Direct Potable Reuse - Getting Operations Ready for the Next Bold Leap

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ABSTRACT

Many water agencies in the United States and around the world have been turning to the potable reuse of municipal wastewater, either directly or indirectly, to help meet growing demands. Direct Potable Reuse (DPR) is the supply of highly treated reclaimed water directly to a drinking water treatment plant or distribution system, with or without an engineered storage buffer. This differs from Indirect Potable Reuse (IPR) which is already practiced in many areas of the US and involves the inclusion of an environmental buffer (such as a lake, reservoir or aquifer) prior to arriving at the intake of a drinking water treatment plant. There are a number of potential benefits of DPR relative to IPR, including reduced energy requirements, reduced construction costs and reduced operational costs. DPR may even provide an opportunity to allow potable reuse in situations where a suitable environmental buffer is not available for IPR.

All water treatment facilities require a high level of reliability to ensure water is delivered to an acceptable quality and the risk to public health is minimized. This importance is underlined in the case of DPR, where the real risks of higher contaminant levels in plant feed water (e.g., during epidemics or after industrial accidents), along with perceived risks associated with public perception of reuse, require a high level of operational certainty. Consistent and assured levels of reliability can be met only with a holistic asset management framework including a robust design, effective and transparent operational management, a carefully managed maintenance strategy, and proven response procedures. The plant must be designed correctly, it must be operated well with realistic and practical demands on operations staff, and the assets and infrastructure must be maintained in a highly reliable condition.

As the perceived "human element" in the process, operations must have robust and reliable operational plans, systems, and processes to ensure safety and reliability - essential elements for the advancement of public acceptance of recycling for potable use. Relative to existing water and wastewater treatment systems, operations teams are under much greater scrutiny for performance, and must therefore have adequate training and certification processes in place to provide a framework for developing and evaluating the necessary skills for successful operation and management of water recycling systems.

This paper will present some of the work of Watereuse Research Foundation Study (WRRF 13-13 - Development of Operation and Maintenance Plan and Training and Certification Framework for Direct Potable Reuse Systems, which outlines an Operations and Maintenance Framework for DPR.

KEYWORDS

Direct potable reuse, DPR, DPR operations, Reuse Training and Certification, Operational Framework, Critical Control Points CCPs, HACCP, multi-barrier, risk assessment.

INTRODUCTION

As continued population growth, increasing urban density, and varying climate place heavy burdens on our nation's water supplies, water agencies and policy makers are examining innovative ways to stretch water supplies, to sustain population growth rates, and to provide reliability and redundancy in their supply portfolio. As such, many water agencies around the United States and around the world have been turning to the potable reuse of municipal wastewater, either directly or indirectly, to help meet growing demands.

Indirect potable reuse (IPR) is already practiced in many areas of the country, both as part of intentional IPR projects as well as part of *de facto* environmental processes whereby one community's effluent becomes the next community's drinking water supply (Rice, Wutich and Westerhoff 2013). In all IPR projects, be they intentional or unintentional, the reclaimed water spends time in an environmental buffer such as a river, lake, reservoir, or aquifer prior to being recovered, further treated and then distributed to drinking water customers. Environmental buffers in IPR projects have had a number of important functions attributed to them, including additional treatment of waterborne pathogens and chemical contaminants, the provision of 'time to respond' to potential water treatment incidents, and improvement of the public's perception of potable water reuse (Schroeder, Tchobanoglous, Levernz, et al. 2012; Trussell, Anderson, Archuleta, et al. 2012). In contrast to IPR, the supply of highly treated reclaimed water directly to a drinking water treatment plant or distribution system is known internationally as direct potable reuse (DPR). DPR differs from more established approaches to potable water recycling by the absence of a so-called 'environmental buffer'.

Many utilities and practitioners within the water community are finding an increasing number of potential benefits of DPR relative to IPR, including reduced energy requirements, reduced construction costs, reduced operational costs, and the ability to better control and maintain water within engineered buffer systems (Schroeder, Tchobanoglous, Levernz, et al. 2012; Trussell, Anderson, Archuleta, et al. 2012; Trussell, Salveson, Snyder, et al. 2013). DPR may even provide an opportunity to allow potable reuse in situations where a suitable environmental buffer is not available for IPR. However, potential obstacles or disadvantages for DPR, relative to IPR, are primarily related to public perception and acceptance rather than science or engineering. A number of technical issues relating to the perceived functions of an environmental buffer need to be addressed in a transparent process, including in particular the need to ensure consistent and assured levels of reliability.

A key element of success of any water treatment system, including DPR facilities, relies on its operators and the ability of those operators to evaluate and respond to any issues that may arise There is little disagreement that the technology to successfully and reliably treat municipal effluent to a level suitable for human consumption. However, the success of any treatment facility relies on an effective operational team, the "human element". Operations must have robust and reliable plans, systems, and processes to ensure safety and reliability – essential elements for the advancement of public acceptance of DPR. Relative to existing water and wastewater treatment systems, operations teams will be under much greater scrutiny for performance, and must therefore have adequate training and certification processes in place to provide a framework for developing and evaluating the necessary skills for successful operation and management of water recycling systems.

Currently underway under the auspices of the Watereuse Research Foundation, Project 13-13, “Development of Operation and Maintenance Plan and Training and Certification Framework for Direct Potable Reuse (DPR) Systems”, is developing the required outlines of such a plan. The framework addresses the key requirements necessary to ensure safety and reliability including:

- Operational Monitoring – including on line monitoring, water quality sampling and analysis and process performance monitoring. Knowing when processes are working and when they require corrective action relies upon ensuring that the right things are monitored, analyzers are correctly validated and calibrated and deviations from correct performance are anticipated and corrected.

- Managing process or water quality non-conformances. Making sure communication protocols to stakeholders are timely and factual, ensuring corrective actions have been taken and ensuring lessons are learned to prevent the non-conformance from recurring.

- Operating Interface Protocols to provide detail on management at important operational management interfaces. Often, wastewater treatment plants and recycled water facilities are operated independently with inconsistent treatment goals and focus. For DPR, this protocol importantly will lay out agreed operating procedures, communications protocols, data sharing and other elements necessary to integrate the multiple entities of wastewater treatment, advanced recycling treatment and water treatment in one overall DPR scheme.

- Operating procedures to identify key procedures that will be required for DPR schemes. Importantly, they will include dedicated response procedures at each critical process barrier or critical control point to ensure a consistent approach for managing health risk.

Managing Health Risk – Integrating the HACCP Methodology

Initially developed for the food industry, the Hazard Analysis and Critical Control Point (HACCP) framework has been adopted internationally by a number of utilities to manage microbiological and chemical contaminants in water treatment systems, including recycled water systems (Halliwell et al, 2012). HACCP is a logical, scientific process control system designed to identify, evaluate and control hazards. Its purpose is to put in place process controls that will detect and correct deviations in quality processes at the earliest possible opportunity. It focuses on performance and quality monitoring and maintaining the barriers of treatment, rather than on end of pipe sampling and treatment.

In brief, the HACCP system was originally developed as an engineering means of controlling microbial hazards in consumed food. HACCP is a logical, scientific process control system designed to identify, evaluate and control hazards, which are significant for food safety. The purpose of a HACCP system is to put in place process controls that will detect and correct deviations in quality processes at the earliest possible opportunity. HACCP focuses on monitoring and maintaining the barriers of treatment, rather than on end of pipe sampling and testing. This provides the dual advantage of ensuring poor quality is prevented in the first place, and allows for a reduction in end of pipe monitoring and associated costs.

In its essence, the HACCP process is categorized into seven principles that are used to assess risk and determine a well-defined path forward for managing those risks and operation of the facility. The principles, whether part of true HACCP/ISO 22000 accredited system or one that is using the principles to guide them through DPR assessment and operation, can be used to guide the process of developing critical control points for potable reuse:

Principle 1: Conduct a hazard analysis

Principle 2: Determine the Critical Control Points

Principle 3: Establish Critical Limits

Principle 4: Establish a system to monitor the control of a CCP

Principle 5: Establish the corrective action to be taken when monitoring a CCP is not under control

Principle 6: Establish procedures for verification to confirm that the HACCP system is working effectively

Principle 7: Establish documentation concerning all procedures and records appropriate to these principles and their application

It is important to note that the HACCP system identifies critical control points (CCPs) as points in the treatment process that are specifically designed to protect against a human health threat. The methodology provides a strict definition that allows the HACCP team to focus on risks that are relevant to human health and therefore identify the processes and response procedures that are necessary to protect public health.

1. Is there a hazard at this process step? (And what is it?)
2. Do control measure(s) exist for the identified hazard?
3. Is the step required to achieve a log removal of microorganisms and/or to meet water quality targets?
4. Could contamination occur at or increase to unacceptable level(s)?
5. Will a subsequent step or action eliminate or reduce the hazard to an acceptable level?

The Watereuse Research Foundation Study WRRF -13-03 (Critical Control Point Assessment to Quantify Robustness and Reliability of Multiple Treatment Barriers of a DPR Scheme), has used this approach to identify health risks, identify water quality objectives and identify critical control points for both desalting-based treatment train of MF-RO-UV/H_2O_2-Cl_2 and the non-desalting treatment train of O_3-BAC-GAC-UV-Cl_2. For both of these processes, specific control points are identified, along with their corresponding monitoring parameters. These are outlined in the two tables below:

Table 1 - Critical Control Point Selection (MF-RO-UV/AOP-Cl_2-Engineered Storage)

Critical Control Point	Hazard/s Controlled	CCP Monitoring Parameters	Comments
Pre-chloramination	Disinfection byproducts, NDMA, chlorate, perchlorate.	Total (combined) chlorine;	Chloramine is used primarily for RO biofouling control. However it qualifies as a CCP as we must control it to limit NDMA formation and other DBPs.
MF/UF	Microorganisms	Pressure Decay Integrity Test and Individual (or combined) filter effluent	Pressure decay integrity testing provides superior resolution, however it is a discrete test. Turbidity can provide an effective continuous back up measure.
RO	Microorganisms and chemicals of concern	Electrical conductivity On line TOC	Electrical conductivity and/or on line TOC are currently the most sensitive analyzers for this task. More sensitive on line analytical techniques are emerging which will improve the resolution of this monitoring point.
UV/H_2O_2	Microorganisms and chemicals of concern	UV Present Power Ratio (Ratio of EED/EER) Confirmed dose of Hydrogen peroxide; UVT of feed water	The UV dose provided for advanced oxidation is significantly higher than required for disinfection. Operationally the energy utilized to meet NDMA removal will provide sufficient UV dose for disinfection targets.
Stabilization	Lead and copper in distribution system.	pH, applied chemical dose, TDS, periodic alkalinity checks, CCPP (calculation) LSI (calculation) (Breaks down as hardness, alkalinity, pH and TDS	This was included as a CCP, which was unexpected. Driver: prevent lead or copper leaching from existing distribution systems due to poor water stability. May depend on where the recycled water is reintroduced (either water plant or directly to the distribution system).
Chlorine	Microorganisms	Free chlorine residual, chlorine dose, CT (calculated)	This depends on the location of the recycled water plant, where recycled water will re-enter, hydraulic detention time

Table 2 - CCPs and Monitoring Points – Floc/Sed-O3-BAC-GAC-UV-Cl_2-Engineered Storage

Process Step	Hazards Controlled	CCP Monitoring Parameters	Comments
Ozone	Microorganisms and DBP formation control.	Ozone dose, ozone residual, CT (calculated), Change in UVT	Delta UVT is an excellent parameter that indicates disinfection, dose, and chemical oxidation. It may be considered a possible monitoring point.
Ozone-BAC	Organic compounds.	Ozone dose EBCT	The team did not believe that we could achieve sufficient micro-organism removal without use of a coagulant/sedimentation processes. This necessitated an addition to the process.
Coagulant-BAC	Microorganisms	Filtered water turbidity Coagulant Dose	TOC in feed water compared with TOC post-BAC to determine overall removal efficiency. This could be grab samples, however, not necessarily on-line TOC
GAC	TOC, DBP, DBP Precursors	Carbon life TOC and/or UVT	GAC systems must be operated with a number of filters in parallel, to ensure a staggering of carbon life for the process.
UV	Microorganisms	UV Dose, UV Transmissivity	
Chlorine	Microorganisms	Free chlorine residual, chlorine dose, CT (calculated)	This depends on the location of the recycled water plant, and where recycled water will enter the distribution system. Additional disinfection may be achieved at the water treatment plant if recycled water is added to the feed.

Importantly for operations, for each one of these critical control points a clear, concise and unambiguous operating response procedure has been developed, to provide clear guidance to operations in managing each specific control point. All efforts are made of course to limit failures to an absolute minimum, however failures can and do occur. The vast majority of these failures are managed with highly automated responses. For example, an RO unit with a higher than acceptable permeate conductivity will be shut down by the control system automatically, similarly, a MF unit that suffers a poor integrity test will also be placed automatically in to a shutdown condition.

Response procedures are produced for two distinct conditions:

- **Alert or Warning –** this is a response procedure for when a critical limit is close to being exceeded, but has not at this point exceeded. It provides pro-active checks and troubleshooting steps to minimize actual exceedances.

- **Critical –** this is a response procedure for when the critical limit has been exceeded.

Both responses contain clear advice on appropriate checks of analyzers and instruments, validation and check of data to ensure the exceedance is real, troubleshooting steps and checks prior to returning the equipment or process safely back to service. In addition, they provide clear direction on communication so that all stakeholders can be aware of the process in a transparent fashion. Figure 1 below provides an example of a critical control response procedure for a MF/UF system.

Parameter	Alert level
Unit Pressure Decay Rate (Daily Integrity Test)	PDR > 0.2 psi/min (eq 4 LRVs)
Unit Filtrate Turbidity (15 min moving average)	> 0.2 NTU (unit/combined)

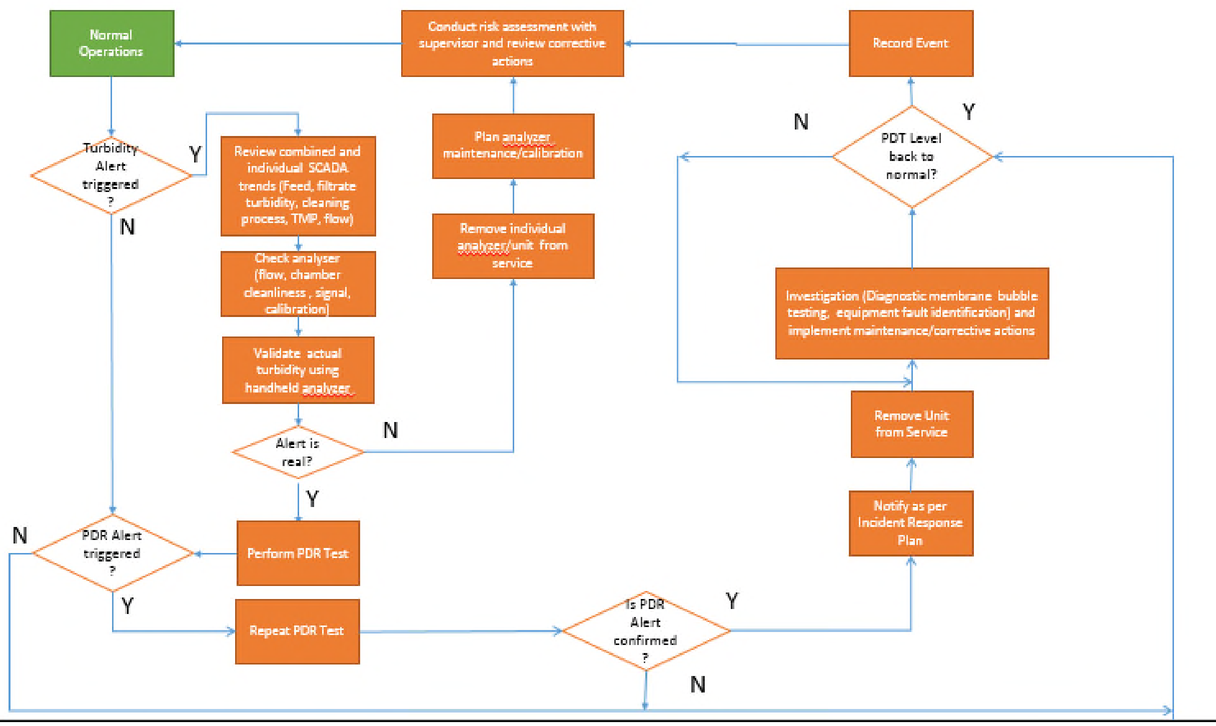

Figure 1 - MF/UF Critical Response Procedure

Critical Operating Points

Critical control points as noted above are strictly focused on the protection of public health. They are separated as a distinct group of operational controls, alarms and procedures to highlight their importance to operators and to provide transparency to various stakeholders including regulators.

Operators of course must focus on many other elements to ensure effective, optimized operation and to safeguard plant and equipment. Using the same format as critical control points, key critical operating points (COPs) have also been developed which focus on other important process and operational parameters. Some of these will include:

- pH control upstream of RO systems to avoid system scaling.
- Protection of the RO membranes from free chlorine damage.

- Managing head loss across BAC and GAC filters.
- Monitor of UV lamp life.

COPs response procedures are to a similar format to CCP response procedures, thus providing consistency for operations.

Operations and Maintenance Framework.

Standard operating responses are only a piece of the overall operations and maintenance system that is required to support the successful operation of a DPR system. These need to be part of a broader, over-arching operational framework that would contain the objectives, strategies, and management actions required for the supply of recycled water for DPR. With the principles of Critical Control Points as its foundation, the operations and maintenance plan would contain within it all of the important elements that are required to ensure safe, reliable operations of the DPR treatment infrastructure. An outline of the DPR Operations Management Plan is shown in figure 2 below.

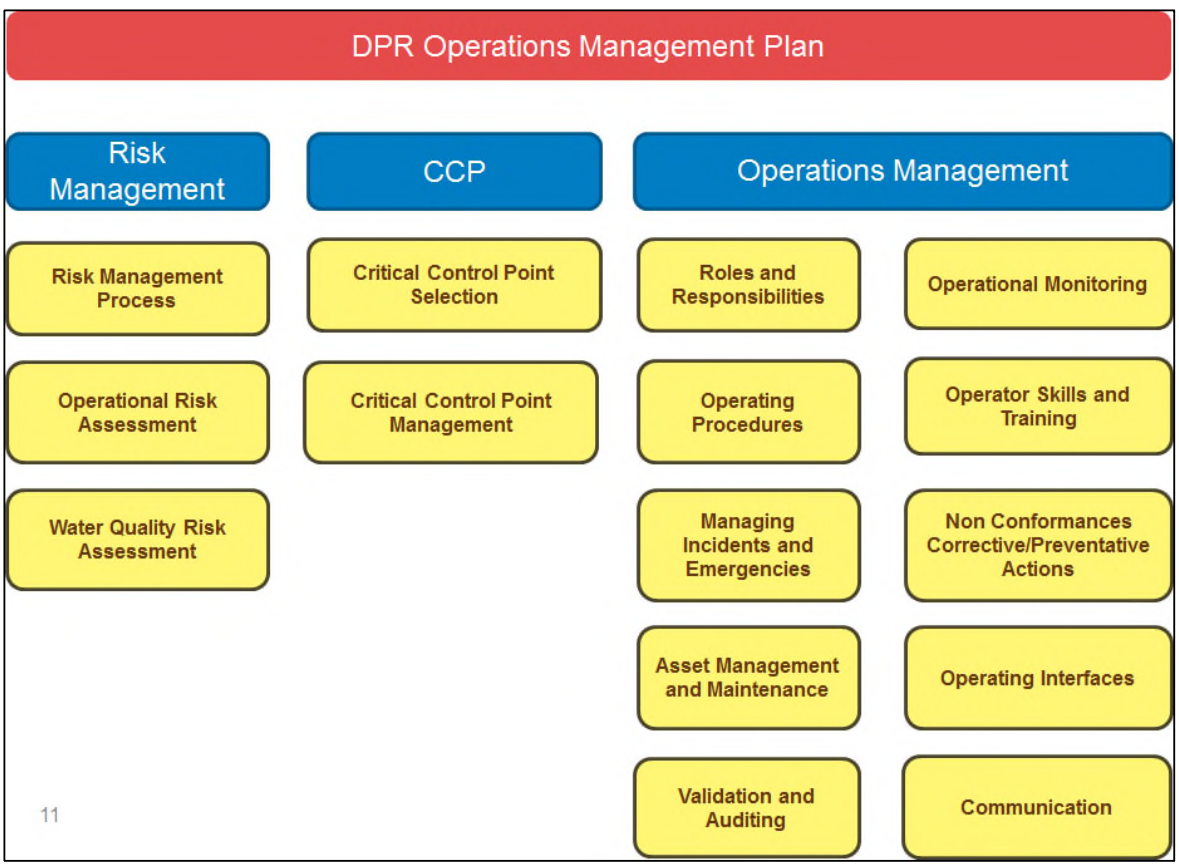

Figure 2 - DPR Operations Management Plan

Risk Management

The key to successful operations is finding the right balance between risk and cost. Key to managing those risks is to identify and quantify them. In the same way that HACCP identifies hazards to human health with a health risk assessment, so to operational risk assessments can be developed which can identify and quantify the range of operational risks such as:

- Risks to assets and equipment.
- Risk of loss of production.
- Environmental risks.
- Health and safety risks.

The operational framework will include the development and maintenance of risk registers to identify, characterize, rank and prioritize risks for management. The specific operational areas that follow must demonstrate how they effectively address each of the risks identified. Importantly, risks change with time and circumstance. The management of risk is a living process that operational teams must continually inform operational planning.

Operational Monitoring

Correct operational monitoring both for individual processes and for the treatment train performance overall is important to the success of the operations. The operational monitoring portion of the operating framework outlines not only the key parameters that must be monitored for each process area, but also provides guidance on data management, data sampling frequency and data reporting approaches. Many highly automated advanced treatment systems are monitored with highly sophisticated Supervisory Control and Data Acquisition (SCADA) systems that can gather extensive amounts of data. However if not well managed, operating facilities can often be data rich and knowledge poor. This portion of the framework will outline strategies for data management and data reporting.

In addition, there is a high reliance in these systems on instrumentation and analysis. Core to the success of operational monitoring is a high reliability and veracity of instrument readings. Recommendations for instrument verification and calibration schedules will be included.

Managing Operational Interfaces

A large number of advanced treatment facilities for IPR operate downstream of wastewater treatment plants that are operated by other entities. Even in the case where the advanced treatment facility is operated under the auspices of the same organization, different process approaches and treatment goals can result in difficulties at the operational interface. Successful operation relies on successful co-operation and communication at the interface between wastewater treatment, advanced water treatment and drinking water treatment facilities – and the development of effective protocols is critical. As a part of the review of regulation in the

Californian context, a recommendation of this study is to consider the wastewater, advanced water treatment plant and drinking water plant (if not direct to distribution) under a single permit for DPR.

Asset Management

The success of DPR operation relies on a well-designed and maintained set of assets.

Asset management processes and practices not only support planning for equipment failure by identifying the failure modes and predicting failures but also support optimized rehabilitation and replacement efforts through an effective maintenance management system. The goal of asset management is to ensure getting the right information, in the right format, at the right time to make informed decisions.

The core questions for asset management are:

1. What is the current state of my assets?
2. Which assets are critical to sustained performance?
3. What are my optimized O&M and capital replacement strategies?

The operational framework contains a review of asset management principles and an example of their application to advanced treatment systems in the DPR context.

Operator Training and Certification.

Operator certification and training programs are used across the United States in order to provide a minimum standard of operational skill and knowledge for the operations of wastewater treatment plants, water treatment plants and the management of drinking water distribution systems. Currently, potable reuse does not have its own certification curricula, but rather utilities rely on these existing wastewater and water certifications from which the pool of operations staff is drawn. While this covers a number of important elements for potable reuse, there currently remain gaps for both some of the technologies applied, as well as some of the operational tasks and methodologies.

As well as identifying gaps in technology training, it is also important to consider the over-arching training requirements to cover including:

- Risk management.
- Understanding of regulations.
- Critical Control Points.
- Understanding of upstream and downstream interfaces (wastewater and water treatment)
- Sampling and analysis.

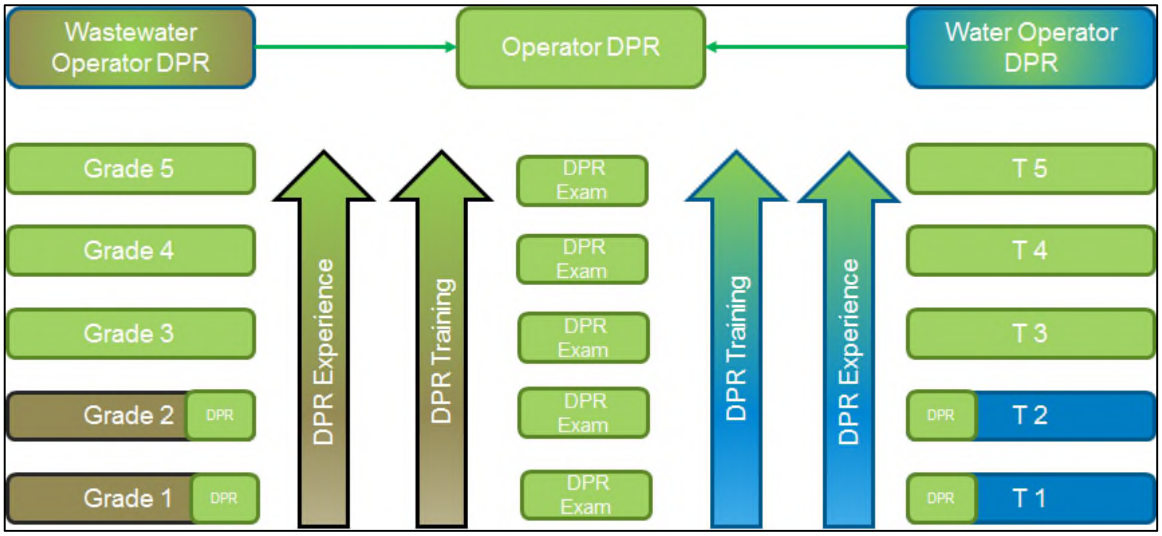

Figure 3 - Potential Certification Framework

Operator certification programs in the United States generally cover drinking water and wastewater treatment, with reuse applications covered broadly under wastewater treatment. A consideration of this study is to include a separate DPR (potentially combined with IPR) stream which may leverage from existing water and wastewater systems.

In one approach (shown in figure 3 and based on the Californian operator training environment) operators can initially be drawn from either water or wastewater streams. In early levels of certification, DPR can be appended as an additional training component. Once operators are at a grade 3 or above, a specific DPR training certification program will be adopted.

It should be noted this is one concept among a few considerations. Concurrently with this study, the California Nevada section of AWWA, along with other organizations are also independently reviewing possible training frameworks.

Concluding Remarks

This paper provides a summary of the operations and maintenance framework and highlights some of the key components that must be considered in the successful operational planning DPR systems. At the time of writing this manuscript, the report is still under way and some details remain under development. These will be outlined in the upcoming Watereuse Research Foundation study report.