
can be salvaged for human purposes) is determined by multiplying the area of phreatophytes by the unit consumptive use. Depending on the type of phreatophyte, the unit consumptive use shows a wide range, from about 3 to about 10 acre-feet per acre per year. A one-acre patch of phreatophytes would require a minimum of one million gallons of water per year, and probably much more.

As an aid in recognizing the appearance of phreatophytes on airphotos, a classification of the patterns will be presented, along with diagrams traced from actual airphotos. In addition, some data on the geology and hydrology of the various patterns will be included.

**Point Phreatophyte Patterns.**

Point discharges of ground water at the surface are called springs, for which there are numerous geological explanations. In desert areas these springs are invariably marked by phreatophytes with an areal extent dependent upon the flow of the spring. Where the spring exits along a fault, quite often the trace of the fault is evident on the airphoto. In large dune areas, especially near the periphery of the sand mass, a shallow water table may be tapped by lone phreatophytes or by small groups of phreatophytes in the hollows (fig. 4).

![Fig. 4 — Tracing of small-scale airphoto showing dune ridges and phreatophytes in hollows.](image)

**Linear Phreatophyte Patterns**

More often than not, a fault along which a single spring appears, will be the locus of a series of springs. In fact, on airphotos such a spring line may be the most useful feature for detecting or confirming a fault. If the flow of a spring is large, a pronounced line of dark vegetation extending downstream is supported by the effluent water. Where a fault acts as a ground-water dam, it may appear on airphotos as a nearly continuous line of seepage. Such an occurrence, traced from an airphoto taken along the San Andreas Fault Zone, appears in fig. 5. The seepage line is limited abruptly on the down-gradient side and is scalloped as a result of re-entrants on the up-gradient side. Another line of phreatophytes marks the canyon where the
Fig. 5 — Tracing of airphoto showing lines of phreatophytes along San Andreas Fault Zone, California.

water spills across the barrier block. In another part of the San Andreas Fault Zone, where Recent alluvium has been dammed, the same two linear patterns can be detected, but are more obscure (fig. 6).

Fig. 6 — Tracing of airphoto showing phreatophytes in area of shallow water created through damming of Recent alluvium by San Andreas Fault Zone, California.

Strip Phreatophyte Patterns

Fan-toe phreatophyte strips. In the lower parts of alluvial fans, where the water table is close to the ground surface, there may be a broad strip of phreatophytes
(fig. 7). In such strips, especially in the upslope portions, there is a good chance of obtaining large quantities of potable water at shallow depth. A unique modification of the fan-toe phreaticphyte strip is shown in fig. 8. This is in Death Valley, where the Furnace Creek alluvial fan has been deposited on impervious lake beds. This unusually well-watered fan has a fault spring near its apex. Spring flow and runoff can travel downward no farther than the impervious lake beds, then must move downslope and appear as seepage at the fan toe. Beyond the fan toe, excess water percolates radially outward as subterranean flow in the alluvium deposited in channels out in the lake beds. The channel underflow is traced as numerous sinuous lines of phreaticphyles arranged like the spokes of a wheel. Thus there is the arrangement of linear patterns to form an arcuate strip pattern.
Wadi phreatophyte strips. The nearest relative of the Saharan wadis in the California deserts is perhaps the Mojave River. It has a very large tributary drainage of high elevation feeding a long thick strip of alluvium which ends in a closed desert basin. There is continuous surface flow only in a few stretches associated with alluvial constrictions where the subsurface cross-section is insufficient to transmit all the water as underflow. Upstream from these constrictions are dense areas of phreatophytes covering the entire width of the alluviated valley. Downstream from some of the constrictions the river flows as a surface stream; downstream from others the water table drops quickly and there are no phreatophytes. Along certain reaches of the dry river bed, some of the deeper-rooted phreatophytes are abundant.

Perennial stream phreatophyte strips. Distinct from the wadis are large rivers such as the Nile and the Colorado which rise in regions of high elevation and rainfall, and carry large volumes of water across desert regions to the sea. Although these have continuous perennial flow, they are characterized by tremendous changes in the volume of flow. Because of evaporation from free water surfaces, and from the capillary fringe where the water table is close to the ground surface, the shallow ground waters often have a high salinity. Beneath the shallowest waters are usually large volumes of potable water.

Patchy Phreatophyte Patterns.

The largest and darkest-colored phreatophyte spots on airphotos of the California deserts are usually mesquite. Because of a long tap root which can go 50 feet and more, the mesquite can grow in many places where more shallow-rooted phreatophytes cannot. Mesquite is very widespread and produces a characteristic patchy pattern due to an uneven distribution of the individual plots or groups of plants. On small dunes the mesquite may cover the entire sand surface and show as solid subcircular disks (fig. 9). As the dune increases in size, the mesquite dies in the central part of the dune, and the dark vigorous bushes are confined to the periphery of the sand patch (fig. 10).

![Fig. 9 — Tracing of airphoto showing dunes completely covered by living mesquite.](image-url)
Problems of salinity determination on airphotos

The problem of estimating the salinity of water being used by phreatophytes, from a study of airphotos alone, is a difficult, though not impossible, one. First of all, the particular species of plant must be identified from the airphoto. On scales of 1:20,000 and smaller, mesquite (*Prosopis*) may be type only the that can be recognized in the California deserts. On scales of 1:10,000 or larger, the identification of many other types is possible. Beyond identification, the salinity tolerance of the species must be known. Few phreatophytes are so intolerant of salinity that they grow only in potable water, although many are usually found associated with it. A considerable number of species tolerate a wide range of salinities, from potable water to 10,000 or more parts per million total dissolved solids. To resolve this part of the problem it will be necessary to accumulate statistical information on water salinity vs. plant species; this approach was used by Meinzer (1927). Fortunately, most phreatophyte occurrences which have been investigated were found associated with potable waters. In some instances, if the shallow waters prove to be saline, deeper drilling and casing off the shallow waters may result in waters of lower salinity.

Ground-water occurrence inferred through recognition of land forms

Many of the principles discussed in the preceding analysis of plant patterns on airphotos could be applied by a person with little knowledge of geology. For locating small supplies of water for emergency or temporary purposes, such an approach may be quite adequate. If larger, continuing supplies are desired, a more thorough geologic analysis of the airphotos is necessary. A geologist trained in desert hydrology can infer a great deal about deeper sources of water from the airphotos alone; such a study, logically following the approaches used in this paper, would be an effective prelude to the field study and test drilling which must follow.
REFERENCES

Note: As defined for the deserts of California, dry-type playas are those flat clayey surfaces of ephemeral lake bottoms associated with deep water tables, where the ground surface is well above the reach of the capillary fringe. On the other hand, moist-type playas are found where the water table is within a few feet of the ground surface; the capillary fringe reaches the ground surface and there is generally a salt crust overlying the permanently moist clays. Halophytes are specialized plants which can thrive where the soil moisture is of abnormally high salinity.