THE USE OF AIRPHOTO-INTERPRETATION TECHNIQUES
IN WATER RESOURCES SURVEYS

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SUMMARY

Interpretation and measurement of various features visible on the stereoscopic image
or on single photographs will permit a distinction between and mapping of areas with
low, moderate, high and very high peak runoffs, and with large or small baseflows.
Zones can be determined where groundwater recharge or storage are likely and
where groundwater development seems feasible. Areas of shallow watertable can be
mapped by the presence of phreatophytic plants and trees; salt efflorescences or the
presence of halophile plants point to a salinization of the groundwater.
Use can be made of conventional photography, special film and filter combinations,
satellite photography and remote sensing techniques.

RÉSUMÉ

La distinction et la cartographie de zones à crues basses, moyennes, élevées ou
violentes ou à écoulement de base importante ou réduite se laissent faire à l'aide de
l'interprétation et de mesures faites sur des photographies isolées ou sur des modèles
stéréoscopiques.
Il est possible d'indiquer des zones d'alimentation des nappes souterraines ainsi que
les endroits apparemment propices à l'exploitation. La présence d'associations végé-
tales phreatophytes indique que la nappe phréatique se trouve à faible profondeur,
alors que des efflorescences salines ou des associations de plantes halophiles dénotent
une salure progressive des eaux souterraines.
L'inventaire des ressources en eau peut utiliser la photographie conventionnelle,
des sélections de films et de filtres, la photographie spatiale ou des techniques de
«remote sensing».

1. INTRODUCTION

The last few years several papers have been published on the application of aerial
photography in the description and appraisal of surface water and groundwater
resources (f.i. Howe (1960), Lohman and Robinove (1964); Setzer (1966); Zinke,
et al. (1960); various books and papers in Russian, still awaiting translation.) Only too often
however, a systematic approach to the problems concerned is lacking. Benefit derived
from the use of aerial photographs in many cases is less than could have been because
the work done is purely descriptive without a quantitative or at least a semi-quantitative
appraisal of the watershed characteristics and water resources within a certain area.
Many complex and often interrelated morphological, geological, vegetational and
soils characteristics determine the hydrological regime within the drainage basin, in
addition to climatological factors. The co-operation is therefore needed of earth
scientists, ecologists and hydrologists to relate quantitatively the features visible and
measurable on the photographs to runoff and infiltration characteristics.
A program of experimentation and of instruction in a systematic use of photo-
interpretation as a tool in hydrological surveys has been started in the Netherlands.
The present contribution will be restricted to a discussion of some fundamental aspects.
It is hoped that soon other papers by one or more of the scientists taking part in the
program can be published giving results of the experimental work.
This paper summarizes reports and notes prepared by various persons. Although it
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2. ESTIMATES OF AVAILABLE SURFACE WATER RESOURCES

A distinction must be made between estimates of available base-flow, of frequency and magnitude of fast runoff or floods, of natural storage within the drainage basin and of possibilities for artificial storage.

Base flow and natural storage are of direct importance for a water supply during all seasons. The determination of magnitude and frequency of floods is of great interest when drainage problems are involved; flood protection measures have to be taken, bridges, culverts or regularization works have to be designed. Artificial storage may be required either for a regularization of a river or for an optimal use of the available water.

Of course the availability of water either as surface water or as groundwater depends in the first place upon the supply by precipitation and losses by evapo-transpiration, thus on climatic factors. Whereas quantitative data on evapo-transpiration and on precipitation, including total rainfall, rainfall-intensity and duration, daily and seasonal rainfall-distribution and variation can only be supplied by meteorological observations made at suitable sites, some general knowledge on the climate in the region to be surveyed can also be obtained by an analysis of its morphology and vegetation with the help of aerial photographs. Morphology and vegetation pattern of a region reflect to a certain extent its rainfall characteristics and climate. In mountainous regions elevation and exposition in turn have great influence on amounts and distribution of precipitation (Zeilmaker, 1966; Rijckborst, 1967). Study of aerial photographs and of topographical maps will indicate therefore to what extent a certain meteorological station can be deemed representative for a large area. Mapping of plant and tree associations also permits an estimate of transpiration losses due to the vegetation.

The total amount of water available within a catchment-area with a known or estimated precipitation depends on its size. Water divides can be drawn very easily on aerial photographs and watershed areas can be measured with high accuracy. Channel length and drainage area being inter-related, areas can be determined easily and very rapidly by measuring channel lengths only, provided this relationship has been established priorily and plotted graphically for each morphological unit separately which occurs in the region studied.

The distribution of available water between surface water and groundwater depends upon the geology and morphology as well as on the rainfall-intensity and distribution. An experienced photo-geologist can differentiate between various rock and soil types, indicating whether they are pervious or impermeable, mapping at the same time their area and distribution. Taking into account morphology as well as geology areas of groundwater recharge and of groundwater discharge can be delineated and the probable groundwater divides and directions of groundwater flow can be indicated. This is very important as surface water divides and groundwater divides need not coincide. Thus a drainage basin can either be supplemented by groundwater from elsewhere or loose part of its surface water underground into neighbouring or distant watersheds. The importance of these phenomena should be understood as baseflow depends to a large extent on groundwater supply and bankstorage. Estimates of the amount of groundwater recharge therefore should also be made using experience, obtained under similar conditions elsewhere. Extreme examples of the influence of groundwater infiltration and discharge on the hydrological regime can be found in areas of karstified limestones or of some strongly fractured volcanic rocks, where most of the water drains and circulates underground.

As already stated, the hydrologist has to differentiate between base flow and fast runoff. Moreover, determining the runoff characteristics of a drainage basin as a function of precipitation forms an integral part of his task as this will allow him to predict the discharge to be expected from a specific rainfall pattern and precipitation
amount and to foretell the probability of floods or minimum discharges of a certain magnitude. There is no need to stress the importance of knowing the precipitation-discharge characteristics of a drainage area for many different practical purposes.

The translation and transformation of precipitation into runoff is a function of the temporal water-storage, both in water courses, lakes and temporary on the ground surface and in ponds as well as in the non-saturated and the saturated portions of soils and permeable rocks. A number of features interact in these processes, for instance size and shape of the catchment area, channel roughness, channel length and channel slope, terrain slope and ruggedness, drainage pattern and drainage density, composition and distribution of soils and rocks and vegetation pattern. These features which characterise a drainage basin can be studied on aerial photographs. They can be described quantitatively by measuring various elements in the stereoscopic image.

Normally the relationship between precipitation and runoff for a basin is derived from a statistical analysis of precipitation records and discharge measurements from a number of stations. The observations and measurements have to be carried out during sufficiently long periods in order to cover the effects of seasonal and interannual variations.

Very often, however, neither time nor financial means and manpower arc available for such longterm investigations while nevertheless information on drainage basin-characteristics is urgently required for planning of regional development or for the design of engineering works. It is tempting under such conditions to try and substitute a description of the various morphological, geological, soils and vegetation features mentioned above for the statistical analysis of hydrometric data. As a matter of fact the interaction of these features constitutes the basic elements of the runoff characteristics, to be expressed as: percentage of the area contributing to a fast runoff, the reservoir value of that fast runoff, and, the base flow or the reservoir coefficient of the slow runoff (de Jager, 1965). The advantage of this method would be to put into the hands of the hydrologists and the engineers a tool for a rapid determination of the runoff characteristics with the help of an airphoto coverage of the catchment areas to be studied. A check of the results could then be obtained by measurements in selected representative basins, resulting in a considerable gain of time and funds.

Although some progress has been made, this approach is still hampered by many uncertainties and difficulties. As a matter of fact many of the variables concerned can be described quantitatively by morphometric analysis on the stereoscopic model but others still defy attempts to be expressed by numerical values, either by airphoto analysis or even by measurements in the field. Amongst the parameters which as yet are difficult to define are the effects of geology, soils and vegetation. The nature of these features and their influence on the hydrological regime may not only vary from place to place, but it may also change with time, the time-influence in a number of circumstances being more or less diurnal or seasonal. Moreover various degrees of correlation exist between a number of these parameters (Gray, 1961). For instance extent, thickness, porosity and permeability of scree and soil covers depend on steepness of slope, nature of parent rocks and geology. Morphology and geology are also interrelated but climatic conditions act also on the evolution of the landscape. Vegetation in turn is influenced by soils and climate, in mountain regions also to some extent by steepness and exposure of slopes. Nevertheless recent studies have shown that morphometric analysis and mapping of geology, soils and vegetation cover form an integral part of hydrological studies, carried out on the basis of statistical treatment of hydrological and meteorological data (Rijksebort, 1967).

The geometrical properties of the watershed can be determined numerically by morphometric analysis, using various criteria. Of great significance with respect to runoff characteristics are size of drainage area (correlated with stream length, Benson, 1964), relief ratio (Schumm, 1956) and bifurcation ratios (Horton, 1945). Moreover the
effects have to be included of rocks and soils, basic data for which can be obtained from aerial photographs by applying standard techniques of photo-interpretation with adjustments for the special requirements of a hydrological analysis, taking into account porosity and permeability factors. The influence of the vegetation, in particular forests and grasslands (Kittredge, 1948; Hewlett and Hibbert, 1966, and others) can be estimated, mapping in the usual way the vegetation on the aerial photographs. The complete morphometric analysis can be carried out with aerial photographs, also for those areas for which topographical maps at suitable scales do not yet exist. It is not necessary therefore to carry out a topographical survey prior to the photo-interpretation, which in many parts of the world still decidedly is a great advantage.

The above procedure does not provide quantitative information on the available water resources either as base flow or as fast runoff, but permits subdivision and classification of an area into zones of low, medium, high and very high runoff. Delimitation of zones of uniform runoff characteristics and a qualitative appraisal of the hydrological characteristics forms a first very useful step in the water resources inventory. Comparisons can be made with areas of known characteristics and representative basins can be selected for the various zones. An additional advantage of this method is the fact that often morphological units differentiated by photo-interpretation on qualitative criteria alone in our experience proved to be of sufficient morphometric homogeneity to be useful in the hydrological study, thus making the work even more rapid and efficient, morphometric analysis being restricted to a few watersheds within each zone.

A special word should be said about the role of phreatophyte associations, plants and trees which thrive under very shallow watertable conditions and which are responsible for very high transpiration rates (i.e. Horton, Robinson and Mac Donal 1964; Robinson 1965). These phreatophytes may deplete surface water and groundwater resources in a very serious way, making it imperative to map their density and aerial extent as a measure for an estimate of non-productive waterlosses in the area under consideration.

3. **Regularization of Surface Flow by Storage**

There is no need to go into much detail on this subject, the use of aerial photographs having become a standard procedure for the location and selection of sites suitable for dams and reservoirs. Morphological features determine in the first place the choice of reservoir areas with a sufficient storage capacity and of valley sections where a dam could be economically constructed. For a reservoir dam to be efficient for river regularization a certain relationship should exist between reservoir capacity and river discharge. The larger the fluctuations in discharge (ratio between minimum discharge and maximum flood) the larger the volume of the reservoir has to be with respect to the annual discharge of the catchment area. Size and runoff characteristics of the catchment area have to be analysed as well along the lines stated in the preceding paragraph.

Furthermore the geological photo-interpretation, combined with a hydrogeological and geotechnical appraisal of the features observed, has to indicate whether or not underground losses from the reservoir or at the site of the dam could occur; whether the slopes around the reservoir are stable, and whether the rocks at the dam site form a suitable foundation. Sedimentation in the reservoir may effect considerably its life-time, and the sediment-transport will have to be estimated from the watershed characteristics (Gottschalk, 1957).
4. EVALUATION OF GROUNDWATER RESOURCES

It is becoming more and more a common practice in hydrogeological surveys to start with a photogeological study of the area of interest, noting especially those features which indicate presence of groundwater discharge in springs or marshy zones and recharge zones. (Howe, 1958; Lohman and Robinove, 1964; Setzer, 1966 and others). Rock composition and geological structures (folds and faults) are noted. Phreatophytes may indicate a shallow watertable; halophyte plant associations and white efflorescences the occurrence of brackish or saline groundwater.

Because of the many interrelationships between surface water and groundwater, many of the elements of the surface water study as stated before may have to be incorporated in the inventory of groundwater resources.

5. SELECTION OF SITES FOR HYDROLOGICAL STATIONS

The aerial photographs of course will also serve for the planning of the hydrological fieldwork. Selection of sites for hydrological stations and areas to be visited for the purpose of checking conclusions derived from photo-interpretation or for the collection of additional data will primarily be a function of the classification of the region into hydrological units. As much as feasible representative basins have to be selected for field measurements within each of these units.

The choice of the individual representative basins will depend on local conditions, amongst which accessibility is of major importance. The geographical position of representative basins with respect to planned engineering works of course also should be taken into consideration.

The exact site of each hydrological station, whether intended for gaging of discharges or for measuring of meteorological data, has to be selected carefully, taking into account local conditions of topography, vegetation cover (forests), erosion and sedimentation phenomena, slope exposure etc. (Zeilmaker, 1966; Rijckborst, 1967). Careful scrutiny of the photographs, especially of scales of 1:15.000 and larger, will reveal many important features permitting a judicious choice of the sites for the planned stations.

6. TYPES OF PHOTOGRAPHY AND REMOTE SENSING TECHNIQUES

More and more attention is being given to the use of color-photography, infrared photography, special film/filter combinations and remote sensing techniques such as infrared scanning (e.g. Lohman and Robinove, 1964). Many advantages can be expected from a more general adoption of these materials, procedures and techniques. The same can be said of the application of satellite photography, which had provided us with interesting results in desert-areas of the Arabian Peninsula.

Many of these techniques however are still in the experimental stage and often also much more expensive than conventional photography. Some of the techniques are still restricted and not yet released by the authorities concerned for public use. As conventional photography is widely used for many different purposes, the hydrologist and hydrogeologist generally will have little or no difficulties in obtaining existing photographs of the areas he is interested in or in having new coverage made for planned water resources development projects.

For this reason, and also because we believe that the limitations of the application of conventional photography in photo-interpretation are far from having been reached, the present work is being concentrated on the use of normal panchromatic photographs.
The experience thus far gained indicates that photo-scales from 1:25,000 to 1:40,000 are suitable for many hydrological surveys. Scales larger than 1:15,000 normally would not be required and even may present certain disadvantages in overall studies. For special purposes, such as the selection of sites for hydrological studies, they may be extremely useful as said before.

List of references: