Gray and Osborne

1. In previously submitted comments, Gray and Osborne recommended that under WAC-173-219-340 Disinfection Process Standards, Section (1a) be changed to reflect free chlorine disinfection and adequate detention time for 4-log virus removal. In addition, the section should note that these requirements could potentially be relaxed on a case by case basis by Ecology when adequate virus removal is thoroughly documented, and adequate safeguards are provided, upstream of the disinfection process, for instance, through a membrane bioreactor.

2. For UV Disinfection, it appears that the State is not requiring checkpoint bioassays on-site. It is recommended that, at plants where checkpoint bioassays are not completed, that a field commissioning checklist be completed and signed by both the manufacturer and engineer, at a minimum, to ensure that hydraulics and construction tolerances, etc., are within specification to provide the necessary pathogen inactivation. In lieu of the field commissioning checklist, or as specifically required by Ecology, the checkpoint bioassay could be conducted. See attachments.

Disinfection Guidance for Reclaimed Water in Washington State's New "Purple Book"

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ABSTRACT

Washington State issued a new draft "Reclaimed Water Rule" and developed a *Reclaimed Water Facilities Manual* ("Purple Book") for supplemental guidance on implementing the Rule in 2010 - 2011. The draft Rule and Purple Book include new guidelines for design, commissioning and operation of disinfection systems for reclaimed water facilities. The Purple Book includes a checklist for use in field commissioning of ultraviolet disinfection systems used to disinfect reclaimed water. In this paper, the draft Rule and Purple Book are described, and the field commissioning checklist is presented and explained.

KEYWORDS

Purple Book, disinfection, water reuse, reclaimed water, checkpoint bioassay, computational fluid dynamics

INTRODUCTION AND BACKGROUND

There are over 30 water reuse facilities in Washington State, in areas ranging from the more heavily populated Puget Sound region, to the drier, less populated eastern side of the State. (See Figure 1.) Washington State began a rulemaking process in 2006 to update and convert the State's 1997 *Water Reclamation and Reuse Standards* into a regulation, the Reclaimed Water Rule. The draft Rule refers to a *Reclaimed Water Facilities Manual* (Gray and Osborne, 2010), a.k.a. the "Purple Book," for supplemental guidance on implementing the Rule. The manual was developed and released for review by stakeholders in 2011. Rule adoption and publication of the Purple Book are anticipated in 2013. The draft Rule and Purple Book include new guidelines for design, commissioning and operation of disinfection systems for reclaimed water facilities.

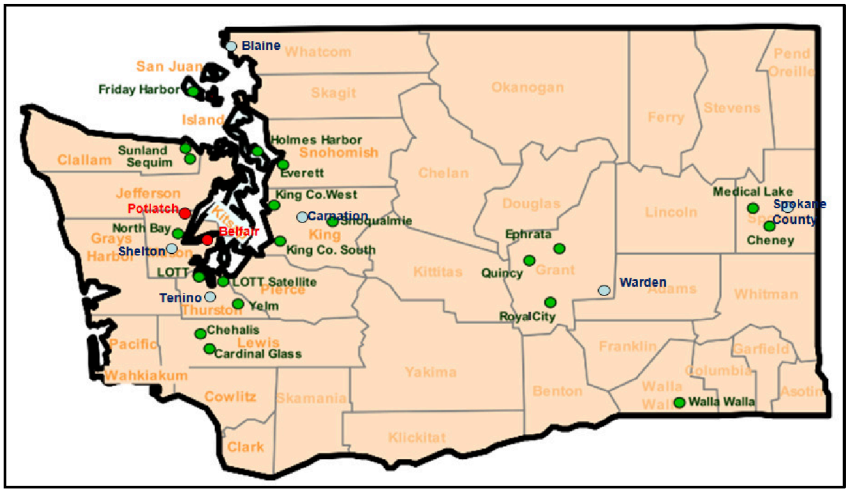

Figure 1. Water Reuse Facilities in Washington State (based on information from the Wa. St. Dept. of Ecology, 2011)

DISINFECTION STANDARDS IN THE DRAFT RECLAIMED WATER RULE

The current *Water Reclamation and Reuse Standards* (WRRS) provide requirements for four classes of reclaimed water, Class A, B, C and D, with Class A having the strictest treatment requirements and the most allowed uses. The current water quality standards associated with each class of reclaimed water are primarily distinguished by bacterial pathogen standards, using total coliform as the indicator microorganism as measured in the final product water of the overall reclaimed water treatment process. Although Class A and B have the same pathogen standard, achieving Class A treatment standards requires coagulation and filtration unit treatment processes. The regulatory intent of coagulation and filtration is to achieve increased levels of pathogen reduction, including virus removal, in the overall treatment process.

In Table 1, treatment processes and water quality requirements are summarized for the four current classes of reclaimed water. In the draft Rule, the current four classes of reclaimed water have been streamlined to two: Class A and Class B. Class A is similar to the current Class A requirements in terms of the bacterial pathogen standard applied to the final product water; Class B has the same bacterial pathogen requirements as the current Class C reclaimed water. In Table 2, the treatment processes and water quality requirements are summarized for the two classes of reclaimed water in the draft Rule.

Table 1. Summary of Water Quality Limits for Reclaimed Water in WRRS Guidelines

Class Level	Oxidized		Coagulated	Filtered	Disinfected	
	Secondary BOD_5/TSS Concentrations (mg/L)	Dissolved Oxygen		Turbidity (NTU)	Total Coliform (MPN/ 100 mL)	
					7-Day Median	Single Sample
A	30	Must be present	YES	2 NTU avg. 5 NTU max.	≤ 2.2	23
B	30	Must be present	NO	NO	≤ 2.2	23
C	30	Must be present	NO	NO	≤ 23	240
D	30	Must be present	NO	NO	240	N/A

In the draft Rule, new treatment methods are included for production of Class A reclaimed water: membrane filtration and membrane bioreactor (MBR) processes. The current WRRS do not directly accommodate the MBR process, as coagulation is required at all times for Class A reclaimed water. The draft Rule does not require coagulation for membrane filtration processes, but institutes stricter turbidity standards for membrane filtration (0.2 NTU average; 0.5 NTU maximum). In the draft Rule, more detailed requirements are provided for chlorine disinfection, and alternative design methods are authorized. UV disinfection systems are required to be designed in accordance with recognized standards, of which two are listed: *Ultraviolet Disinfection: Guidelines for Drinking Water and Water Reuse* by the National Water Research

Institute and American Water Works Research Foundation (NWRI/AwwaRF) and *The Reclaimed Water Facilities Manual (Purple Book).*

The draft Rule applies virus reduction standards to the filtration and disinfection unit treatment processes stipulated for Class A reclaimed water for the first time. In addition to an operational performance standard based on total coliform, disinfection facilities must be designed to provide 5-log virus removal or inactivation (unless a 1-log credit is provided for conventional filtration processes preceded by coagulation, flocculation and sedimentation, or for membrane filtration processes, resulting in a 4-log removal requirement in the disinfection process). The inclusion of virus removal standards in the new Rule significantly increases the complexity and stringency of disinfection system design for Class A reclaimed water facilities. Therefore, to provide greater flexibility in design, the draft Rules allows for the demonstration of achieving virus removal standards through one of four methods: (1) Design and operational limits derived from other reclaimed water programs, deemed acceptable to the lead agency; (2) Accepted empirical design standards and practices; (3) A third-party challenge study or equipment verification study, acceptable to the lead agency; or (4) A challenge study or pilot plant demonstration specific to the project conditions. Reclaimed water disinfection facilities must also be validated prior to producing reclaimed water through a "field commissioning test." The field testing should be performed according to procedures described in the Purple Book.

Table 2. Summary of Water Quality Limits for Reclaimed Water in the Draft Rule

Class Level	Oxidized			Coagulated	Filtered		Disinfected	
	Secondary BOD_5/TSS Concentrations (mg/L)	Dissolved Oxygen	pH		Turbidity (NTU)		Total Coliform (MPN/ 100 mL)	
					Traditional	Membrane	7-Day Median	Single Sample
A	30	Must be present	6 to 9	YES	2 NTU average 5 NTU max.	0.2 NTU average 0.5 NTU max.	$\leq 2.2^{(1)}$	23
B	30	Must be present	6 to 9	NO	NO	NO	≤ 23	240

1. A virus challenge study or equivalent third party study shall demonstrate 5-log virus inactivation through the filtration and disinfection processes.

NWRI/AwwaRF GUIDELINES

One of the options specified for in the draft Rule for ultraviolet disinfection system design and operational standards is based on the NWRI/AwwaRF "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse" (NWRI/AwwaRF Guidelines) (NWRI/AwwaRF, 2003). The NWRI/AwwaRF Guidelines, which specify design and testing protocols for ultraviolet disinfection systems for water reuse, are de facto standards in a number of states, including California, Texas, Florida, Washington and Hawaii. The NWRI/AwwaRF Guidelines require that UV disinfection systems be sized based on bioassays. The NWRI/AwwaRF Guidelines

protocols allow manufacturers to demonstrate that their equipment meets emerging industry standards for UV disinfection for effluent reuse. An important part of the protocols are biodosimetry evaluations of UV systems — also known as bioassays.

A bioassay is an empirical procedure that quantifies the UV dose delivered by a particular UV system. *Dose* (fluence) is defined as the intensity (fluence rate) of UV light multiplied by the time a particle is exposed to the light (usually reported in mJ/cm^2). In an ideal reactor, all particles of water would be exposed to the same dose. In reality, however, non-ideal hydraulics and the non-uniform distribution of UV radiation provide a range of doses (a dose distribution), which may result in insufficient disinfection for the particles traveling through the reactor. Because the goal of UV disinfection, as specified in the NWRI/AwwaRF Guidelines, the Reclaimed Water Rule and the Purple Book, is to inactivate 99.999% or more of the target pathogen(s) (5-log removal), failure to provide an adequate dose to as little as 0.001% of the wastewater flow can be a regulatory problem. Doses in UV reactors often are estimated by mathematical models (increasingly supplemented by computational fluid dynamic (CFD) modeling), but a bioassay is considered to be the most accurate means to establish the dose and is used to develop data for calibrating and verifying UV reactor models, per the requirements of the NWRI/AwwaRF Guidelines in the Reclaimed Water Rule and the Purple Book.

A bioassay is an empirical determination of the delivered dose in a reactor through the use of a technically defensible test methodology in which an appropriate indicator organism — typically a non-pathogenic virus such as MS-2 — is subjected to varying UV doses in the laboratory using a collimated-beam apparatus. The apparatus is designed to permit accurate measurement of UV intensity and controllable, discrete exposure times so analysts can measure defined biological responses (such as log survival ratio) to each dose. The "calibrated" test organism then is introduced to an operating UV reactor, under a wide range of water qualities (i.e. UV transmittances), flowrates and lamp power levels, and the reactor's dose can be inferred based on comparisons of the organism's response in the reactor and in the laboratory.

According to the NWRI/AwwaRF guidelines, bioassays are performed by measuring the reduction in the concentration (inactivation) of a non-pathogenic bioassay microorganism (MS-2 coliphage) across a UV system. To do this, MS-2 is injected to wastewater in front of the UV system and then samples of the UV influent (at a well-mixed location downstream of the MS-2 injection point) and effluent are collected. The samples are analyzed for MS-2. The MS-2 reduction from the influent and effluent samples are compared to that in a collimated beam test to determine the dose delivered by the UV system.

Although not specified in the NWRI/AwwaRF Guidelines, it has become common for sites designed to produce reclaimed water to undergo a Checkpoint Bioassay for field commissioning. A Checkpoint Bioassay (CPB) is a term for a small bioassay (typically eight tests) of a full scale system where the intent is to measure disinfection performance and verify that the system is operating properly. Verification comes by comparing measured performance to expected performance based on the original product bioassay validation. Various approaches for comparing and judging installed systems have been employed.

DISINFECTION GUIDANCE IN THE RECLAIMED WATER FACILITIES MANUAL

The Purple Book provides guidance on implementing the Rule with regard to reclaimed water planning, permitting, design and operation processes. In addition, detailed design guidance is provided for coagulation, filtration, chlorine disinfection and ultraviolet disinfection processes. If full conventional filtration is provided (i.e., coagulation, flocculation and sedimentation then filtration), a one-log credit is provided towards the 5-log virus removal requirement. Direct filtration (without sedimentation) or in-line filtration (without flocculation basins or sedimentation) may be used with lower turbidity secondary effluent. Checklists are provided for planners and design engineers to ensure that all Rule requirements are met and that the treatment and reuse facilities provide adequate reliability in their operation and maintenance. The draft Rule defers to the Purple Book for disinfection process standards. The Purple Book contains specific guidance for designing chemical disinfection systems for reclaimed water production utilizing ozone or chlorine (gaseous, hypochlorite or on-site generation) including optimizing initial chemical mixing, evaluating reactor dynamics, reducing short-circuiting, and designing to meet modal contact time and log reduction requirements. In addition, guidance is provided for minimizing disinfection byproduct formation and avoiding reintroduction of microbes after reclaimed water production (into effluent).

The Purple Book provides design and operational guidance for ultraviolet disinfection, and exempts Class B reclaimed water from certain NWRI/AwwaRF guidelines. The Purple Book describes acceptable protocols for field commissioning tests for Class A and Class B reclaimed water, and provides guidance on design and operational protocols to ensure continuous disinfection performance.

The disinfection section of the Purple Book utilizes information from, and references, the current (2003) NWRI/AwwaRF Guidelines, WEF's 2009 *Design of Wastewater Treatment Plants* (MOP No. 8), and EPA's *Ultraviolet Disinfection Guidance Manual for the Final Long-Term 2 Enhanced Surface Water Treatment Rule* (UVDGM) (USEPA, 2006), addressing design guidance for hydraulics, inlet and outlet criteria and surroundings. In addition, the Purple Book includes general guidance for Computational Fluid Dynamics (CFD), a revised NWRI/AwwaRF design example, and a rerating procedure.

Prior to developing the Purple Book guidance for ultraviolet disinfection for reclaimed water systems for the State, a number of stakeholders (including operators, manufacturers, other consultants and regulators) were contacted to solicit their views regarding the existing State policies and the 2003 NWRI/AwwaRF Guidelines. Based on these discussions, several challenges were identified to implementing the new disinfection guidance standards in the State of Washington:

- Only three of the ten reclaimed water facilities using ultraviolet disinfection permitted by the Department of Ecology were designed in accordance with 2003 NWRI/AwwaRF Guidelines. (Most were designed based on an earlier, outdated computer program called "UVDIS" using total coliform as an indicator, which was the only standard at the time.)

- Only one of these Washington State facilities has undergone a checkpoint bioassay (CPB), the current *de facto* standard for field commissioning tests. The CPB for this facility was designed and performed in accordance with procedures used at reclaimed water facilities in other states, but the regulatory review and approval of the CPB results was hindered by the lack of recognized standards for CPB validation. (As noted elsewhere in this paper, checkpoint bioassays are often difficult to complete accurately at some WWTP sites. In addition, they can be time-consuming, expensive and an economic barrier for the application of UV for lower flow reclaimed water systems.)

- Most of these Washington State facilities do not have UV intensity sensors accurate or reliable enough for use in conjunction with NWRI/AwwaRF Guidelines. (Some manufacturers suggested that UV intensity sensors compliant with German criteria, "DVGW", be mandated instead of "relative" sensors. The DVGW sensors provide actual intensity to the control algorithm instead of a relative intensity reading.) An additional consideration is the sensor fouling rate; many of these systems are in water limited areas with high hardness and the sensors foul rapidly.

- For many of the existing Washington State facilities, additional data is needed (ultraviolet transmittance, hydraulic parameters, etc.) to determine modifications necessary for compliance with NWRI/AwwaRF criteria.

UV INTENSITY MONITORING

Several additional features regarding ultraviolet intensity sensors are under consideration for the final version of the Purple Book: (1) A more prescriptive approach to compliance, similar to the UVDGM; (2) Compliance schedules for existing systems (consider 3rd party sensor systems as an interim measure); (3) Two alternatives for ongoing dose verification similar to the UVDGM for water systems (an option for interim use of a "calculated dose method" or the established "intensity sensor setpoint method"). The calculated dose method has significantly reduced intensity monitoring requirements.

FIELD COMMISSIONING TESTS

Several additional features regarding field commissioning tests are under consideration for the final version of the Purple Book. This includes the possibility of implementing an alternative to a checkpoint bioassay with use of a commissioning checklist, developed with assistance from Trojan Technologies and input from other manufacturers and stakeholders.

Issues with Checkpoint Bioassays

As noted by Petri, An and Moreland (2011), bioassay validations of UV reactors are typically executed with high accuracy, using a test center that has been setup to do microbiological validations with all of the required considerations (e.g. wide ranges of flow capacity and water quality, good control of variables, accurate measurement of operating variables, proper mixing of injected constituents, proper placement of sample ports to collect representative samples). However, it is often more challenging to control variables and perform the testing accurately for

a CPB. In the full-scale installations where CPBs are performed, it can be difficult to achieve steady state conditions and representative sampling. Dead zones, including any branches in piping or channels that do not have through flow, will lead to non-steady conditions. Suitable sampling positions are often difficult to locate properly. Thus, despite the intent of CPBs to verify and/or demonstrate safe operation, they often can only be done at a lower level of accuracy than the product validation testing.

For pressurized UV reactors, performance cannot be scaled to different sized reactors because the flow and UV light fields will differ between them. The performance of tested units must be added in series or in parallel to achieve the design for systems requiring higher doses or higher total flows, respectively. Open-channel UV reactors with uniform lamp spacing are a special case of reactors that can be scaled due to modularity, given certain constraints. This scaling enables the design of UV systems that can be very large, beyond the practical size limit that can be bioassay validated with current best practices. Thus, CPBs serve to answer two questions: (1.) does performance scale-up for modular UV systems? (2.) are there any site-specific issues that change the performance of the UV system?

Petri, An and Moreland (2011) compiled the results of CPBs from nine different sites for an open-channel modular UV reactor. They compared measured MS-2 doses from CPBs for the installed UV reactors to the predicted MS-2 doses (from the original product validation) at the same tested conditions. The CPB and predicted MS-2 doses were well correlated, with a slope near to unity and a high coefficient of determination ($r^2 = 0.8707$). It was determined that, for properly conducted CPBs, two main root causes were identified for UV system performance to be impacted at a site: challenging hydraulics and civil works out of tolerance.

Hydraulic Issues

Typically modular UV reactors have lamps arranged in a grid with uniform spacing between lamps. If the water entering the reactor is not evenly distributed, velocities will be different in different zones of the reactor. This situation can arise if water is forced to abruptly change direction immediately prior to the UV reactor: water will be accelerated to the outside of the turn and the lamps on that side of the grid will see flow at a higher velocity than lamps on the other side of the grid. Water travelling rapidly through the UV reactor will have a shorter residence time ("short-circuit") and a lower UV dose, while the water travelling slowly will receive a higher UV dose. These non-uniform hydraulics result in a broadening of the dose distribution relative to UV systems with uniform hydraulics (see Figure 2), resulting in a substantial increase in the amount of pathogens receiving lower doses. This can be problematic for compliance, because of the requirement for delivery of adequate dose to 99.999% of pathogens (5-log removal).

If these hydraulic issues exist at a given site, they can be mitigated and/or eliminated in a number of ways. The main cause of hydraulic impacts is an abrupt change in direction. Firstly, such changes in direction can be avoided in the design phase. In some cases UV systems are added to existing channels; the hydraulic impacts being considered do get mitigated with distance, so by allowing some distance from a turn to the start of the UV system the impacts can be minimized or eliminated. Relatively small changes to the channels that make directional changes less abrupt (e.g. rounding corners) can result in large mitigations of hydraulic impacts. Finally, flow modifiers such as stilling plates could also be considered to help minimize hydraulic impacts, but such devices are often considered a last resort in severe cases. Hydraulic issues are site specific, and any required mitigations can only be considered and evaluated by experts on a site-specific basis (Petri, An and Moreland, 2011).

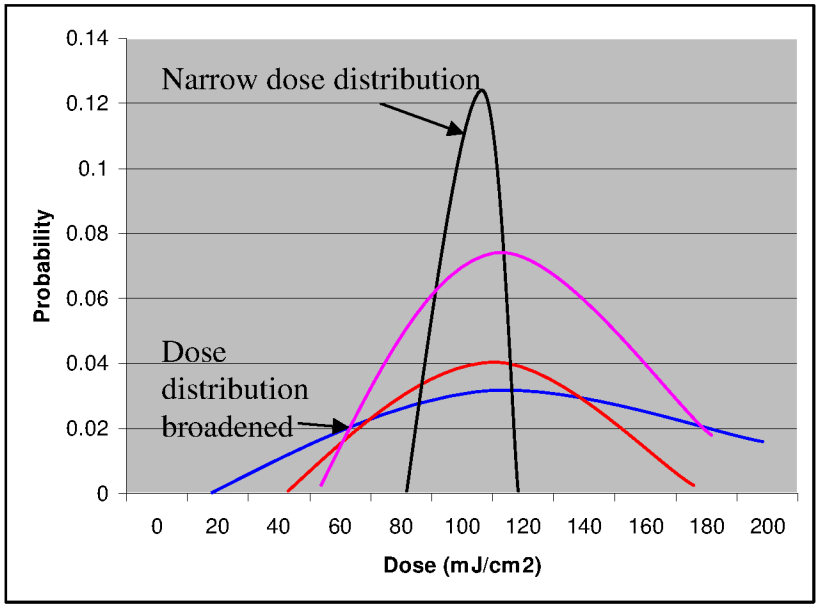

Figure 2. Hypothetical Dose Distributions from Ultraviolet Disinfection Systems (based on Wright, et. al. IUVA, 2001)

Civil Works Out of Tolerance

Petri, An and Moreland (2011) identified a second issue that often affects UV reactor performance: off-specification civil works. Because modular UV reactors are designed and manufactured with precise lamp spacings, it is necessary that those same spacings are maintained at reactor edges (channel walls and channel bottom). If civil works are completed out of specification (out of tolerance), then the lamp spacings at the edges of the UV system will not be at design values. If for example the channel walls are built too wide, or the channel bottom elevation is too deep, then lamp spacing at UV reactor edges will be larger than design and zones with UV intensities lower than design will be created. Microbes traveling through the low intensity zones will receive relatively low UV doses, and a higher number of survivors will exit the UV reactor. Ultimately, the population of microbes passing through the reactor will contain a higher proportion of survivors, and the corresponding overall UV dose will be necessarily lower (as dose is defined in terms of microbiological inactivation).

Petri, An and Moreland (2011) described one CPB site in which the initial CPB tests identified one bank of lamps performing differently (lower) than the others. In a second CPB, this was verified and an additional bank was also identified with lower performance. Both banks were the last banks in two different channels, and upon investigation it was determined that the channels were too low in elevation at the position of the last banks. Microbes traveling along the bottom of each channel were probably being exposed to lower UV doses in the last bank. As a mitigation measure, the UV module support structures in the last banks were re-installed at a

lower elevation that returned the spacing at the bottom to the design value. A final CPB of the modified UV system confirmed that the performance of all banks was similar and at expected levels. In another of the CPB sites, the initial CPB tests identified UV reactor performance significantly lower than expected. Given the prior experience above, the civil works were inspected and it was determined that the channel width was too wide. Microbes traveling near the walls of the channel were probably being exposed to lower UV doses than at other positions in the UV reactor. As a mitigation, the channel width was narrowed by applying an epoxy coating to the channel walls. A final CPB of the UV system verified that the performance had increased to expected levels.

Because of the challenges of completing accurate CPBs and the ability to use other techniques to identify the two most common issues (hydraulics and out-of-tolerance construction), Petri, An and Moreland (2011) recommended that CPBs not be mandated as commissioning tests unless special circumstances require them. Consistent with this recommendation, a checklist is proposed that can be used to ensure proper consideration of hydraulics and construction tolerances. If challenging hydraulic designs already exist, or civil works get completed out of tolerance, there are relatively simple modifications that can be done to mitigate performance impacts.

FIELD COMMISSIONING CHECKLIST

With the commissioning checklist approach (summarized in Table 3), one or more of the criteria below must be met. (If these commissioning checklist criteria cannot be adequately met, a checkpoint bioassay would be required.)

1. The system must be designed with adherence to inlet hydraulic criteria, including limitations on the velocity in the entrance pipe and provision of a stilling well to dissipate energy and prevent flow field distortions. Sharp turns and bends must be avoided within three hydraulic diameters of the first UV bank. Chamfers and rounding of inside corners must be provided. Construction tolerances (channel width and depth) must be verified on-site to be within manufacturer's specifications.

2. CPBs are required unless the system is compliant with the criteria identified under Items 1 thru 7 in Table 3 (as applicable).

3. Compliance with the criteria identified in Item # 5 in Table 3 requires CFD modeling or site velocity profiling.

4. If sharp turns, bends or edges cannot be avoided, flow conditioning must be provided and its performance verified (perforated plates or flow-directing vanes).

5. CFD modeling, if selected, must be performed to validate commissioning and scale-up by experienced personnel and reviewed by a licensed engineer, and must comply with the 2006 UVDGM Appendix D guidelines (EPA, 2006), as described below.

As noted in the Checklist and above, CFD modeling is one approach that is acceptable for system commissioning under certain circumstances. Under these circumstances, CFD modeling of UV dose delivery at full-scale installation can be used to quantify full-scale dose delivery relative to dose delivery achieved during validation. When performed to meet system commissioning requirements in the Checklist, the CFD modeling must comply with the 2006 UVDGM Appendix D guidelines.

As noted in UVDGM Appendix D, there are several issues that should be considered and addressed before a CFD-based approach is implemented for the purposes of the UV Field Commissioning Checklist:

- There is little agreement on appropriate procedures for assessing the credibility of CFD models.

- CFD models for prediction of UV dose delivered by a reactor comprise coupled submodels for turbulent flow, microbial transport, UV intensity, and microbial inactivation. Many options and approaches are available for each sub-model. Currently, no consensus has been reached for which approaches are most suitable for predicting UV dose delivery in a full-scale reactor.

- CFD modeling of UV dose delivery requires a multi-disciplinary approach. Knowledge of fluid mechanics, light physics, microbial inactivation, numerical modeling, and UV process engineering is essential for credible CFD modeling of UV dose delivery. The pool of this type of integrated expertise is currently limited, which presents a challenge for states tasked to review CFD modeling reports.

Table 3. UV System Commissioning Checklist Proposed in Draft Reclaimed Water Facilities Manual

ITEM #1 - SCALE UP - CLOSED VESSEL REACTORS

Checklist Item - Valid Bioassay

Comment / Recommended Change - For pressurized UV reactors performance cannot be scaled to different sized reactors.

Rationale - The flow and UV light fields will differ between reactors.

Scientific Reference - – N/A

Recommended Checklist Compliance Criteria - 3rd party bioassay validation following NWRI/AwwaRF protocol. Scale up not acceptable.

ITEM #2 - SCALE UP - OPEN CHANNEL REACTORS

Checklist Item - Valid Bioassay

Comment / Recommended Change - Open-channel UV reactors with uniform lamp spacing are a special case of reactors that can be scaled due to modularity, given certain constraints. The modularity translates to uniform lamp arrangements and lamp spacings between smaller and larger versions.

Rationale - See NWRI/AwwaRF guidelines

Scientific Reference - Results of CPBs from nine different sites for TrojanUV3000Plus™ open-channel modular UV reactor demonstrated that the CPB and predicted MS-2 doses were well correlated, with a slope near to unity and a high coefficient of determination ($r^2 = 0.8707$). The strength of this relationship together with the uncertainty inherent in full scale testing the scale-up assumption is effectively proven to be valid for modular open-channel UV reactors. Trojan Technologies paper "UV System Checkpoint Bioassays: Proof of Scale-up, Challenges from the Field, and Comparison Methodology".

Recommended Checklist Compliance Criteria - 3rd party bioassay validation following NWRI/AwwaRF protocol. Scale up limited to 10x as per NWRI/AwwaRF protocol.

ITEM #3 - SITE ISSUE - INLET HYDRAULICS TO REACTOR

Checklist Item - Providing adequate stilling basin(s)/well(s) leading into UV channels

Comment / Recommended Change –

1. Need to restrict inlet jet velocity of inlet pipes; therefore, size inlet pipes for a maximum of 1.5 m/s max pipe velocity.

2. Size inlet well to adequately dissipate energy of inlet jet and avoid aiming directly into UV channel by incorporating a minimum size of:

   - Depth sufficient to locate inlet pipe 1.5 to 2.5 pipe dia. below floor of UV channel

   - Width at 1.5 x the UV Channel width x number of Channels in parallel

   - Length at the greater of the UV Channel width or nominal depth.

Rationale - Helps to keep head loss, large scale turbulence and flow field distortions to manageable levels

Scientific Reference - The intent of these points is to the keep velocity profiles leading into reactors within adequate tolerances and to ensure impact on expected and/or validated reactor performance remains negligible.

Recommended Checklist Compliance Criteria - Inlet pipe velocity $\leq$ 1.5 m/s. Inlet well dimensions meet comments (1) and (2).

ITEM #4 - SITE ISSUE - INLET HYDRAULICS TO REACTOR (II)

Checklist Item - Avoid sharp turns/bends/edges within 3 x Hydraulic Diameters of 1st UV bank

Comment / Recommended Change - Locate 1st Bank with sufficient lead-in distance.

1. Set lead-in distance at least 3 hydraulic diameters downstream of Inlet Well where hydraulic diameter is defined as 4 x Rh where Rh = Hydraulic Radius = Flow cross section/wetted perimeter

2. Avoid Inlet Edges and Bends/Elbows. Chamfer or round edges and corners approximately equal to Rh of UV Channel.

Rationale

1. Reduces risk of UV Banks being in location with flow trips and/or recirculation zones.

Use of hydraulic diameter allows the lead-in to scale with reactor size and hence maintain similar inlet hydraulic conditions regardless of the scale-up of the reactor.

2. If possible, chamfers and rounding of inside corners (e.g. 8x8 to 12x12 inch chamfers and 12" rounding) helps to reduce distortion of velocity profiles leading into reactor.

Scientific Reference - The intent of these points is to the keep velocity profiles leading into reactors within adequate tolerances and to ensure the impact on expected and/or validated reactor performance remains negligible

Recommended Checklist Compliance Criteria
1st UV bank lead-in distance ≥ 3 hydraulic diameters. Chamfers and rounding inside corners required as necessary.

ITEM #5 - SITE ISSUE - INLET HYDRAULICS TO REACTOR (III)

Checklist Item - If sharp turns/bends/edges cannot be avoided, provide adequate flow conditioning to remove their effects.

Comment / Recommended Change

1. Use perforated plates each with between 40 to 60% open area to correct velocity profiles.

2. If necessary use guide vanes to correct flow field distortions due to turns or bends within UV Channels

Rationale

1. Avoid perforated plates with less than 40% open area since they can produce their own flow distortions and recirculation zones. Space multiple perforated plates at least 5 to 6 times the hole diameter of perforations; this allows sufficient spacing for individual jets to recombine ahead of subsequent plates in order to achieve maximum flow field correction with minimal footprint.

2. Design of guide vanes should be performed by specialists expert in hydrodynamic and/or hydraulic design.

Scientific Reference - The intent of these points is to the keep velocity profiles leading into reactors to within adequate tolerances and to ensure impact on expected and/or validated reactor performance remains negligible.

Recommended Checklist Compliance Criteria

Provide on-site velocity profiling or CFD modeling; Perforated plate(s) in compliance with the above comments (1) and (2)

ITEM #6 - SITE ISSUE - HYDRAULICS IN REACTOR

Checklist Item - Water Level Check

Comment / Recommended Change - Confirm the level control device(s) is set up at manufacturer's recommended elevation relative to reactor. Also confirm that Level Control Devices across multiple channels are located at the same elevation.

Rationale - Incorrect weir setup can result in water level exceeding design limits and short circuiting over the UV bank. Elevation offsets of level control devices across multiple channels can produce large flow imbalances which can negatively affect disinfection performance and discharge capacity.

Scientific Reference - Elevation effects in Multi-channel arrangements can results in different hydraulic gradients among channels which results in flow imbalances.

Recommended Checklist Compliance Criteria - Confirm Level Control Device is installed and set properly as per manufacturer's instructions. Measure water level at the design flow rate for all UV banks and ensure level is less than the UV manufacturer's maximum water level limit for all UV banks.

In multi-channel applications confirm elevation of Level Control Devices is within manufacturer's required tolerances. Any expected residual imbalance should be accounted for in overall design and sizing of system by consulting engineers.

ITEM #7 - SITE ISSUE - OFF SPECIFICATION CIVIL WORKS

Checklist Item - Channel Construction Tolerance

Comment / Recommended Change - Because modular UV reactors are designed and manufactured with precise lamp spacings, it is necessary that those same spacings are maintained at reactor edges (channel walls and channel bottom). If civil works are completed out of specification (out of tolerance), then the lamp spacings at the edges of the UV system will not be at design values.

Rationale - If the channel walls are built too wide, or the channel bottom elevation is too deep, then lamp spacings at UV reactor edges will be larger than design and zones with UV intensities lower than design will be created. Microbes travelling through the low intensity zones will receive relatively low UV doses, and a higher number of survivors will exit the UV reactor. Ultimately, the population of microbes passing through the reactor will contain a higher proportion of survivors, and the corresponding overall UV dose will be necessarily lower (as dose is defined in terms of microbiological inactivation).

Scientific Reference - Results of CPBs showed that banks in channels have been found installed too high and, in others, channels built too wide/deep. As mitigation, the UV module support structures were re-installed returning the spacing at the bottom to the design value. For the other, the channel width/depth was corrected. Repeated CPBs confirmed that the performance of all banks were at expected levels after civil/installation works were returned to recommended tolerances.

Recommended Checklist Compliance Criteria - Channel civil works within construction tolerance stated by manufacturer for all UV banks.

Reactor installation is within tolerances stated by the manufacturer.

If the criteria identified in Items 1 through 7 has not been met for an installation, a CPB must be performed in accordance with the criteria in Items 8 through 11.

ITEM #8 - SITE ISSUE - CPB TESTING PROTOCOLS MET (STEADY STATE & WATER QUALITY)

Checklist Item - CPB Protocols

Comment / Recommended Change - There are numerous details that must be considered to ensure accurate CPB results. Without proper appreciation for all of the requirements of accurate measurements and assignment of performance to accurate conditions (flow rate and water quality), CPBs can result in misleading information.

Rationale - See NWRI/AwwaRF guidelines

Scientific Reference - See NWRI/AwwaRF guidelines and "UV System Checkpoint Bioassays: Proof of Scale-up, Challenges from the Field, and Comparison Methodology" (Petri, An and Moreland)

Recommended Checklist Compliance Criteria - 3rd party bioassay validation following NWRI/AwwaRF protocol including the following protocol steps: tests to determine the time to reach steady state; mixing tests to prove that the position of the upstream sampling port is appropriate; mixing tests to prove that the position of the downstream sampling port is appropriate; the verification of flow meter accuracy; the verification of UV transmittance monitor accuracy; approved method to monitor flow stability and water quality stability during testing to ensure the maintenance of steady state; documented & approved microbiological sample handling; documented & approved UV collimated beam methodology.

ITEM #9 - SITE TESTING ISSUE – AVOIDING CPB DEAD ZONES

Checklist Item - CPB Dead Zones

Comment / Recommended Change - Any branches in piping or channels that do not have through flow will be dead zones that will complicate steady state.

Rationale - Dead zones can lead to erroneous results because they can be transient sources or sinks of microbes that can contaminate samples in later tests.

Scientific Reference -

Recommended Checklist Compliance Criteria - Site CPB process flow chart documenting all piping/channels, etc. and all possible dead zones identified. CPB testing protocol to document how each potential dead zone will be mitigated to not impact test and how they will be mitigated during the CPB test.

ITEM #10 - SITE TESTING ISSUE - CPB DATA ACCURACY

Checklist Item - CPB Results Accuracy

Comment / Recommended Change - Utilizing CPB data at face value without consideration of whether it has a bias (e.g. flow or UV transmittance offset) or whether it has lower accuracy than the data it is being compared to will result in incorrect determination of pass/fail (criteria).

Rationale - The accuracy or uncertainty of the CPB results should be estimated. The uncertainty should be used in comparisons to product validation efforts.

Scientific Reference – UV systems could be judged by whether their CPB results fall within an acceptable band that could be based upon statistics or upon a sensitivity analysis (how much is dose expected to change if the UVT or the flow were different by a given amount)

Recommended Checklist Compliance Criteria – Statistical or sensitivity analysis

ITEM #11 - CPB PASS FAIL CRITERIA

Checklist Item - CPB Pass

Comment / Recommended Change - TBD

Rationale -- TBD

Scientific Reference - - TBD

Recommended Checklist Compliance Criteria - Pass / fail criteria are under consideration by NWRI/AwwaRF. Current pass fail criteria methodology is not well defined and needs to be further clarified by NWRI/AwwaRF.

ITEM #12 - CFD CRITERIA

Checklist Item – CFD Criteria (proposed)

Comment / Recommended Change - As noted in the UVDGM CFD guidelines (EPA, 2006), a generalized modeling approach for using CFD for predicting UV dose delivery involves the following:

1. Construct a 3-D computational model of the UV system, including all major components that influence the flow patterns in the reactor. This includes resolution of all wetted surfaces in the reactor and the upstream/downstream piping systems.

2. Perform a steady-state CFD simulation by solving governing flow equations (i.e., Navier-Stokes and turbulence equations). This results in a prediction of point velocities across the interior of the UV system for the specified inlet flow rate.

3. Perform a UV intensity simulation for the UV system using a UV light intensity model. This results in a prediction of point UV intensity values across the interior of the UV system for specified values of UV lamp intensity and UVT.

4. Perform a particle tracking simulation using the combined numerical flow/UV intensity field. A random walk or particle physics model may be employed. Hundreds of numerical particles are randomly "injected" at the model inlet, and their x,y,z coordinates are predicted as a function of time. The result is a predicted path line for each injected particle, which represents a random microbial path through the reactor.

5. Calculate the estimated UV dose for each injected particle by summing the cumulative UV dose at a series of points along the predicted particle path. The result is a UV dose distribution.

6. Determine the log inactivation and RED for a microorganism with known UV inactivation kinetics based on the UV dose distribution calculated in Step 5. If CFD is applied for simulation of UV dose delivery, it should adhere to the following guidelines:

    a. Only a qualified party with appropriate expertise should develop a CFD-based hydraulic or full UV reactor performance model. Such parties could include a professional engineer with extensive modeling experience, a CFD consulting firm, or a manufacturer with review by an independent CFD consultant.

    b. The same overall modeling approach and sub-models should be used for both the

validation site model and the WTP model. At a minimum, the following QA/QC procedures should be used during CFD model development and execution:

c. The density of the numerical grid and size of the time step used in simulations affect CFD results. In general, results become more accurate as the grid becomes finer and the time step becomes smaller. Grid and time-step convergence analysis should be performed to verify that grid and time-step sizes are sufficiently resolved such that smaller grid and time step sizes do not change predicted results. Procedures for this analysis are presented in the *Guide for the Verification and Validation of Computational Fluid Dynamics Simulations* (AIAA 1998). Numerical convergence and consistency of the CFD models should be verified and documented. Procedures for this analysis are presented in the above referenced AIAA guide.

d. A sensitivity analysis of the major parameters that affect UV-dose prediction should be conducted. Examples include (but are not limited to) boundary conditions for lamp UV output and reactor wall reflection, number of particles used in a microbial transport simulation, and UV dose-response inactivation constants.

e. CFD models should not be calibrated with experimental RED data for the purposes of obtaining agreement between model predictions and field measured values. Calibration to RED data for a limited set of conditions does not necessarily improve the accuracy of future predictions, particularly because hydraulic conditions can greatly differ between the validation site and the WWTP installation.

f. Error estimates and confidence intervals for the CFD model predictions should be developed for both the validation site and the WWTP installation. This could be performed by comparing CFD model predictions and experimental data for the validation site, then assuming the same level of error for the CFD model prediction for the WWTP installation (EPA, 2006).

Rationale -- As discussed previously, CFD is still an emerging technology, and CFD models for UV dose delivery are complex. Uncertainty and error ranges for these models are not known. Given these issues, CFD-based UV dose delivery models should undergo a formal industry-wide verification and validation process. As noted in the UVDGM CFD guidance (EPA, 2006), and discussed below, a possible approach for verification and validation of hydraulic CFD models is outlined in the American Institute of Aeronautics and Astronautics (AIAA) CFD guide (1998).

The AIAA guide provides a reasonable means for assessing the credibility of modeling and simulation for CFD in a broad range of applications. However, since it has been developed outside the water/wastewater sector, and is focused on astronautics and aeronautics, there will be challenges in adapting this guidance to ultraviolet disinfection. Because of this, experienced CFD modelers are required in order to use CFD for the purposes identified in the UV Field Commissioning Checklist.

Scientific Reference - - UVDGM CFD guidelines (EPA, 2006), *Guide for the Verification and Validation of Computational Fluid Dynamics Simulations* (AIAA 1998).

Recommended Checklist Compliance Criteria - Conduct model verification and validation per the applicable guidance in the 1998 AIAA guide.

The AIAA guide defines verification as "the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model." Verification assessment examines if the computational models are the correct implementation of the conceptual models, and if the resulting code can be properly used for an analysis. The strategy is to identify and quantify the errors in the model implementation and the solution.

Verification involves error estimation, which is determining the accuracy of a single calculation and putting an error band on the final value. This approach involves performing a grid convergence study and determine the observed order of convergence, error bands, and grid convergence indices (GCI). Per the AIAA guidelines, the process for Verification Assessment of a CFD code and / or simulation can be summarized as evaluation of the following elements: the Computer Code, Iterative Convergence, Consistency, Spatial (Grid) Convergence, Temporal Convergence, and a comparison of CFD Results to Highly Accurate Solutions.

The AIAA guide defines validation is defined as "the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model." Validation examines if the conceptual models, computational models as implemented into the CFD code, and computational simulation agree with real world observations. Per the AIAA guidelines, the process for Validation Assessment of a CFD simulation can be summarized as an evaluation of the following elements: Iterative Convergence, Consistency, Spatial (Grid) Convergence, Temporal Convergence, a comparison of CFD Results to Experimental Data, and an examination of Model Uncertainties.

Additional review and development is currently being conducted regarding this commissioning checklist, including (1) how to apply this checklist to different manufacturers and applications (2) methods for extrapolation of existing data to different systems with different hydraulics, lamp spacing, ultraviolet transmittance, and (3) requirements for regulator or third-party reviews.

CONCLUSIONS

Washington State's new draft "Reclaimed Water Rule" and draft *Reclaimed Water Facilities Manual* ("Purple Book") includes new guidelines for design, commissioning and operation of disinfection systems for reclaimed water facilities. The disinfection section of the Purple Book addresses the design guidance for hydraulics, inlet and outlet criteria and surroundings.

The Purple Book includes a checklist for use in field commissioning of ultraviolet disinfection systems used to disinfect reclaimed water. The checklist includes criteria for key factors that influence the performance of UV systems, including hydraulics and construction tolerances. The checklist includes provisions for checkpoint bioassays and computational fluid dynamics (both of which are suggested only under certain circumstances). Additional review and development is currently being conducted regarding this commissioning checklist, including (1) how to apply this checklist to different manufacturers and applications (2) methods for extrapolation of existing data to different systems with different hydraulics, lamp spacing, ultraviolet transmittance, and (3) requirements for regulator or third-party reviews.

REFERENCES

1. American Institute of Aeronautics and Astronautics (AIAA), *Guide for the Verification and Validation of Computational Fluid Dynamics Simulations,* 1998.

2. EPA, *Ultraviolet Disinfection Guidance Manual for the Final Long-Term 2 Enhanced Surface Water Treatment Rule* (UVDGM) (USEPA, 2006).

3. Gray and Osborne, Inc., the Washington State Department of Ecology, and the Washington State Department of Health, *Washington State Reclaimed Water Facilities Manual* (Draft), January 2011.

4. NWRI/AwwaRF. *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*, 2nd ed.; Fountain Valley, CA, 2003.

5. Petri, An and Moreland, *UV System Checkpoint Bioassays: Looking Back and Moving Forward, Applying the Lessons,* presented at WEFTEC 2011.

6. Washington State Departments of Ecology and Health, *Water Reclamation and Reuse Standards*, September 1997.

7. Water Environment Federation, Manual of Practice No. 8, *Design of Municipal Wastewater Treatment Plants*, 2010.

8. Wright, H.B., Understanding Reduction Equivalent Dose with UV Disinfection Reactors, IUVA News, **3(6)**, 16–20. 2001.

Notes:
Velocity profiling can be performed in lieu of a CPB.
No CPB is required if complaint with points 1 thru 7 (as appropriate).
Compliance with item 5 requires CFD modelling or site velocity profiling.
CFD modelling must comply with the 2006 UVDGM Appendix D guidelines.

	Issue	Checklist Item	Comment / Recommended change	Rationale	Scientific reference	Recommended Check List Compliance Criteria
1	Scale Up - Closed vessel reactors	Valid Bioassay	For pressurized UV reactors performance cannot be scaled to different sized reactors.	The flow and UV light fields will differ between reactors.		3rd party bioassay validation following NWRI protocol. Scale up not acceptable.
2	Scale Up - open channel reactors	Valid Bioassay	Open-channel UV reactors with uniform lamp spacing are a special case of reactors that can be scaled due to modularity, given certain constraints. the modularity translates to uniform lamp arrangements and lamp spacing's between smaller and larger versions.	See NWRI guidelines	Results of CPBs from nine different sites for 3000+ open-channel modular UV reactor demonstrated that the CPB and predicted MS2 doses were well correlated, with a slope near to unity and a high coefficient of determination (r2 = 0.8707). The strength of this relationship together with the uncertainty inherent in full scale testing the scale-up assumption is effectively proven to be valid for modular open-channel UV reactors. Trojan Technologies paper "UV System Checkpoint Bioassays: Proof of Scale-up, Challenges from the Field, and Comparison Methodology".	3rd party bioassay validation following NWRI protocol. Scale up limited to 10x as per NWRI protocol.
3	Site Issue - Inlet hydraulics to reactor	Providing adequate stilling basin(s)/well(s) leading into UV channels	1) Need to restrict inlet jet velocity of inlet pipes therefore size inlet pipes for a maximum of 1.5 m/s max pipe velocity. 2) Size inlet well to adequately dissipate energy of inlet jet and avoid aiming directly into UV channel by incorporating a minimum size of: - Depth sufficient to locate inlet pipe 1.5 to 2.5 pipe diameters below floor of UV channel - Width at 1.5 x the UV Channel width x number of Channels in parallel - Length at the greater of the UV Channel width or nominal depth.	Helps to keep head loss, large scale turbulence and flow field distortions to manageable levels	The intent of these points is to the keep velocity profiles leading into reactors to within adequate tolerances and to ensure impact on expected and/or validated reactor performance remains negligible	Inlet pipe velocity ≤ 1.5 m/s. Inlet well dimensions meet comments 1) & 2).
4		Avoid sharp turns/bends/edges within 3 x Hydraulic Diameters of 1st UV bank	Locate 1st Bank with sufficient lead-in distance. 1) Set lead-in distance at least 3 hydraulic diameters downstream of Inlet Well where hydraulic diameter is defined as 4 x Rh where Rh = Hydraulic Radius = Flow cross section/wetted perimeter 2) Avoid Inlet Edges and Bends/Elbows. Chamfer or round edges and corners approximately equal to Rh of UV Channel.	1) Reduces risk of UV Banks being in location with flow trips and/or recirculation zones. Use of hydraulic diameter allows the lead-in to scale with reactor size and hence maintain similar inlet hydraulic conditions regardless of scale-up of reactor 2) If possible, Chamfers & rounding of inside corners (e.g. 8x8 to 12x12 inch chamfers and 12" rounding) helps to reduce distortion of velocity profiles leading into reactor.		1st UV bank lead in distance ≥ 3 hydraulic diameters. Chamfers and rounding inside corners done - Yes.
5		If sharp turns/bends/edges cannot be avoided provide adequate flow conditioning to remove the their effects	1) Use one or more perforated plates each with between 40 to 60% open area to correct velocity profiles. 2) If necessary use guide vanes to correct flow field distortions due to turns or bends within UV Channels	1) Avoid perforated plates with less than 40% open area since they can produce their own flow distortions and recirculation zones. Space multiple perforated plates at least 5 to 6 times the hole diameter of perforations; this allows sufficient spacing for individual jets to recombine ahead of subsequent plates in order to achieve maximum flow field correction with minimal footprint. 2) Design of guide vanes should be performed by specialists expert in hydrodynamic and/or hydraulic design.		Perforated plate(s) in compliance to points 1) & 2)

6		Water Level Check	Confirm the level control device(s) is set up at manufactures recommended elevation relative to reactor. Also confirm that Level Control Devices across multiple channels are located at the same elevation.	Incorrect weir set up can result in water level exceeding design limit and having short circuiting over the UV bank. Elevation offsets of level control devices across multiple channels can produce large flow imbalances which can negatively affect disinfection performance and discharge capacity.	Elevation effects in Multi-channel arrangements can results in different hydraulic gradients among channels which results in flow imbalances.	Confirm Level Control Device is installed & set properly as per manufacturer's instructions. Measure water level at the design flow rate for all UV banks and ensure level is less than the UV manufactures maximum water level limit for all UV banks. In multi-channel applications confirm elevation of Level Control Devices is within manufacturer's required tolerances. Any expected residual imbalance should be accounted for in overall design and sizing of system by consulting engineers.
	Issue	**Checklist Item**	**Comment / Recommended change**	**Rationale**	**Scientific reference**	**Recommended Check List Compliance Criteria**
7	Site Issue - off specification civil works	Channel Construction Tolerance	Because modular UV reactors are designed and manufactured with precise lamp spacing's, it is necessary that those same spacing's are maintained at reactor edges (channel walls and channel bottom). If civil works are completed out of specification (out of tolerance), then the lamp spacing's at the edges of the UV system will not be at design values.	If the channel walls are built too wide, or the channel bottom elevation is too deep, then lamp spacing's at UV reactor edges will be larger than design and zones with UV intensities lower than design will be created. Microbes travelling through the low intensity zones will receive relatively low UV doses, and a higher number of survivors will exit the UV reactor. Ultimately, the population of microbes passing through the reactor will contain a higher proportion of survivors, and the corresponding overall UV dose will be necessarily lower (as dose is defined in terms of microbiological inactivation).	Results of CPBs showed that banks in channels have been found installed too high and, in others, channels built too wide/deep. As mitigation, the UV module support structures were re-installed returning the spacing at the bottom to the design value. For the other, the channel width/depth was corrected. Repeated CPB's confirmed that the performance of all banks were at expected levels after civil/installation works were returned to recommended tolerances.	Channel civil works within construction tolerance stated by manufacturer for all UV banks. Reactor installation is within tolerances stated by the manufacturer.
8	Site Testing Issue - CPB Testing Protocols met (steady state & water quality)	CPB Protocols	There are numerous details that must be considered to ensure accurate CPB results. Without proper appreciation for all of the requirements of accurate measurements and assignment of performance to accurate conditions (flow rate and water quality), CPBs can result in misleading information.	See NWRI guidelines	See NWRI guidelines; Trojan Technologies paper "UV System Checkpoint Bioassays: Proof of Scale-up, Challenges from the Field, and Comparison Methodology".	3rd party bioassay validation following NWRI protocol including the following protocol steps: tests to determine the time to reach steady state; mixing tests to prove that the position of the upstream sampling port is appropriate; mixing tests to prove that the position of the downstream sampling port is appropriate; the verification of flow meter accuracy; the verification of UV transmittance monitor accuracy; approved method to monitor flow stability and water quality stability during testing to ensure the maintenance of steady state; documented & approved microbiological sample handling; documented & approved UV collimated beam methodology.
9	Site Testing Issue - CPB Dead Zones	CPB Dead Zones	Any branches in piping or channels that do not have through flow will be dead zones that will complicate steady state.	Dead zones can lead to erroneous results because they can be transient sources or sinks of microbes that can contaminate samples in later tests.		Site CPB process flow chart documenting all piping/channels, etc. and all possible dead zones identified. CPB testing protocol to document how each potential dead zone will be mitigated to not impact test and how they will be mitigated during the CPB test.
10	Site Testing Issue - CPB Data Accuracy	CPB Results Accuracy	Utilizing CPB data at face value without consideration of whether it has a bias (e.g. flow or UV transmittance offset) or whether it has lower accuracy than the data it is being compared to will result in incorrect determination of pass/fail (criteria).	The accuracy or uncertainty of the CPB results should be estimated. The uncertainty should be used in comparisons to product validation efforts.	UV systems could be judged by whether their CPB results fall within an acceptable band that could be based upon statistics or upon a sensitivity analysis (how much is dose expected to change if the UVT or the flow were different by a given amount)	
11	CPB Pass Fail Criteria	CPB Pass	TBD	TBD	TBD	Pass / fail criteria are under consideration by NWRI. Current pass fail criteria methodology is not well defined and needs to be further clarified by NWRI.

No CPB is required if complaint with points 1 thru 7 (as appropriate).
Compliance with item 5 requires CFD modelling or site velocity profiling.
CFD modelling must comply with the 2006 UVDGM Appendix D guidelines.