ULTRA-VIOLET (UV) TREATMENT OF IRRIGATION WATER AT FARM LEVEL TO REDUCE MICROBIAL CONTAMINATION FOR IMPROVED FOOD SAFETY

Volume II: Guidelines and recommendations for the cost feasibility estimation of UV treatment of irrigation water

Report to the
Water Research Commission

by

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WRC Report No. 2965/2/23

ISBN 978-0-6392-0548-9

November 2023

Obtainable from
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This is the second in a set of two reports. The other report is Ultra-violet (UV) treatment of irrigation water at farm level to reduce microbial contamination for improved food safety, Volume I: Laboratory-scale collimated beam and Pilot-scale UV treatment dose responses of selected indicators and specific food pathogens present in various irrigation water sources and screening of environmental isolates for antimicrobial resistance (WRC Report No. 2965/1/23)

EXECUTIVE SUMMARY

BACKGROUND

The poor microbial quality of many South African rivers is an undeniable threat to consumer health. Previous and current research (as discussed in Chapters 1 and 2) has highlighted the continuing deterioration of the microbial quality of South African surface waters. Various sources of pollution, both of point source and non-point source origin, have been reported, and include, among others, the poor state of municipal wastewater treatment facilities across South Africa. The recent Green Drop Report (DWS, 2022) furthermore emphasises the fact that a very limited number of WWTP's function properly, which implies that improperly treated wastewater is released into the environment on a daily basis in the South African context. This is concerning from both a food security and food safety perspective, as most of South Africa's irrigation water is sourced from surface waters. The potential health implications this could have for the consumers of fresh produce urgently warrants some form of water treatment prior to crop irrigation, to prevent pathogens from entering the food distribution chain. Disinfection of surface water prior to agricultural irrigation has thus become a necessity rather than a choice, given the current South African context.

A variety of water treatment methods have been used in the past, of which the most commonly used ones are of a chemical nature. As concerns rise regarding the environmental impact, and detrimental health effects of disinfection byproducts, the advantages of residue-free UV-based disinfection become apparent. It is, however, not without its challenges and it is against this backdrop that the previous scoping study (Sigge et al., 2016), as well as the current project have been undertaken. The technology has its limitations, and certain knowledge gaps were revealed which included the following:

- The previous scoping study (WRC Report No. 2174/1/16) focussed only on the effect of UV irradiation on the levels of *E. coli* (< 1000 cfu.100 mL^{-1}) (WHO, 1989; DWAF, 1996) in river water. Other important food pathogens linked to fresh produce outbreaks, such as *Salmonella*, *Listeria monocytogenes* and Shiga toxin-producing *E.coli* (STEC), might, however, also be present in river water. Further research into the efficacy of UV disinfection on these pathogens is warranted.
- One of the limitations of the previous scoping study was that the effect of water quality on the UV treatment of river water was previously investigated using water from one site only. Fluctuations in water quality and composition (measured with quality parameters such as UVT%) could impact UV treatment efficacy, and this critical knowledge area should be expanded by including different river water sources.
- The effect of water quality on photo reactivation and dark repair of microbial populations after UV treatment, and how recovery can be minimised by increased UV dosages should be considered.
- Make recommendations as to expanding current guidelines pertaining to the microbiological quality of irrigation water for fresh produce, over and above the faecal coliform guideline levels;
- To provide practical guidelines around implementation costs (capital and operational) that should be considered for full-scale UV treatment of river water prior to irrigation.

AIMS AND OBJECTIVES OF THIS STUDY:

The purpose of the current project was thus to address the issues listed above, and expand the existing body of knowledge by formulating the following separate and specific aims:

Chapter 4.1 The aim of this study was to determine how specific microbial populations (including Heterotrophic plate count (HPC), Total Psychrotrophic Aerobic counts (TPACs), *Enterobacteriaceae* populations, as well as *E. coli* naturally present in river water (from four different sources) responded to three different doses of UV radiation (20, 40 & 60 $mJ.cm^{-2}$). The presence of specific pathogens (STEC, *Salmonella* and *Listeria monocytogenes*) was also determined before and after UV irradiation treatment. This was done in order to establish the dose response information of the selected microbial populations. In addition, some of the bacterial strains present after UV radiation were isolated and identified to ascertain the potential risk to the consumer. The antimicrobial resistance of the environmental isolates to a limited number of antibiotics were also determined as part of this study.

Chapter 4.2 The aim of this study was to determine the recovery potential of specific food pathogens and microbial populations in water after UV-C treatment. This was done to establish which UV dose would decrease the recovery ability of the selected microbial populations most.

Specific objectives included:

- Comparison of UV susceptibility of six environmental isolates and reference strains to three UV doses in a collimated beam device.
- Comparison of microbial recovery, under light and dark conditions, of selected strains after three different UV doses in three different sterile water matrices in a collimated beam device.
- Comparison of microbial recovery, under light and dark conditions, of certain microbial populations (naturally present in river water) after UV treatment in a collimated beam device.

Chapter 4.3 The aim of this study was to determine the disinfection efficiency of a pilot-scale, medium pressure UV-C system treating larger volumes of river water (from different sources), with a single UV radiation dose (1 x 20 $mJ.cm^{-2}$), a double (2 x 20 $mJ.cm^{-2}$) or triple (3 x 20 $mJ.cm^{-2}$) UV radiation dose.

- The first objective was to establish the efficacy of the UV system by comparing microbial loads present before and directly after each of the UV treatments.
- The second objective was to determine the recovery potential of microbial populations naturally present in river water by comparing microbial loads directly after UV treatment with samples that had time to recover for three hours after different UV treatments. Both objectives were tested as part of two studies (Study 1 and Study 2) conducted in 2021 and 2022.
- The third objective was to isolate and identify surviving colonies after UV treatment AND recovery and comment on the health risk these isolates may have for consumer health.

Chapter 4.4 Antimicrobial resistant microbes in general, and extended spectrum beta lactamase (ESBL) producers in particular, pose a threat to human health globally. In this study it is of particular interest as ESBL positive isolates have been identified in the rivers included in this project (Mosselbank, Eerste, Plankenburg and Franschhoek rivers)

(Oosthuizen, 2022; Chapter 4.1, Tables 4.1.16 and A1). Thus, while the presence of ESBL-producing microorganisms in the above-mentioned rivers has been investigated and reported on in previous chapters, more in-depth antibiotic susceptibility profiles have not yet been established. This study therefore aimed to expand on the work performed by Oosthuizen (2022) and Jankowitz (In press) included in previous chapters and determine the extent of the antimicrobial resistance observed. This was done by extensively testing antibiotic resistance of river isolates to 19 antibiotics: ampicillin, amoxicillin/clavulanic acid, cefalexin, cefalotin, cefpodoxime, cefovecin, ceftiofur, imipenem, amikacin, gentamicin, neomycin, enrofloxacin, marbofloxacin, pradofloxacin, doxycycline, tetracycline, nitrofurantoin, chloramphenicol, trimethoprim/sulfamethoxazole, using the Vitek® 2 compact system.

GENERAL CONCLUSIONS

In order to fill the knowledge gaps previously identified various iinvestigations (summarised in Chapters 4.1, 4.2 and 4.3) included testing for the presence of *Listeria monocytogenes,* STEC and *Salmonella* spp. before and after UV treatment. UV resistance profiles and recovery potential of isolates obtained from the rivers were also tested (Chapters 4.2 and 4.3), and included antimicrobial resistance testing (Chapters 4.1, 4.2, 4.3 and 4.4). Lastly, by moving from an LP laboratory-scale UV system (Chapters 4.1 and 4.2) to a pilot-scale MP UV system (Chapter 4.3) this study intended to fill knowledge gaps and contribute towards the successful future application of UV radiation in irrigation water treatment at farm-scale.

Findings related to the physico-chemical and microbial profiles of rivers

As the previous scoping study (Sigge et al, 2016) evaluated aspects of UV disinfection while focusing on water from only one site, this project aimed to evaluate the efficacy of UV radiation – both at laboratory-scale and pilot-scale – on a variety of river water sources of varying water qualities. Based on irrigation water guidelines (summarised in Section 3.1, Chapter 3), the previous scoping study and other research (Sigge et al., 2016; Banach et al., 2021) have focused mainly on *E. coli* as indicator organism for UV disinfection efficiency. This is in spite of the fact that a number of other pathogens can be associated with contaminated fresh produce and cause disease (as discussed in Chapter 2). The effect of UV on important food pathogens other than *E. coli* was thus an important aim of this project. Including this research aim in the project was well justified considering the findings that related to the presence of specific pathogens in river water samples during the course of this study. Evidence of the presence of *Salmonella*, *Listeria monocytogenes*, ESBL positive strains and *E. coli* (>3 log CFU.mL^{-1}) and STEC was found (as summarised in Table 5.1).

The motivation to include other river water sources in this study was also based on the findings of the previous study which reported fluctuations in the physico-chemical nature of river water quality over time at the same site. This observation was also confirmed by the results of the current project. UVT% is an important parameter to consider in UV-irradiation applications, and if the results of this project over time are considered (as summarised in Figure 5.1), it is apparent that substantial variations occurred in UVT% over time at the different sites included in this project (Figure 5.1).

As highlighted in Figure 5.1 (and in Chapters 4.1-4.3), the Mosselbank river consistently had the poorest UVT%, compared to the Franschhoek river, which had the best UVT% profile. The causes for the poor quality observed at the Mosselbank site – both in terms of physico-chemical profiles and microbial risks (Table 5.1) have been discussed in detail (Chapters 4.1-4.3, Bursey, 2021; Oosthuizen, 2022) and could be directly related to the WWTP situated upstream of the sampling site, which is not unique in the South African context (Green Drop Report, 2022). What should be noted, though, are the variations in UVT% observed at the three "better" sites over time. If these variations are compared UVT% values reported in literature for water in other countries (Table 5.2), and how UVT% values should be classified (Table 5.3), it can be concluded that at some sampling occasions during the course of this project, water from all four sites could have been classified as similar to a standard of secondary wastewater effluent (UVT% equal to 60% and lower). This brings with it certain design requirements for wastewater (USEPA, 1999) that should be considered in large-scale UV installations treating river water in the South African setting.

Findings related to UV treatment efficacy

Considering the poor UVT% values observed in this study, the addition of pre-treatments is also a possibility, but it does inevitably add to the total cost of treatment and might also have additional environmental impacts. The only pre-treatment included as part of the pilot plant UV treatment done in this study was 5 µm bag filtration (Chapter 4.3, Appendix D). It has however, been demonstrated in other research (Cantwell & Hoffmann, 2008) that UV disinfection of unfiltered surface waters, although partially inhibited, still lead to significant reductions in coliform levels.

In agreement with the findings of Catwell & Hoffmann (2008) significant reductions in microbial indicator levels were observed throughout this project, for UV doses up to 60 $mJ.cm^2$ in both the LP UV and the MP UV-based studies in spite of the varying UVT% levels observed. In addition, UV treatments could also successfully inactivate *Listeria monocytogenes* and *Salmonella* at the levels that they were present in the river water samples. Molecular detection of STEC also did not show any presence after UV treatment. Laboratory studies on the UV susceptibility of pure *Salmonella* (Chapter 4.2) did reveal that it might be more prone to recovery post-UV than *L. monocytogenes*.

It has also been demonstrated that certain bacteria can survive and recover post-UV after the doses applied (20-60 $mJ.cm^2$) (Chapters 4.1-4.3). Identification and characterisation of the strains has revealed the presence of opportunistic pathogens and strains that carry a wide range of antimicrobial resistance (AMR) determinants, even to critically important antibiotics (Chapter 4.1-4.4). The latter is a great concern, as this study provides further proof of the rapid spread of AMR within the South African aquatic environment.

Treatment cost considerations and implications

It is clear from the results presented throughout this project that UV-C treatment of irrigation water is an efficient treatment technology to reduce microbial contamination in the water. It has, however, also become clear (and this is stated in the relevant literature also) that there are several factors which influence the efficiency of the UV disinfection process. Many of the parameters are interlinked to varying degrees, but measurement of only a few parameters is often not enough to make an informed decision.

The parameters which affect the UV efficiency are as follows:

1) UV Transmittance (UVT%)
2) Total Suspended Solids (TSS)
3) Total Dissolved Solids (TDS) and/or Electrical Conductivity (EC)
4) Turbidity
5) Alkalinity & pH
6) Anions and Cations
7) Chemical Oxygen Demand (COD)
8) Microbial population
9) Flow rate and flow type
10) Water Guidelines or Targets
11) Geography on site
12) Manufacturer and reactor design

Recommendations:

From the discussion in the WRC Report: *Ultra-violet (UV) treatment of irrigation water at farm level to reduce microbial contamination for improved food safety, Volume II - Guidelines and recommendations for the cost feasibility estimation of UV treatment of irrigation water*, the following information, without which an accurate estimation of cost cannot be made, should be gathered and supplied to reputable UV installers to be able to quote on a UV disinfection system for irrigation water treatment:

- Full description of the current (or required) irrigation system, including:
    - Pumps sizes and power ratings
    - Filtration equipment specifications
    - Pipe lengths and diameters
    - Head pressures
    - Flowrates required/used during irrigation
    - Hours of operation

- Full physico-chemical analysis of the irrigation water (covering seasonal variations) including:
    - UV Transmittance (UVT%)
    - Total Suspended Solids (TSS)
    - Total Dissolved Solids (TDS) and/or Electrical Conductivity (EC)
    - Turbidity
    - Alkalinity & pH
    - Anions and Cations
    - Chemical Oxygen Demand (COD)
- Full microbiological analysis (covering seasonal variations) including:
    - Coliforms
    - Faecal coliforms or *E. coli* (indicator organisms)
    - Pathogens of interest (*E.coli*, *Salmonella*, *Listeria* or others)
- Target reduction required (a decision is needed as to which organism/s are selected as the target reduction organism, and what reduction is required (e.g. 3 log reduction)

The full discussion and explanation of the above recommendations can be found in the WRC Report: *Ultra-violet (UV) treatment of irrigation water at farm level to reduce microbial contamination for improved food safety, Volume II - Guidelines and recommendations for the cost feasibility estimation of UV treatment of irrigation water*

PROPOSALS FOR FUTURE RESEARCH

The potential threat that UV surviving strains entering the fresh produce food chain holds for the consumers of fresh products does, however, depend on a variety of factors. These factors do, for instance, include the microbes' ability to attach and form biofilms in irrigation water distribution systems and on plant surfaces. This is an area that warrants urgent further research within the South African agricultural production chain.

Considering the impact that the Mosselbank river's poor quality had on results, it is recommended that the impact of municipal wastewater treatment plants (WWTPs) on both the South African environment and human health be investigated further. These WWTPs can facilitate the spread of AMR phenotypes in the environment by two means: 1. Through the discharge of diluted antimicrobials not fully metabolised by the human body; 2. Through the discharge of resistant bacteria not removed during the water treatment processes. Diluted antimicrobials in the environment can further select for resistant environmental strains as it is not present at lethal concentrations. UV disinfection leaves no residue and would be the treatment method of choice for disinfection before discharging WWTP effluent into the environment. A very important consideration would however be humic substances, which are naturally present at high concentrations in faecal matter, and in the resultant effluent. These substances have very high UV absorption characteristics and can interfere with UV treatment efficacy. The true impact it may have on South African rivers in general, and on the UV technology implementation in particular, need to be determined.

Lastly, as mentioned in the literature, LED-based UV treatment is a new field of research which aims to address some of the most important practical issues associated with UV lamps by: 1. lowering energy requirements by using LED-based lamps; and 2. replacing the mercury-based UV lamps with more environmentally friendly alternatives. Given the current energy crisis, further research in the application of UV-LEDs in the disinfection of river water in the South African context is justified.

CAPACITY BUILDING AND PRODUCTS

This WRC Project has culminated with the completion of four MSc projects and two WRC Reports.

Capacity Building:

1. Caroline Rose Bursey (MSc in Food Science - graduated March/April 2021)

Thesis title: CHARACTERISING THE MICROBIAL PROFILES OF VARIOUS RIVER SOURCES AND INVESTIGATING THE EFFICACY OF UV RADIATION TO REDUCE MICROBIAL LOADS FOR IMPROVED CROP SAFETY

2. Marco Oosthuizen (MSc in Food Science - graduated March/April 2022)

Thesis title: THE QUEST FOR SAFE IRRIGATION WATER: INVESTIGATING UV IRRADIATION TREATMENT OF RIVER WATER TO REDUCE MICROBIAL LOADS

3. Corani Jankowitz (MSc in Food Science – In process)

Thesis title: SURVIVAL POTENTIAL OF FOOD PATHOGENS IN RIVER WATER AFTER UV-C IRRADIATION TREATMENT

In process – Estimated graduation date: December 2023

4. Margot Küster (MSc in Food Science – In process)

Preliminary thesis title (still to be finalised): THE IMPACT OF UV ON ANTIBIOTIC RESISTANT BACTERIA FROM RIVER WATER

In process – Estimated graduation date: December 2023

Products (WRC Reports):

1. Ultra-violet (UV) treatment of irrigation water at farm level to reduce microbial contamination for improved food safety, Volume I: Laboratory-scale collimated beam and Pilot-scale UV treatment dose responses of selected indicators and specific food pathogens present in various irrigation water sources and screening of environmental isolates for antimicrobial resistance
2. Ultra-violet (UV) treatment of irrigation water at farm level to reduce microbial contamination for improved food safety, Volume II: Guidelines and recommendations for the cost feasibility estimation of UV treatment of irrigation water

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the Water Research Commission for initiating and funding the directed project (WRC K5/2965//4) and to the Department of Agriculture, Land Reform and Rural Development for co-funding.

The authors would like to thank the Reference Group of the WRC Project K5/2965//4 for the assistance and the constructive discussions during the duration of the project:

Dr SN Hlophe-Ginindza	Water Research Commission (Chair)
Prof NS Mpandeli	Water Research Commission
Dr L Nhamo	Water Research Commission
Dr E du Plessis	University of Pretoria
Prof O Fatoki	Cape Peninsula University of Technology
Dr WM Gitari	University of Venda
Ms N Mjadu	Department of Agriculture, Land Reform and Rural Development
Dr N Moyo	University of Limpopo
Dr MM Rapatsa	University of Limpopo
Prof S Schmidt	University of KwaZulu-Natal
Mr P Thompson	Umgeni Water
Mr E van der Walt	Agricultral Research Council
Mr F Rabothata	Department of Agriculture, Land Reform and Rural Development
Mr E Mametja	Department of Agriculture, Land Reform and Rural Development

The authors would also like to thank organisations, companies and individuals who gave inputs through personal communication, suggestions and advice, additional funding, and allowing sampling on their premises or by commenting on documents and workshop results.

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1. TREATMENT COST CONSIDERATIONS AND IMPLICATIONS

1.1 Introduction

It is clear from the results presented throughout WRC Report K5/2965//4 -*Ultra-violet (UV) treatment of irrigation water at farm level to reduce microbial contamination for improved food safety, Volume I: Laboratory-scale collimated beam and Pilot-scale UV treatment dose responses of selected indicators and specific food pathogens present in various irrigation water sources and screening of environmental isolates for antimicrobial resistance* that UV-C treatment of irrigation water is an efficient treatment technology to reduce microbial contamination in the water. It has, however, also become clear (and this is stated in the relevant literature also) that there are several factors which influence the efficiency of the UV disinfection process. Many of the parameters are interlinked to varying degrees, but measurement of only a few parameters is often not enough to make an informed decision.

The parameters which affect the UV efficiency are as follows:

1) UV Transmittance (UVT%)
2) Total Suspended Solids (TSS)
3) Total Dissolved Solids (TDS) and/or Electrical Conductivity (EC)
4) Turbidity
5) Alkalinity & pH
6) Anions and Cations
7) Chemical Oxygen Demand (COD)
8) Microbial population
9) Flow rate and flow type
10) Water Guidelines or Targets
11) Geography on site
12) Manufacturer and reactor design

UV Transmittance (UVT%) is generally regarded as the parameter of choice in deciding if UV treatment will be feasible. The higher the UVT%, the better the penetration of UV into the medium. It is generally accepted that UV efficacy increases with an increase in the UVT%. This research project has, however, shown that it is not always that simple. Other parameters also need to be measured to make a more informed decision. UVT% is affected by some of the other parameters listed such as, TSS, TDS, Alkalinity and COD. Some of these parameters are also interlinked as components of TSS, TDS and Alkalinity could also contribute to the COD. It is difficult to make direct correlations such as: if the UVT% is low, then TSS or TDS or COD will be high this can be the case, but is not necessarily always so.

Total Suspended Solids (TSS) is often directly linked to UVT%, but as has been seen in this project, the TSS can be low, but if the TDS is high then the UVT% will also be low. The TSS is an important parameter as it can reduce the UV% in general, but can also specifically shield bacteria if they are attached to the TSS. The type of compounds contributing to the TSS can thus also affect the UVT% to varying degrees (i.e. similar TSS values could have different effects on the UVT% and even on the shielding of the bacteria).

Total Dissolved Solids (TDS) also affect the UVT% negatively, but it also seems from the results in this project that the correlation is not linear. It is therefore important to not only monitor TSS, but also TDS. It seems that at very high TDS values (> 450 mg.L^{-1}) the negative effect is increased. TDS is directly correlated to Electrical Conductivity (EC) and values can be converted with the aid of specific conversion factors. It is, however, sometimes worthwhile to determine the anion and cation concentrations in water samples, as this can help identify pollution sources (as was seen in Chapter 4.3. in the Mosselbank river. In the case of the Mosselbank river, the excessively high TDS concentrations correlated with very low UVT% values. Whereas TSS values can often be lowered to some extent by filtration, lowering TDS in water can be much more complicated, often requiring either distillation or reverse osmosis. Both of these options are expensive.

Turbidity, measured in NTU, is often compared to TSS, but they are not always directly correlated. A low Turbidity (i.e. a sugar solution) can have a low UVT%. If UVT%, TSS and TDS are measured, turbidity measurement if most likely not necessary, but it can be a good parameter to measure.

Alkalinity (or the buffering capacity of water) and pH may play a role in negatively impacting treatment, as an increased pH may result in dissolved metals precipitating out of solution, leading to an increase in turbidity, and a subsequent decreased inactivation efficacy (Farrell *et al.,* 2018)

The **COD** provides an indication of the level of organic pollution within a water sample. Total organic carbon and phenols contribute to the absorption coefficient of water. TSS and TDS can both also contribute to the COD of the water and since both organic and inorganic compounds are able to absorb UV light in water, it is important to also monitor this parameter in irrigation water.

The **flow rate and type of flow** will also impact the UV disinfection efficiency. Flow rate has a direct correlation to the UV dose that can be applied at a specific UVT%. If the flow rate decreases then the UV dose would increase and vice versa (if all other parameters remained constant). The type of flow in the UV reactor (laminar vs turbulent) will also influence the UV efficiency and will differ slightly from one manufacturer to another, but this difference should be nullified by the **design** which should be such that it delivers a verified dose to the water passing through the reactor. It is generally accepted that turbulent flow is more efficient, but this efficiency could change with changes in the UVT%. Designing a system to achieve specific flow rates (this will depend on the amount of water to be irrigated in a specific period of time) will need to take into account the head pressure required, distance to be pumped and pressure required at the point of irrigation. This will impact the costing of the system, as this will be **site geography** specific. Some sites may be able to make use of gravity feed, whereas others will need to pump water uphill.

The make-up or composition of the **microbial population** will also have an impact on the UV efficacy, as has been repeatedly shown throughout this project. Certain bacteria are more resistant or sensitive to UV disinfection than others, while some even have the ability to repair some of the damage caused by UV. As mentioned before, several guidelines only specify Coliforms and *E. coli*, but not specific pathogens, ESBL producers or other microbes (Protozoa or viruses). Therefore, it is imperative that the water source be tested regularly to establish a better understanding of the microbial population and their numbers, that have to be reduced by the UV treatment. A target logarithmic reduction is usually one of the design parameters required in designing a UV disinfection system. merely applying the guideline target of *E.coli* for instance, may not render a water safe to use as irrigation water, if it still contains pathogens or organisms of concern at levels which could result in foodborne disease.

Usually, the first step in sizing a UV disinfection system is to ensure that three parameters are known, namely UVT% of the water, the flowrate at which the water needs to be treated and the **target reduction** required. Initially that seems a fairly easy exercise – measure the UVT% of the water, provide the flowrate and the desired target reduction.

The flowrate is probably easy to provide as one would have an idea of the rate at which water needs to be irrigated. But, achieving that flowrate will be very site specific as explained above – size of pumps, head pressures etc.

Measuring the UVT% of a water sample is quite easy also, but as we have seen the UVT% can change over time (sometimes quite rapidly) and the UVT% is also affected differently by other parameters such as TSS, TDS, COD, etc. Thus, UVT% and these other parameters should ideally be monitored over time to provide an average water quality breakdown to work with.

Lastly, the target reduction that is required is more complicated. This is will depend on which organism is selected and what the target reduction is (i.e. 3 log). The organism selection is the complicated part, as it has been shown that the populations in irrigation water differ, their numbers differ and the total numbers differ over time. Even though a decision can be made to administer a very high dose to ensure that a large variety of organisms are reduced by a specific log reduction target, all the other parameters must be kept in mind to be able to consistently administer that dose (i.e. UVT% and flow rate).

Hence, it is very difficult to provide cost implications without undertaking a site-specific analysis of all the pertinent parameters.

A simplified cost estimation, using only flow rate, UVT% and applied UV dose is given below in Table 5.1, to give an indication of the cost, but also of the effect UVT% has on cost. This cost estimate is solely for the UV disinfection unit (excluding any pumps, pre-filtration, piping, irrigation sprayers, etc.)

Table 1.1 Comparison of estimated costs of UV disinfection systems taking only set UV dose, flow rate and UVT% into consideration

UV dose	Flow rate ($m^3.h^{-1}$)	UV Transmittance (%)	Estimated Cost
60 $mJ.cm^{-2}$	10 $m^3.h^{-1}$	45	R455 000*
		75	R250 000**
60 $mJ.cm^{-2}$	50 $m^3.h^{-1}$	45	R690 000***
		75	R455 000*
60 $mJ.cm^{-2}$	200 $m^3.h^{-1}$	45	R1 595 000[&]
		75	R650 000[&&]

*Based on a Berson/Hanovia/Aquionics WW Proline IL 250

** Based on a Berson/Hanovia/Aquionics WW Proline IL 100

*** Based on a Berson/Hanovia/Aquionics WW Proline IL 1250

[&]Based on a Berson/Hanovia/Aquionics WW Proline IL 7500

[&&]Based on a Berson/Hanovia/Aquionics WW Proline IL 400

Cost estimates are only for the UV disinfection unit, thus excluding pumps, pipes, pre-filtration, etc. which would be different for

Cost estimates at August 2022 exchange rate with the Euro.

Furthermore, if we assume scenario of 60 $mJ.cm^{-2}$, 10 m^3/h^{-1}, UVT% = 45, 200 days of operation for 8 hours per day and an electricity tariff of R2.72 (this can vary) then the following cost applies:

200 d x 8 h/d^{-1} x 5.6 kW (max. energy consumption of WW IL 250) x R2.72 = R24 371 for 16 000 m^3 or R1.52/m^3

The above cost would have to be added to the overall cost of irrigation based on equipment CAPEX costs (pumps, pipes, UV unit, irrigation equipment, filters etc.), other irrigation operational costs (electricity consumption of pumps, labour, maintenance, etc.).

There are also other factors which would influence this UV treatment cost estimate (R1.52/m^3):

- If the UVT% of the water changes, the UV units are dimmable and then the power consumption would decrease and vice versa. Too large an decrease in UVT% will also potentially lower the UV dose that can be achieved
- The time of day of operation will change the electricity tariff being charged, which will later the cost
- Use of solar energy to power the units would also alter the operational cost

1.2 Recommendations

Taking all the above into account, the following information should be gathered and supplied to reputable UV installers to be able to quote on a UV disinfection system for irrigation water treatment:

- Full description of the current (or required) irrigation system, including:
    - Pumps sizes and power ratings
    - Filtration equipment specifications
    - Pipe lengths and diameters
    - Head pressures
    - Flowrates required/used during irrigation
    - Hours of operation
- Full physico-chemical analysis of the irrigation water (covering seasonal variations) including:
    - UV Transmittance (UVT%)
    - Total Suspended Solids (TSS)
    - Total Dissolved Solids (TDS) and/or Electrical Conductivity (EC)
    - Turbidity
    - Alkalinity & pH
    - Anions and Cations
    - Chemical Oxygen Demand (COD)
- Full microbiological analysis (covering seasonal variations) including:
    - Coliforms
    - Faecal coliforms or *E. coli* (indicator organisms)
    - Pathogens of interest (*E.coli*, *Salmonella*, *Listeria* or others)
- Target reduction required (a decision is needed as to which organism/s are selected as the target reduction organism, and what reduction is required (e.g. 3 log reduction)

The design of any UV disinfection treatment system should thus take the above into account to provide a realistic, fact-based cost estimation for each specific site.