

Water in Cyprus

PDF Edition

September 2009

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Introduction to the first edition (1998)

Due partially to prolonged unfavourable meteorological conditions, possibly even climate change, the Republic of Cyprus is experiencing an almost unprecedented water shortage. It is possible that this may continue indefinitely. While the Government is examining means of introducing new sources of water, some of them *in extremis*, a long-term reliable supply of sufficient quality and quantity to supply the unlimited needs of all the inhabitants is far from assured. In the meanwhile, agriculture, tourism, industry and the private individual must suffer from increasingly severe restrictions unless the overall consumption can be reduced. Rationing by time-sharing is not a reliable means of significant reduction as users will install larger tanks to store their needs for the "dry" period. At the best, it can only serve to make the people conscious that a problem does exist, but does not really concern them.

This document is designed to outline the problem in more detail with a view to bringing the attention of the reader to how each one of us can help to alleviate the impact to a minimum. By careful conservation of our resources, we can all contribute to reducing the consumption, without any reduction in our lifestyle. As a public service, this document is offered by EnviroTech Limited to all public authorities and to all who wish to read it.

It is obviously impossible to enter into great technical detail in such a document, but the Directors and Staff of EnviroTech Limited will be happy to reply to e-mail questions that may result from reading this document. To assist the reader, there is a glossary defining the more technical terms.

As the leading Cypriot company in the field of Environmental Technology, we thank you for the time to read it.

We are grateful to Protonique SA in Switzerland for the time and effort spent in preparing what we believe is a valuable document.

Introduction to the second edition (2008)

This document is a qualitative appreciation of the supply of potable and non-potable water in Cyprus, intended for any person or organisation interested in the question. It was researched, compiled and written by experts from Protonique S.A., Romanel-sur-Lausanne, Switzerland, in 1998 with subsequent updates, under a mandate from EnviroTech Limited, Larnaka, Cyprus. The authors are grateful to various persons in Cyprus who have provided invaluable data and help.

The 1998 edition of this document was originally intended as a printed document. However, its size exceeded all expectations and, because it is offered to the public as a non-commercial service, the cost of printing became prohibitive for no expected returns. It was therefore decided to modify it to be published uniquely as an Internet document. This 2008 edition is essentially an updated version of the earlier version with a few modifications and a number of additions.

The original authors, EnviroTech Ltd, have changed their course and name and are no longer interested in the subject; Protonique SA have been voluntarily liquidated. The rights to this document have devolved to the original lead author, Brian Ellis.

Introduction to the PDF edition (2009)

This edition is essentially the 2008 edition except that it has been modified where necessary to suit the new format, with a few minor corrections.

Executive Summary

Nearly all our practical water resources start as rain falling on the mountains. There are ample quantities but only a small proportion is exploitable. However, much, easily captured, rain falls on man-made structures from where it would be easy to recover literally millions of tonnes per year for irrigation purposes, relieving some of the burden from underground sources. Additionally, some considerable quantity could still be derived from natural sources, by exploiting seasonal water better.

Ground water is currently very badly over-exploited. The problem is that there are many gaps in our knowledge of the hydrology of Cyprus and a detailed survey is an urgent necessity. In many places, water tables are running dry or are suffering badly in quality. Urgent measures are needed to ensure continuing supplies, including restricting the use of wells and borehole water. It will be difficult to offer an equitable distribution of this resource which has hitherto been regarded as a natural right; only a scientifically established knowledge can be used to do this.

Man-made resources, such as desalination, are urgently required to make up the shortfall from dams, reservoirs and underground sources, even if rainfall over the next decade is restored to average levels, which is unlikely. At least 150,000 tonnes per day are required, increasing annually. About 10 per cent of this, or 25% of existing desalination capacity, could be working within six months with small equipment installed in or close to hotels and holiday apartments to take the pressure off the requirements of the tourist industry. In the low season, the water produced by these plants could be a useful supplement to fill coastal town reservoirs. The cost per tonne for this water would be similar to that from large desalination plants.

The quality of water should be matched to the use to which it is put. Potable water should be kept for where it is required and lower quality water used for irrigation and other purposes. This implies that water must be periodically analysed. Where the quality is insufficient, for whatever purpose, means of purification must be used.

Water distribution is an important source of wastage. It is believed that well over 10,000 tonnes of water are lost every day in distribution systems throughout the country. Much of this could be eliminated by stop-gap methods until the system is overhauled and, where necessary, replaced.

Recycling used water is possible in many cases. Controversially, the technically feasible and economical recycling of sewage is a case in point. Even if the psychological problems of converting sewage to potable water prohibit its use for this purpose, purified sewage is ideal for irrigation, swimming pools etc. New habitations and hotels should be constructed with grey water systems

which will reduce the consumption of potable water by about half and provide a substantial quantity for garden irrigation.

Agriculture, market gardening and smallholding do not always use irrigation water to the best advantage and ways are possible to improve crop yields with less water and, in some cases, less synthetic fertilisers. Likewise, industry can recycle water to a larger extent, especially if waste water requirements are stringently adhered to. Householders can also economise by numerous ways.

"Tiger-teams" of trained persons should be made available to help ordinary persons to economise and, where appropriate, stop abuse. Complementary to this, paid advertising in all newspapers, periodicals, radio and television channels should inform everybody how to save water, with little practical tips. The important point is that no one should feel that their standard of life must drop as a result of economy measures.

The private garden is a particularly difficult problem. There are ways of using non-potable water to make up the shortfall from the economy measures and these must be implemented, otherwise there will be illicit use of potable water, as well as from water tables.

Some of the measures which will be necessary will not be popular. There is therefore a very real risk that they will not be observed; even existing laws in the matter are not respected everywhere. It is imperative that very severe sanctions be applied for contraventions to both existing and necessary new legislation. The problem remains as to how to police them effectively. This could be a secondary function of the "tiger-teams" if the senior members were sworn in accordingly.

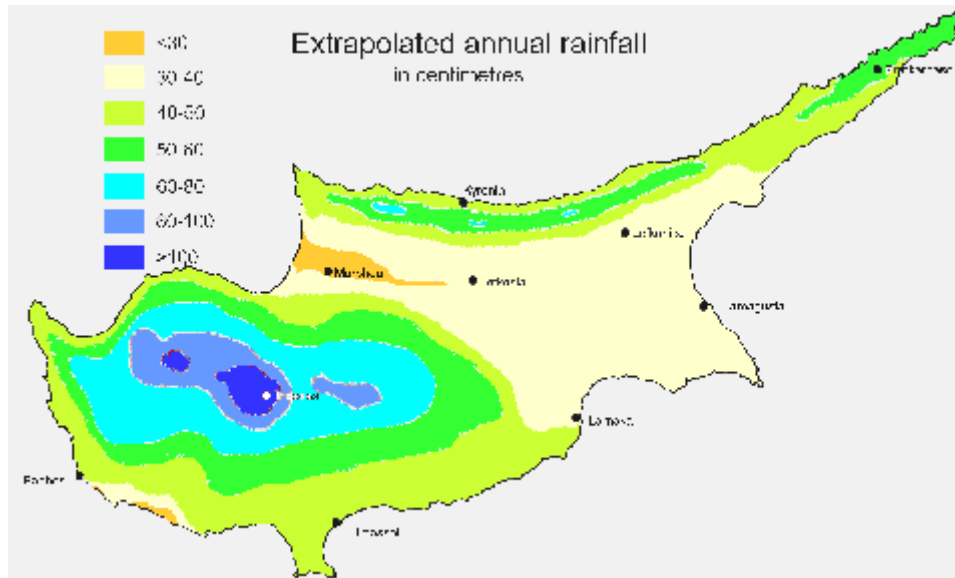
It is concluded that both short and long-term measures are required to restore normality within the next ten years, especially if the current drought is due to climate change, as may be supposed. By applying these sensibly, but rigorously, adequate water supplies will be available. The problem will be within the first four years, during which, especially if rainfall is inadequate, strict emergency regulation will be required. The population must be informed accurately, so that profligate use of water can be stopped in the shortest term, without causing hardship or a loss in the quality of life. With goodwill, the worst of the problems can be rapidly resolved.

Sources of water

Natural sources

Practically all our natural water is derived from precipitation, which we shall call rain water even though it is partially in the form of snow in the mountains and, to a much lesser extent, cloud, mist and dew. A popular belief holds that the wells in the Mesaoria are fed from water which comes from the Turkish Taurus mountains, but there is no scientific confirmation of this idea, which is geologically highly improbable.

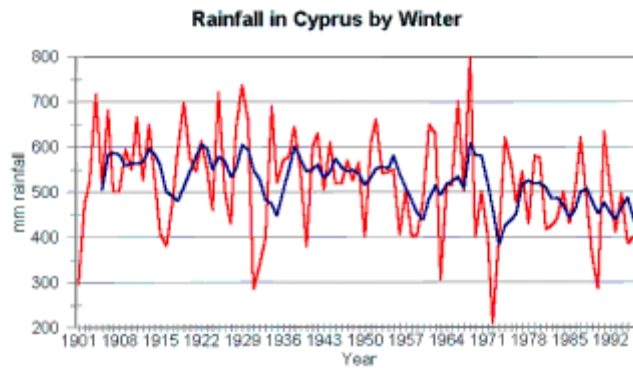
Rain Water



The average annual rainfall in Cyprus is about 48 cm, with a geographical distribution of most in the Troodos massif, in the Kyrenia mountains and least in the Western Mesaoria (see map). It should be noted that the map and the table of the rainfall in the major towns diverge slightly, as they do not cover the same period. This represents a total annual precipitation of about 4,500,000,000 tonnes (cubic metres) or almost 6,500 tonnes per inhabitant. In reality, the water consumption per inhabitant, including all usage, is less than 300 tonnes per year or about 4½ per cent of the total precipitation. If we are short of water, it means that over 95% of our natural resource goes to waste. By careful conservation measures, we should be able to improve this ratio considerably.

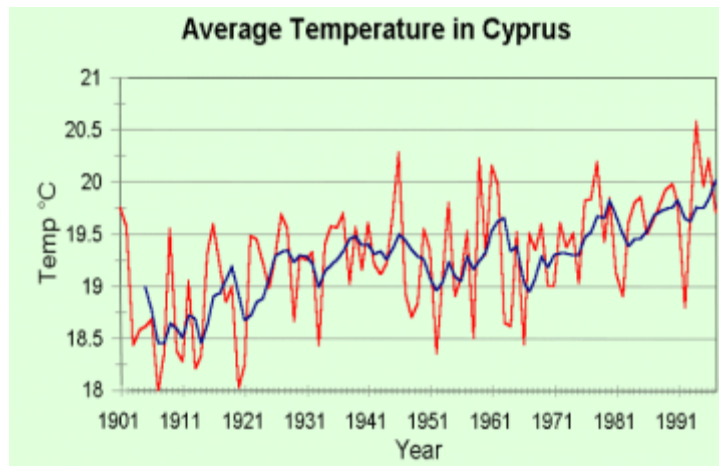
Rainfall in Cyprus towns, centimetres, averaged 1923-1970

	January	February	March	April	May	June	July	August	September	October	November	December	Total
Famagusta	12.38	7.11	3.11	1.54	0.85	0.39	0.08	0.08	0.38	3.15	5.29	9.41	43.76
Kyrenia	15.10	11.75	4.26	1.81	1.54	0.31	0.00	0.06	0.39	2.96	7.68	12.45	58.30
Larnaka	13.46	7.48	3.10	1.95	1.03	0.89	0.11	0.00	0.89	3.09	4.39	10.44	46.82
Lefkosia	8.93	5.91	2.62	1.65	2.87	0.77	0.06	0.23	0.77	2.56	3.47	6.70	36.56
Limassol	12.38	7.74	3.61	2.06	0.85	0.91	0.00	0.00	0.06	2.83	4.90	10.81	46.16
Paphos	11.41	9.95	4.39	2.10	1.04	0.16	0.00	0.00	0.39	3.26	5.68	11.60	49.97
Platres	20.94	11.96	8.32	4.75	3.02	1.21	0.65	1.35	2.06	3.94	7.58	21.13	86.91
Troodos	13.53	24.24	12.40	7.01	3.98	2.06	0.65	1.08	1.65	6.23	8.77	24.29	105.90



The above graph shows the rainfall between October and April of each year in the past century (red line) and the 5 year moving average (dark blue line). It can be seen that the rainfall is quite variable, ranging from just over 200 mm to just under 800 mm in extreme years. The 2007/8 winter did not reach even 200 mm. The 2008/9 winter reached slightly above average in the Paphos District, about average in the Troodos massif and well below average on the Eastern side of the island. Over the winters of 1995/6, 1996/7 and 1997/8, the rainfall has been consistently about 400 mm or about 15% less than average. This does not explain why the dams have dropped to 90% less than maximum: the "drought" has been an excuse for an increased and profligate use and wastage of water. The rainfall situation was far worse in the early 1970s, but there was no real water shortage, then. At the time of writing the first edition, the winter of 1998/9 is still in course, but it would appear likely that the rainfall will be somewhat over-average, probably between 500 and 600 mm. This will surely be insufficient to fill the dams to more than a few percent more than they were a year earlier.

It is interesting to note that the 5-year average rainfall is consistently falling over time and has dropped by about 100 mm since the start of the 20th century. It is impossible to draw conclusions as to the cause or causes, but it seems likely that climate change is a major contributory factor. The cause of this change is considered controversial by some but there would seem to be increasing evidence, although no scientific proof, as yet, that it is due, at least partially, by man-made activities, notably fossil fuel combustion, methane production and the use of fluorocarbons. The 2007 IPCC report states that this is "very likely" with a fractile probability exceeding 0.95. These emitted gases capture the infra-red radiation from the earth's surface and cause "global warming". The following graph shows the average temperature in Cyprus over the last century (red line) and the 5-year moving average (dark blue line). It can be clearly seen that there has been a temperature rise averaging about 1°C over the century, although there is no correlation between the temperature and rainfall on a yearly basis. This is the difference between weather and climate.



Conservation

Without doubt, there is little likelihood of being able to increase significantly the capture of rain by more large dams. The major valleys suitable for this are already exploited and further development would be environmentally and economically undesirable. Large numbers of small dams (surface areas of water from 1,000 m² to 10,000 m²) could be constructed on seasonal water courses, often in small gullies up to 20 m deep which are unsuitable for agriculture or other development. An average one could be constructed to hold 75,000 tonnes. This seems small but, if it is exploited in late spring to near-dryness, it would save so much water from being drawn off the major dams or from ground water aquifers. This volume is typically that consumed by a village of about 1,000 inhabitants for household use in a year. The dams could be of earth construction, reinforced by boulders and a concrete armature to prevent seismic collapse due to liquefaction of the soil under stress, with a typical constructional volume of 5,000 m³ of earth, mostly removed from the flooded part. The most important point to consider is that no single dam should retain more than about 25 or 30 per cent of the inflow at any time and no watercourse should be restricted by more than 50 per cent of the natural water flow at any given place. This would ensure that the impact on the downstream natural ecosystem would be small. Automatic flow-control would be desirable. The water quality may be potable in favourable areas, but may be suitable only for agricultural irrigation in regions where there are free toxic metallic ions¹ or microorganism contamination from upstream.

There are several other ways that rain water may be conserved for some uses. Over 25,000,000 tonnes of rain fall on metalled roads each year. If just half of this could be collected into reservoirs, the volume would be equivalent to almost the total potable water requirements of Lefkosia in a whole year. It is emphasised that such water, untreated, would not be potable, being polluted with asphalt, oil drips, rubber decomposition products, and organic particles from diesel exhausts, but it could be easily and cheaply rendered suitable for irrigation. As root absorption of water is by osmosis, the weak salts would not be absorbed significantly into edible crops. Such water would not be suitable for pisciculture as the pollutants may enter into phytoplankton which would be at the low end of a food chain, entering via fish into humans. No significant harm would result from their entering the sea, as the dilution would be sufficient that marine life would be unaffected.

Another way that rain could be conserved would be from the roofs of houses. A typical modern villa may have a roof area of 100 m². With the average rainfall figure of 48 cm, the water falling onto it

¹ There is a glossary at the end of this document which explains some of the more technical terminology.

each year would therefore be 48 tonnes. It would be possible to collect at least 25 tonnes of this, which would suffice for at least a quarter of the annual requirements for watering a large (say, 1000 m²) garden. The cost of this would be the guttering and downpiping, in UPVC or metal, plus an underground reservoir and a pump. The reservoir could be in an excavated hole of, say, 4 m by 5 m by 2 m deep, lined with 2 mm thick welded polyethylene sheeting with a 10 cm reinforced concrete cap, over which 30 cm of soil could be placed. If such a construction were to become standard in new property, the extra cost would be typically about €1,000. If it saved 25 tonnes per water per year, it would take about 15 years to amortise, not counting interest on the investment, with water at an indicative price of €2/tonne. This would therefore not be viable, if looked at from a strictly economic point of view, but water, if it is lacking, has no price. The government may care to consider the feasibility of offering small subsidies for such constructions to reduce the amortisation period from 15 to 10 years, say €200 per house with 100 m² of roof and 25 tonnes of approved reservoir capacity (pro rata for other sizes), or even to render such conservation as required on new constructions, in an analogue manner to anti-seismic measures. The cost of adding this to existing property would be higher and more difficult, but not impossible to implement. This may also be combined with a grey water system (see later), reducing the overall cost of both.

With new multi-dwelling property developments, the situation would be much more favourable, in that all roof and service road water runoff could be piped to a central reservoir close to the lowest point. It could then be pumped back to the individual houses via a second plastic water pipe system. Amortisation and equitable distribution could be assured by metering the individual consumptions. As a rough estimation, this would cost about 20 per cent less than individual construction for a 20-house development and would conserve almost twice as much water, probably sufficient for the garden requirements of the whole estate, because of the captured road runoff. This would be economically viable for the investment, with a write-off period of 7-8 years, again not counting interest.

Not all rainwater can be made available because of losses through evapotranspiration.

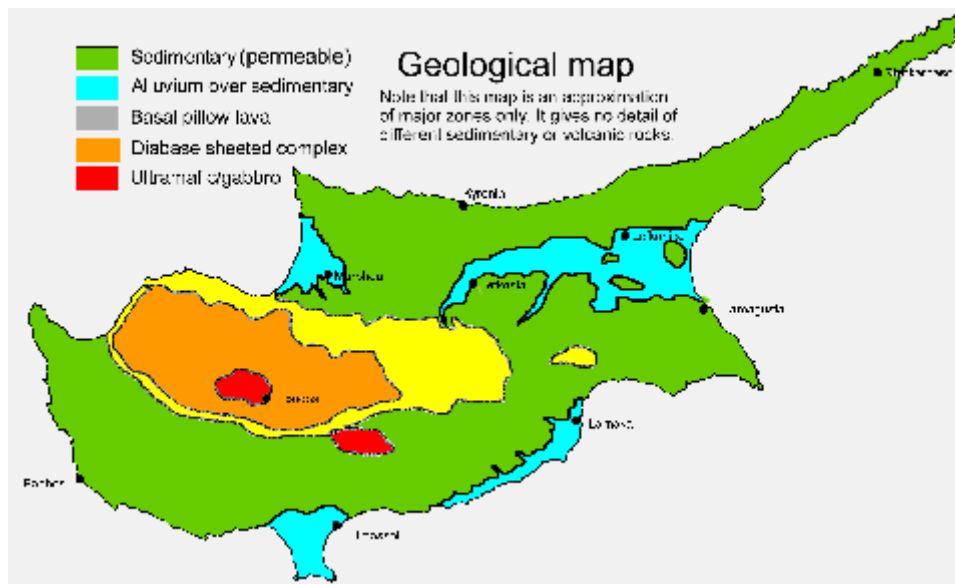
Surface Water

Surface water is defined as that flowing in perennial and seasonal water courses and natural springs and fresh water marshes, lakes and ponds, but excluding existing dams. If any further action is taken to conserve surface water for human activities, care must be taken not to upset local ecosystems which may already be stretched to their limit.

Conservation

Little further can be done to conserve surface water, other than a multitude of small dams mentioned above.

Ground water



In the opinion of Protonique experts, the use of ground water in Cyprus has become dangerously anarchic and requires the severe application of existing and new regulations. Even under the best conditions, the aquifers will require a decade or more of rainy winters to re-establish themselves with fresh water to a normal water level. In reality, it is possible that this wonderful resource will be lost for ever in some places through over-exploitation.

There are several kinds of water table and aquifer. The two mountain systems on the island feed them in different manners. The accompanying geological map is an approximation with minimal detail. The Pentadaktylos (Kyrenia) mountains are essentially permeable sedimentary rocks, largely limestones and sandstones of many types and ages, raised by seismic activity. Much of the rainfall is absorbed into the rock and can flow downhill for as far as the rock remains porous or meets a fault line which allows the water to move to another porous layer. On the southern slopes, these porous layers extend to many kilometres south of the foothills into the Mesaoria and provide water to, for example, the Lefkosia region. There are several phreatic aquifers, allowing water to be pumped up from different levels. There is practically no vadose water in this region. The water quality is generally fairly hard, as it contains dissolved calcium salts from the limestone.

In many places, sedimentary rocks are overlaid by geologically-recent alluvial deposits brought down by ancient river systems flowing from the Troodos massif. The most important one covers much of the Eastern half of the Mesaoria, north-west of Famagusta, as far as south-west of Lefkosia, but there are other ones round Morphou and Larnaka, the latter stretching along the littoral to Zygi. The Akrotiri peninsula is almost entirely alluvial. Other patches exist in many other regions. This alluvium consists essentially of clays and marl which can form an impermeous cap over the underlying rock formations.

The Troodos mountain massif is essentially older, non-porous, metamorphosed igneous (volcanic) rock. Rain water is absorbed into the structure by a honeycomb of seismic faults and other structural cracks, some of them less than a millimetre wide. Gravitation forces the water downwards, but there

is no true water table or aquifer. This water is essentially vadose and is relatively soft as there is little sedimentary calcic rock, but with a variety of dissolved mineral salts depending on the rock structure through which it passes. When such vadose water is led to the surface, this forms a spring, such as is exploited for the bottling of mineral water. The pressure of hundreds of metres of water at higher altitudes ensures an almost constant perennial flow from such sources, in many cases. Most of the water flows out of the volcanic region and, through fault lines, enters into more porous rock in the Mesaoria and coastal plains, frequently below sea level and eventually into the sea. Normally, the hydrostatic pressure of the fresh water prevents it becoming contaminated by sea water, as the flow is towards the sea. This passage through porous rock, sandstone or limestone, is phreatic in nature.

In the plains, much water is pumped out of the phreatic aquifers from boreholes and wells and this is done to such an extent that some aquifers are being totally dried out and the water tables are dropping in practically all regions. In the Troodos massif region and in the foothills, such as towards Stavrovouni, the ground water supply is less reliable as a well or borehole would need to penetrate a water-carrying crack or fault to fill. This would depend to some extent on chance but a hydrological survey could plot the major water-carrying fissures. Some areas have virtually no ground water down to the limit of normal borehole-drilling capacity, whereas a seemingly unlimited supply may sometimes be found just a few tens of metres away. Some villages (e.g. Pyrga) in this region have very adequate water supplies from boreholes, where neighbouring ones (e.g. Mosfiloti) have practically none. A borehole has recently been drilled just above Mosfiloti, but it is not yet being exploited (July 2008). Worse, as the water tables drop in coastal regions, the hydrostatic pressure falls and sea water is infiltrating into aquifers which are exploited, especially for agriculture. This is especially serious in the south-eastern part of the island in the triangle circumscribed by Cape Greco, Dhekelia and Famagusta, where well water is becoming brackish. An aquifer contaminated by sea water could remain unusable for decades, even if it is restored to full freshwater flow after adequate rainfall. This is partially because of the time lag between rain falling in the mountains and reaching the lower levels and partially because flushing the salt out from contaminated aquifers is a process of continuously successive dilutions. Other regions, including the market gardens around Maroni, with important tomato and cucumber production, are beginning to experience similar problems.

Conservation

With little doubt, it is the conservation of ground water that requires to be addressed the most urgently. New regulations must be implemented based on hydrological surveys, forbidding aggregate water to be pumped out of aquifers at a faster rate than water is arriving. This will be an expensive operation and may even close down some supplies of water. It is without any doubt that this is essential if the future economy of the island is to survive, particularly in the agricultural and related sectors.

The first thing that must be realised by everyone is that water pumped up from under the ground is not an unlimited free gift from heaven. Every drop wasted in one place may be depriving other users downstream of what they need for economical survival. The implication here is that every well and borehole in the country must be catalogued along with the water source that is being exploited by it, derived from a precise hydrological survey. However, it is not sufficient for the quantity of water extracted to be reduced to what is arriving, the depleted aquifers must be allowed to regenerate themselves. This can be done by pumping out only, say, half of the water that arrives. Even so, it

would probably take at least a decade of normally wet winters before all the aquifers would be restored to a more-or-less normal situation.

It is recommended that existing subsidies on borehole drilling be stopped with immediate effect and possibly replaced by a taxation on new drillings.

A precise and complete hydrological survey will have the advantage that currently unexploited sources may be discovered. These may be from aquifers underlying existing ones but separated from them by a cap of impervious rock. It is possible that large quantities of new water at depths of between 500 and 1,000 metres may be found.

The implication of the foregoing is that owners and users of wells and boreholes would need to be severely rationed as to the quantity of water they would be permitted to extract, derived from the data established by the hydrological survey and their probable requirements. Metering of each source would therefore need to become a legal obligation. We suggest that extraction beyond the annual limit laid down would best be discouraged by the payment of charges on a sliding scale, at an increasingly swingeing rate according to the extra extracted volume. It is clear that this kind of measure would not be popular, but Protonique experts are unanimous that it is only by stringent measures that the situation can be resolved in the medium term.

The extractable ration under such a regime could be adjusted annually, according to the rainfall. On a more controversial note, there is the question to be resolved as to whether certain classes of users require a priority supply which would be detrimental to other classes. For example, it may be felt that private individuals who use well water for their gardens should obtain proportionally less than agricultural exploitations. This would be logical, but there would be two disadvantages:

- the psychological impact of restricting water to the extent that their gardens would suffer unduly would not be favourable to the implementation of such plans;
- a minority of individuals would be inclined to use municipal potable water for their gardens to make up the shortfall.

Man-made resources

There are several ways in which it is possible for man to convert water to his own use. As Cyprus is a small island, it is obvious that one is never far from an almost infinite supply of water, the sea. The problem is to treat the sea water in such a way that it becomes potable. This is never easy and always costly.

Desalination

Sea water contains about 35,000 milligrams of dissolved solids per litre of water. These solids are mostly ionic salts, the main one being sodium chloride or common salt. It is generally considered that the maximum salt content for water to be potable is 800 milligrams per litre. Even this may be considered too high for persons suffering from certain chronic medical conditions. A value of 500 milligrams per litre would be better as a target figure. The basic problem is that to separate the salt from the water requires energy to break the ionic bonds. The question remains as to how to do this in a reasonable and economical manner. The two main contenders for this are reverse osmosis and multi-stage flash distillation. Each is capable of producing potable water from sea water at a cost

which is not too prohibitive. However, it must be thoroughly realised that desalinated sea water will never be as cheap as water from natural resources.

Reverse Osmosis

Reverse osmosis consists basically of pumping sea water up to a very high pressure and allowing it to percolate through semi-permeable membranes. This would seem to be similar to filtration but, in fact, it is not the case. Without going into the technical details, reverse osmosis depends on the use of a totally different physical principle, differential surface tension. The advantage of reverse osmosis is that it does not require an enormous space to implement and that it can be applied for purifying volumes from about 1 tonne per day up to hundreds of thousands of tonnes per day, depending on local requirements. The astonishing fact about reverse osmosis is that the cost does not vary very much from throughputs of a few hundred tons per day right up to the largest installations. The process is very energy-intensive, particularly if a very high purity water is required. The cost of installation is high, as well as the running costs. It always requires automatic monitoring to ensure that the water quality is sufficient.

The question must be asked whether the energy requirements of RO desalination will upset the island's commitments to the Kyoto Protocol and the EU's plans for greenhouse gas reductions. If, because we need more water, we have to buy the right to emit more carbon, this water is going to become even more expensive.

Large-scale

Large scale reverse osmosis is already well-known on the island, from the installation at Dhekelia and south of Larnaka airport and elsewhere. Such installations are very expensive to implement and to run but can produce a continuous supply of potable quality water at a cost of between €0.50 and €1.00 per tonne. The Dhekelia plant has a throughput of about 40,000 tonnes per day, with a planned upgrade to 50,000 t/day, while the Larnaka one is also 50,000 t/day. Of course, there is almost no theoretical limit to the amount of water that can be treated if enough large-scale desalination plants are installed, but the consumption of electricity would become prohibitive for the island's generating resources. To circumvent this, they frequently have internal generators, running off fuel oil, but this electricity is much more costly than that produced from the power stations, due to a lower overall efficiency. Internal generators may be either gas turbine or diesel, the latter being more common. Either is a severe source of air pollution unless the exhaust gases are carefully treated: even so, additional carbon dioxide, the main "greenhouse gas", is emitted. The motor-generators are also noisy and this causes considerable resistance to the installation of such plants by local residents. It is recommended that any new plants of this nature be installed only in industrial zones, away from any habitation. Combined with the high cost of production, the practical limit would not be greater than about 100,000 tonnes per day on a full time basis. If, in combination with restored natural resources, the total output from such desalination plants exceeded the demand at any time in the future, the excess water produced could be pumped into existing reservoirs. More especially, they could be operated at night when there is an excess supply of electricity available. When calculating the capacity of such large plants, the down time for repairs and maintenance should be considered at between 5 and 10 per cent because of membrane failures. There is no evidence that the return of high-concentration salt water to the sea will cause any severe environmental damage except within a radius of a few tens of metres from the outlet pipe, which is

totally negligible. Notwithstanding, it is recommended that this be placed at least 1 kilometre offshore in deep water to minimise any potential risk.

Plans to build a couple of new RO plants for Limassol and Paphos, which were shelved by the Papadopoulos government, have been resuscitated by the Christofias government and it is thought that construction of them may be completed by 2010.

Small-scale

A wide choice of commercially available containerised reverse osmosis units exists, with throughputs of 1 tonne per day up to a few thousand tonnes. The very small ones are not economically viable, costing typically €5 to run a 1 tonne per day unit. From about 250 - 500 tonnes per day, the cost is typically between €0.50 and €1.50 per tonne, similar to large-scale units. An installation of this size could be installed in a basement room of about 20 m² floor space, in a lorry or in a small external prefabricated building, as well as being supplied in a ready-to-use container. This scale of unit can also be equipped to run off diesel fuel, with low-noise engines, rather than from a mains electricity supply, at a slight increase in overall costs. It would therefore be viable at places without an adequate high-power electricity supply available and, above all, as portable units which could be trucked to any place on the littoral where there is an emergency supply required. The small units are capable of supplying potable water of the required purity, including bacterial count, to meet any standards, depending on equipment specifications.

Multi-stage Solar Flash Distillation

Multi-stage solar flash distillation is a very economical process for large-scale desalination, both in terms of capital investment and, above all, running costs. The main disadvantage is that it requires very large tracts of land with unsightly panels, close to the sea. This is really incompatible with most of the littoral in Cyprus. The principle of operation is very simple: sea water is heated in solar panels to a temperature of about 60°C and then sprayed into a chamber at a reduced pressure. It boils off instantaneously and the vapours are condensed. The process is repeated, typically three times, until the quality of the water is sufficiently good. Because most of the energy required to operate the system comes from the sun, the consumption of electricity is usually less than one-fifth of that required for reverse osmosis for an equal production. It is therefore less polluting and less likely to over-burden existing electricity supplies.

Maintenance costs of this process is high because of the corrosivity of the brackish water in the intermediate stages.

Air Conditioning

Air conditioning can also supply large quantities of high-quality distilled water. This is the condensate from the coolers within the individual rooms, whether the system be a central one with a chiller or with separate compressors for each room. Obviously, this source of water is seasonal but, in summer, one litre of water per person in a room is lost through perspiration and respiration every four hours. This can be collected at virtually no cost and added to other water for any use. In reality, this water would be too pure for use by itself, except possibly for washing purposes. The taste would be unpleasant due to a lack of mineralisation, although it should be safe to drink if the recipient is changed frequently. If used consistently for watering plants, it would require some additives to ensure the good health of the plants, because there is no nutritive value in the water.

The major obstacle to collecting this valuable water is in the small quantity produced per room. Nevertheless, it is foreseeable that aggregate quantities in the order of hundreds of tonnes could be collected every day over the hottest six months of the year, particularly from large buildings.

Importing water

In 2008, as an *in extremis* emergency measure, it was decided to import water from Greece. This turned out to be a Comedy of Errors, as 50 kilotonnes of precious water sat in the Limassol roads for 3 weeks, unable to be offloaded from the tanker ship because of a succession of stupid errors due to a lack of foresight and planning. At the time of writing, the first tanker load has still not been offloaded while a second tanker is now sitting there, figuratively twiddling its thumbs, and a third one is due to arrive. Has anyone bothered to work out how much it costs to have tankers sitting idle because a pipe was a few metres too short?

Be that as it may, importing water by tanker is a horrendously expensive exercise and has become necessary only because of the incompetence of the authorities in previous years. Technically, there is no reason why it should not be done, but it places the country at the mercy of the supplying country. It is hoped that this temporary measure will never become permanent because Greece has its own water problems and may close the tap if water becomes scarce there.

It would be much more logical to have a pipeline from a country with an assured supply. Turkey springs to mind, but for the political aspects: no one would favour an essential supply from a country that could use it as a stranglehold. Of the surrounding countries, only Egypt has an assured supply of fresh water, from the Nile. A pipeline from the delta region to, say, Dhekelia would be technically feasible, even over the Cyprian Arc fault line. It would probably be cheaper than using tankers over more than a few years but the political aspects of ensuring a constant supply would have to be negotiated as a long-term agreement. This would allow the reservoirs in Cyprus to be constantly topped up, giving a good autonomy in the event of a catastrophic failure. The big advantage is that the presence of a quasi-unlimited supply would allow agriculture and forestry to improve, increasing transpiration and improving the local microclimates. This is something that should be seriously studied.

Purity

Water Quality

It is very important that water used for any purpose is of a quality suitable for that purpose. If the quality is superior by a small amount, then no harm can result. Pure water is unsuitable for many purposes, including drinking and irrigation. It is therefore important that the impurities present are compatible with the use to which the water is put.

Ordinary water as distributed by municipal systems should be lightly mineralised and, preferably, with a small amount of lime and carbonates (soft). If the water is too hard, washing with soap will require a heavier consumption due to the presence of scum formed by the chemical reaction between the soap and the lime and carbonates. It is therefore in the interest of economy to ensure that municipal water is not too hard. This may be done by diluting the hard water from limestone sources with the very soft water produced by reverse osmosis desalination. Municipal water has to be exempt from harmful bacteria and other microorganisms and this is usually done by one of two

methods. Throughout the world, the most usual one is chlorination which is very effective but requires careful dosing. If the quantity of chlorine is insufficient, there is a risk that bacterial contamination may proliferate, especially if the water source may be contaminated from septic tank seepage. Too much chlorine is wasteful and gives the water an unpleasant odour. The other method is by ultraviolet radiation and is achieved by passing the water through quartz pipes surrounded by intense ultraviolet lamps. These lamps ionise the dissolved oxygen in the water to form ozone which is a powerful sterilant. Some of the microorganisms may also be directly attacked by the ultraviolet light. This method is, by far, the most reliable and easy way of ensuring the sterility of potable water for small installations, because there is no handling of obnoxious chemicals and dosing is not a problem.

One impurity that is common in some areas of Cyprus and may also be present in desalinated water is boron. The quantities present are usually so small that it has no effect for any use, although the concentration does have to be kept within specifications for potable water. Citrus trees need boron at a concentration of 0.1-0.5 ppm for healthy growth and production. In alkaline soils, there may be boron present but it may be sequestered from the plant. However, citrus is very intolerant of excessive quantities of boron and a concentration of 20 ppm in irrigation water may be sufficient to kill otherwise healthy trees.

Wet Analysis

Wet chemical analysis is used extensively for determining water quality. It can measure the exact quantities of any dissolved solids and also such components as oils and organic solvents. In addition, modern laboratory equipment can automate many of the procedures by means of infra-red spectrography, ionic chromatography and liquid chromatography.

Electrical Conductivity

Electrical conductivity can easily be measured with cheap, portable equipment. The conductivity of the purest water possible is 0.056 microsiemens-centimetre, but this value is obtainable only under laboratory conditions. In practice, values in the range of 100 to 10,000 microsiemens-centimetre are common for potable water. This type of measurement gives a certain measure of all dissolved ionic (metallic) salts, without indicating which ones are present.

Total Dissolved Solids

Total dissolved solids are a measure of the weight of the residues, in milligrams, after evaporating one litre of carefully filtered water. The conditions under which this test is conducted are carefully laid down in international specifications.

Undissolved Solids

Undissolved solids are the aggregate of silt and microorganisms which are retained in a mechanical filter with a pore size of given dimensions, according to the required specifications. As a general rule, the pore size will be within the range of 0.5 to 5 micrometres.

Organic Matter

There are several types of organic matter which may be found in water and their determination depends on the nature of the matter. Basically, the organic matter can be divided into living and chemical natures. The living matter or microorganisms comprise a wide variety of life forms. The chemical matter may be either natural or man-made pollution. As an example of natural pollution,

the presence of decayed vegetable matter may be cited as one example. By far the more serious type of chemical pollution is that produced by human activities. The worst examples are the addition of non-biodegradable or poorly-biodegradable products into water, e.g., lubricating oil, organic solvents and suchlike. One litre of oil or solvent may render hundreds of tonnes of water unsuitable for human consumption and care must be taken always never to allow such pollutants to enter the soil or water courses. Less serious, but nevertheless not negligible, sources of pollution include biodegradable compounds such as soaps and detergents and inorganic additives to them, such as phosphates.

The identification of non-living organic pollutants can be done by chemical analysis. There are two useful methods of determining whether water polluted from organic sources is likely to present problems in the long term. The chemical oxygen demand can be determined in laboratories as a measure of the oxygen required to convert organic matter into water and carbon dioxide under given conditions. The biological oxygen demand is a similar measure of the oxygen required to sustain bacteria which will naturally break down some organic pollutants. This bacterial action is similar to that which takes place in septic tanks and sewage treatment plants.

Some organic products are very toxic, whether they are biodegradable or not. One example is the use of certain types of specialised non-ionic detergents called octyl- and nonyl-oxyphenoxylates. These biodegrade readily but incompletely, one of their decomposition products being particularly toxic to aquatic life and down the food chain. Such detergents are still found in some specialised industrial products.

The microorganisms that can be found in water fall into a wide number of categories. The major ones include:

- Viruses
- Bacteria
- Amoebae
- Algae and their spores
- Microplankton of vegetable and animal origin
- Etc

Of these, the viruses and bacteria may be very dangerous to human health in drinking water, being direct disease vectors, and must be killed by chlorination or ultraviolet radiation. They are responsible for such diseases as cholera, typhoid, paratyphoid and other s. Amoebae can be responsible for some very severe forms of dysentery and microplankton can cause a number of other serious diseases, often through parasites having undergone development in other vectors, such as liver fluke, bilharzia and elephantiasis.

The detection of larger microorganisms is done through microscopic examination. Smaller microorganisms can be detected only after culture in a suitable medium, which may take considerable time. Electron microscopy may also be a useful tool for identifying species.

The major source of dangerous microorganism pollution is through the infiltration of faecal matter into the water. The large number of septic tanks in Cyprus, some of very old or doubtful construction, makes this a real risk for water which is pumped from sources close to the surface.

Such water should never be used as potable water except after controlled treatment. Another source of similar pollution is from leakages in sewage systems. Similarly, it must never be assumed that any surface water is free from harmful microorganisms.

Hardness

The hardness of water depends on the presence of calcium or magnesium hydroxides and carbonates. The effect of hard water is to form a scum when soap is added. This has a double effect in that it requires more soap to generate a lather hence increasing the pollution in the waste water and that it requires more water to eliminate the scum and extra soap in what has been washed. There are several ways of expressing the hardness of water, some of them being used in a specific country: these ways are not necessarily convertible as the method of measurement may be different. One of the commonest methods of measurement is to add enough of a standard soap solution to form a stable lather, the hardness being related to the quantity of soap used.

Whereas hard water is not desirable, neither is very soft water which is unpalatable for drinking. In many areas where the water is naturally soft, lime is often added to increase the hardness, such as in Scotland. Much purified water is very soft.

Purification of water

Other than the methods already evoked, there are several ways of purifying water and these may be used under specific circumstances. In particular, these methods can be used for treating waste water or water polluted with waste water, especially from industrial sources but also from natural sources. This may allow such water to be used for other purposes.

It must be realised that most pollutants can never be eliminated. Some may be converted to a less polluting form. For example, biodegrading a detergent may result in the production of less polluted water, but at the cost of oxidising the carbon atoms, producing carbon dioxide (also methane if the degradation is partially anaerobic). In particular, heavy metal salts are eliminated only by ion exchange or electrowinning, where they are converted back to their metallic form. Otherwise, all the other processes for their elimination or reduction as a pollutant merely shift them from one form to another, perhaps into a more concentrated waste stream.

Filtration of Particulate Matter

Filtration allows any particulate matter to be mechanically or physically removed from water.

Mechanical filtration is the most familiar form. On a medium to large scale, it may be done by passing the water through a clean sand bed. On a smaller scale, various forms of wire mesh, cloth filters and treated paper filters are all used. In time, all these filters tend to clog and need treatment or replacement to ensure adequate throughput. Depending on the material retained by a filter, the disposal of this material may present a problem. Correct disposal is essential.

Microfiltration consists in passing the water through a membrane with a pore size in the sub-micron range (less than one micrometre). This will retain contaminants which have passed through a conventional mechanical filtration stage, such as suspensions and sols. It will not remove substances at a molecular level.

Ultrafiltration is similar to microfiltration, except that the membrane has a much smaller pore size which will retain large organic molecules, particularly natural and synthetic polymers derived from

some types of detergent or cosmetic products. Although it may superficially resemble reverse osmosis, ultrafiltration is not the same as it is still a mechanical process.

Carbon filtration

Carbon filtration consists of passing the water through a column containing a special form of activated carbon which can retain some non- or poorly-biodegradable organic pollutants such as oils and solvents, by adsorption. The type of carbon must be matched to the type of pollutant. This is a very expensive but highly efficient method on condition that it is correctly applied. Carbon filtration may also be used to remove some natural pollutants. The carbon is usually derived from lampblack, bone charcoal or coconut shell charcoal, but it is essential that the carbon type and activation treatment be matched to the pollutant being adsorbed.

Softening

Water softening consists of the replacement of calcium and magnesium salts in hard water by sodium salts. It is a specialised form of ion exchange which is particularly economical to operate, by passing the water through a bed of special mineral matter which allows the calcium and magnesium to be exchanged for sodium, derived from common salt. As such, it is not a true purification. Most domestic dishwashing machines contain a small water softening unit. This prevents the formation of a white deposit appearing on glassware. Softened water is useful to reduce the production of soap scum where the water is hard, but is unpleasant to drink.

Ion Exchange

Ion exchange is a very efficient but expensive method of purifying water containing salts, consisting of passing the water through one or more columns containing a special synthetic resin. The resin may be regenerated, sometimes in situ, sometimes in a central regeneration facility. Ion exchange produces water of a very high purity and low conductivity, but it does not eliminate any organic matter. It is frequently used in industry for applications where a high purity water with a low electrical conductivity is required and it may also be used as a method of purifying waste water containing metal pollutants that are difficult to remove by other methods.

Polymer Filtration

Polymer filtration is a specialised method, recently developed, for the removal of specific ions from waste water. Special heavy metal ions fix themselves on specific polymers. These can then be removed by ultrafiltration. The polymers can be easily regenerated, releasing the ions in a concentrated stream which may be recycled back to the process using them. The polymers themselves are also recycled, making this process very economical. If there is a mixture of heavy metal ions, then more than one polymer may be required. Because of the specificity of the process, it may also be used to extracting passively high-value metals from sea water; much research has been done to extract uranium, for example.

Electrowinning

Electrowinning consists of passing water containing heavy metal salts through a cell fitted with electrodes which are connected to a d.c. supply. The heavy metals are precipitated to the bottom of the cell or adhere to one of the electrodes where they may be mechanically removed. The advantage of this system is that the metal may be easily recycled, particularly important if the metals are precious or semi-precious. With base metals, the value of the recovered metal will never recuperate the running costs. Nevertheless, if it allows the waste water to conform to national

regulations, the running costs are relatively small, compared to some other methods of eliminating metals from waste water. This method may be particularly useful for removing metals from the waste streams of other purification methods, such as reverse osmosis or the regeneration liquids from ion exchange.

Precipitation

Many polluting metals, if the concentration is reasonably high, may be removed from waste water by chemically converting the salts to insoluble hydroxides or ferrites, allowing them to precipitate and filtering them out of the water. In large plants, this process produces large amounts of sludge which constitutes a hazardous waste and must be recycled back into the metals or possibly disposed of correctly in certified chemically safe landfills.

Water losses

Evapotranspiration

Evapotranspiration represents the part of precipitation that is both evaporated from the soil and transpired by vegetation. Depending on conditions, this can vary from about 10% to about 75% of rainfall.

Evaporation of rain falling on the soil depends on the rate that the water is absorbed into the ground, the temperature of the soil and of the rain, the humidity of the air etc. To take an extreme example, the evaporation of rain falling onto a hot road surface without good drainage may reach almost 100%. At the other extreme, rain falling on coarse sand under cool conditions would hardly evaporate to any significant extent. The presence of vegetation can have a double effect. It can prevent some of the rain from reaching the soil, in which case the evaporation may be greater; on the other hand, it can also inhibit the evaporation of rain having reached the soil. Much depends on the nature of the vegetation.

Transpiration of vegetation is also a two way process. Some rain is absorbed into the plants directly by the leaves and some is absorbed from the soil by means of the roots. The amount that evaporates through transpiration is very variable according to the type of plant and the condition of its water balance. Many plants have means to reduce the transpiration to a minimum, especially those growing in desert regions. On the other hand, plants which grow under wet conditions may transpire abundantly.

In Cyprus, we have two general sets of conditions. In summer, there is little rain but, when a storm breaks, the ground is often too hard to absorb water, which runs or puddles until it is largely evaporated. Except where there is ground water or cultivation there is almost no transpiration from plants, despite low relative humidities and high temperatures. Pine forests transpire little, compared to deciduous forests.

In winter, the soil becomes absorbent after the first rains because of bacterial activity and the water is quickly absorbed before it has a chance to evaporate. Much of this will be absorbed by plants and they start to grow. Transpiration will increase as the plants grow, and will become important towards the end of the rainy season.

In order to be useful, the most rainwater and groundwater can be collected in the dams from precipitation from the second or third major rainfall in the autumn through towards the end of February, not counting melt waters from snow on the Troodos massif, which are obviously delayed from earlier falls. March and April rains are less effective due to the increased transpiration losses.

Distribution of water

The distribution of municipal water is a very major source of wastage. All such distribution systems leak, with losses ranging from typically 3 to 10 per cent in most continental European countries. In some cases, losses in Cyprus and elsewhere have been reported of over 25 per cent². The major cause of these losses is the use of iron or reinforced cement pipes with overlapping joints which are sealed with tow. In time, the vibration of traffic, minor seismic activity and expansion and contraction from seasonal water temperature variations will create sufficient movement that the seals are no longer watertight. Even worse, glazed terra cotta pipes are also porous, where the glazing has been damaged: they are also provided in shorter lengths, so that there are more joints per kilometre. Flanged cast iron pipes have gaskets that deteriorate with time and conditions and the pipes themselves can break or rust through. Smaller leaks from underground pipes can pass undetected for years, wasting thousands of tonnes of water. Instruments are available for leak detection, either through measured pressure loss under given conditions or acoustically. Deep soil conductivity is also sometimes used.

For the anecdote, a leak from a cast iron pipe had washed away the soil under a road in a Swiss city. It is estimated to have been leaking for over five years. It was discovered only when the road collapsed under a 28 tonne articulated truck. The resultant hole completely swallowed up the truck and its trailer. It is estimated that over 200 m³ of soil had been washed away through storm channels.

There is an additional danger: sewage pipes are no less insecure and leaks of raw sewage occur all too often. If a potable water pipe should develop a leak in the same area, it is possible for microorganisms to be drawn into the drinking water by the Bernoulli effect.

Ideally, all new underground water distribution systems should be made from welded plastic pipes of suitable quality and which would have a typical leak-free lifetime of more than 25 years.

Conservation

It is strongly recommended that all existing pipework dating from more than 10 – 15 years be replaced as rapidly as possible. The cost of this will not be negligible but the savings in water could amount to more than 10,000 tonnes per day, which is far from negligible. There exists a technology which could provide a temporary palliative for the longer stretches of pipe which are particularly leaky and which is neither very costly in materials nor expensive to install. This consists of accessing the pipe through a manhole or a pit every hundred metres. A polyethylene tubing of the same diameter as the inside of the pipe is introduced and the water pressure forces the tubing against the walls of the pipe for the length of the stretch. Obviously, this can only be applied where there is no

² In one UNDP document concerning a study in Turkish-controlled Nicosia, it stated, "The water leak detection pilot study showed estimated losses due to leakage of 55-75% in one area and 50-70% in the other." However, bad though these figures suggest, they are probably (hopefully?) not representative of the whole Nicosia area. http://mirror.undp.org/cyprus/projects/project_details.asp?ProjectID=19

branching. In places where this system has been installed, it is claimed that leaks have been reduced by over 90 per cent at relatively little cost and with relatively short interruptions of the water supply. Nevertheless, it is emphasised that this method is suitable only as a temporary stop-gap, typically for a maximum of two or three years, while new pipelines are installed.

Utilisation of water

Water is used in every walk of life, but it is frequently wasted or used to less than the best advantage. The purpose of this section is to indicate how water may be saved in each sector.

Agriculture

Without doubt, agriculture is the sector with the highest aggregate consumption of water and significant savings are possible. However, this will often meet with opposition from farmers because of an innate conservatism and resistance to change within the agricultural community. The methods of using water vary greatly according to the nature of the crop.

The secret of efficient use of water is to place it where the plant needs it. A 20 cm long carrot does not need water in the top 5 cm of soil, still less above the soil. Spraying a carrot or potato crop every two or three days is totally useless, because only a very small fraction of the water leaving the irrigation nozzles will eventually reach the level where the plant needs the water. The rest will be unnecessarily lost by evaporation. Worse, if the plant detects water at a higher level than the optimum, it will tend to direct its root system upwards. If the roots are too close to the surface, they will be more vulnerable to damage by the heat from the sun, reducing the health of the plant and making it more susceptible to attack by disease and pests. A healthy plant is one that has a deep root system because it detects the most water below it. In the case of many crops, a good soaking of the soil by surface or, better, sub-surface flooding once every week or ten days is much better than spraying every other day for a comparatively short time.

There are obvious practical difficulties to the above. Where crop rotation is practised, because different crops have different requirements, no permanent installation is possible. The only practical method is to have irrigation pipes between every other row, with trickle nozzles (not sprays) at suitable spacings. The cost of such pipework is relatively high and there is the labour of laying them after each sowing and removing, maintaining and storing them after the product is harvested. An alternative, where it is feasible, is to have the pipes underground, 10 cm deeper than the soil is ever tilled. These can be used after the crop has germinated and the root system has developed to a few centimetres.

Spraying is the most wasteful method of irrigation and should be reserved for only where it is strictly necessary, such as before germination. When it is used, the spray should be adjusted for the largest possible droplet size and the lowest pressure. A fine mist will evaporate up to half the water before it reaches the plant and droplets will remain on leaves where it will evaporate further. With large-leaved plants, such as established cabbages, as little as 10 per cent of the water being sprayed will enter the soil and less than one-quarter of this will be absorbed by the roots. Too high a pressure will cause water to rebound off the soil or plants in the form of a mist, where it will readily evaporate. Spray irrigation should be done in calm weather.

Channel irrigation is better than spraying but is also wasteful because the soil round the channels is also wetted, even where there are no crops to benefit from it. If it is practised, the channels should

be cut only where there are crops and the water led to them through pipes, which will also reduce evaporation.

All irrigation should be done in the evening or during the night, so that the water can penetrate to the roots at the coolest time, reducing surface evaporation. The health of the plants will also improve because surface pipework in sunlight will heat the water beyond the desirable limits for the plants. Another advantage is that, although the evaporation will be reduced at night, there will still be some and this may condense as dew on the plants, due to the high local relative humidity, especially if there is not a high wind.

Even experienced farmers can misjudge the amount of moisture in the soil. Simple, cheap, portable, soil moisture meters are available and should be used regularly to the depth of the crop roots to determine when irrigation is necessary. Instruction in the use of these instruments for each crop type is necessary, because each type has different requirements of soil moisture. Better still, a fully automatic system can control the irrigation, in conjunction with a time switch, so that no human intervention is required. This could reliably increase crop yields for a reduced water consumption, at a small extra capital outlay.

As a general rule, the use of water for animal husbandry is difficult to reduce substantially. Animals will drink only the water they need but adequate quantities of clean, fresh drinking water are necessary. When the water is drained from drinking troughs or they are being cleaned out, rather than waste it, it would be better to use it for swilling out stables, byres and pens. This implies a simple collection system.

Industrial Horticulture, Market Gardens and Smallholdings

The same general remarks as applied for agriculture are equally valid in this case. In addition, there are the cases where restricted areas are intensively cultivated, such as in greenhouses, for periods of many years, even decades, frequently with a monoculture or biculture (e.g. tomatoes and cucumbers). This implies the addition of large quantities of nutrients such as natural and chemical fertilisers, as well as water. Much of both the water and the fertilisers drain through to below the plant root level, where they are lost for ever. It is possible to recover about half these wasted fertilisers and water under these conditions, before a new greenhouse is constructed. This is done by excavating the site to a depth of about 1 metre minimum, but with a sloping bottom to the fosse which is then lined with a welded polyethylene 2 mm thick sheet. A collector pipe, with a mesh filter, is fixed close to the lowest point (leave a few centimetres for silt collection) and the excess nutritive water is transported to a storage tank for re-use. Stones should be replaced into the bottom of the pit, followed by the excavated subsoil and then the top soil, before the greenhouse is constructed over it. Water and fertiliser consumption can be significantly reduced. Within the greenhouse, each plant can be trickle irrigated. Because excess water is recovered, it is possible to irrigate at more frequent intervals and with more water than would otherwise be economical. Spraying with clean water is occasionally desirable to remove excess dust from the crop fruit. This is not such a catastrophic waste as in the open, as the evaporated water, along with transpired water from the plant leaves, is more or less retained to raise the relative humidity within the greenhouse and to condense as dew on the plants at night. Even some of this will be recovered. Forced ventilation should not be switched on between the time that spraying is started to the following morning. The extreme theoretical limit to this technique — but not practical, it is emphasised — is to have

hermetically sealed "greenhouses" where, once equilibrium has been reached, the only water that needs to be added is equal to that contained in the crops removed from the enclosure (typically 90 per cent of the crop weight).

Market gardeners like to present clean vegetables for sale, as they will fetch higher prices. The housewife prefers to buy clean vegetables, especially root crops. Many producers use flowing water for hand or machine cleaning. Over three-quarters of this water can be recovered for re-use if it is directed to one of two open lined concrete sedimentation tanks of about 2 – 5 tonnes capacity where the silt can settle out. When the silt reaches the level of the exit pipe, the other tank should be put into service, while the silt is shovelled out from the first one. For heavy crops, such as potatoes, the tank capacities may require to be greater and automatic silt removal may be considered.

Industry

The use of water in industry is varied and it is almost impossible to generalise about it. Whole books have been written on the subject as applied to one sector alone. However, it is proposed here to mention a few salient points, illustrated with a few examples. Experts from Protonique SA, including this author, worked in this field for decades.

Without doubt, the largest obstacle to saving water in Cyprus industry is the fact that most of the enterprises are very small and many family businesses are not even registered. They are very frequently under-capitalised and have no resources for installations which will allow water to be recycled. Even those companies which have the financial resources probably could not justify recycling on purely economic grounds. Whether a company is small or large, the capital and running costs of recycling are not very different. The implication is that only industrial enterprises classed as medium or large could, generally, economically justify recycling. However, the equation becomes distorted if waste water quality legislation is very strictly enforced. In this case, the waste water would frequently need to be purified to a degree that recycling may be possible without much extra cost. This could even apply, at times, to small industry.

The five types of pollution in waste water which may require treatment for recycling purposes or for disposal to sewers are the presence of heavy metal or other ions, the correction of acidity or alkalinity, the presence of non-miscible organic materials, the presence of sediments and the presence of poorly-biodegradable dissolved organics.

Without doubt, the most serious type of pollution is the presence of heavy metals. These include relatively benign ones such as tin, but this category also includes the very toxic metals such as arsenic, mercury, lead, antimony, cadmium and many others. Between these extremes, there are moderately toxic metals such as iron, copper and zinc. The presence of these metals are regulated in waste water, but it should be noted that many of them will also halt the bacterial action within septic tanks and sewage treatment works. If water containing these metals is allowed to percolate through permeable rock, some of them may reach water tables which are used for supplying potable water, rendering this water unfit for human consumption. If waste water reaches a dried water bed, dissolved salts will remain, so that the first rains will become so heavily polluted that downstream wild life may be endangered. In addition to metals other similar pollutants such as cyanides, phosphates, nitrates etc should also be removed from waste water.

Heavy metals may enter into water whenever soluble metal salts are present. The most obvious case would be in the rinse water used for cleaning metal parts after electroplating. However, almost any industrial cleaning of metal parts, including electronics assemblies, will pollute water. This includes pickling iron parts before galvanising, removing rust from iron or steel, acidic deoxidation of base metals, removal of brazing or soldering fluxes, and, even to a certain extent, washing cars which will have some metals from the exhaust fumes of other cars adhering to the surface. Similarly, other pollutants may enter into waste water through similar channels.

If the process is electroplating, polymer filtration offers an interesting solution in that the removed metal ions can be recycled back into the original plating bath, at the same time as the water is purified. Apart from the economic advantage, this ensures that there are no waste streams with a more concentrated metal content, producing hazardous waste. Otherwise, ion exchange and reverse osmosis are the most usual ways of reducing metal and other ionic content. Both of these methods produce, sooner or later, concentrated waste streams which are hazardous waste. Precipitation is particularly useful in electroplating applications on a large scale but it produces large quantities of very hazardous sludge which must be recycled to collect the metals; otherwise, they would be dangerous for landfills.

The correction of acidity or alkalinity or, more correctly, the pH is usually done after the removal of other pollutants by the addition of an alkali or an acid until the pH is within the range of 6.0 to 9.0. This can be done entirely automatically. It is usual to monitor the pH of waste water with a strip chart recorder.

Non-miscible organic contaminants fall into two categories: those which are lighter than water, such as oil or petrol, and those which are heavier than water, such as chlorinated or fluorinated solvents. In both cases, they may be removed with the help of a separator whose design must take into account the nature of the pollutant, the speed at which it will separate from the water and the water flow rate.

The method of removing sediments out of waste water will depend on the nature of the pollutant. It is obvious, even to the uninitiated, that a coarse sediment, such as sand, is not the same as a very fine suspended sediment, such as some chemical precipitates. Generally speaking, heavy, coarse sediments will be separated from the water in a settling tank. Finer sediments will require filtration.

Poorly biodegradable pollutants in waste water present difficulties for the bacterial digestion of the water in septic tanks or public sewage treatment systems. If they are present in large quantities, then it may be possible for the digestion to be retarded to such a point that the outflow water will still be considerably polluted and could be dangerous for public health. For this reason, legislative limits must be applied. The method of removal will depend on the nature of the molecule causing the problem. If the molecule itself is very large, such as some soluble polymers, then it may be removed by ultrafiltration. Smaller molecules may be chemically attached to larger molecules which are added to allow ultrafiltration to take place, but this is not universally applicable. Other methods include chemically breaking down the molecule into simpler forms which biodegrade more rapidly or, as a last resort, a large pre-digestion tank will reduce the quantity of poorly biodegradable matter to acceptable amounts.

By combining these methods, it is frequently possible to produce water which is very clean, indeed, and is suitable for recycling. This is of particular interest where the quality of the water required for the process must be very high. In some cases, some useful pollutants may be recovered. For example, in a large hospital with several departments with photographic processes, for record, diagnostic and radiographic purposes, it would be economically justified to pipe the fixer baths to a central treatment unit which would remove the silver and recirculate the treated fixer back to the individual development machines. At the same time, by a similar process, the rinse water would also be treated and sent back to the development machines for recycling. The payback time for such an installation would generally be less than twelve months.

Hotels, Holiday Apartments

It is estimated that about 8,000 to 10,000 tonnes of potable water are consumed daily by hotels situated along the southern coastline of Cyprus, during the high season. These are all situated within reach of a practically infinite amount of water, the sea. Small desalination plants capable of producing a very high quality potable water at a cost of about €1.25 per tonne are available in sizes capable of producing between 50 and 500 tonnes per day. The size of these units is such that they could be placed in the basement of the hotel or in a small prefabricated structure in the hotel grounds. About 40 or 50 strategically placed units could supply the majority of the requirements of the major part of the Cyprus tourist industry, provided that co-ordination between hotels was arranged. Some of the larger hotels could justify their own unit but smaller hotels would have to share a desalination plant between two or three establishments. Obviously, the cost of this water is higher than that which hotels are commonly used to paying but this can be justified when compared with the cost of the water from large desalination plants.

The requirements of the tourist industry are very seasonal and if small desalination plants were scaled to suit the requirements of the high season, a large quantity of surplus water would be produced in the low season. This could be pumped to reservoirs feeding the larger municipalities such as Paphos, Limassol, Larnaka and Ayia Napa. This would reduce the demand on traditional water supplies.

Holiday apartments present a similar situation, in that the demand is largely seasonal, but they have a different infrastructure in that each household is metered separately. If desalinated water from small units was supplied to blocks of holiday apartments, some means of equitable payment would require to be found but this would be best done by the municipalities, as for the traditional water supplies.

In view of the critical situation regarding water supplies, it is suggested that the authorities may consider the installation of such small plants. These could be placed in service within four to six months of ordering, typically one-fifth of the lead time for a major desalination plant, so this is a valid short-term solution. Where such plants are installed by individual hotels on a private basis, consideration may be given to an incentive subsidy and to reduced energy costs in order that the overall costs per tonne of water produced would be comparable to that paid for traditional supplies. Alternatively, the water supplied by the hotel to the municipalities could be purchased at a rate compatible with the same aim.

Regarding the quality of the water supplied by such small units, as has already been stated, this is a high-quality water capable of meeting all standards for both mineral and microorganism content. As

this water is being used as potable water either within or outside the hotel, it is essential that the units be fitted with an automatic shutdown system in the event of something going wrong. Most of the units which are commercially available are already equipped with this feature.

Private Habitations

Many of the possibilities for economising water in private habitations have already been evoked. However, it is still very common to find dripping taps and leaky toilet cisterns in houses which are more than a few years old, it is suggested that a major information publicity campaign offering free replacement of tap washers and similar joints could be organised. It would not be surprising if this produced savings of the order of several hundreds of tonnes per day. The capital cost of materials would be very small and a "tiger-team" could go from village to village on a prearranged schedule. At the same time, toilet cisterns could be fitted with volume-reducing bags. The publicity campaign should include television and radio spots, newspaper advertisements and leaflets showing users exactly how much water can be economised without any reduction in the quality of lifestyle. For example, simple acts like shutting off the water during hand washing or teeth-brushing or using a small plastic bowl rather than the kitchen sink for washing salads can all economise water. Above all, baths should be discouraged in favour of showers, wherever possible.

An important saving can be made in many houses because the plumbing systems are operating at low pressures, from roof height, but they are designed for higher pressures. The throughput of water is therefore low. This means that hot water takes a long time to reach some taps. When taking a shower, it reduces wastage to turn on the hot water alone until it starts to run hot and then to adjust the temperature. The shower heads are also dimensioned for higher pressures and volumes. A much more satisfactory shower, using less water, can be had by reducing the number of holes in the shower head by blocking off alternate ones with, for example, a droplet of epoxy cement. The water will flow in a more discrete series of jets and the reduced flow will be compensated by the pressure within the head itself being increased. Special recirculating pumps are available to ensure hot water is instantly available at all times from all taps. Such an installation is expensive (€300-1,000) but a small subsidy is offered by the government to encourage users to install them. Retrofitting to existing houses is possible but may require some external small diameter pipework.

The implementation of grey water systems should also receive considerable publicity so that the private householder could consider them, as well as roof rain capture, the next time that there is a major structural change to the house.

It is felt that the average householder probably wastes between five and 10 per cent of the water he consumes, possibly amounting to an aggregate of well over 5,000 tons of potable water per day.

Private Gardens

This is a thorny problem. Gardens do need considerable quantities of water, averaging a minimum of some 3 tonnes per hectare per day, or about 150-200 litres per day for a medium sized garden, to keep it green. Stopping this completely could be catastrophic. Some persons are dependent on their garden for fruit and vegetables that they could not otherwise afford. Even the most public-spirited person would resent his garden looking like a brown wilderness after he has spent much time building it up from a stony desert. It is therefore necessary for a minimum of water to be available for every garden owner. As already suggested, private well owners should be allocated a volume they can use at no cost and this should never exceed the 3 tonnes per hectare per day scale, pro rata

for smaller surfaces, less if the aquifer cannot support such extraction. It is suggested that all village and town municipalities offer transported water for gardens at a cost similar to that for potable water, up to allocated volume. The charge of this could be transferred to private enterprises, if such exist in the region. Any requirements for transported water above the allocated volume would be charged at a commercial rate. This water can be derived from non-potable sources and recycled water or small local dams. This would relieve the pressure on illicit use of valuable potable water.

Any rain captured from house roofs and grey water could be freely used, in addition to transported or well water allocated for the surface. This alone could be sufficient incentive to install roof water collection.

Even thornier is the question of private swimming pools. These often hold 100 to 200 tonnes of water, or more for large ones. In addition, there are considerable losses by evaporation, by drag-out during cleaning and by routine maintenance, typically upwards of 1 tonne/day in very hot, dry, windy weather. In some cases, if they are not kept filled, the linings will deteriorate. Alternate wetting and drying of tiles in full sunlight will cause grouting to fall, increasing the cost of maintenance. There is therefore no cut and dried answer to the problem. Until the crisis shows signs of being resorbed, consideration may be given to some form of fiscal help to swimming-pool owners who volunteer to keep it empty, as compensation for the deterioration that may be expected. Conversely, fiscal discouragement may be charged for those who continue to use a pool. As part of this, the Land Registry may charge an extra fee for all immovable property that changes hands with a swimming pool. The question of taxing swimming pools has been raised recently in Parliament. At least, these measures would bring the owners' attention to the problem.

It is suggested that swimming pools be filled and maintained only with transported non-potable water of a quality supplied for gardens, never directly from potable sources, wells or boreholes. This would be an additional sensitisation of the owners towards the fact that water is scarce.

Above all, it should be made mandatory to have a plastic cover over swimming pools at all times when they are not actually in use. This would reduce evaporation. Electrically operate covers are available.

Water Savings

Have the government's appeals to economise water been effective? To some extent, yes! However, at this time, the real answer can only be anecdotal. One village, with a population of about 1,500 may give us a clue. It is a mixed village with everything from old-style houses with no garden, through small houses with a small garden, often paved, to luxury villas with gardens of 1,000 m² or more, some with swimming pools. This village has kept records and its water consumption for April, May and June 2008 fell by 17.9%, compared with the same period in 2007. This, of course, does not take into account water from wells and boreholes (or bottled water!). It is known that some of the boreholes dried out during this period and it is probable that some users made up the shortfall with municipal water. Some of the inhabitants have deliberately stopped irrigating grass lawns, as well as obeying the hosepipe ban. Also, the population of the village has increased by almost 5% during the year. It is felt that this figure of 17.9% is possibly quite representative, pending further information.

In raw figures, the *per capita* consumption of this village is about 160 litres per day. Is this high or low? The World Health Organisation has a minimum recommendation of 100 l/day but anyone who

has experienced living on 100 l/day in modern sanitary conditions will tell you that it is a real minimum, requiring care. 160 l is therefore not excessive, especially as it includes infrastructure use. Can we compare this with other countries? This is difficult because we can never know what is counted in the figure. Elsewhere in Europe, the figures would lie between 120 to 300 l/day but in N. America, some authorities quote more than 600 l/day. If our figure of 160 l/day were representative of the island, then this would seem reasonable, bearing in mind that it is often hotter here than in other parts of Europe.

Recycling and re-use of water

Without doubt, recycling or re-using water can offer very considerable economies. It has been said that the average water molecule entering Chesapeake Bay from the Potomac River has been used seven times, although this may be apocryphal. Nevertheless, it is a very real possibility. One of the greatest obstacles to this in Cyprus is the fact that much of the waste water is disposed of through septic tanks or other small systems of disposal, even into the sea. Ideally, all waste water should be collected as sewage, treated and recycled for some use or another. The obstacle to this is that sewage treatment plants should be sited close to the sea, a perennial river or a large lake, to receive water which has been treated but is unsuitable for re-use. Obviously, perennial rivers and large lakes do not exist in Cyprus. The implication is that sewage plants should be placed close to the sea and sewage piped to them or, if they are sited inland, pipes to the sea will need to be installed for the waste water. The latter may be more economical if water is recycled for any purpose.

Recycling of Water in Raw Sewage

The notion of recycling sewage is often fraught with psychological difficulties. Let it be said from the start that it is perfectly feasible to turn raw sewage into potable water. In many countries, treated sewage is poured into water courses which are used as a source of potable water downstream. Sewage treatment consists of mechanical filtration to remove solid matter which is converted to a sludge. It then passes to a digestion chamber where aerobic acting bacteria convert most of the organic matter to water and carbon dioxide. An anaerobic chamber removes the remaining organic matter by converting it to methane. This process may take two, three or more days. The final stage is usually filtration through a sand bed. The resultant water is clear but may still contain dangerous microorganisms. If it is necessary to recycle to potable water, these microorganisms may be eliminated by chlorination or ultraviolet radiation.

There are two ways in which agriculture may use treated sewage. The sludge which is formed by the collection of solid matter, when fermented, makes an excellent compost with high nitrogen contents. It also contains reasonably high potash and phosphorus levels and may be used for providing humus-rich additives. If the fermentation was correctly achieved, the sludge is without odour if it is supplied in a dried condition – sun-drying may be sufficient, without any energy consumption. It would also be free of weed seeds, such as are common in poorly fermented animal manure. However, the important point is that the water may be used for irrigation with minimal treatment. Generally speaking, spraying the water after the aerobic digestion would provide sufficient oxygen to finish the digestion and the water percolating into the soil will naturally perform the anaerobic digestion, provide nutritive value to the soil and water to the crops. The odour produced by this is usually not objectionable. It is not recommended to spray this water on crops

which are likely to be harvested within two weeks, particularly if the crop is eaten raw, such as salads and fruit.

Swimming pools can be filled with recycled sewage. The quality of the water should be as for potable, except that it is not necessary to kill off microorganisms because the pool's chlorination system will be sufficient.

The great problem in recycling sewage to potable quality is not technical, it is the psychological barrier that most people feel in the idea of drinking sewage. As a general rule, in a large municipal system, 50 to 60 per cent of sewage can be recycled to potable water quality. However, it is important to note that industrial users feeding the plant must adhere strictly to waste water regulations. An excess of heavy metals in the sewage could affect deleteriously the bacterial digestion processes and may render the water unfit for consumption by the presence of toxic ions. It is also possible to recycle sewage to potable quality with small plants, producing 100 to 500 tonnes per day, generally at about the same cost as desalination, but it may require some more space than is required for treating salt water. The process consists of aerobic digestion in a tank with a small quantity of air pumped through, mechanical filtration, microfiltration, single-stage reverse osmosis with automatic declogging and ultraviolet irradiation. This water will be pure enough to drink, but it will require remineralisation to make it more palatable.

In 2008, potable water was supplied to farmers in the Limassol region for irrigation, at the peak of the water crisis. Yet the purified water from the sewage treatment works was discharged into the sea because the farmers preferred the purer water. This illustrates the problems of persuading people that recycled water is as good as drinking water (in this case even better, because it still had some nutritive value). Perhaps it may have been a good idea to tell the farmers that only recycled water would be supplied to them!

One thing that is essential is that a great effort should be made to connect as many villages as possible to sewage systems, covering wide areas, with suitable treatment plants. This would have a threefold advantage:

- Cyprus would conform to EU regulations
- more water would be available for recycling
- there would be less microbial infiltration into aquifers, providing more potable water from boreholes.

Grey Water

Grey water is a means of reducing the consumption of water in households, other living quarters such as hotels and a few types of industry such as laundries. In households, it may reduce water consumption by 50 per cent. Water which is used for washing (wash-hand basins, baths, showers, clothes washing machines and dishwashers, but not kitchen sink or toilets) is collected in a separate system. This "grey" water, so called because of its cloudy aspect, can be used for filling lavatory cisterns and for irrigation, after filtration. Experience in many countries has proven its efficacy. There is a slight psychological adjustment to be made, because we are not used to seeing cloudy water in toilet bowls, but this is quickly made. It requires major alterations to fit a grey water system to existing houses but the additional cost in new buildings represents a very small investment. In countries where it has been made obligatory for new constructions and where the components are

cheap, the extra cost is typically of the order of a few hundred dollars. It has the added advantage that the excess water can be used for irrigating the garden and the presence of detergents and soap has been proved to be beneficial to plant life. Legislators may consider the advantages of including a compulsory grey water system in all new and renovated constructions, in much the same way as houses must be constructed to anti-seismic standards.

Where houses are connected to a municipal sewer, grey water systems will reduce the volume and increase the concentration of waste. This will render the digestion of the sewage in the public treatment plant more efficient. In the case of connection to a septic tank, the reduced volume will render the displacement of nauseous gases from the ventilation system less likely.

Grey water systems may be easily combined with rain water collection from the roof of a building. This will significantly reduce the cost of separate systems and will also have the advantage that the grey water would be diluted by the rain water, permitting the water in the toilets to be clear for much of the year.

Legal requirements and policing

In 2008, we have seen some regulations promulgated, including the ban on the use of hosepipes for cleaning verandas, washing cars and watering gardens, etc. A minority of the population have totally ignored these measures and it is not unusual to see hoses being used illegally, despite the risk of fines. This shows that the only way to enforce this is repression, but how?

There are many suggestions in this site that currently have no legal base by which they can be implemented. The water situation as we enter into 1999 — or 2009 — constitutes a contingency that justifies new legislation for the state of emergency. This should be conjoined with heavy sanctions against anyone found to contravene this new and existing legislation regarding water, during the emergency.

Of course, no laws are useful if they cannot be enforced. The police have their hands full with more serious matters than to check whether water is being used correctly. The "tiger-teams" mentioned previously could be made up of sworn officers with the technical requirements to fulfil their primary duty but with also the power to denounce major violations and to impose on-the-spot penalties for minor ones, naturally with a right of appeal.

Of course, the most severe penalty for the misuse of water is to have the water cut off for a period and force the user to carry water into the house from a standpipe. After a month of that, it is pretty sure that the garden will no longer be watered with a hosepipe!

One point that should not be ignored: water is water, no matter where it comes from, and there is only a limited quantity on the island. It makes no difference whether it comes from a well, a borehole or a municipal supply. It is all water from the rain that falls on Cyprus and must be treated in exactly the same way. It is not an excuse to wash the road outside the house and say it comes from one's own well.

Glossary

The following table defines some of the more technical terms used in this document.

Aerobic	describes a process requiring oxygen to work
Alluvium	deposits brought down by rivers. Initially, alluvium is often a clay, sand or fertile marl but, in time, can compress into a frequently impermeous rock
Anaerobic	describes a process where oxygen must be excluded
Aquifer	a permeable layer of rock which has water flowing within it, forming a water table
Flash distillation	a method of purifying water by pumping it at a medium temperature into a partial vacuum chamber, causing it to "flash" into steam which is then condensed. It can be done over a number of stages and the heating of the water may be solar.
Hard water	water rich in calcium or magnesium salts which form a scum with soap
Heavy metal	there is no formal definition, but is generally considered as metals with an atomic weight of more than about 44
Hydrology	the study of underground water, its flow and its exploitation
Igneous rock	rock which is formed from some volcanic action, e.g. basalt, pumice, pillow lava
Ion	an electrically charged particle, dissociated when a salt is dissolved in water, e.g. when table salt dissolves, it dissociates into positive (cation) sodium ions and negative (anion) chlorine ions.
Ion exchange	a method of water purification whereby dissociated ions from salts in water are replaced by hydrogen and hydroxyl ions which combine to form pure water.
Metamorphosis	a process where the structure or chemical nature of a rock changes with age, pressure or temperature e.g. limestone changing into marble
Microorganism	any living matter of microscopic size, including viruses, bacteria, amoebae etc. Although many microorganisms in water are dangerous to human health when drunk, even fatal, there are many others which are not.
Osmosis	the passage of water from a purer quality to a saltier quality through a semi-permeable membrane, such as organic tissue.

Phreatic	describes water within an aquifer, which may be pumped to the surface by a borehole
Phytoplankton	the smallest vegetable microorganisms which form the lowest member of an aquatic food chain.
Potable	describes water which is both palatable and safe to drink
Reverse osmosis	a method of water purification whereby water containing impurities (such as salt) is forced through a semi-permeable membrane by high pressure: requires much energy.
Sedimentary rock	rock which is formed by the compression of deposited silt, sand, organic matter or shells, e.g. chalk, limestone, sandstone
Soft water	water low in calcium and magnesium hydroxides and carbonates but which may contain other salts
Vadose	describes underground water flowing through fissures in impermeable rock
Water softening	a method whereby calcium and magnesium ions, dissolved in hard water, are replaced by sodium ions. This is not a purification but a change in chemical composition to prevent scum formation in the presence of soap.