PUMP & TREAT (P&T) IMPROVEMENT INITIATIVE

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

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APPROVED
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Executive Summary

The CH2M HILL Plateau Remediation Company Vice President of the Soil and Groundwater Remediation Project chartered a pump and treat (P&T) special assessment team, called the P&T Improvement Initiative (PTII) Team. Team members were selected for their varied areas of technical and operational expertise, providing both cross-functional and cross-organizational perspectives.

The general charter was to assess and improve efficiency and effectiveness of the groundwater P&T plant operations. Specifically, the PTII Team was to review, deliberate, and reach consensus (both pro and con) about multiple recommendations from several recent studies (e.g., Pacific Northwest National Laboratory and Savannah River National Laboratory studies) identified in Chapter 6 of this report.

Additionally and importantly, these detailed PTII Team deliberations on suggested P&T improvements also resulted in the Team generating its own new and novel recommendations, many of which appear to be implementable in the short to medium term, as follows (complete listing is in Chapter 7):

- Attempt to revive marginal or out-of-service injection wells with more extensive and aggressive cleaning techniques. If successful, additional injection well capacity, without drilling more wells, may become available for enhanced production rates and may also be sufficient offline test beds for other suggestions (like lower pumping rates) to minimize clogging forces.
- Fabricate injection well screens from a round wire that has a more favorable flow impedance geometry than the present use of triangular wire (i.e., more resistant to clogging).
- Use a metered pump to add well development water gradually back into the P&T plant, versus the present method of dumping it in all at once. This method avoids large spikes in contaminants (e.g., manganese) and prevents episodic distortion of the incoming water chemistry.
- Engineer, fabricate, and place a trial pair of aboveground switchable screening segments, just before the connection to injection well pumping, where these screen segments duplicate the injection well screen configuration and flow characteristics (the Team noted that other filter/screen designs and approaches may be more

effective overall). This should remove most clogging materials because they are caught by this cleanable screen before entering and clogging the well screen.

- Add a hypochlorite metered feed system to control and minimize biological growth in the distribution system pipelines, tanks, and injection wells (especially effective after system cleaning).

The PTII Team recommends injection well trials using lower water injection rates because the impedance match between well screen and present maximum injection flow rates may not be optimum for long-term well performance. Some field performance evidence suggests that lower injection rates may extend the overall time for the well screen performance. For example, the three iodine wells (operating ~18 months below their maximum flow potential) have exhibited no appreciable degradation.

The PTII Team also rejected some recommendations; a few were already in place at P&T, or had been tried and rejected, but most rejections were based on Team deliberations of pros and cons of the idea. A good example was the rejection of any scheme to utilize surface infiltration of processed water (as opposed to the present use of injection wells). The surface infiltrated water would not readily reach the aquifer since there is an underlying, low permeability, geologic layer (Cold Creek unit) within the vadose zone between the ground surface and contaminated aquifer.

Overall, the Team provided 27 recommendation dispositions (PowerPoint® presentation, P&T Improvement Initiative, provided to the U.S. Department of Energy), along with the Team deliberation notes in the Pump and Treat Improvement Initiative Team Deliberations, that when laid out in a roadmap plan approach, should allow for many potential opportunities of significant improvements to P&T operations and plant capacity.

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Appendices

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Terms

CHPRC	CH2M HILL Plateau Remediation Company
CCU	Cold Creek unit
COD	chemical oxygen demand
DOE	U.S. Department of Energy
FBR	fluidized bed reactor
GAC	granular activated carbon
HSB	Herbert Stanton Berman
MBR	membrane bioreactor
P&T	pump and treat
PNNL	Pacific Northwest National Laboratory
PTII	Pump and Treat Improvement Initiative
S&GRP	Soil and Groundwater Remediation Project
SRNL	Savannah River National Laboratory
VP	Vice President

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1 Background

CH2M HILL Plateau Remediation Company (CHPRC), under the Soil and Groundwater Remediation Project (S&GRP), presently operates the Hanford Site 200 West Area pump and treat (P&T) system for the U.S. Department of Energy (DOE). The P&T system is designed to capture and treat contaminated groundwater resulting from the former plutonium production years at the Hanford Site. Groundwater is pumped from the aquifer system through 30 extraction wells, treated at the Water Treatment Plant, and then reinjected into the aquifer nominally using 28 injection wells. The injection wells are orientated in a way to help contain or herd the contamination plume and drive the plume toward the centrally located extraction wells. The P&T process had a design basis to treat a maximum flow of 2,500 gal/min.

The treatment process at the 200 West Area site incorporates a biological process that results in a treated water stream that contains biological micronutrients, particularly manganese. Water to the injection wells also contains particles (e.g., iron oxide, manganese oxide, and bug parts) from post-P&T process precipitation and/or deposits from the interior of the extensive pumping lines to the injection wells.

These micronutrients and particles have created a problematic injected water stream that has resulted in biological and particle injection well fouling and plugging. This has led to continuous maintenance efforts in an effort to restore injection well capacity and drilling of new injection wells, as necessary.
While CHPRC has been able to meet its aggressive water remediation goals (P&T processed 3.8 billion gallons through May 1, 2017), the S&GRP Vice President (VP) considered that a comprehensive look at recommendations from recent P&T studies, as well as an expert cross-functional dialog and recommendations, would enhance present and future P&T operations.

2 Introduction

Maintenance of the injection wells consists of various techniques using mechanical and chemical cleaning. To date, no maintenance techniques have proven entirely successful in maintaining injection flows into the wells. In fact, many injection wells degrade to the point where they are too slow for practical use, and new injection wells must be developed. Because of this injection well problem, numerous recent studies have investigated the problem (mostly from a biofouling perspective) and made a host of various recommendations that need to be evaluated.

Therefore, the S&GRP VP requested that an expert team be chartered to evaluate recommendations from the recent studies, as well as deliberate on additional potential improvements, for short-term, intermediate, and long-term considerations.

3 Pump and Treat Improvement Initiative Team

As a precursor to this report, the Pump and Treat Improvement Initiative (PTII) Team charter and assessment plan were developed, and team members were chosen, interviewed, and chartered. The Team lead is a senior CHPRC technical consultant (former chief engineer for Hanford Tank Farms, Rocky Flats, and Pantex). Other members included the following experienced CHPRC personnel:

- Field well and maintenance operations supervisor
- Senior S&GRP environmental process engineer
- Hanford knowledgeable hydrogeologist
- Senior P&T operations supervisor

Biographies of these PTII Team members and the PTII Team Charter, Chartering Session, and Assessment Plan are included in Appendix A. The Team was chartered onsite, at the 200 West Area offices near the P&T facilities, on April 19, 2017.

4 PTII Team Scope

The PTII Team subject matter experts will analyze existing equipment, operations, and published studies to derive the following optimizations that are expected to achieve higher water treatment volume rates, along with better injection well results:

- Identification of technical or operational issues within S&GRP that may compromise the integrity of the facility or jeopardize the readiness of the facility for operation
- Providing recommendations for short-term improvement initiatives and activities to be addressed in the upcoming CHPRC yearly optimization plan
- Providing recommendations for longer-term activities and improvement initiatives, some which may need to be addressed as new scope (e.g., might require an adjustment of DOE goals/metrics to achieve)
- Assessing and/or incorporating recommendations on current studies of issues with fluidized bed reactors (FBRs) and membrane bioreactors (MBRs) from the recent equipment manufacturers and national laboratory (e.g., Pacific Northwest National Laboratory [PNNL] and Savannah River National Laboratory [SRNL]) reviews of P&T operations issues

5 PTII Team Methodology

The assessment of improvement initiatives for P&T operation will include (as necessary) briefings; facility walkdowns; personnel interviews; and reviews of studies, plans, documentation, and procedures.

The PTII Review Team performs independent reviews of P&T plant operations, rate limiting issues and concerns (e.g., heterotrophic biological fouling of injection wells), and maintenance/reliability of P&T equipment and operations. The PTII Team members (based on their diverse and extensive experience and knowledge of how safe, effective, and compliant plant operations are performed) provide their review results and improvement suggestions to the CHPRC senior management.

The Team will also look at any overarching topics (e.g., maintenance and process chemistry) to see if there are changes or equipment changes/additions that will enhance overall P&T operations.

PTII optimization efforts are intended to complete an overall assessment of plant status, reliability, and integration. P&T operational elements will be looked at from mechanical, chemistry, and biological points of view.

The PTII Team individual areas of expertise, along with team discussions and brainstorming, will identify areas of improvement and reach conclusions on improving and optimizing performance. The PTII Team review recommendations will include suggested actions necessary to implement these improvements and any noted concerns. The PTII Team will also provide a projected priority of recommendation implementation, as appropriate, and suggestions on modeling or prototyping recommendation actions.

6 Systematic Mapping of P&T Recommendations versus P&T Functions/Systems

The main sources of recommendations evaluated by the PTII Team were from the following draft studies:

- Envirogen, 2017, *Evaluation Report of 200 West Pump & Treat Fluidized Bed Reactors*
- One Water Solutions, 2016, *Assessment of the 200 West Pump and Treat (P&T) Treatment Facility Fouling*
- PNNL, 2017, *200 West Pump-and-Treat Facility Biofouling Assessment*
- SGW-60655, *Surface Infiltration Evaluation Report for the 200 West P&T Facility*
- SRNL-STI-2017-0163, *Evaluation of the Hanford 200 West Groundwater Treatment System*
- Appendix D, "Evaluation and Diagnosis of Inject Well Fouling at the 200 West Pump and Treat"

Recommendations from each of these studies were extracted and listed with a study recommendation identifier (e.g., Herbert Stanton Berman (HSB)-5.a.i, and HSB-1.h) and are contained in Appendix B.

All of the listed study recommendations in Appendix B were mapped against the P&T systems and functions, using the noted study recommendation number identifiers (e.g., HSB-6.b.iii); some of the study recommendations may appear in more than one category. The following P&T systems and functions were used for the study recommendation mapping and analyses:

- Extraction wells and conveyances
- Treatment
  - Ion exchange resin beds (radiological)
  - Equalization tank
  - FBRs (granular activated carbon (GAC) and microbial growth substrate)
    - GAC
    - FBR controls/measurement
    - FBR chemistry
    - FBR operations, equipment, maintenance, and design
  - MBR, sludge effluent, and air strippers
    - MBR chemistry
    - MBR operations, equipment, maintenance, and design
    - MBR bed solids
    - MBR effluent tank changes and additions (e.g., sand filters)
- Injection wells and conveyances
  - Well reinjection design, operations, and maintenance
  - Well reinjection chemistry
  - Well fouling diagnostics
  - Biofouling and cleaning
  - Well reinjection diagnostics

- Surface infiltration/injection galleries (design and operations)

The mapping of study recommendations versus P&T systems and functions is located in Appendix B. The PTII Team followed the mapping to discuss each P&T element and function systematically, versus the study recommendations, along with ideas and insights from the Team itself. Detailed PTII Team discussions and conclusions are in Appendix C. The PTII Team derived recommendations (both for and against various actions) are summarized as follows:

- Recommendations are designated in Chapter 7 and Appendix C as PTII-1 up to PTII-27.
- Appendix D provides technical reasoning for the PTII Team conclusion that a majority of injection well fouling and degradation is caused by particulates (e.g., metal oxides and biobreakdown particles) introduced into the injection wells and not just from biological growth in the well.
- The 27 recommendation dispositions were summarized on a PowerPoint® presentation provided to DOE (included as Appendix E).

7 Summary Listing of PTII Team Recommendations from Appendix C Deliberations

The following PTII Team recommendations can be pro or con to the various outside study recommendations (information in the Team deliberations (Appendix C) leading up to the recommendations is valuable for deeper understanding of the recommendation bases; number of the recommendations only represents the order in which topics were discussed):

- **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).
- **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.
- **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.
- **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 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).
- **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.
- **PTII-6:** Due to the immaturity of technology reasons, the changeout of bed solids substrate to a new material idea should not be given further consideration at this time.

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- **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.
- **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.
- **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 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.
- **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).
- **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.
- **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).
- **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.
- **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.
- **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 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.
- **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 Appendix D for suggested parametric measurements.

- **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 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.
- **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.
- **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.
- **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 action work plan modification will be required with a process change, followed by well performance monitoring.
- **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 wells). 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.
- **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.
- **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).
- **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 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.

- **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.

8 Discussion and Conclusions

The PTII Team, with their individual areas of expertise and both cross-functional and cross-organizational perspectives, was able to review, deliberate, and reach consensus (both pro and con) regarding multiple recommendations from the six studies identified in Chapter 6. Additionally and importantly, PTII Team deliberations also resulted in the following new and novel recommendations (complete listing in Chapter 7), many of which can be implemented in the short to medium term:

- Fabricate injection well screens from a round wire that has a more favorable flow impedance geometry than the present use of triangular wire (i.e., more resistant to clogging).
- Attempt to revive injection wells now out of service with more extensive and aggressive cleaning techniques. If successful, they would add to the pump capability of the site and also be sufficient offline test beds for other suggestions like lower pumping rates to minimize clogging.
- Use a metered pump engineered approach for gradually adding well development water back into the P&T plant, versus the present method of dumping it in all at once. This will avoid large spikes in contaminants (e.g., metal oxides) and prevent episodic distortion of the incoming water chemistry.
- Engineer, fabricate, and place a trial pair of switchable screening segments aboveground, just before the connection to injection well pumping, that duplicate the injection well screen configuration and flow characteristics. This should remove most clogging materials (by being caught by this cleanable screen before they enter and clog the well screen).
- Add a hypochlorite drip feed system to control and minimize biological growth in the distribution system pipelines and tanks.
- Add injection well trials, using lower water injection rates, because the impedance match between well screen and present maximum injection flow rates may not be optimum for long-term well performance. Some field performance evidence suggests that lower injection rates may extend the overall time for the well screen performance. For example, the three iodine wells (operating ~18 months below their maximum flow potential) have exhibited no appreciable degradation.

The PTII Team also rejected some study recommendations; a few were already in place at P&T, or had been tried and rejected, but most rejections were based on Team deliberations of the pros and cons of the idea. A good example was the rejection of any scheme to utilize surface infiltration of processed water (as opposed to the present use of injection wells). The surface infiltrated water would not readily reach the aquifer, since there is an underlying geologic layer (CCU) above the aquifer that is highly impermeable.

Looking at all the wide range of endorsed recommendations, the PTII Team has also recommended that all these items be included and sequenced into S&GRP improvement planning (roadmap) to meet and expand P&T capability.

Overall, the Team considers that this interdisciplinary and interfunctional method of assessing the value, feasibility, adequacy, or appropriateness of technical fixes or innovations was very productive and successful. The Team believes that the listed recommendations (along with the deliberation notes in Appendix C) should provide for many potential opportunities for significant improvements in P&T operation and capacity.

9 References

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Appendix A

Pump and Treat Improvement Initiative Team Biographies, Charter, and Assessment Plan

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Contents

Tables

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Terms

AWWARF	American Water Works Association Research Foundation
CH2M	CH2M
CHPRC	CH2M HILL Plateau Remediation Company
DOE	U.S. Department of Energy
FBR	fluidized bed reactor
HSB	Herbert Stanton Berman
MBR	membrane bioreactor
P&T	pump and treat
PTII	Pump and Treat Improvement Initiative
S&GRP	Soil and Groundwater Remediation Project
SME	subject matter expert

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A1 Pump and Treat Improvement Initiative Team Biographies

Biographies for the Pump and Treat Improvement Initiative (PTII) Team members are provided in the following sections.

A1.1 Herbert Stanton Berman (HSB) – Senior Technical Consultant and PTII Team Lead

Mr. Berman, team leader for the CH2M HILL (CH2M) pump and treat (P&T) process analysis and improvement initiative, is a graduate of the Massachusetts Institute of Technology and brings more than 42 years of experience in the management, supervision, and performance of nuclear/radiological work, conduct of operations, and engineering controls. Along with his distinguished career in chief engineer positions at the Pearl Harbor Naval Shipyard, U.S. Department of Energy (DOE) Rocky Flats Plant, DOE Pantex Plant, and DOE Hanford Tank Farms, he is recognized for turning around the performance of engineering and nuclear operations organizations. Mr. Berman's work involved directing numerous investigations of materials or process chemistry related problems with nuclear materials, waste storage, nuclear weapons and nuclear and chemical facilities, and operations safety bases.

A1.2 Charles Miller – Hydrogeologist and Team Member

Charles W. Miller is a Licensed Professional Hydrogeologist with CH2M HILL Plateau Remediation Company (CHPRC). Mr. Miller is a senior hydrogeologist at CHPRC in the Remedy Selection and Implementation group of the Soil and Groundwater Remediation Project (S&GRP). He received a B.S. in Soil Science from the University of Idaho followed by graduate study in Biological Science at Washington State University.

Mr. Miller has spent the last 30 years performing characterization and remediation of contaminated soil and groundwater at commercial, U.S. Department of Defense, and DOE facilities. His experience includes design, fabrication, construction, startup, and operation of groundwater remediation systems with focus on removal of volatile organic compounds and toxic metals. He has supported performance of remedial investigations/feasibility studies for multiple groundwater operable units at the DOE Hanford Site and served for five years as project scientist for the 100-KR-4 Groundwater Operable Unit. Mr. Miller currently provides technical support to groundwater characterization, well field operations, and remediation in the Hanford Central Plateau.

A1.3 Dr. Mark Carlson – Environmental Process Engineer and PTII Team Member

Dr. Carlson has a Ph.D. in Environmental Engineering from Virginia Polytechnic Institute and State University and is a Registered Professional Engineer in Oregon and Washington. As a part-time faculty member at Johns Hopkins University, Dr. Carlson taught graduate level classes in physical-chemical treatment and biological treatment of water. He has been involved in water restoration and treatment for over 30 years. He is currently serving as the process engineer at the 200 West P&T Facility and previously was a consulting engineer at CH2M where he provided technical expertise on over 50 projects for several municipalities and research organizations covering all phases of engineering: applied research, alternative evaluation, engineering design, construction, and startup. His select experience on processes pertinent to this initiative include the following:

- Technical Manager – CH2M Internal Research of Fluidized Bed Reactor (FBR) (1988 to 1989). Led the basic research of FBR for biological treatment of water.
- Technical Manager – Upper Occoquan Sewage Authority, Virginia (1989-1992). Led the study of fluidized bed biological reactor used to develop proof of concept for full-scale treatment.

- Project Manager; Pilot-Scale Water Treatment – Great Dismal Swamp Canal; City of Chesapeake, Virginia (1991 to 1992). Developed treatment needed for injection of water to aquifer for storage. Treatment processes included Superpulsator, rapid sand filtration, ozone, biologically activated carbon, and ultrafiltration.
- Project Manager; Demonstration-scale treatment of FBR for water treatment for Portsmouth, Virginia Department of Public Works (1991 to 1992).
- Lead Investigator; Development of an Implementation Protocol for the Integrated Disinfection Design Framework – American Water Works Association Research Foundation (AWWARF) (1998 to 2001). Developed protocols to establish disinfection strategies and avoid byproduct formation.
- Project Manager; Algal Toxin Treatment Project – AWWARF (2001 to 2005). Evaluated ultraviolet, ozone, activated carbon, and membranes for destruction of microcystin-LR.
- Senior Advisor; Tacoma Water Treatment Facility Conceptual Facility/Siting Plan and Treatability Study – City of Tacoma; Tacoma, Washington (2002 to 2004). Developed conceptual design which included clarification, biological filtration, and ozone oxidation.

A1.4 Richard Bernal – P&T Operations Supervisor and Team Member

Mr. Bernal (Retired, U.S. Navy) had a successful 20-year career in Naval Nuclear Power Operations. He now has had over 17 years of the following Hanford Site operations experience:

- 7 years on spent nuclear fuel
- 3 years at T Plant transuranic waste repackaging
- 7 years at S&GRP P&T

His P&T experience included bringing the newly constructed P&T facility through construction and acceptance testing up to operations. As a Senior P&T Operations Supervisor, Mr. Bernal’s duties include supervising a crew of 12 nuclear chemical operators for the safe and compliant operation of the 200 West P&T Facility, realigning systems and equipment in support of maintenance and well sampling, and ensuring that the facility is operating effectively to meet all 200 West P&T goals.

A1.5 James Geiger – Field Well and Maintenance Manager and PTII Team Member

Mr. Geiger has 30 years of broad construction and operations experience in both domestic and international projects including field engineering, field supervision, project planning, and project management. Mr. Geiger has extensive experience working internationally, including the Middle East in the United Arab Emirates and Johannesburg, South Africa. During that time, he was responsible for bid center operations developing construction proposals for major construction and military contracts in the Middle East and Africa.

Mr. Geiger also has extensive knowledge and experience at the DOE Hanford Site, dating back to 1995, with well drilling, well operations, and well maintenance. Additional DOE Hanford experience includes work on other construction related projects such as providing field engineering and field oversight for the successful installation of the fuel retrieval system in the 100-K West Facility. He was the project manager for Fluor Corporation on the Air Force Augmentation Program from 2000-2004 supporting contracts globally during Operation Enduring Freedom. Mr. Geiger’s hands-on practical experience and technical expertise in these projects, and his long experience in keeping Hanford P&T injection well operations online, provides a unique perspective for this P&T Improvement Initiative.

A2 PTII Team Charter

Table A-1 describes the PTII Team charter in detail.

Table A-1. PTII Team Charter

1.0 Purpose	CHPRC senior leadership has begun an effort to assess and improve efficiency, and effectiveness of the groundwater pump and treat (P&T) plant operations. This P&T improvement initiative (PTII) consists of establishing a subject matter expert (SME) team to develop a path forward to improve plant reliability, availability, and operability and optimize P&T operations. The PTII Team SMEs will analyze existing equipment, operations, and studies to derive optimizations expected to achieve higher water treatment volume rates, along with better injection well results, including the following: • Identification of technical issues within S&GRP that may compromise the integrity of the facility or jeopardize the readiness of the facility for operation • Providing recommendations for short-term improvement initiatives and activities to be addressed in the CHPRC yearly optimization plan • Providing recommendations for longer-term activities/goals/improvement initiatives, some of which might be addressed as new scope (e.g., might require an adjustment of DOE goals/metrics to achieve) • Assessing and/or incorporating recommendations on current studies on issues with FBR and membrane bioreactor (MBR) from the recent equipment manufacturer's reviews of P&T operations issues The PTII Team performs independent reviews of P&T plant operations and rate limiting issues and concerns (e.g., heterotrophic biological fouling of injection wells) and reliability of P&T equipment and operations. The PTII Team members, based on their diverse and extensive experience and knowledge of how safe, effective, and compliant, plant operations are performed, provide their review results and improvement suggestions to CHPRC senior management. The PTII Team will identify areas of improvement and reach conclusions on optimizing performance. The PTII Team review recommendations will include suggested actions necessary to implement the improvements and any noted concerns. The PTII Team also provides a resource to assist CHPRC senior leadership in the broad range of continuous improvement actions aimed at raising project performance to the next level.
2.0 Membership	CHPRC Vice President of S&GRP will designate the PTII Team leader. Team leader will interview PTII Team candidates, assess SME roles and responsibilities and any skill mix issues, and charter the PTII Team members with CHPRC management concurrence. PTII Team leader coordinates Team efforts and reports to the CHPRC Operations Director and Deputy Vice President for S&GRP and oversees issuance of PTII Team report.
3.0 General Responsibilities	1. Develop the appropriate methods of review and analysis for the various project elements (e.g., extraction, treatment, and injection), including review of existing information and interviews with CHPRC management and operations personnel. 2. Complete the assessment report and brief the PTII assessment results to CHPRC management and other appropriate managers in the project chain of command and project oversight, as requested. 3. As requested, assist CHPRC P&T management and staff in the following activities: a. Investigating/evaluating abnormal events b. Developing and executing any corrective actions c. Problem solving techniques to fuel continuous improvement

Table A-1. PTII Team Charter

	d. Mentoring of project and staff managers, as requested
3.1 Review Team Leader	1. Provide overall leadership of the following Team activities: a. Rigor of assessments b. Brainstorming approaches/topics with the PTII Team to ensure a controlled and consistent approach to PTII Team activities c. Assist in scheduling Team activities d. Identification of any needed additional PTII Team members or resources and recommendations to CHPRC management e. Determining team member assignments for assessments and other activities 2. Provide Team reports, including conclusions and recommendations, to CHPRC and other appropriate managers. 3. Maintain the Team calendar and records of the Team activities.

The PTII chartering session on April 19, 2017 is outlined on the following agenda:

1. Introduction of personnel
2. Purpose and scope of assessment (and PTII Team hour allotment)
3. Ensuring that Team has all provided P&T studies, PTII Team charter, PTII assessment plan, summary recommendation listing, and recommendation mapping versus P&T systems/functions
4. Questions and answers (note any issues/comments)
5. Notional schedule for assessment (e.g., complete by June 2, 2017)
6. Team communication and availability discussion (e.g., phone, text, and email)
7. Strategy for establishing Team scope and dividing of P&T systems/functions for evaluation and converging on team recommendations.
8. Bring in other P&T aspects (e.g., critical operational path, standard operating procedures, predictive maintenance, robotics, hydrocleaning, staffing, and equipment capital investment (not limited to topics of prior studies)
9. Team member assignments and expectations
10. Obtaining list of P&T procedures, reportable events, and sample P&T status reports
11. Team to develop any document requests and P&T personnel interviews desired
12. Team path forward and deliberation

A3 PTII Team Assessment Plan

The PTII Team assessment plan was developed in advance of the team meeting and is outlined in the following sections. Note that the meeting dates in the following schedule are listed as TBD as the final schedule was developed by comparing schedules.

A3.1 Purpose

A management review and assessment of the CHPRC groundwater pump and treat (P&T) plant design and operations will be completed to determine areas for improving efficiency and effectiveness of S&GRP.

A3.2 Scope

The PTII consists of establishing a subject matter expert (SME) team to develop a path forward for improving plant reliability, availability and operability and to optimize P&T operations. The PTII Team SMEs will analyze existing equipment, operations, and published studies to derive optimizations that are expected to achieve higher water treatment volume rates, along with better injection well results, including the following:

- Identifying technical or operational issues within S&GRP that may compromise the integrity of the facility or jeopardize the readiness of the facility for operation
- Providing recommendations for short-term improvement initiatives and activities to be addressed in the upcoming CHPRC yearly optimization plan
- Providing recommendations for longer-term activities and improvement initiatives, some of which might need to be addressed as new scope (e.g., might require an adjustment of DOE goals/metrics to achieve)
- Assessing and/or incorporating recommendations on current studies regarding issues with FBRs and membrane bioreactors (MBRs) from the recent equipment manufacturer reviews of P&T operations issues

A3.3 Assessment Methodology

The assessment will include briefings; facility walkdowns; personnel interviews; and review of plans, documentation, and procedures. The PTII Team performs independent reviews of P&T plant operations, rate limiting issues and concerns (e.g., heterotrophic biological fouling of injection wells), and reliability of P&T equipment and operations.

The PTII Team members, based on their diverse and extensive experience and knowledge of how safe, effective, and compliant plant operations are performed, provide their review results and improvement suggestions to the CHPRC senior management. The PTII Team members' individual expertise, along with team discussions and brainstorming, will identify areas of improvement and reach conclusions on improving and optimizing performance. The PTII Team review recommendations will include suggested actions necessary to implement these improvements and any noted concerns. The PTII Team will also provide priority of recommendation implementation, as appropriate, as well as suggestions on modeling or prototyping of recommendation actions.

The PTII Team, as requested, also provides a resource to assist CHPRC senior leadership in the broad range of continuous improvement actions aimed at raising project performance to the next level.

A3.4 Assessment Lines of Inquiry

The lines of inquiry for this evaluation are categorized under the three main P&T elements of groundwater processing: extraction, treatment, and injection.

The Team will look at any overarching topics (e.g., maintenance and process chemistry) to see if there are changes that will enhance overall P&T operations.

It is the intent of PTII optimization efforts to do an overall assessment of plant status, reliability, and integration. P&T operational elements will be looked at from mechanical, chemistry, and biological points of view.

PTII Team specific inquiry elements within these main topics include the following P&T technical/efficiency and operational issues:

- Evaluate current known technical issues or concerns (e.g., injection well biofouling) and provide recommendations and a path forward to resolution.
- Assess and incorporate or modify external recommendations on current commercial studies on issues with FBRs and MBRs from the recent equipment manufacturer reviews of P&T operations issues.
- Identify any potential or unaddressed technical and operational issues within S&GRP that may compromise the integrity of the facility or jeopardize the readiness of the facility for operation.

A3.5 Assessment Schedule

The assessment will notionally be conducted from April 18 through June 2, 2017 according to following preliminary schedule (there will be three onsite meetings, tours, and interviews as well as PTII Team telephone conference calls):

- Team leader meetings with senior managers and DOE representative – April 19, 2017
- Team Chartering and Team Meetings to Finalize Team Charter and Assessment Plan – April 20, 2017
- Begin document review and preliminary Team discussions and topic assignments – April 20-28, 2017
- Onsite team meetings and P&T tours and interviews – May (date to be determined [TBD])
- Preliminary team recommendation discussions – May (date TBD)
- Management status outbrief – May (TBD)
- Draft assessment report for CHPRC review and comments – May TBD
- Final assessment report issued – June 2, 2017

A3.6 Assessment Report

The PTII Team (assessment team members listed in Table A-2) output includes a formal written report and, if requested, a management outbrief before or after issuance of the report.

Table A-2. PTII Assessment Team

Role	Name	Organization
Team Lead/Assessor	Herb Berman	CH2M HILL, Inc.
Assessor	Mark Carlson	CHPRC
Assessor	Jim Geiger	CHPRC
Assessor	Chuck Miller	CHPRC
Assessor	Rich Bernal	CHPRC

Note: Estimated level of effort is 120 hours per assessor (includes pre-review, assessment, and writing final report).

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A4 Plan Review and Approval

Approved at Chartering Session 4/19/2017

Approved by: ______________________ 4/19/17

Herb Berman, Team Leader Date

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Appendix B

Compilation of Recommendations

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Contents

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Terms

AOP	advanced oxidation process
COD	chemical oxygen demand
DOE	U.S. Department of Energy
FBR	fluidized bed reactor
GAC	granular activated carbon
gpm	gallons per minute
HSB	Herbert Stanton Berman
MBR	membrane bioreactor
P&T	pump and treat

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B1 Pump and Treat Improvement Initiative Recommendations from Other Studies

Recommendations of the Pump and Treat Improvement Initiative (PTII) Team were based on reviews of other studies that are summarized in the following sections.

B1.1 Envirogen Technologies Evaluation Report of 200 West Pump & Treat Fluidized Bed Reactors

Envirogen Technologies, Inc. personnel (Mr. Jeff Lambeth and Mr. Sam Wong) performed site visits on March 7 to March 9, 2017 to meet with the CH2M HILL Plateau Remediation Company engineering and operations teams on the fluidized bed reactor (FBR) performance. This document summarizes site activities, documents observations, and provides the following recommendations as part of the performance evaluation report that are later referenced by a Herbert Stanton Berman (HSB) number:

- HSB.1.a. Physical properties of the recovered granular activated carbon (GAC), makeup GAC, and GAC currently in the FBR should be tested and compared with original specifications.
- HSB.1.b. Alternative FBR control strategy utilizing properly selected pneumatic diaphragm pump should be tested and implemented, if applicable.
- HSB.1.c.The cause(s) and types of GAC carry-over should be further investigated (i.e., continuous outflow of GAC or periodic) to help refine process parameters.
- HSB.1.d FBR level transmitter (bubbler) system that sends alarms to operators should be tested and implemented, if applicable.
- HSB.1.e The residual Ortho-P level should be increased to between 0.5 to 1.0 mg/L.
- HSB.1.f The NO2-N concentrations at FBR effluent should be routinely monitored as an indicator for upset condition.
- HSB.1.g If possible, a lower dosage of sodium hypochlorite at the plant effluent may be injected at the plant effluent stream to inhibit biological growth at the injection well.
- HSB.1.h Currently, the residual chemical oxygen demand (COD) level at the FBR effluent is limited due to concerns relating to fouling at the downstream injection wells. If possible, the residual COD level may be maintained at or above 10 mg/L to ensure excess COD is available for the microbes.
- HSB.1.i Alternative electron donors may be evaluated.

B1.2 One Water Solutions, 2016, Assessment of the 200 West Pump and Treat (P&T) Treatment Facility Fouling

The PTII Team made the following recommendations based on this study:

- HSB.2.a. Continue to direct the solids handling recycle streams (rotary drum thickener filtrate and centrate) to the FBR recycle tank.
- HSB.2.b.Remove FBR B from service, inspect it, and make any indicated repairs. Recent operating results (Figure 4 in the One Water Solutions assessment) suggest that it is not performing as well as the recently repaired FBR A.

- HSB.2.c.Optimize the FBRs. Each of the measures listed in Table 1 from the One Water Solutions Assessment are reasonable to consider and should be evaluated and implemented as possible. Optimization would also include adding online instrumentation to measure the plant influent nitrate concentration and use it to automatically control carbon and nutrient dosing. The laboratory studies described above to determine the optimum nutrient mixture should also be conducted to avoid adding un-needed nutrients, which are both costly and can contribute to injection well fouling. The goal should be to consistently achieve an FBR effluent COD concentration less than 10 mg/L and an FBR effluent nitrate concentration less than 5 mg-N/L, with a plant effluent COD concentration less than about 3 mg/L.

- HSB.2.d.Determine the performance capabilities and capacity of the optimized system by gradually increasing the nitrate loading to one FBR and monitor its performance. As above, a treatment objective of 3 mg/L effluent COD and 5 mg-N/L effluent nitrate would appear to be appropriate. If sufficient plant capacity and performance is demonstrated, then no further action is required.

- HSB.2.e.Should further improvements to plant performance and/or capacity be desired, adding a bioreactor to the membrane bioreactor (MBR) system would appear to be the best option, compared to adding more FBR's. Adding the bioreactor would provide the capability to remove an FBR from service for maintenance without decreasing plant capacity, and it is also likely to be less expensive than adding additional FBR capacity.

- HSB.2.f.A consultant would be retained to develop a preliminary design and cost estimate. Provisions to further expand the hydraulic and treatment capacity of the system by the addition of two more submerged membrane modules should be included in the design, along with the identification of other plant modifications that may be required (such as increasing the capacity of the air strippers).
  This latter information on plant expansion options could be useful to DOE as they consider increasing the plant throughput. Such expansion would not be necessary if the current plant hydraulic capacity (2,500 gpm) is maintained, although adding the bioreactor itself would provide more consistent removal of COD and nitrate, and allow the nitrate mass loading design capacity to be increased.
  The selected modifications would then be constructed and placed in service. Their performance would be assessed by the increased nitrate removal achieved and by lowered and less variable (mean and standard deviation) plant effluent COD concentrations.

- HSB.2.g.The capacity of the bioreactor and submerged membrane system would be tested by diverting flow around the FBR's to determine removal capacity.

B1.3 Pacific Northwest National Laboratory, 2017, 200 West Pump-and-Treat Facility Biofouling Assessment

Three categories of mitigation approaches were identified in this study. Improved well maintenance approaches may also be a component of mitigation considering that under all circumstances, some level of well maintenance will be required. This report provides information about the cause of the observed biofouling issues and compiles information about potential mitigation approaches. It is anticipated that this information will be used in a subsequent engineering assessment to select the most appropriate approach.

- HSB.3.a. There are several types of potential pump and treat (P&T) facility operational changes that could be considered either to reduce the production of constituents that lead to biofouling or use processes within the facility to decrease the concentration of constituents that lead to biofouling. One option for decreasing the amount of carbon, phosphorus, and metals such as iron and manganese in the facility effluent is to decrease amounts of amendments used for the FBR biological treatment system. Caution must be taken because there appear to be fine ranges of macro- and micronutrients that lead to optimum operation of the FBR system.

- HSB.3.b. Changing the type of carbon substrate (electron donor) in the FBR to a simpler, more readily degradable material with fewer byproducts is another option for modification of the FBR. However, the efficacy of these simpler substrates for maintaining appropriate FBR biomass characteristics and contaminant treatment would need to be evaluated.

- HSB.3.c. Adding chemicals to the effluent of the FBRs could be considered to enhance removal of organic carbon, iron, manganese, and phosphate in the MBRs. This change would also need to consider the residence time before and in the MBRs to maintain efficient operation of the MBRs.

- HSB.3.d. A liquid-phase granulated activated carbon or a biological tower treatment system could be used as a replacement for the air stripper tower better reduce biofouling constituents in the facility effluent. This type of change would need to consider the ability to still meet contaminant treatment goals.

- HSB.3.e. There are multiple treatment options that could be applied to reduce the concentration of biofouling constituents prior to the injection wells. Candidate processes include biologically active sand filters, biological treatment towers, adsorption media, precipitation, and chemical treatment. Literature information is available that describes the use of these technologies for other applications. While not directly addressing the root cause of biofouling constituent production in the facility, these options may be robust in that they could be designed to enable efficient operation of the facility under conditions less constrained than would be required to reduce production of biofouling constituents. This flexibility in operational conditions may be important given the potential need to adjust operations to address influent conditions as different influent sources are added to the facility (e.g., BP-5 and perched-water). However, candidates need to be evaluated with respect to their ability to effectively reduce low concentrations of the biofouling constituents to lower concentrations that minimize biofouling accumulation in injection wells.

- HSB.3.f. Modifying or changing the injection system could be used to manage biofouling issues. The injection system could be modified by installing additional wells, using infiltration galleries, or changing to a surface-water discharge.

  - HSB.3.f.i. Adding more injection wells could be used to sustain the treatment capacity by applying a more intense well cleaning schedule with sufficient wells on-line at all times to meet injection needs. Infiltration galleries may enable a means of discharging effluent that is less prone to frequent biofouling than wells are. However, use of injection galleries would need to consider the potential problems due to the thick vadose zone and would provide less focused hydraulic mounding as part of maintaining plume containment and enhanced extraction.

- HSB.3.g. Surface discharge is a potential option for the facility effluent, but would need to consider the location of the surface water discharge and would not provide hydraulic mounding as part of maintaining plume containment and enhanced extraction.

- HSB.3.h.Removal of residual COD using supplemental bioreactors (in-plant technology) – the aerobic MBRs are the principal unit operation for removing COD and residual macronutrients from the treated water following the FBR. This sub-option focuses on improving the performance of the aerobic MBRs so to improve the performance toward those objectives. In general, this sub-option would add an aerobic pretreatment and preconditioning reactor in front of the aerobic MBRs. This would allow time to develop a more robust aerobic microbial community, initiate the removal processes for COD and macronutrients, and provide water into the MBRs that is geochemically and biologically ready for maximum treatment rates. Positioning supplemental biological treatment in front of the aerobic membranes would allow these units to perform at maximum effectiveness and provide for the clear-filtered water to the air stripper and reinjection system. The high target flow rate of the 200 West system limits the hydraulic residence time in the MBRs. Conceptually, the input of anoxic water to the MBR, with an anaerobic microbial assemblage and a limited residence time may not allow for sufficient conversion of COD and uptake of macronutrients. One approach to supplementing the bioreactors would be to add a preconditioning vessel, basin or trench in which the water is aerated and time for the initial growth phases for the required aerobic microbial assemblage is provided.

- HSB.3.i.Processing of bed solids using integral inlet eductor(s):
  - An eductor based alternative concept for continuous or semicontinuous bed solids processing/cleaning has been developed, and such a system is projected to perform similarly to the recirculating diaphragm pump. For deployment, an eductor is placed just below the target FBR bed height. FBR inlet water (rather than finished process water) is used as the motive fluid. The eductor would pump FBR fluids and remove biomass from the contained bed solids as a result of internal turbulence.
  - Figure 5 in the Pacific Northwest National Laboratory report provides a simplified schematic of this concept. Using an industry standard booster pump, the motive fluid would be drawn from the FBR inlet (at a location where the fluids are clear and do not contain entrained solids). The outlet of the eductor would be released into the lower portion of the FBR where it would mix with the remaining fluidization flow. The booster pump would be packaged with standard components to maintain a constant outlet line pressure. This pressure could be adjusted (or the booster pump cycled) to vary the bed solids cleaning intensity, thus supporting continuous or semi-continuous operation.

B1.4 SGW-60655, Surface Infiltration Evaluation Report for the 200 West P&T Facility

This preliminary evaluation identified both the feasibility and numerous points of uncertainty associated with the infiltration basin concept. The principal area of uncertainty is the range of possible hydraulic conditions of the vadose zone underlying the area of interest. The identified range of uncertainty brackets failure of the system to successfully infiltrate water to recharge the aquifer at a satisfactory rate and embraces a potential range of cost estimates incorporating a range of as much as a factor of 15. Barring the uncertainty related to vadose zone hydraulic properties, the use of surface infiltration basins to return treated groundwater to the aquifer appears to be a feasible alternative action. Additional effort is required to address the uncertainties described.

The following actions are recommended to reduce planning uncertainty and provide sufficient information to make a go/no go decision and to support preparation of a sufficiently detailed cost estimate and schedule:

- HSB.4.a. Perform a detailed siting study to evaluate candidate infiltration basin locations relative to the 200-ZP-1 remedial action, and the presence/absence of the Cold Creek unit.
- HSB.4.b. Based on preliminary siting study, perform detailed vadose zone hydraulic property characterization to ensure adequate facility sizing and define expected performance.

- HSB.4.c. Prepare a feasibility decision document and detailed cost estimate based on the characterization results.
- HSB.4.d. Prepare a detailed schedule including design and construction of the basin(s).

B1.5 SRNL-STI-2017-0163, Evaluation of the Hanford 200 West Groundwater Treatment System

The alternative strategies and technologies were binned as follows:

- Viable and recommended
  - HSB.5.a.i. Cleaning of bed solids – recirculation of bed solids using diaphragm pump
  - HSB.5.a.ii.Bed solids core substrate – consider changeout of bed solids substrate to a new material (bed solids separator design); adding a continuous anticlogging system
  - HSB.5.a.iii.Post-treatment options to support reinjection – reinjection well screen design
- Viable and conditionally recommended
  - HSB.5.b.i.Cleaning of bed solids – in-tank sonic cleaning
  - HSB.5.b.ii.Electron donor – type of liquid carbon substrate
  - HSB.5.b.iii.Microbial nutrients and FBR geochemistry – use of chelating agent salts for some trace nutrients (Fluidized Bed Vessel Design and Hydraulics) – adjusting recycle flow in response to bed solids density (Fluidized Bed Vessel Design and Hydraulics) – replacing components to increase resilience (bed solids separator design) – increasing bed solids separator capacity
  - HSB.5.b.iv.Bed solids separator pretreatment – in-line static mixer
  - HSB.5.b.v.Bed solids separator pretreatment – in-line sonicator
  - HSB.5.b.vi.Post-treatment options to support reinjection – alternative antiscalant
  - HSB.5.b.vii.Post-treatment options to support reinjection – disinfection
  - HSB.5.b.viii.Post-treatment options to support reinjection – removal of residual COD using an advanced oxidation process (AOP)
  - HSB.5.b.viii.Post-treatment options to support reinjection – vadose zone infiltration
- Viable but not recommended
  - HSB.5.c.i. Nitrate treatment goals and alternatives – develop alternate concentration limits – baseline
  - HSB.5.c.i.Nitrate treatment goals and alternatives – wetland treatment system
- Not viable
  - HSB.5.d.i. Fluidized bed vessel design and hydraulics; modifying FBR vessel geometry (bed solids separator design) Increasing the slurry flow rate

  - HSB.5.d.ii. Bed solids separator design redesigning the recycle/effluent line collection funnels (bed solids separator design relocating the recycle line location/configuration)

- Affirmed baseline

  - HSB.5.e.i. Electron donor – quantity of liquid carbon substrate (electron donor) – control strategy

  - HSB.5.e.ii. Microbial nutrients and FBR geochemistry – control strategy (monitoring) – Chemical parameters and hydraulics – baseline

- Extend baseline or continue baseline until alternative is in place

  - HSB.5.f.i. Cleaning of bed solids multilevel eductor (manual operation) – baseline (monitoring) – FBR bed height

  - HSB.5.f.ii. Post-treatment options to support reinjection – alternative well cleaning

The challenges of the 200 West FBR system are complex and inter-related. Therefore, a combination of actions will be needed to move toward more stable and robust operations. Assembling a portfolio of compatible technologies from the viable and baseline bins above is recommended. Alternative portfolios will have different levels of cost and risk. Many portfolios are possible that range from relatively low cost (likely to improve performance but with a lower level of confidence) to very high cost options that would substantially improve performance with a high level of confidence (low, medium, and high cost options are just re-sorting of prior recommendations and are, therefore, duplicates):

- Low cost options (improved bed solids control and reinjection capability):

  - HSB.5.g.i. Cleaning of bed solids – recirculation of bed solids using diaphragm pump

  - HSB.5.g.ii. Bed solids core substrate – consider changeout of bed solids substrate to a new material

  - HSB.5.g.iii. Bed solids separator design – adding a continuous anticlogging system

  - HSB.5.g.iv. Electron donor – type of liquid carbon substrate

  - HSB.5.g.v. Microbial nutrients and FBR geochemistry – use of chelating agent salts for some trace nutrients

  - HSB.5.g.vi.Fluidized bed vessel design and hydraulics – adjusting recycle flow in response to bed solids density

  - HSB.5.g.vii. Fluidized bed vessel design and hydraulics – replacing components to increase resilience

  - HSB.5.g.viii.Bed solids separator pretreatment – in-line static mixer

  - HSB.5.g.ix. Post-treatment options to support reinjection – alternative antiscalant

  - HSB.5.g.x. Post-treatment options to support reinjection – disinfection

  - HSB.5.g.xi.Post-treatment options to support reinjection – reinjection well screen design

  - HSB.5.g.xii.Monitoring – FBR bed height

- HSB.5.g.xiii.Consider post-treatment options to support reinjection – vadose zone infiltration

- Medium cost options (further improves reinjection capability over low cost portfolio):
  - HSB.5.h.xiv. All items in low cost option plus
  - HSB.5.h.xv. Post-treatment options to support reinjection – removal of residual COD using AOP
- High cost options (further improve all capabilities over low cost option):
  - HSB.5.i.xvi. All items in low cost option plus
  - HSB.5.i.xvii. Bed solids separator design – increasing the bed solids separator capacity
  - HSB.5.i.xviii. Post-treatment options to support reinjection – removal of residual COD using AOP
- A reasonable path forward would be to phase key activities in the low cost portfolio and determine performance and effectiveness.

B1.6 Appendix D, "Evaluation and Diagnosis of Injection Well Fouling at the 200 West Pump and Treat"

The report notes that; "… following well rehabilitation (i.e., nearly linear increase in dynamic water level and corresponding decrease in injection capacity) indicate that fouling accumulations begin immediately after restarting injection of effluent. This behavior indicates that a substantial fraction of the accumulated fouling materials consist of suspended solids carried in the effluent that are deposited directly into the wells. Biological fouling then compounds the condition.

The presence of suspended solids is further indicated by the observed fouling and reduced capacity of the air stripping towers at the treatment plan. Chronic fouling of the air strippers is indicated by substantial increases in the differential pressure across the strippers.

- HSB.6.a.The recommended approach to defining a corrective action includes comprehensive diagnosis of the problem through:
  - HSB.6.a.i. Visual inspection of all system components downstream of the MBRs
  - HSB.6.a.ii. Chemical and biological characterization of the effluent and any accumulated solids within the conveyance system
  - HSB.6.a.iii. Dynamic measurement of suspended solids in the effluent stream using silt density index
  - HSB.6.a.iv. Assessment of scaling indices at points upstream of the air strippers and any other component that may be subject to modification of pH's of calcium carbonate (e.g., accumulation tanks and surface laid distribution piping); scaling indices are expected to be extreme
- HSB.6.b. Continued operation of the 200 West P&T plant appears to be contingent upon controlling the release of suspended solids, reactive solids, and biological material from the plant to the effluent conveyance system and subsequently the injection wells. Controlling solids in the effluent will likely include the following actions:
  - HSB.6.b.i. Cleaning (to remove all existing precipitated solids) and sanitizing (to remove all existing microbial colonies) all effluent conveyance components between the MBRs and the injection wells (this may include steam and/or chemical cleaning of tanks, valves, pumps, and

conveyance lines, and pigging of conveyance lines; air strippers may have to be stripped of their packing, chemically and steam cleaned, and refilled with new packing)

- HSB.6.b.ii. Incorporating pH control ahead of the air stripping towers to prevent precipitation of calcium carbonate
- HSB.6.b.iii. Chemically modifying the effluent stream to minimize direct oxidation and precipitation of iron and manganese in the stripping towers
- HSB.6.b.iv. Adding a solids removal unit process after the air strippers to remove suspended solids from the effluent stream (e.g., centrifugal or filtration-based process, depending on the physical properties of the solids)
- HSB.6.b.v. Implementing routine cleaning and sanitation of effluent conveyance and components downstream of the MBRs

- HSB.6.c. The diagnostic approach recommended is intended to quantify the contribution of fouling materials from each major component in the system, starting with the air strippers and continuing to the injection wells. Characterize:
  - HSB.6.c.i. Effluent entering air strippers
  - HSB.6.c.ii. Effluent from air strippers/entering effluent tank
  - HSB.6.c.iii. Effluent leaving effluent tank
  - HSB.6.c.iv. Effluent entering injection transfer buildings 1 and 2 tanks
  - HSB.6.c.v. Effluent leaving injection transfer buildings 1 and 2 tanks
  - HSB.6.c.vi. Effluent arriving at each injection well
  - HSB.6.c.vii. Visual inspections:
    - HSB.6.c.vii.1. Interior of both air strippers for solid fouling deposits
    - HSB.6.c. vii.2. Interior of all tanks for solid fouling deposits
    - HSB.6.c. vii.3. Exposed ends of all pipes and hoses for solid fouling deposits
  - HSB.6.c.viii. Collect water sample at each inspection point and analyze for the detailed species and characteristics specified in this report.

B2 PTII Mapping of Study Recommendations by P&T Function

B2.1 P&T Overview

P&T System Description:

- Extraction Wells
- Treatment Facility
  - The facility consists of two buildings:
    - A radiological building houses ion exchange resin beds, which are designed to remove uranium and technetium-99 at a maximum flow rate of 600 gpm.
    - The effluent from the radiological building is pumped to an equalization tank where it is mixed with groundwater containing other non-radioactive contaminants as the influent to the biological treatment building.

    - The effluent of the equalization tank is mixed with recycled waters in a recycle tank and the flow is then split, to be treated in two parallel FBRs.

        - The FBRs contain biofilms attached to GAC particles. These FBRs were designed to remove nitrate by denitrification and hexavalent chromium by biological reduction and precipitation (Chen and Hao, 1997, "Biological Removal of Aqueous Hexavalent Chromium").

    - The amendments added to the FBRs to induce this treatment include a substrate for microbial growth (e.g., a commercial organic carbon substrate such as MicroCg™), phosphoric acid, and a micronutrient solution (SGW-58170-FP, *Finding Balance Between Biological Groundwater Treatment and Treated Injection Water*).

  - Treated effluent from the FBRs flows to four parallel MBRs that are used to remove suspended solids and aerobically degrade carbon from earlier processes:

    - In the MBRs, oxygen is added to the water, and membrane filter material is used to retain suspended solids, including biological materials.
    - Sludge is removed from the groundwater in the MBRs and pumped to the rotary-drum thickener and a centrifuge.
    - MBR Effluent sludge is treated with lime to kill bacteria and reduce odor. This sludge is then disposed of at the Environmental Restoration Disposal Facility at Hanford.
    - The MBR permeate effluent water flows into the two parallel air strippers to remove any volatile organic compounds still remaining in the water.

  - This treated groundwater is stored in an effluent tank before being pumped to more than 24 aquifer injection wells.

- Injection wells

  - The ~24 aquifer injection wells are designed for flow rates up to 150 gpm per well (potential injection capacity 3,600 gpm).

B2.2 P&T System to Recommendation Mapping

Using nomenclature from Appendix B1 (e.g., Herbert Stanton Berman [HSB]-1.g.iv). Note: Items can appear in more than one category.

- Extraction wells and conveyances: no recommendations from P&T studies
- Treatment
  - Ion exchange resin beds (radiological)
  - Equalization tank
  - FBRs; GAC and microbial growth substrate
    - GAC
      - HSB-1.a HSB-1.c, HSB-3.b, HSB-3.d, HSB-5.a.i, HSB-5.a.ii, HSB-5.g.iv

™ MicroCg is a trademark of Environmental Operating Solutions, Inc., Bourne, Massachusetts.

    - FBR controls/measurement
        - HSB-1.b, HSB-1.d, HSB-1.f
    - FBR chemistry
        - HSB-1.e, HSB-1.g, HSB-1.h, HSB-1.i, HSB-2.c, HSB-2.d, HSB-5.b.iii, HSB-5.g.v, HSB-5.h.ii, HSB-3.h
    - FBR operations/equipment/maintenance/design
        - HSB-2.a, HSB-2.b, HSB-2.c, HSB-3.a, HSB-3.c, HSB-3.i, HSB-5.f.i, HSB-5.g.vi, HSB-5.g.vii, HSB-5.g.xii, HSB-5.g.xiii, HSB-5.i.ii, HSB-6.b.iii, HSB-7.b.iv, HSB-6.b.v
  - MBRs and sludge effluent, air strippers
    - MBR chemistry
        - HSB-3.a, HSB-3.h, HSB-6.b.iii
    - MBR operations/equipment/maintenance/design
        - HSB-2.e, HSB-2.f, HSB-2g, HSB-5giii, HSB-5gviii, HSB-6.b.ii, HSB-6.b.iv
    - MBR bed solids
        - HSB-5aii, HSB-5bi, HSB-5.b.iv, HSB-5.b.v, HSB-5.g.i, HSB-5.g.ii, HSB-6.b.i
  - MBR effluent tank
    - Effluent tank changes/additions (e.g., add sand filters)
        - HSB-3.e
- Injection wells and conveyances
  - Well reinjection design, operations, and maintenance
    - HSB-5.a.iii, HSB-5.b.vi, HSB-5.b.vii, HSB-5.g.ix, HSB-5.g.xi, HSB-5.i.iii
  - Well reinjection chemistry
    - HSB-5.b.viii, HSB-5.g.ix, HSB-5.g.x
  - Well fouling diagnostics
    - HSB-6.c.i–viii
  - Biofouling (and cleaning)
    - HSB-3.f.i, HSB-3.g, HSB-5.b.i, HSB-5.f.ii
  - Well reinjection diagnostics
    - HSB-6.a.i, HSB-6.a.ii, HSB-6.a.iii, HSB-6.a.iv
- Surface infiltration/injection galleries option
  - Design and operations
    - HSB-3.g, HSB-4.a, HSB-4.b HSB-4.c, HSB-4.d

B3 References

Chen and Hao, 1997, "Biological Removal of Aqueous Hexavalent Chromium," *Journal of Chemical Technology and Biotechnology* 69:70-76.

Envirogen, 2017, *Evaluation Report of 200 West Pump & Treat Fluidized Bed Reactors*, Envirogen Technologies, Kingwood, Texas, March 7-9.

One Water Solutions, 2016, *Assessment of the 200 West Pump and Treat (P&T) Treatment Facility Fouling*, Effluent Technical Review Services Contract No. 60073, One Water Solutions, Ann Arbor, Michigan, September 22.

PNNL, 2017, 200 *West Pump-and-Treat Facility Biofouling Assessment*, Draft, Pacific Northwest National Laboratory, Richland, Washington.

SGW-58170-FP, 2015, *Finding Balance Between Biological Groundwater Treatment and Treated Injection Water,"* Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-60655, 2017, *Surface Infiltration Evaluation Report for the 200 West P&T Facility*, Draft, CH2M HILL Plateau Remediation Company, Richland, Washington.

SRNL-STI-2017-0163, 2017, *Evaluation of the Hanford 200 West Groundwater Treatment System*, Draft, Savannah River National Laboratory, Aiken, South Carolina.

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Appendix C

Pump and Treat Improvement Initiative Team Deliberations

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Contents

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Terms

CHPRC	CH2M HILL Plateau Remediation Company
CST	carbon separator tank
FBR	fluidized bed reactor
GAC	granular activated carbon
gpm	gallons per minute
HSB	Herbert Stanton Berman
MBR	membrane bioreactor
P&T	pump and treat
PNNL	Pacific Northwest National Laboratory
PTII	Pump and Treat Improvement Initiative
RD/RAWP	remedial design/remedial action work plan
S&GRP	Soil and Groundwater Remediation Project
SRNL	Savannah River National Laboratory

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C1 Pump and Treat Improvement Initiative Deliberations on Study and Team Recommendations by Function (5/18/17)

The main sources of recommendations evaluated by the Pump and Treat Improvement Initiative (PTII) Team come from the following studies:

- Envirogen, 2017, *Evaluation Report of 200 West Pump & Treat Fluidized Bed Reactors*
- One Water Solutions, 2016, *Assessment of the 200 West Pump and Treat (P&T) Treatment Facility Fouling*
- PNNL, 2017, *200 West Pump-and-Treat Facility Biofouling Assessment*
- SGW-60655, 2017*, Surface Infiltration Evaluation Report for the 200 West P&T Facility*
- SRNL-STI-2017-0163, *Evaluation of the Hanford 200 West Groundwater Treatment System*
- Appendix D, "Evaluation and Diagnosis of Inject Well Fouling at the 200 West Pump and Treat"

C2 PTII Team Deliberations on Pump and Treat System/Functions to Recommendation Mapping (from Appendix B)

Note: PTII Team deliberations are tied to the study recommendations nomenclature from Herbert Stanton Berman (HSB) Summary Improvement Recommendations (e.g., HSB-1.g.iv), revised 5/12/17.

Note 1: Study Recommendation Items can appear in more than one category.

Note 2: PTII Team recommendations (pro and con) are designated as PTII-1, PTII- 2, etc., and can be either in support of PTII Team and study recommendations, or rejection/modification of study recommendations.

- Extraction wells and conveyances

  No recommendations from pump and treat (P&T) studies or PTII Team

- Treatment
  - Ion exchange resin beds (radiological)
  - Equalization tank
  - Fluidized bed reactors (FBRs) (GAC and microbial growth substrate)
    - GAC
      - HSB-1.a, HSB-1.c, HSB-3.b, HSB-3.d, HSB-5.a.i, HSB-5.a.ii, HSB-5.g.iv
      - PTII deliberations
        a. Because of notable levels of GAC loss in the FBRs, Envirogen (2017) (HSB-1.a, HSB-1.c) considers that the physical properties of the recovered GAC, makeup GAC, and the GAC currently in the FBR should be tested and compared with original specifications. The PTII reviewed this and did not

consider this a sufficiently promising approach, especially with the work on recovered GAC already underway at P&T. At CH2M HILL Plateau Remediation Company (CHPRC), the recovered GAC is already being tested for particle size distribution. Samples were collected the week of 4/17/2017 and results are expected 5/17/2017. There are no plans to sample the GAC currently in the FBRs. The GAC that is in the FBR, by definition, is large enough to stay in the FBR. Carbon lost from the FBR will periodically be sampled for sieve analysis.

PTII-1 The Team recommends that at present, no additional GAC analyses be done over and above the Soil and Groundwater Remediation Project (S&GRP) program underway, where GAC lost from the FBR will periodically be sampled for sieve analysis, and compared against the specification for the GAC that was originally provided for the FBR (viz., Effective Size of 1.1 mm and uniformity coefficient of 1.02).

PTII-2 The Team considers that the various recommendations to minimize micronutrient content are no longer necessary; as S&GRP already is confident from actual tests, that the proper process parameters and micronutrient levels have been established.

b. HSB-3.b, HSB-1.i, HSB-5.g.iv; Changing the type of carbon substrate (electron donor) in the FBR to a simpler, more readily degradable material with fewer byproducts is another option for modification of the FBR.

   The PTII Team believes, however, that efficacy of these simpler substrates for maintaining appropriate FBR biomass characteristics and contaminant treatment would need to be thoroughly evaluated.

   The Team understands that viable alternatives exist that, by virtue of their faster microbial kinetics, may be more completely removed in the existing treatment system and have potential for long term improvement. For example glycerin or acetate have been used with great success in FBRs. However, due to the complex factors that influence the FBR substrate selection (e.g., feed pump sizing and compatibility check), changing the type of carbon substrate (electron donor) requires further study on a pilot scale and a careful engineering evaluation.

   Therefore, **PTII-3** Do a literature search and discuss with other sites with related P&T activities, to determine potentially viable alternate FBR substrates. If changing or enhancing use of carbon substrate in FBRs appears to have a good chance to enhance efficiency of P&T operations and is a cost-benefit; proceed to pilot scale testing.

c. Pacific Northwest National Laboratory (PNNL); HSB-3.d suggests that a liquid phase GAC or biological tower treatment system could be used as a replacement for the air stripper tower better reduce biofouling constituents in the facility effluent. This type of change would need to consider the ability to still meet contaminant treatment goals.

However, upon deliberations, **PTII-4** the Team considers that replacing the air stripper with a liquid phase GAC or a biological tower treatment system is not a viable option. The air stripper is needed to remove residual carbon tetrachloride that is not removed in the FBR or membrane bioreactor (MBR).

However, the Team does note that the concept of additional time for biological reactions to occur is a good one. But, how you provide additional bio-reactor time is a matter for further engineering evaluation (See also **PTII-14.1 & 14.2**).

d. HSB-5.a.i, HSB-1.b (Cleaning of Bed Solids) – recirculation of bed solids using diaphragm pump.

The PTII Team considers that this is a viable alternative worthy of engineering evaluation to determine whether the capture zone and shear force are significantly superior to the existing educator system and to determine implementation issues such as freeze protection and air supply. Additionally, this diaphragm pump has a small benefit in that it would not introduce additional water to the FBR, while the existing educator system does add about 25 gallons per minute (gpm) water to each FBR.

Therefore, **PTII-5** It is recommended that an engineering evaluation of recirculation of bed solids using a diaphragm pump be conducted to determine complexity and benefits.

e. HSB-5.a.ii (bed solids "core" substrate) – consider changeout of bed solids substrate to a new material (bed solids separator design) and adding a continuous anticlogging system.

The PTII Team likes the idea of using something like a sintered iron substrate, which can then be removed magnetically. However the potential abrasion of the sintered iron, coupled with the fact that there are no fluidized bed biological systems currently operating that contain sintered iron would require a prolonged test to develop and prove the concept. **PTII-6** For the immaturity of technology reasons, this changeout of bed solids substrate to a new material idea should not be given further consideration at this time.

- FBR controls/measurement
  - HSB-1.b, HSB-1.d, HSB-1.f
  - PTII Team Deliberations

a. HSB-1.d; FBR bed level transmitter (bubbler) system that sends alarms to operators should be tested and implemented if applicable.

The concept of a bed level instrument/transmitter is a good one. Envirogen (2017) has reported that the bubble system instrument has been successfully used at other fluidized bed installations. However, the original instrument (Echo-Smart) was not able to provide reliable signal.

PTII-7. The PTII Team recommends that other installations using the bubbler level system be contacted to verify good performance. If these calls go well, two instruments should be ordered and installed in the FBRs. After 6 months of reliable performance consider an automatic callout alarm or an interlock with the eductor system or both.

b. HSB-1.f; Per Envirogen (2017), the NO2-N concentrations at FBR effluent should be routinely monitored as an indicator for upset condition. The PTII Team notes that NO3 is already monitored but considers that this addition of NO2 – N monitoring may be very beneficial in quickly detecting imminent upset conditions. Therefore, **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 chemistry
  - HSB-1.e, HSB-1.g, HSB-1.h, HSB-1.i, HSB-2.c, HSB-2.d, HSB-5.b.iii, HSB-5.g.v, HSB-5.h.ii, HSB-3.h
  - PTII Team deliberations

a. HSB-1.e; Residual Ortho-P level should be increased to between 0.5 to 1.0 mg/L.

This is a good idea, supported by operational data, and has already been implemented by CHPRC.

b. HSB-1.g; If possible, a low dosage of sodium hypochlorite at the plant effluent may be injected at the plant effluent stream to inhibit biological growth at the injection well.

The PTII Team thinks that this alternative is technically viable. The use of sodium hypochlorite to control growth in distribution system pipelines and tanks has a long history in water treatment. For over 25 years aquifer storage and recovery systems have injected chlorinated water.

However, in addition to engineering design, there are regulatory concerns that need to be addressed. First, the remedial design/remedial action work plan (RD/RAWP) needs to be changed with a process change. Second, the potential for disinfection byproducts, especially chloroform, need to be addressed. Chloroform is a contaminant of concern, but studies have shown that it may not be of concern. A 1994 study of aquifer storage and recovery found that chloroform introduced by aquifer pumping naturally decays in 8 to 20 weeks after storage and is of little concern.

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 pipe/conveyance to the injection wells; see also **PTII-21**).

c. HSB-1.h; Currently, the residual COD level at the FBR effluent is limited due to concerns relating to fouling at the downstream injection wells. If possible, the residual COD level may be maintained at or above 10 mg/L to ensure excess COD is available for the microbes.

   The PTII Team rejects this Envirogen (2017) idea, as it is expected to add to well fouling and is not necessary for us to maintain a proper bio-growth environment. Operational experience has shown that a relatively low effluent COD is consistent with stable operation. **PTII-10** The Team rejects the Envirogen idea of increasing COD levels above that necessary for healthy growth.

d. HSB-2.c; One Water Solutions (2016) recommends optimizing the FBRs per a list of measures listed in Table 1 of their report. The PTII Team thinks many of their recommendations are reasonable and several have already been implemented at P&T. Several instrumentation upgrades, like adding new better sized flow gages is already underway at P&T. Their optimization also includes adding on-line instrumentation to measure the plant influent nitrate concentration and use it to automatically control carbon and nutrient dosing. However, P&T already monitors well NO_3 with periodic laboratory samples.

   The laboratory studies One Water Solutions (2016) recommends to determine the optimum nutrient mixture (to avoid adding un-needed nutrients, which are both costly and can contribute to injection well fouling); has already been accomplished, and no further work need be done; the following recommendations from that study have been completed at Hanford P&T:

   i. Placing eductors at varying distances from the floor to provide flexibility to clean the top of the fluidized bed for a range of fluidized bed levels

   ii. Laboratory studies to determine optimum nutrient mixture

   The PTII Team also notes that the recommended influent nitrate analyzers have been abandoned because they frequently failed causing an imbalance in chemical dosing. An alternative method has been employed by CHPRC whereby the nitrate concentration in each well is measured quarterly. The supervisory control and data acquisition system is being used to calculate a flow-weighted average influent nitrate concentration. This system works much better reliably providing nitrate concentrations within 4% of the value measured by laboratory testing. The chemical dosing algorithm has been based on this calculated nitrate value for about a year with good success. **PTII-11** Other than supporting the recommendation for a permanent FBR camera installation, no further actions are considered necessary for these One Water Solutions (2016) suggested optimizations.

e. HSB-2.d; One Water Solutions recommends determining the performance capabilities and capacity of the optimized system by gradually increasing the nitrate loading to one FBR and then measure the FBR performance. If sufficient plant capacity and performance is demonstrated, then no further action is required.

   The PTII Team considers this is a viable recommendation and is already being implemented at CHPRC P&T within the constraints of production of expected levels of processed groundwater and other flow limitations imposed by typical operational constraints.

f. HSB-5.b.iii (Microbial Nutrients and FBR Geochemistry) – SRNL-STI-2017-0163 recommends:

   a) Use of chelating agent salts for some trace nutrients (fluidized bed vessel design and hydraulics)

   b) Adjusting recycle flow in response to bed solids density (fluidized bed vessel design and hydraulics)

   c) Replacing components to increase resilience (bed solids separator design)

   d) Increasing the bed solids separator capacity

   The PTII Team evaluated the above with the following conclusions:

   For a) above, not necessary – micronutrient solution currently contains organic-based chelating agents. The micronutrient recipe was changed, and salting out is no longer a problem.

   For b) above, decreasing the fluidization flow would limit carbon carryover. However, recent P&T experience at reduced fluidization flows has revealed the potential for nozzle plugging. At lower fluidization velocities the shear force through the nozzle opening is reduced and biological growth and carbon can accumulate. This was revealed when the fluidization flow was reduced to aid in the carbon removal process from FBR B. In contrast to the nozzles removed one year previously several nozzles had biological growth. The only difference is that the previous year a different carbon removal process was used that did not require a reduction in fluidization flow.

   For c) above, the PTII consider that this is a good idea and is already underway at CHPRC P&T. The PVC nozzles and distribution system have been replaced with stainless steel. In addition a ¼-in thick layer of stainless steel (erosion plate) has been placed on the bottom of the FBR.

   For d) above, the idea of increasing the bed solids separator capacity is a good one. However the methods of removing the existing separator and replacing it with a larger one, or adding a second separator are not practical for the existing FBR/carbon separator tank (CST) system. These ideas should be considered if another FBR/CST system is installed.

Therefore (**PTII-12)**, No further actions are necessary for these microbial nutrient optimizations proposed in SRNL-STI-2017-0163, unless a new FBR/CST system will be designed and installed.

- FBR operations/equipment/maintenance/design
  - HSB-2.a, HSB-2.b, HSB-2.c, HSB-3.a, HSB-3.c, HSB-3.i, HSB-5.f.i, HSB-5.g.vi, HSB-5.g.vii, HSB-5.g.xii, HSB-5.g.xiii, HSB-5.i.ii, HSB-6.b.iii, HSB-7.b.iv, HSB-6.b.v
  - PTII deliberations

a. HSB-2.e, &3.i; One Water Solutions (2016) and SRNL-STI-2017-0163 recommend adding a bioreactor to the MBR system to be the best option, compared to adding more FBRs. Adding the bioreactor would provide the capability to remove an FBR from service for maintenance without decreasing plant capacity, and it is also likely to be less expensive than adding additional FBR capacity.

The PTII considers that adding a bioreactor has the potential to add time for biological and chemical reactions come to completion. Chemical oxygen demand (COD) fuels bacterial growth in the distribution system that will clog wells. Therefore, additional reaction time in a bioreactor will help remove excess COD and form bacterial solids in the treatment plant where it can be screened out by the microfiltration membranes (the membranes have nominal pore size of 0.04 micron, much smaller than typical bacterial cross sections [0.5 to 5 microns]).

Also, chemical reactions will have more time to complete, in particular the oxidation of iron and manganese to iron hydroxide and manganese dioxide, respectively. Iron and manganese are concentrated in the biofilms found in the distribution system, where they can mineralize and cause particulate fouling. Manganese is typically slower to oxidize than iron. At the pH (7.2 to 7.5) of the water, iron will oxidize in two hours, however, additional manganese oxidation will be limited. In the absence of catalysts, measureable oxidation of Mn does not occur at pH's less than 8.0. A bioreactor may not provide much benefit for the oxidation and removal of manganese.

One Water Solutions (2016) recommends a bioreactor of 250,000 to 300,000 gal. At 2,500 gpm, this volume would provide a theoretical contact time of 100 to 120 minutes. SRNL-STI-2017-0163 recommends a contact time of 2 to 4 hours as a starting point. The sizing of a bioreactor would be subject to further evaluation to determine sizing, aeration requirements, ventilation impacts, and potential efficacy. The evaluation points out that this recommendation comes at a moderate to high cost depending on size and aeration requirements.

b. The PTII Team has two recommendations: First, **PTII-13**: Conduct further engineering evaluation of adding another bioreactor, and if practical, following the analysis with a pilot test is recommended to define the size and aeration requirements further, as well as the benefits (e.g., how much additional COD, iron, and manganese can be removed).

c. Second, during deliberations the PTII Team developed an alternative that has the potential to accomplish increasing bioreactor effectiveness, by simply adding insulation or a heat blanket to the existing unit. Thereby using increased temperature as a means to provide more complete biological and chemical reactions (as a rule of thumb bio-reactions ~double every 10 degrees C).

   This can be done in two levels of commitment/investment: First, just to better optimize the present system, **PTII-14.1**: Instead of a second bio-reactor unit, at this time, as an inexpensive first step, add Insulation blankets for the existing aerated membrane tanks to minimize heat loss in the winter (bio systems 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.

   Second, instead of a second unit, and to optimize the bioreactor both winter and summer, The PTII Team recommends adding heating blankets to the existing units. **PTII-14.2**: After engineering design and utility requirements determination, add heating blankets to the existing unit, and maintain a more consistent and higher unit operating temperature, both winter and summer.

– MBR and sludge effluent, air strippers

- o MBR chemistry

  - ▪ HSB-3.a, HSB-3.h, HSB-6.b.iii

  - ▪ PTII deliberations

a. There are several types of potential P&T facility operational changes that could be considered either to reduce the production of constituents that lead to biofouling or use processes within the facility to decrease the concentration of constituents that lead to biofouling. One option for decreasing the amount of carbon, phosphorus and metals such as iron and manganese in the facility effluent is to decrease amounts of amendments used for the FBR biological treatment system. Caution must be taken because there appear to be fine ranges of macronutrients and micronutrients that lead to optimum operation of the FBR system.

   However, the ideas in this recommendation have been pursued over the course of the past 18 months. These feeds have been decreased to their lowest reasonable levels, and no further action is deemed necessary.

- o MBR Operations/Equipment/Maintenance/Design

  - ▪ HSB-2.e, HSB-2.f, HSB-2g, HSB-5giii, HSB-5gviii, HSB-6.b.ii, HSB-6.b.iv

  - ▪ PTII Team discussions on item ii:

a. HSB-2.f; One Water Solutions (2016) recommends that a consultant would be retained to develop a preliminary design and cost estimate to further expand the hydraulic and treatment capacity of the system by the addition of two more submerged membrane modules. However, such expansion would not be necessary if the current plant hydraulic capacity (2,500 gpm) is maintained. However, adding the bioreactor itself would provide more consistent removal of COD and nitrate, and allow the nitrate mass loading design capacity to be increased. The selected modifications would then be constructed and placed in service. Their performance would be assessed by the increased nitrate removal achieved and by lowered and less variable (mean and standard deviation) plant effluent COD concentrations.

PTII-15 – The PTII 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 the easy to implement 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 on ideas provided by SRNL-STI-2017-0163, Envirogen (2017), and PNNL (2017) as well as CHPRC staff.

b. HSB-2g; One Water Solutions suggests that the capacity of the bioreactor and submerged membrane system should be tested by diverting flow around the FBR's to determine removal capacity.

The PTII Team considers that this is simply a means of evaluating the performance of a new bioreactor, not a new idea, and in and of itself would not improve P&T operations. **PTII-16** recommends that a longer term comprehensive operations parameter monitoring plan be developed to provide performance data to highlight areas needing improvements, or to detect degradations. Where 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 in Appendix D for suggested parametric measurements.

- FBR bed solids
  - HSB-5aii, HSB-5bi, HSB-5.b.iv, HSB-5.b.v, HSB-5.g.i, HSB-5.g.ii, HSB-6.b.i
  - PTII Team deliberations on bed solids

a. HSB-5giii, HSB-5gviii; SRNL-STI-2017-0163 recommends improvement in bed solids separator design – adding a continuous anticlogging system

b. The PTII Team considers that the concept of adding additional turbulence to separate the biofilm from the GAC is a good one. There are many ways to accomplish this. SRNL-STI-2017-0163 recommends installing a static mixer. Another option is to place a highly turbulent jet nozzle in the water stream as it exits the FBR. There is a water collection trough where such a nozzle could be placed while keeping the FBR in production.

PTII-17: Further technical evaluation of SRNL-STI-2017-0163 turbulence/shear force ideas is recommended. 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 and design a means to provide this force.

- Air Stripper
  - HSB-5.b.vi
  - PTII Team deliberations
    - Alternative antiscalants that do not contain phosphorus, a key nutrient, are available. **PTII-18** recommended that the SRNL-STI-2017-0163 proposed alternative antiscalants 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.
- MBR effluent tank
  - Effluent tank changes/additions (e.g., add sand filters)
    - HSB-3.e
    - PTII Team deliberations

      a. This set of PNNL topics covers methods to clean both particles and bionutrients from the effluent stream (e.g., sand filters and adsorption media) to the injection wells. This topic will be covered in the next section on injection wells and conveyances.

- Injection wells and conveyances
  - Well reinjection design, operations, maintenance
    - HSB-5.a.iii, HSB-5.b.vi, HSB-5.b.vii, HSB-5.g.ix, HSB-5.g.xi, HSB-5.i.iii
      - PTII deliberations

        a. The injection wells have a similar screen/mesh design as the extraction wells; where V-shaped wires are used to construct the casing screen. The small opening sits on the outer casing and the open "V" faces the interior. This design is apparently appropriate for Extraction (i.e., the water being extracted from the aquifer enters the small opening and then sees a larger space).

        However, for the Injection wells this V-shape opening (leading to the smaller orifice) has water driven into it with high pressure, with a propensity for any particles to be forced together by the V-shape. Per Appendix D, the Injection well fouling appears to be dominated by particulate fouling (e.g., metal oxides and biodebris particles) versus biological growth.

Therefore, **PTII-19** it is recommended that a more favorable well-casing screen wire geometry be tried for a few new Injection Wells. The Team suggests using round wire cross-section geometry; providing symmetrical flow direction impedance).

Injection well operations to meet production goals usually mean driving the well at maximum flow and pressure, and there is some evidence that lower forced flow (e.g., hydrogen injection well) tends to minimize well degradation. If this can be demonstrated, it would imply using more injection wells but at lower flow rates, but where the injection wells would potentially have a greatly extended life.

PTII-20 The PTII Team recommends injection well trials using lower water injection rates. Due to the desire to not impact P&T processing goals, this approach may be combined with the recovered "dead' well recommendation **PTII-22** discussed under Biofouling and Cleaning.

– Well reinjection chemistry
  - o HSB-5.b.viii, HSB-5.g.ix, HSB-5.g.ix
    - ▪ PTII deliberations noted that reinjection chemistry fixes (e.g., additional MBR) are already covered in prior topics that recommend altering various pre-air stripper chemical additions/processes. However, under the topic below of Biofouling and Cleaning this is discussed further.

– Well fouling diagnostics
  - o HSB-6.c.i-viii
    - ▪ PTII deliberations – See **PTII-16** for data gathering, analysis and parametric studies.

– Biofouling (and cleaning)
  - o HSB-3.f.i, HSB-3.g, HSB-5.b.i, HSB-5.f.ii
    - ▪ PTII deliberations on this topic went in several diverse and productive directions. A great deal of time was spent on this topic, as injection well fouling and degradation is a major problem for P&T operations.

      For injection well fouling, there are basically two approaches: eliminate the source of the bio-nutrients and particles entering the injection well, or not deal with the source, and remove or filter out the clogging materials before they reach the injection well. Based on these deliberations several ideas emerged, as discussed below.

      First, it was noted that although the processed water from the MBRs was of high quality before it entered the conveyances (pipelines) leading to the injection wells; the first 500 to 1,000 gal reaching the wells after well rehabilitation were visibly compromised with unwanted material (e.g., visually appeared like a dark oily liquid). Recently, this clearly compromised first water was trucked off for separate disposal.

The Team considered that a thorough cleaning of deposits and particulate contaminates in the system followed by a small continuous hypochlorite or Chlorine additions would maintain the cleanliness of the system, as well as, suppressing and biological growth in the injection well. **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. An RD/RAWP modification will be required with a process change, followed by well performance monitoring.

In similar light, it was noted that injection well cleaning and rehabilitation was often time limited (e.g., 2 to 4 days), due to the need to maintain water remediation goals. The Team considered that more extensive cleaning time (~15 days) or use of a more aggressive cleaning solution (e.g., higher concentration of sulfuric acid).

The idea arose of using one or more injection wells that had degraded to the point where there were considered no longer useful (i.e., “dead” wells). Work on these dead wells would not be in conflict with P&T production goals; with the reasonable possibility of bringing the well back into production.

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 wells). 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 more wells may become available for enhanced production rates.

Under the approach of removing well screen clogging contaminants before they enter the injection well, two approaches were noted. Use of two large-scale sand filters (i.e., one on line while the other is recovered) for each injection well conveyance, was considered impractical by the Team (i.e., cost, complexity, long-term for implementation and significant supporting equipment. **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.

The second effluent cleaning approach was to use filter discs just before the water is injected into the wells. Notionally, the thought was to use filter material that was basically the same as the injection well screen, i.e., pre-clog these screens to remove materials that would otherwise clog the actual well casing screens. **PTII-24** design and install (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 these pre-well screens experience the same level of pressure and flow, as the actual well screen will experience. Other types of filters may also be considered. Note that this concept can be tried on any recovered dead wells (see **PTII-22**).

- Recycling of well purge water:
  - The PTII team believes that the system used to recycle well redevelopment water should be revised. Currently spent cleaning solution from well redevelopment is pumped into a tanker truck and then transported to either the modutanks, if turbid, or to 200 West, if not turbid. The destination of the spent cleaning solution is at the discretion of the well development staff.

    Factors such as whether modutanks are getting full or if the water has a low pH will also impact the decision. At 200 West, the water is filtered through 200 micron bag filters, then directed to the z-line trench. The z-line trench is pumped to the recycle tank when it gets full. The pumps operate at a flow of 150 to 200 gpm depending on the level in the trench.

    The PTII Team concern is that if this water were laden with dissolved manganese it has the opportunity to pass through the plant and back into the wells, especially when added back all at once. There are several days when the amount of manganese in the plant effluent exceeds the concentration added as a micronutrient.

    The PTII Team recommends **PTII-25** that a new pump be added that can slowly bleed well development water back into the plant at a rate of 5 to 10 gpm to slowly add the recycled water back into the recycle tank. If necessary, a small manganese filter system could be added to the recycle line. Placing pyrolusite in existing 9-pack filter system would provide sufficient contact time for manganese removal. The media would need to be periodically soaked 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.
  - Well Reinjection Diagnostics
    - HSB-6.a.i, HSB-6.a.ii, HSB-6.a.iii, HSB-6.a.iv
      - PTII Deliberations – See **PTII-16** for parametric studies
- Surface Infiltration/Injection Galleries Option
  - Design, Operations
    - HSB-3.g, HSB-4.a, HSB-4.b, HSB-4.c, HSB-4.d
    - PTII Team Deliberations
      - The PTII Team considers that efforts to reestablish the surface disposal of treated groundwater (versus the Injection Wells) are laden with too many problems and functional concerns to be viable.
        a. First, underlying a large area fraction of the Hanford site is a geologic layer of cementitious gravel a formation called the Coal Creek Unit (CCU), which lies between the surface and the contaminated aquifer.

           The CCU, which looks and feels like a typical poured concrete, has very low water permeability compared to the soil formations above. Where it has been estimated that it would take ~50-years for the added processed water to percolate through to the region of our contaminated aquifer.

b. As a result, one would expect water mounding above the CCU, which might even create an unwanted pond or lake on the surface. Additionally, the water above the CCU can potentially run for great distances, and would be unlikely both by location and time to provide the “herding” effect to the present contaminated plume.

c. It might be possible to find gaps in the CCU that are located such that the added water would approximate the herding effect to our contaminated plume, but there may still be other underlying geological problems.

d. Therefore, **PTII-26** The Team does not recommend pursuing surface infiltration approaches at this time due to the CCU. If this surface infiltration option might be pursued in the future, it would be valuable to determine where CCU gaps are located to either dismiss or still consider this approach.

- PTII Team Overarching Recommendation
  - The effectiveness and value of using this interdisciplinary and inter-organizational PTII Team to review all technical aspects of P&T operation and design was clearly very value added and provided insight and perspective to improvement and operational initiatives. Therefore, **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 Vice President of S&GRP.

C3 References

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