5 Transition and Termination

This section provides decision support to transition from a P&T system and into another remedial option that is more effective at achieving the remediation goals and objectives. It assumes that a performance evaluation was completed (Section 3) and the P&T system has already been optimized (Section 4), in accordance with previous sections of this document, and there is no further need for the P&T system or P&T will not achieve the remediation objectives. The Optimization Life Cycle Navigation Diagram below shows implementation of the P&T transition and termination phase as the last phase in the performance-based optimization framework.

Optimization Life Cycle Navigation Diagram
Source: E. Madden, ITRC. Used with Permission.

An introduction is provided in this section to explain how to use the content in this section, including how it may be applied, prerequisites, limitations, and typical scenarios for its use. Next, the section establishes a stepwise process to develop the rationale for the transition, implement the transition, and decommission the P&T system. Finally, it provides example transition scenario briefings that summarize actual transition success stories.

This section is intended to help project teams, stakeholders, and regulators work through typical impediments to a successful P&T transition and eliminates the waste of resources associated with continuing to operate deficient P&T systems. The overall objective is to facilitate expedited transition of a P&T remedy such that the site remedial strategy is executed more efficiently and effectively. A reader of this section will have already optimized their P&T system, possibly multiple times, and will be working with at least one of the following:

- deficient P&T system, with a failing performance evaluation
- controlling document without transition metrics/milestones
- new P&T system or restarted an existing P&T system for which a pilot test evaluation has been completed and for which guidance is needed to specify future transition metrics/milestones (e.g., PFAS sites)

5.1 Introduction

There may come a time when the optimized P&T system is deemed unable to meet the remediation objectives as originally intended or alternate technologies are available that are more effective, efficient, or cost-effective. The content of this section can be used to support the decision to transition out of P&T and into a more effective remedial option. It may be applied to the entirety or portions of the P&T operation and thereby allow implementation of other remedial options where necessary and continued use of the P&T system where it remains effective.

5.1.1 Prerequisites to Use of This Section

This section applies to the end-of-life stage for a P&T system. It assumes that the P&T system has already been optimized in accordance with previous sections of this document and there is no further need for the P&T system or P&T will not achieve remediation objectives in a reasonable time frame. For example, the P&T system may have been determined to be ineffective after a performance evaluation following Section 3 and optimized using the guidance provided in Section 4. This section applies to cases where more effective, efficient, or cost-effective options are determined to be available to meet the remediation objectives. This section supports the transition out of P&T (as narrowly defined to consist of groundwater extraction with aboveground treatment) and to a more effective remedial option.

5.1.2 Limitations of This Section

Specific requirements of the state and/or federal regulatory program(s) governing site remediation and stakeholder engagement will likely impact the P&T transition and termination processes. Those aspects, including the varied regulatory and stakeholder perspectives, are covered in Sections 7 and 8 of this document, respectively.

This section provides a process and examples that a project team can use to support transition off P&T and shutdown or termination of the P&T system. It only addresses those sites where P&T is determined unnecessary or more effective or cost-effective options are available. This section does not address the following actions:

- It does not address adjusting or switching P&T performance objectives from one (e.g., hydraulic containment) to another (e.g., source control). Guidance on this can be found in Section 3 and in various references listed in Appendix D, Existing Optimization Programs.

- It does not support identification or selection of a more effective remedial technology or option. Guidance on this can be found in ITRC documents for complex sites (ITRC 2017[GMA6VGKV] ITRC. 2017. “Remediation Management of Complex Sites.” Washington D.C.: Interstate Technology & Regulatory Council, Remediation Management of Complex Sites Team. https://rmcs-1.itrcweb.org/.) and petroleum sites (ITRC 2018[QJNTKDVM] ITRC. 2018. “TPH Risk Evaluation at Petroleum-Contaminated Sites.” Washington, D.C.: Interstate Technology & Regulatory Council, TPH Risk Evaluation Team. https://tphrisk-1.itrcweb.org/.) and USEPA documents for CERCLA sites (USEPA 1988[5EUSVMWV] USEPA. 1988. “Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.” U.S. Environmental Protection Agency.) and RCRA sites (USEPA 2016[S7AXNFFB] USEPA. 2016. “Resource Conservation and Recovery Act (RCRA) Facilities Investigation Remedy Selection Track (FIRST): A Toolbox for Corrective Action.” https://www.epa.gov/sites/default/files/2016-06/documents/a_toolbox_for_corrective_action_resource_conservation_and_recovery_act_facilities_investigation_remedy_selection_track_rcra_first.pdf.). The process for technology selection should be consistent with the guiding regulations.
- It does not address the scenario of shutting down P&T after its performance objectives are achieved. This is a more traditional exit strategy topic, and more information on it can be found in an ITRC document (ITRC 2006[CPWL4VKE] ITRC. 2006. “Exit Strategy–Seeing the Forest Beyond the Trees.” Washington D.C.: Interstate Technology & Regulatory Council, Remediation Process Optimization Team. https://itrcweb.org/GuidanceDocuments/RPO-3.pdf.) and USEPA documents (USEPA 2014[7PDE2BMK] USEPA. 2014. “Groundwater Remedy Completion Strategy.” Office of Solid Waste and Emergency Response. http://semspub.epa.gov/src/document/HQ/100000021.USEPA 2013[MNR9Q54L] USEPA. 2013. “Guidance for Evaluating Completion of Groundwater Restoration Remedial Actions.” Office of Solid Waste and Emergency Response. http://semspub.epa.gov/src/document/HQ/175206.USEPA 1992[VNB5NJQE] USEPA. 1992. “Methods for Evaluating the Attainment of Cleanup Standards, Volume 2: Ground Water.” Office of Policy, Planning, and Evaluation. https://semspub.epa.gov/work/HQ/175643.pdf.).

5.1.3 Summary of Typical Scenarios for Pump and Treat Transition

This subsection presents typical scenarios for which the content of this section may be useful. In general, these are sites where P&T is known to be deficient (i.e., has poor performance evaluation results), but impediments to P&T transition result in wasted resources.

5.1.3.1 Defined Controlling Document

Controlling documents (those regulating operation of the P&T system) provide the reasoning for the choice of or changes to a site remediation project and outline how the remediation is expected to be conducted. Controlling documents guide remedial activities, but they may not have included steps for a change in the remedial technology or may have exclude provisions to transition from a P&T system to another technology. The content of this section may be useful if the controlling document does not contain the decision logic necessary to facilitate a transition. Section 7.5, Changes to Controlling Documents, provides further discussion on controlling documentation considerations.

5.1.3.2 Transition Process Inexperience

The project team and regulator (if not already a part of the project team) may be unfamiliar or uncomfortable with changing the remedial approach without a basis prescribed in the controlling document. Prior publications are available on this topic (NRC 2013[26RFNQD2] NRC. 2013. Alternatives for Managing the Nation’s Complex Contaminated Groundwater Sites: Washington, D.C.: National Academies of Sciences, Engineering, and Medicine. https://doi.org/10.17226/14668., Truex et al. 2015[VKN225ST] Truex, M.J., C.D. Johnson, D.J. Becker, M.H. Lee, and M.J. Nimmons. 2015. “Performance Assessment for Pump and Treat Closure or Transition.” Pacific Northwest National Laboratory. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24696.pdf., USEPA 1994[NSKP8SN6] USEPA. 1994. “Methods for Monitoring Pump-and-Treat Performance.” https://semspub.epa.gov/work/HQ/174486.pdf.), but they are not well known. This section is generally consistent with prior publications and provides teams and regulators with a step-by-step process that can be followed to confidently make the transition into a more effective remedial option. It includes references to various case-study synopses in Appendix B of real P&T transitions to help explain the process for the reader.

5.1.3.3 Uncertain Funding

Remedial option transition requires additional funding to perform the steps prescribed in this section. Insufficient funding or uncertainty in the funding source may stall or impede the execution of the remedy change. This section presents a general scope of work that can be used to support supplemental funding discussions.

5.1.3.4 Misperceptions

Various misperceptions may hinder P&T transition, including administrative rigor or capability of the transition technology to maintain the same level of protectiveness as the P&T system. This section eliminates the scope uncertainty associated with transition so that the administrative pathway can be defined and made clear to the project team and regulator (if not already part of the project team). Additionally, it includes references to other published literature that can be used to help select an equally protective or more protective replacement remedy.

5.1.3.5 Complacency or Lack of Resources

After the intensive process of identifying, constructing, and verifying the operational performance of a remediation system, the last thing a project team wants is a discussion about shutting it down and transitioning to a new remedial approach. Nevertheless, after some operation time and optimization, it may become evident that the P&T system is not capable of achieving its objectives. The process prescribed herein will take some time and effort; however, continuing to operate an ineffective system over the long term (life cycle) will be more costly and unproductive. This section attempts to encourage project teams, if applicable and necessary, to look beyond the P&T remedy and efficiently continue to make remedial progress.

5.1.4 Existing Related Publications

This section supplements but does not replace the available publications related to existing or transitioning P&T. Section 5.6 and Table 5-1 contain a list of references with specific information related to P&T transition technology. Prior publications were used to prepare this section and are referenced appropriately. The content of this section is an attempt to compile the existing material and supplement it with current best practice information to be helpful to P&T project teams.

5.2 Transition Planning

Ideally prior to initiating the use of a P&T system, but at least during the performance evaluation and optimization process, a transition plan should be developed to connect the results of the above-grade and below-grade performance evaluations to the need for continued operation of the P&T system. A transition plan specifies one or more criteria that when triggered will signify the need for and start of a transition from P&T into a remedy that is more effective and efficient. For example, a plan could be developed to specify a transition from P&T if any of the following conditions occur:

- COCs concentration and/or mass removal rate becomes asymptotic
- an alternate technology or combination of technologies can achieve COC reduction more efficiently and effectively than the existing P&T system and result in less total greenhouse gas (GHG) emissions
- the remedial strategy objectives change such that the P&T system is no longer necessary

Figure 5-1 shows a graphical example of how the first criteria above can be tracked and measured. The mass removal rate and GHG emission at the vertical line are used as the transition metrics and are documented in the transition plan. The performance monitoring program tracks these parameters regularly and compares them to the established threshold values. When the operating conditions fall below (mass removal rate) or exceed (GHG emission) the threshold values, then the remedy proceeds to the next transition step.

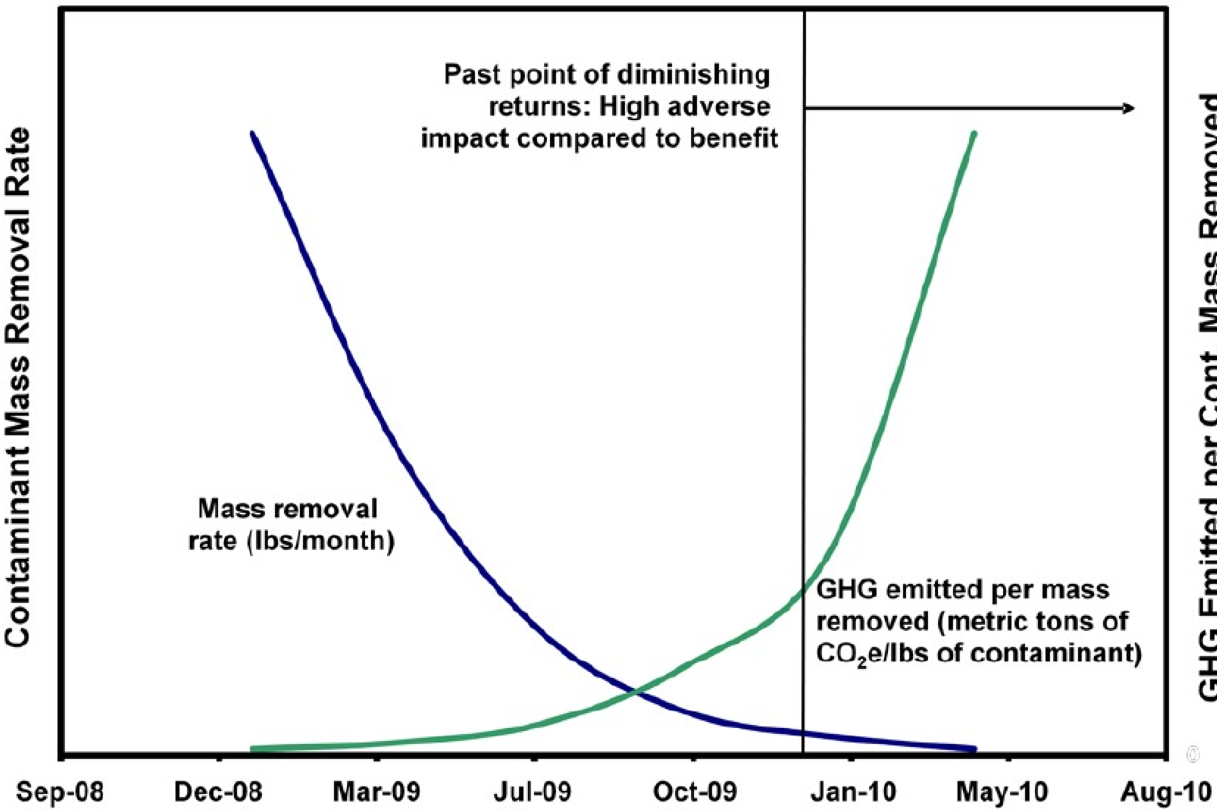

Figure 5-1. Graphical presentation using mass removal and GHG emission transition metrics.
Source: Figure 4-8 of the Naval Facilities Engineering Command (NAVFAC) guidance (NAVFAC 2012[WSLI4CNQ] NAVFAC, U.S. 2012. "US Navy NAVFAC Optimization UG-NAVFAC EXWC-EV-1301." U.S. Department of Defense. https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/ev/go_erb/program-support/optimization.html., 45, Figure 7-1). Used with permission.

The identification of an alternate more effective and efficient technology (the second transition criterion in the above example) is a dynamic process based on a changing understanding of the CSM and continuous remedial technology innovation in the industry. When the P&T remedy was implemented, the basis for its operation was predicated on the site conditions known at the time and on the alternate technology options analysis contained in the controlling document. As the remedy monitoring progresses, the CSM is revised to confirm the understanding of the CSM or update the CSM, if required. For example, the rate of back diffusion on groundwater rebound concentrations may be significant and could cause a change in the CSM understanding such that a P&T remedy may no longer be the most effective technology to achieve the remedial objectives in a reasonable time frame. Advances in existing or new technology may also prompt reconsideration of the remedial alternatives to treat the site. In either case, when this important new information arises, it is prudent to reevaluate the original CSM assumptions and remedial alternative selection criteria to ensure the project is on the best path forward. In most cases, after multiple years of P&T operation and apparent treatment effectiveness limitations, an alternate technology will be able to achieve COC reduction more efficiently and effectively than P&T.

5.3 Step 1—Identify the Trigger Conditions and Affirm the Need for Pump and Treat Transition

***Step 1** is a screening process to answer this question: Is P&T the wrong remedial solution to achieve the remedial objectives at my site and, if so, why?*

The first step in transitioning from P&T is determining or affirming the need for the transition. Ideally a transition plan (see Section 5.2) is prepared in advance, but this is uncommon in current practice. With a transition plan, the transition criteria can be monitored and tracked and the need for P&T transition affirmed when the performance evaluation indicates that certain transition threshold metrics are met. For many P&T systems there is no transition plan, and the project team and regulator are left to navigate the process without a plan. This section was prepared to address and help guide this common scenario. As noted in the introduction to this section, the content herein can also be used by project teams developing new P&T system designs and doing forward planning on existing P&T systems.

Over the period of P&T O&M, the project team develops an understanding of the effectiveness of the system through routine performance evaluations and optimization and tracks progress toward achieving the remediation objectives. At some P&T sites, the progress made does not meet expectations or misses milestones. It may then become evident that P&T may not or will not meet the remediation objectives. The time frame over which evidence of this performance deficiency materializes varies depending on site-specific procedures related to the frequency of monitoring, data evaluation, and performance review with the regulator. In an ideal situation there is a short lag time between discovery of the performance deficiency and implementation of P&T transition. All too often, however, that does not occur and there is a delay; at some sites, the delay can be long and costly.

This subsection discusses various ways in which affirmation of the need for transition can be made efficiently, through the identification and evaluation of transition triggers. It essentially determines when enough is enough and it is time for a transition from P&T.

5.3.1 Determining When Enough is Enough

In practice, P&T system monitoring data from above grade and below grade are collected and synthesized to evaluate its performance. The results from these two data sources are used together to determine the need and timing for P&T transition.

The above-grade data includes groundwater treatment system monitoring results such as pumping pressures and rates, process unit COC destruction efficiency, and treated water discharge concentrations. The above-grade data is solely used to determine compliance and performance of the treatment system for the groundwater extracted from the subsurface. A failing grade on the above-grade performance evaluations means the groundwater extraction and treatment system should be optimized for better performance. Operation of a consistently optimized pumping and above-grade treatment system is an important prerequisite for maximizing the potential for below-grade success.

The below-grade data include groundwater elevations, COC concentrations in groundwater, and mass discharge. The results are used to evaluate the effectiveness and efficiency of the P&T system to treat the COCs and meet environmental risk reduction goals. A consistently failing grade on the below-grade performance combined with a consistently passing grade on the above-grade system performance indicates it is time for a transition. The failing grade for below-grade performance must have been determined even after optimization attempts.

Appendix A, Common Concepts, includes various calculation tools that are available to support quantification and visualization of the need for P&T transition. For example, statistical trend analysis of concentrations over time and mass removal decline curve analysis can be useful to show the effectiveness of P&T.

5.3.2 Potential Pump and Treat Transition Trigger Conditions

The conditions that trigger transition of P&T can vary depending on the system's operational objective. The relevant P&T limitations, operational factors, and alternative technologies to evaluate are based on the remediation objectives. The typical operational objectives discussed in this document include (1) source mass removal/control, (2) plume/concentration reduction, and (3) plume/hydraulic containment. This subsection includes examples of typical trigger conditions that can be qualitatively assessed (i.e., using a yes/no checklist) in **Step 1** to help establish the need for transition. These trigger conditions should be considered collectively to capture their potential compounded effects.

Typical transition trigger conditions for systems where P&T is used for source mass removal/control, or plume/concentration reduction are listed below:

- Limitations on meeting remediation objectives apply.
    - Concentration reduction reaches an asymptotic level and no significant further reduction in COC concentration is occurring as compared to historical reductions.
    - Mass removal rate declines such that the P&T system is no longer removing significant mass as compared to historical achievements. Insurmountable operability or reliability challenges (e.g., corrosion, fouling) or poor local power supply results in excessive downtime that limits the ability of P&T to achieve the necessary groundwater recovery.
    - An updated CSM (e.g., back diffusion limits mass transfer) renders the original expectations of P&T unattainable, and the P&T system won't achieve remediation objectives in a reasonable time frame as established from regulator and stakeholder communications.

    - Additional characterization indicates a different contaminant distribution (e.g., highest concentration zone exists in an isolated sand lens) that is hydrogeologically disconnected from the P&T capture zone.
    - An updated CSM identifies a new source of contamination and/or new COCs (e.g., CECs) that result in a change in the remediation objectives for the site that P&T won't be able to achieve most effectively.
    - New or fewer receptors are identified from changed groundwater use due to alterations in land use, which may trigger an aquifer reclassification. This may trigger a change in remedial objectives for a site.
    - Changed regulatory drivers (e.g., changed regulations, toxicity values for COCs, or cleanup concentrations changed from MCLs to other criteria) render P&T unable to or unnecessary to achieve the remediation objectives as predicted in the original controlling document.
    - P&T is unable to meet other regulatory or stakeholder requirements (e.g., aesthetic considerations, nuisance concerns).

- Economic/resource factors have changed.
    - Costs of mass removal / concentration reduction increase to an economically unsustainable level; despite cost reduction measures taken as part of system optimization, annual O&M cost consistently increases more than inflation.
    - The environmental footprint, such as GHG/criteria pollutant emissions and energy consumption per unit of mass removed, reaches an unacceptable level.

- More effective and efficient alternative technologies are identified.
    - Mass removed by natural processes (e.g., MNA) is greater than that removed by P&T.
    - An alternate remedial technology can achieve more efficient and effective removal of mass from the source or reduction of COC concentrations in groundwater (e.g., direct injection of emulsified oil to stimulate anaerobic biodegradation of chlorinated volatile organic compounds (CVOCs) in lower permeability zones).
    - Changed regulatory drivers (e.g., applicability of land-use controls) render further operation of the P&T unnecessary to achieve the remediation objectives.

- An acceptable alternative performance objective is achieved.
    - Remaining COC mass discharge from the source zone decreases to a level that can be naturally assimilated by MNA and remain protective of human health and the environment.

Typical transition trigger conditions for systems where P&T is used for management of migration or containment/hydraulic control specifically are listed below:

- More effective and efficient alternative approaches/technologies are identified.
    - An alternate remedial technology can achieve more efficient and effective control of migration (e.g., at lower cost, with a smaller environmental footprint, and with an improved resilience to climate-related events).
    - Changed regulatory drivers (e.g., applicability of land-use controls) render further operation of the P&T system unnecessary to achieve the remediation objectives.

- An acceptable alternative performance objective is achieved.
    - Remaining COC mass discharge in the plume decreases to a level that can be naturally assimilated by MNA and remain protective of human health and the environment.
    - Changed regulatory drivers (e.g., a reduced cleanup standard due to a change in toxicity criteria, acceptability of land-use controls) render further operation of the P&T system unnecessary to achieve the remediation objectives.

Completion of **Step 1** results in screening and identifying relevant trigger conditions to support the transition off P&T. The conditions selected from the above list that match the project-specific P&T system performance objectives will be further evaluated in **Step 2** using detailed quantitative analysis.

5.4 Step 2—Identify the Transition Approach and Develop the Lines of Evidence for Pump and Treat Transition

Step 2 *is a detailed evaluation process intended to answer this question: If P&T is the wrong remedial solution, then what remedial option is most effective and efficient to achieve the remediation objectives and why?*

After the need for transition is determined through identification of project-specific trigger conditions in **Step 1**, it is time to develop the detailed rationale that will be used to support the transition in a controlling document. The primary purpose of **Step 2** is to clearly demonstrate, through multiple lines of evidence, that better options exist.

An example utilizing a "multiple lines of evidence" approach to determine P&T transition options is presented in Table 5-2 (Truex et al. 2015[VKN225ST] Truex, M.J., C.D. Johnson, D.J. Becker, M.H. Lee, and M.J. Nimmons. 2015. "Performance Assessment for Pump and Treat Closure or Transition." Pacific Northwest National Laboratory. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24696.pdf.). It shows how several key elements of the CSM are selected and quantified and then, depending upon comparison to certain predefined criteria, a decision can be made to continue with optimized P&T, MNA, supplements, or a new remedy. For example, using the example decision logic in Table 5-2, if the following conditions are true, then a transition to MNA is feasible:

- COC concentrations are declining but remain above the remediation goals
- assimilative capacity (AC), or the ability of a resource (aquifer) to contain or receive a mass of contaminants and subsequently remain within acceptable limits of groundwater degradation, is greater than the contaminant mass discharge (CMD)
- there is evidence of significant attenuation mechanisms (e.g., biotic or abiotic degradation)
- the plume is not expected to migrate outside an area with exposure controls
- remediation objectives will be achieved within a reasonable time frame

Other transition scenarios addressed in Table 5-2 include sites where the CMD is greater than the AC, sites where significant attenuation mechanisms are not evident, and sites where P&T will have difficulty meeting remediation objectives cost-effectively.

Table 5-2. Example set of multiple lines of evidence (Decision Elements), transition options (Outcomes), and specific criteria for P&T transition

	Outcomes and Associated Criteria				
Steps in the P&T Optimization Life Cycle	**Process Optimization (Section 4)**		**Transition and Termination (Section 5)**		**Closure**
Decision Element	**Continue/Optimize P&T**	**Supplement P&T**	**MNA**	**New Remedy Approach**	**P&T Closure**
Contaminant Concentration (C)	C > goal but is expected to decline with continued/ optimized P&T	C > goal	C > goal and concentration has declined	C > goal	C < goal
Contaminant Mass Discharge (CMD) and Assimilative Capacity (AC)	CMD > AC CMD expected to decline with continued/optimized P&T	CMD > AC CMD expected to decline with supplemented P&T	CMD < AC CMD has declined	CMD > AC CMD expected to decline with new remedy approach	NA

Natural Attenuation Processes	Attenuation mechanisms may not be significant; if they are, MNA may be a component of the remedy with P&T	Attenuation mechanisms may not be significant. If they are, MNA may be a component of the remedy with supplemented P&T	Documentation of significant attenuation mechanisms	Attenuation mechanisms may not be significant; if they are, MNA may be a component of a new remedy	NA
Plume Behavior	Plume is unstable but expected to decline with continued/optimized P&T; remediation time frame is substantially better than MNA alone	Plume is unstable but will stabilize/decline with supplemental P&T and result in substantially better remedial time frame	Plume is expected to stabilize/decline and stay within an area with control of exposure pathways; remediation time frame is similar to P&T	Plume is unstable but will stabilize/decline with a new remedy approach; remediation time frame may or may not be improved compared to P&T	NA
Achievement of Remediation Objectives	Optimizing P&T will enable remediation objectives to be reached	Supplementing P&T will enable remediation objectives to be reached	Plume is expected to meet remediation objectives within a reasonable time	Neither P&T nor MNA will meet remediation objectives, and a new remedy approach is needed	Met and complete
Cost-Effectiveness of Continued P&T	Continue/optimize P&T and focus on achieving risk reduction and reducing O&M costs	Implement a cost-effective supplement to P&T to improve attainment of remediation objectives	The cost for P&T O&M is no longer justified, and MNA is demonstrated to achieve the remediation objectives	P&T is ineffective, and more cost-effective options are available to achieve the remediation objectives	NA

Source: Modified with permission from Truex and colleagues (2015).
Notes: AC = assimilative capacity, C = contaminant, CMD = contaminant mass discharge, MNA = monitored natural attenuation, NA = not applicable, O&M = operations and maintenance, P&T = Pump and Treat.

5.4.1 Conceptual Site Model Refinement

Prior to additional analysis, the CSM must be updated with available information to support the required data analysis and technical evaluations. It is possible that some additional characterization may be needed to refine the CSM to the level needed for the transition decision. The following list includes examples of typical CSM refinements that are useful to figuring out the best transition option:

- Updating geology and lithostratigraphy (most often by revisiting soil boring logs) and developing CSMs based on environmental sequence stratigraphy aimed at determining preferential pathways to understand adequacy of a treatment system and monitoring network.
- Collecting additional site-specific data to refine the geology and hydrogeology using advanced site characterization or HRSC methods to enhance details and fill data gaps to improve the CSM.
- Analyzing rates of back diffusion and associated mass discharge as determined by passive flux meters to determine whether alternate technologies such as MNA and in situ treatment may be more efficient and effective long-term remedies than P&T. For example, laser-induced fluorescence (LIF) or dye-enhanced LIF (Dye-LIF) may be used to delineate the residual NAPL source zones at a resolution high enough to conceptually design an in situ treatment system.

- Using passive sampling in situ monitoring tools, such as BioTrap or MinTrap samplers, to evaluate the biotic and abiotic capacity of the aquifer, respectively.
- Using CO_2 efflux survey, thermal profiling, or NAPL chemical composition analysis to evaluate the degree of natural source zone depletion (NSZD)/weathering that has occurred on petroleum source zones.
- Using continuous real-time direct-measure sensors for remote monitoring of dynamic site conditions that may affect biogeochemical states that drive the selection of appropriate remedial technology (e.g., at coastal or tidally influenced sites).
- Monitoring the groundwater–surface water interface using probes and sensors to evaluate temporal and spatial variations in mass discharge and natural attenuation to better determine groundwater remediation goals inclusive of AC (NAVFAC 2020[8EJD8T3C] NAVFAC. 2020. "Groundwater to Surface Water Interface: Summary of Tools and Techniques (Part 2)." U.S. Department of Defense. https://exwc.navfac.navy.mil/Portals/88/Documents/EXWC/Restoration/er_pdfs/rits/GroundWaterToSufaceWater_Fact%20Sheet_Part2.pdf?ver=qozZXMtY1UCVkIO2v5n7Kg%3D%3D.).
- Using drones equipped with various sensors, such as thermal infrared from an unmanned aircraft system, to refine the CSM by improving the mapping and monitoring of groundwater discharges to surface water (e.g., ESTCP Project ER21-5237) and the data used to better evaluate whether hydraulic control is needed.
- Logging tracer testing and pressure transducer data to understand existing patterns of groundwater flow with and without pumping.

Appendix A, Common Concepts, contains additional detailed information on various available options to refine the CSM for the purposes of P&T optimization and transition.

5.4.2 Reevaluation of Remedial Alternatives

A reevaluation of remedial alternatives is often required by regulations to support the transition decision. This can be facilitated by performing additional studies or additional assessment (e.g., focused feasibility study, remedial action plan, corrective measures study addendum, technical memorandum), depending upon the regulatory framework governing the site (see Section 7). It often contains a technology screening, alternatives development and analysis, and comparative cost evaluation. The reevaluation performed for the P&T transition can often be streamlined, but it is fundamentally the same as that originally performed to select P&T, although there are several significant differences: it is based on the revised CSM, incorporates lessons learned during operations and monitoring, incorporates new remedial alternatives using up-to-date information on available technologies, includes the selection of a new remedy, and formally eliminates P&T as the preferred option. The remedial alternative evaluation includes a refreshed technology screening and possibly a bench/pilot test of the preferred technology/approach to demonstrate its applicability to the COCs, geochemistry, and hydrogeology at the site and its ability to achieve the remediation objectives. It also typically includes a cost-benefit analysis showing that the alternative technology can expedite achievement of remediation objectives; reduce the life cycle cost; reduce environmental, social, and economic impacts; and improve resiliency over P&T. The reader is advised to consult the applicable state or federal regulations for detailed guidance on how to perform the correct alternatives evaluation for P&T transition purposes.

5.4.3 Definition of the Pump and Treat Transition Approach

The outcome of **Step 1** and the reevaluation of remedial alternatives (Section 5.4.2) will identify which of the following general approaches, or combination thereof, will be most appropriate for the transition:

- MNA
- in situ treatment
- engineering/institutional controls

Table 5-1 is organized by plume/source area and performance objective and provides detailed guidance on the lines of evidence that provide useful support for the following transition scenarios:

- P&T to MNA (including NSZD for petroleum sites as described in Appendix B of ITRC 2018[SMJT9P55] ITRC. 2018. "Light Non-Aqueous Phase Liquid (LNAPL) Site Management: LCSM Evolution, Decision Process, and Remedial Technologies." Washington D.C.: Interstate Technology & Regulatory Council, LNAPL Update Team. https://lnapl-3.itrcweb.org/.)

- P&T to in situ bioremediation treatment (e.g., enhanced aerobic or anaerobic)
- P&T to ISCO treatment
- P&T to ISCR treatment (including PRBs)
- P&T to in situ sorptive reactive media (SRM) treatment (including activated carbon)
- P&T to ISTT
- P&T to engineering/institutional controls and long-term monitoring

The transition remedy may include temporary use of a portion or entirety of the P&T system to enhance treatment reagent distribution and provide hydraulic circulation and/or control.

Data analysis and technical evaluation are performed to assemble multiple lines of evidence that collectively demonstrate that the selected transition approach is preferred over P&T. Multiple lines of evidence are typically necessary to cover the spectrum of decision criteria (e.g., regulatory compliance, effectiveness, and cost-benefit analysis) involved with selection of a remedy. The number of lines of evidence is a site-specific judgment call and should be agreed upon with the regulator and stakeholders during the initial phase of the transition process. Sections 7 and 8 discuss regulatory considerations and stakeholder communications, respectively, that should be addressed during the P&T transition process. Because each line of evidence requires data analysis and technical evaluation, a minimum number of lines of evidence should be selected to cover only the site-specific concerns with the transition.

The lines of evidence options in Table 5-1 are accompanied by links and references to supporting documents that state how to perform the associated data analyses. The technical steps for most of these data analyses are adequately covered elsewhere and are beyond the scope of this document. The subsections below generally describe the effort involved with compiling the lines of evidence for each type of transition.

5.4.4 Short-term Shutdown Evaluation

Once lines of evidence indicate that the P&T system has reached the end of its useful life (e.g., asymptotic conditions in the cumulative mass removed, influent concentrations are below remedial goals, or sources have been depleted and the CMD from the aquifer matrix is below the AC of the aquifer), additional evaluation can be performed to gather empirical data to demonstrate that certain conditions have been achieved. One of the most significant pieces of information needed to assess the performance of the P&T system and transition from the P&T system is an understanding of how the plume responds under non-pumping conditions.

It is difficult to prove stability, or acceptable plume expansion, without turning off the groundwater extraction pumps. All data collected from within the capture zone during P&T operation is hydraulically biased and not representative of ambient/natural conditions and cannot be used for plume stability evaluation. For example, resaturation of the residual contaminants in long-dewatered soils in the cone of depression may contribute to contaminant rebound after shutdown of pumping. A short-term shutdown evaluation is performed to assess the following performance criteria:

- static flow conditions (groundwater flow direction and gradient)
- COC concentration rebound (e.g., due to back diffusion) and mass flux
- evaluate plume stability and determine if the plume is expanding, stable, or receding (see Section 3.10 of Appendix A)

To confirm whether a plume is stable and the P&T system can be turned off, it may be possible to perform a short-duration pilot test where either a portion of the system (i.e., extraction wells in a specific area) or the entire system is shut down. The duration of the test will vary based on site-specific conditions (e.g., groundwater flow rate or distance to potential receptors) and may have to be approved by the appropriate regulatory authority. One critical aspect of a proposal to shut down a P&T system is the establishment of criteria that will trigger a restart of the system. The criteria could be a certain concentration of a specific COC at a designated monitoring location, a statistically significant increase in concentration, unacceptable geospatial migration of the plume center of mass, or other site-specific criteria. For example, shutdown/restart criteria were established for the P&T system at the Groveland Wells case study site (see Appendix B) based on the results of the optimization conducted by USEPA for the facility. After shutdown, the Massachusetts Department of Environmental Protection (MassDEP) kept the system in a readiness state to turn back on and monitored the groundwater at the site for three years before the decision was made by USEPA and MassDEP that P&T was no longer needed.

A pilot test shutdown plan should be developed and discussed with the regulator(s) for their review and approval. The plan might include an increased sampling frequency of monitoring wells or the addition of monitoring wells between the plume and potential receptors. One important aspect of the plan is the ability to restart the P&T system (or specific extraction wells if only one area was shut down) with minimal delay. Therefore, if the system is shut down, its components, including in-ground and in-plant equipment, must be maintained (the pumps must be periodically exercised). Stakeholders may also be involved in the decision-making for the temporary shutdown; minimally, they should be informed of the pilot test plan.

If the plume is determined to be stable or receding and lies within an acceptable horizontal and vertical geospatial extent, then MNA may be an appropriate transition approach. Conversely, if the plume is found to be migrating/expanding horizontally and/or vertically or the steady-state position of the plume is unacceptable, then continued P&T (optimized) or an alternate transition approach is needed. Because a plume stability evaluation is an element common to other phases in the P&T optimization framework, details on how to perform the evaluation are included in Appendix A, Common Concepts.

5.4.5 Transition to Monitored Natural Attenuation

Perhaps the most common P&T transition approach prior to achievement of remediation objectives is to allow natural attenuation processes, including biodegradation, volatilization, advection, adsorption, and dispersion, to complete remediation and achieve the remediation goals. This is applicable if the natural attenuation processes will continue to remediate the site and meet the remediation objectives, including preventing unacceptable exposures, mitigating undesirable expansion of the groundwater plume, and achieving the numerical remediation goals.

In order to progress to an MNA remedy from P&T, results of a short-term shutdown evaluation must typically be stable or receding (see Section 5.4.4) and no unacceptable exposures should occur. Short-term shutdown is often 6–12 months; however, the specific duration is to be agreed upon by the proponent and the regulators involved. Even after the shutdown evaluation, monitoring of the plume is normally required to verify the plume is stable or shrinking and no unacceptable exposures are occurring.

Table 5-1 contains a list of lines of evidence options that can be used to support a transition to MNA for source and plume areas and various combinations of remediation objectives and performance goals. This is a list for consideration; the lines of evidence selected for use is ultimately a site- and regulation-specific judgment call and may include other options that are more appropriate for demonstrating regulatory compliance. Refer to Section 7 for a detailed discussion of common regulatory considerations applicable to a P&T system transition.

5.4.5.1 Monitored Natural Attenuation Evaluation to Estimate Assimilative Capacity of the Aquifer

When assessing the point at which a transition to MNA can safely occur, it is usually necessary to assess the mass discharge from the source/plume to the area outside of the P&T system capture zone or area where the P&T is shut down and the AC of the groundwater environment. If the mass discharge is below the capacity of the aquifer to degrade and disperse the contaminant(s), the plume should be stable or shrinking. Therefore, the estimation of the AC and the measurement of mass discharge across the plume need to be determined as part of the MNA transition approach. Figure 5-2 presents an example of the decision logic showing how CMD and attenuation capacity are used to determine the transition of P&T to MNA. For additional case studies involving MNA, please see Appendix. B, Case Studies.

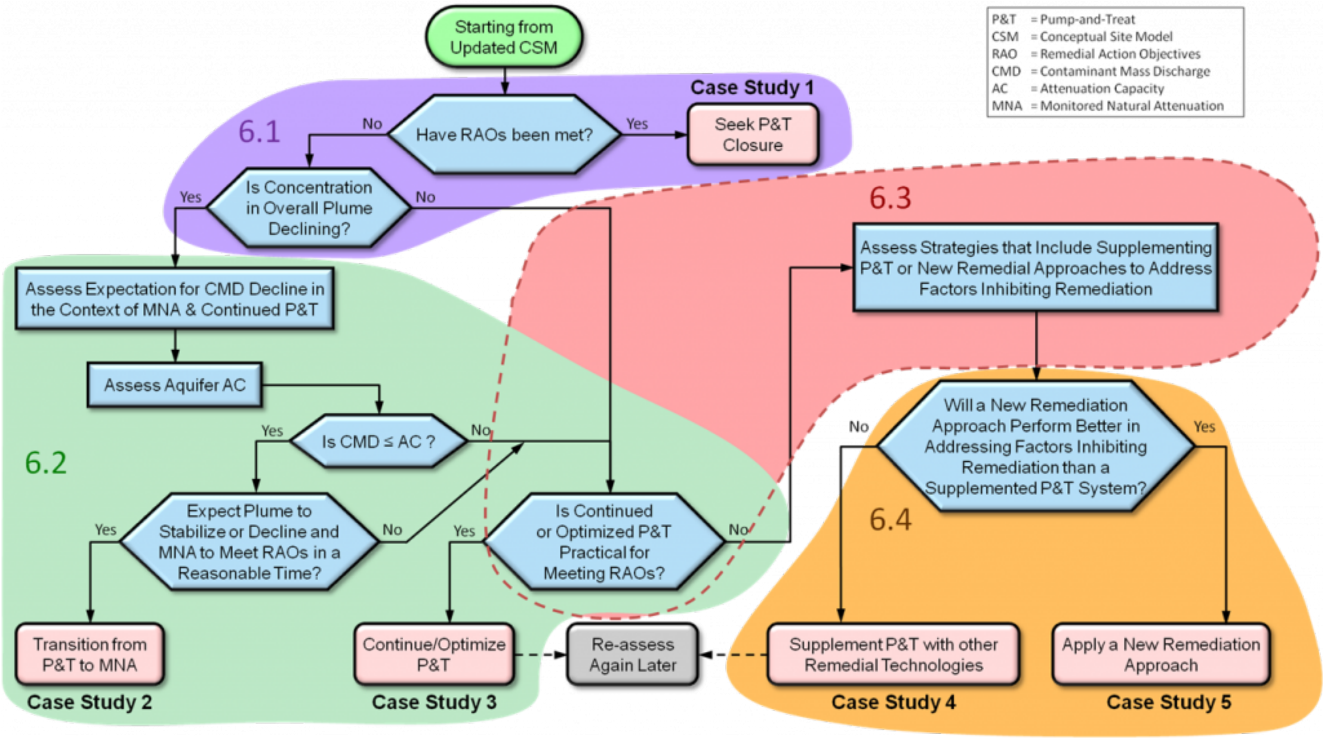

Figure 5-2. Example decision logic for transition of P&T to MNA using mass discharge and AC criteria.
Source: Reprinted with permission from Truex and colleagues (2015).

Various software tools are available to assess AC, such as REMChlor and REMFuel, as well as more powerful numerical transport modeling codes such as MT3DMS and RT3D. Degradation rates for the contaminants are important, as are the availability of various electron acceptors (e.g., oxygen, nitrate, sulfate). Depending upon the data quality objectives of the analysis, degradation rates can be approximated using literature values, or site-specific degradation rates can be estimated using various calculation methods (USEPA 2002[4ZTZFUU8] USEPA. 2002. “Ground Water Issue: Calculation And Use Of First-Order Rate Constants For Monitored Natural Attenuation Studies.” https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=10004674.txt.). The BioPIC software developed under the DOD Environmental Security Technology Certification Program helps identify an appropriate bioremediation strategy, including MNA, given the specific site conditions and can inform optimization recommendations. See Appendix A, Common Concepts, for more information on modeling options.

Justifying a transition from P&T to MNA in one step may be challenging because it relies on a robust demonstration that active, significant processes are at work and will continue to function after P&T ceases and will function at an equal or greater degree than when P&T was active. The degree of the challenge in demonstrating the viability of MNA will depend on the scope and breadth of the preceding P&T system (source control versus mass removal versus plume control versus all the above) plus contaminant type, future land use, and regulatory framework.

5.4.5.2 Natural Source Zone Depletion Evaluation to Estimate Assimilative Capacity of the Aquifer

Justifying a transition from P&T to NSZD may be slightly less challenging than for MNA because it could be somewhat easily demonstrated that the weathered NAPL does not have a water-soluble component that could enter groundwater and thus migrate great distances with the groundwater in response to gradient and permeability distributions in the aquifer. In such cases, the presence of NAPL may constitute the potential risks posed only by gravity-induced flow, vapor generation, direct-human contact, or aesthetics, which are generally less spatially extensive and are limited to the near-environs of the NAPL-affected media itself.

Regulatory frameworks associated with response actions like MNA and NSZD typically involve applying a reasonable time frame to the response action; they are not open ended or undefined.

For MNA and NSZD to be justified as viable options for transitioning from a P&T system, the ACs of the affected water-bearing zone(s) and adjacent subsurface environs must be shown to be sufficient to control net migration and reduce mass at a rate that supports the response action time frames imposed on the project. AC in the groundwater context refers to the ability of a resource (aquifer) to contain or receive a mass of contaminants and subsequently remain within acceptable limits of groundwater degradation. The limits of degradation are typically related to quantitative standards such as contaminant concentrations or a related measure of protection to human and ecological receptors, but they can also be qualitative and subjective in nature. Aesthetic or safety measures can also form the basis for the limit of degradation definition. The acceptable limits of degradation can vary substantially in degree of quantification.

The AC as it applies to MNA is primarily related to mechanisms that occur in the saturated zone where dissolved contaminants are the concern. Physical, chemical, and biological processes that act on contaminant mass combine to represent the overall AC of the aquifer, generally including advection (mixing/dilution in pore spaces), dispersion, hydrolysis, adsorption, precipitation, and biodegradation. AC is often estimated by comparing background or upgradient conditions (e.g., a chemical parameter) to those of the saturated zone plume core and attributing any changes to one or more of the various mechanisms through which contaminants would become degraded (e.g., oxidation of chemicals).

The following three types of data can be collected to support a site-specific evaluation that demonstrates the suitability of a transition from P&T to MNA (USEPA 1992[VNB5NJQE] USEPA. 1992. “Methods for Evaluating the Attainment of Cleanup Standards, Volume 2: Ground Water.” Office of Policy, Planning, and Evaluation. https://semspub.epa.gov/work/HQ/175643.pdf.):

1. historical groundwater and/or soil chemistry data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time at appropriate monitoring or sampling points
2. hydrogeologic and geochemical data that can be used to demonstrate indirectly the type(s) of natural attenuation processes active at the site and the rate at which such processes will reduce contaminant concentrations to required levels
3. data from field or microcosm studies (conducted in or with actual contaminated site media) that directly demonstrate the occurrence of a particular natural attenuation process at the site and its ability to degrade the COCs (typically used to demonstrate biological degradation processes only).

The soil quality/chemistry and hydrogeologic data are likely already obtained from the initial P&T decision and/or P&T optimization efforts or an updated CSM. Groundwater COC data should be readily available from historic site data (performance/compliance data). Geochemical info will need to be recent and updated, although historical data may have some forensic value. A microcosm study data may be needed given that the new system will rely solely on MNA rather than P&T, with little room for misinterpretation of less-direct lines of evidence that MNA is occurring at a sufficient rate.

The AC for NAPL, particularly LNAPL, includes that of the saturated zone as well as the unsaturated (vadose) zone. Chemical and biological processes that degrade contaminants in the liquid or vapor phase can take place in micropores and macropores in the unsaturated zone.

Alternatively, an observational approach may be appropriate once a substantial reduction in concentrations has occurred. In this approach, the groundwater extraction is halted, and the response of the plume is monitored. A short-term shutdown evaluation can be performed as described in Section 5.4.4. The inactivated portions of the extraction and treatment system may be held in a readiness state for restart as a contingency in case the plume shows unacceptable expansion, or another technology may be implemented.

5.4.6 Transition to In Situ Treatment

Groundwater extraction alone may not be adequate to remediate a site in a reasonable or necessary time frame or may not be able to completely meet the objectives for containment. Enhancements, using in situ remediation technologies, can often work in conjunction with P&T to improve outcomes when applied to high-concentration source areas or hot spots; this optimization option is addressed in Section 4.4.2. In other cases where P&T has been determined to be inadequate, a complete transition to in situ treatment technology is the preferred approach where downgradient dissolved groundwater plumes are not large.

The use of in situ remediation technologies has grown tremendously over the past several decades and can replace older technologies like P&T to improve and accelerate remediation. Treatment of high-concentration source areas or hot spots by in situ techniques, such as ISTR bioremediation, or chemical oxidation can make restoration of the remaining contaminated aquifer more likely. In one hypothetical example, a groundwater extraction system is gradually replaced by a series of enhanced in situ bioremediation injections (using a simultaneous transition implementation approach as described in Section 5.5.1.3) in the dissolved-phase plume until there is no need for the P&T system to contain the plume. Applied in a simultaneous manner, the in situ treatment facilitates a gradual transition off P&T.

Cost-effective replacement of P&T by in situ treatment technologies using amendment injection techniques is most amenable in cases where the dissolved groundwater plume is not large or deep. An excellent overview of the optimization of injection remedies is provided in ITRC guidance on the topic (ITRC 2020[SKNUVGR8] ITRC. 2020. “Optimizing Injection Strategies and In Situ Remediation Performance.” Washington, D.C.: Interstate Technology & Regulatory Council, OIS-ISRP Team. https://ois-isrp-1.itrcweb.org/.).

In situ remedial technologies should be evaluated to determine whether they can more efficiently achieve the remediation objectives and/or reduce the source / plume mass / concentrations such that a transition to MNA can be made. Examples of in situ remedial technologies include air sparge/SVE, enhanced bioremediation, ISCO, ISCR, SRM, and thermal. These types of active remedial technologies should be considered if the plume remains unacceptably unstable after P&T shutdown and/or MNA is not yet protective. The first step would be to identify the criteria under which MNA would be protective and use that as an endpoint for the in situ treatment.

Table 5-1 contains a list of lines of evidence options that can be used to support a transition to various in situ treatment technologies for source and plume areas and various combinations of remediation objectives and performance goals. This is a list of options to consider; the lines of evidence ultimately selected for use is a site- and regulation-specific judgment call and may include other options that are more appropriate for demonstrating regulatory compliance. Refer to Section 7.4 for a detailed discussion of common regulatory considerations during P&T system transition.

5.4.6.1 Fate and Transport Modeling for Reduction within the Remedial Time Frame

Even with a pilot test, it can be difficult to prove that an in situ treatment alternative (e.g., enhanced bioremediation or PRBs) will prevent plume migration due to the long time frames associated with COC fate and transport in aquifers with slow velocities. Therefore, it can be helpful to support the transition to in situ treatment with fate and transport modeling. Similar to the modeling considered for evaluating plume stability (see Appendix A, Section 3.10, Plume Stability Evaluation), an appropriate model is selected based on the available data and data quality objectives. Modeling for the purpose of evaluating the reduction in the remedial time frame from in situ treatment goes a step further. It starts with a model calibrated to baseline (steady-state) conditions without pumping and then applies a mass removal scenario matching that which can be achieved with the in situ treatment (e.g., 50% mass reduction in the source zone by ISCO). The model is rerun to evaluate the resultant reduction within the remedial time frame. The results of the modeling work are ultimately used as a line of evidence to demonstrate that not only is the in situ alternative viable, but it is also more effective or efficient at achieving the remediation objectives than P&T.

For some sites with CSMs that contain a large COC mass in matrix diffusion, the numerical transport modeling could indicate a negligible improvement or even an increase in the remedial time frame from in situ treatment due to back diffusion of the COC mass stored in low-permeability zones. In this case, the model results are still valuable and may actually point the project team to consider other P&T transition approaches such as engineering/institutional controls (see the Saco Defense case study).

Appendix A, Common Concepts, contains more detailed information on modeling options to evaluate the effectiveness of P&T optimization and the time frame to transition to another remedial technology. One model was developed to prepare costs and evaluate the performance of remediation technologies, including P&T and several in situ remediation technologies, to optimize system operation and monitoring and evaluate the transition time frame for alternate remedial technologies (Parker et al. 2018[NKDZMPKX] Parker, J., U. Kim, B. Borden, and A. Fortune. 2018. “A Practical Approach for Remediation Performance Assessment and Optimization at DNAPL Sites for Early Identification and Correction of Problems Considering Uncertainty.” SERDP. https://serdp-estcp-storage.s3.us-gov-west-1.amazonaws.com/s3fs-public/project_documents/ER-2310%2BFinal%2BReport.pdf?VersionId=mR6zVhgUdf9p1AIes1YjZLJzIPQkysBW.).

5.4.7 Transition to Engineering/Institutional/Land-Use Controls

In some cases, the P&T system may be replaced by the creation of appropriate land-use or institutional controls. Section 7.4.3 addresses regulatory issues important to ensuring that controls are consistent with local and state statutes and regulations and acceptable to those affected by the controls. A transition to controls may be prudent if the extent of the plume after shutdown of the P&T or source area is larger than the land affected by the existing controls, or if no controls had been previously implemented. It may also be appropriate as part of a recommendation to transition from P&T to MNA.

Table 5-1 contains a list of lines of evidence options that can be used to support a transition to engineering/institutional controls for protection of human health and the environment. This is a list of options to consider; the lines of evidence ultimately selected for use is a site- and regulation-specific judgment call and may include other options that are more appropriate for demonstrating regulatory compliance. As listed on Table 5-1, ITRC 2016[BQHK82Z8] ITRC. 2016. "Long-Term Contaminant Management Using Institutional Controls." Washington, D.C.: Interstate Technology & Regulatory Council, Long-Term Contaminant Management Using Institutional Controls Team. https://institutionalcontrols.itrcweb.org/.and USEPA 1994[NSKP8SN6] USEPA. 1994. "Methods for Monitoring Pump-and-Treat Performance." https://semspub.epa.gov/work/HQ/174486.pdf.have guidance regarding this topic. Additionally, see Sections 7.4 and 7.5 for detailed discussions of common regulatory considerations during P&T system transition.

5.5 Step 3—Implement the Pump and Treat Transition

After the P&T transition approach is selected and the lines of evidence to support the transition are assembled, it is written into a controlling document for approval. Upon approval by the regulator, the transition can be implemented.

Implementation of the P&T transition can take various forms, depending on the regulatory program and the remedial strategy. For example, implementation of the transition remedy might not even require a new controlling document if the transition remedy (e.g., in situ heating) can be considered a logical enhancement of a previously accepted remedy (e.g., SVE). In other situations, a feasibility study addendum may be required to document the optimization steps that were taken to evaluate and transition to a more efficient and cost-effective remedial action, and to amend the record of decision, if required. The project team is advised to consider whether the P&T transition can be included within the context of the existing approved remedy to minimize the administrative rigor involved with P&T transition. Sections 7 and 8 contain more detail on the regulatory and stakeholder perspectives on P&T optimization and transition.

The concept of transitioning off P&T to a more cost-effective remedy follows commonly accepted adaptive site management principles (ITRC 2017[GMA6VGKV] ITRC. 2017. "Remediation Management of Complex Sites." Washington D.C.: Interstate Technology & Regulatory Council, Remediation Management of Complex Sites Team. https://rmcs-1.itrcweb.org/., NRC 2003[JY6XD72Q] NRC. 2003. Environmental Cleanup at Navy Facilities: Adaptive Site Management. Washington, DC: The National Academies Press. https://doi.org/10.17226/10599.). Therefore, acceptance of the P&T transition should be expected as part of the remediation strategy, and the process of transitioning should be streamlined to avoid the waste of time and resources.

5.5.1 Options for the Pump and Treat Transition

P&T transition can be implemented in three main ways—hard stop, phased, or simultaneous. All options involve the ultimate shut down of the P&T system. These transition implementation options are discussed in detail below. For optimization options that involve keeping all or a portion of the P&T system (enhancements), refer to Section 4.4.

5.5.1.1 Hard Stop Transition

The hard stop type of transition involves shutting down all components of the P&T and subsequently beginning implementation of the transition option (MNA, in situ treatment, or controls). Site and project conditions amenable to this include plumes for which there is a reasonably high level of confidence in their stability, sites where technology pilot tests were conducted to show rapid effectiveness, or sites where the alternative technology may have a detrimental impact on the P&T system performance (e.g., ISTT may damage the extraction system and impact the treatment system).

Another scenario where a hard stop transition is appropriate is where components of the P&T system will be used for an in situ treatment system (e.g., enhanced bioremediation). A recirculation system, incorporating some of the former P&T extraction wells, may be used for groundwater extraction and paired with new amendment delivery and reinjection wells, in that sequence. As such, since the treatment will occur in situ and no above-grade groundwater treatment process units are retained, it is not considered a traditional P&T system. The former P&T system is shut down (hard stop), and its components are repurposed for the new in situ remedy.

Finally, a hard stop type of transition is also appropriate for sites where P&T was simply misapplied, significantly underperformed, and never effectively captured the plume and/or removed the mass. In this case, shutting the P&T system off would have negligible effects on the plume configuration and a negligible risk to human health and the environment.

5.5.1.2 Phased Transition

A phased type of P&T transition is relevant mostly to MNA and involves a gradual reduction in groundwater pumping rates or a sequential discontinuation of pumping in select areas, based on progress monitoring results. As monitoring results in the shutdown areas affirm the effectiveness of the transition remedy, additional reductions are made in pumping rates and/or more pumps are shutdown. Eventually all well pumping is stopped.

A phased type of transition is typically performed at sites where there is a moderate level of confidence in plume stability, perhaps based only on screening-level modeling results. It requires close monitoring and a contingency plan with restart logic in case of unacceptable instability. A phased type of transition essentially attempts a concurrent technology transition and shutdown evaluation.

The duration of each phase is site specific and will depend on how quickly plume stability can be proven at each phase. Given that plume stability can require years for sites with slow reequilibrium kinetics, a phased type of transition can take many years to complete.

A phased transition approach may be appropriate where the P&T system has achieved remediation objectives in some areas of the site but not others. In this way, a phased transition could also be considered part of the P&T optimization process that results in shutdown of most containment/control wells and potentially only leaves one or more source area extraction wells operating. Shutdown of the last groundwater extraction well occurs when the transition metrics are achieved or when the transition remedy (e.g., in situ treatment or institutional controls) is ready to be implemented.

5.5.1.3 Simultaneous Transition

A simultaneous type of P&T transition occurs where a migrating plume condition remains and P&T is needed to retain hydraulic control while in situ treatment proceeds in source and downgradient areas. P&T continues until the in situ treatment achieves the requisite amount of mass/concentration reduction that will result in a stable plume.

A simultaneous type of transition is typically performed at sites where there is a very low level of confidence in plume stability or perhaps known instability based on prior shutdown experience. It inherently includes additional treatment technology and requires close monitoring.

5.5.2 Transition Monitoring

As is conventionally done with monitoring of any remedy, a set of SMART functional objectives (specific, measurable, achievable, relevant, time-bound) should be established for the transition remedy. As introduced in the ITRC Integrated DNAPL Site Strategy (ITRC 2020[JWKDF22N] ITRC. 2020. “Integrated DNAPL Site Strategy.” Washington D.C.: Interstate Technology & Regulatory Council, IDSS Team. https://idss-2.itrcweb.org/.) guidance, the acronym “SMART” was developed by the American Management Association to convey the attributes of functional objectives. SMART functional objectives and the resulting transition monitoring should be approved by the regulator and acceptable to the stakeholders. The establishment of these objectives must consider the specific requirements of the state and/or federal regulatory program governing site remediation as well as stakeholder communications, which are covered in Section 7 and Section 8 of this document. A data collection program designed to monitor the SMART functional objectives should be implemented to track remedy performance. Setting interim objectives to ensure remedial progress advances as expected is sometimes prudent.

5.5.3 Example Transition Scenarios

Table 5-1 provides links to the following example transition scenarios contained in Appendix B:

- P&T to MNA/NSZD
- P&T to enhanced bioremediation (e.g., ERD)
- P&T to ISCO
- P&T to ISCR
- P&T to PRB
- P&T to SRM
- P&T to thermal
- P&T to ICs

These are not entire case studies; rather, they are brief, focused summaries of actual transition success stories. They contain figures showing the site CSM and pre- and post-transition plume conditions and the following elements in the two-page mixed graphical and text format:

- P&T transition approach
- Site name, geographic location, type of facility, year of transition, and regulatory framework
- P&T remediation objectives
- Performance evaluation summary—identification of P&T deficiencies
- Starting transition hypothesis: Why is another technology more appropriate than P&T?
- Summary of the remedial technology or strategy to replace P&T
- Lines of evidence used to support transition
- Transition technology decision description
- Type of P&T transition (hard stop, phased, or simultaneous) and description of how it was done
- Brief summary of the regulatory approval to decommission the P&T
- P&T transition conclusion including the time span, annual O&M cost savings, description of the new remedy effectiveness and/or risk-reduction improvement, and a statement of the sustainability/resiliency benefits

The case studies provided in Appendix B and referenced in Table 5-1 are intended to provide the reader with an ample diversity of transition examples so they can identify one or two to help guide them through their own P&T system transitions. A range of transition technologies, regulatory frameworks (e.g., CERCLA, RCRA, state), and transition drivers (e.g., change in remediation objectives and COCs) is provided. The intent is to show how a transition was (and can be again) successfully completed and to demonstrate the tangible benefits of transition, including improvement in sustainability/resiliency metrics.

5.6 Pump and Treat Termination

The logical last step in the process of transitioning off P&T is terminating its use. P&T termination includes administrative and physical actions and signifies the end of the optimization life cycle for that technology. Additionally, other types of remedial technologies that may have been implemented in its stead could also benefit by the optimization process.

5.6.1 Administrative Termination Actions

Subject to the regulatory framework, there are typically administrative requirements for obtaining regulatory and/or stakeholder agreements to formally remove P&T from the remediation plan. The agreement may also include specific details on the fate of the P&T system equipment and wells. A detailed discussion of the expected changes to the controlling documents, such as a permit modification and an explanation of significant difference (ESD), is included in Section 7.5.

5.6.2 Physical Termination Actions

Once the administrative actions are completed and approval is obtained, the physical actions to terminate the P&T system may commence. Depending on the agreed-upon fate of the equipment and wells, the physical actions can range from complete system deconstruction and well abandonment to mothballing or deactivating the system and placing it in a stand-by mode in case of future needs. The state of P&T system termination is collectively determined by the project team and regulators.

If deconstruction is selected, the below-grade components of the system can be properly abandoned. Because abandonment requirements vary widely, it is of utmost importance that the below-grade infrastructure (e.g., wells and piping) be abandoned according to all applicable local, state, and/or federal codes. A thorough review should be performed to ensure that the requirements are known and met with the planned procedures.

Above-grade system components can be decommissioned and removed from the site as necessary to restore the site to its intended future land use. Leaving components of the system in place as a contingency for possible future needs (e.g., to address CECs) may be considered prior to any removal activities.

Key Takeaways

Ultimately, all P&T systems will either meet their remediation objectives after optimizations and be terminated, or transition from P&T into more efficient remedial options (e.g., MNA, in situ treatment, or engineering/institutional/land-use controls). Section 5 provides information and strategy to help project teams make an efficient transition before being terminated. The process involves three basic steps:

Step 1—Identify the Trigger Conditions and Affirm the Need for P&T Transition

Step 2—Identify the Transition Approach and Develop the Lines of Evidence for P&T Transition

Step 3—Implement the P&T Transition