Rolling literature review on pathogen reduction by water treatment processes

Patrick W.M.H. Smeets, *KWR Watercycle Research Institute, Nieuwegein, The Netherlands; Karl Linden, University of Colorado, Boulder, USA; Ulf Miehe, Kompetenzzentrum Wasser Berlin (KWB), Berlin, Germany*

Water treatment to manage risks of water reuse

Water that is contaminated with pathogenic microorganisms can lead to spreading of contagious diseases. Reuse of municipal wastewater for drinking water production or irrigation and reuse of water in the food industry are clear examples of such risks. Water treatment is generally required to provide safe, fit for purpose water. To design adequate treatment, often a quantitative microbial risk assessment (QMRA) is carried out with the aim to meet health based targets expressed as risk of infection or disability adjusted life years (DALY). Based on the level of pathogenic microorganisms in the water source and their reduction by treatment, the concentration in the treated water can be calculated. Then the exposure and health effects of various applications and exposed persons can be simulated. The presented work focuses on providing state of the art knowledge on pathogen reduction by treatment in this context.

Rolling literature review

There are many scientific studies on the effect of water treatment on pathogens. Each focuses on a different microbial pathogen, treatment process or water matrix. Incidentally a review study is carried out that combines results from various of these studies to reach more generic conclusions. These may lead to concise overview tables such as the Table 7.7 in the WHO Guidelines for Drinking Water Quality (WHO 2017). However such reviews are rapidly outdated, as new scientific studies are published. Also a lot of information is lost when reducing all the data into a basic table. Therefore a rolling literature review was initiated that allows continuous updating of the underlying data and provides access through a web tool that allows selection and interpretation of the data. This allows users to quickly select the data that is most relevant for their situation. Since the original publications are all listed with the selected data, the information source is transparent and users can refer back to the original publications. Figure 1 shows the web tool for UV disinfection.

Figure 1 Screenshot of the web tool that provides access to the data from the rolling literature review

Joint efforts for data collection

The data collection starts with a systematic literature review using standardized keywords and several literature databases. The selected publications then undergo a series of quality checks based on title, abstract, provided details and quality of the data provided. Data is extracted from the publication by hand, which requires a joint effort. Currently efforts from various projects and partners are joined. KWR reviews drinking water treatment processes for the joint research of the Dutch drinking water companies. University of Colorado does the same for the update of Tables 7.7 and 7.8 in the WHO GDWQ. In the AquaNES project, KWB focuses on treatment processes which combine nature-based and engineered treatments steps,. By joining forces the work load is shared, knowledge is exchanged and quality is checked.

Outlook and discussion with the audience

It is expected that the databases will be up to date for all treatment processes by mid 2019, which will be followed by the gradual completion of the web tools per treatment process. Meanwhile, a QMRA web tool is being developed in the AquaNES project that incorporates the treatment tools. In addition a similar tool for pathogen concentrations in water sources of different qualities is being developed. At the IWA reuse conference we will present the status of the online QMRA tool and its specific functions (e.g. as oral presentation and live demonstration at a booth) and hope to initiate further cooperation with partners to continue this development into the future. We are also open for other formats such as a workshop on risk management and QMRA during the conference.

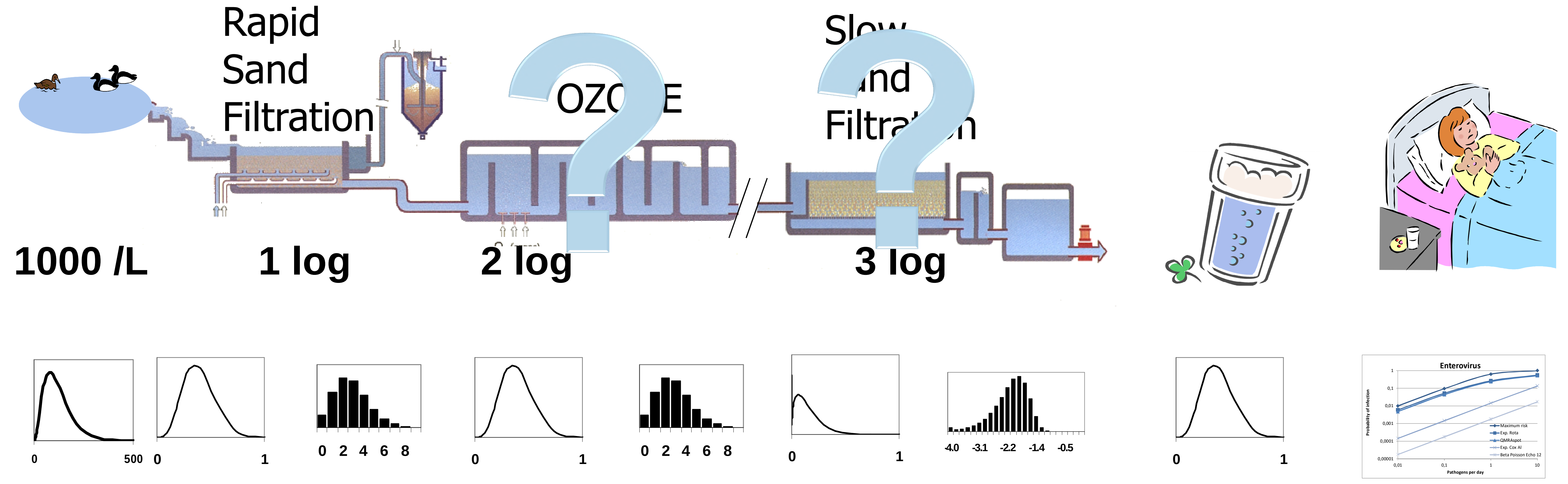
Rolling literature review on pathogen reduction by water treatment processes

Patrick Smeets[1], Karl Linden[2], Ulf Miehe[3],
[1]KWR Watercycle Research Institute, Nieuwegein, The Netherlands
[2]University of Colorado, Boulder, USA,
[3]Kompetenzzentrum Wasser Berlin (KWB), Berlin, Germany

Need for data on pathogen reduction by water treatment

QMRA applied for safe water reuse (de facto or intentional)

Legivelative requirement for QMRA in the Netherlands



Existing guidelines and reviews

- WHO GDWQ (2011)
- Hijnen and Medema (2010)
- Hijnen et al. UV disinfection (2006)
- WHO reuse in agriculture (2006)
- LeChevallier and Au (2004)

Generic LRV tables (min-max)

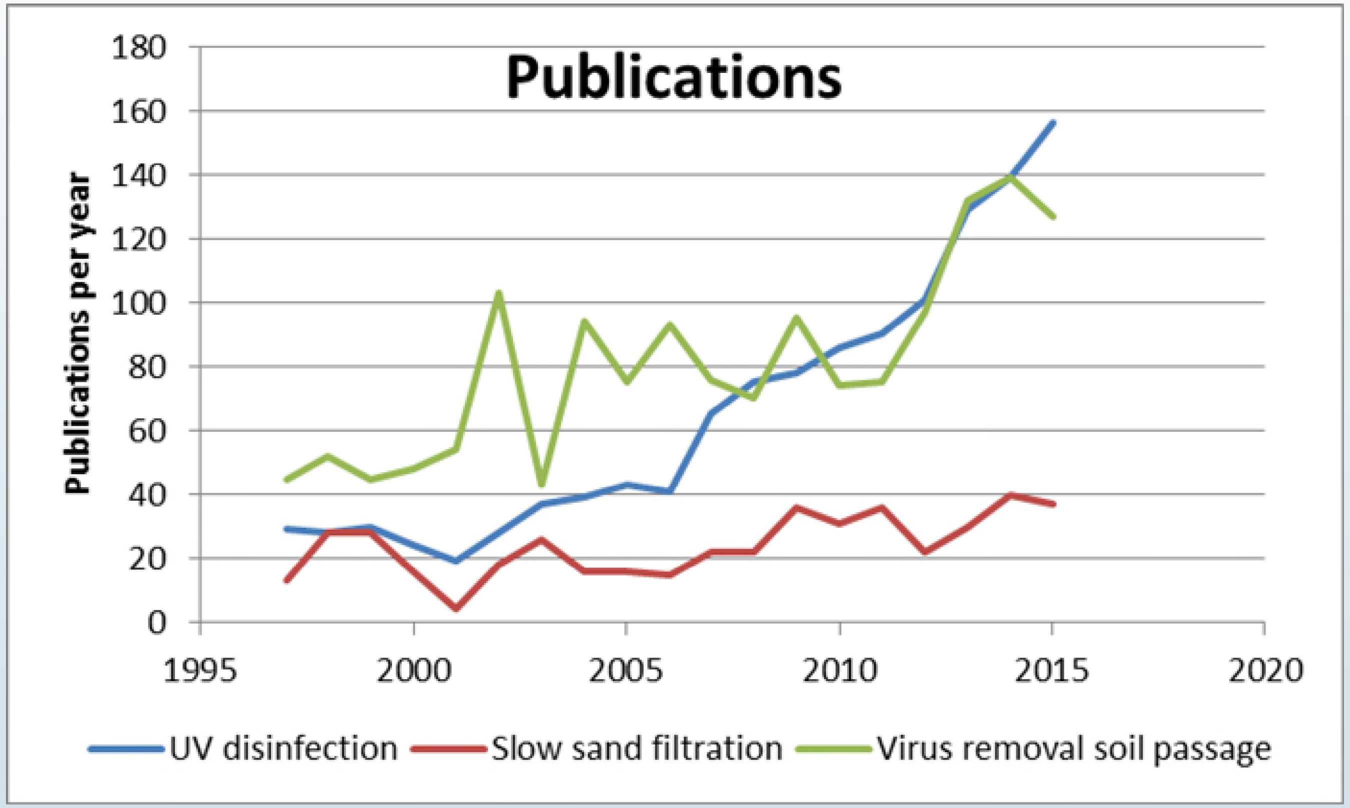
Table 7.7 Reductions of bacteria, viruses and protozoa achieved by water treatment technologies at drinking-water treatment plants for large communities

Treatment process	Enteric pathogen group	Minimum removal (LRV)	Maximum removal (LRV)	Notes
Pretreatment				
Roughing filters	Bacteria	0.2	2.3	Depends on filter medium, coagulant
Storage reservoirs	Bacteria	0.7	2.2	Residence time > 40 days
	Protozoa	1.4	2.3	Residence time 160 days
Bank filtration	Viruses	> 2.1	8.3	Depends on travel distance, soil type, pumping rate, pH, ionic strength
	Bacteria	2	> 6	
	Protozoa	> 1	> 2	
Coagulation, flocculation and sedimentation				
Conventional clarification	Viruses	0.1	3.4	Depends on coagulation conditions
	Bacteria	0.2	2	
	Protozoa	1	2	
High-rate clarification	Protozoa	> 2	2.8	Depends on use of appropriate blanket polymer

WHO GUIDELINES FOR DRINKING WATER QUALITY (2011)

Challenges of literature data for QMRA

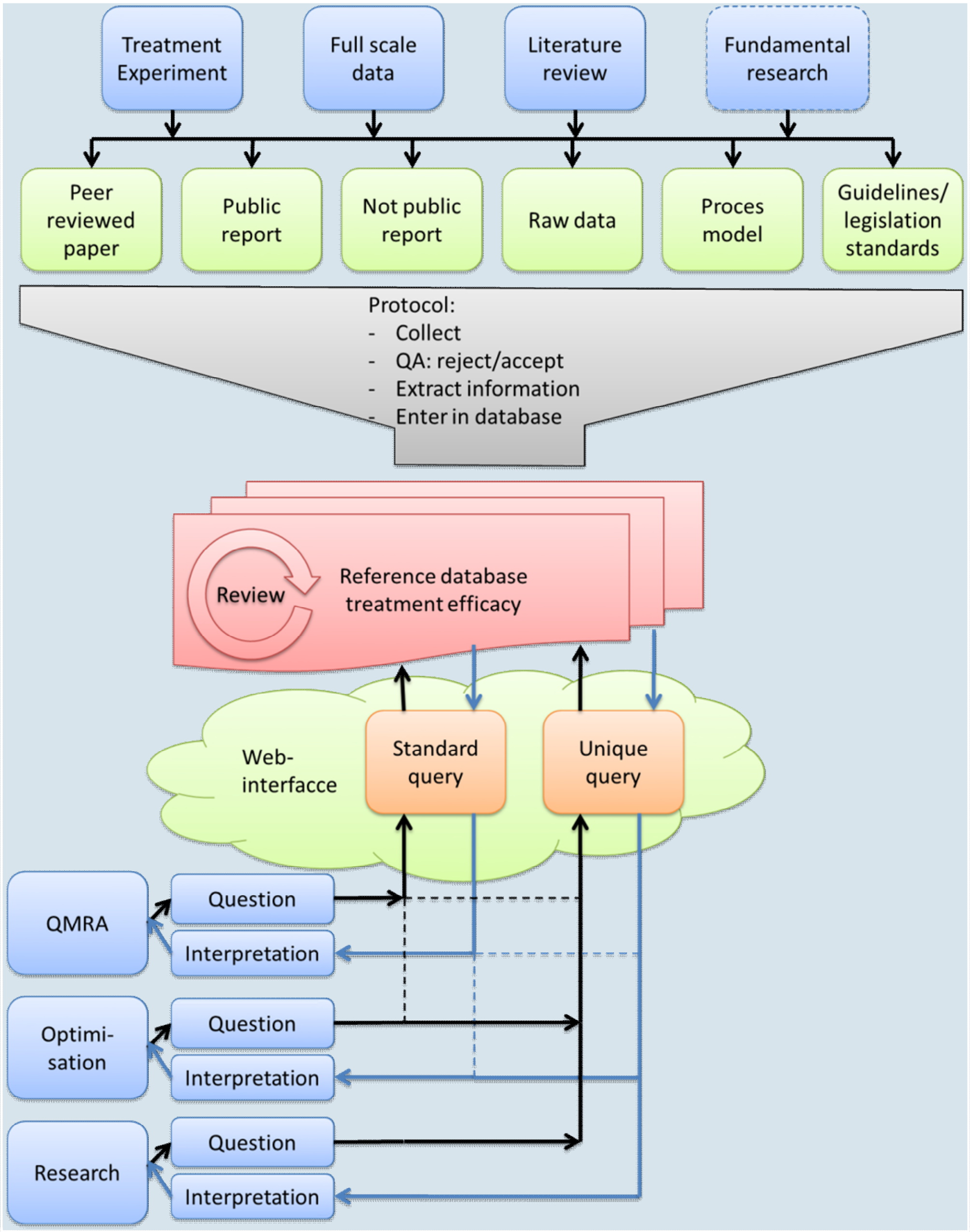
- Increasing rate of publication of studies
- Review publications rapidly age (Hijnen 2006)
- Which data is appropriate for your situation?
- Interpretation of experimental data can differ between authors



ANNUAL NUMBER OF PUBLICATIONS ON TREATMENT PROCESSES

Rolling literature revision
Database + webtool + interpretation for QMRA

- Single knowledge base
- Science based, evidence based
- Transparent
- Quantitative, original LRV data
- Include relevant conditions (proces, waterquality)
- Complete, easily updated
- Easy access, interactive webtool
- Interpretation of data, proces model parameters
- Expert advice for use in QMRA
- Identify knowledge gaps for future research



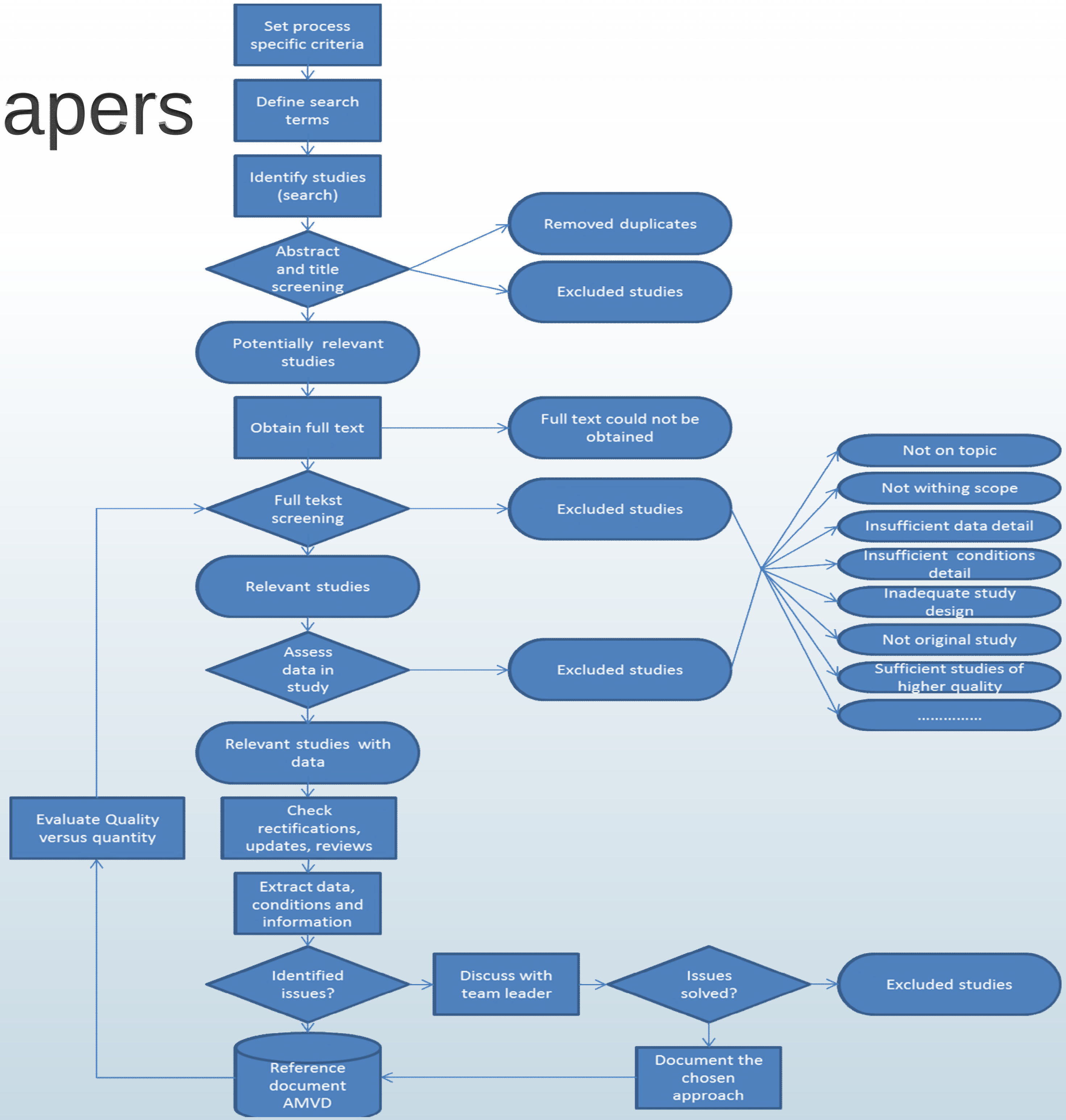
Systematic combination of search terms

Terms for soil passage	Terms for microbes	Terms for removal	Exclude
{soil passage}	microbial	removal	{Geochimica et Cosmochimica Acta}
subsurface	microbes	reduction	{Chemical Geology}
{bank filtration}	bacteria	inactivation	Chemosphere
aquifer	virus	filtration	{Applied Geochemistry}
{porous media}	protozoa	transport	{Journal of Hazardous Materials}
	spores	movement	
	pathogen	leaching	
	{e. coli}	fate	
	cryptosporidium	retention	
	phage	straining	
	giardia		

tak({soil passage} OR subsurface OR {bank filtration} OR aquifer OR {porous media}) AND tak(microbial OR microbes OR bacteria OR virus OR protozoa OR spores OR pathogen OR {e. coli} OR cryptosporidium OR phage OR giardia) AND tak(removal OR reduction OR inactivation OR filtration OR transport OR movement OR leaching OR fate OR retention OR straining) AND NOT({Geochimica et Cosmochimica Acta} OR {Chemical Geology} OR Chemosphere OR {Applied Geochemistry} OR {Journal of Hazardous Materials})

Include/exclude criteria for papers

- Systematic literature review
- Efficient screening of literature
- Checks with multiple reviewers
- Transparent exclusion criteria

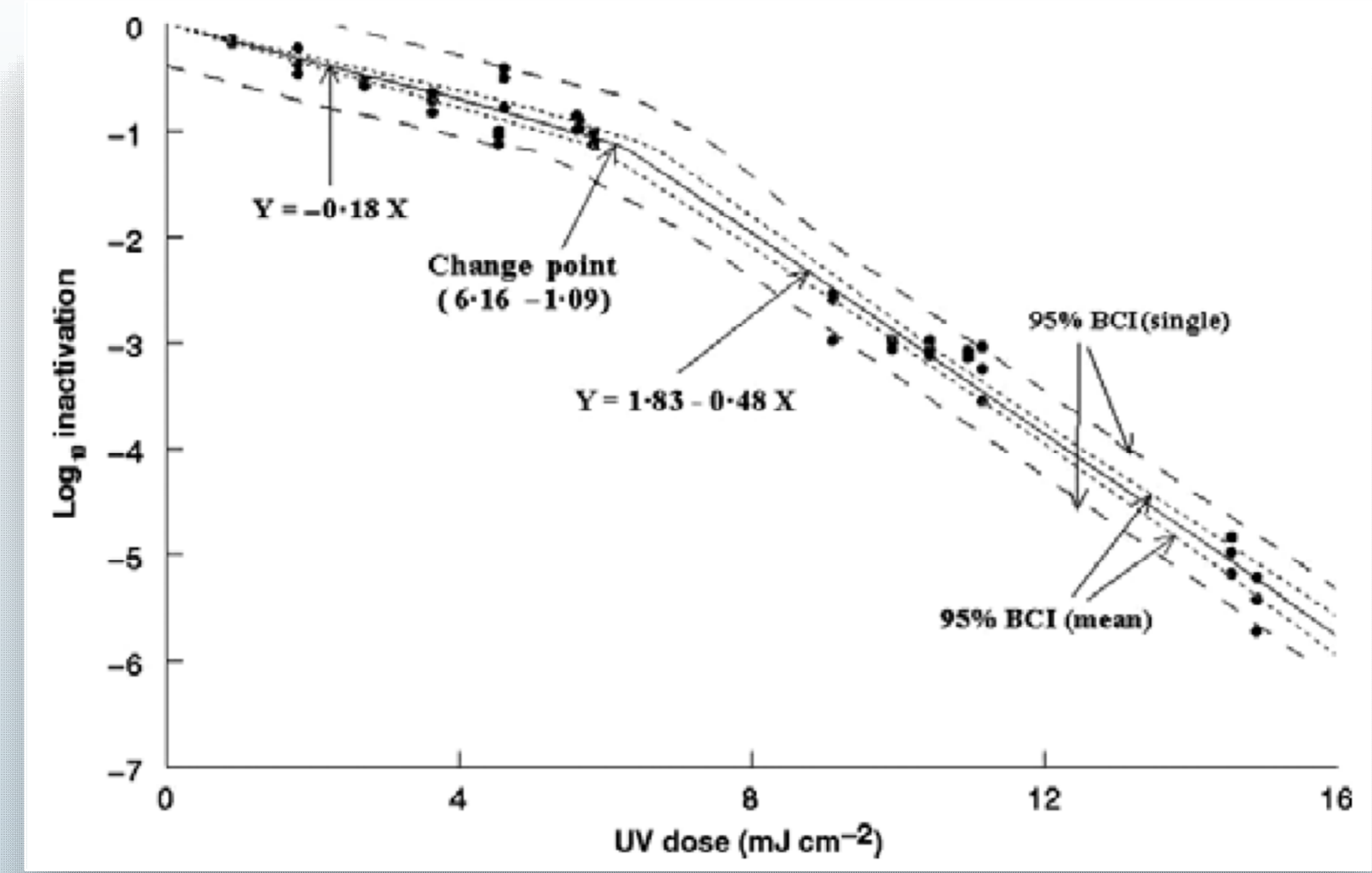


Track included /excluded papers

Include/Excluc	Gecontroleerc	ExperimentID	Comments	Reden afwijzing	Authors		Year	Title
Include					Elena Timchak;Vitaly Gitis	Timchak, E.;Gitis, V.	2012	A combined degradation of dyes and inactivation of viruses by UV and UV/H2O2
Exclude				Insufficient UV details	O. Mi Lee;Hyun Young Kim;Wooshin Park;Tae-Hun Kim;Seungh	#N/A	2015	A comparative study of disinfection efficiency and regrowth control of microorganism in s
Exclude				Insufficient UV details	M. Gómez;F. Plaza;G. Garralón;J. Pérez;M. A. Gómez	Gómez, M.;Plaza, F.;(	2007	A comparative study of tertiary wastewater treatment by physico-chemical-UV process an
Exclude				Insufficient UV details	M. Garvey;N. Thokala;N. Rowan	Garvey, M.;Thokala,	2014	A comparative study on the pulsed UV and the low-pressure UV inactivation of a range of
Exclude				Insufficient UV details	S. F. Thomas;P. Rooks;F. Rudin;S. Atkinson;P. Goddard;R. M. Br	Thomas, S.F.;Rooks,	2014	A comparison between ultraviolet disinfection and copper alginate beads within a vortex
Include					J. L. Zimmer-Thomas;R. M. Slawson;P. M. Huck	Zimmer-Thomas, J.L.	2007	A comparison of DNA repair and survival of Escherichia coli O157:H7 following exposure to
Exclude				Insufficient UV details	Marisol D. Labas;Rodolfo J. Brandi;Carlos A. Martín;Alberto E. C	Labas, M.D.;Brandi, R	2006	A contribution to the UV dose concept for bacteria disinfection in well mixed photoreacto
Include					J. L. Rand;R. Hofmann;M. Z. B. Alam;C. Chauret;R. Cantwell;R. C	Rand, J.L.;Hofmann,	2007	A field study evaluation for mitigating biofouling with chlorine dioxide or chlorine integra
Exclude				Off-topic	Gang Lu;Chaolin Li;Yinggang Zheng;Qian Zhang;Juan Peng;Ming	Lu, G.;Li, C.;Zheng, Y.	2008	A novel fiber optical device for ultraviolet disinfection of water
Exclude	Completed			Off-topic	J. Langmark;M. V. Storey;N. J. Ashbolt;T. A. Stenstrom	Langmark, J.;Storey,	2005	Accumulation and fate of microorganisms and microspheres in biofilms formed in a pilot-s
Include	Completed	627-636			S. E. Beck;H. B. Wright;T. M. Hargy;T. C. Larason;K. G. Linden	Beck, S.E.;Wright, H.I	2015	Action spectra for validation of pathogen disinfection in medium-pressure ultraviolet (UV
Exclude	Completed			Off-topic	G. C. Gray	Gray, G.C.	2006	Adenovirus transmission--worthy of our attention
Exclude	Completed			Insufficient UV details	P. Bilotta;L. A. Daniel	Bilotta, P.;Daniel, L.A	2010	Advanced process of microbiological control of wastewater in combined system of disinfe
Exclude	Completed			Inadequate study desig	Luigi Rizzo;Antonino Fiorentino;Antonella Anselmo	Rizzo, L.;Fiorentino,	2013	Advanced treatment of urban wastewater by UV radiation: Effect on antibiotics and antibi
Exclude	Completed			Multiple inadequate de	H. C. Su;G. G. Ying;L. Y. He;Y. S. Liu;R. Q. Zhang;R. Tao	Su, H.C.;Ying, G.G.;He	2014	Antibiotic resistance, plasmid-mediated quinolone resistance (PMQR) genes and ampC ge
Exclude				Multiple inadequate de	A. Luczkiewicz;K. Jankowska;R. Bray;E. Kulbat;B. Quant;A. Soko	Luczkiewicz, A.;Jankc	2011	Antimicrobial resistance of fecal indicators in disinfected wastewater
Exclude	Completed			Off-topic	J. Suss;S. Volz;U. Obst;T. Schwartz	Suss, J.;Volz, S.;Obst	2009	Application of a molecular biology concept for the detection of DNA damage and repair du
Exclude	Completed			Off-topic	M. A. Würtele;T. Kolbe;M. Lipsz;A. Külberg;M. Weyers;M. Kneis	Würtele, M.A.;Kolbe	2011	Application of GaN-based ultraviolet-C light emitting diodes – UV LEDs – for water disinfec
Exclude	Completed			Off-topic	K. Oguma;R. Kita;H. Sakai;M. Murakami;S. Takizawa	Oguma, K.;Kita, R.;Sa	2013	Application of UV light emitting diodes to batch and flow-through water disinfection syste
Exclude	Completed			Not applicable to drinki	S. J. Connelly;E. A. Wolyniak;C. E. Williamson;K. L. Jellison	Connelly, S.J.;Wolyn	2007	Artificial UV-B and solar radiation reduce in vitro infectivity of the human pathogen Crypto
Exclude	Completed			Insufficient UV details	C. K. Barstow;A. D. Dotson;K. G. Linden	Barstow, C.K.;Dotson	2014	Assessing point-of-use ultraviolet disinfection for safe water in urban developing commu
Include	Completed	1220-1259	Only included graph of M a W15, other sti		S. L. Hayes;M. Sivaganesan;K. M. White;S. L. Pfaller	Hayes, S.L.;Sivaganes	2008	Assessing the effectiveness of low-pressure ultraviolet light for inactivating Mycobacteriu
					M. E. Rubiano;M. Agulló-Barceló;R. Casas-Mangas;J. Jofre;F. Luc	Rubiano, M.E.;Agulló	2012	Assessing the effects of tertiary treated wastewater reuse on a Mediterranean river (Llobr
Exclude				Not applicable to drinki	S. A. Brownell;A. R. Chakrabarti;F. M. Kaser;L. G. Connelly;R. L. I	Brownell, S.A.;Chakr	2008	Assessment of a low-cost, point-of-use, ultraviolet water disinfection technology
Exclude				Insufficient UV details	S. Abd-Elmaksoud;J. E. Naranjo;C. P. Gerba	Abd-Elmaksoud, S.;N	2013	Assessment of a portable handheld UV light device for the disinfection of viruses and bact
Include	Completed	See figure extrat	Note: 95% CI based on 5 samples		Z. Bohrerova;K. G. Linden	Bohrerova, Z.;Linden	2006	Assessment of DNA damage and repair in Mycobacterium terrae after exposure to UV irra
					P. Liu;O. Herzegh;M. Fernandez;S. Hooper;W. Shu;J. Sobolik;R.	Liu, P.;Herzegh, O.;Fe	2013	Assessment of human adenovirus removal by qPCR in an advanced water reclamation plar
Exclude	Completed			Not applicable to drinki	Daniel Rubio;José F. Casanueva;Enrique Nebot	Rubio, D.;Casanueva	2015	Assessment of the antifouling effect of five different treatment strategies on a seawater c
Include	Completed				S. L. Hayes;K. M. White;M. R. Rodgers	Hayes, S.L.;White, K.	2006	Assessment of the effectiveness of low-pressure UV light for inactivation of Helicobacter
Include	Completed				Dorothée Lénès;Nathalie Deboosere;Florence Ménard-Szczeba	Lenes, D.;Deboosere	2010	Assessment of the removal and inactivation of influenza viruses H5N1 and H1N1 by drinki
Exclude				Off-topic	L. E. Murdoch;M. Maclean;E. Endarko;S. J. MacGregor;J. G. Ande	Murdoch, L.E.;Macle	2012	Bactericidal effects of 405 nm light exposure demonstrated by inactivation of Escherichia,
Exclude	Completed			Not applicable to drinki	S. Pigeot-Rémy;F. Simonet;D. Atlan;J. C. Lazzaroni;C. Guillard	Pigeot-Remy, S.;Sim	2012	Bactericidal efficiency and mode of action: A comparative study of photochemistry and ph
Exclude				Insufficient inactivation	B. Mounaouer;H. Abdennaceur	Mounaouer, B.;Abde	2015	Bacteriological quality of effluent submitted consecutively to a macrofiltration and ultravi
Exclude	Completed			Not applicable to drinki	Y. Liu;K. Ogden	Liu, Y.;Ogden, K.	2010	Benefits of high energy UV185nm light to inactivate bacteria
Exclude				Insufficient inactivation	N. Saidi;S. Kouki;I. Mehri;A. Ben Rejeb;A. Belila;A. Hassen;H. O	Saidi, N.;Kouki, S.;M	2011	Biofilm and siderophore effects on secondary waste water disinfection
Exclude				Off-topic	D. Page;P. Dillon;S. Toze;J. P. Sidhu	Page, D.;Dillon, P.;To	2010	Characterising aquifer treatment for pathogens in managed aquifer recharge

Extraction of data from tables, figures and methods

LRV MOSTLY REPORTED IN TABLES



MATERIALS AND METHODS: ESSENTIAL INFORMATION OFTEN MISSING

Materials and Methods

Experimental Static Mixer Apparatus

The experimental ozone contacting system (Figure 3) was comprised of a static mixer for rapid ozone dissolution, a vertical bubble column for additional ozone dissolution and gas-liquid separation, and a tubular RFS to provide the dissolved ozone contact required for *C. parvum* oocyst inactivation. The water source was tap water that was regulated to 22±1°C by blending hot and cold tap sources and was then passed over a set of granular activated carbon columns to reduce the combined chlorine

Example of literature study harvest

UV disinfection update

- 1172 publications from search terms
- 564 left after title screening
- 410 left after abstract screening
- 208 exclusion based on full paper (data)
- 252 inclusion based on full paper
- 234 publications processed
- 2457 records in database (LRVs)
- 90 pathogens and surrogate organisms

Previous review UV disinfection (Hijnen et al. 2006)

- 42 publications
- 814 LRV's
- 42 pathogens and surrogate organisms

International collaboration

Similar time consuming activities → share data

JOINT RESEARCH FOR LEGISLATIVE QMRA

KWR Watercycle Research Institute

BTO

WHO GDWQ REVISION TABLES 7.7 AND 7.8

University of Colorado
Boulder | Colorado Springs | Denver | Anschutz Medical Campus

World Health Organization

AQUANES RISK ASSESSMENT TOOL

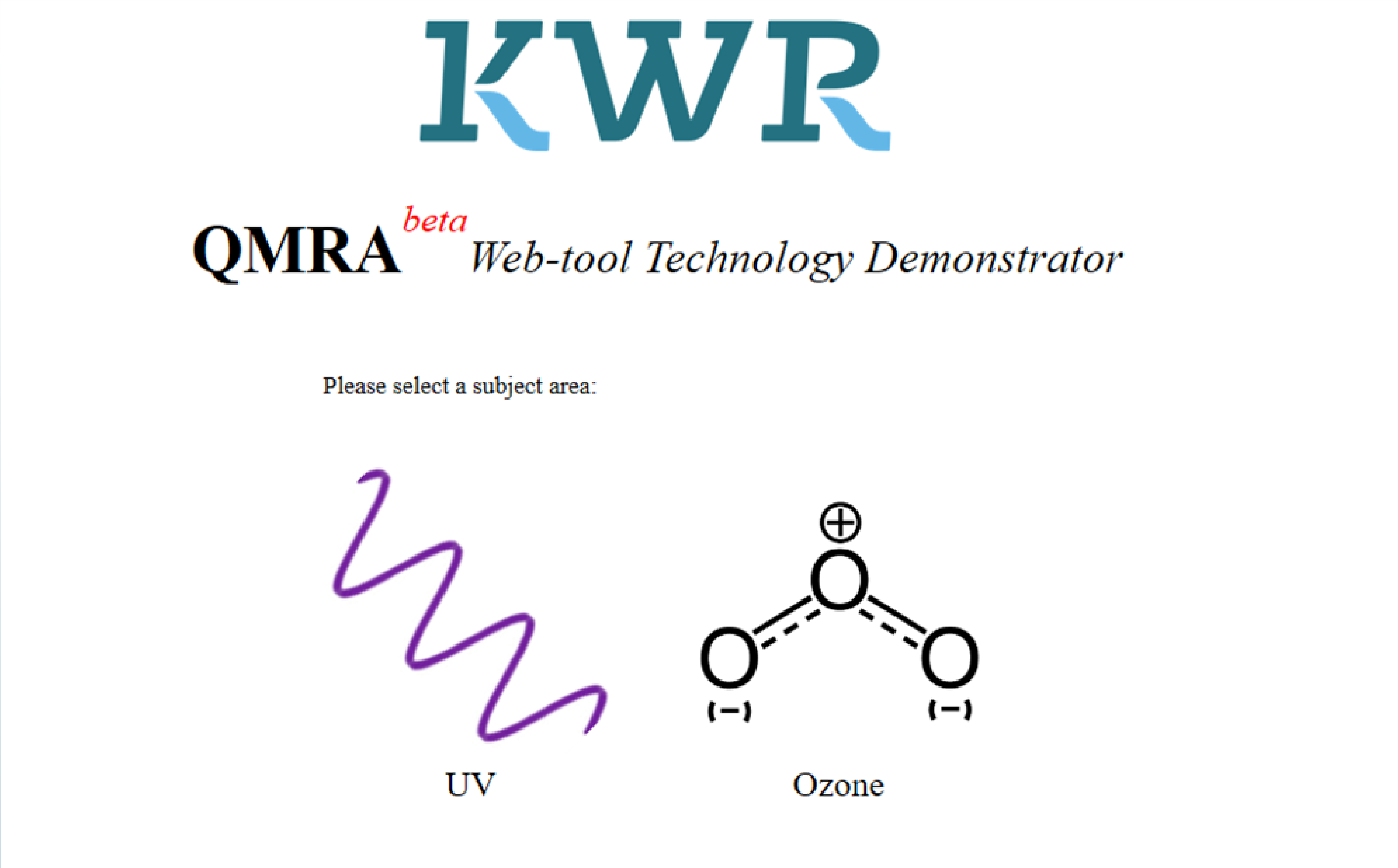
KOMPETENZZENTRUM Wasser Berlin

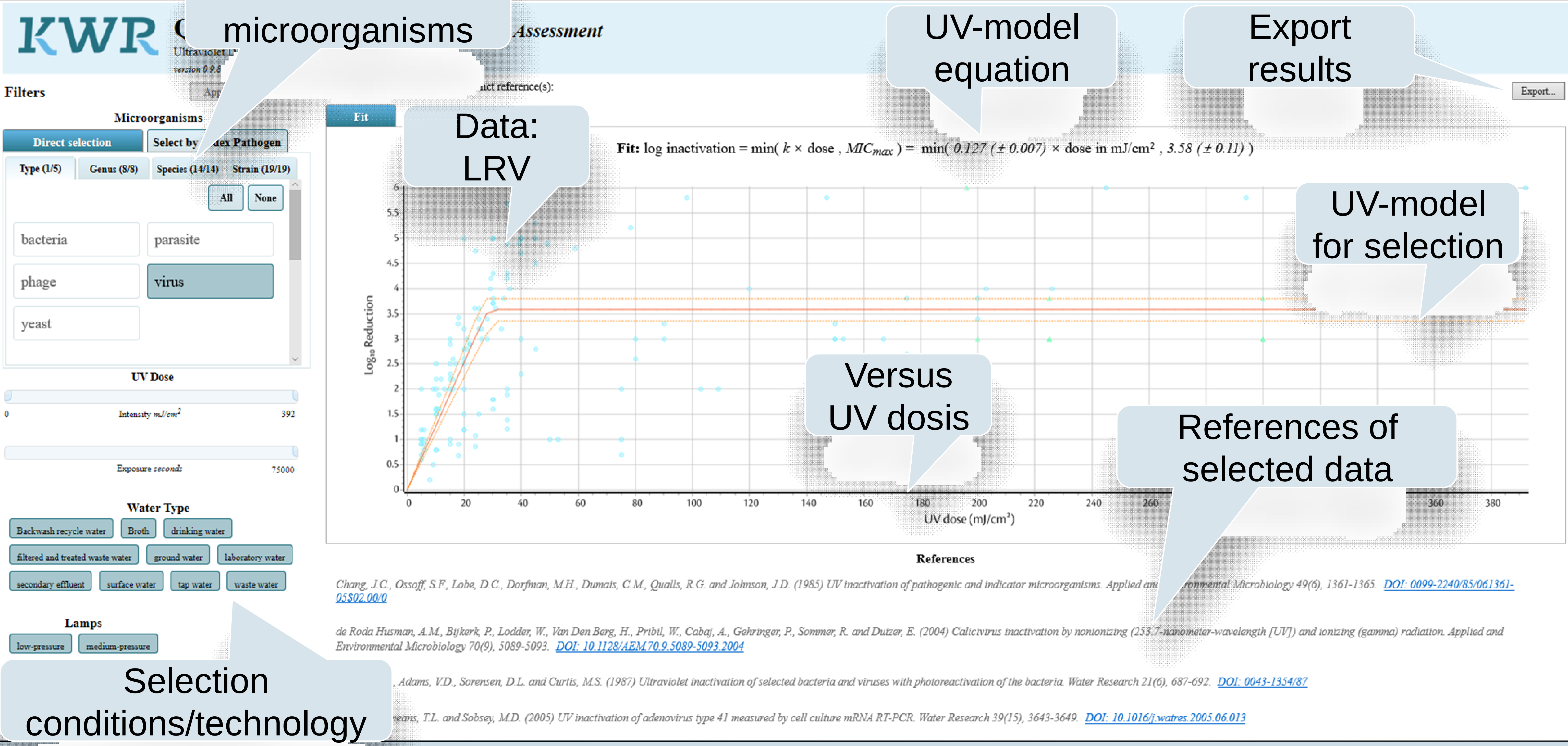
AquaNES

Current status

Process	References	LRVs	Leading
Coagulation-sedimentation	51		UCB
Rapid Sand Filtration			UCB
Chlorination	78		UCB
Infiltration/bank filtration	45	209	KWR
UV-disinfection	234	2457	KWR
Ozonation	61	1700	KWR
Slow sand filtration	7	282	KWR
MF, UF, NF membranes	37		UCB
Reverse Osmosis	16	125	KWR
Household treatment systems			UCB
Constructed wetlands	28	429	KWB

Data presentation through interactive webtool




Select microorganisms
UV-model equation
Export results
Data: LRV
UV-model for selection
Versus UV dosis
References of selected data
Selection conditions/technology
KWR
Assessment
Ultraviolet
version 0.9.8
Filters
Export...
Fit
Microorganisms
Direct selection
Select by Index Pathogen
Type (1/5)
Genus (8/8)
Species (14/14)
Strain (19/19)
All
None
bacteria
parasite
phage
virus
yeast
UV Dose
0
Intensity mJ/cm²
392
Exposure seconds
75000
Water Type
Backwash recycle water
Broth
drinking water
filtered and treated waste water
ground water
laboratory water
secondary effluent
surface water
tap water
waste water
Lamps
low-pressure
medium-pressure
Fit: log inactivation = min(k × dose , MICmax) = min(0.127 (± 0.007) × dose in mJ/cm² , 3.58 (± 0.11))
Log₁₀ Reduction
UV dose (mJ/cm²)
References
Chang, J.C., Ossoff, S.F., Lobe, D.C., Dorfman, M.H., Dumais, C.M., Qualls, R.G. and Johnson, J.D. (1985) UV inactivation of pathogenic and indicator microorganisms. Applied and Environmental Microbiology 49(6), 1361-1365. DOI: 0099-2240/85/061361-05$02.00/0
de Roda Husman, A.M., Bijkerk, P., Lodder, W., Van Den Berg, H., Pribil, W., Cabaj, A., Gehringer, P., Sommer, R. and Duizer, E. (2004) Calicivirus inactivation by nonionizing (253.7-nanometer-wavelength [UV]) and ionizing (gamma) radiation. Applied and Environmental Microbiology 70(9), 5089-5093. DOI: 10.1128/AEM.70.9.5089-5093.2004
Adams, V.D., Sorensen, D.L. and Curtis, M.S. (1987) Ultraviolet inactivation of selected bacteria and viruses with photoreactivation of the bacteria. Water Research 21(6), 687-692. DOI: 0043-1354/87
T.L. and Sobsey, M.D. (2005) UV inactivation of adenovirus type 41 measured by cell culture mRNA RT-PCR. Water Research 39(15), 3643-3649. DOI: 10.1016/j.watres.2005.06.013

Expert selection of data for use in QMRA

RIVM[1] + KWR

- Balance specificy and amount of data
- Transparent decision
- Uniformity in QMRA
- New data interpreted the same way
- User can assess the effect of these choices in the tool

Selectie data			
Index pathogen	Cryptosporidium	Species/subtype	Strain
Type+variant	Parasite-oocysts		
Group/Genus	Cryptosporidium	ALL	ALL
Lamp	ALL		
Water type	Backwash recycle water; drinking water, laboratory water		
UV dose	>1 -500<	mJ/cm²	
Exposure time	>0-10<	s	
Resultaat			
k_{UV}	0.67	± 0.039	
MIC_{max}	3.5	± 0.1	
Opmerkingen: Een sterk afwijkende studie liet veel minder inactivatie zien. Deze studie is beoordeeld als te afwijkend en vervalt bij de analyse door de Exposure Time te beperken. (NB Voor deze studie is geen ET gerapporteerd).			

[1] National Institute for Public Health and the Environment

Challenges: meta-analysis may give inconsistent results

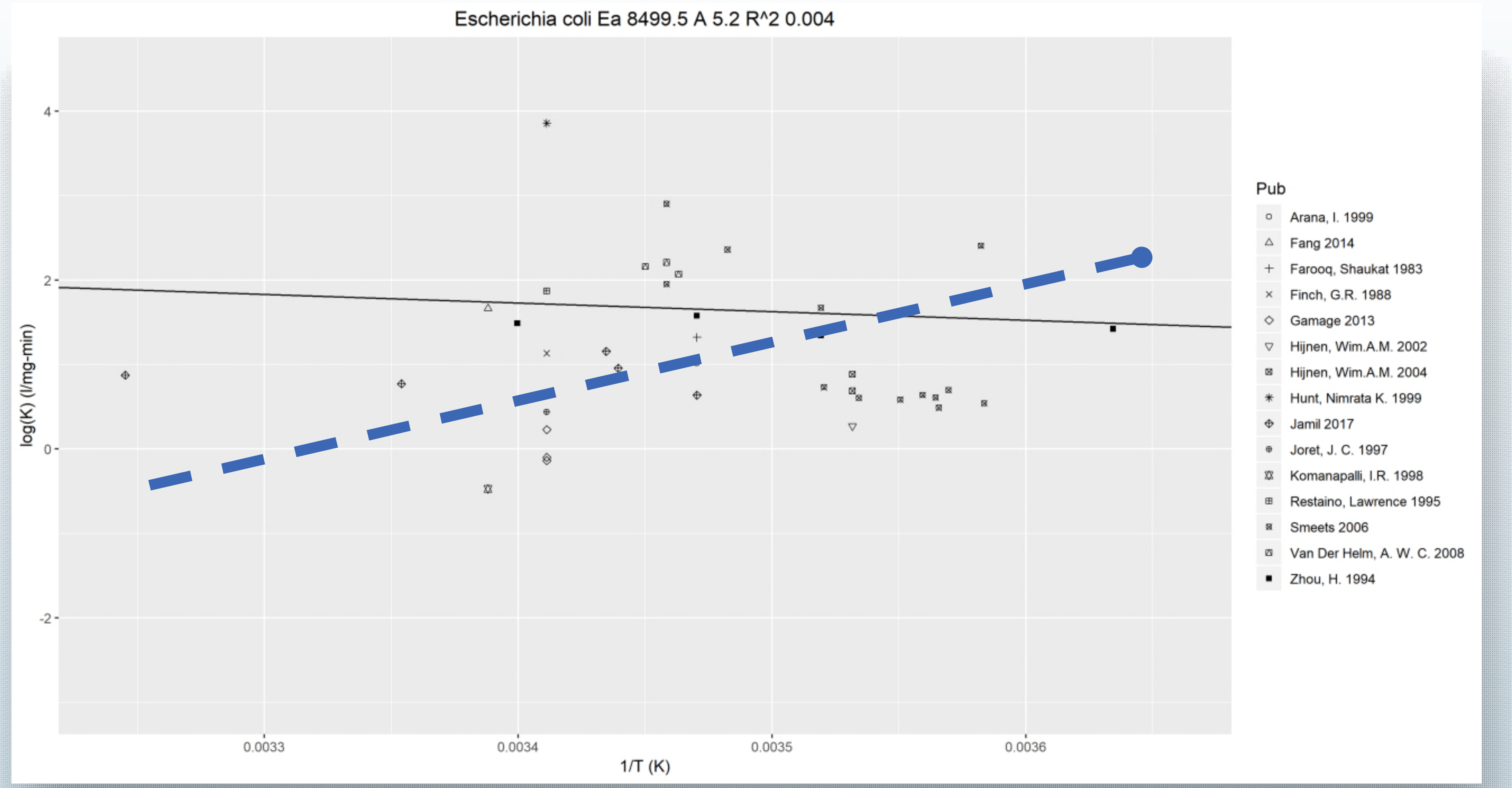
Example *E. coli*-inactivation Ozone: less inactivation at higher temperature?

Reasons

- Differences in non-reported conditions
- Inaccuracies in measurements/analysis
- Differences between microorganisms
- Lab, pilot, full scale
- Data gaps

Tool value:

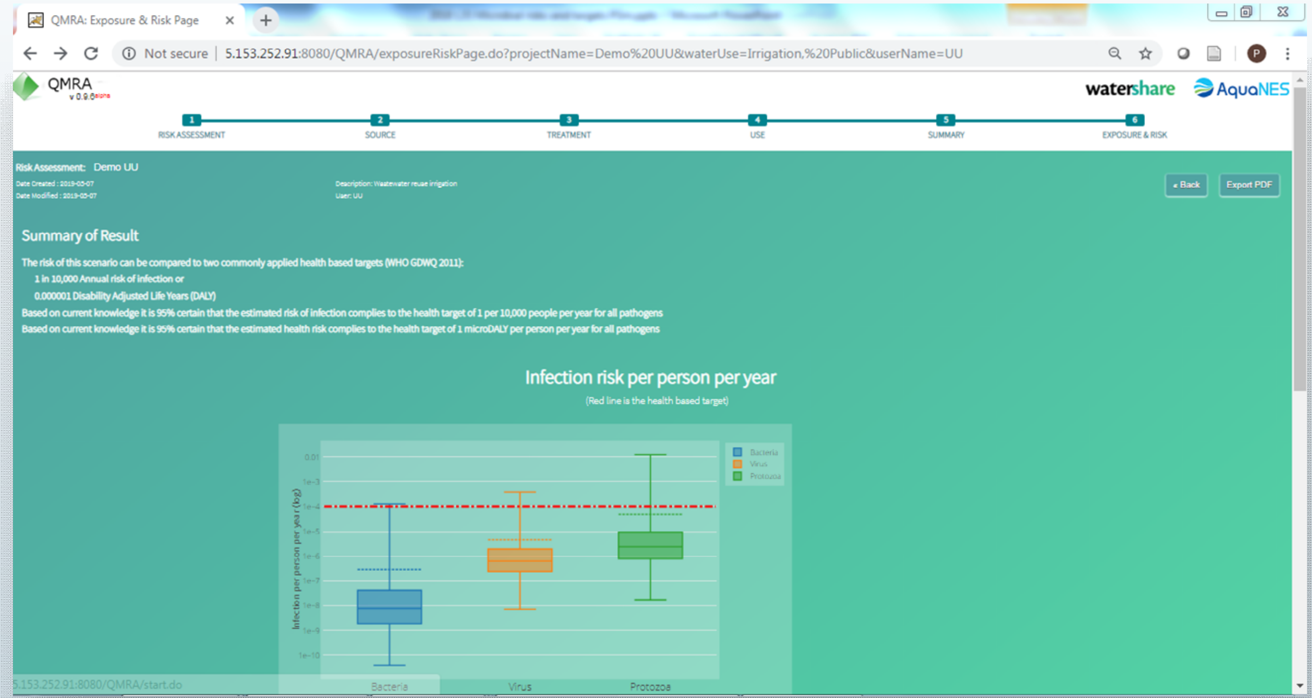
- Actual state of knowledge
- Transparent
- Avoid false sense of accuracy of current models from single studies



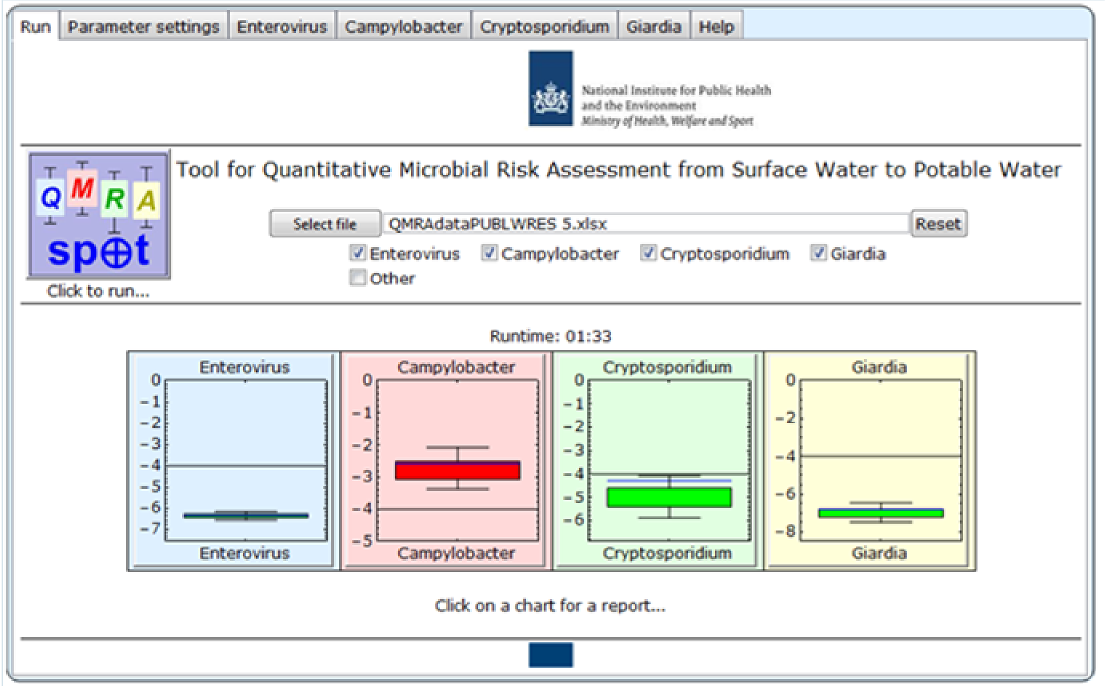
ARRHENIUS PLOT TO DETERMINE INACTIVATION RATE OF OZONATION

Outlook: linking to other tools and projects

AQUANES QMRA TOOL (VALUES FROM GUIDELINES)



QMRASPOT TOOL FOR LEGISLATIVE QMRA IN THE NETHERLANDS



IWA Water Reuse Berlin: Workshop Sunday 17-6-2019

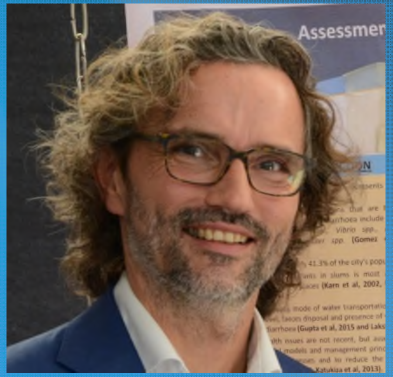
Acknowledgements

Alex Hockin, Kimberly Learbuch, Nikki van Bel, Sotirios Paraskevopoulos (KWR)
Kaitlyn Jeanis, William Seites-Rundlett, Yarrow Linden (UCB)

All students that contributed to the massive work

Please join us!

@KWR_Water



patrick.smeets@kwrwater.nl

https://nl.linkedin.com/in/patrickxsmeets

University of Colorado
Boulder | Colorado Springs | Denver | Anschutz Medical Campus

KOMPETENZZENTRUM Wasser Berlin