WATER RESOURCES

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Summary

Hydrological parameters important for wind pumping technology are treated, both for normal as well as for extreme operating conditions. It is explained how topographical features may influence the hydrological cycle and may affect rainfall. An introduction is given to analysis of rainfall data and the use of isocharts. Rivers as a main water resource for pumping are treated. Methods to use rivers as a water resource for wind pumping are described, including analysis of river flow rates and watershed. Practical and theoretical aspects of ground water assessment are introduced, such as aquifers and their behaviour under pumping action; water finding methods: the use of topographical maps, electrical resistivity surveys, seismic surveys, water devining. Finally methods for borehole drilling and well characteristics, are described.

Objectives

- to outline climatological factors which influence water resources, and their implications for site selection and wind pumping;
- to explain which data should be collected and how to evaluate and analyse them;
- to provide basic knowledge for groundwater exploration and exploitation purposes, including drilling methods.

Concepts

- hydrological cycle; evaporation; transpiration;
- topographical features influencing rainfall;
- time series; isochart maps; statistics;
- watershed; hydrographs; water years;
- aquifers; aquitards; specific storage; permeability; drawdown; well yield; specific capacity;
- resistivity; seismic surveys; water devining methods;
- shallow wells; well jetting; driven wells; boreholes;
- cable tool (percussion) rigs; rotary drilling rigs.

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1 INTRODUCTION

In the case of wind pumping water is a resource as important as wind. The water resource should be studied as much in detail as the wind resource in order to achieve sustainable water supply.
It requires other disciplines, such as hydraulic engineering and hydrology, which have often been neglected in wind pumping technology to be incorporated by the institutions that have developed second generation wind pumps. Wind pump developers often considered the water flow as constant and sufficient, with the water at a constant level. In 99% of all cases none of these assumptions is true. Water level and flow may vary due to a large number of parameters, such as the type of water source (river or groundwater), orographic conditions, climatologic parameters such as precipitation, etc. This module presents an introduction to the parameters playing a role in determining the water resources necessary for the application of wind pumping.

2 OPERATING CONDITIONS

Normal conditions:

For the design of a wind pump system at a particular site, the designer needs to know the following for the reasons given [1]:

- mean head between resource and outlet - sizing the system;
- mean flow available with mean drawdown - sizing the system;
- seasonal availability - storage and use of system.

Extreme Conditions:

- maximum head occuring - sizing the pump, siting the pump and pump inlet, loading on the pump;
- limits on extraction - sizing of the system, providing the limit on maximum wind pump capacity;
- frequency of flooding (rivers) - siting of turbine and pump inlet, loading on ground components;
- minimum flow - siting the pump.

Physical parameters

- site of the water resource - siting the system components (transmissions);

- diameter of well and access to the resource - physical size of components;

- quality of the water - materials used, inlet/filter requirement;

- pollution feedback into the source - outlet design.

3 HYDROLOGICAL CYCLE

Terrestrial moisture is in a constant motion and all near surface water participates in what is called the hydrologic cycle [2]. Water coming from the ocean ultimately returns into it, hence the cycle concept. Water in the hydrological cycle is not only transported from one location to another but it also continuously changes state. Water can be solid, liquid, or gas (vapor). During evaporation, water molecules near a water surface absorb sufficient energy from solar radiation to vaporize. Two other processes contribute to total evaporation: transpiration and sublimation. In transpiration, moisture released by plants is returned into the atmosphere. Sublimation occurs when ice and snow pass directly into vapor without going through the liquid phase. In most parts of the world, transpiration and ordinary evaporation cannot be distinguished, hence the loss of water from a land surface is called evapotranspiration.
The principle of the hydrological cycle is shown in Figure 1.
It should be noted that for some distance below ground there is an unsaturated zone, below this is the saturated or groundwater zone, which is the water resource used by boreholes.

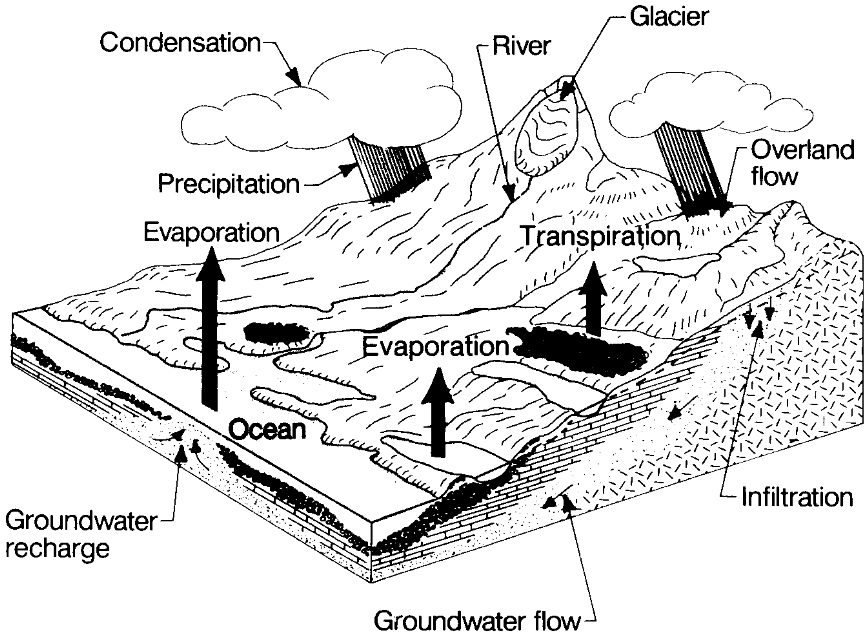


Figure 1: Hydrological cycle

The water resources of interest for wind pumping are:

• surface waters - rivers, streams, ponds, lakes and some shallow wells;

• groundwater - boreholes (tubewells), shallow wells, artesian springs, springs.

Oceans and seas account for by far the greatest amount of water resources on earth, about 94%; of the remainder 4% is stored as groundwater and 2% in the form of ice. Atmospheric water, though important to life on earth, accounts for only 0.01% of the total storage. However, it is this atmospheric water that finaaly closes the hydrologic cycle.

4 DERIVING THE WATER RESOURCE FROM CLIMATIC DATA

We use climatic data (rainfall data, temperature, humidity, wind regime) to determine the recharge of a resource. Of these data the most important is rainfall. It can be measured by collecting the amount falling on a given area in a given period. The collection point can be sampled at fixed time intervals; usually 60 minutes or two days (standardized). Unlike wind data, frequent sampling is not so important obtain accurate information about the water availability.

4.1 Confirming the data

Although there are generally many more rainfall stations than winddata stations, and their accuracy is better than that for wind, it may still be necessary to apply some correction factor. The record of rainfall at one location for a certain time may not be typical for the surrounding region, or of the rainfall over a longer period. Therefore data should be checked and corrected, if necessary.

4.2 Time based factors

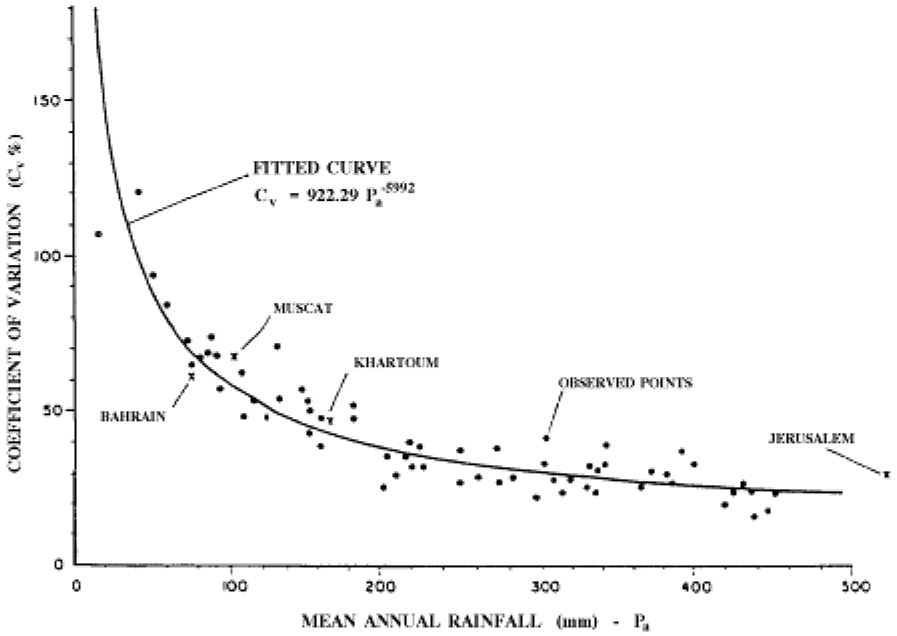


Figure 2: Dependence of annual variation in rainfall with mean annual value

The mean windspeed for a single year was said to be statistically highly significant, as we assume it to be within 10% of the long term (20 years) average. In the case of rainfall, deviation from the long-term average may be much larger, which is particularly true for arid zones. While for temperate regions the average for a year is within 20% of the long term mean, for arid zones (200 mm precipitation per year) this figure may be as much as 200% more, or 40% less.

4.3 Physical factors

It should be checked whether the fall on the small area of the instrument is representative of the regional precipitation. Precipitation events can be very limited to a small area. Large mountains cause rain shadows, i.e. force the atmospheric water to precipitate. The leeside barely receives any rain. There is an analogy with the topographical corrections applied for wind regimes.

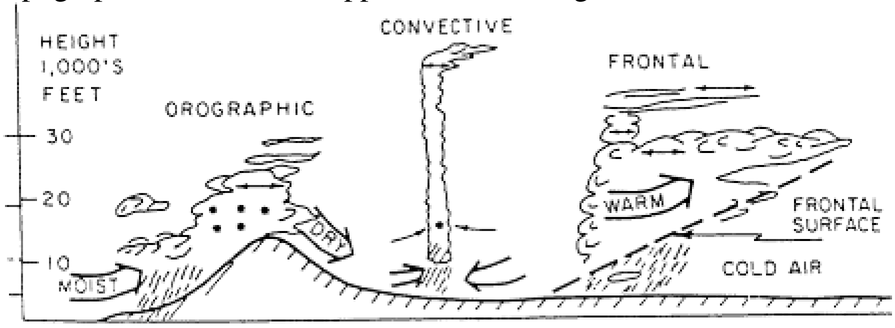


Figure 3:Physical conditions influencing the rainfall pattern

4.4 Analysing rainfall data

• topography large scale - has the gauge been set in a rain shadow, is the measuring altitude typical for the region, etc.

• installation - is the gauge well exposed, at the correct height, etc

4.5 Time series

Rainfall data is generally presented as a monthly histogram. It is not practical to plot only the long term average since the yearly variations may be so large. The normal practice is to indicate the amount exceeded in a part of the measuring period, i.e. 4 years out 10, 7 out of 10, and 9 out of 10. These limits are obtained from the duration curve as can be derived from the long term records. These probabilities for a given minimum amount of water are very useful to calculate the irrigation needs of an area. By accounting for temperature, humidity and irradiation, the soil water balance can be determined and the Net Irrigation Factor be calculated applying a crop adjustment factor.

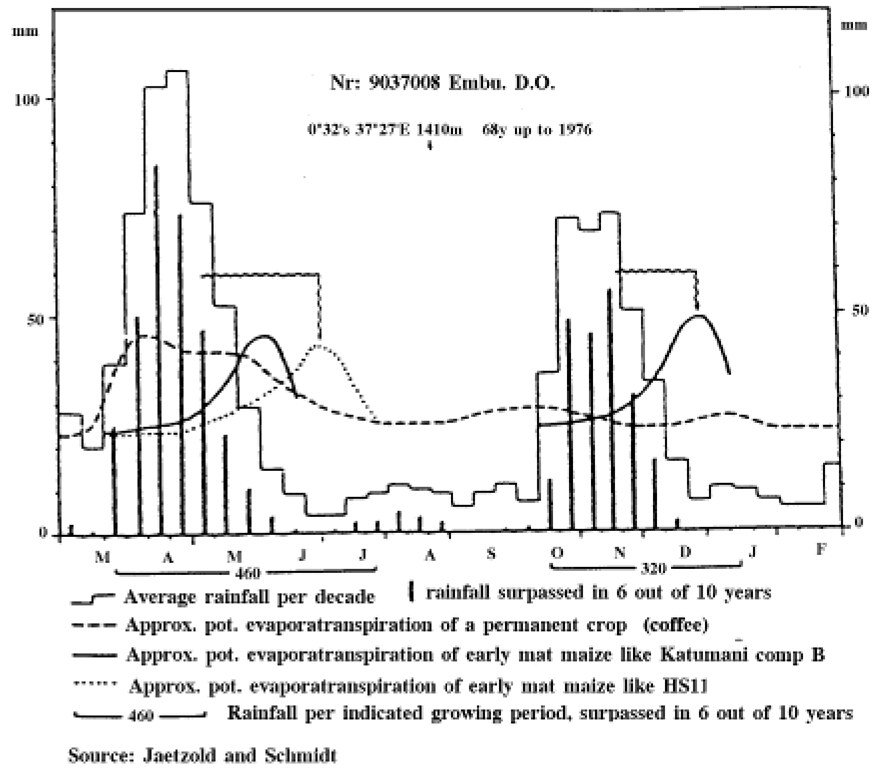
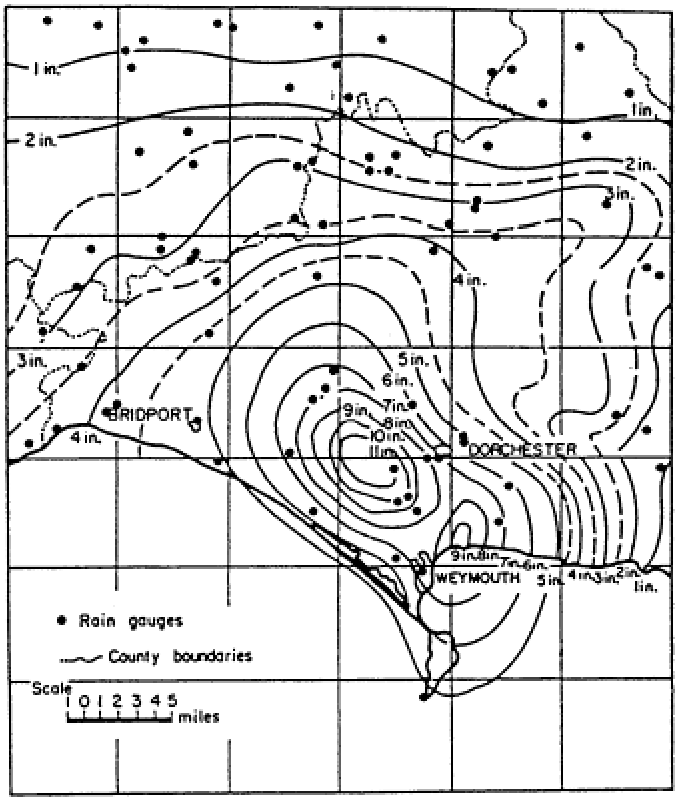
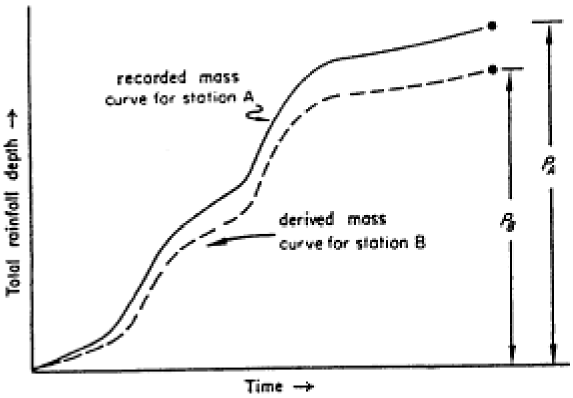


Figure 4: Rainfall and evaporation in Embu (from Jaetzold and Schmidt)

It is reasonable to expect a positive correlation between the rainfall and the availability of the water at the resource. This is true, but with some time delay due to buffer effects. For example, rain falling on an area may run off into the nearby river, but the run off will take some days to reach the river bed. In the case of groundwater the time constant may be seasons or even years rather than days. For this reason we are not so interested in rapid events. A sharp heavy rainfall may not infiltrate the ground as much as a slow steady rain of the same



Rainfall over part of Dorset, 18 July 1955. (reproduced from British Rainfall 1955. HMSO, London, 1957)



Derivation of rainfall data

Figure 5: Isochart for rainfall - an example (from HMSO, London, 1957)

quantity, but at the level of analysis relevant to windpumps, this is not taken into account. The one short term occurence that may affect the windpump, is a storm or flood. This is dealt with under statistics.

4.6 Spatial distribution

If sufficient measurement stations are available then isochart maps can be made. These can be used for calculating both water availability and pumping needs.

4.7 Statistics

If long-term rainfall measurements (20 years or more) are available then the frequency of occurence can be easily gathered. The procedure is simply to rank the amounts, noting that the distribution will be approximately normal. The ranked rainfall can then be plotted on probability paper and a best fit line traced through the points. This is similar to the procedure applied on wind data using Weibull paper, but for rainfall we use normal probability paper. Then a figure for the minimum rainfall can be chosen and the probability that this figure will be exceeded, be found.
Return periods for the maximums can be determined as well. An adopted standard is M5, that is the depth of rainfall with a return period of 5 years, i.e. on average it will be equalled or exceeded at least once every 5 years. M5 values can be for different durations, i.e. one could have a 2 minute M5 or a 25 day M5.

5 SURFACE WATER SOURCES

A second step of the analysis should be relating the climatic data to the water resource. Therefore major surface sources must be related to their catchment areas.

The catchment of a river, or as it is sometimes called, the watershed, is the area from which rain fall is recollected into the river. How the rainfall on the catchment actually feeds the river or stream, depends on the size and shape of the catchment and its location with respect to the passing rainfall fronts.

Run-off depends not only on the orientation and shape of the catchment area, but also on the evapotranspiration and soil compaction. These parameters may change in time, particularly if surface water is pumped within the watershed changing the environmental ecosystem.

Lakes and man-made dams may buffer the flow of water. In this case water either seeps down to add to the groundwater or evaporates. After evaporation, the dissolved minerals remain in the lake and consequently quickly deteriorate the water quality (e.g. Lake Turkana in Kenya).

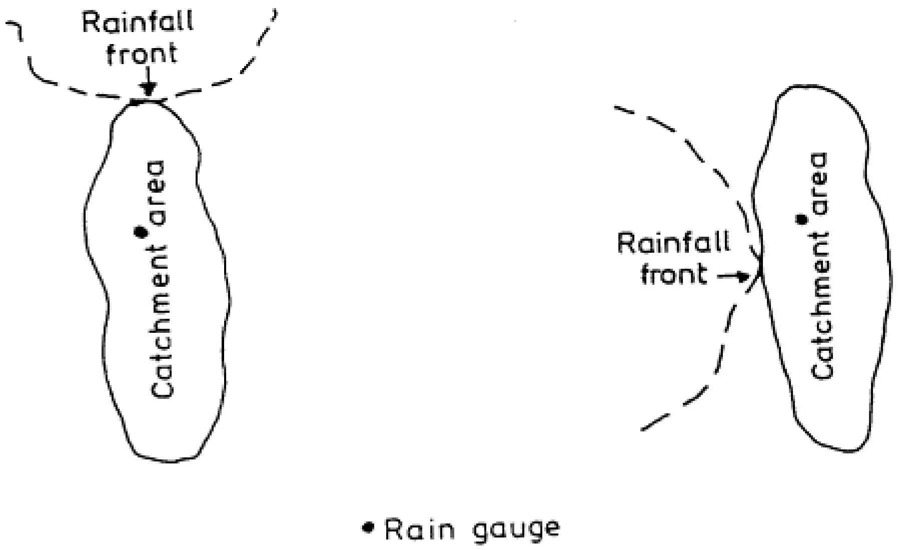


Figure 6: Catchment effects and rainfall

6 THE FLOW OF A RIVER

The flow rate of rivers and streams is shows long term fluctuations due to the character of precipitation and evaporation. The seasonal change may be from several metres deep to a dry river bed. On a short term, floods may occur which may cause damage to an installed windpump system. Part of our investigation of the water resources should include an understanding of these height variations. A full hydrological study is generally unnecessary however there should be some attempt to relate the rainfall on the catchment, to the flow of the river.

Information about the available water flow is usually presented in flow rating curves and hydrographs, that can be derived from existing measured data. Major rivers sometimes have flow measuring stations at determined distances along their course. If no data is available, or a small river is to be used as a water resource for wind pumping, a feasibility study should wisely include a temporary flow measurement program.
Flow rating curves show the connection between the discharge and the water level elevation, or stage of a river channel at a certain cross section. This is important to avoid locations where flood conditions might destroy or damage the equipment. It is unlikely that the head change of a river will seriously effect the performance of the windpump except in the following circumstances:

• the water level drops below the inlet;

• the water level drops such that a suction pump can no longer raise water;

• the pump is particularly sensitive to head variations, e.g. an archimedes screw;

• flood causes damage to the system, for instance by blocking the inlet, washing away the pump or inlet, or the tower;

• the river may change course during flood periods, thus leaving the windpumps very much high and dry!

The rating curve relates the flow to the head. A hydrograph plots the flow of the river with time and can be used to relate the flow to climatic data.

Hydrograph data can be further processed to give hydrographs of run-off volumes and flood duration curves. Such standardised curves allow a synthesis of data for an ungauged point on the river and for points on other rivers of similar geomorphological nature and climate. The slope of the FDC gives an indication of the character of the river.

Once having established the character of the river, flow rate and precipitation data may be correlated and plotted on a yearly basis. There should be a direct cause-and-effect relationship between rainfall and run-off if the catchment has been defined well.

Effects like evaporation, interception, depression storage, infiltration and soil moisture deficiency may worsen correlation. This means that correlation can only be found over a long time period. This period is generally taken as a water year.

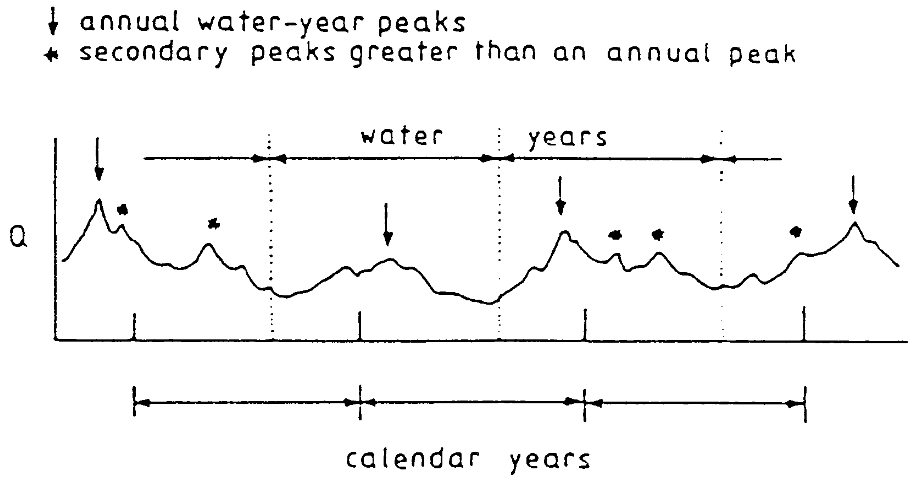
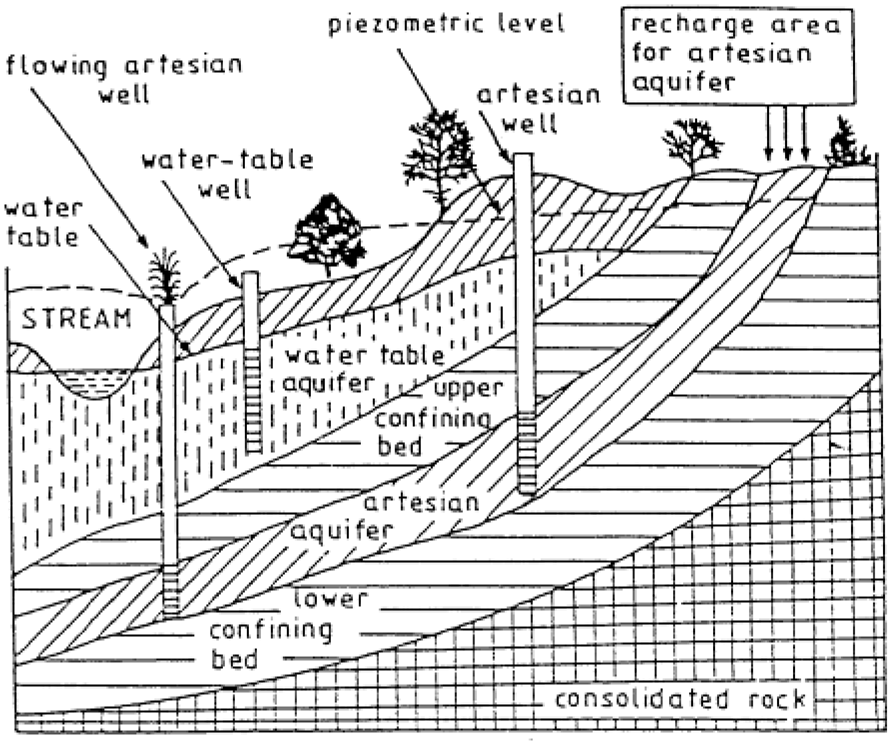


Figure 7: Typical seasonal variations for a given river

7 GROUND WATER

Many of the principles established for surface water apply to groundwater as well.



Modes Of Occurrance Of Groundwater Illustrating Terminology Used (Gibson and Singer 1971)

Figure 8: Modes of occurrence of groundwater

7.1 Aquifers and aquitards

An aquifer is defined as a layer or strata of saturated, permeable material. It is the source of ground water and is both a source of water since it is sufficiently permeable to let the water flow. The term aquitard refers to a layer of only slightly permeable material. Both terms are not precise. A third kind of geological layer is of course the impermeable strata which does not allow any water flow. Where an aquifer is contained between two impermeable layers it is known as a confined aquifer; where there is no top layer it is called an unconfined aquifer. Where an aquifer is bounded by an aquitard below it, it is known as a leaky aquifer.
The water level in an aquifer is called the water table. When a well or borehole is bored into the aquifer the water rises to reach its potentiometric or piezometric level. When the piezometric level is above the surface level the water actually rises out of the hole, a condition known as artesian flow.

7.2 Water pumping from groundwater

An aquifer consists of a porous solid matrix filled with water. The pores of the matrix interconnect so that water can flow under the influence of a pressure gradient. When water is pumped from a hole, the water level will drop to a lower level H. The difference (H-Ho) is known as drawdown and will depend on the rate Q at which the water is pumped. There is an increase in head with increase in the radial distance r from the centre of the borehole. This gradient causes the water to flow radially from the surrounding aquifer into the borehole.

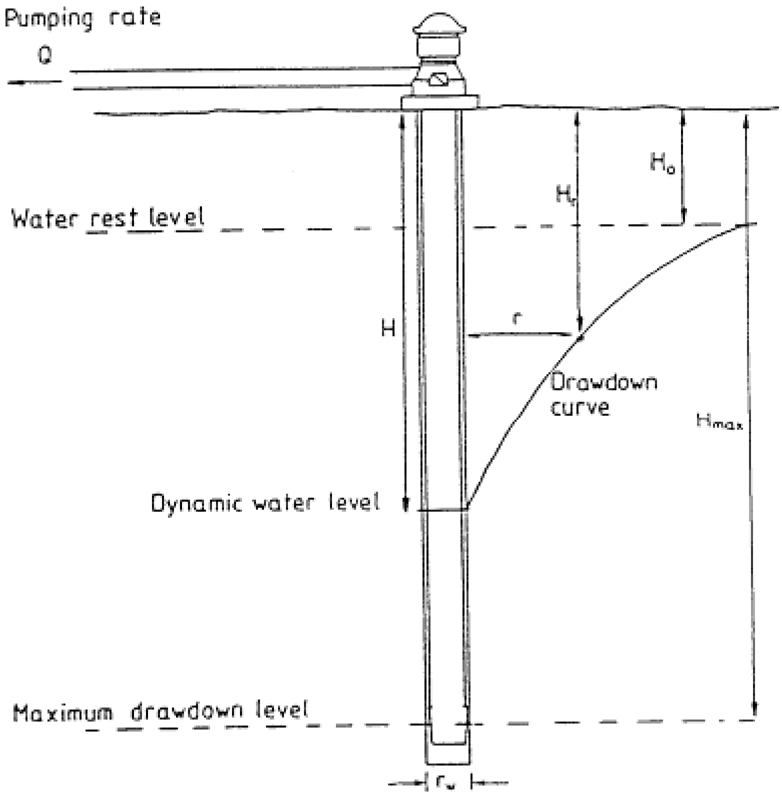


Figure 9: Water flow towards a borehole

In the case of an unconfined aquifer the head gradient is results from the change in level of the water table. Initially water will be provided from the region adjacent to the hole and as pumping continues the level will progressively fall away from the hole until an equilibrium is reached. Similarly when pumping ceases the drawdown will not recover immediately.

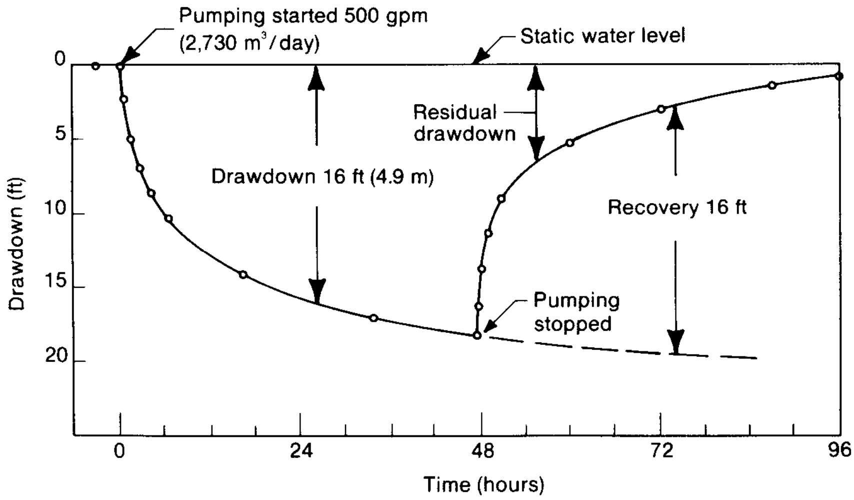


Figure 10: Typical drawdown curve for a borehole

It is important to note that the initial recovery is rapid and behaves in a similar manner to drawdown. The dynamic characteristics of a confined aquifer behave in a qualitatively similar manner to the unconfined, but the in detail the mechanism is somewhat different. If the water and the matrix were incompressible then the head reduction would occur immediately after pumping has started. In fact, somewhat suprisingly, water release is often appreciable; first, water is slightly compressible and will expand if the head is reduced, making available the excess volume for pumping; second; matrix expansion under head reduction reduces porosity, effectively further squeezing out water.

7.3 Physical properties of an aquifer

The hydraulic behaviour of an aquifer is determined by the physical properties of the water-filled matrix.

Porosity
The pores of the matrix are assumed to be interconnected. Not all the water in the pores is available for extraction, some will be retained by capillary and other effects. This can be seen in your bathroom sponge, which releases water if placed wet on a surface. However when water flow has stopped, further water can be extracted by squeezing.

Specific storage
The available water is called the specific storage (S). S is defined by the volume of water released per unit area of surface when the head is reduced by one unit. The term storativity (St) is used for confined aquifers where St = Sb, where b is the depth of the aquifer.

Permeability (transmissivity)
The flow of water through the matrix is specified in terms of permeability (k). Darcy's Law states that when a liquid flows through a porous media the velocity is proportional to the pressure gradient (in our case the head gradient). Transmissivity is used for confined aquifers where T = kb.

7.4 Behaviour of a pumped aquifer

We will not go into the equations here but suffice to say that it is possible to determine the type of aquifer from knowing the flow, drawdown, recharge, etc. Any standard text on hydrology can be used to gain further understanding. What is important here are the practical implications of this flow of water.

7.5 Important issues of ground water for wind pumping

The sections above dealt with some theory of groundwater flow to provide background for the windpump engineer to assess the resource. The following sections deal with the actual action taken with groundwater.

Catchment recharge
Groundwater is recharged by rainfall. However, there may be no correllation between the rain on site and the groundwater. The catchment area for the groundwater may be hundreds of kilometres away and the water may have taken hundreds of years to reach the aquifer. At an extreme some groundwater stores are fossil water i.e. they are pockets formed years ago and have no recharge. Australia has so overused its fossil supplies that the water table has dropped in some places. Groundwater then needs careful assessment when used in semi-arid regions to determine where the recharge will be coming from and what to expect over in the future.

Seasonal variation
Where recharge is tightly linked to the available groundwater, the water table may vary in height due to seasons or years of drought or plenty. The pumping rate and position must take into account the possible head variation over the years.

Water quality
When a borehole is near a brackish source of water, like a sea, then the pumping rate must take into account the need to retain pressure to keep the brackish water out. If a windpump programme is to be implemented on a small island a hydrologist MUST be consulted.

8 FINDING THE WATER

The first step to finding the location for a borehole is to inventory the existing water resources. This should include boreholes, wells and springs. This step is relatively simple, inexpensive and can avoid unnecessary further expensive steps in developing the borehole. Whether the details of nearby sources are abundant or scarce, a reconnaissance survey should be the second step. Topographic maps of the area, aerial photographs, geological maps, satellite photos should all be studied, if available. Satellite photos for almost anywhere in the world can now be obtained from various sources with a little effort. Recent advances in the quality of photos (aerial and landsat) mean that rock and soil types can be found from these observations. This "paper" study must be part of a field visit. The visit should record observations on vegetation, topography, etc. A groundwater balance sheet can be made, containing probable storage, inputs, recharge, output quantities.

If these steps have not led to a clear unambiguous conclusion, then geophysical methods can be employed in a field survey. The two common techniques are:

- electrical resistivity surveys;
- seismic surveys.

8.1 Resistivity surveys

They are relatively simple to carry out and require simple equipment. A known electric current is passed between two electrodes. Voltage electrodes are used to measure potential differences along the current paths in order to assess the apparent resistivity of the rocks at that strata. The resistivity is affected by density, fractures, fissures and the presence of water. Evaluation of the results should be left to a specialist.

8.2 Seismic surveys

Seismic surveys rely on the different velocities of shock or sound waves through a rock material. Sound waves travel faster in dense rocks and water-filled spaces. A geophone pickup measures the travel times of the sound reflecting off the various strata; moving the sound source a picture of the ground below will be built up. As above, interpretation of results should be left to a specialist.

8.3 Water divining

The two detailed surveys indicated above require equipment and hence expense. An debated alternative is water divining. This is the seeming ability of some people to determine the presence of groundwater by the use of a stick or rods. Many people have attempted to study the principle involved but no firm conclusions have been reached. People involved in divining vary in religious faith; among them are atheists, catholics, animists, fundamental protestants, each attributing the ability to a different source both physical and spiritual. Most would agree that the success rate of a reliable diviner is comparable to electrical and seismic surveys. Ministries of Water worldwide, including those in the western countries continue to use this method as it is cheap with a reasonable success rate.

8.4 Who to hire

When wanting to drill a hole, the site choice can be made by either the local people (field survey only), the ministry of water (steps 1 & 2, possibly 3), or a qualified hydrologist (1, 2 & 3).

9. DIGGING A SHALLOW WELL

Accessing surface water does not always mean using a river or lake. In some cases, "surface water" can be found just below the surface. A shallow well may be dug to access this water. This differs from groundwater as the sub strata may not be saturated. The water in the well is subject to the variations of the rainfall and may dry up during some periods of the year.

Digging a well is an art in itself. Generally, a man or men literally dig the hole and therefore the diameter is at least 3m so that he can work comfortably. In unconsolidated soil the well sides must be supported and this is often done by using concrete rings or brickwork, backfilled to secure them in position. Windpump engineers intending to implement a large programme involving shallow wells should familiarise themselves with how to make a well, particularly the head works.

It is important that the water can not be contaminated by the users or by animals. A recommended text is the DHV book on "Shallow Wells in Tanzania".

10 WELL JETTING AND DRIVEN WELLS

It should perhaps be mentioned that there are a number of other techniques for accessing surface water. One of those which is gaining in popularity is well jetting. A pump draws water from a nearby river and blasts away sandy strata around the tip of a pipe. The plastic pipe therefore buries itself and one finishes with a neat 2 or 3 inch pipe reaching the water table of the river, next to the river. A driven well is a steel pipe driven by intermittent pressure into the ground near the river or for shallow water sources.

Filters

If a channel is dug and backfilled near the river, or a well created with good sides and headworks, or a hole is jetted, then the water will more than likely be clean from large contaminants. However if the river is accessed directly, some thought should be given to filters and inlets. In lakes or ponds, a sand filter covering the inlet to the pump is appropriate. As the absolute minimum, gauze or cloth should be used to keep frogs out the pump! Blocking of the filter can become a problem, and design of filters will be dealt with in the layout or installation module.

11. DRILLING A BOREHOLE

Whereas the windpump engineer might be actively involved with the choice of a proposed borehole site, it is unlikely, but not impossible, that drilling will be part of the engineers responsibility. A contractor will be hired, the project will set up its own drilling team, or the ministry of water will drill the hole. However, there are very small drilling rigs available now and it is possible that the drilling might be part of the project. He might be more likely to be involved with digging or boring a hole.

The two main methods of drilling are cable or percussion drilling, and rotary drilling. With percussion drilling a drill hammer pounds away at the ground. Very little extra water is required but drilling can be as slow as 0.5m per day. With rotary drills the rotating bit cuts away at the ground and the drill rate can be as high as 100m per day. The disadvantage of the rotary drill is that it requires lubrication.

As the drilling proceeds decisions have to be made regarding casing and screens. The purpose of casing is to stabilise the sides of the hole. Plastic or metal casing is used. Screens are used to stabilise the hole and allow passage of water. It may be necessary to use screens at the useable aquifer, and casing to block the entry of a higher salty aquifer. There are a number of refinements such as gravel packing, back filling, etc.

11.1 Checking the contractor

The responsibilities of the driller of the borehole is to:

Inform the relevant authorities
and register the borehole. In almost every country it is law that use of groundwater be approved and then registered.

Drill the hole
Some contractors drill holes off the vertical, or with a bend. This is particularly easy with percussion rigs. A bent borehole will wear the pumprods of the windpump so it is important to check and supervise the drilling if at all possible. The borehole can be checked after it is finished but it may be difficult to persuade the contractor to change things once he is finished.

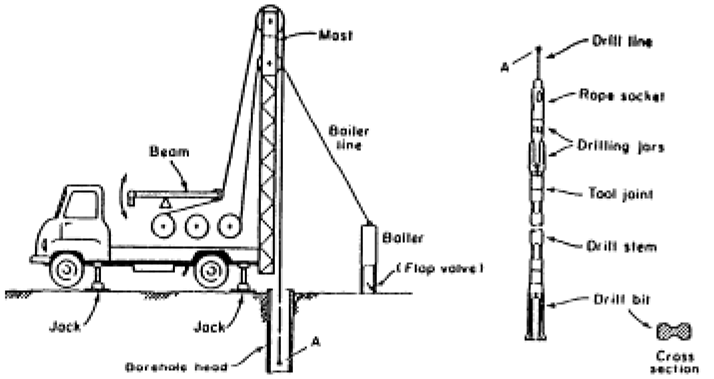
Secure the sides of the hole
During drilling the contractor may have used drilling mud to stop the hole collapsing behind his drill bit. If the hole is not then cased properly, it will collapse after about 2 years of use. A windpump may well be blamed for the non operation of the hole. Always check while the casing enters the hole. Some contractors will say they have put casing, when in fact they have not.

Log the material of the hole
The contractor should take samples of the rock every one or two metres and at the end this should be written up as a profile. This is often a legal requirement and the owner of the hole may be taken to court by the government, for the contractors negligence.

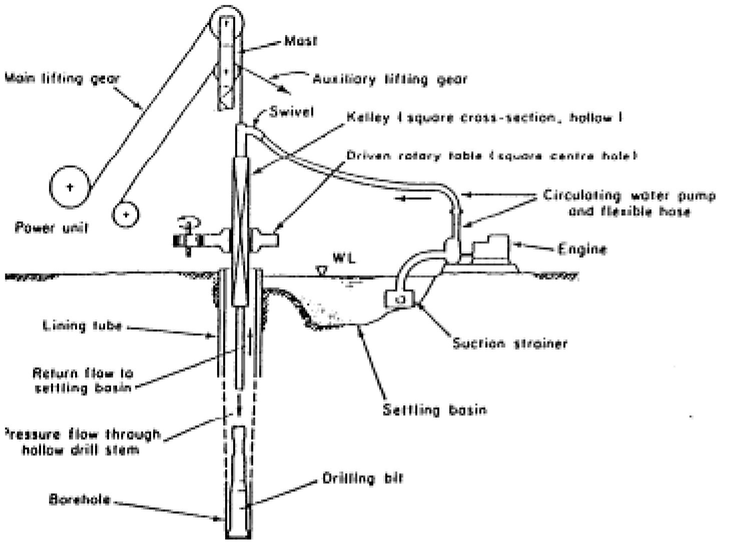
Test pump the borehole
At the finish the hole should be test pumped. This may include developing the hole by pumping and backwashing which improves the stream channels into the hole. Nevertheless it is vital that the hole have at least 24 hours of heavy pumping, to allow the output characteristics of the hole to be determined.

Send a sample for quality check

A sample should be sent to determine the mineral quantity in the water and its potability. This is vital if the water is to be used for either potable, livestock or irrigation. Many people and animals will taste water and decide that it is unfit to drink, but soil damage can occur very easily with only mild contamination of water with minerals.



Medium capacity cable tool rig and components of a string of drill tools



Main components of hydraulic rotary drilling rig with straight circulation

Figure 11: Drilling a borehole

11.2 Borehole records

When the hole is finished, the water rest level is recorded. A test pump draws the water level down and records its progress over time. This will be presented alongside the hole profile and the quality check in a record. A copy of this record should be given to the ministry of water.

11.3 Analysing the records

The windpump engineer will need to know:

- the reliability of the hole: will the rest level change with the seasons, over the years? This is determined from the recovery rate;

- the maximum pumping rate available. This will affect the size of the pumping system particularly the furling characteristics;

- the dynamic level of the water at the maximum pumping rate, which determines where the pump should be placed, and the amount of piping;

- the quality of the water, both in respect of its use (good for humans, animals or the soil?) and with regard to the materials of the pump (water just suitable for animals can corrode a pump in a few months!);

- the physical size of the hole: can a pump fit down the hole?

A final factor that should be considered when putting a windpump with a borehole is the cost reliability. Since a borehole may have a high cost, its cost should be considered in the economic value of each litre pumped. For instance, if a borehole costs US$ 10,000 (100 m in Kenya) it is unwise to put a cheap unreliable pump on it. If the down time is 80% of the time, the price per litre pumped may work out higher than if a reliable expensive windpump were placed on it.

11.4 Maintenance of the supply

The supply itself requires maintenance during operation. the most important single factor is the amount of time the level of water spends at its maximum drawdown. If an uncased hole is continually subjected to rapid fluctuations of the pumping rate, the sides may collapse through drying and swelling. The correct range of pumping rates should be chosen.
If the recharge catchment is being farmed then environmentally sound measures should be included in the programme to avoid groundwater pollution. The hole should be sealed so that pollution, whether it is excretia seeping downwards through the soil, or children throwing stones, cannot affect the hole. It is worth noting that many undereducated persons believe that dropping stones into a borehole will make the water rise, as putting stones in a jar would. Boreholes are often destroyed by such action and it should be prevented, since such a borehole cannot be repaired. Over a long period of time, a borehole may silt up. Fine particles may be drawn into the hole, or it may partially collapse. The pump may then take in silt and be subject to continual breakdown. In this case the borehole should be cleaned.

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