Review of the Pump-and-Treat Improvement Initiative Report and Plume Containment and Remediation Utilization Plan and Associated Recommendations

Communication to DOE/RL

August 10, 2017

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Introduction

This document is prepared by PNNL and SRNL and provides comments and suggestions on the CHPRC documents, "Pump-and-Treat (P&T) Improvement Initiative (well-fouling) report (PTII, SGW-60832, Draft, June 2017) and the 2018 Plume Containment and Remediation Utilization Plan (PCRUP, SGW-60843, Draft, June 2017). The CHPRC documents identify actions to improve the operations of the 200 West Pump and Treat System and reduce the observed injection well fouling issues. The main components of the 200 West Pump and Treat System addressed in the CHPRC report are the Fluidized Bed Reactors (FBRs), Membrane Bio-Reactors (MBRs), Air Stripper System (A/S), Well-Field Conveyance System for Treated Effluent (effluent system), and the Injection Wells.

The recommendations in the CHPRC documents include near-, mid- and far-term actions. Mechanical, chemical, and operational modifications to the system components as well as field tests and data analysis to further evaluate conditions causing the well fouling are included in the documents. These recommendations build on information collected to data through analysis of operational conditions and water/solids characterization of the system and injection wells. The categories of recommendations from the CHPRC documents include:

- FBR changes to improve performance and operational stability;
- MBR changes to enhance performance of dissolved-phase component treatment and filtration;
- Changing additives used in the A/S to decrease phosphorus in the effluent system;
- Evaluating effluent system conditions;
- Evaluating effluent treatment options; and
- Implementing improved injection well cleaning approaches.

Review of the PTII) and the PCRUP was conducted with the intent of providing constructive input as the site moves forward with implementing actions to address the observed decrease in injection well capacity. Based on our review of these documents, we concur with applying near-term actions to optimize the performance of key 200W treatment system unit operations (e.g., FBR, MBR). We recommend applying a balanced portfolio of actions would address the "root-causes" of well fouling as well as the engineering and maintenance required to sustainably operate a large injection well system. We advocate an evaluation that 1) defines a reasonable envelope of effluent water chemistry that addresses observed well-fouling issues, 2) identifies technically-based performance metrics and water chemistry parameters for each major unit operation to provide target operating envelopes, and 3) identifies actions to improve or optimize underperforming unit operations and, where necessary, includes identifying, designing, and implementing supplemental/polishing actions to bring the overall water chemistry into specification. Once a "comprehensive" portfolio of actions is defined, the sequencing of the actions needs to be strategically developed. Activities need to move forward together in a strategic and logical manner to maximize the overall value of the investment toward robust and sustainable operations.

This review includes an initial section that describes overall comments and recommendations. A special-topics section highlights key recommendations from the review team. This section includes a discussion of the type of objectives and implementation metrics appropriate for each of the recommended items. The appendix contains sections that provide input on the individual actions identified in the 2018 Plume Containment and Remediation Utilization Plan (PCRUP, SGW-60843, Draft, June 2017) and the Pump-and-Treat (P&T) Improvement Initiative (well-fouling) report (SGW-60832, Draft, June 2017).

Overall Recommendations

To facilitate robust operation of the 200W P&T system, the review team recommends that actions associated with mitigating well-fouling issues be organized as shown in Figure 1. Operational and mitigation actions have been identified for the Fluidized Bed Reactor (FBR), Membrane Biofilter Reactor (MBR), Air Stripper (A/S), effluent system, and injection wells associated with addressing the current well-fouling issue. To organize and manage implementation of these actions, the review team recommends compiling baseline information for the influent and effluent water chemistry and operational parameters of each unit operation. We recommend establishing target values (or ranges) for these measured constituents that lead to conditions that will meet the goals for sustainable injection operations. As changes are made, monitoring of progress toward these targets can provide feedback to decisions about any additional changes that are needed. It is recognized that the targets may need to be adjusted as information is obtained over time about how these values relate to injection well performance. The review team recognizes that along with the technical evaluations described herein, there are also monitoring and maintenance categories of actions that need to be managed in conjunction with mitigation actions.

In addition to Figure 1, a sequencing of actions should be developed to guide implementation of mitigation actions. Figure 2 provides an example sequencing of actions with identification of outputs that may alter subsequent actions. It will be important to use the objectives and implementation metric information compiled for near-and mid-term mitigation options to inform subsequent actions.

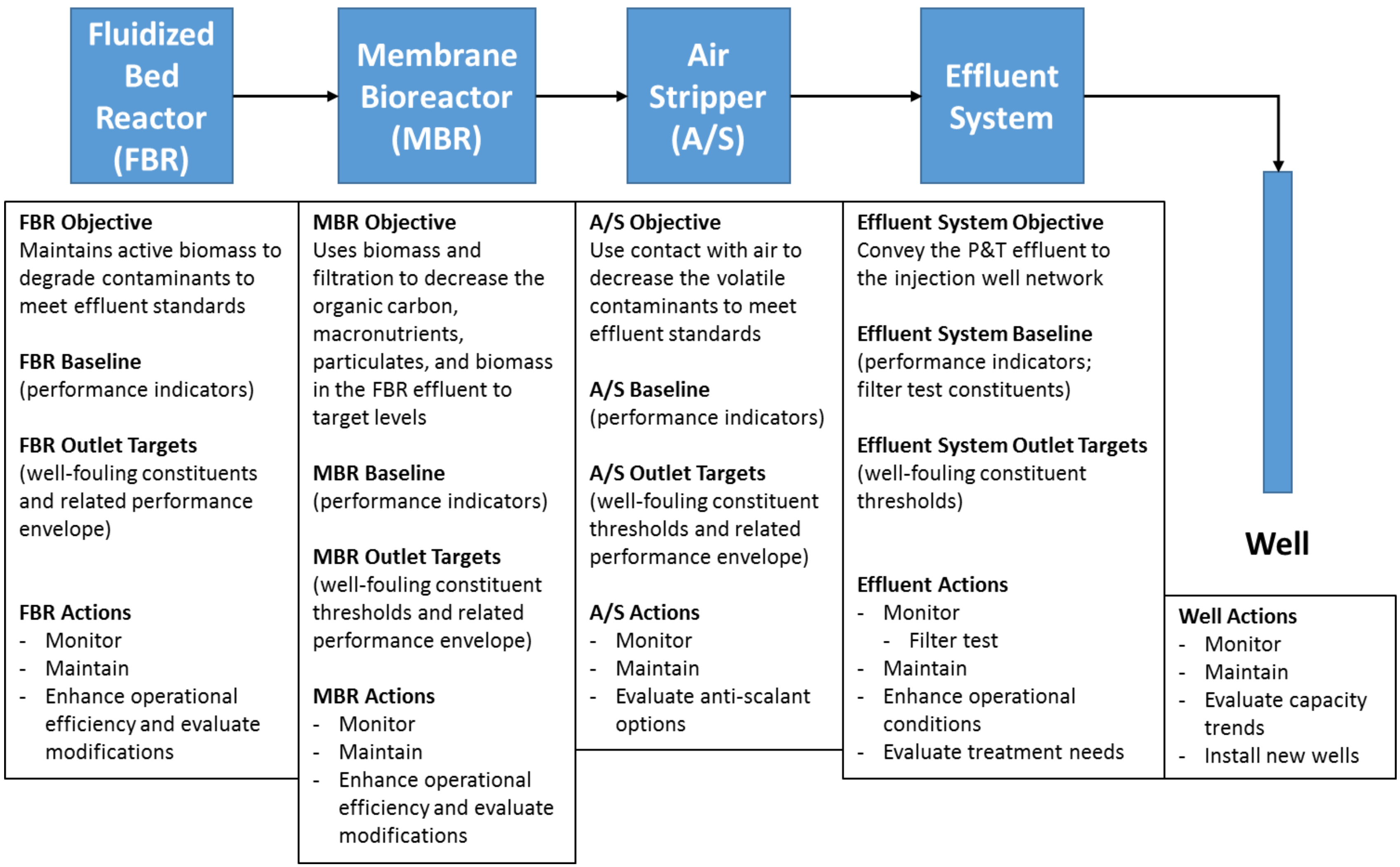

Figure 1. Example depiction of the components of P&T system operational and mitigation actions to address well-fouling issues.

Near-Term (6 mo)		Mid-Term (6-mo to 1 yr)		Long-Term (1 yr +)	
Actions	**Outcomes**	**Actions**	**Outcomes**	**Actions**	**Outcomes**
Data mining and supplmentary analyses, injection capacity trending	Provide benchmark of current performance and targets for future performance for components of the system as identified in Figure 1	Supplementary analyses to monitor performance and update benchmarks, injection capacity trending	Track system performance improvements, progress toward targets, and need for updated performance benchmarks or targets to guide the mitigation process	Supplementary analyses to monitor performance and update benchmarks, injection capacity trending	Track system performance improvements, progress toward targets, and need for updated performance benchmarks or targets to guide the mitigation process
FBR B upgrade	Complete upgrade so that FBR B performance matches FBR A and evaluate how performance stabilizes production of well-fouling constituents and helps performance of the MBR as input to determining future upgrades to the FBR and MBR	Initiate flow to new injection wells	Increase capacity of the system by starting to use new injection wells after determining that operational conditions are stable enough to not rapidly (e.g., < 1 yr) foul these wells	Install and initiate flow to new injection wells	Increase capacity of the system by starting to use new injection wells after determining that operational conditions are stable enough to not rapidly foul these wells
Z-line bleed	Complete planned upgrade and evaluate stability of FBR operation as input to future FBR upgrades	Implement revised well cleaning for all wells on a regular schedule	Increase capacity of the system by optimizing and updating the well-cleaning approach	Implement disinfectant system as needed	Increase capacity of the system by minimizing biological growth in the effluent system
Filtration test	Provide information on well-fouling constituents in the effluent system as input to mitigation evaluation and design activities	MBR cassettes and optimization changes	Reduce the well-fouling constituents in the P&T system effluent and inform the need for additional MBR or other changes	Implement additional FBR changes as needed	Implement upgrades to improve FBR performance and evaluate how performance stabilizes production of well-fouling constituents and helps performance of the MBR as input to determining future upgrades to the FBR and MBR
Well cleaning upgrade	Evaluate and define upgraded well-cleaning protocol fo rthe injection wells and effluent system	pre-MBR evaluation	Evaluate how pre-MBR changes (e.g., residence time and/or additives) would enhance MBR performance	Implement pre-MBR changes as needed	Reduce the well-fouling constituents in the P&T system effluent and inform the need for additional MBR or other changes

Figure 2. Example binning and sequencing of mitigation and related activities (continued on next page).

Near-Term (6 mo)		Mid-Term (6-mo to 1 yr)		Long-Term (1 yr +)	
Actions	**Outcomes**	**Actions**	**Outcomes**	**Actions**	**Outcomes**
MBR optimization evaluation	Determine initial optimization changes for the MBR to provide input to design and implementation of changes	FBR biomass control evaluation	Evaluate how FBR changes could be used to improve biomass control and how this could help meet FBR operational targets (e.g., shear-force study for potential bed-solid separator pretreatment)	Design supplemental effluent treatment as needed	Design a system for effluent treatment that is compatible with other operations and helps meet performance targets in the effluent system if the evaluation shows that effluent treatment is appropriate in the context of other mitigation changes being made
Antiscalant evaluation	Determine appropriate antiscalant change with consideration of other ptential changes such as a disinfectant system	FBR liquid substrate evaluation	Evaluate how FBR liquid substrate changes could help meet FBR operational targets (e.g., use of simple organic acid carbon liquid subsrates)	Effluent treatment evaluation	Evaluate potential effluent treatment systems in the context of other mitigation changes being made and the observed changes in performance from the initial mitigation actions
Disinfectant evaluation	Determine an appropriate design and performance enhancements from a disinfectant system	FBR physical substrate evaluation	Evaluate how FBR physical substrate changes could help meet FBR operational targets (e.g., need for GAC hardness specification)		
		Change antiscalant	Reduce the concentration of phosphorus in the system effluent		
		Disinfectant design	Design a system for use of disinfectant to limit biological growth in the effluent system if the evaluation shows that this change is appropriate in the context of other mitigation changes being made		

Figure 2. (continued) Example binning and sequencing of mitigation and related activities.

Improving and maintaining FBR operations to limit the number and magnitude of upset conditions and meet operational goals is one component of addressing well-fouling issues. The FBR generates well-fouling constituents as a necessary part of its operation, but actions can be taken to limit and stabilize the amount of these constituents in the FBR effluent. The recent upgrades for FBR A and FBR B are expected to be important and useful in helping improve FBR operational performance and stability. Monitoring to establish baseline conditions, monitoring to evaluate transient conditions during and after changes are made, and routine monitoring for comparison to effluent targets is needed. Periodic and routine maintenance are also important for consistent FBR effectiveness. Several types of changes associated with improving and maintaining FBR operations have been identified. The review team concurs with updates to the physical configuration (e.g., recent nozzle adjustments) and the Z-line bleed update identified in the PCRUP as part of the recommended actions. In addition, changes to enhance the FBR operational conditions and stability should be evaluated in the near-term to provide potential upgrades that are likely to be important for meeting FBR operational targets. These FBR enhancements include improved biomass control, alternative physical substrates, and alternative liquid organic substrates. These enhancements are discussed in the special-topics section. Evaluations for each of these enhancements is recommended.

Improving the performance of the MBR is of significant importance because the objective of this system component is to remove well-fouling constituents from the P&T system effluent. Thus, the efficiency of this component and ability to meet operational goals associated with limiting well-fouling issues need to be established and optimized. Operational success of the MBR will relate to the magnitude and need for other down-stream mitigation actions. As for the FBR, MBR monitoring to establish baseline conditions, monitoring to evaluate transient conditions during and after changes are made, and routine monitoring for comparison to effluent targets is needed. Maintenance includes cassette replacement as need (e.g., as identified in the PCRUP) and the other periodic and routine maintenance to achieve consistent MBR effectiveness. The review team concurs with evaluation of temperature and increased solids modifications to the MBR that are identified in the PCRUP as part of the recommended actions. In addition, an evaluation of whether changes to the P&T system configuration to allow increased residence or to change additives before the MBR are recommended as a potential follow-on activity pending the current MBR optimization efforts.

The primary effect of the A/S on well-fouling constituents is the current addition of a phosphate-based anti-scalant. The review team concurs with updating to a non-phosphate anti-scalant as identified in the PCRUP as part of the recommended actions (see special topics section). While, otherwise, the A/S is not a direct contributor to well-fouling issues, it can indirectly contribute as a location of post-MBR biogeochemical reactions that produce particulates. As for the FBR and MBR, A/S monitoring to establish baseline conditions, monitoring to evaluate transient conditions during and after changes are made, and routine monitoring for comparison to effluent targets is needed along with periodic and routine maintenance. A key monitoring point for system evaluation is the outlet of the A/S (or at the system effluent tank) to define system effluent and enable determination of any changes in well-fouling constituents within the effluent distribution system.

The effluent system can indirectly contribute as a location of post-P&T Facility biogeochemical reactions that produce particulates. The review team recognizes that the current filter test will provide some additional information about the nature of the well fouling constituents entering the effluent system and just prior to an injection well. Thus, monitoring of the effluent system consists of information from this filter test and other baseline monitoring, monitoring to evaluate transient conditions during and after changes are made, and routine monitoring for comparison to injection targets. The review team recommends that maintenance cleaning of the effluent system is linked to the cleaning of injection wells so that the entire post-facility system is cleaned at the same time. In addition, the review team recommends evaluating, designing, and testing use of a disinfectant applied in the effluent system (see special topic section). Pending near-term monitoring data and performance of the system associated with recommended actions for the FBR, MBR, A/S, and effluent system, additional evaluation of post-facility effluent treatment to reduce well-fouling constituents may be needed. A number of effluent treatment options were identified in previous reviews that provide the starting point for this type of evaluation. As with the other evaluations, the cost of a mitigation action would need to be considered relative to the cost avoidance for well cleaning and replacement.

Injection wells are the location of well-fouling issues. However, several actions can be taken to help mitigate the overall effect of well fouling on injection capacity. Monitoring of injection flow, pressure, and calculation of individual well and overall injection capacity trends should be conducted as baseline information for well-fouling mitigation and P&T operational management. The review team does not agree with lowering the injection rate to decrease the well-cleaning frequency as a primary mitigation approach listed in the PCRUP. However, the review team concurs with the aggressive well cleaning identified in the PCRUP as part of the recommended actions. The review team also recommends that new wells consider well screen design and screened interval (e.g., extending into the vadose zone) to optimize performance.

Special Topics

The special topic narratives provide a synopsis of key information and recommended technical direction for several key lines of inquiry. It is recommended that tables are developed, as shown in the example item b, to document the activity, objectives, and implementation metrics. The special topics include the following subsections: a) developing actionable metrics and associated responses for each major future activity, b) eliminating root causes of biofouling (b.1 improving aerobic biotreatment and b.2 removing added phosphate), c) evaluating filtration for the injection wells , d) evaluating disinfectants to control biofilms in the distribution/injection well system, e) data mining the database of information on past injection well network performance, f) evaluating alternative bed-solid substrates for the fluidized bed reactor (FBR), and g) consideration of a booster pump system for internal water supply within the FBR unit operation.

<u>a. Developing actionable metrics and associated responses for each major future activity</u>

The PTII Team report did not include much information or detail on <u>how</u> the proposed activities will be implemented. In general, we recommend developing the following standardized information for each major activity: a clear conceptual framework of what is being done and why, a short description of the planned action and steps for implementation, a listing of the key performance metrics and data to be collected, and a linked list that describes planned response actions (and/or contingencies) based on the measured data/outcomes. The example table shown for item b below is a recommended format to identify/describe actions, metrics, and concomitant responses in a simple and organized manner.

<u>b.1 Eliminating root causes of biofouling – Aerobic Membrane Bioreactor (MBR)</u>

The PTII team proposed wellfield and injection well actions are important and prudent. However, the long-term stability and robustness of the 200W P&T operations requires understanding and controlling the root causes of the accumulation of biological and mineral films in the distribution system and wells. The root cause(s) of the clogging include the presence of carbon substrate (COD) and nutrients (e.g., P and N) and some scale forming elements (e.g., Mn and Fe) in the treated water (well-fouling constituents). The primary 200W unit operation that is intended to remove COD and nutrients is the aerobic membrane bioreactor (MBR) – thus the underperformance of the MBR is a primary root cause of injection system fouling. We recommend a near term focus on improving and optimizing the MBR. If, after additional testing and optimization, the MBR is: a) still not removing COD and macronutrients to the degree required for sustainable operation of the injection well network <u>and</u> b) determined to be operating within expected performance norms for and aerobic MBR; then, other mitigation measures that reduce the concentration of well-fouling constituents should be explored and developed further. One recommended follow-on activity is to evaluate changes to the P&T system configuration to allow increased residence or to change additives before the MBR to provide information about potential upgrades that may be important for meeting MBR operational targets and minimizing the need for down-stream actions.

The Hanford team is currently modifying the conditions in the MBR (e.g., the quantity of biomass solids that are maintained in the system) to optimize performance. Biomass levels that are too high (for the input carbon and nutrients) will result in process upsets and biomass levels that are too low will not provide sufficient degradation of carbon and removal of nutrients. After some initial process upsets, the biomass level targets were reduced to levels that did not support sufficient treatment. CHPRC has identified this issue and is actively working to improve the performance of the MBR -- currently, the low levels of biomass are being increased incrementally and data collected on the impacts. Additional balancing of COD and macro-nutrients may be needed to achieve the best performance. This is an important, commendable, and significant activity. Table 1 provides example "linked actionable metrics" for such optimization. This table lays out a notional conceptual approach, data needs/metrics, and linked actions and is intended as input for consideration of this mitigation action and as a template for the type of organizational table that can be applied to guide other mitigation actions.

b.2 Eliminating root causes of biofouling – Eliminate phosphate containing antiscalant used in the air stripper

After the MBR, the addition of a phosphate based antiscalant in the water feeding the 200W air stripper contributes to downstream formation of biomass. Stoichiometric calculations indicate that the potential biomass added to the reinjection system would be about 10 to 100 dry Kg/day based on the amount of P in the water is sufficient COD is also present. Alternative antiscalants that do not contain phosphorus would help mitigate the potential to form this added biomass – but the alternatives would add COD (a trade-off). Evaluation of alternative non-phosphate antiscalants would include a number of technical lines-of-inquiry. We support the recommended efforts to assess alternative antiscalants for the air stripper and would urge consideration of eliminating antiscalants altogether if the technical evaluation indicates a net benefit. Elimination of antiscalants would avoid adding any phosphate or any COD (with the tradeoff being a slight potential for Mn precipitation in the air stripper – a factor that may have alternative management options).

Table 1. Aerobic Membrane Bioreactor (Root Cause) Linked Actionable Metric Table

TOPIC/ISSUE		
Underperformance of the Aerobic Membrane Biotreatment (AMB) -- insufficient treatment and "pass through" of COD and macronutrients		
PROPOSED ACTIVITY	OBJECTVE(S)	DESCRIPTION
Increase biomass ("MLSS" or mixed liquor suspended solids") in AMB system.	**Increase utilization and removal of COD and macronutrients in AMB by determining an "optimal" operating range target for biomass**	**Activity would incrementally increase MLSS levels and observe system behaviors to determine levels that provide effective treatment and stable operation. MLSS levels that are too high result in unstable operation (e.g., carry over, filamentous organisms, slimes, foaming etc.) and MLSS levels that are too low do not provide sufficient removal of COD and macronutrients. Initial operations used MLSS levels that were too high for the influent COD/nutrient situation -- operations were then modified to maintain low MLSS levels (below the traditional operating envelope for aerobic treatment systems). Higher MLSS levels would likely improve performance. For testing... After each change in biomass, the system would be operated for approximately two weeks to allow the system to stabilize under the new conditions. The resulting information would be used to set the target biomass/MLSS to levels that provide maximum COD/nutrient removal performance while maintaining a stable and well behaved sludge.**
METRIC(S)		
Biomass in AMB (MLSS) and operational (hydraulic and aeration parameters)		
AMB effluent COD and macronutrients (P and N)		
Standard System and Sludge Tests : cell residence time (CRT) in a reasonable range (e.g., 5 to 10 days), settleometer, sludge volume index (SVI e.g., 80 to 100), sludge density index (SDI e.g., 0.8 to 1.2), food to microorganism ration (F:M e.g., 0.1 to 0.4), C:N:P Ratio inlet approx 100:5:1, and microscopic examination of sludge (e.g., demonstrating a predominance of ciliates and rotifers and lesser amounts of filamentous organisms)		
Operator feedback on sludge handling, filter performance		
DATA/OBSERVATION	IMPLICATION	ACTION/RESPONSE
Low CRT (e.g., < 3 or 4 days)	**insufficient MLSS for effective treatment - insufficient amount of multicellular biomass -- confirm with operator feedback, microscopic examination and sludge characteristics**	**indicates need to increase MLSS**
High CRT (e.g., > approx 10 days)	**too much MLSS - potential for filamentous biomass -- confirm with operator feedback, microscopic examination and sludge characteristics**	**indicates need to decrease MLSS**
high F:M ratio	**insufficient MLSS for effective treatment - insufficient amount of multicellular biomass -- confirm with operator feedback, microscopic examination and sludge characteristics**	**indicates need to increase MLSS**
low F:M ratio	**too much MLSS - potential for filamentous biomass -- confirm with operator feedback, microscopic examination and sludge characteristics**	**indicates need to decrease MLSS**
inlet C:N:P Ratio out of spec	**Nutrient balance not conducive to complete COD removal**	**consider macronutrient adjustment**
Repeat above at each tested MLSS level	**Collect listed information and distribute to process engineers after each incremental increase -- implement a process engineer decision process and final report**	**When filamentous organisms fraction begins increasing to significant levels, discontinue increments, and dial back to previous level. Use multiple lines of evidence to set operating targets**

c. Evaluating filtration for the injection wells

The PTII team report included consideration of filtration as a potential solution to injection well fouling and clogging. As noted above, filtration is not likely to directly address the root causes of the well clogging, so this option should be considered an adjunct activity and any implementation should be done in a manner that minimizes the potential for adverse collateral impacts. If dissolved COD/nutrients/minerals are present in the water, then the benefits of filtration will be reduced – biofilms and mineral precipitation can still occur in the downstream distribution piping or in the well/well screen. It is likely that the air stripper, storage tank, distribution piping and all wells will require aggressive cleaning to remove the current biogeochemical coatings that are present. Biogeochemical fouling root causes need to be addressed to avoid future formation of such coatings. The planned filtration test will provide data to better quantify the nature of the well-fouling constituents in the effluent system. These data will be instructive in assessing filtration and other mitigation approaches. We recommend that the Hanford team set clear go / no-go decision points for filtration evaluation and have clear plans to couple filtration evaluation with system/piping cleaning activities and root cause mitigation.

As a practical matter, for a filter to effectively remove microbial biomass, it must remove very small particles (<0.5 to 1 um) unless biomass aggregates into larger particles. Small pore-size filters are difficult to maintain and tend to clog or generate high backpressure in real-world settings outside the laboratory. The filters proposed for testing are large and robust, however, and with the multiple cartridges would provide a high capacity. While this maximizes the potential for successful filtration, installation of such systems on all of the wells (or clusters of closely located wells) would be costly, thus, if filtration were determined to be part of the overall mitigation solution, an evaluation of appropriate filter designs and costs would be needed. Filters that remove larger particles would be effective at removing large debris (e.g., chunks of broken-off / entrained biogeochemical films from upstream piping). However, even these larger "pore size" filter deployed for injection wells often require frequent attention and maintenance with the associated costs and labor. In some previous DOE injection well systems, wellhead filtering has been installed and then abandoned (i.e., removed or operated without filter cartridges while leaving the housings in place).

d. Evaluating disinfectants to control biofilms in the distribution/injection well system

Disinfection of the effluent water that is sent to the reinjection well network is a straightforward and promising approach to help mitigate biofouling of the injection wells. Conceptually, this type of disinfection is analogous to a potable water distribution network – where added residual free chlorine in sustained to protect the piping from biological growth and maintain sanitary conditions for the consumer. Use of a disinfectant is a potentially important/significant process improvement. According to the PTII team report, a standard disinfection system based in injection of concentrated liquid hypochlorite ("bleach") is currently being evaluated by the

Hanford team. An alternative approach -- on-site generation of disinfectant should be considered. On site generation of disinfectant using a simple-compact electrode system and a salt solution has many benefits. The generated disinfectant can be either hypochlorite or – preferably – a mixed oxide solution (MOS) that also contains peroxide and free radicals. There is a significant body of literature on MOS documenting that it provides better downstream system cleaning and maintenance compared to straight hypochlorite and has a number of other potential advantages. On-site generation of disinfectant would significantly improve worker safety, eliminate transport and handling of large quantities of hazardous liquid hypochlorite, and result in substantial cost savings. We recommend initiating/maintaining topical technical discussions with regulators and stakeholders and developing the required technical and engineering data (e.g., disinfectant breakpoint curve using treated 200W effluent, evaluation of performance potential, evaluation of safety benefits and risks, etc.).

Notably, there may be substantive advantages associated with adding the disinfectant before the air stripper (i.e., minimizing biofilm growth and/or scaling in the air stripper) – this type of disinfectant-related reconfiguration was not identified in the PTII report and is of potentially significant impact (Figure 3). If disinfection were added before the air stripper it might provide a secondary benefit of altering the need for antiscalant. Any disinfection system will impact the geochemistry of the effluent (by raising the redox potential to 600 or 700 mv) and result in precipitation of some elements such as iron and manganese. As a collateral benefit of pre-stripper disinfection, with the addition of a simple sand filter, the precipitation/removal of these metals has the potential to reduce mineral fouling in the reinjection well screens and reduce/eliminate the need for antiscalant in the air stripper.

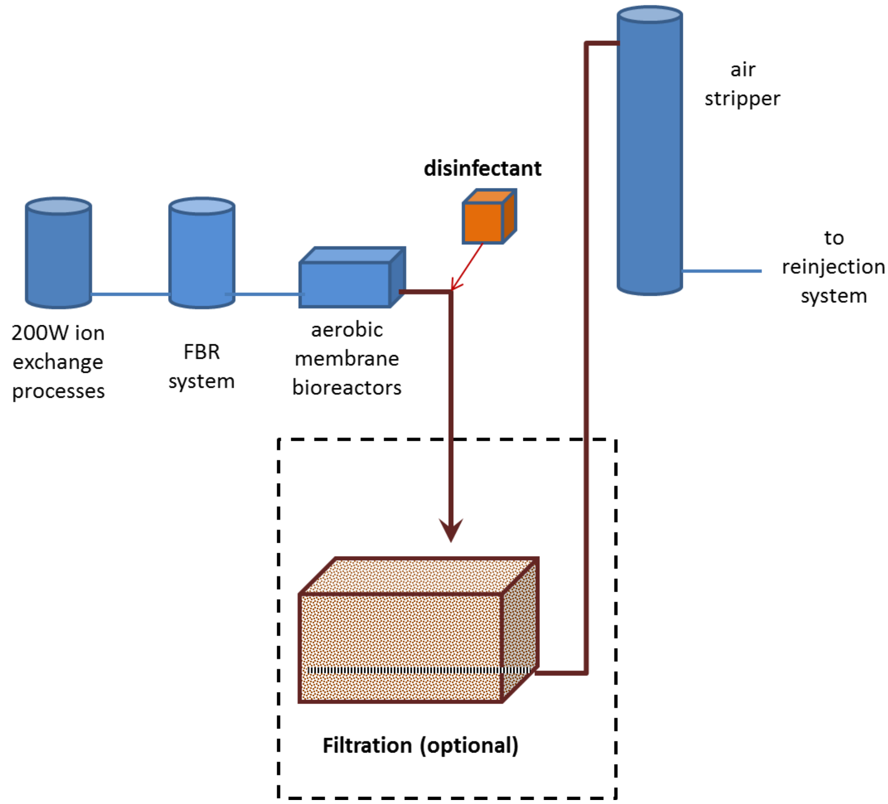

Figure 3. Example configuration showing disinfectant addition before the air stripper

e. Data mining the database of information on past injection well network performance,

A large data base of injection well data has been collected by CHPRC and is available in a spreadsheet assembled by Chuck Miller. The information in this database should be mined for information on the contributing factors to well fouling. A quick survey of the information shows obvious and significant differences in the decline in well injection capacity for the various wells. Factors most likely include when and where the wells are installed, well construction, lengths and degree of contamination in the conveyance piping, and changes in operational conditions (improvements in effluent water quality, outages and plant upsets, and facility upgrades). A review of the historical operational conditions for the wells should help identify those factors that have the most effect on well fouling. This information along with the other ongoing evaluations should help identify where and how to conduct field testing such as the proposed filter test, line cleaning etc. The wells tend to group somewhat by location and when installed. The wells on the west side of the site seem to perform better than those on the east and the more recent installations also seem to perform better. However, a close look at the data may identify other factors that are controlling. It is recommended that the injection well database continue to be evaluated in depth (mined) to help further the well fouling evaluation and identify effective optimization actions. This database should also be augmented over time with the planned and recommended monitoring activities.

f. Evaluating alternative bed-solid substrates for the fluidized bed reactor (FBR)

In the PTII team evaluation, the evaluation focused primarily on the baseline solid carbon substrate – noting that the attrition of bed solids could be kept in control by assuring that the particle size can be maintained in a fairly narrow range. Toward this end, the report highlights that the carbon substrate procurements need to require tight control on these parameters (size and standard deviation). The report does not similarly emphasize the need for tight control on the ability of the particles to maintain these key parameters under the challenging conditions of the FBR – e.g., by having requirements for hardness and resistance to abrasion. These requirements may be in existing procurements but were not discussed in the PTII team evaluation so we have provided a short technical narrative to highlight this issue. In the FBR, particle breakdown can occur in the fluidized bed (e.g., by particle to particle contact, particle wall contact, and high turbulence) – once particle carryover begins, the breakdown of carbon substrate can be accelerated because recycled particles are subject to the harsh conditions in pumps and nozzles. Thus, resistance to particle breakdown and maintenance of the desired particle size in a narrow-controlled range is key to sustainable and straightforward operations of the 200W P&T system.

Hardness and abrasion resistance are key characteristics of granular activated carbons (GACs) that are used in dynamic systems like a FBR. Notably, there are large differences in the hardness of activated carbons, depending on the raw material and the handling/production steps. For example, coconut shell based activated carbons are typically the hardest and most abrasion resistant GACs. Therefore, we recommend that the procurement specification for GACs used in an FBR include the requirement that the source raw material for the carbon be coconut shell. Similarly, there are a number of standardized tests and indices that characterize GACs – such as the hardness index and abrasion number (see ASTM D3802 and AWWA B604). For reliable operation, the particles in an FBR need to have a high score on such indices (e.g., > approximately 98%). We recommend that the specification for GACs used in an FBR include a minimum required carbon hardness/abrasion index. These provisions may already be in place, but we have noted them since they were not discussed in the PTII team report.

The PTII team report did not fully flesh out the potential for alternative bed-solid substrates, for instance the SRNL review suggested zeolites. It appears that bed-solids carryover has been brought into better control under the current conditions (after some maintenance, modifications and reloading); however, if carry over increases over time, a clear strategy to consider alternative bed-solid substrates would be prudent. This evaluation would include hydraulic, density, surface area, resilience, biocompatibility, cost and other considerations (and would be best performed as collaboration among the Hanford contractor team, their subject matter experts, and independent technical resources such as partner labs, universities and industry). As an example (to provide a direct comparison to carbon) the hardness/abrasion resistance of potential alternatives could be measured using protocols for carbon (this would provide a differential performance metric to the baseline). In evaluating the resulting indices, it should be noted that GAC hardness values are not equivalent to the hardness scales used for other materials such as minerals. A carbon of

ASTM D3802 hardness of 98 is quantitatively harder than one of 80, but many minerals and other materials will be even harder and would report as 100 on the basis of the GAC hardness test. We recommend including evaluation of alternative bed solid substrates as a near-term effort (particularly focusing on zeolites) to provide options in response to continued observations of FBR performance.

g. Consideration of a booster pump system for internal water supply within the FBR unit operation

There are a number of locations within the FBR unit operation that use pumped water as a motive or operating fluid – these include eductor pumps for recycling bed-solid slurries, eductors used in bed solids cleaning, and (proposed in the PTII team report) a spray wash for the outlet tray of the FBR to help strip biofilms from particles to improve performance of the bed-solids separator. The process water currently used is treated water and the net effect of the various injections is to add to the hydraulic flow load within the FBR. These water additions could be significant if they strain the capacity of a bed solids separator and other FBR subsystems. In the SRNL review, the team suggested that FBR inlet water (rather than finished process water) can be used internally – within the FBR unit operation boundary – e.g. as the motive fluid for eductors. This would require that an internal process water system be set up that circulates FBR feed water for all appropriate internal water needs (thus the overall FBR processing would be satisfied without adding additional flow). The system could be inexpensively and easily constructed from industry standard booster pumps (and controllers on a skid). The booster pumps would be packaged with standard components to maintain a desired outlet-line pressure. A system to support all of the water needs throughout the FBR system (including transferring solids back to the FBR, bed solids cleaning, spray cleaning, etc.) could be assembled after some technical evaluation by properly sizing and deploying a packaged pressure controlled booster pump system (e.g. a Grundfos Multi-E with three CRE3 or CRE5 pumps) combined with simple piping modifications.

Consolidated Comments on PCRUP Items

The following table provides comments on the items identified in the PCRUP. As discussed in the introduction, incorporating these elements as part of an implementation plan with associated performance metrics and decision logic is recommended.

PCRUP Item	Comment
Install LEAP cassettes purchased in FY18	We concur with this activity to maintain and improve MBR effectiveness.
Add metering pump to bleed in Z-line trench water	We concur with this activity to decrease the frequency and magnitude of upset conditions in the FBR.
Change stripping tower anti-scalant	We concur with a change to remove/reduce phosphorus concentration in the effluent, but recognize that there are several options that need to be considered for implementing this change.
Issue design to enhance shearing of FBR biomass	We concur with this activity to maintain and improve FBR effectiveness.
Perform thermal analysis on MBR to allow increase in operating temperature	We concur with this activity to improve MBR effectiveness, but recognize that this activity should be conducted and considered in light of other MBR optimization options.
Perform engineering evaluation to increase MBR solids to lower COD in plant effluent	We concur with this activity to improve MBR effectiveness, but recognize that this activity should be conducted and considered in light of other MBR optimization options.
Install filter pack at one injection well and evaluate solids collected	We concur with this activity if this test is conducted to improve the quantitative information about effluent system conditions.
Perform aggressive cleaning on three wells and lower injection well flow rates to decrease well cleaning frequency	We concur with applying more aggressive cleaning of the wells, recognizing that this cleaning also needs to be linked to cleaning of the effluent system. We do not agree that implementing lower well injection rates is an effective measure to address biofouling in the long term.
Construct and connect 200-ZP-1 injection well drilled in FY17 (2)	We concur that adding injection capacity is needed, but recognize that these wells should not be brought on line without considering whether injection conditions would cause rapid biofouling and that there is a need to address the root cause of well-fouling.
Install new 200-ZP-1 injection well (2)	We concur that adding injection capacity is needed to replace lost capacity, but recognize that there is a need to address the root cause of well-fouling.

Consolidation of Detailed Comments on PTII Report

The following table compiles comments on the specific numbered recommendations listed in the PTII report.

		PNNL	SRNL	Recommendation
PTII-1	The Team recommends that at present, no additional GAC analyses be done over and above the S&GRP program underway, where GAC lost from the FBR will be sampled periodically for sieve analysis and compared against the specification for the GAC that was originally provided for the FBR (effective size of 1.1 mm and uniformity coefficient of 1.02).	FBR – It is reasonable to not do this analysis if GAC information other than the current monitoring is not needed for operational decisions. Given that some changes might be introduced for the FBR, would that drive the need for more GAC information?	Concur that the baseline carbon is a reasonable bed-solid substrate choice for the near-term – see additional detail in special topic section.	Concur. The need to sample the GAC is not deemed necessary at this point, however changes in the system or performance of the FBRs may deem it appropriate in the future.
PTII-2	The Team considers that the various recommendations to minimize micronutrient content are no longer necessary because S&GRP is already confident from actual tests that the proper process parameters and micronutrient levels have been established.	FBR nutrients already tuned – The metrics for why the nutrient levels are optimized could be added to this statement.	Concur that the established baseline micronutrient scenario in reasonable and technically defensible	Concur. Adjustments to micronutrient concentrations may be needed in the future as FBR changes are made.
PTII-3	The Team recommends a literature search and discussion with other sites that have related P&T activities to determine potentially viable alternate FBR substrates. If changing or enhancing use of GAC in FBRs appears to have a good chance to enhance efficiency of P&T operations and is a cost benefit, then proceed to pilot scale testing.	May consider new substrate – Agree, however, it would be good to define the process to test options and metrics for selection.	Concur with idea to perform additional technical analysis of alternative bed-solid substrates – see additional detail in special topic sections Encourage additional study of other operating FBR systems to determine how alternatives such as liquid carbon to feed the FBR microbial communities is performing.	Concur. The evaluation of potential increase in overall FBR efficiency and treatment through use of alternate substrates is supported. A thorough plan for the evaluation is advised.
PTII-4	The Team considers that replacing the air stripper with a liquid-phase GAC or biological tower treatment system is not a viable option. The air stripper is needed to remove residual carbon	Bioreactor not at end of line – Adding reaction time and MBR changes are potentially viable alternatives to revised post-MBR effluent treatment. However, effluent liquid-	Concur with conclusion to not pursue replacement of air stripper with an alternative biological treatment. Air stripping is demonstrably superior in terms of cost and	Concur. Under the present operating conditions, it may not be appropriate to evaluate replacement or enhancement of the A/S with a

	tetrachloride that is not removed in the membrane bioreactor. However, the Team does note that the concept of additional time for biological reactions to occur is valid, but the manner for providing additional bioreactor time requires further engineering evaluation (see also PTII-14.1 and PTII-14.2).	phase treatment may also be viable and needed if MBR/pre-MBR changes can't meet effluent goals. Could consider conducting a field test of liquid phase carbon for more effective removal of chemicals from the effluent water.	robustness for VOCs such as carbon tetrachloride. Additional biotreatment is redundant with the upstream anaerobic FBR and aerobic membrane bioreactor. As noted in the PTII evaluation, underperformance in the aerobic membrane bioreactor is best addressed by process modification (increasing residence time or increasing biomass "MLSS" in the system). Replacing the air-stripper and vapor phase carbon system with a liquid phase carbon system may be considered in the long term if effluent goals from current A/S prove to be unattainable	liquid-phase system; the goal should be to optimize the current systems in place. However future evaluations of this technology should be considered (>1 yr).
PTII-5	The Team recommends that an engineering evaluation for recirculation of bed solids using a diaphragm pump be conducted to determine complexity and benefits.	FBR enhance solids handling – Agree	Concur with recommendation for additional analysis of diaphragm pumping for bed-solids cleaning. We recommend expanding this to include straightforward alternatives such as continuous operation of the existing eductors for bed-solids cleaning and providing supplemental bed solids cleaning at the outlet of the FBR to improve the performance of the downstream bed-solids separator (see special topic on booster pump to supply water).	Concur. Encourage a more complete evaluation of alternatives, not limited to diaphragm pump.
PTII-6	Due to the immaturity of technology reasons, the change out of bed solids substrate to a	FBR keep GAC as substrate – Agree	This recommendation overlaps with 1 and possibly 3 -- Concur that the baseline carbon is a	GAC is reasonable substrate; do not collectively agree that other alternatives should not be

	new material idea should not be given further consideration at this time.		reasonable bed-solid substrate choice. DO NOT Concur with recommendation that alternative bed-solid substrates should not be considered. See special topics discussion.	evaluated. An evaluation of alternatives could weigh cost, downtime, projected long term performance etc. could determine efficacy of alternatives.
PTII-7	The Team recommends that other installations using the bubbler level system be contacted to verify adequate performance. If these go well, two instruments should be ordered and installed in the FBRs. After 6 months of reliable performance, consider an automatic callout alarm, an interlock with the eductor system, or both.	FBR new operational feedback – Agree	Generally concur with concept to contact other installations and potentially test bubbler-based bed solids level monitoring systems – We are skeptical that such systems will provide reliable data in a moving fluid (agitated flowing) system with and expanded bed of composite bed solids. Consider revisting sound based sensors and modified geophysical methods.	Concur that new feedback systems would be beneficial; an evaluation of available methods or systems prior to installation may prove valuable for successful implementation.
PTII-8	Evaluate the Envirogen recommended nitrite (NO2 – N) measurement kits available for operators; with a goal to find one with benign chemicals and compatible with the HACH 3900 spectrophotometer currently used by P&T operations staff to monitor NO3.	FBR nitrate monitoring for feedback – Agree	Generally concur with testing alternative NO_2 test kit as a good proactive and continuous improvement idea (but this will have minimal impact on overall system performance and injection well fouling).	Concur.
PTII-9	The Team recommends that both an engineering evaluation and a regulatory change plan be developed for management decision about implementation of a hypochlorite feed system to control growth in distribution system pipelines and tanks (this recommendation is also linked to cleaning by pigging the	Chlorination – Agree. Need to calculate chlorination parameters and residual chlorine at injection well as part of an engineering assessment. Testing in a portion of the injection system is reasonable.	Concur **--** This is an important recommendation – see special topic narrative – I recommend also considering use of on-site generated MOS.	Concur. This is considered an important evaluation to be completed this year.

	pipe/conveyance to the injection wells; see also PTII-21).			
PTII-10	Reject the Envirogen idea of increasing chemical oxygen demand (COD) levels above that necessary for healthy growth.	No extra COD – Agree	Conditionally Concur – Liquid carbon substrate should be maintained to support healthy growth in the FBR and downstream aerobic membrane reactor (so that the composite performance is effective utilization of both carbon and nutrients with minimal release in the treated water). Note that if COD is insufficient to stoichiometrically treat macro-nutrients, then some additional liquid carbon substrate might be needed to close the mass balance and to maintain sufficient biomass in the aerobic membrane bioreactor (or vice versa). See special topics discussion.	Concur, conditionally. An effort to determine the mass balance of the FBR should be completed; determining the liquid carbon load for optimal microbial degradation is an important step for optimizing the degradation (performance) of both FBRs.
PTII-11	Other than supporting the recommendation for a permanent FBR camera installation, no further actions are considered necessary for the optimizations suggested by One Water Solutions (2016).	No One Water report changes other than camera – Agree	No opinion.	Concur.
PTII-12	No further actions are necessary for these proposed SRNL microbial nutrient optimizations, unless a new FBR/carbon separator tank system will be designed and installed.	No FBR total revision – Agree because this may be costly with little direct injection-well impact. However, could consider FBR change over time if current FBRs become problematic	Concur.	Concur. Consider complete system (FBR) evaluations at some future date if maintaining and/or overall performance of the FBRs cannot be maintained (following modifications).

PTII-13	Conduct further engineering evaluation of adding another bioreactor; if practical, the Team also recommends following the analysis with a pilot test to define the size and aeration requirements and the benefits more accurately (e.g., amount of additional COD, iron, and manganese that can be removed).	In-facility increased reaction residence time – Agree that an engineering evaluation is warranted. Should tie this evaluation to monitoring of initial responses to FBR and MBR changes with metrics for deciding on the need to add reaction residence time.	Conditionally Concur. Further analysis of additional aerobic bioreactor capacity (and also including increasing biomass in the existing aerobic membrane bioreactor or optimizing conditions in the existing reactors) is reasonable. Developing technically-based engineered solutions may be a key in eliminating root causes of well clogging.	Concur, conditionally. A thorough engineering and overall pump and treat system evaluation could result in the determination that an additional system is needed OR would greatly increase the overall capacity. However the priority should be operation and efficiency of existing units.
PTII-14.1	Instead of a second bioreactor unit as an inexpensive first step, add insulation blankets at this time for the existing aerated membrane tanks to minimize heat loss in the winter (Biosystems generally work more efficiently with higher temperature). The temperature change during the winter should be evaluated first to determine how much heat is lost during cold weather and to estimate the change in biological activity.	Enhance MBR performance by controlling temperature – Agree	A Reasonable Concept -- No specific opinion.	Concur.
PTII-14.2	After engineering design and utility requirements determination, add heating blankets to the existing bioreactor unit and maintain a more consistent and higher unit operating temperature during both winter and summer.		A Reasonable Concept -- No specific opinion.	Concur.
PTII-15	The Team agrees with the One Water Solutions (2016) concept that a P&T capacity increase plan (e.g., a 5-year plan) should be developed that would first identify	P&T enhancement plan – Agree. This element should be highlighted in the executive summary and conclusions as a need for managing the process	Concur with the development of an integrated strategic plan to increase P&T throughput.	Concur. The development of an integrated plan for managing the process is much needed.

	easily implementable suggestions, followed by more extensive and perhaps capital intensive longer term planning. However, this roadmap approach needs to be developed in concert with DOE P&T operational goals and ideas provided by SRNL, Envirogen, PNNL, and CHPRC staff.	of P&T changes/optimization to address well fouling and other performance goals.		
PTII-16	The Team recommends that a longer term comprehensive operations parameter monitoring plan be developed to provide performance data to highlight areas needing improvements or detect degradations. The first step would be to capture, review, and analyze existing P&T data to identify patterns and gaps, with focused efforts to fill those gaps. As part of this effort, the Team also recommends utilizing and applying selected ideas from Miller (2017) for suggested parametric measurements.	Enhanced monitoring to provide feedback on performance related to well fouling – Agree. This element should be highlighted in the executive summary and conclusions as a need for managing the process of P&T changes/optimization to address well fouling and other performance goals.	Concur with the development of a parametric monitoring plan – this is an extension of the existing best practices already being used by the CHPRC process engineers to review data and integrate the evaluation into operational decisions each month – documentation of the process and some formalization would be helpful in assuring that the practices continue moving forward.	Concur. The development of a formalized process ensures continued best practices.
PTII-17	The Team recommends further technical evaluation of these SRNL turbulence/shear force ideas. One key consideration is the shear force needed to separate biofilm from the GAC media. Whatever the method, it should have enough force to separate biofilm from the media. The design of a system requires a modest investment of engineering to estimate the shear force needed	FBR shear for biosolids handling – Agree with conducting a study. What are the metrics for deciding on implementation?	Concur with the development of technical information about the shear forces needed to remove/control biofilm on bed solids.	Concur. A thorough evaluation of methods / ideas to enhance shear force should be completed and include overall impacts to the operation of the FBRs as well as the system as whole (benefit worth investment).

	and design a means to provide this force.			
PTII-18	The Team recommends that alternative anti-scalants proposed by SRNL be evaluated for effectiveness by contacting current customers. Pending positive review of effectiveness, the capacity and material compatibility of the existing feed pumps should be assessed.	Anti scalant change – Agree, see discussion in both SRNL and PNNL reports	Concur with the development of technical information toward elimination of phosphate containing antiscalants. We think the evaluation should also include benefits and risks of eliminating antiscalants.	Concur. This is considered an important evaluation to be completed this year.
PTII-19	The Team recommends that a more favorable well casing screen wire geometry be tried for new injection wells. The Team suggests using round wire cross-section geometry, providing symmetrical flow direction impedance.	New well screen design – Agree	Concur with the use of alternative wire type in the well screen design/construction for future injection wells (this is a best practice).	Concur.
PTII-20	The Team recommends injection well trials using lower water injection rates. Because of the desire not to impact P&T processing goals, this approach may be combined with the recovered "dead' well recommendation (PTII-22) discussed under biofouling and cleaning.	Lower specific water injection rate – How do we know this is an issue other than mass/time of clogging material? How is overdriving a well determined? The justification for this recommendation is not clear in the report.	Generally concur with the testing of lower injection rates – recognizing the potential trade-offs this may have limited overall benefit – i.e. require additional wells but extend the operation life of the wells.	Generally do not Concur. Data to support the reduced injectivity versus well-fouling has not been established; also root cause of fouling not adequately addressed.
PTII-21	The Team recommends the selection of at least one injection well conveyance system to clean (e.g., pipeline pigging via inexpensive and reusable foam pigs), followed by a small constant addition of hypochlorite or chlorine into the pipeline and well. A remedial design/remedial	Clean a line and use for a trial for chlorination – Agree. Need metrics for engineering evaluation and deciding on full implementation.	Concur with a pilot test of distribution pipe cleaning and hypochlorite addition – the pilot test could use simple equipment such as a small system for a "swimming pool". See special topics discussion – alternative full scale systems that generate	Concur. An remedial design evaluation should be completed prior to implementation.

	action work plan modification will be required with a process change, followed by well performance monitoring.		disinfectant on-site would improve safety and reduce costs.	
PTII-22	The Team recommends trying extended cleaning times and/or more aggressive well cleaning techniques on injection wells no longer in service (i.e., dead well s). If such a recovery works, these recovered wells can be used to test other aspects, such as reduced injection flow effects on clogging. Additionally, if successful, additional injection well capacity, without drilling new wells, may become available for enhanced production rates.	Aggressive cleaning – Agree	Concur with plan to perform aggressive cleaning tests to try to restore existing clogged or underperforming wells – aggressive techniques selected should be consistent with previous data on biogeochemical fouling in the wells and the subsurface biogeochemistry.	Concur.
PTII-23	The Team does not recommend pursuing design and installation of pairs of large-scale sand filters for cleaning effluent to the injection wells.	Sand filter – Decision on use of some form of filtration should be based on the filter test (below) and a cost/benefit assessment. Slow sand filter systems have been used for over a hundred years and do more than just filter solids. The bioactive film that forms on the top of the filter acts to remove or change some chemical constituents. The slow sand filter would serve as a large pre-well reaction site for chemical and biological activity.	Partially concur -- This PTII team recommendation is reasonable for near term conditions – pre-filtration at this time would have minimal benefit since the distribution lines and wells currently contain large quantities of biogeochemical films. Nonetheless, if the root causes of the fouling are addressed (i.e. minimizing the presence of COD, macronutrients and mineral forming ions) and if the distribution lines are cleaned of the existing biogeochemical films, then filtration might be justified and beneficial. A specific example is… if disinfectant is added	Do not concur. At the current design point, the additional sand filter is not likely appropriate, however many of the evaluations of both the FBR and/or MBR may conclude that a polishing technology is warranted. It is a technology that should be shelved for the moment but could be re-considered if biofouling constituents cannot be controlled.

			(precipitating trace Mn and Fe), then a filtration step has the potential to provide a substantial benefit to the overall performance by removing those solids prior to release to the distribution system.	
PTII-24	The Team recommends designing and installing (notionally) discs of the same geometry as the injection well screens, to pre-clog these above ground cleanable screens, where they can be subsequently cleaned (e.g., filter pairs) and reconditioned. The design should try to ensure that these pre-well screens experience the same level of pressure and flow that the actual well screen will experience. Other types of filters may also be considered. This concept can be tried on any recovered dead wells (PTII-22).	Above ground well filters – Exact duplicate of the screen configuration does not seem useful or needed for this test. A pilot test would be best to 1) verify the effluent characteristics related to well fouling (particulates and dissolved constituents before and after the filters, and 2) designed to enable scale up if continued filtration is needed as part of a long-term solution. The current description of the filter configuration in the report doesn't describe these sorts of goals for how and why this would be implemented. Need to have metrics (performance and cost/benefit) for using this information to evaluate the long-term use of filtration prior to the injection wells (related to recommendation 23).	Do not concur with installing replaceable up hole screens (screen discs) to clog – this idea is predicated that the clogging of the up hole screen will effectively remove dissolved and particulate water content so that it will not clog the down hole screen – the biofilm formation is occurring along the entire length of the distribution system and will continue downstream of a up hole well screen. I do not think this is a viable technical idea.	Do not concur. There are a number of technical reasons that this filter design approach will not be successful. The currently planned filtration test using the filter skid to quantify the characteristics of the effluent system will provide useful data, but should not be considered as a filter design for implementation.
PTII-25	The Team recommends addition of a new pump that can slowly bleed well development water back into the plant, at a rate of 5 to 10 gal/min, to add recycled	Slow bleed of well cleaning water – Agree	Concur – this is a reasonable best practice idea.	Concur.

	water slowly back into the recycle tank. If necessary, a small manganese filter system could be added to the recycle line. Placing pyrolusite in an existing 9-pack filter system would provide sufficient contact time for manganese removal. The media would need to be soaked periodically in a strong oxidant, such as hypochlorite, to maintain effectiveness. The spent cleaning solution should be tested for the presence of manganese, iron, and calcium, especially when low pH well cleaning agents are used.			
PTII-26	The Team does not recommend pursuing surface infiltration approaches at this time because of the Cold Creek unit (CCU). If this surface infiltration option might be pursued in the future, it would be valuable to determine where CCU gaps are located either to dismiss or consider this approach further.	No surface infiltration – Agree	Partially concur – see special topic discussion.	Concur.
PTII-27	Due to the power and effectiveness of this PTII Team to evaluate technical approaches and adequacy, it is recommended that CHPRC create a similar team to meet periodically and act as a technical/operational advisory committee, where the team leader reports directly to the VP of S&GRP.		Concur with the idea of periodic PTII team evaluation for this important system	Concur.