Providing Support To Wastewater Treatment Plants in the Yakima Basin: Implementing Sustainable Strategies for Reducing Nutrient Discharge in Rural and Low Income Communities

Report to the South Central Washington Resource Conservation & Development Council

H David Stensel Inc.
James L. Barnard, Ph.D., D.Ing. h.c., PE. BCEE WEF Fellow
H. David Stensel Ph.D., PE, BCEE WEF Fellow

Aerial Photo of Toppenish, WA Wastewater Treatment Plant

Table of Contents

1.0 Introduction and Background …………………………………………………6

2.0 Objectives and Activities……………….…………………………………………8

3.0 Review of Enhanced Biological Phosphorus Removal Process Technology ……………………………………………………………9

4.0 Description of WWTPs Involved in the Implementation Program…………..17

4.1 Description of the Toppenish WWTP……………………………………….…17

4.2 Description of the Kittitas WWTP……………………………..……………19

4.3 Description of the Peshastin WWTP…………………………….…………….21

5.0 Implementation Program………………….…………………………….…….24

5.1 Operating Changes for the Toppenish WWTP…………………………….….24

5.1.1 Toppenish Implementation Program Activities……………….…………24

5.1.2 Effect of Operational Changes on EBPR Performance………..….25

5.2 Operating Changes for the Kittitas WWTP…………..…………..……….31

5.2.1 Kittitas Implementation Program Activities……………………...….32

5.2.2 Effect of Operating Changes on Plant Performance……......….32

5.2.3 Kittitas WWTP Class A equivalent effluent……….……………….35

5.3 Evaluation of Operating Changes to Advance EBPR at the Peshastin WWTP……...…………………………………………………..…………35

6.0 Summary and Conclusions……………………………..………..……………..39

Acknowlegements.. ……………………………..………..……………………………...42

Appendix A – Updated Evaluation of Facilities for Conversion to EBPR…………43

A.1 Oxidation Ditch WWTPs…………..…………………………..…………………44

A.2 Activated sludge WWTPs…………..…………………….………………..……...46

A.3 Sequencing Batch Reactor WWTPs…………..………..……………………48

List of Figures

Figure 1. Schematic of two phosphorus removal alternatives for biological wastewater treatment facilities: chemical precipitation and enhanced biological phosphorus removal……………………………………………….…..9

Figure 2. Representation of the impact of chemical addition for phosphorus removal by chemical precipitation. The ratio of the WWTP capital and operating costs compared to conventional treatment increases with lower effluent phosphorus concentration…………………………………………………..…10

Figure 3. Conventional flow sheets for biological phosphorus removal…...……….11

Figure 4 Original Bardenpho plant with phosphorus removal…………..…………12

Figure 5. Modifications to Henderson, NV WWTP………….……………..…………13

Figure 6. Aerial view of the Toppenish, WA WWTP…………..………………….……17

Figure 7. Schematic of one train of the two-train Toppenish WWTP Bardenpho-like biological nutrient removal process……………...…………………………18

Figure 8. Aerial view of the Kittitas WWTP…………..……………………………….20

Figure 9. Example of activated sludge flocs. A is highly filamentous and has poor settling and thickening properties. B has good floc-forming organisms and settles and thickens well…………..……………………..………………….21

Figure 10. Aerial view of the Peshastin WWTP…………...…………………………...22

Figure 11. Monthly average flowrates during 2014 for the Peshastin WWTP……….22

Figure 12. Effluent soluble P concentration during Toppenish implementation program from August 2014 to August 2015………………………………...27

Figure 13. Amount of P removed in Toppenish secondary treatment system during the implementation program from August 2014 to August 2015……..….27

Figure 14. Percent P removal and primary effluent BOD:P ratio versus time during the implementation program from August 2014 to August 2015. % P removal values are on the left axis and the BOD:P ratio values are on the right axis…………………………………...…………………………….…28

Figure 15. P removal and effluent NO3-N concentration versus time during the implementation program from August 2014 to August 2015…………..….29

Figure 16. Photomicrographs of Toppenish mixed liquor sample with neisser staining at a1000 magnification. Purple-black clumps are PAOs. (Left- November 19, 2014 sample and Right- June 10, 2015 sample) …………………..…….30

Figure 17. Comparison of monthly average effluent P concentration from April to August for the 2015 implementation period to previous years 2014 and 2013……………………………………………………………………….…30

Figure 18. SVI and MLSS concentration versus time for SBRs #1 and #2 for Kittitas WWTP. Operating changes to reduce aeration in fill time were done in October 2014………..…………………………………………...…………32

Figure 19. Photomicrograph of Kittitas mixed liquor sample at 1000X after Neisser staining indicates presence of PAOs. Sample taken on April 30, 2015 from SBR 1………...…………………………………………………...…………34

Figure 20. Kittitas WWTP April 30, 2015 effluent sample after filtration and UV disinfection has Class A water reuse quality…………………….......….35

Figure 21. Proposed cycle operating pattern to promote EBPR without any changes to the SBR system structure and equipment (M indicates mixing only)....36

Figure 22. Proposed cycle operating pattern to promote EBPR by installing feed pipe to direct influent wastewater flow into the settled sludge blanket…….….37

Figure 23. Modification of influent feeding method and conversion of previous anaerobic digesters to a fermentation tank for Alternative 3……………..….37

Figure 24. Proposed cycle operating pattern to promote EBPR with Alternative 3 when the existing aerobic digesters become available for fermentation of influent wastewater and recycled mixed liquor…………………...…..….38

List of Tables

Table 1. Technology toolbox for implementation of EBPR in existing WWTPs…...15

Table 2. Summary of volumes and design flow detention times for different process zones in one train of the Toppenish WWTP nutrient removal process (Design flow is 1.67 MGD) ……………………………….……………...…….18

Table 3. Process steps and times used for the Kittitas SBR system…………...….21

Table 4. Process steps and times used for the Peshastin SBR system…………...23

Table 5. Operational changes made during the Toppenish EBPR optimization implementation test program…………………….………………………..….25

Table 6. Analyses performed on weekly composites samples……………………..….26

Table 7. Overview of operating conditions and P removal efficiency during implementation program………..………………………………..……..….29

Table 8. SBR operational change for Kittitas WWTP implementation program started in October 2014………………………….………...……..31

Table 9. SBR effluent nutrient data for Kittitas SBRs……………………………...33

Table 10. Results of sampling and phosphorus analyses for one cycle of Kittitas SBRs on June 5, 2015. Influent value is for total reactive phosphorus and the end of fill and effluent values are for soluble reactive phosphorus (all in mg/L) ………...……………………………………………...…………33

1.0 Introduction and Background

The Yakima River Watershed, as with many watersheds across the nation, is faced with increasing threats to the ecosystem due to nitrogen and phosphorus (nutrient) loads from municipal, agriculture, and industrial sources. In the Yakima River Basin significant investments have been made to improve water quality and overall watershed function but nutrient enrichment in the lower Yakima River has been found high enough to periodically support high levels of periphytic algae and macrophytes to cause significant daily fluctuations in dissolved oxygen (DO) and pH. The low DO concentrations and high pH periods associated with the increased photosynthetic activity is detrimental to migrating salmon and other aquatic life.

A common approach to mitigating nutrient-related water quality problems has been increased regulatory pressures on municipal point dischargers to very stringent effluent nutrient discharge levels, which forces communities to invest in highly expensive and unsustainable technology and chemical treatment alternatives that alone are do not sufficiently improve overall water quality goals. Those costs are passed on to rural residents, food processors, and other local businesses. Such an approach can place an unacceptable financial hardship on rural communities and also impede investments to increase industrial activity and economic growth.

The South Central Washington Resource Conservation and Development Council (RC&D) has been an active advocate for implementing a holistic approach to water quality management in the Yakima basin. This management approach promotes low cost alternatives that can be easily implemented within existing wastewater treatment plants (WWTPs) to move to higher levels of phosphorus and nitrogen removal. This is part of an initial first step to identify relatively simple and cost-effective approaches that have a high incremental impact on reducing nutrient enrichment of surface waters. A basic element of this approach is the use of advanced biological nutrient processes that provide both nitrogen and phosphorus removal, which is a sustainable nutrient removal method in lieu of adding chemicals. The addition and dependence on chemicals for nutrient removal raises major concerns, which include 1) a large increase in operating costs, 2) the production of a high amount of sludge with poor recycle value, and 3) a significant increase in carbon footprint due to processing and transportation of the chemicals.

In prior work that was supported by the USDA and completed in December 2012, RC&D with our assistance evaluated the potential for using this appropriate nutrient removal technology at 17 existing WWTPs in the Yakima River Basin. Each of the existing facilities had site-specific process designs and operating approaches to meet their current effluent permit limits. We obtained design, performance, and operating information for each facility and determined possible operating changes and possible simple minimal cost facility changes to significantly increase nitrogen and phosphorus removal. A report titled "Yakima Basin Point Source Watershed Assessment" was issued in December 2012 and workshops were presented and attended by Yakima Valley stakeholders, including utilities, design engineers, and regulators.

Many of the public entities were interested in implementing the methods outlined for their facility but technical assistance and training was needed to support their staff efforts. This report addresses our work under a grant from USDA to support technical assistance and training to carry out this implementation demonstration phase of the program. The objective and activities are reviewed first in Section 2.0. Section 3.0 provides a review of the key technology methods available for upgrading WWTPs for nutrient removal with important current advances. In Section 4.0 the WWTPs involved in the site technical assistance and training and demonstration of site-specific plant modification methods are described along with their phosphorus removal ability before the implementation program. The results of the plant modification evaluation and implementation are provided in Section 5.0. The previous evaluation of the other Yakima facilities addressed in our previous work was upgraded to consider more current technology advances in EBPR and these are summarized in Appendix A.

2.0 Objectives and Activities

The South Central Washington Resource Conservation and Development Council (RC&D) is committed to providing hands-on assistance to several Wastewater Treatment Plants (WWTPs) in rural and low income communities in the Yakima Basin to implement enhanced biological nutrient removal (EBNR) upgrades to their facilities. The work provides demonstration projects to provide useful information on low cost improvements for EBNR both within and outside the Yakima watershed. In addition, the program provides monitoring assistance during and after implementation along with training and outreach to all other communities with WWTPs that discharge to the Yakima River. The activity by us described in this report was the second phase of assistance to rural communities, which first began with the 2012 project in which we assessed all WWTPs in the Yakima Basin and identified specific approaches for EBNR implementation.

To meet the overall aims of the RC&D project we addressed the following objectives.

1. Develop EBNR demonstration projects with at least 3 WWTPs, and provide necessary technical assistance, training, and oversight during implementation of the demonstration projects.

The 17 facilities from the 2012 were revisited and the list was screened based on which facilities could be modified to EBNR without capital costs and had sufficient staff support and interest at the time to carry out process changes and additional sampling and analyses. Site visits were made to the following facilities for reviews and discussions: Toppenish, Zillah, Kittitas, Peshastin, Leavenworth, and Mabton. Of these, plant modification programs were set up for Toppenish, Kittitas and Peshastin.

2. Develop and implement a monitoring plan to evaluate and document improved nutrient removal for each demonstration project.

Guidance was given to plant operating changes and monitoring programs as well as meetings to review process fundamentals and provide process technology training. Data collected by the facilities was provided on a monthly basis. RC&D facilitated conference calls with the project participants for review and discussion of operating conditions and test results. RC&D also arranged for sampling and laboratory analyses support from the Yakima Valley Community College. This also provided an excellent outreach and educational assistance for the students to learn about biological nutrient removal processes in wastewater treatment and analytical methods for wastewater characteristics, reactor conditions and nutrients.

3. Provide outreach on nutrient management strategies to WWTP owners and operators, regulatory agencies, engineers, and other stakeholders in the Yakima basin and communities in other watersheds.

A workshop and technology transfer information was provided at a conference center in Yakima, Washington on September 16, 2015. This workshop provided information and discussion on advances in EBNR technology, integrated sustainable nutrient management methods, and results of the demonstration sites.

3.0 Review of Enhanced Biological Phosphorus Removal Process Technology

Phosphorus has been identified as the main nutrient of concern for the Yakima Valley watershed, but cost effective technology used for phosphorus removal will also remove over 50% of the nitrogen in a WWTP. This section reviews the fate of phosphorus in wastewater treatment and enhanced biological phosphorus removal (EBRR) technology that can often be applied to existing WWTPs with operational changes or with minimal capital expenditure. EBPR offer a sustainable approach for phosphorus removal with the addition of chemicals. In addition EBPR is the first step in applying demonstrated available economical technology for phosphorus recovery from wastewater. As the finite phosphorus resources on the earth become more depleted phosphorus recovery in WWTPs will be more urgent. Some facilities in the U.S. have pursued phosphorus recovery as a sustainable approach to curtail wasting a valuable resource and instead provide reuse.

The phosphorus concentration in influent wastewater to WWTPs treating mainly domestic wastewater is in the range of 4 to 8 mg/L. About half of that is as orthophosphate. The remainder is found in organic and polyphosphate compounds, which mostly converted to orthophosphate by biological reactions. Phosphorus is a conservative element and exits the WWTP in the treated effluent or in waste sludge. Moving the phosphorus from the influent to the waste sludge is accomplished by EBPR and/or chemical precipitation (Figure 1). EBPR relies on unique biological processes that can be incorporated into many reactor designs, the availability of the wastewater BOD, and operating conditions to select and maintain bacteria that have a remarkable capacity for phosphorus uptake and cellular storage. The phosphorus content of these, bacteria, on a dry weight basis, may range from 20 to 30 percent as compared to about 1.5 percent for the bacteria typically grown in a biological wastewater treatment system. The phosphorus-rich biomass grown is removed from the EBPR system in the daily excess sludge wasting. The phosphate rich sludge can then be used beneficially for direct phosphorus recovery or in the production of a phosphorus-rich compost. If supplied to the soil in a sustainable way, it would not find it's way back to surface waters.

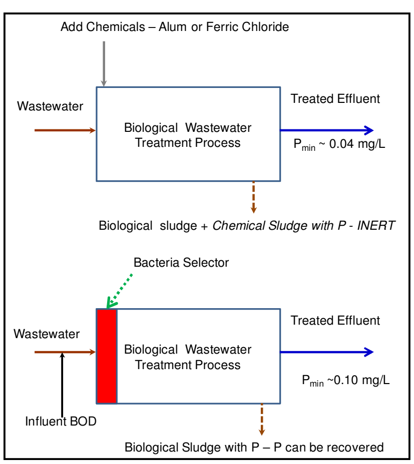


Figure 1. Schematic of two phosphorus removal alternatives for biological wastewater treatment facilities: chemical precipitation and enhanced biological phosphorus removal.

The other removal mechanism, chemical precipitation, is accomplished by adding metal salts (alum or ferric chloride) to the wastewater treatment process to form aluminum or iron phosphorus precipitates, which are then removed via the waste sludge. This method involves the manufacturing and transport of the chemicals to the plant and more sludge production at the wastewater facility. In comparison, the EBPR process uses a free chemical contained in the influent wastewater, which is a portion of the influent organic material or BOD.

The advantage of the chemical precipitation method is that a very low effluent phosphorus concentration can be achieved, with minimal concentrations between 0.03 and 0.05 mg/L possible. However, the wastewater treatment plant capital and operating costs increases and more rapidly for lower effluent P concentrations due to the chemical and sludge handling costs as indicated in Figure 2. On the other hand, an EBPR process represents a more sustainable technology at lower costs. It generally requires some modest plant modifications and/or operating changes, but cannot achieve the very low effluent phosphorus concentrations (less than 0.20 mg/L) possible by chemical precipitation. However, a combination of biological and chemical processes can achieve low effluent concentrations with low chemical dosages and reduced sludge production.

There are many factors that affect the phosphorus removal efficiency with EBPR technology, and thus site-specific factors for each wastewater treatment plant were considered and reviewed in our studies. The next section provides a further background on the fundamentals of EBPR and methods for incorporating it into existing WWTPs.

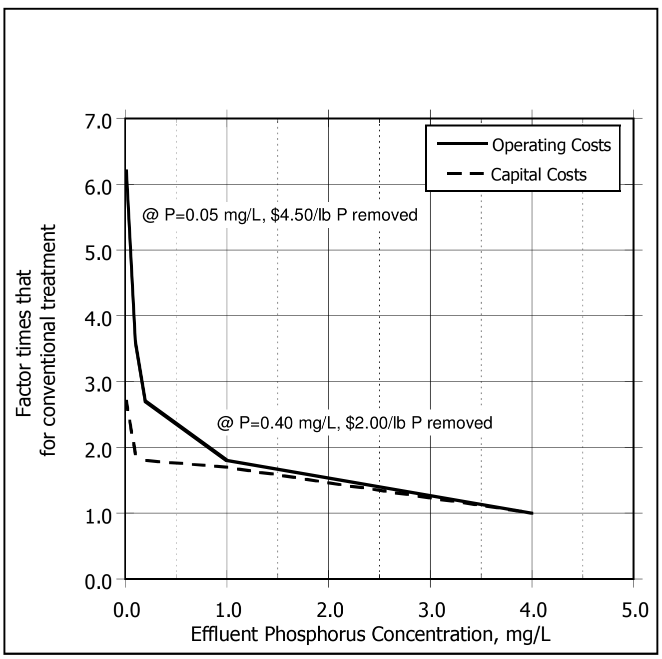


Figure 2. Representation of the impact of chemical addition for phosphorus removal by chemical precipitation. The ratio of the WWTP capital and operating costs compared to conventional treatment increases with lower effluent phosphorus concentration.

3.1 Enhanced Biological Phosphorus Removal

Biological phosphorus removal involves the selection of phosphorus accumulation organisms (PAOs) and the incorporation of phosphorus in the PAOs produced in the treatment system and subsequently the removal of the biomass and phosphorus during sludge wasting. The key to the process is providing an anaerobic condition prior to an aerobic condition (Figure 3). In the anaerobic zone, acetate and propionate (volatile fatty acids or VFAs) are produced by fermentation of soluble, readily biodegradable carbon (as measured by chemical oxygen demand), which is referred to as rbCOD. The VFAs are then taken up and stored as complex carbon compounds by the PAOs in the anaerobic zone. In subsequent anoxic (nitrate or nitrite present, but no oxygen) and aerobic zones, the PAOs oxidize the stored carbon, which results in energy production and the uptake of orthophosphate with minimal soluble phosphorus remaining in the treated effluent.

The mechanism of biological phosphorus removal and the need for volatile fatty acids (VFA) have been well researched and documented to the point where it is now possible to design a plant with a very reliable phosphorus removal process using formal flow sheets, as shown in Figure 3. However, biological phosphorus removal is still observed in a number of plants that have no designated anaerobic zone, which has been considered essential for phosphorus removal. In such unconventional plants, mostly mixed liquor or return sludge is fermented, whether in separate vessels or on the floor of the main basins. Exploiting these new approaches to old technologies has encouraged many plant operators to experiment with these originally observed technologies, sometimes at little or no increase in cost and with remarkable results. This section will briefly summarize existing technology and then explain how recent observations can be applied to get biological phosphorus removal in plants not designed for it or how to get reliable phosphorus removal in plants that were designed using formal flow sheets but that do not operate effectively.

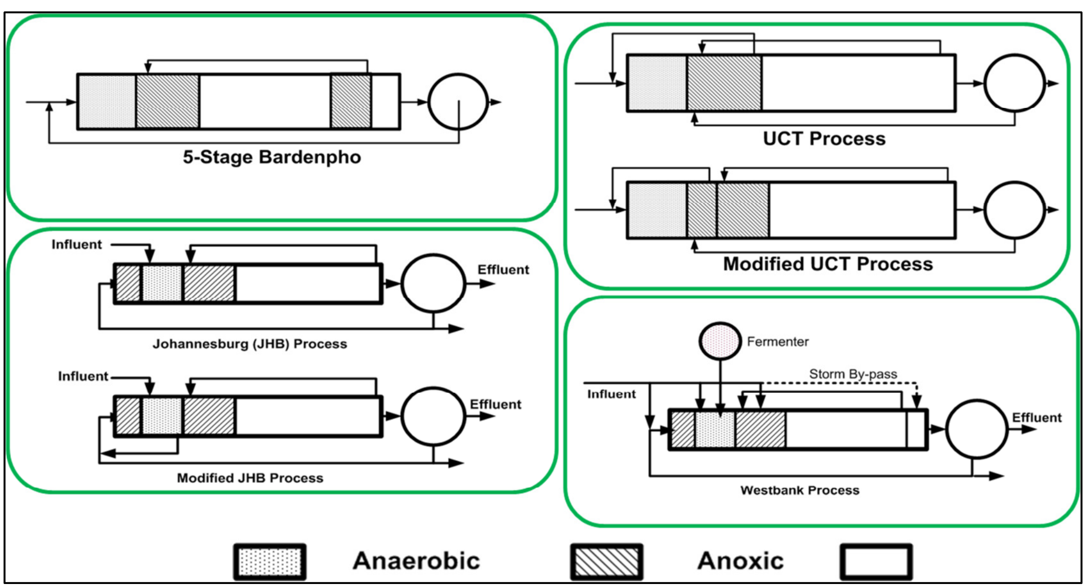


Figure 3. Conventional flow sheets for biological phosphorus removal.

When the theory for biological phosphorus removal were developed after the initial observations in plants that could now be described as “unconventional”, the importance of VFA was emphasized in that the phosphate accumulating organisms (PAO) could take up VFA (basically only propionic and acetic acids which are end products of fermentation of organic carbon matter) under anaerobic conditions, using previously stored phosphorus as an energy source while releasing the phosphorus to gain the energy to take up the VFA, then taking up the released phosphorus and all surplus phosphorus in the influent upon aeration of the mixed liquor in the next stage to where most of the phosphorus in solution is taken up in the biological cells. When sludge is wasted the phosphorus is removed from the liquid stream. Most wastewater does not contain enough VFA and it was necessary to achieve some fermentation in an anaerobic zone free of nitrates and oxygen to supply the needed VFA. This led to some of the formal flow sheets, shown in Figure 3, that were considered necessary to avoid nitrates being discharged to the anaerobic zone which would stop fermentation of readily biodegradable COD to VFA.

Even when designed according to such conventional flow sheets, some of these plants did not perform well since there was just not enough fermentable material in the influent to sustain phosphorus removal. It was then necessary to ferment some of the primary sludge to produce enough VFA to sustain the process. This added additional BOD to the plant, which would increase sludge production.

In his initial investigations on biological nutrient removal in 1972 James Barnard noticed that phosphorus was release in the second anoxic zone of a 4-stage Bardenpho plant when testing the process in a 100-m3/d pilot plant for nitrogen removal. Phosphorus was released in the second anoxic zone to more than 30 mg/L as P, with rapid uptake in the re-aeration zone, achieving soluble effluent phosphorus concentrations of less than 0.2 mg/L. The layout of the pilot plant is shown on Figure 4. The pilot plant was formed by partitioning an existing set of two tanks. A dead zone was created inadvertently in an effort to establish four zones with predetermined volumes. The circled numbers in the sketch on Figure 4 show the soluble phosphorus concentrations in the mixed liquor in each zone. In this case there was no anaerobic zone and it was realized much later that some mixed liquor passed to a fermenter (Dead Zone) and was returned which confirmed that more than an anaerobic zone, anaerobic conditions are required to form somewhere in the plant.

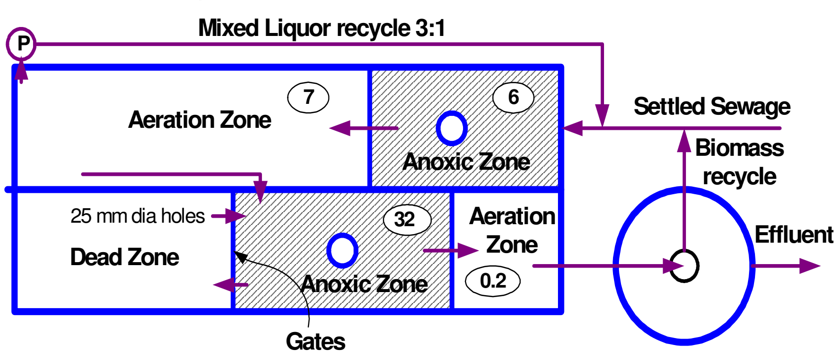


Figure 4. Original Bardenpho plant with phosphorus removal.

Since that time many observations were made of “unconventional” processes that removed phosphorus, and it was established that in all cases some of the mixed liquor was fermented either in a separate zone or on the floor of the tanks when mixers were switched off or even where aeration was switched off. Oxygen and nitrates were soon depleted and the redox potential lowered sufficiently to promote fermentation of solids to VFA. It was possible to achieve phosphorus removal in an experiment in which mixed liquor was pumped from the anoxic zone of a small MLE (anoxic/aerobic) plant at the Iowa Hill plant in Colorado to an unmixed basin, where the mixed liquor was fermented and passed back to the anoxic zone. Even with no anaerobic zone it was possible to achieve effluent phosphorus removal to levels of 0.03 mg/L ortho-phosphorus.

In many plants that were designed for phosphorus removal but where the influent wastewater characteristics were not favorable, it was possible to reduce the phosphorus by switching off a mixer in the anaerobic zone, allowing mixed liquor to ferment on the floor. The thickening of the sludge in the basin allows fermentation to take place and the new mixed liquor seems to float over the thicker sludge while exchanging VFA and fresh sludge.

An example of a conversion to mixed liquor fermentation is the Henderson NV plant, which treats an average flow of 21.5 MGD. Regulations required that effluent total P concentrations be limited to 0.14 mg/L. Two existing Carousel plants were upgraded to high-rate operation and retrofitted with anaerobic and anoxic basins to treat 12 million gallons per day (MGD) each. A new parallel biological phosphorus removal (BNR) plant, (Figure 5), was constructed to treat an additional 6 MGD. There are no primary sedimentation tanks. The combined effluent from the old and new plants is pumped to rapid mixing, chemical clarifiers and sand filters. During plant construction, long pumping mains and wastewater temperature ranging from 20 to 28 ºC produced sufficient VFA in the influent for achieving good biological phosphorus removal and no additional acid fermentation units were provided. Both the Carousel and the BNR plants are operated in the Johannesburg (JHB) configuration. A pre-anoxic zone was provided for denitrification of the return activated sludge in all the parallel trains.

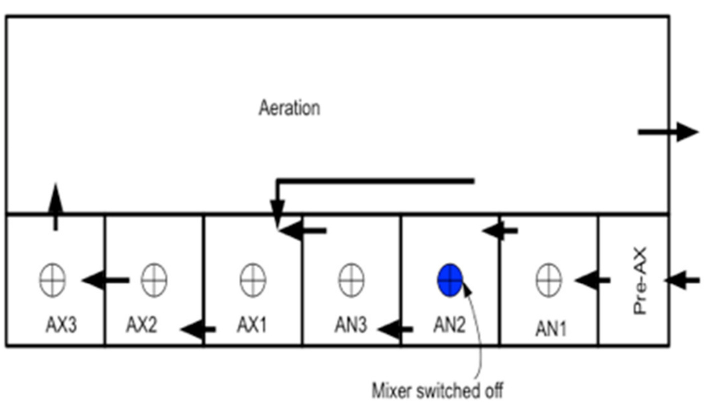


Figure 5. Modifications to Henderson, NV WWTP

During startup of the plant, the concentration of the VFA in the influent was about 5 mg/L, which was not sufficient to sustain biological phosphorus removal. It appeared that a nitrate solution that was added to the sewer system to combat odors also oxidized the VFA or prevented their formation. It was decided to operate the second anaerobic zone of each of the three plants as in-basin fermenters by stopping the mixers for all but 15 minutes each day. The short mixing period was needed to prevent permanent accumulation of solids on the basin floor or in the corners away from the main flow. Biological phosphorus removal was greatly improved. Effluent ortho-phosphorus concentration averages 0.1 mg/L.

Since the our 2012 report, more studies have confirmed this approach and today we have a better understanding of the requirements for achieving phosphorus removal in unconventional plants. The key is to have a zone (as opposed to a basin) where some of the sludge or mixed liquor can pass through a stage where anaerobic conditions could be created to lower the Oxidation/reduction potential (ORP) to below -300 mV. This could be done on the floor of existing tanks by switching off mixers or aeration as discussed above but also by pumping a portion of the sludge or mixed liquor through a separate basin to maintain a solids retention time of at least 2 days at which time some non-PAO organisms die off and gets fermented to produce the necessary VFA. The PAO survive this condition since they take up and store any VFA produced and thus has an energy source to sustain themselves through the adverse conditions to the point where they see dissolved oxygen again and can then process the stored food. Unconfirmed evidence would indicate that PAO so treated seem to be more energized to take up phosphorus at a more rapid rate those in conventional plants.

3.2. Technology Toolbox for Modification of Existing WWTPs to EBPR

The potential for converting existing WWTPS to incorporate an EBPR process depends on the existing process, and the plant layout. The biological process treatment technology at the 17 Yakima basin WWTPs fit into one of 3 basic process types: (1) activated sludge (A.S.), (2). Sequencing batch reactor (SBR), or (3) oxidation ditch (Ditch). To provide a roadmap for the evaluation of retrofitting these types of facilities to an EBPR process, a technology toolbox that considered the various aspects of in EBPR process and conditions to optimize his performance was developed (Table 1). Past experience showed that it was possible to have all these variations converted to EBPR by fermenting some mixed liquor.

The toolbox considered the basic process functions for a successful EBPR system. First of all, it is necessary to have an anaerobic contact zone in which the VFAs are provided for the population selection of PAOs. There are various ways to do this, depending on the type of biological process. Activated sludge plants with no unaerated zones and having a plug-flow arrangement render them better to manipulation since some phosphorus removal is possible even by switching off aerators at the front end. In more complete mixed tanks this is not possible and the strategy would be to look for external tanks that could be used for fermentation of mixed liquor. In activated sludge plants with un-aerated zones, some may be designed for phosphorus removal but have difficulty in achieving BPR; it may merely be a case of switching off some mixers. The same applies to oxidation ditches while SBRs have the flexibility of re-arrangements of various cycles to create the necessary conditions for phosphorus removal. Even here some outside vessel could be used for side-stream fermentation of mixed liquor.

Successful EBPR performance depends on having a minimal amount of nitrate fed to the anaerobic contact zone. All of the WWTPS in the study were showing successful nitrification, and thus nitrate was in their aerobic treatment zones, which could be fed to an EBPR contact zone by the addition of necessary return activated sludge. Thus different methods to remove nitrate were identified for the different types of processes. These methods employed biological denitrification and conversion of nitrate to nitrogen gas. Thus, nitrogen removal (at least partial) was also an important part of evaluating methods for conversion of the existing WWTPs to EBPR facilities.

The technology toolbox also points out the need to minimize the amount of dissolved oxygen added to the anaerobic contact zone, as this also hinders the efficiency of the PAOs in EBPR systems. The biological process, solids retention time (SRT) is also critical to the level of performance of an EBPR system. Systems with longer SRTs result in more time for biomass reduction due to endogenous decay. The less biomass or PAOs produced, the less is the phosphorus removal via the waste sludge. To maximize EBPR system performance, it is best to operate at SRT values that are above that are just above that needed for complete nitrification.

Table 1. Technology toolbox for implementation of EBPR in existing WWTPs.

Function	Tools	A.S.	SBR	Ditch
Anaerobic Contact	Turn off some aerators	x		
	Divide/baffle tanks	x		
	Add external tank		x	x
	React/fill is anaerobic		x	
Minimize NO3 to Anaerobic Tank	Aeration on/off or low DO	x	x	x
	Convert to anoxic/aerobic tanks	x		
	Convert to Bardenpho	x		
	Add anoxic contact tank	x	x	
	Provide anoxic zone for RAS (JHB)	x	x	x
	Step feed SBR		x	
Minimize DO to Anaerobic Tank	Check influent head drop/aeration	x	x	x
Optimize SRT	Sludge wasting control	x	x	x
Get more food for PAOs	Create settling periods in anaerobic	x		x
	Industrial sources	x	x	x
	Onsite fermentation of waste solids	x	x	x
Minimize P in recycle	Keep waste sludge aerobic	x	x	x
	Off-site sludge processing	x	x	x
	Composting	x	x	x
	Anaerobic digester struvite recovery	x	x	x
Optimize P uptake	Provide sufficient aerobic time	x	x	x
	Provide sufficient DO	x	x	x
	Modify to staged kinetics	x		
	Waste sludge from aerobic zone	x	x	x

The amount of PAO growth and thus the amount of phosphorus removed in an EBPR system is dependent on how much readily degradable BOD is fed to the PAOs under an anaerobic contact condition. Thus the technology toolbox points out the need to consider any other sources of food that could be added to the retrofitted EBPR system. For the Yakima basin WWTPS, there are some opportunities for the use of food processing wastewater to provide more VFAs to improve the efficiency of an EBPR system.

If more phosphorus is fed to an EBPR system without increasing the readily available BOD, a higher effluent P concentration will result. Thus, recycle streams that have a high amount of phosphorus are of concern. Such recycle streams originate from aerobic or anaerobic sludge digestion. A final function shown in a technology toolbox is to optimize the conditions for phosphorus uptake by the PAOs. There must be sufficient time under aerobic conditions. More recent studies emphasized the need for the use ORP as a measure of the intensity of anaerobic conditions achieved. Ideally a value of -300 MV should be achieved. This is easier to achieve when having more than two zones in succession rather than one mixed zone. This could also be the reason for the good performance when simply switching off mixers, which stop oxygen entrainment from the surface. The toolbox indicates that the reactor configuration, dissolved oxygen concentration, and methods of sludge wasting should be considered to optimize phosphorus uptake.

4.0 Description of WWTPs Involved in the Implementation Program

Based on available resources at the time, the staff at the following WWTPs were involved in an EBPR implementation program: 1) Toppenish, 2) Kittitas and 3) Peshastin. This section describes their treatment processes and phosphorus removal capability before the implementation program.

It was not possible to carry out an implementation program at the other Yakima Basin facilities evaluated in the 2012 report. However, because of technology developments in EBPR, the previously recommended process modifications were reevaluated and updated to reflect current state of art. The updated process modification summaries for these facilities are given in Appendix A.

4.1 Description of the Toppenish WWTP

Figure 6 shows an aerial view of the Toppenish WWTP. The facility treats primarily domestic wastewater and the liquid processing steps are screening and grit removal, primary clarification, a Bardenpho-like activated sludge process, secondary clarification, and ultraviolet (UV) disinfection. Waste sludge from primary clarification and the biological treatment process are thickened and treated in anaerobic digestion. The digester sludge dewatering centrate return is sent to the primary clarifier.

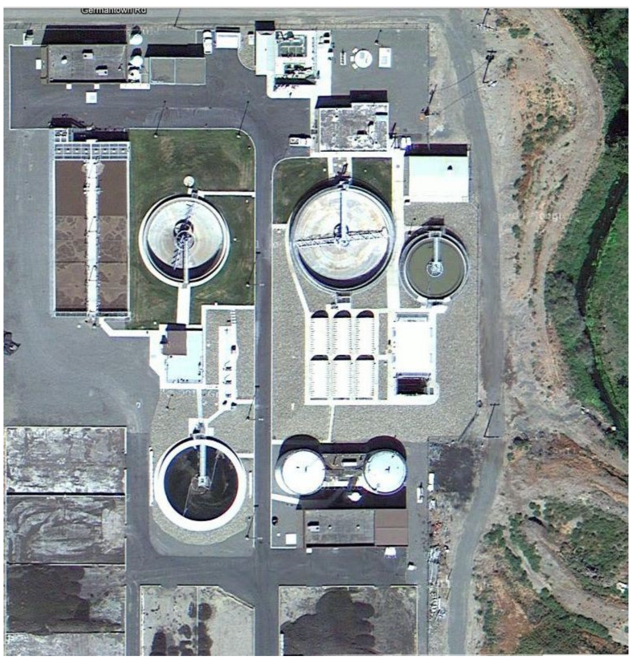


Figure 6. Aerial view of the Toppenish, WA WWTP.

The secondary activated sludge Bardenpho-like process is divided into two identical parallel trains. A schematic of a Bardenpho-like activated sludge process train is shown in Figure 7 and the volumes and design flow detention times for each zone of the activated sludge process are summarized in Table 2. Anaerobic means that no DO and NO3 and NO2 (NOx) are present, anoxic means that no DO is present but NOx is present, and aerobic means that the zone has a positive DO concentration, possibly in the range of 0.5 to 4.0 mg/L. The primary effluent and return activated sludge (RAS) are fed to the first stage of a 4-stage anaerobic zone. The mixed liquor then flows to a 2-stage anoxic zone, which is mixed and not aerated. After the anoxic zone, the mixed liquor flows to an aerobic zone, which is aerated and mixed with fine bubble diffusers. It then flows to the low DO aerobic zone, which is mixed and aerated with fine bubble diffusers, but at a low enough rate to keep the DO concentration below 1.0 mg/L and often below 0.50 mg/L. This is followed by a final aeration zone kept at a higher DO with fine bubble aeration before flow to the secondary clarifier.

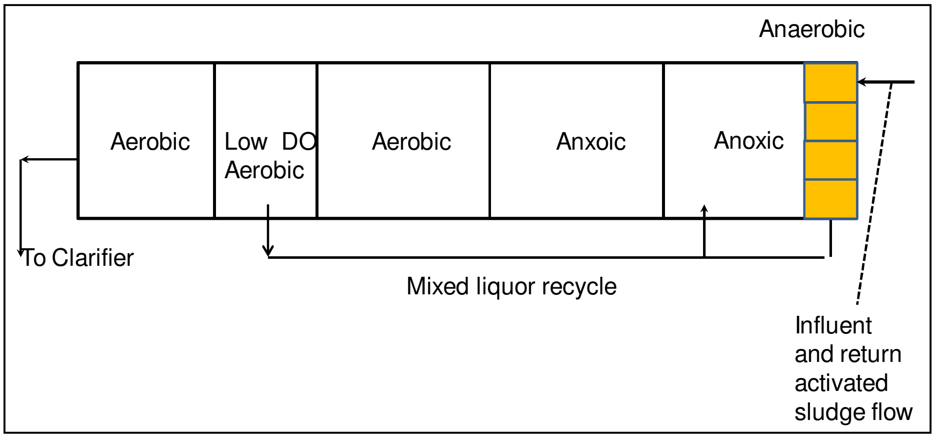


Figure 7. Schematic of one train of the two-train Toppenish WWTP Bardenpho-like biological nutrient removal process.

Table 2. Summary of volumes and design flow detention times for different process zones in one train of the Toppenish WWTP nutrient removal process (Design flow is 1.67 MGD).

Zone	Volume/Train gallons	Design Flow Detention Time, hrs
Anaerobic	42,000	1.2
First Anoxic	73,250	2.1
Second Anoxic	73,250	2.1
Aerobic	128,000	3.7
Low Do Aerobic	64,000	1.8
Aerobic	64,000	1.8
Total	444,500	12.8

The process is termed Bardenpho-like in that the tank between the two aerobic zones in the more common Bardenpho process is anoxic (not aerated but mechanically mixed) and the recycle to the upstream anoxic zone is from the first aerobic zone and not the low DO zone after the aerobic zone as shown in Figure 7. Recycle from the low DO aerobic zone in the Toppenish facility is directed to the anoxic zone at a rate that may range from 2-6 times the average influent flowrate depending on the operator's decision. The recycle provides nitrate (NO3) to the anoxic zone that can be used by PAOs in the mixed liquor flow from the anaerobic zone to oxidized their stored substrate and by other heterotrophic bacteria to oxidized readily available biodegradable COD (rbCOD) remaining in the incoming wastewater or produced by hydrolysis of particulate and colloidal biodegradable COD in the incoming wastewater. An issue with the mixed liquor recycle at the Toppenish facility is that some of the recycle gets pushed into the 4^{th} stage of the anaerobic zone and thus that zone is more likely operating as an anoxic zone.

The anaerobic zone detention time is within typical values used for EBPR processes. The anoxic volume accounts for 33% of the total volume, which places it on the conservative side compared to the anoxic zone being 15-25% of the total volume for many municipal Bardenpho processes.

For liquid solids separation, one train has a secondary clarifier diameter of 70 ft and the secondary clarifier diameter in the other train is 65 ft. This result in conservative hydraulic application rates of 430 and 500 gpd/ft^2, respectively, at average design flow.

The lack of a true postanoxic zone and the relative long aeration time for the final aerobic zone compared to a Bardenpho process suggests that the effluent NO3-N concentration would be higher than typical for a true Bardenpho process. The effluent NO3-N is not a regulated parameter for the Toppenish discharge, but nevertheless, the elevated level can affect the phosphorus removal efficiency of the EBPR process.

Higher system effluent NO3-N concentration also means a higher RAS NO3-N concentration. The NO3-N present in the RAS is consumed by other heterotrophs (not PAOs), which take up rbCOD in the anaerobic zone that would otherwise be available for PAOs. If less rbCOD is taken up in the anaerobic zone, there is less PAO growth and subsequently less P removal. It is estimated that 1 mg/L of NO3-N uptake in the anaerobic zone results in enough rbCOD uptake by other heterotrophs that could have been used by PAOs to result in a reduction in P removal by 0.30 to 0.50 mg/L. If the feed wastewater is high enough in rbCOD concentration it is possible to feed both the bacteria consuming NO3-N and enough PAOs to achieve a low effluent P concentration. For weaker strength wastewaters the NO3-consuming bacteria outcompete the PAOs for rbCOD and the effluent P concentration is higher.

EBPR occurs as expected for the Bardenpho-like design but effluent phosphorus concentrations at the facility have been variable with monthly average values ranging from 0.4 to 3.2 mg/L over the 12 months (September 2013 to September 2014) prior to the implementation study. Some of the higher effluent values corresponded with lower strength influent wastewater due to higher flows associated with agriculture irrigation, which increased the groundwater table and infiltration flow. These results suggest that EBPR performance could be improved by increasing the rbCOD. This was also addressed in recommendations in the 2012 report. The next section provides an overview of these recommendations and efforts of implementation in a 1-year testing program with the plant staff from August 2014 to August 2015.

4.2 Description of the Kittitas WWTP

The Kittitas wastewater treatment facility consists of headworks for grit removal and screening, secondary activated sludge treatment, effluent filtration, and UV disinfection. Sludge is wasted to a large lagoon system that had previously served as the wastewater treatment system. Two sequencing batch reactors (SBRs) provide the secondary treatment and these can be seen in the upper right side of the aerial view in Figure 8.

The SBR system was designed for a maximum month daily flowrate of 0.50 MGD. Each SBR tank has a volume of 0.71 million gallons (MG) and a maximum fill depth of 16 ft and minimum depth after settling and decanting of 11 ft. Oxygen for biological activity is provided by jet aeration, which allows mixing by pumping without aeration when desired as well as aeration. A unique and fortuitous feature of the feed piping is that the feed pipe outlet is located at the bottom of the SBR tank instead of feeding from the top, which is more common.

Figure 8. Aerial view of the Kittitas WWTP

The Kittitas SBR system was designed to provide BOD removal and nitrification, but not biological nutrient removal. The SBR was programmed by the manufacturer to provide the time periods for the feeding, mixing, mixing/aeration, settling, and decanting steps, which are shown in Table 3. The total cycle time for each of the Kittitas SBR tanks is 6.0 hours, with 3 hours of that for feeding. In this way there is always one tank feeding while the other tank is working through the last half of the cycle with aeration, settling, and decanting. Aerating during the fill period, (2/3rd of fill time) results in a smaller SBR tank volume compared to no aeration during the fill for a given MLSS concentration. However, the fallacy with this approach is that aeration during more than 25% to 50% of the fill provides an environment that selects for filamentous bacteria, which then limits the MLSS concentration that can be obtained. A filamentous activated sludge causes poor sludge settling and thickening in contrast to a good settling floc-forming sludge (Figure 9), and thus results in a lower operating MLSS. At the start of the program the SVI of the mixed liquor was in excess of 400 mL/g, which is indicative of a highly filamentous population.

Table 3. Process steps and times used for the Kittitas SBR system.

Process Step	Time, hours
Fill	0.5
Fill, Mix	0.5
Fill, Aerate	2.0
Aerate	1.8
Settle	0.9
Decant	0.3
Total Time Per Cycle	6.0

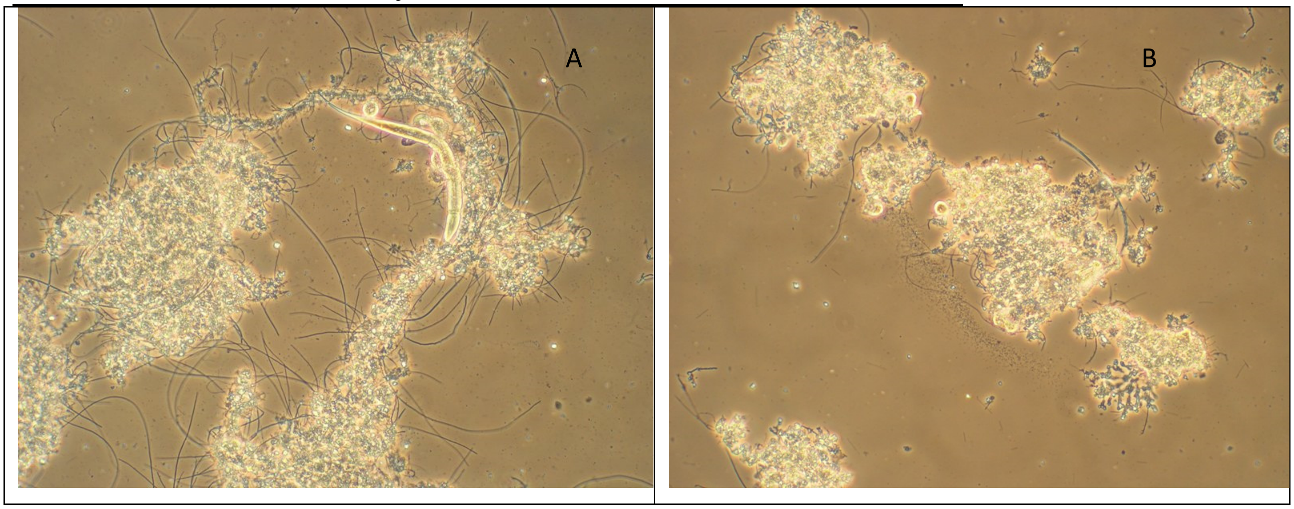


Figure 9. Example of activated sludge flocs. A is highly filamentous and has poor settling and thickening properties. B has good floc-forming organisms and settles and thickens well.

When there is not aeration in the fill period good floc formers are normally favored and nutrient removal is achieved. Typically for an SBR operation there is some nitrate remaining in the settled volume before the fill. The nitrate is denitrified in during the fill, which is done by good floc-forming bacteria instead of filamentous bacteria so that the operation selects for good settling mixed liquor. If there is very little or no nitrate remaining in the settled volume before the fill the fill occurs under anaerobic conditions, which is a perfect situation for the uptake of rbCOD from influent wastewater by PAOs. Thus, they are selected and besides EBPR occurring they also have excellent sludge settling and thickening characteristics.

4.3 Description of the Peshastin WWTP

The Peshastin WWTP uses an SBR process to treat septic tank effluent wastewater. An aerial view of the facility is shown in Figure 10. The existing treatment plant consist of two SBR basins having a volume of 143,600 gal with the lowest liquid depth at 13.1 ft and maximum liquid depth at 17 ft. There are two 15,26 gallon aerobic digesters, which gives an overall SRT of 49 days. Detention time in the SBRs at the design flowrate of 0.105 MGD is 33 hours. The actual monthly flowrate is much lower and more so in the summer as can be seen in Figure 11.

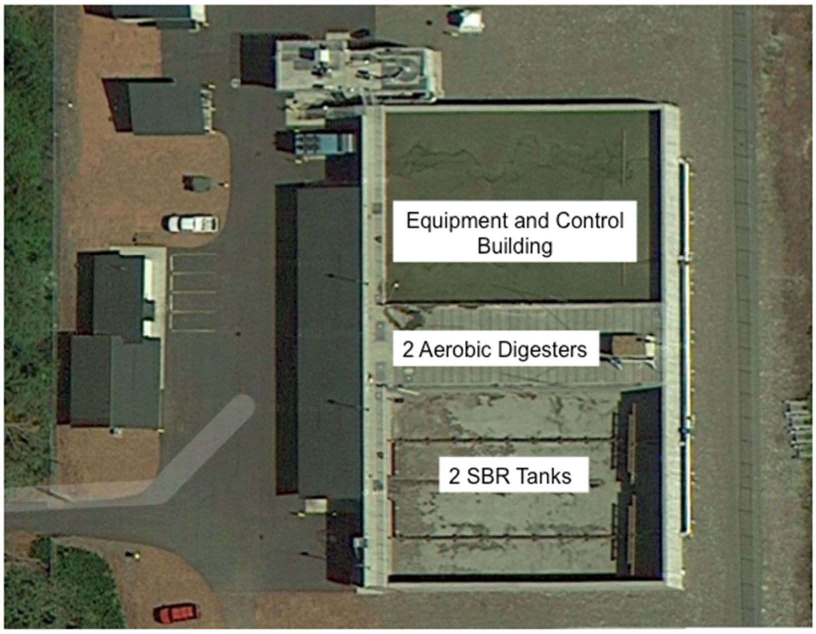


Figure 10. Aerial view of the Peshastin WWTP.

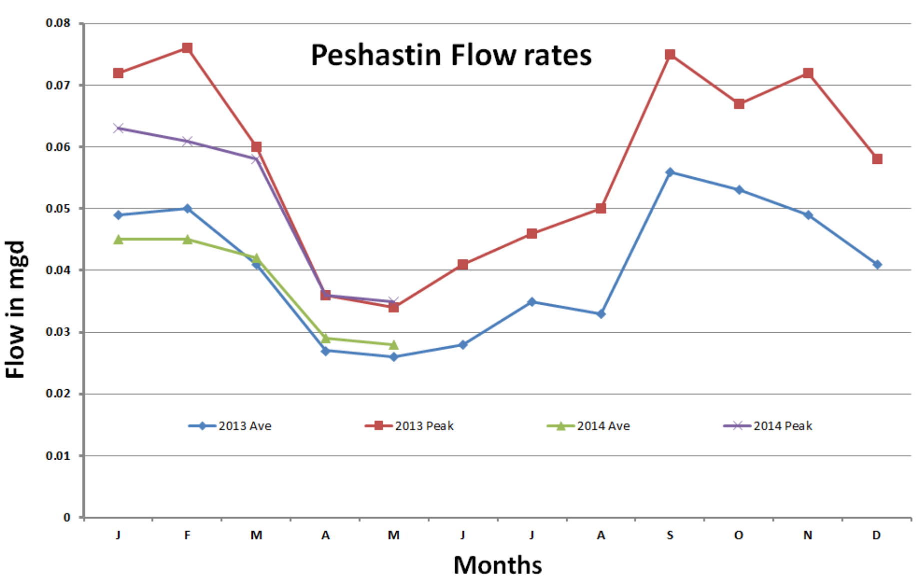


Figure 11. Monthly average flowrates during 2014 for the Peshastin WWTP.

A copy of a Peshastin/Dryden Facility plan provided by Gray & Osborne Engineers, date January 2015, indicates that in the future septic tank effluent wastewater from nearby Dryden will also be fed to Peshastin WWTP and that two new external aerobic digesters will be constructed. This would free up the existing digesters for use in modifications to promote EBPR within the existing facility.

The process steps and times programmed for the SBR system are summarized in Table 4. There are 6 cycles per day for each SBR tank.

Table 4. Process steps and times used for the Peshastin SBR system.

Process Step	Time, hours
Mixed Fill	0.50
Fill, Aerate	1.50
Settle	0.75
Decant	0.75
Idle	0.50
Total Time Per Cycle	4.0

Alkalinity is currently fed to the plant to prevent the pH from dropping below 7.0. The amount of alkalinity needed depends on the degree of denitrification achieved as it can be assumed, based on the loading and operating conditions, that full nitrification takes place. Minimal denitrification is likely due to the extensive fill/aeration time. The facility was designed primarily for ammonia removal by nitrification and thus the plant was not designed for nutrient removal.

5.0 Implementation Program

5.1 Operating Changes for the Toppenish WWTP

A major recommendation to improve EBPR for the Toppenish WWTP was to increase the amount of readily bioavailable COD (rbCOD) fed to the anaerobic contact tank. Three possible methods were identified for the production of rbCOD within the facility and all involve some degree of fermentation of the waste primary sludge to produce volatile fatty acid, which would primarily be acetate and propionate:

- Turn off some mixers in the anaerobic contact zone so that mixed liquor will be detained for fermentation.
- Increase the sludge holding time in the primary clarifiers and recycle settled sludge to the influent to elutriate volatile fatty acids.
- Ferment waste primary sludge in a separate fermenter prior to feeding the waste sludge to the anaerobic digester. Settle supernatant or elutriated would be directed to the anaerobic contact zone to provide VFA. A small extra primary clarifier at the site was identified as a possible tank.

The first two of the above methods could be done at the facility by applying operational changes and were thus applied in the implementation program. The third method involves some equipment and pump additions and piping changes with associated capital cost and were thus not feasible within the time, budget, and scope of the implementation program.

Other changes identified to improve EBPR performance are as follows:

- Lower the SRT at warmer temperatures.
- Decrease the RAS feed rate to the anaerobic zone to reduce the NO3-N addition and decrease the internal recycle flow from the low DO aeration zone to also reduce flow and NO3-N addition to the last stage of the anaerobic contact zone.
- Add an additional outlet port in anoxic recycle line so that return activated sludge recycle only goes to the anoxic zone.

Of these the first two were within the operational capabilities at the facility and were applied in the implementation program. The third method requires engineering and capital cost, and thus was not addressed in the implementation program.

5.1.1 Toppenish Implementation Program Activities

Table 5 shows the operational changes made and the dates of the changes in the implementation program from August 2014 to August 2015. The operational variables manipulated were 1) the solids retention time (SRT), 2) the RAS ratio, 3) the anaerobic zone mixers on/off schedule, and 4) the depth of settled sludge maintained in the primary clarifier. Starting in September the anaerobic zone mixers were turned off for extended period; the first period had a 30-minute on/mixing time once per day. In this way the RAS mixed liquor solids were detained in the anaerobic contactor to provide for mixed liquor fermentation, which as discussed in Section 3 may promote improved EBPR by VFA production and PAO population selection. Starting in February 2015 the mixer off time was further extended with mixing only turned on twice per week for 30 minutes. In Mach 2015 the mixer on time was decreased to 15 minutes and this mixing strategy was maintained for the rest of the test program. During this time from March to August 2015 the only changes were a 50-60% decrease in the RAS ratio and changes in SRT. First the SRT was increased as an option by the plant operator and later decreased back to 12 days.

Table 5. Operational changes made during the Toppenish EBPR optimization implementation test program.

PHASE	DATE 2014-2015	SRT d	RAS Ratio	Mixers On Time, Min.	Primary Sludge Depth, in.
1	AUG6-SEP10	8	0.3	ON-	8
2	SEP18-OCT1	8	0.4	30/d	13
3	OCT8-NOV6	10	0.6	30/d	21
4	NOV12-JAN7	11	0.8	ON	17
5	FEB14-MAR4	12	0.8	2/WK-30	
6	MAR18-APR22	15	0.4	3/WK-15	
7	MAY7-JUL23	18	0.3	3/WK-15	
8	JUL30-AUG12	12	0.35	3/WK-15	

The primary sludge blanket depth was increased from 8 inches to 21 inches by October 2014. The blanket depth was not at a high enough level to expect significant fermentation but it was limited by the capacity and structural design for the clarifier scrapping mechanism. The recycle elutriation flow was also limited by the existing pump capacity. Because of these factors and no apparent improvement in EBPR performance related to sludge blanket fermentation this operating method was abandoned in early February 2014.

During the testing program an auto sampler was provided to the facility so that 24-hour composite samples could be obtained for the primary clarifier effluent that feeds the secondary treatment system. The plant was carefully monitored for the daily flowratre, activated sludge temperature, mixed liquor suspended solids (MLSS) concentration, SRT, sludge characteristics by the sludge volume index (SVI) test, aeration zone DO concentrations, and sludge recycle rates. Microscopic observations for filamentous organisms and floc characteristics, as well as staining to identify the presence of PAOs were done periodically. Once per week the Toppenish labs performed the analysis listed in Table 6 for composite samples on the raw wastewater, primary effluent, and secondary effluent.

5.1.2 Effect of Operational Changes on EBPR Performance

A secondary effluent soluble P concentration of 1 mg/L was set as the goal for the implementation program. As shown in Figure 12 this was achieved in the early phase of the study (Phase 2) and then later during Phases 6-8. A comparison of the operating conditions for the different phases helps to understand why the P removal improved in Phases 2, 6, 7, and 8.

Table 6. Analyses performed on weekly composites samples.

Parameter	Raw Wastewater	Primary Effluent	Secondary Effluent
COD		X	X
BOD	X	X	X
TOTAL, P	X	X	X
SOLUBLE, P		X	X
TSS	X	X	X
VSS	X	X	X
TKN		X	X
pH		X	X
NH3-N	X		X
NO3-N			X

The improvement during Phase 2 is attributed to mixed liquor fermentation in the anaerobic contact time with the mixers on only 30 minutes per day compared to continuously mixed in Phase 1 (Table 5), which had higher effluent P concentrations.In Phase 3 the effluent soluble P concentration increased to above 1.0 mg/L even though the primary clarifier sludge blanket was increased. The only other operating change was an increase in the RAS ratio. In Phase 4 with the anaerobic contact zone mixers operating continuously and a further increase in the RAS ratio the effluent soluble P concentration was generally above 2.0 mg/L. In Phase 5 the anaerobic mixer operation was changed to again being off most of the time with mixing for 30 minutes twice per week. The RAS ratio was still at 0.80 and no improvement was seen in effluent soluble P concentration. A dramatic change was seen after the start of Phase 6 in which the RAS recycle ratio was cut in half. It was further decreased by small amounts from 0.40 to 0.30 in Phase 7 and then up to 0.35 in Phase 8. After Phase 6 the SRT was increased and the effluent soluble P concentration increased to above 1.0 mg/L as expected based on EBPR principles. At excessively long SRTs the PAO biomass net production declines due to endogenous decay and with less PAO biomass production less P is removed from the system waste sludge in PAOs to results in a higher effluent soluble P concentration. A reduction in the SRT in Phase 8 resulted in the effluent soluble P decreasing to below 1.0 mg/L.

The lower effluent P concentrations in Phases 6-8 were not due to decreases in the influent P concentration but in deed to an increase in P removal as shown by the plot of P removal versus time in Figure 13.

Another possible explanation for the greatly improved performance after the start of Phase 6, based on fundamental principles of EBPR, is that the primary effluent BOD:P concentration increased. A higher influent BOD may be associated with an increase in rbCOD, which would lead to a greater amount of PAO biomass production and respective increase in P removal. However, the results in Figure 14 show that the primary effluent BOD:P ratio in fact was similar to the previous operating periods or lower when the P removal efficiency increased after the start of Phase 6. It also shows that the BOD:P ratio is in a range less favorable for achieving low effluent P concentrations with values usually below 30:1 and some below 20:1.

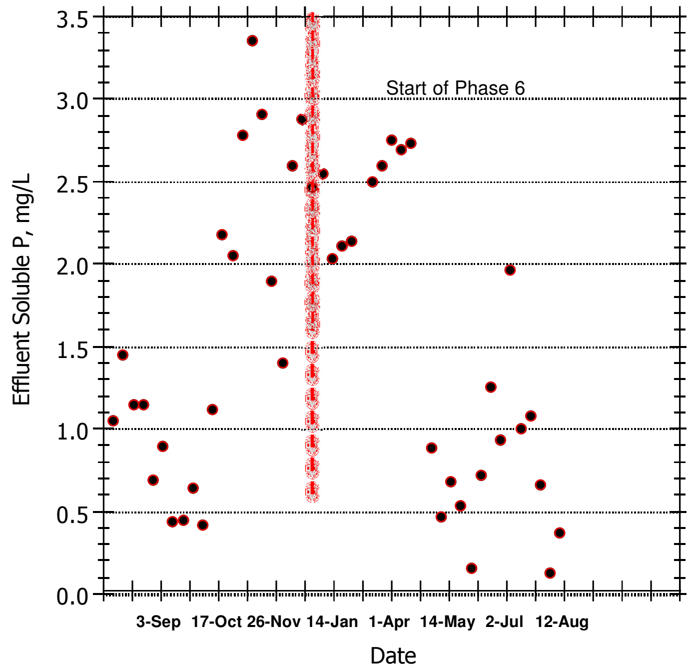


Figure 12. Effluent soluble P concentration during Toppenish implementation program from August 2014 to August 2015.

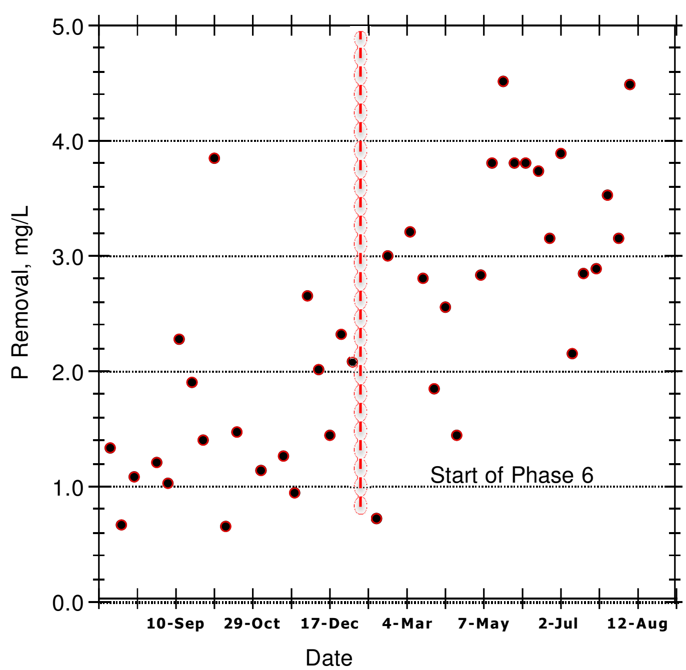


Figure 13. Amount of P removed in Toppenish secondary treatment system during the implementation program from August 2014 to August 2015.

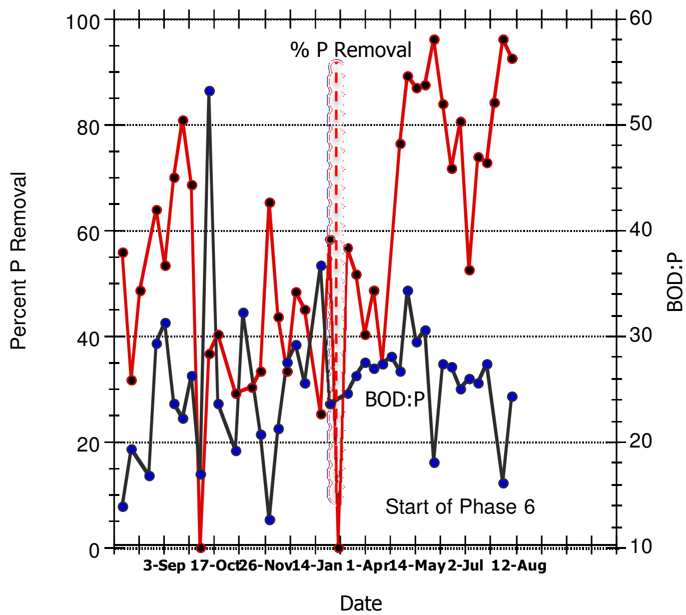


Figure 14. Percent P removal and primary effluent BOD:P ratio versus time during the implementation program from August 2014 to August 2015. % P removal values are on the left axis and the BOD:P ratio values are on the right axis.

As discussed on the fundamentals of EBPR in Section 3, the amount of NO3-N fed to the anaerobic contact tank has a significant affect of P removal. The more NO3-N fed results in more rbCOD used in the anaerobic zone for nitrate reduction with less available for PAOs and thus there is less P removal. As shown in Figure 15 the effluent NO3-N was in the same range of 3.0 to 4.0 mg/L before and after the start of Phase 6. Assuming that the RAS NO3-N concentration is similar to the effluent concentration, the amount of NO3-N fed to the anaerobic zone after the start of Phase 6 was about 50% less due the reduction in the RAS flowrate as indicated by a reduction in the recycle ratio from 0.80 to 0.40 (Table 5). Other factors may also have been contributing to the improved P removal in after the start of Phase 6 shown in Figure 13, but the reduction in the amount of NO3-N fed to the anaerobic zone in may have been an important factor.

An overview of the P removal efficiency and operating conditions imposed during the implementation study (Table 7) shows that the anaerobic contact zone mixing off time to promote mixed liquor fermentation, a reduction in the RAS ratio, and decreasing the SRT improved P removal. For example, a comparison of Phase 1 removal efficiency to that for Phase 7 shows having the mixers off most of the time to allow mixed liquor fermentation the removal efficiency was increased. For same RAS ratio, but without the mixers on all the time, the removal efficiency was 51% compared to 73%. Comparison of Phases 5 and 8 show the importance of the lower RAS ratio as with similar mixer off operating conditions, the P removal efficiency increased from 42% to 91% when the RAS ratio was reduced from 0.80 to 0.30. The lower P removal efficiency for Phase 6 compared to 7 and 8 reflects the effect of the lower removal efficiency at the start of the phase. The increased P removal efficiency from 73% to 91% in Phase 7 versus Phase 8 was likely due to decreasing the SRT to increase the amount of PAOs in the waste sludge and thus the amount of P removed from the liquid stream.

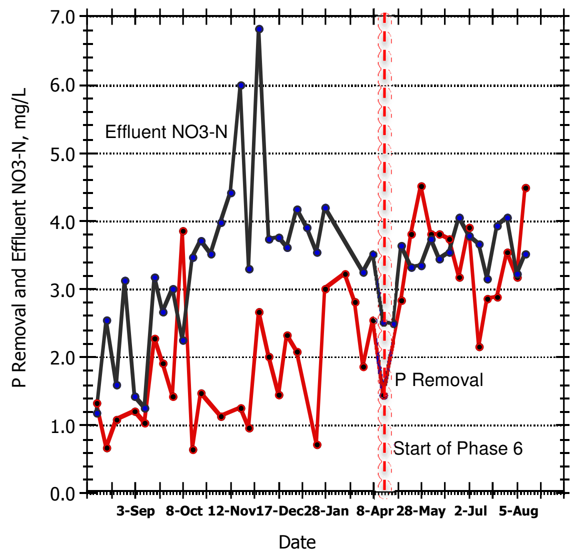


Figure 15. P removal and effluent NO3-N concentration versus time during the implementation program from August 2014 to August 2015.

Table 7. Overview of operating conditions and P removal efficiency during implementation program.

PHASE	SRT d	RAS Ratio	Mixers On Time, Min.	Primary Sludge Depth, in.	% P Removal
1	8	0.3	ON	8	51
2	8	0.4	30/d	13	73
3	10	0.6	30/d	21	36
4	11	0.8	ON	17	43
5	12	0.8	2/WK-30		42
6	15	0.4	3/WK-15		46
7	18	0.3	3/WK-15		73
8	12	0.35	3/WK-15		91

As discussed in Section 3 mixed liquor fermentation has been shown to improve P removal in other applications. The lower RAS ratio appears to help improve P removal in two ways. First, less NO3-N is fed to the anaerobic zone to consume food needed by the PAOs. Secondly, the lower total flow results in more time for settled mixed liquor in the anaerobic contact zone as there is less of a hydraulic force to move solids through the contact zone. This seems especially important for the particular anaerobic contact zone design for the Toppenish facility, because of its baffle arrangement that encourages an upflow pattern with the mixers off. A more ideal approach and one that could likely increase the improved P removal benefits observed by the operational changes in this study would be to use a separate longer detention time external tank for hold up and fermentation of the mixed liquor without influent flow dilution of the solids.

Mixed liquor samples from the Toppenish WWTP were fixed and dried on a microscope slide and subject to a Neisser stain, which detects the stored phosphorus in PAOs to indirectly indicate the abundance of PAOs in a system. Photomicrographs from samples for November 19, 2014 during Phase 4 and June 10, 2015 during Phase 7 are shown in Figure 16. The P removal efficiency for these two phases averaged 43% and 73%, respectively. The Neisser staining showed a greater PAO population for the Phase 7 samples, which is in agreement with the greater amount of P removed during that phase.

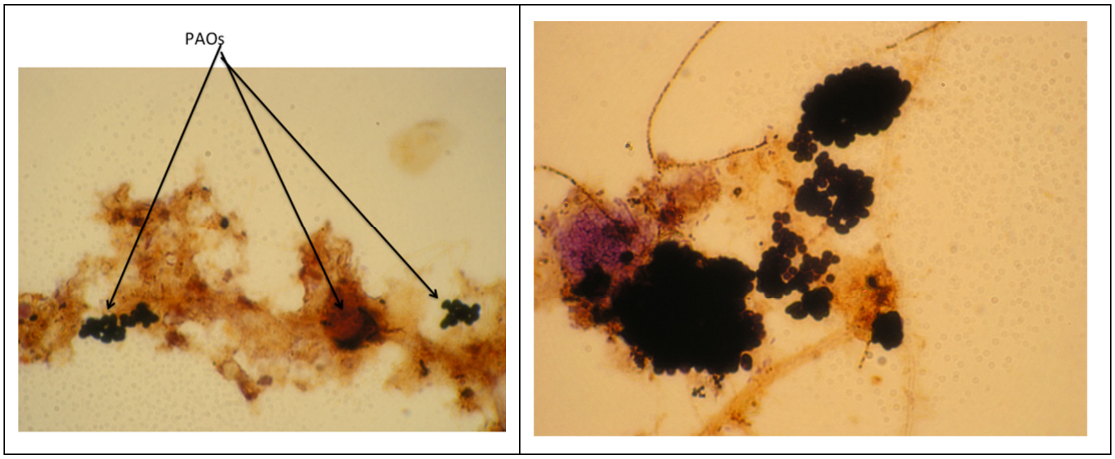


Figure 16. Photomicrographs of Toppenish mixed liquor sample with neisser staining at a 1000 magnification. Purple-black clumps are PAOs. (Left- November 19, 2014 sample and Right- June 10, 2015 sample)

The success of the operational changes on improving P removal was based on fundamental principles of EBPR and the observations that the phosphorus removal performance at the Toppenish facility was greatly affected by a limited food supply for the PAOs. The situation presented a good challenge and training opportunity in this implementation study. The improved performance for Phases 6-8 is illustrated by comparing the monthly average effluent P concentrations for 2015 to the prior two years as shown in Figure 17.

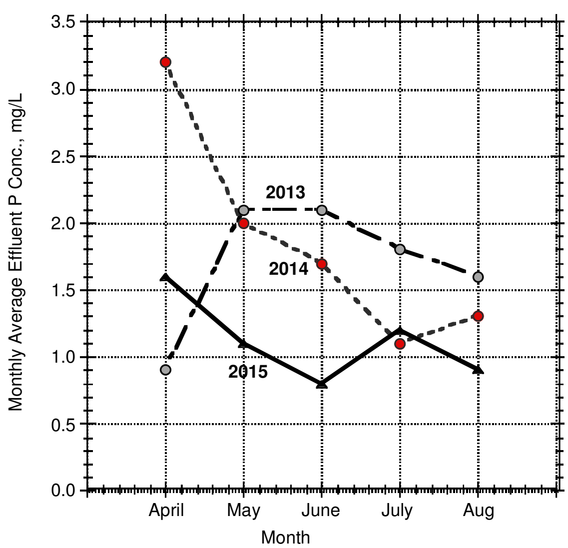


Figure 17. Comparison of monthly average effluent P concentration from April to August for the 2015 implementation period to previous years 2014 and 2013.

5.2 Operating Changes for the Kittitas WWTP

The existing Kittitas SBR operating condition and design presented significant obstacles for the goal of implementing EBPR by operational changes. There was little flexibility available in modifying the existing program at the plant operations level and the system was in a condition of poor sludge settling due to the filamentous growth problem. Another limitation was that the design did not afford an anoxic period after the aeration period for denitrification of NOx produced during aeration and ammonia oxidation. This meant the more NOx would be present during the fill period to deprive PAOs of influent rbCOD and thus a lower P removal efficiency. On the positive side the ability to add the influent wastewater feed to the bottom of the tank offered the advantage of being able to feed the system during decanting. An overall evaluation for converting the facility to EBPR identified the following possible actions:

- Fill without aeration.
- Lower the aeration DO concentration during the aeration period.
- Fill during the decant.
- Provide a post anoxic period by mixing without aeration after fully nitrifying in the aeration period.
- Provide surface wasting of mixed liquor and scum.
- Add an external tank to receive settled mixed liquor after the settling/decant period and provide time for mixed liquor fermentation.

The only actions that could be done without any capital expenditures were to 1) reduce the aeration time during fill, lower the aeration DO set points during the aeration period, and 3) feed during the decant period. The implementation program was started in October 2014 by changing the SBR cycle program as shown in Table 8 to provide conditions that would have the best chance for anaerobic conditions to develop in the fill time and allow substrate uptake by PAOs and thus some EBPR. Part of the fill time was provided during decanting and the aeration time in the fill was reduced from 2.0 hours to 0.7 hours. The aeration period DO set point was also reduced from 3.0 to 2.0 mg/L.

Table 8. SBR operational change for Kittitas WWTP implementation program started in October 2014.

Prior Program		Implementation Program	
Cycle Steps	Time, hours	Cycle Steps	Time, hours
Fill	0.5	Fill	1.0
Fill, Mix	0.5	Fill, Mix	1.0
Fill, Aerate	2.0	Fill, Aerate	0.7
Aerate	1.8	Aerate	2.1
Settle	0.9	Settle	0.9
Decant	0.3	Decant/Fill	0.3
Total	6.0	Total	6.0

5.2.1 Kittitas Implementation Program Activities

The Kittitas facility has limited laboratory space and equipment but the plant staff was especially efficient and eager to use what they have to produce good wastewater treatment results and data. The staff routinely follows the influent and effluent BOD, ammonia-N, and TSS, MLSS and MLVSS concentrations, SVI and SRT. It was necessary to get phosphorus analyses on composite influent and grab effluent samples done by an outside lab. Budget considerations limited the frequency of these analyses. Phosphorus analyses were done by Yakima Valley Community College students in the summer 2015 under the direction of Dr. Tanya Knickerbocker.

5.2.2 Effect of Operating Changes on Plant Performance

The mixed liquor settling and thickening properties improved after the SBR cycle time steps changes and feeding during decant change in October 2014 as indicated by the drop in SVI values from October to December in Figure 18. With the decrease in SVI and improved thickening characteristics the plant staff were able to increase the MLSS concentrations in the SBRs as also indicated in the figure. Plant performance data was available from August 2014 through June 2014. The implementation study could not be continued after June, because the plant experienced operating problems and one SBR tank was taken off line for maintenance. Additional planned operating conditions to further advance EBPR was no longer possible and EBPR was also hindered in the one remaining SBR in operation because it now had to continuously receive the influent flow. Phosphorus analyses by the YVCC students could not be done until July but that was during a period in which it was not possible to operate the system under the recommended conditions for EBPR. In fact their data showed higher P concentrations in the effluent versus the influent concentrations. It is possible that this may be proof of EBPR occurring prior to that period and that there was P release by PAOs with inadequate conditions sufficient P uptake.

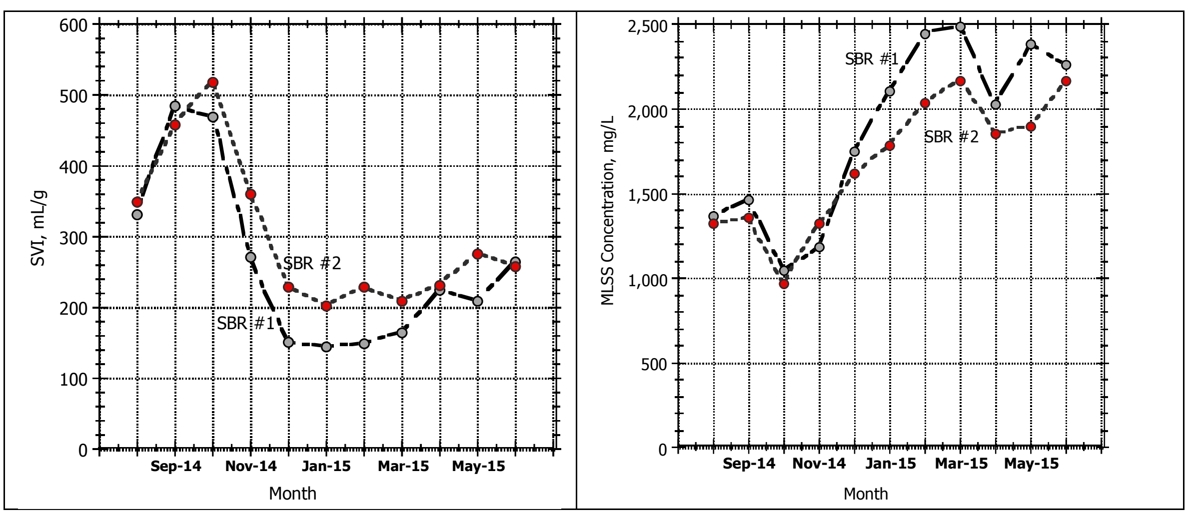


Figure 18. SVI and MLSS concentration versus time for SBRs #1 and #2 for Kittitas WWTP. Operating changes to reduce aeration in fill time were done in October 2014.

Effluent nutrient concentration data collected by the Kittitas staff are summarized in Table 9. The effluent NH3-N concentrations were always below the discharge permit level and often below 0.5 mg/L. After October the effluent NO3-N concentrations were low and within the range to be expected for the new operating conditions imposed in the implementation study. These results show success for feeding during the decant and the extended anaerobic fill time. Effluent total P concentrations were quite variable ranging from 1.6 to 3.2 mg/L for SBR 1 and 0.1 to 2.8 mg/L for SBR 2. Influent data was not obtained during the collection of these effluent samples but the influent total P concentrations from 5.9 to 6.3 mg/L measured in the June 5th sample, as shown in Table 8, suggests that the influent total P concentration is much higher than the effluent P concentrations shown and thus EBPR was occurring. Without EBPR only about 20% P removal typically occurs to satisfy the P needed for biomass growth in removing influent BOD, but these results suggest greater than 50% P removal.

Table 9. SBR effluent nutrient data for Kittitas SBRs.

	Total P, mg/L		NO3-N, mg/L		NH3-N, mg/L	
Date	SBR 1	SBR 2	SBR 1	SBR 2	SBR 1	SBR 2
10/21/14	1.7	1.7	6.3	2.6	0.1	
10/30/14	1.9					0.8
11/5/14	1.8	0.1	2.6	2.0	0.1	
11/13/14	2.2	0.2				0.1
12/10/14	3.2	0.4	1.4	1.8	0.1	0.3
12/17/14	2.4	2.3	0.4		0.2	1.2
2/11/15	1.6	2.8	2.6	3.7	0.1	0.1

Phosphorus analyses for sampling on June 5, 2015 (Table 10) also suggest EBPR was occurring as well as the results of Neisser staining of a mixed liquor sample taken on April 30, 2015. The phosphorus removal efficiency shown in Table 10 for the SBR cycle was 70% for SBR 1 and 36% for SBR 2. The phosphorus profile for SBR 1 is indicative of the P concentration characteristics for EBPR in a SBR. The soluble P concentration at the end of the fill is greater than the influent total phosphorus concentration and it is reduced by 6.0 mg/L after the aerobic period, very likely by PAO uptake. The presence of PAOs shown in Figure 19 for Neisser staining of the April 30th sample also shows that EBPR activity was occurring.

Table 10. Results of sampling and phosphorus analyses for one cycle of Kittitas SBRs on June 5, 2015. Influent value is for total reactive phosphorus and the end of fill and effluent values are for soluble reactive phosphorus (all in mg/L).

	SBR 1	SBR 2
Influent	6.3	5.9
End of Fill	7.9	N/A
Effluent	1.9	3.8

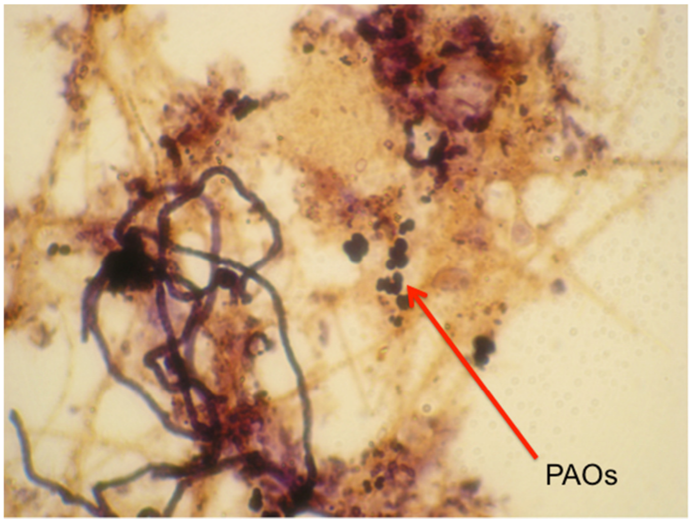


Figure 19. Photomicrograph of Kittitas mixed liquor sample at 1000X after Neisser staining indicates presence of PAOs. Sample taken on April 30, 2015 from SBR 1.

It was recognized during the evaluation of the potential for EBPR at the Kittitas facility that conditions were far from ideal for implementing EBPR without some capital expenditure. However, it provided a good example of how fundamental principles of EBPR could be applied to achieve some degree of successful enhanced phosphorus removal. The evaluation and implementation study provided a very useful training and technology transfer for the Kittitas staff and also provided similar benefits to the attendees in our technology transfer workshop on September 16, 2015.

Technology transfer at this workshop also indicated some other future potential avenues for low cost upgrading for EBPR at the Kittitas facility and other similar SBR processes that were not designed for effective nutrient removal. There are two ways to increase EBPR removal in such system. The first one that has been presented in our previous analyses is to provide more tankage and perhaps some piping changes. A second approach is to operate with a much higher biomass or mixed liquor concentration. Even with good settling floc-forming mixed liquor the reasonable maximum operating level would be an MLSS concentration of about 4,000 mg/L. However new technology has found ways to produce a different type of biomass, a very large size, dense granular sludge. Granular sludge also can settle 10 times faster than conventional floc-forming activated sludge. With implementation of granular sludge technology, the MLSS concentration could be increased to at least 6,000 mg/L and possibly 8,000 mg/L to provide conditions for highly effective EBPR and nitrogen removal in existing SBR facilities like Kittitas, which were designed primarily for only ammonia removal.

An objective of our study reported here was also to update technology transfer for EBPR since our 2012 report. In the last few years the potential for developing granular sludge, is becoming more feasible and it is possible that this technology can be applied to existing SBRs in the near future. The background, status, our current research activities, and potential for granular sludge technology was presented by us at the September 16th workshop and received with great interest.

5.2.3 Kittitas WWTP Class A equivalent effluent

Though the study was focused on improving phosphorus removal, it also afforded the opportunity to observe the final effluent produced at the facility. After effluent polishing by granular media filtration and UV disinfection a Class A equivalent effluent in terms of fecal coliform and turbidity is produced. Reuse opportunities have not yet been explored for this effluent but the staff should be commended for the excellent treatment product. A picture of the sparkling clear effluent taken during our site visit on April 30, 2015 is shown in Figure 20.

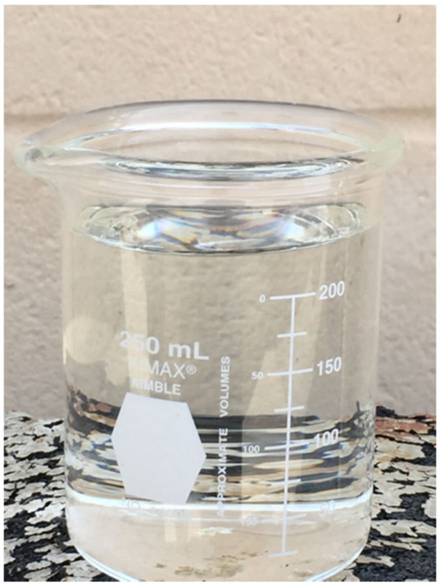


Figure 20. Kittitas WWTP April 30, 2015 effluent sample after filtration and UV disinfection has Class A water reuse quality.

5.3 Evaluation of Operating Changes to Advance EBPR at the Peshastin WWTP

Drs. Barnard and Stensel visited the Peshastin WWTP on March 17, 2015. The utility was interested in how the existing facility operation could be modified to advance EBPR, so an evaluation was undertaken. The results of this evaluation identified possible 3 alternatives that are presented in this section. However, it was not possible for the utility to implement any of these alternatives within the time frame of our study but the groundwork has been done for future action by the utility.

The first part of the analysis was to obtain information on the wastewater characteristics. Most of the flow to the plant originates from septic tank effluent, which in essence behaves as a primary settling tank with bottom storage of the settled solids. The BOD/P, BOD/TKN, and rbCOD/P ratios were 25, 5.3, and 38, respectively. These wastewater characteristics indicated favorable conditions for good nitrogen and phosphorus removal if the required process configurations to provide anaerobic contacting of the influent wastewater under anaerobic conditions could be achieved.

Three alternatives developed from this evaluation are described in the following.

Alternative 1

Without changes to the existing structure, this alternative strives to provide anaerobic contacting with mixed liquor and influent wastewater by adjusting the SBR operational sequence. This alternative will also result in more denitrification, which in turn could decrease the need for alkalinity addition. With the present under-loaded conditions, especially during certain time of the year it may be possible to decrease the settle and/or decant periods or even the aeration time to allow for more anaerobic conditions during the first part of the cycle. A need for this alternative is to introduce the influent wastewater into the sludge blanket after settling without too much mixing. Some fermentation will then take place in the sludge blanket to assist in denitrification and phosphorus removal.

The main problem obstacle to this approach is that the feed pipe enters the tank near the top, which would not help to get intimate mix while allowing for some fermentation in the bottom of the tank. The flow is directed downward which may help to get some mixing during fermentation if the downward velocity of the feed could penetrate the sludge blanket. This alternative is to start feeding after decantation for about 30 minutes to allow for some denitrification in the sludge blanket, then mix for 5 minutes, followed by feeding without mixing, then mix briefly again as shown in Figure 21. If the feed could be held back or backed up in the pipeline to allow less feed during aeration this would increase potential for phosphorus removal. The SBR cycle operating conditions to implement this approach are shown in Figure 21. For this alternative the aeration time remains at 90 minutes per cycle

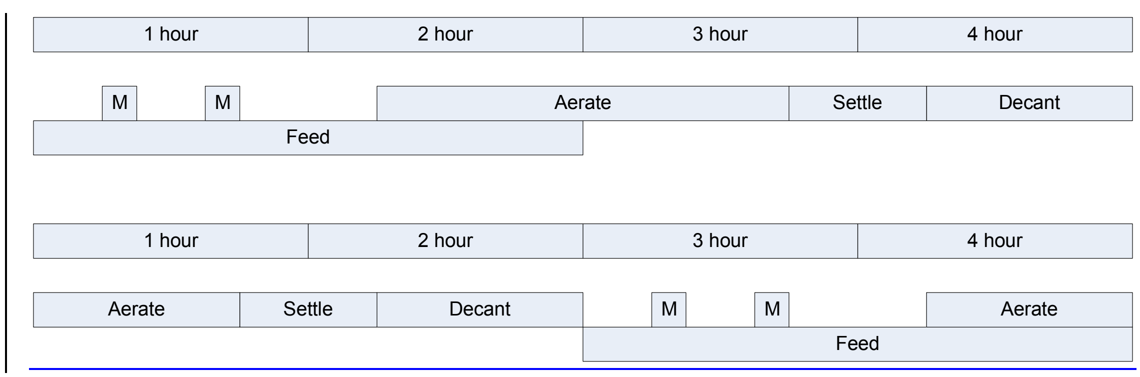


Figure 21. Proposed cycle operating pattern to promote EBPR without any changes to the SBR system structure and equipment (M indicates mixing only).

Alternative 2

This alternative requires that the feed be pumped into the sludge blanket, which could be achieved by installing a pipe with a diffuser near the floor from the feed pipe which already points downward. This may require the tank to be emptied for a short period or it may even be possible to install a downpipe with the tank only drawn down enough to install the pipe. Under this scenario it may be possible to pump into the basin during decant without mixing. Experience has shown that this will result in a well settling sludge that will make the process work even better while good phosphorus removal could be achieved. It will be necessary to see if there is short-circuiting in which case the feed period during decant should be shortened. This procedure has been effective in some large SBR plants and produced very low SVI values. The operating sequences for this alternative are given in Figure 22 below.

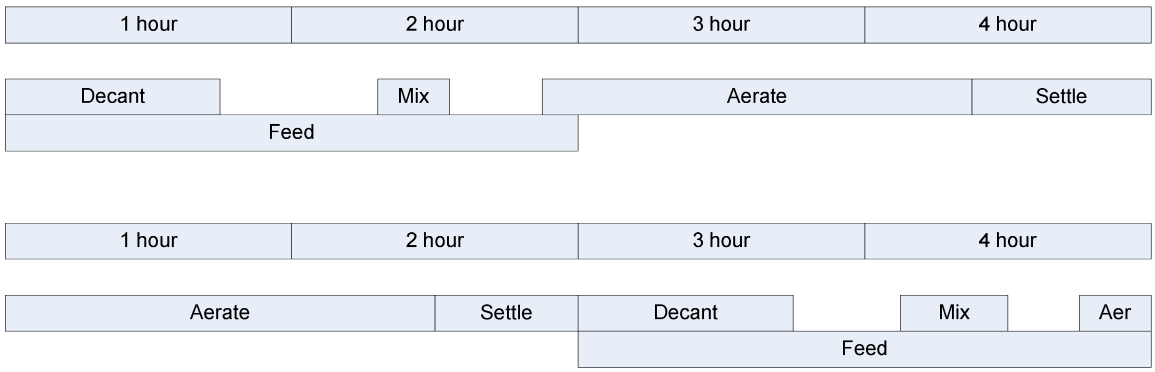
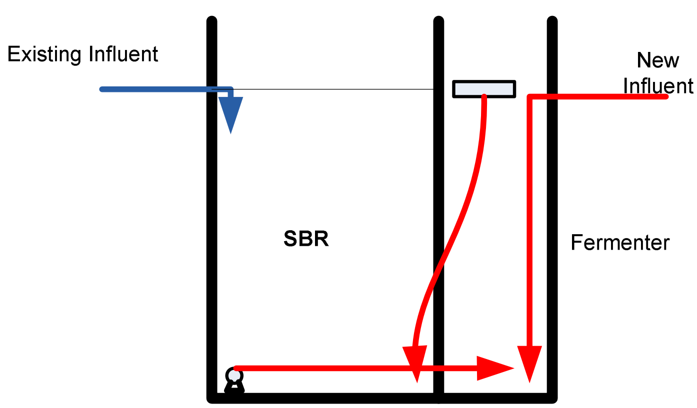


Figure 22. Proposed cycle operating pattern to promote EBPR by installing feed pipe to direct influent wastewater flow into the settled sludge blanket.

Alternative 3

This alternative uses the existing aerobic digesters as fermenters. This will be possible after the addition of new larger aerobic digesters as proposed in the recent facility report. In this scenario the influent wastewater feed will first be directed into the fermenter zone, while a portion of the mixed liquor is pumped from the reactors to the fermenter zone. There will then be an overflow from the fermenter zone to the SBR reactors. A schematic of this approach is shown in Figure 23. Additional floats and some mixing would be necessary in the present aerobic digesters to keep the levels in the fermenter and reactor the same and prevent scum from accumulating in the fermenters. The mixers may also be placed on timers to improve fermentation or they could run full time if that proved to give better results.

The SBR operating sequences and respective times for this alternative are shown in Figure 24.



Proposed Conversion for Alternative 3

Figure 23. Modification of influent feeding method and conversion of previous anaerobic digesters to a fermentation tank for Alternative 3.

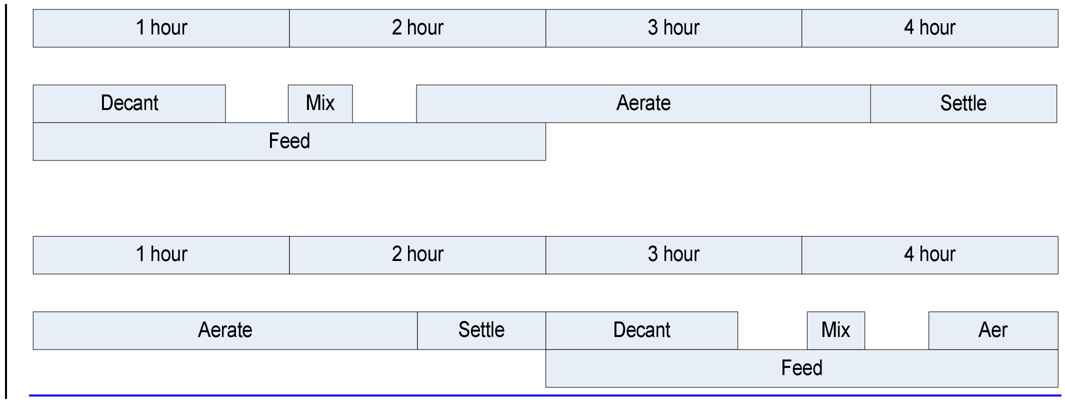


Figure 24. Proposed cycle operating pattern to promote EBPR with Alternative 3 when the existing aerobic digesters become available for fermentation of influent wastewater and recycled mixed liquor.

Though Alternative 1 could be implemented by simple changes to the SBR operating program, the other alternatives can be further considered as part of the site work and engineering to accommodate the Dryden wastewater flows in the future.

6.0 Summary and Conclusions

The discharge of nitrogen and phosphorus to surface waters in the Yakima River Basin from municipal, agriculture, and industrial sources are a threat to water quality due to the acceleration of eutrophication and its impact on fish survival and other aquatic life. The South Central Washington Resource Conservation and Development Council (RC&D) has been an active advocate for implementing a holistic approach to water quality management in the Yakima Basin, which includes the management of nutrients discharge from the various sources. A recommended first step in the management of nutrients from point discharges at municipal wastewater treatment plants is to implement changes in operation and/or design that have a low cost but high incremental reduction of effluent nutrients and have minimal impact on other environmental concerns such as energy use and greenhouse gas emissions. One such approach is to apply enhanced biological phosphorus removal (EBPR) technology, which biologically removes phosphorus by using specific treatment process designs that also biologically remove nitrogen. EBPR is a cost effective method of providing modest to good levels of phosphorus removal without adding chemicals, which have significant costs and greenhouse gas implications.

In prior work by us, 17 WWTPs in the Yakima River Basin were evaluated to determine options for implementing EBPR by operational changes and/or simple plant tankage and equipment additions. Many of these facilities were interested in implementing the methods outlined for their facility but technical assistance and training was needed to support their staff efforts and to demonstrate the feasibility of low cost nutrient removal.

WWTPs included in the previous study were considered for this technical assistance, training, and technology demonstration program. Our goal was to work with three facilities that could accommodate this program. Requirements for the facility selection were that the staff could implement the program within the time frame for this project and could carry out additional sampling and analyses on the treated effluent or obtain assistance for such work. Site visits were made to Toppenish, Zillah, Kittitas, Peshastin, Leavenworth, and Mabton WWTPs to discuss the program goals and the ability to participate. Subsequently, a partnership was developed with the Toppenish, Kittitas and Peshastin WWTPs to implement this program.

Our technical assistance to the facilities for the program implementation involved the following activities: 1) reviewed the facilities to determine the most optimal approach for applying EBPR, including consideration to more recent technology advances in this area, 2) provided instructions on the plant operations, 3) provided a sampling and analysis monitoring program to determine the effects of plant operating changes including oversight on analytical methods, 4) provided periodic data review, 5) communicated on regular basis to discuss the program and technical aspects of the process, 6) provided microscopic analyses of plant samples, and 7) made additional site visits to Toppenish and Kittitas for review and discussions.

The Toppenish facility already had a process configuration for EBPR, and the challenge was to determine operating methods that would increase the readily bioavailable COD (rbCOD) needed by the phosphorus accumulating organisms (PAOs). Based on fundamental principles of EBPR various alternatives were discussed amongst ourselves and with the plant staff. The methods used to increase the feed rbCOD were to operate the primary clarifier with a higher sludge blanket and with elutriation to promote some fermentation of settled solids to volatile fatty acids (VFAs), and to minimize mixing in the anaerobic contact tank for holdup and fermentation of return activated sludge (RAS). Other plant operating conditions that were adjusted to improve EBPR were a reduction in the RAS flowrate to the anaerobic contact tank, a reduction in the dissolved oxygen (DO) concentration in the final aeration tank, and a reduction in the system solids retention (SRT) time. The phosphorus removal was improved by these activities and the major factors contributed for this improvement were 1) mixed liquor fermentation in the anaerobic contact tank, 2) reduction in the RAS flow rate, and 3) a reduction in the SRT. By the end of the study, 73% to 91% phosphorus removal was achieved compared to 40 to 50% earlier.

The Kittitas facility is an SBR process designed primarily for ammonia removal and nitrification. At the start of the implementation program it was not achieving EBPR and had very poor settling mixed liquor. A major challenge was to determine how to modify the operation so that an anaerobic contact with mixed liquor would occur during the influent feeding step. The SBR cycle program was modified to address this need. Because of the tank configuration, it was possible to start the influent feeding during the decanting step. The aeration time during the feeding was also reduced at the beginning of the feed period. The operational modifications resulted in a dramatic improvement in the mixed liquor settling characteristics. The effluent phosphorus concentrations during the program were variable, but EBPR was initiated and some improvement in phosphorus removal was occurring. Plans for further changes and optimization of the EBPR were cut short in the last two months of the study due to the need to remove one of the two operating SBR tanks for maintenance.

The Peshastin facility was also an SBR system with similar initial design goals that negated the possibility of EBPR. The facility had different characteristics than the Kittitas WWTP and offered the opportunity to consider additional methods for converting the SBR system to accomplish EBPR. Three alternatives are presented in the report, which could be accomplished in a progressive manner and lead to incrementally higher phosphorus removal efficiencies by EBPR.

The program implementation provided a good opportunity for technology transfer and training. It also identified recent advances in EBPR technology including mixed liquor fermentation, which appeared to have a significant impact in phosphorus removal performance in the Toppenish study, and the potential for granular sludge technology for future plant conversions to EBPR. These technologies and results of the implementation program were included in our September 16, 2015 nutrient management workshop to WWTP owners and operators, regulatory agencies, engineers, and other stakeholders in the Yakima Basin and other interested communities. Overall, the program has demonstrated how the application of fundamental principals on EBPR can be used to address site-specific applications to greatly improve nutrient removal at minimal cost.

Acknowledgements

Many participants contributed to the success of the program described in this report. The work accomplished in this study was not possible without the cooperation and assistance of the various facilities in the Yakima Basin and the leadership of Ryan Anderson for the South Central Washington Resource Conservation & Development Council and assistance by Melanie Tucker. We are especially appreciative of the commitment and efforts by the wastewater treatment plant staff at Toppenish and Eric Bakker and at Kittitas and Brenda Bach and their interest in optimizing their plant performance and contributing to the advancement of nutrient removal technology. The support and interest from the Yakima Valley Community College led by Dr. Tanya Knickerbocker was appreciated and added another important educational dimension to the project. The assistance provided by Nancy Wetch of Gray & Osborne Engineers was essential for our process evaluations for the Toppenish, Kittitas, and Peshastin facilities and was greatly appreciated.

Appendix A – Updated Evaluation of Facilities for Conversion to EBPR

This appendix updates the summary of identified operational and low cost changes for existing WWTPs in the Yakima Basin for implementation of enhanced biological phosphorus removal (EBPR) technology. This update reflects technology developments in EBPR that have occurred since the 2012 report on the evaluation of facilities in the basin for nutrient removal.

The 2012 report noted that after an initial screening of Yakima Basin WWTPs, 17 were identified for having potential for conversion to EBPR. These WWTPs are organized here under one of the following three categories.

- Oxidation ditch
- Activated sludge
- SBRs

A list of these facilities with their design flows is given in Table A2.

TABLE A1. LIST OF 17 WWTPS IN PLANT EVALUATIONS

WWTP	Annual Average Design Flow, MGD	Comments
Activated Sludge		
Toppenish	1.2	Has an operating EBPR process
Yakima	11.3	Is being modified to an EBPR process
Benton City	1.0	Waste sludge lagoon
Ellensburg	5.0	Square aeration tanks, sloped walls
Richland	8.9	Surface aerators in aeration basins
Kennewick	6.6	Secondary system design information sought
Selah	1.5	Square aeration tanks, sloped walls
Oxidation Ditch		
Grandview	1.5	Carrousel -existing tankage for EBPR
Granger	0.3	Brush- new parallel ditch to be built
Mabton	0.25	Brush –new design - provide EBPR potential
Naches	0.14	Shallow trapezoidal brush ditch design
Zillah	0.42	As external tank, brush design
Sequencing Batch Reactors (SBRs)		
Kittitas	0.5	2 tanks, waste sludge lagoon
Cowiche	0.25	4 tanks, waste sludge lagoon
Cle Elum	3.6	2 tanks, waste sludge lagoon
Prosser	0.63	2 tanks, preceded by trickling filter
Port of Sunnyside	0.55	2 tanks, Industrial wastewater treatment

A.1 Oxidation Ditch WWTPs

Oxidation ditch designs are used for secondary treatment at Grandview, Mabton, Naches, Granger, and Zillah. The Grandview facility has 2 mixed, unaerated tanks before the oxidation ditch, which can serve as anaerobic and anoxic contact zones (Figure A1). The anaerobic zone provides conditions necessary for EBPR. The amount of phosphorus removal for the facility is not well known because it is currently not a permit parameter. Excellent EBPR performance may be expected for the facility in view of the fact that it has a fairly strong wastewater due to a high level of industrial waste food processing sources.

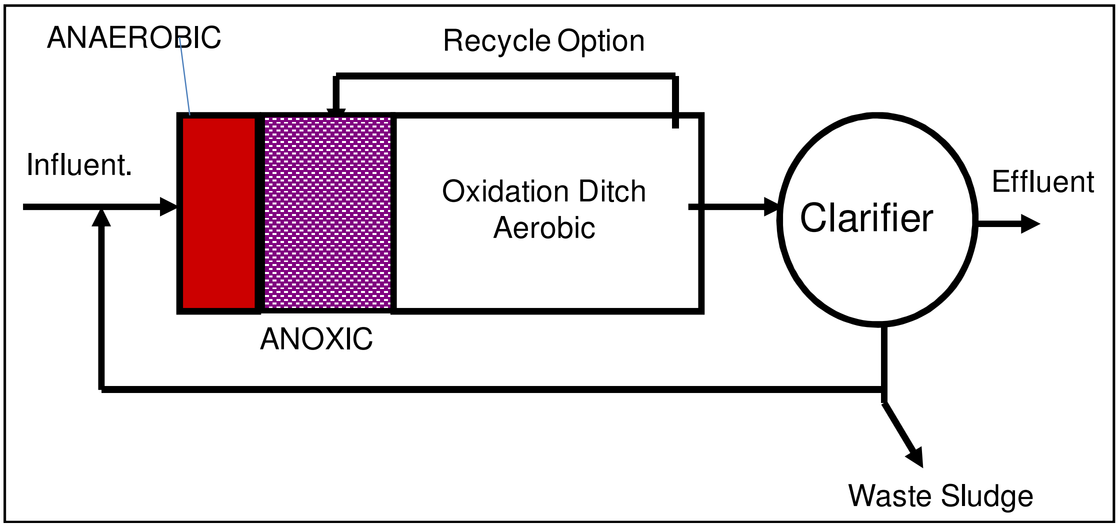


FIGURE A1. SCHEMATIC OF GRANDVIEW OXIDATION DITCH PROCESS WITH ANAEROBIC AND ANOXIC ZONES.

The following recommendations are made concerning the implementation and optimization of EBPR at the Grandview WWTP.

- Simultaneous nitrification and denitrification in the oxidation ditches
- Using internal recycle to maximize nitrate removal.
- Achieve more simultaneous nitrification and denitrification in the oxidation ditches by using ORP control and possibly variable frequency drives on the aerator motors.
- Provide more monitoring information to assess the level of phosphorus removal.
- If there is a desire to remove more phosphorus also from the ponds, then discharge pond effluent to the aeration basin. This has been use with great success in other plants

The Mabton facility is to be modified with the installation of anaerobic, anoxic, and aerobic zones prior to the existing oxidation ditch process (Figure A2). These modifications provide an excellent opportunity for EBPR. The following recommendations were made for the new installation.

- Use mixers in anaerobic contact and anoxic contact zones instead of air for mixing.
- Optimize performance by increasing the feed readily degradable BOD by providing more fermentation in the anaerobic zone by turning off the mixer for most of the time.
- Divide the aerobic tank before the oxidation ditch into multiple tanks in series (staging) to improve phosphorus uptake rates.
- Control digester supernatant return flow rates. If possible aerate and settle returning solids to sludge disposal
- Operate at a minimal SRT just above that needed for nitrification to improve phosphorus removal efficiency.
- Construct a by-pass to limit the flow to the anaerobic zone. If necessary, use a VFD pump to pump only a constant flow to the anaerobic zone and allow the remainder including storm flows to anaerobic zone.

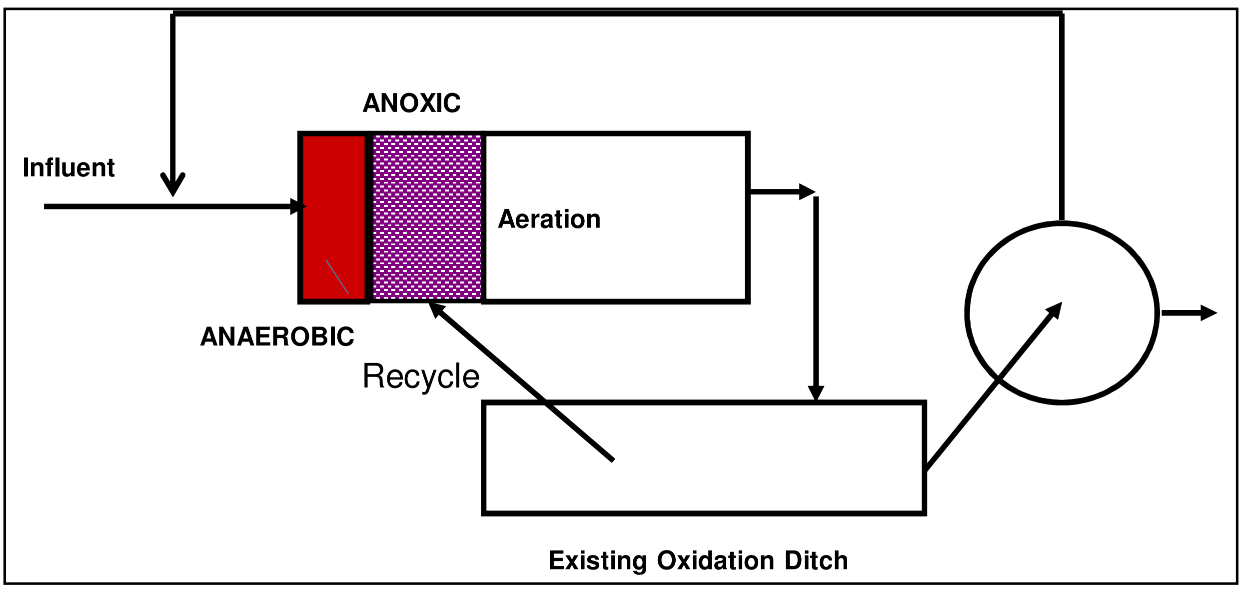


FIGURE A2. MODIFICATIONS PLANNED FOR ADDITION OF ANAEROBIC, ANOXIC, AND AEROBIC STAGES BEFORE THE MABTON EXISTING OXIDATION DITCH SYSTEM.

The Naches WWTP is a conventional oxidation ditch system. For such systems, it is necessary to find an external tank to provide in anaerobic contact zone for EBPR. Fortunately, an old chlorine contact tank is available at the site for consideration for use as an anaerobic contact zone. Additionally recommendations were made to improve the nitrate removal in the oxidation ditch by using either aeration or oxidation-reduction potential (ORP) control. The following summarizes the recommendations.

- Use an existing abandoned chlorine contact tank for an external tank for anaerobic contact zone.
- Control nitrates in the oxidation ditch by control of aeration and DO.
- Add a mixer to the oxidation ditch with the ability to reduce aeration to improve for NO_3 removal.

- Use an ORP control system to minimized effluent NO_3.
- Operate at a minimal SRT just above that needed for nitrification to improve phosphorus removal efficiency.
- Pump some of the mixed liquor back to the old chlorine tank for fermentation allowing for an anaerobic solids retention time of around 2 days.

It is quite difficult to control aeration in oxidation ditches with DO probes since the range of operation is very small. Standardized control systems using ORP has been developed to control the nitrates in the effluent, which should also have a beneficial effect on the phosphorus removal.

The Zillah facility has a long narrow aerated tank before the existing oxidation ditch. The tank receives return activated sludge and the influent wastewater, and is aerated in three baffled zones with coarse bubble diffused aeration. Following that, fine bubble diffused aeration is used in the rest of the tank with a detention time of about 4 hours. This tank provides an excellent opportunity for a simple conversion to provide EBPR by converting the initial contact zones into anaerobic contact zones. The following summarize the recommendations for progressive steps to reach this goal:

- Turn off air in the 3 initial coarse bubble zones or periodically turn the air on and off to provide an operational change for EBPR without capital investment.
- If this approach shows promise, insert baffles and mixers to turn the narrow tank into conventional anaerobic/anoxic zones.
- Use mixers instead of coarse air for the 3 initial contact zones.
- Add mixers and ORP control for NO_3 removal in the oxidation ditch.
- Optimize the SRT to maximize phosphorus removal
- If possible insert a flow diversion so that the flow to the anaerobic zones could be controlled as discussed above for Mabton.

The Granger facility has an existing shallow oxidation ditch with two brush aerators. A new parallel ditch is to be built. Currently the waste sludge from the oxidation ditch is sent to an aerobic digester before decanting and sludge removal. We recommend that the new facility design consider the addition of an anaerobic contact tank and that an ORP probe and mixer be installed at the Granger facility to control nitrogen removal in the ditches. Alternatively, the design engineer could add an anoxic contact tank with the new external anaerobic tank. After further information on the changes made to this plant additional recommendations could be suggested. Control of simultaneous nitrification and denitrification using ORP probes are recommended

A.2 Activated sludge WWTPs

Three activated sludge WWTPs were reviewed; Toppenish, Yakima, and Selah. The Toppenish facility was the subject of our implementation study and is presented in the body of this report.

The Yakima facility was designed as a conventional activated sludge system with nitrification capacity. A retrofit design has been considered to convert the system to an

EBPR process as shown in Figure A3. It is a version of the Johannesburg (JHB) process. The return activated sludge is directed to a designated anoxic zone in which the nitrate is reduced prior to the return sludge contacting the influent wastewater in the anaerobic zone. Aeration zones follow for phosphorus uptake and nitrification.

The Selah WWTP has a good source of readily available BOD for EBPR that comes from an aerated lagoon effluent receiving a food processing industrial wastewater. The lagoon effluent is combined with domestic wastewater in the Selah activated sludge treatment system. Bypassing some of the industrial wastewater provides a higher influent BOD to phosphorus ratio to encourage good EBPR performance. A major challenge at the Selah facility was to develop conditions to provide an anaerobic contact zone. An operational method to vary the aeration in the activated sludge tank was the only logical option in lieu of building an anaerobic contact tank. Cycling the first aerator on and off would allow for periods of anaerobic contact to develop conditions favorable for the growth of PAOs and subsequent EBPR. The following was recommended for the Selah WWTP.

- By-pass some Sunripe food processing wastewater.
- Turn down aeration to develop anaerobic contact.
- Turn off one aerator at night for anaerobic contact.
- Cycle aerators on and off for NO3 removal.
- Use aerobic digester –partition a portion for fermentation of mixed liquor.
- Add some industrial waste to the digester ML fermentation zone.
- Cycle aeration in aerobic digesters for reducing nitrates.
- Use a small basin with a 4 to 8 hour holding time of return activated sludge and with addition of some industrial wastewater to aid in the selection of PAOs and EBPR efficiency.

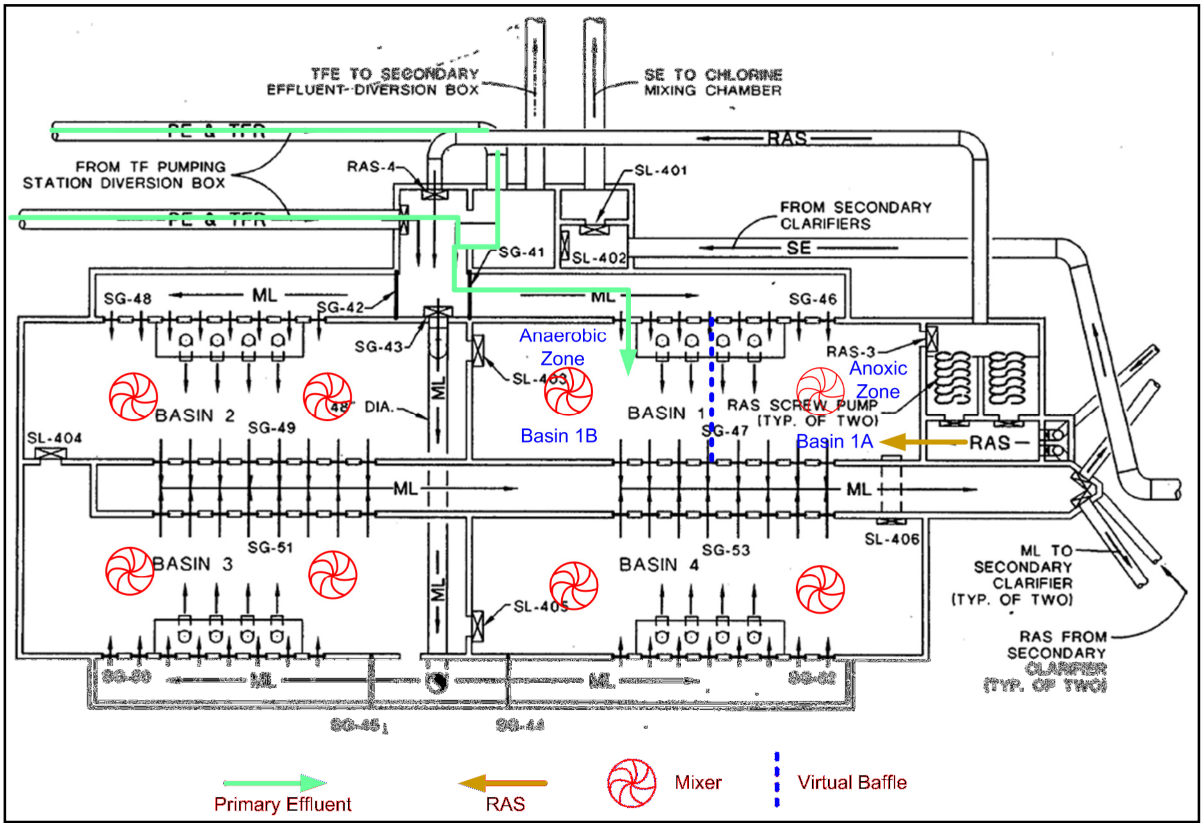


FIGURE A3. SCHEMATIC OF EBPR PROCESS IN RETROFITTED YAKIMA WWTP.

A.3 Sequencing Batch Reactor WWTPs

Three sequencing batch reactor (SBR) designs were evaluated. These were for the Kittitas WWTP, which treats mainly domestic wastewater, the Prosser WWTP, which has a mixture of domestic and industrial food processing wastewater, and the Port of Sunnyside WWTP, which treats industrial wastewater from a dairy operation and seasonal food processing. All of these SBRs were not designed for EBPR and thus did not have any provision for in the anaerobic contact time. Mixing during the entire fill process of an SBR operation would provide an excellent anaerobic contact condition to promote EBPR. However, all of these designs have only a mixed, non-aerated period during about 15 to 25 percent of the fill time. This provides some nitrate removal, but is insufficient for an EBPR operation. The Kittitas system was evaluated in the implementation study and the recommended modifications and results are reported in the above main text of the report.

For the Prosser WWTP, the use of the trickling filter prior to the SBR is likely removing too much readily available BOD that is needed for the EBPR process. One of the recommendations is to bypass the trickling filter operation, but further information on the wastewater characteristics and design is needed to determine if the downstream SBR process has sufficient aeration capacity for this approach. Without the trickling filter in operation, the intermediate clarifier can also be used as a sludge fermentation tank to produce more VFAs for an optimal EBPR performance. The following recommendations were made for the Prosser WWTP.

- By-pass the influent flow around the trickling filter to be added directly to the SBR.
- Mix during fill without aeration for as long as possible.
- Obtain more information on the wastewater characteristics to determine aeration capacity needed in SBR without trickling filter in operation.
- Use the intermediate clarifier as a sludge fermenter when using the smaller trickling filter.
- Get more data on the SBR operation.

Based on out more recent observations other avenues may be exploited. One such option would be to partition the SBRs to have an anaerobic zone at the front end and install a pump to recycle sludge from the main body of the tank to this anaerobic zone. Furthermore it is advised to divert some of the higher strength BOD industrial wastewater to these anaerobic zones. This could be performed in a pilot plant to prove the concept but it would encourage enhanced EBPR at low cost.

The port of Sunnyside has a challenging operation in terms of responding to changing wastewater characteristics from the various dairy and food processing sources. It also has a level of flexibility that could aid in EBPR operation. It is possible to bypass influent wastewater around the initial aerated lagoons provide for BOD for the EBPR operation and it may also be possible to feed the SBR over a shorter time so that the fill period can be used for an anaerobic contact time. The following recommendations are made for the port of Sunnyside facilities.

- Increase the mix fill time in the SBR cycle.
- By pass some feed around Lagoon 1.
- Fill the SBR faster to allow more anaerobic contact time after the fill.
- Use 3 cycles per day versus 2 cycles per day.
- Add some of the industrial wastewater directly to the SBR anaerobic fill for a large portion of the fill time followed by the aerobic fill of the pond effluent.
- Pump some mixed liquor from the SBRs to a holding tank for fermentation as has been presented for the some of the previous facility recommendations.