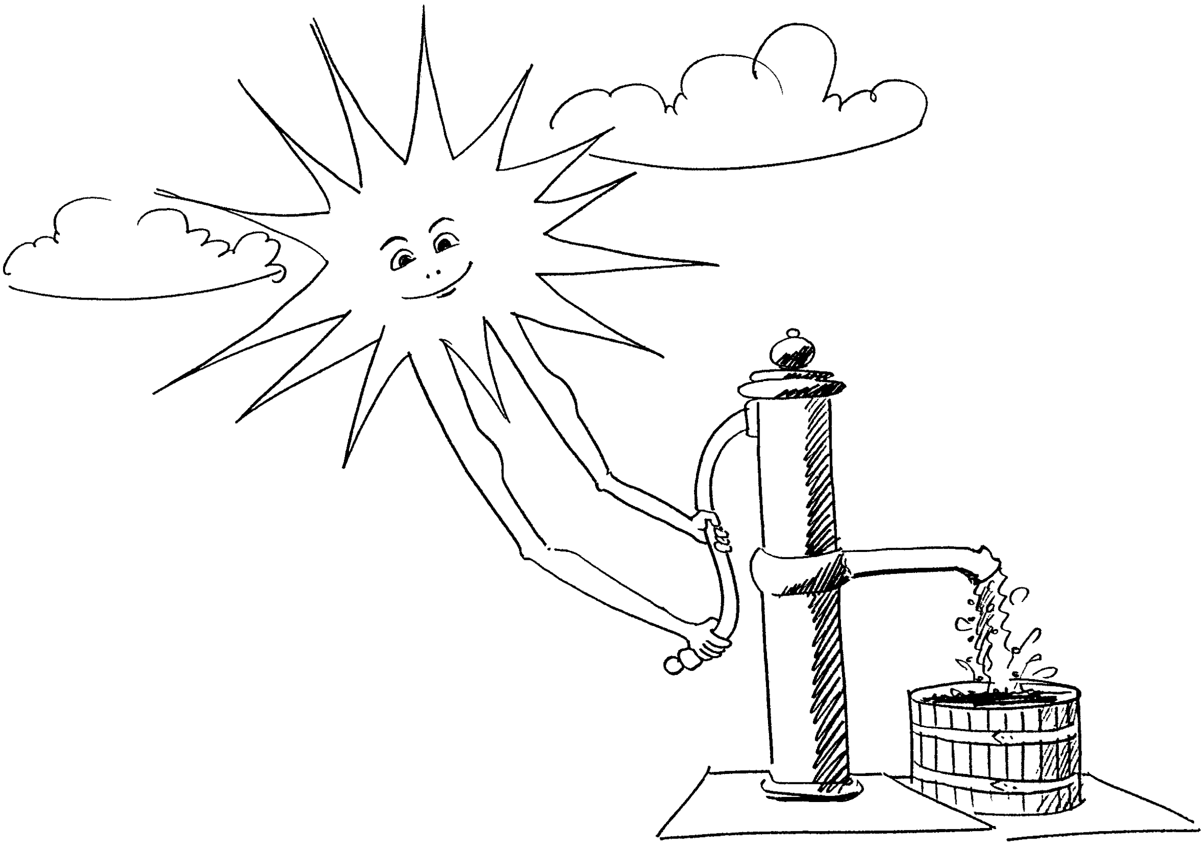
Assessment of and Selection Criteria for Irrigation Methods using PVPS



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1 Preface

Artificial irrigation is based on traditions stretching back thousands of years. During this time, though, the spread and methods of irrigation have changed appreciably. In the early days people were able to content themselves with exploiting the annual flooding of the river banks and at most making slight corrections to distribute the water more evenly. Alongside this seasonal method of irrigation using damming and trickle techniques, long-term and continuous irrigation methods have been developed, which for the most part rely on some sort of auxiliary energy. The aim with these is to use water as sparingly as possible. As a result, the efficiency of water use has been considerably improved, accommodating the necessary enlargement of the area of arable land in spite of limited supplies of water. Regarding the effect of irrigation, 1 m³ of artificially sprinkled water is equivalent to 5 m³ when trickle irrigation is used, or 25 m³ water distributed by means of damming.

2 Irrigation Technology Currently in Use

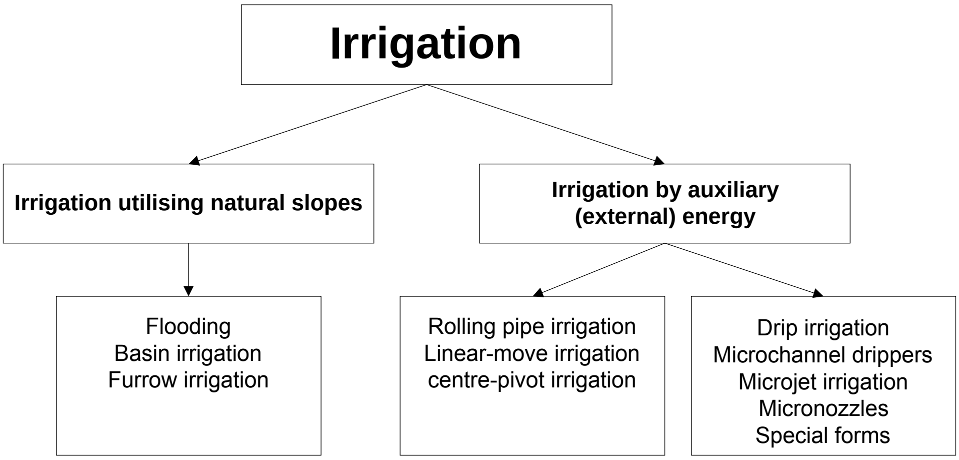
The term "irrigation" refers to technology that serves the purpose of distributing water on a field. The tasks, fundamental concepts and procedures are described in international standards such as ISO 7749, ISO 9912, ISO 8059 or ISO 9261. In Germany, these terms are outlined in DIN 19655, "Irrigation". The associated terms relating to irrigation are defined in DIN 4047, Part 6: Agricultural Hydraulic Engineering. The provision and supply of water are largely ignored in the remainder of this examination.

Crucial advances have been made in the development of irrigation technology during the recent 30 years. In response to farmers demand for irrigation techniques that facilitate regulation, reduce labour-intensive methods and finally warrant optimal results despite of limited water resources, the third generation of irrigation techniques is in service.

The transition from surface irrigation to pipe irrigation, to the use of sprinkling machines and to drip irrigation in intensive cropping has taken place after exhaustive research activity in the fields of plant husbandry, engineering and technology.

2.1 Overview of Methods of Water Distribution

The various methods of field irrigation can be classified as follows:



Systematic classification of irrigation methods

2.1.1 Surface Irrigation

Surface irrigation, one of the oldest methods of irrigation, is familiar in the form of area flooding, basin irrigation, border strip irrigation, furrow trickle irrigation or furrow damming. With this type of gravity assisted or gravity driven irrigation, the natural gradient is exploited and water is directed to the target area via retaining barriers. Surface irrigation of this nature is used in rice or vegetable cultivation, for example, and represents a well established practise since centuries.

Flooding

Basin irrigation

Furrow irrigation

Nowadays these methods are no longer as important in humid climatic regions and have been replaced by sprinkling techniques. In arid and semi-arid climatic regions, however, they are still considered to be the most frequently used methods of irrigation. Among the techniques of surface irrigation, furrow irrigation is the most widespread because in recent years it has undergone further development which leads farmers to expect that it enables them to save water.

2.1.2 Microirrigation

In order to reduce or entirely avoid the losses from evaporation and seepage in field irrigation, from the early 60s onwards development of various techniques of microirrigation has taken place, irrigation methods which facilitate the distribution of the desired amounts of water - defined by the requirements of the plants at their actual stage of growth. This includes the utilisation of metering systems, enabling water losses to be kept to a minimum. The methods of irrigation concerned are microchannel drippers or nozzle drippers, along with microjet irrigation.

Another possibility for microirrigation is the use of concealed components (subsurface installation). This involves the laying of porous pipes which deliver the water directly to the root area of the plants. Alternatively receptacles dispersing a supply of water over a number of days can be buried in the root area.

The use of this irrigation technologies varies widely in the countries of the southern and eastern Mediterranean, as shown in the table below. The figures from Israel and Jordan confirm that a considerable area is already being irrigated by microirrigation in this region. There should therefore be no doubts as to the practicability and economic efficiency of these methods.

Country	1981	1986	1991	Proportion of total irrigated area in 1991
Israel	81,700 ha	126,810 ha	104,303 ha	48.7 %
Egypt	?	68,450 ha	68,450 ha	2.6 %
Jordan	1,020 ha	12,000 ha	12,000 ha	21.1 %
Morocco	3,600	5,825	9,766 ha	0.8 %

Changes in area where microirrigation is used in selected countries of the southern and eastern Mediterranean region

The need to arrange the irrigation network in a closely meshed pattern can, however, act as a restriction on the use of this method, to the extent that it cannot unreservedly be considered an option for all cultures. This partly explains the hesitant rate of spread in certain countries.

Microirrigation laid above ground

Microirrigation laid below ground

Of these methods, drip irrigation has achieved the most widespread distribution. Row crops are particularly well suited to the use of drip irrigation (melons, pumpkins, tomatoes, vines, peaches, apricots, avocados, mangos, cotton etc.); the technique is less well suited to growing cereals, but it is also occasionally used for that purpose too. The use of spray irrigation and small irrigators as microirrigation systems is relatively new for the horticultural sector and is only likely to gain any degree of importance for permanent crops in arid and semi-arid climatic regions. The main characteristic data of the techniques of microirrigation are shown in the table below.

Technique	**Flow rate**	**Pressure**	**Wetted area**
	[l/h]	[bar]	[m²]
Drip irrigation	1 – 4	0.2 – 1,0	Point application
Spray irrigation	10 – 160	> 1.0	0.75 – 12.0
Small irrigators	> 150	> 1.0	12.0 – 75.0

Characteristic data of microirrigation

With drip irrigation, a high degree of efficiency is achieved with the lowest possible operating pressure and a small volume of water, while taking account of plant-specific and soil-specific factors with regard to the supply of water and nutrients to the crops. Targeted wetting of only the soil where roots have penetrated in fields with wide plant spacing means that the area actually irrigated is reduced.

According to this characteristic data and our own experience, the techniques of microirrigation would be the best suited for the application of photovoltaics and use on small farms.

2.1.3 Row Sprinkling Techniques

The row sprinkling techniques generally involve connecting one or more sprinkler lines to a main supply line. Depending on the procedure, either several sprinklers are coupled directly to the sprinkler line, or the sprinklers are connected to the sprinkler line via lateral hoses. They operate with medium-application or slow-application sprinklers, and for an irrigation intensity of 7 to 20 mm/h they require a water pressure of approximately 5 bar at the hydrant. In practice the most common form is pipe irrigation, which, when laid to cover an entire area, is particularly suitable for frost-protection sprinkling, but which on the other hand requires an exceptionally long time for installation and removal, or for relocation. In order to reduce the length of labour there have been a variety of further developments, such as longitudinally moveable pipe irrigation, combined pipe and hose irrigation and hose irrigation.

Row sprinklers

Row sprinkling techniques are suitable for small farms, but the pressure of approximately 5 bar at the hydrant is not well-disposed for its use, when a photovoltaic pump-set is applied to supply water.

2.1.4 Stationary Sprinkling Machines

The term stationary sprinkling machines refers to systems which, although they are movable in operation, cannot be relocated from one field to another without major reconstruction work. The best known stationary irrigation techniques are rolling pipe irrigation, linear-move sprinkling and centre-pivot sprinkling machines.

Rolling pipe irrigation

Linear-move irrigation

Centre-pivot irrigation

A precondition for these techniques to be practicable is a system of land management with a field sizes of at least 40 ha and as uniform a crop as possible, with frequent use of irrigation.

Water is distributed via sprinklers or nozzles at an operating pressure of between 2 and 4 bar. Today preference is given to using low-pressure nozzles, as this has the effect of achieving more even water distribution while at the same time reducing operating pressure.

Designing these systems according to the principle of modular construction means that they can easily be adapted to different-sized areas. The average installation lengths are as follows:

Rolling pipe irrigation	300 m
Linear-move sprinkling machines	800 m
Centre-pivot sprinkling machines	400 m (radius)

The principal components of the three types of system can be summarised thus:

- Central drive and control unit for travel in the forward or reverse direction and speed selection
- Travelling gear
- Water supply pipe (at the same time part of the structure)

Control of a linear-move sprinkler with a guide wire

The type of drive (electric, hydraulic), the control system, dimensions, equipment for water distribution etc. all differ according to manufacturer and application.

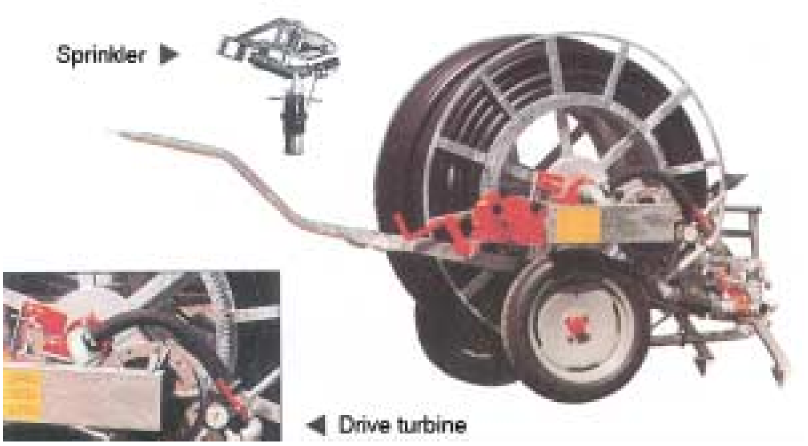
The present state of the art allows fully automated irrigation operation, especially in the case of centre-pivot sprinkling machines. The farmer then only has control and monitoring functions to perform.

Developments to reduce the operating pressure to 1 bar are at the trial stage, which in turn would be a prerequisite for use from the standpoint of photovoltaic water supply. The size of the machine, however, and the necessary volumetric flow rate of 200 m³/h indicate that this technology is not adequate for small farms.

2.1.5 Mobile Sprinkling Machines

From about 1970, the development of plastic pipes capable of being wound on drums (made of polyethylene, PE) paved the way for a further advance in irrigation technology which led to the introduction of sprinkling machines with sprinkler retraction or machine forward feed. Mobile sprinkling machines can be used in a great variety of operating conditions. This has contributed to their use becoming widespread.

The majority of sprinkling machines are equipped with heavy-application sprinklers for an irrigation intensity of 21 to 40 mm/h. To make full use of the possible range of the jet, but above all to obtain good jet dissolution, the water pressure required at the hydrant is about 7 to 8 bar or more (4 to 5 bar at the sprinkler).



Mobile small sprinkling machine with self-contained drive

In addition to mid-sized sprinkling machines (outside pipe diameter 75 to 90 mm, pipe lengths up to 300 m) for an area of application of between 15 and 30 ha, today there are also large sprinkling machines available with pipe lengths up to 500 m for irrigation areas of between 40 and 60 ha and special small sprinkling machines with an outside pipe diameter of 50 mm for areas of between 5 and 10 ha.

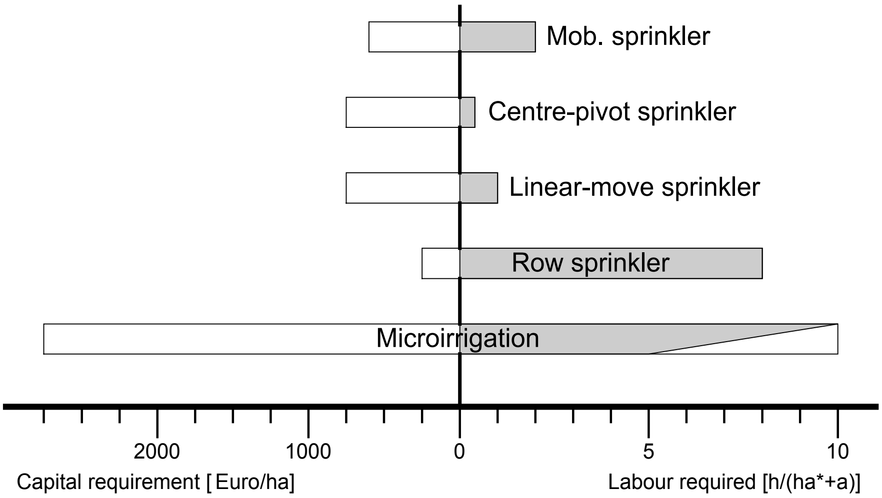
It is obvious that such irrigation equipment is by far too large for farms of less than 2 ha size. The same is true for the application of PV systems, even if a somewhat less powerfull version of such concepts would be technically feasible to cope with the applications in smaller scale.

2.2 Comparative Assessment of Irrigation Methods

2.2.1 Comparison of the Irrigation Techniques

The comparison of techniques relates initially to the four techniques of irrigation used under central European climatic conditions, in other words not including surface irrigation. The comparison encompasses characteristic data relating to the requirements for energy, water, capital and labour.

The capital and labour requirements of the irrigation techniques are specified for average operating conditions with four irrigation applications, each with an irrigation height of 30 mm.



Capital and labour requirements for the most important irrigation techniques

Drip irrigation has the greatest capital requirements. For the other irrigation techniques, which are not installed enduringly, the investment per hectare depends on the area of use. In this case, semi-permanent pipe installation requires the lowest capital investment per hectare. In contrast, sprinkling machines for small areas of application require relatively high capital investment, and it is only when the areas of application are relatively large (above 30 ha) that the capital requirements become reasonable.

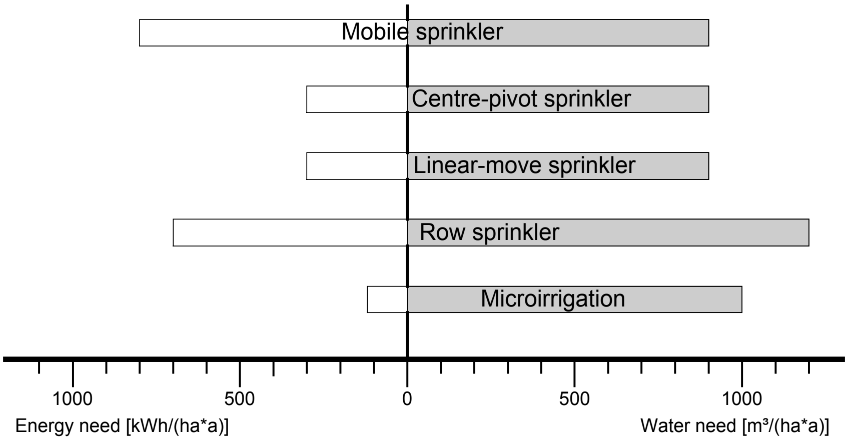
A completely different view of the individual techniques is presented with regard to the labour requirements, which are recorded per hectare and year. The longest labour is required for the movable application of pipe irrigation systems, at eight hours per hectare and year, while the shortest labour requirements are for stationary sprinkling machines. Drip irrigation has relatively high labour requirements where it is designed for area-wide coverage, but this work is not directly tied to particular timing and in some cases arises before or after the irrigation season. The shaded areas of the bars indicate the work on installation and removal, and the unshaded areas the labour required for operating the system.

Overall it can be established that for medium-sized areas of application mobile sprinkling machines require the least labour with relatively high capital requirements, while the same is true of stationary sprinkling machines where the areas of application are larger.

Energy and water requirements are highest for mobile sprinkling machines at 800 kWh per hectare and year – caused by the high water pressure required – and an assumed water volume of 1200 m³ per hectare and year.

In the case of row sprinklers with pipes it is sufficient to have low water pressure, so energy requirements drop to roughly 650 kWh per hectare and year. Further savings can be made with stationary sprinkling machines. When using drip irrigation, because of the low water requirements and low water pressure it is possible to reduce energy requirements to approximately 135 kWh per hectare and year.

Furthermore, as a result of the avoidance of any water losses by straight supply of water directly to the plant, water saving of up to 30% can be achieved without jeopardising yields.



Energy and water requirements of various irrigation techniques

Another measure for assessing the suitability of these techniques for the use of photovoltaics in the pumping station is the energy requirement per cubic metre of water, which is shown in the table below.

Irrigation technique	**Energy requirement in kWh/m³**
Mobile sprinkling machine	
Sprinkler	0.67
Nozzle truck	0.44
Centre-pivot and linear-move machine	0.36
Pipe irrigation	0.54
Microirrigation	0.16

As far as energy and water requirements are concerned, therefore, microirrigation is clearly superior to the other methods.

2.2.2 Characteristic Data of Furrow Irrigation

Characteristic data similar to that available for the technical irrigation methods barely exists for surface irrigation methods. In the literature the labour required for furrow irrigation is given as being between 1.85 and 3.71 h/(ha * application). Empirical values were obtained from comparative investigations into the labour input, energy and capital requirements for furrow irrigation in Turkey. The data in the following relates to traditional furrow irrigation with an open feeding channel and the use of shovels for opening and closing the furrows.

Opening and closing furrows by hand

For an inflow of 50 m³/h, the labour required was identified as being 21.8 h/(ha * application). The capital requirement was calculated at 950 €/ha. Since the water supply may vary widely (depending on the water source, be it superficial sources, basins behind dams, deep wells) an assessment of the energy requirements necessitates some information about local conditions of the water source and the irrigated fields. However, it is very probable that the pumping head will not exceed 20 m, which justifies to consider rather low energy requirements in most cases.

The energy requirement can only really be determined on location in the field, because the water supply varies widely (from dams to deep wells). It can be expected, however, that it is rarely necessary to overcome a pumping head of more than 20 m. All in all, therefore, low energy requirements can be reckoned with in most cases.

In the gated pipe method the feed channel represents a compact (tight) structure and the water is discharged into the furrow via special water outlets. Water losses as encountered with open feed channels are ruled out.

The energy requirement must be calculated in the same way as for traditional furrow irrigation or microirrigation. The specific energy requirement is likely to be between 0.1 and 0.16 kWh/m³. There are no measured results available. The water leaves the gates almost free (natural flow). The handling efforts required are halved compared with conventional furrow irrigation, to 1.9 h/(ha * application) using the customary working procedures in Turkey. Capital requirements were calculated as being 1400 €/ha. The capital requirements for both techniques of furrow irrigation each include an element of roughly 330 € for the pump and 230 €/ha for levelling the fields.

3 Selection of Suitable Irrigation Techniques for Small Farms with a Photovoltaic Water Supply

According to the description of the methods and the characteristic data, mainly two irrigation techniques are suitable for this field of application: microirrigation and – with reservations – furrow irrigation (combined with gated pipes). A third option for very small fields is manual water distribution (tanks on carriages, etc.). Due to the high labour efforts needed, this method is applicable only for very limited times of the plantation period and will therefore not be regarded in the following. Any other methods of irrigation either require too-high operating pressures or are unsuitable for small farms because of the size of the machines or the output per unit area. The two suitable techniques shall therefore be described in more detail.

3.1 Microirrigation

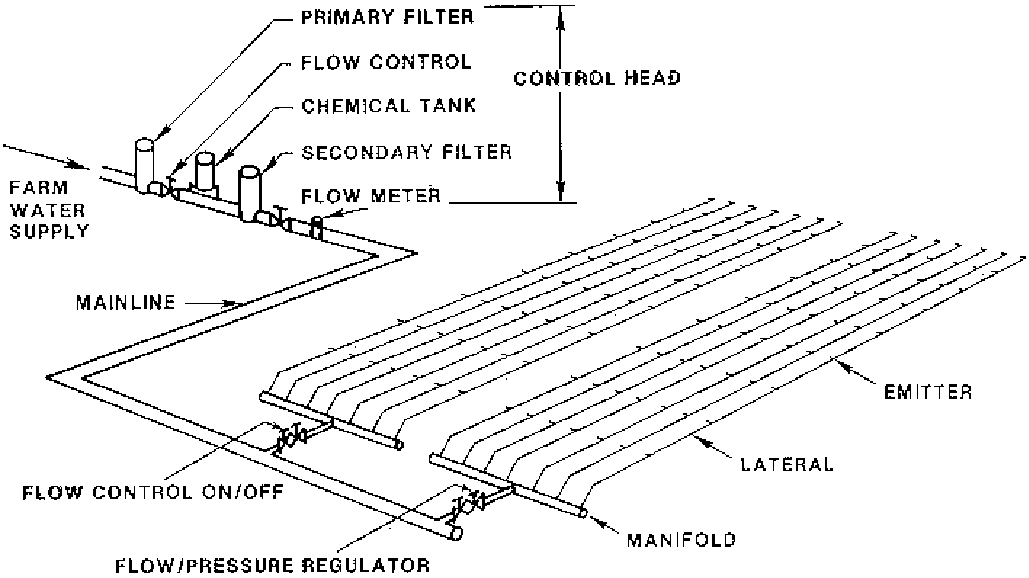
A microirrigation system is largely comparable to a permanent sprinkler installation in terms of the form of the installation. The most significant difference is that with microirrigation the water is applied to the soil drop by drop, in small quantities and at freely selectable intervals. Until it reaches the emitter element, the water is fed through a piping system.

Where crops are grown with wide spacing between rows, it is possible to irrigate only the area of the soil containing roots and leave the remainder of the soil dry. This is a particularly important advantage above all methods for arid regions because of the problem of weed infestation in the inter-rows occurring as a result of irrigation.

A microirrigation system is essentially made up of five components:

- Pumping set with motor
- Head unit or control head with filters and control equipment controlling the flow rate, pressure and if appropriate the addition of fertiliser
- Distribution pipes
- Stop cocks
- Supply lines with emitters (drippers or micro-sprayers). The supply lines are available with either integral or attached emitters.

The irrigation system is divided into quarters or blocks; the laterals in each quarter can be put into operation separately with stop cocks. The water delivery rate of a drip emitter or micro-sprayer lies roughly between 2 and 5 l/h, depending on the manufacturer, allowing relatively precise metering of water delivery over the emission time. Metering of the water throughput rate is set in the drip emitter or micro-sprayer itself. With regard to this point, preference should be given to emitters in which the rate of water application is relatively independent of the pressure difference between the internal pipe pressure and atmospheric pressure.



Schematic diagram of a drip irrigation system with two piping trains

Because emitter spacings vary considerably, in order to be able to compare different systems and plan an installation it is necessary to relate the volumetric flow rate to the running metre of supply pipe according to the following formula:

$$W = \frac{V \cdot D}{A}$$

Where:
W = water delivery per hour and metre [l/(h m)]
D = volumetric flow rate per emission point [l/h]
A = spacing of emitters [cm]
V = installed length [m]

From the figures for the volumetric flow rate per hour and metre and the emitter spacing together with the installed length it is possible to determine the number of supply lines per irrigation loop connected to the head unit.

Example:

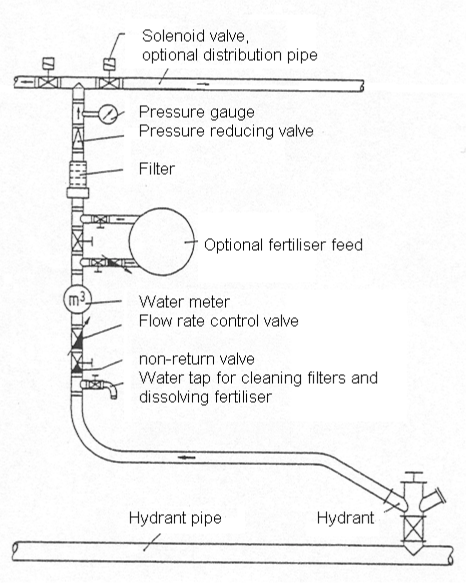
Emitter spacing	1.50 m
Volumetric flow rate	2.50 l/h
Installed length	75 m

$$W = \frac{75m \cdot 2.5l/h}{1.5m} = 125\,l/h/Lateral$$

The irrigation cycle is dependent on the climatic water balance or soil moisture, for example. The location of the head unit is decided according to the size of the installation. In large systems (for example with an irrigated area greater than 5 ha) it is more beneficial to combine the constituent parts of the head unit with the pumping station and to conceal the distribution pipes in trenches. In systems covering less than 5 ha the head unit can be combined directly with the hydrant, and on the field edge also with the pumping station. It is rare that the distribution pipes are laid underground in relatively small systems.

3.1.1 Head Unit

The head unit reduces the pressure in the supply line if it is too high, regulates the volumetric flow rate, apportions the necessary amount of fertiliser and removes from the water any matter that may lead to clogging of the emitters. The main components of the head unit are as follows (listed in the direction of water flow):



Example of the design of a head unit

- Coarse screen to remove any large impurities or stones at the pumping station or hydrant.
- Water tap for cleaning the filter and mixing the fertiliser solution as necessary.
- Shut-off valve, actuated manually or operating automatically as a function of volume or time. If soil moisture sensors or other parameters are used for regulating the use of irrigation, the shut-off valve can also be replaced by an electrically operated or hydraulic valve.
- Non-return flap if a fertiliser feed unit is fitted.

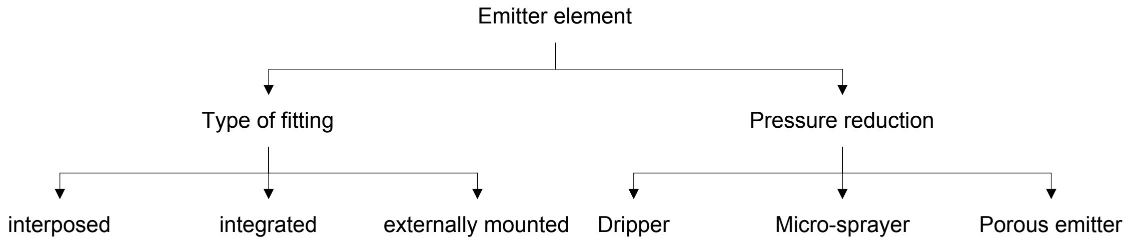
- Fertiliser feed unit with fertiliser reservoir. A range of procedural approaches are offered by industry for this purpose; among these, devices with a hydraulic drive have become most widely established. These devices can also be used for feeding in solvents to clear blocked-up drip pipes.
- A water meter and pressure gauge are essential measuring instruments for monitoring the operating status of the system.
- The purpose of the filters is to remove from the water any constituents which may lead to clogging of the drip emitters or micro-sprinklers. If clean water is used for irrigation, simple baffle-plate filters are sufficient. If there are expected to be any coarser contaminants, a cyclonic separator should be fitted upstream of the filters and a sand media filter downstream. The sand media filters are usually designed such that they can be flushed by reverse (inverted flow) when they become clogged or after adjustable time intervals. The work of cleaning filters can be kept to a minimum by using self-cleaning filters. Self-cleaning is carried out either according to the principle of differential pressure or with time switches.
- The purpose of the pressure reducing valve is to reduce the pressure which may be too high in the supply line upstream of the head unit. In the distribution pipes and emitters it is generally sufficient to maintain a pressure of 0.5 to 2.0 bar, depending on the system. With a photovoltaic water supply, this fitting can be omitted.

3.1.2 Supply Lines

The water is supplied from the head unit via distribution pipes to the emitters. The supply lines are almost exclusively made of UV-resistant polyethylene. The spacings of the emitters and the length of the supply lines to be installed are largely dependent on the specific conditions relating to the soil and plants, or the length of the field may limit the installed length.

3.1.3 Emitter Elements

The possible emitter elements that come into consideration for microirrigation are drip emitters, micro-sprayers and porous emitters. These allow metered delivery of the water. It is also possible to differentiate between the emitters according to the way they are fitted.



Type of fitting and pressure reducing mechanisms of emitter elements

3.1.3.1 Drippers

Among the various forms of drippers there are designs which are referred to as nozzle-type, microchannel-type or pressure-compensating pulse-type.

Nozzle-type design (interposed)

Microchannel-type design (integrated)

Pressure-compensating design (integrated)

Nozzle-type design

With the nozzle-type form of drip emitter, the drip nozzle is either attached to the lateral or it is integrated into the lateral as an intermediate element. The principal advantage is the low purchase price. Handling the perforated drip pipe is simple. There are certain disadvantages, however:

- Risk of clogging because of nozzle width being too narrow
- Relatively high and imprecise water application if there is even only a slight deviation in nozzle diameter or operating pressure

Microchannel-type design

The microchannel-type form of drip emitter is a development of the capillary tube. The water pressure applying in the supply line is reduced with the aid of a small tube with a narrow cross-section. Further development of these drip emitters, which lie on the field in a form resembling spaghetti, as they are also known, is leading to the tubes being wound around the lateral or integrated into the pipe (labyrinth drippers). Integrated microchannel-type drippers have become widely established in open field use.

Pressure-compensating design

In the case of pressure-compensating emitters the water is not delivered in a continuous flow but in pulse form, with the pulse frequency being dependent on the pressure applying in the pipe. This type of emitter consists of a membrane which reduces the pressure applied to the supply line. The water is fed through the membrane into a storage chamber. When the pressure in the chamber has built up to a sufficiently high level, the chamber is suddenly emptied (water is delivered to the plant). The outlet orifice is then closed, and the cycle begins again.

3.1.3.2 Selecting the Drippers

The choice of drippers should be made according to the operating mode of the photovoltaic pumping system. If the pump is run in direct mode, there may be fluctuations in the flow rate as a result of fluctuations in the level of solar irradiation. In such cases, for example, pressure-compensating drippers can be used. It should be noted, however, that this type of dripper generally requires a high working pressure and hence is not necessarily suitable for PV systems. If a battery-backed pump is used, the volumetric capacity can be expected to be constant. In this case there is also greater freedom when it comes to selecting the drippers, and it is not necessary to use pressure-compensating drippers. These non-compensating drippers are also available at lower cost.

Laying pipes with integrated labyrinth drippers

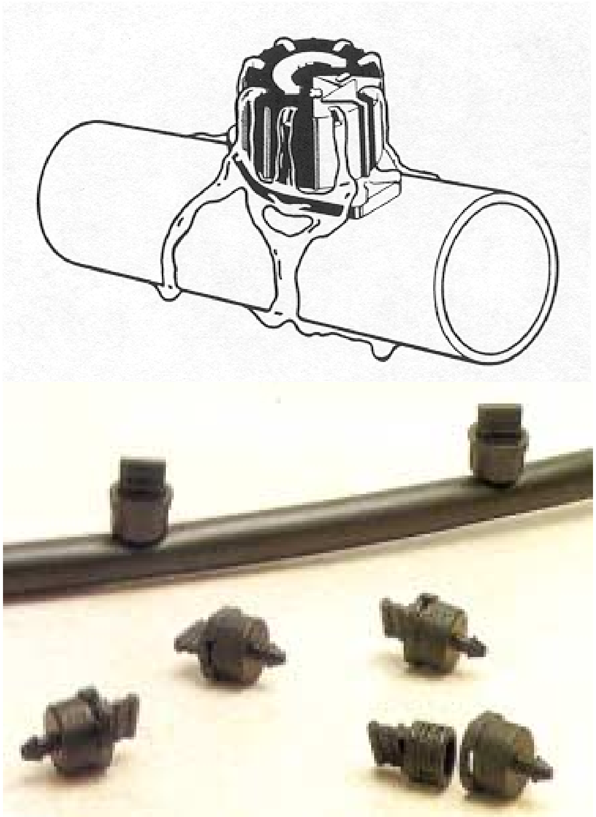
The susceptibility of the various drip emitters to clogging depends on the cross-section of the orifices or outlet openings.

Design	Flow cross-section in mm²	Risk of clogging
Nozzle-type	0.3 – 0.8	moderate
Microchannel	0.9 – 1.8	low
Pressure-compensating	1.2 – 1.8	high

Flow cross-section and risk of clogging for various drip emitters

3.1.3.3 Micro-sprayers

The design corresponds very closely to that of the components described for drip irrigation. Filtering of the water does not need to be performed as carefully as for drip irrigation because the outlet orifices (nozzles) are larger.



Sprinkler attachment fastened directly to the supply line (mounted)

Sprinkler attachment connected to the supply line by a hose

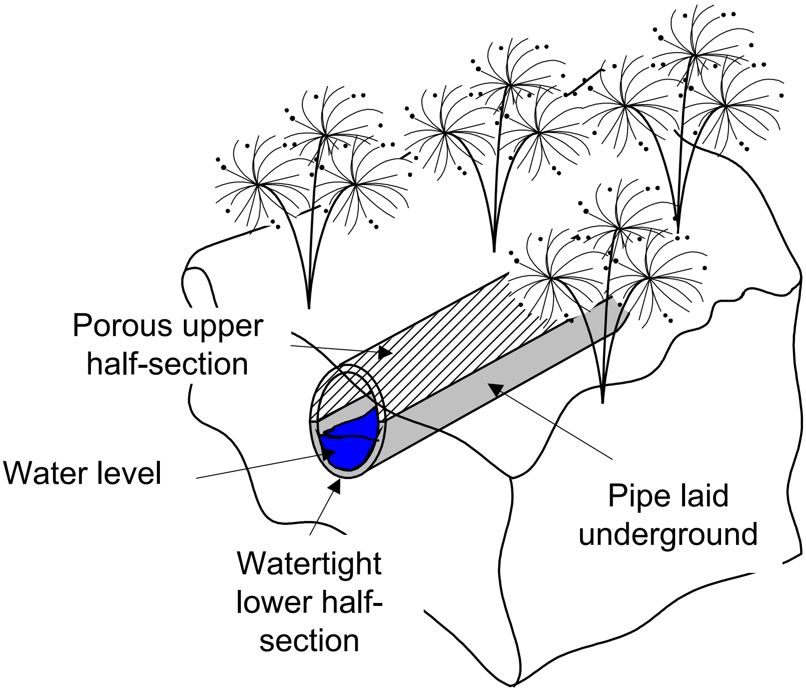
The spray nozzles can either be mounted directly on the distribution pipes or connected to the pipes via thin hoses. In contrast with drip irrigation – despite the fact that the nozzle pressure is almost the same – the water is not distributed drop by drop from the spray nozzles but in the form of single jets or as a mist spray. This results in a higher flow rate and water distribution over a broad area. It is also possible to irrigate sectors of a circle. The risk of clogging is lower than that encountered with drip irrigation.

This type of equipment is mainly installed as a permanent system beneath trees such as citrus, for 10 to 15 years. It is not recommended for mobile use in small farms because then even more fittings and know-how are required than for drip irrigation.

3.1.3.4 Porous Emitters

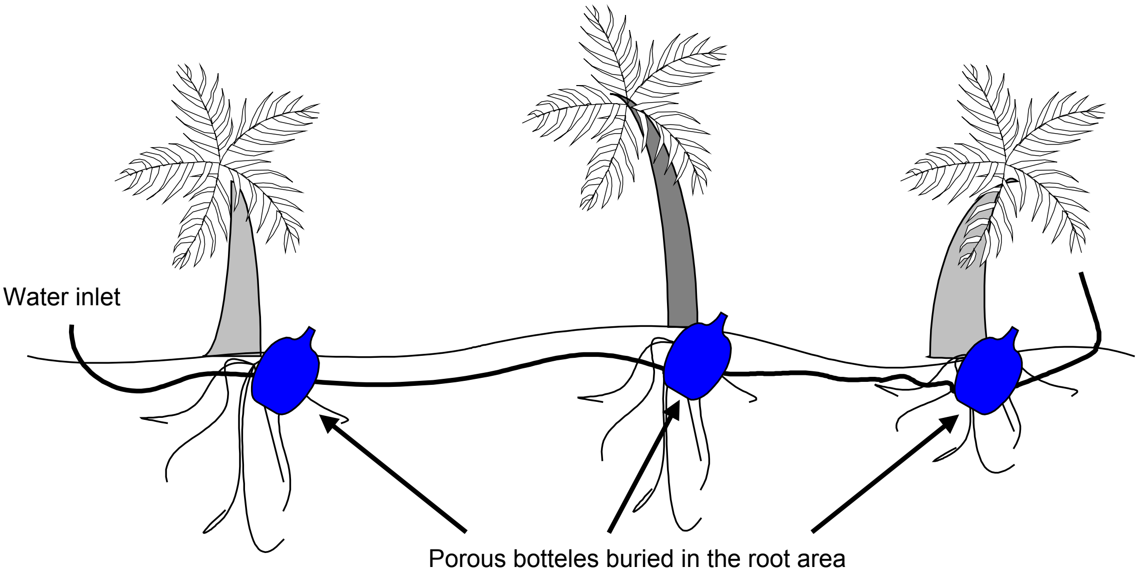
Porous emitters are pipes made of porous plastic, rubber or paper which are laid above ground. This type of drip irrigation is primarily suitable for crops where the water does not have to be applied at specific points for individual plants but can be delivered along a longitudinal line. A slight positive pressure is applied to the pipes, which then “sweat out” the water. Because the drip points are in the form of pores, in order to clean the water these pipes require a filtering system that is even finer than the pores themselves.

A somewhat modified form of this technology uses semi-porous pipes laid underground. In this case the pipe consists of two half-sections: the lower section is watertight, and the upper section porous (vapour-permeable). When only the lower section of the pipes is filled, the difference in vapour pressure with respect to the soil ensures that evaporation takes place, wetting the soil in the root area. The advantage of this approach is that it operates very economically and, within certain limits, it also allows the use of salty water (on account of the evaporation principle). On the other hand there is a risk that roots will grow into the pipes. Furthermore, with this technology precise horizontal installation is crucial for proper functioning. This is a particular concern where there is the possibility of the soil settling or being subjected to loading, for example when driven over by tractors.



Pipes laid underground

As an alternative to porous pipes it is possible to use porous bottles (made of a clay/sand mixture, for example), which are buried in the root area of the plant. The receptacles are filled via a supply line, and deliver the water over a period of 2 to 3 days. On level terrain the bottles can be connected to each other via a simple system of pipes (communicating vessels), while on sloping ground it is necessary to fit a basic float control system in the bottles.



Irrigation with porous bottles

3.2 Furrow Irrigation - Gated Pipe

In countries where furrow irrigation is widely used, the transition to gated-pipe furrow irrigation is more likely to be accepted than drip irrigation because the traditional irrigation structure can be retained.

A detailed description of this technology, as given for drip irrigation, is not necessary here as there are few potential suppliers in the European area. The information provided below is therefore restricted to experience gained by FAL in Turkey.

The objective when using gated pipes is to direct the water from the source (well, dam, weir etc.) to the field through enclosed conduits – in other words in pipes. This prevents the loss of water as a result of evaporation or seepage. Not only that, the water arrives at the field in a relatively clean condition. Weed seeds are not dispersed with the irrigation water. The situation with regard to hygiene and health is also improved, but this is not examined further in this document.

A particularly important point is that gated pipe gives growers or farmers a technique by means of which they are able to determine very precisely what quantity of water is to be applied to each furrow. The gated pipes can be made of either steel or plastic. Each pipe is between 5 and 9 m long, depending on the material and weight. Various pipe diameters are available, from 2.5 to 6 inches. The spacing between the outlet orifices or gates ranges from 0.5 to 1 m. The flow rate per application is variable. The design of the gates differs from manufacturer to manufacturer.

Gated pipe with oblong slits

Gated pipe with screw-type outlets

Metered application is possible with screw-type outlets. The size of the elongated outlet orifice in the screw fitting can be adjusted by screwing the fitting in or out. In another form of the gate, an oblong slit in the pipe can be opened or closed to a greater or lesser extent by means of a sliding plate. Metering of the flow rate is less precise in the latter case.

Gated pipe with screw-adjustable outlets would be an alternative to costly drip irrigation when working with a photovoltaic water supply. There are no know investigations into or literature on the combination of photovoltaics and furrow irrigation.

If after a gated pipe system has been introduced and its suitability tested the grower prefers to use drip pipes after all, the gated pipes could be used as supply lines and the drip pipes could be connected to the screw fittings.

Gated pipe is therefore first and foremost a logical further development of furrow irrigation with the beginnings of an entry into high-tech drip irrigation. It goes without saying that this possible combination is restricted to farm sizes up to 2 ha. The dimensioning of the solar generator can only be determined when it is known which gated-pipe technique will be used. The characteristic hydraulic and energy-related data can then be calculated.

3.3 Typical Features of Irrigation Methods

The most significant features of the various methods of irrigation are shown in the table below. For cost reasons, an irrigation system operated by photovoltaic power should preferably be implemented with microirrigation, so in the remainder of the examination this is the only technology that shall be considered.

Method Characteristic	Gravity irrigation (trickle)	Sprinkling	Microirrigation
Pressure demand [m]	low	20-50	5-35
Energy content (hyd.) [Wh/m³]	low	100 - 150	40 - 100
Autom. water metering	none	good	very good
Water losses **Cause** **Extent**	high seepage up to 100%	moderate evaporation up to 60%	low seepage up to 35%
Erosion	low - moderate	high	low
Salt encrustation of emitters (not soil)	low - moderate	moderate	moderate - high
Handling	manual	automatic	automatic
Maintenance requirements	low	moderate	moderate - high
Costs	low	moderate - high	moderate - high

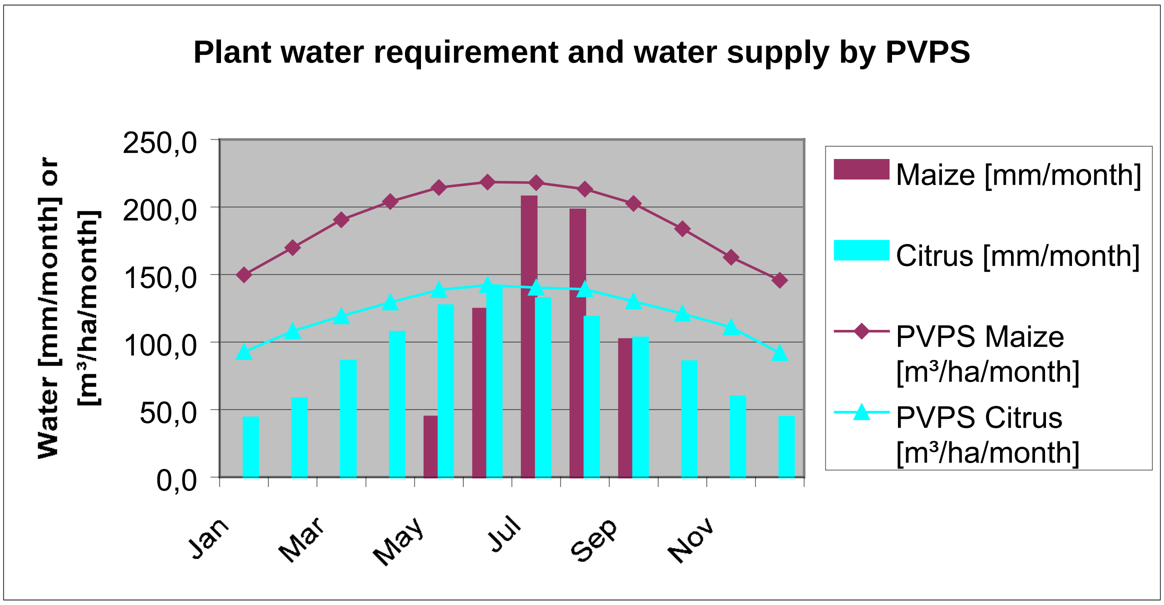
In case of low water consumption being of high priority and presumed that small farm sizes are the main application, microirrigation shows its predominance. In such farms the argument of high labour for system handling is of lower importance as often families and their members are involved in farming. Thus for maintenance labour only few costs will arise.

4 Determination of Water- and Energy Requirements

4.1 Determination of Water Requirements

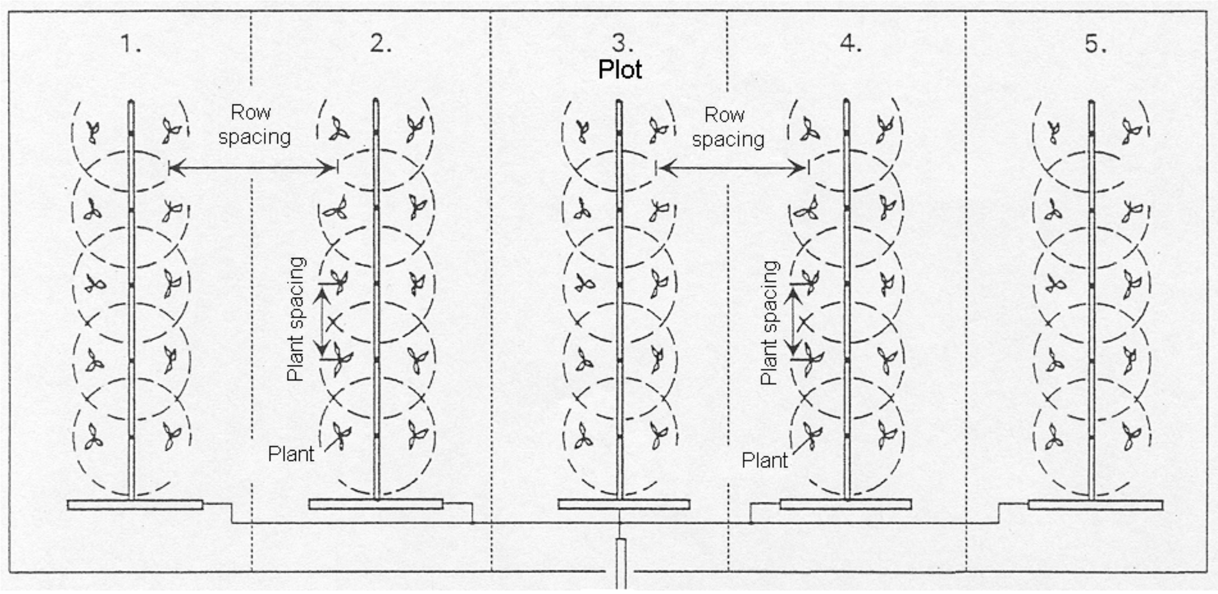
In order to ensure the most economical application of water, and application appropriate to the water consumption of the plants, the water requirements of the various types of crops being grown should be calculated before designing drip irrigation systems. Because the use of photovoltaics makes sense mainly in arid and semi-arid climatic zones, the Blaney-Criddle procedure (Achtnich, W.: Bewässerungslandbau [Irrigation Farming], Verlag Eugen Ulmer, Stuttgart, 1980) is best suited for this type of water demand calculation. To calculate these basic values with computer assistance it is also possible to use the CROPWAT program (Cropwat Paper No. 24, ISBN92-5-100279-7 and Climwat, Paper No. 49, ISBN 92-5-103416-8, FAO (Food and Agriculture Organization of the United Nations), Viale delle Terme di Caracalla, 00100 Rome, Italy).

The basic values enable an initial conclusion to be drawn as to whether or not photovoltaic irrigation would make sense. The chart below shows the solar water supply throughout the year and the irrigation requirements for two types of plants. It can be seen that for citrus fruit the demand is closely correlated with supply, whereas this is not the case for maize.



Correlation of water supply and demand for different types of plants

As well as calculation of the basic values and analysis of the degree of correlation, other crucial factors for determining water requirements are the layout of the entire field that is to be irrigated and the structure of the irrigation system (number of emitters per piping train, number of fields, possibilities of controlling irrigation of individual fields, etc.).

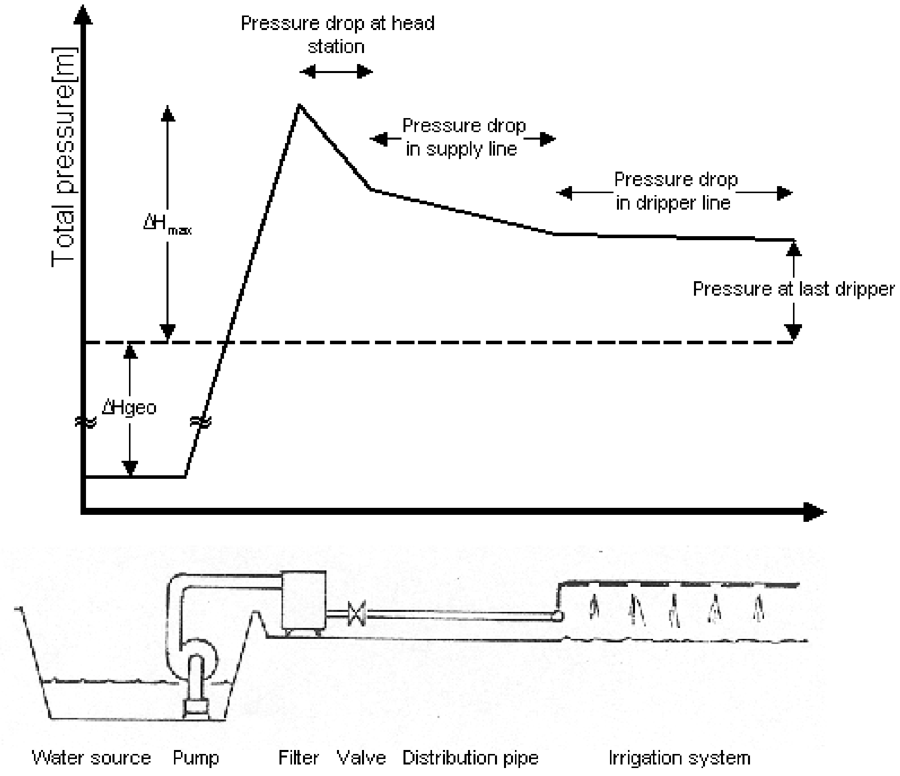


Planning the structure of an irrigation system

The system design also determines what control options the irrigation system will offer, particularly where photovoltaic power is used for the supply. Possible strategies could include, for example, irrigating one part of a field in the morning when irradiation is low, and switching in further parts of the field as the solar radiation increases. In such an arrangement care must be taken that it is not always the same part of the field that is irrigated first over several days but that the various parts are supplied according to a rotational system.

4.2 Determination of Energy Requirements of Irrigation Methods

The energy required for the use of photovoltaics with irrigation systems is determined by the degree of efficiency with which electrical energy is converted to hydraulic energy. If it is assumed that the best possible design of pumping set has been chosen and the quantity of water is appropriate to requirements, the variable that can be used for the purpose of optimisation is the delivery pressure. In addition to the outlay for distributing and metering the water (pressure requirement), the total delivery head includes the geodetic height between the water extraction point (canal, well etc.) and the field. The diagram below illustrates how these factors are connected. From this it becomes apparent that, for example, using a different dripper type after a repair has repercussions on the entire hydraulic behaviour of the system. This should be taken into account at the planning stage.

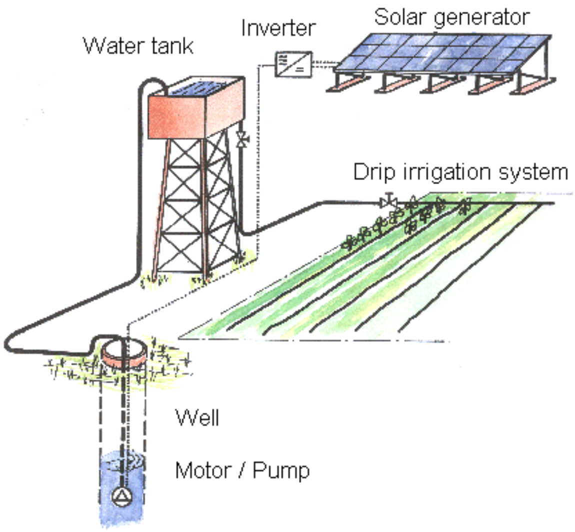


Diagrammatic representation of pressure losses in a drip irrigation system

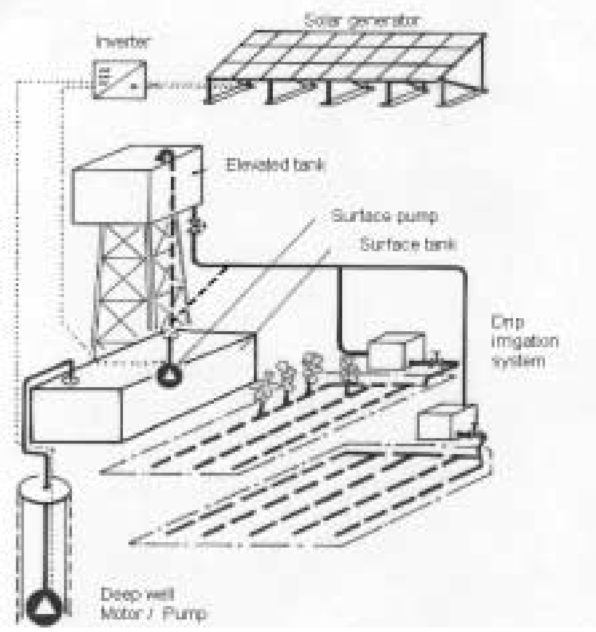
When using a solar-powered irrigation system it is basically possible to differentiate between two types of system:

- Systems feed from a reservoir (water tank)
- Systems feed directly by means of an irrigation pump

In systems with an intermediate storage, the level difference between higher situated tank and irrigation systems will normally be sufficient to run the irrigation without supplementary pump. This is as well valid if the storage tank is feed via a pump from a deep well or other lower situated source. In these cases a well defined head can be assumed being more or less independent from the consumed water. Deviations may be taken into account in places where several irrigation systems (with different pressure needs) have to be supplied or where irrigated areas do not have the same level. In this case it is feasible to run the irrigation systems with several pumps independently. To decide which option to use it is necessary to estimate which variant is more cost-effective, taking into account the construction costs (height of the water tank, investment and maintenance requirements (several pumps), energy efficiency (distribution between several pumps or one pump with greater pumping head), complexity of system operation, maintenance, etc.



Irrigation system with intermediate water storage tank and one pump

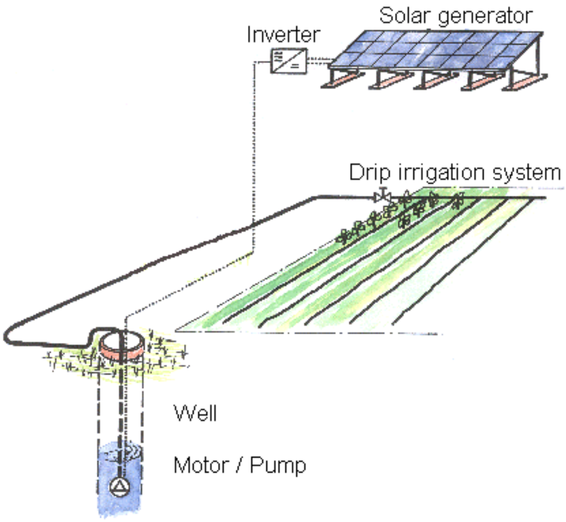


Irrigation system with intermediate water storage tank and two pumps

When an irrigation system is directly feed by a pump, there is an interdependence between the pressure and flow rate according to the pump and irrigation network characteristics. With use of a pump driven at constant speed (in most cases a diesel pump) the system will run in a defined operational point. For a power supply from photovoltaics as a supplementary variable the irradiance has to be taken into account which continuously changes the operational point of the irrigation system.

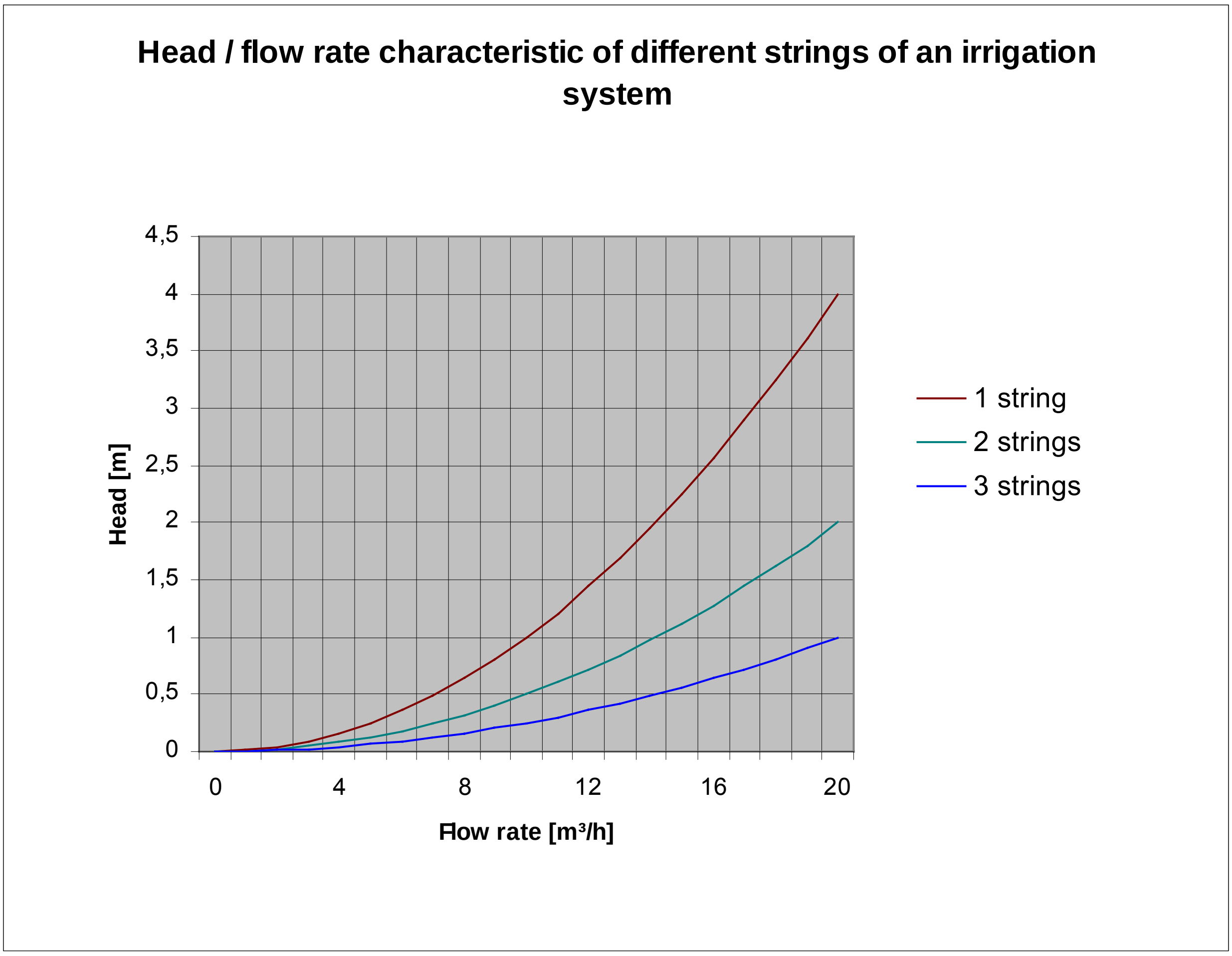
In a direct-feed system attention must be paid to the tolerance of the system to fluctuating pressure. Due to their dependence on irradiation, PV systems produce a variable amount of power. In connection with an irrigation system, though, this must still result in sufficient wetting of the plants. The characteristic curve of the pumps in combination with the irrigation network does not allow reliable stabilisation of quantities for all load states. In some cases batteries can be used to run the pump in a fixed operational point, however, because of costs, reliability and maintenance requirements this seems not to be a feasible solution.

An alternative is the separation of the area for irrigation into sub areas where field control units (which connect or disconnect various irrigation lines) can then be used in a supporting role by adapting the extent of the area being irrigated to the amount of energy available.



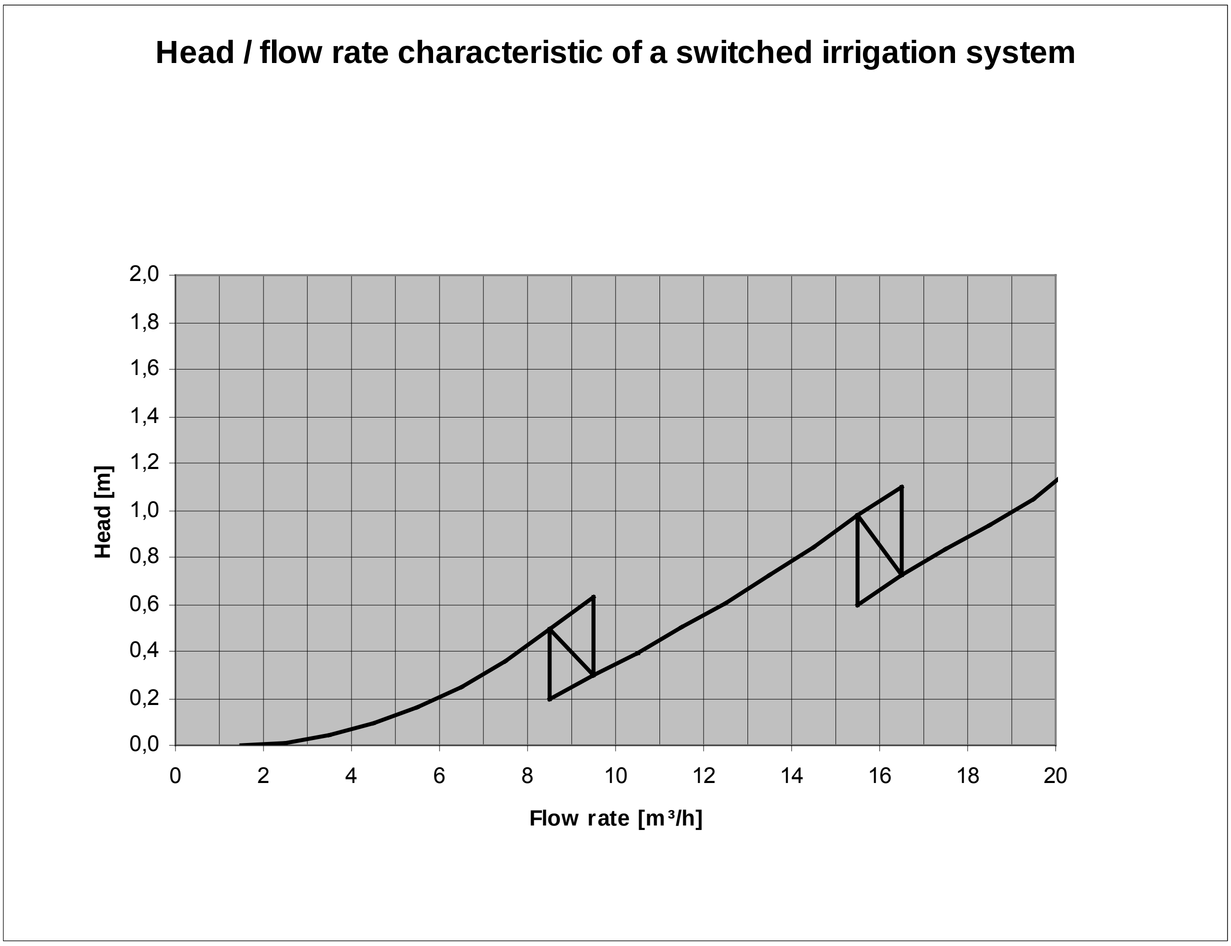
Direct-feed solar irrigation system

In such directly fed solar-powered drip irrigation system, for example, only one piping train can be connected if the pressure and pumping current are low (low irradiation levels). Given higher pressure and pumping current (high irradiation levels), two trains are connected, and at maximum pressure and pumping current (maximum irradiation) three trains are connected. A system of this type has the following hydraulic characteristics for the individual trains:



Hydraulic losses of an irrigation system with one piping train connected (upper curve), two piping trains connected (middle curve) and three piping trains connected (lower curve)

Each individual train can therefore be characterised by a continuous function. As a result of the use of control equipment (such as a PLC: Programmable Logic Control), with which piping trains can be connected and disconnected, the function of the system as a whole may exhibit step changes. It should be noted that for reasons of control stability the switching points are not fixed points but hysteresis.

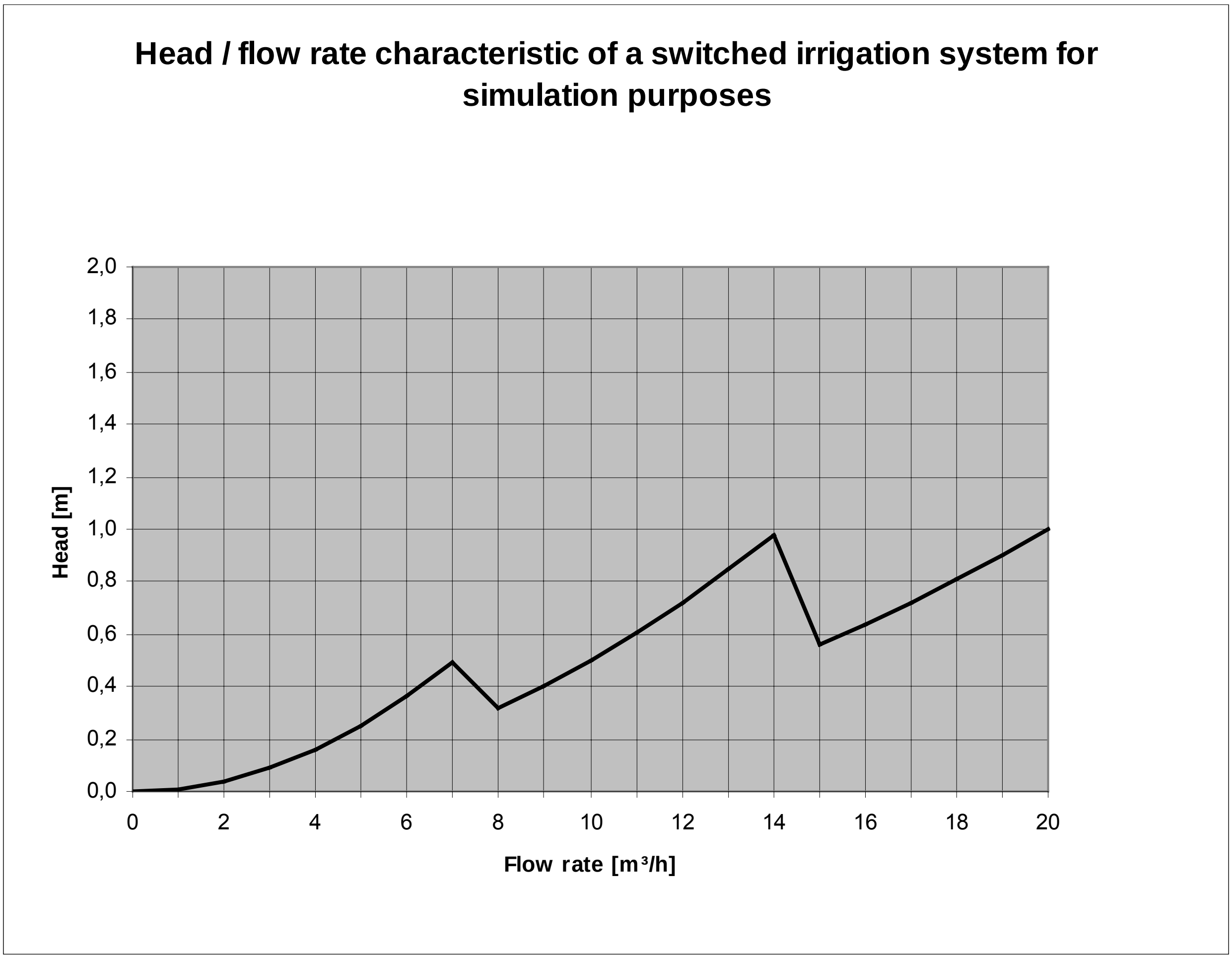


Switched trains with hysteresis and approximate step change

This hysteresis represent a burden for modern simulation tools as the exact modelling of the direction depending ±Δ disturbs the iteration. For practical reasons and under consideration that the working point of the irrigation system is not defined to be exactly on one of the switching points, an approximation with an inclined curve is justifiable. Representation of the system curve as an analytical function with correspondingly approximated parameters could in this case only be achieved with three subdomain definitions taken section by section.

Looking at the overall system with a control unit which for example switches over from one train to two at a flow rate of 8 m³/h (or vice versa when the flow rate drops below 8 m³/h) and switches from two to three trains (or vice versa) at 15 m³/h, we obtain the following approximated overall characteristic for the system, which, for example, can be simulated with DASTPVPS:

The effort for the use of such a model is considerable. For example a simulation of such a system with DASTPVPS requires a data set of 20 values (head, flow rate) for the curve. However, because of the interdependence an in favour of a suitable layout of the system such an effort seems to be adequate.



Hydraulic losses of a switched irrigation system

Although the characteristic curves of centrifugal pumps are largely similar, the quality of the conversion of energy can differ quite widely. It is therefore important to take care in the selection and design of the pumping sets. The typical behaviour of the pumping sets and the ability to guarantee a daily minimum irrigation volume for all plantings must be taken into account at the system design. By means of powerful logic in the control unit it can be assured that even under hard environmental conditions a solar driven irrigation system will show satisfying results.

5 Final considerations

The above detailed explanations refer to applications where photovoltaics might replace conventional power supply or provide energy saving and cost optimised technical solutions.

Upon this theory one must not forget that reality can override theory from another side. For example when PVPS for water supply is used in the evening for irrigation, if drinking water from the storage tank is led into another small tank for irrigation of a small vegetable flied or where water from a river is led into a vessel to get water for irrigation.

Photovoltaics often produces its own markets where no high-tech is required by simple, practicable methods. We must not forget to think about these possibilities if we don't want only technology to get ahead but bear in mind that the final user plays the relevant role.

6 References

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