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Technical Memorandum

To:	Matt Thompson Wisconsin Department of Natural Resources
From:	Ken Quinn and Bruce Iverson TRC Environmental Corporation
Subject:	Development and Screening of Alternatives/List of Alternatives for Revised Groundwater RAOR – Wauleco Site – BRRTS #02-37-000006
Date:	November 15, 2017
CC:	Evan Schreiner – Wauleco
Project No.:	189597.0005

On behalf of Wauleco Inc. (Wauleco), this Technical Memorandum summarizes the identification and screening of technologies and the development and initial screening of remedial alternatives to be included in the revised Groundwater Remedial Action Options Report (Groundwater RAOR) for the Wauleco Project Site. The remedial alternatives identification, screening and development process described in this Technical Memorandum is based on the requirements of Chapter NR 722, Wis. Admin. Code as well as U.S. EPA guidance documents for similar projects.

Based on this process, the alternatives Wauleco proposes to carry forward to the detailed analysis and comparative analysis phase of the NR 722 process for inclusion in the revised Groundwater RAOR are listed in Section 4.0. Wauleco requests WDNR's concurrence regarding the list of alternatives that will be evaluated in the revised Groundwater RAOR.

1.0 Background Information

Wauleco submitted a Groundwater RAOR dated September 2015. A WDNR letter dated August 31, 2016 provided comments on the Groundwater RAOR. Based on the Groundwater RAOR and WDNR's comments, follow-up technical meetings to further discuss potential approaches to address groundwater at the Wauleco Project Site were conducted among WDNR, Wauleco and TRC Environmental Corporation (TRC) representatives beginning on November 29, 2016. Information discussed at these meetings included the Conceptual Site Model (CSM), with specific discussion regarding the following points:

- The WDNR concluded that mobile phase light, nonaqueous-phase liquid (LNAPL) has been addressed to the extent practicable. There is no further expectation that active product recovery efforts continue. The WDNR's focus has moved on to the dissolved phased component.
- TRC's CSM showed that there is evidence of degradation of PCP in product.
- TRC's CSM showed that there is evidence of natural attenuation of dissolved phase PCP in groundwater.
- TRC's Lake Wausau drawdown data showed that even with widespread groundwater decline no significant mobile LNAPL occurred. This conclusively demonstrates that the current residual phase LNAPL on and off the Wauleco Site has insufficient saturation to create mobile, recoverable LNAPL. Refer to Attachment A.

Discussion of these points will be included in the revised Groundwater RAOR.

Per NR 722.05 (5), the objective of the identification, evaluation and documentation of an appropriate set of remedial action options is to address each medium and migration exposure pathway. As discussed in Section 2.1, the medium for this Groundwater RAOR is groundwater. As discussed in Sections 1.6 and 1.7 of the September 2015 Groundwater RAOR:

- There are no groundwater exposure pathways, other than groundwater that discharges to the Wisconsin River.
- For groundwater that discharges to the river, based on the conclusions of the Bureau of Water Quality, the Bureau of Water Quality does not suspect that there is a potential of exceedance for water quality standards.

Based on the requirements of NR 722.05 and 07, the process used for the identification and evaluation of remedial action options is described in the following sections.

2.0 Identification and Screening of Technologies

The objective of the identification and screening of technologies process is to identify a manageable number of applicable LNAPL and groundwater remedial technologies which can then be assembled into groundwater remedial alternatives (see Section 4.0). This process consists of the following tasks:

- Identification of media of concern.
- Identification and screening of remedial technologies for:
  - LNAPL; and
  - Groundwater
- Evaluation and selection of technologies/process options for:
  - LNAPL; and
  - Groundwater

The following subsections provide a discussion of each of these tasks.

2.1 Identification of Media of Concern

The scope of the Groundwater RAOR is limited to groundwater. Groundwater, for the purposes of this Groundwater RAOR, is considered to include LNAPL (mobile and residual phase), and the groundwater containing dissolved phase PCP.

2.2 Identification and Screening of Remedial Technologies

The purpose of this task is to identify and screen a broad range of remedial technologies and process options applicable to each general response action and to eliminate those that cannot be implemented technically at the Wauleco Project Site. Remedial technologies are general categories of technologies. Process options are specific technologies or processes within each technology type. The identification and screening of remedial technologies was performed in consideration of:

- LNAPL; and
- Groundwater

2.2.1 LNAPL Identification and Screening of Remedial Technologies

The Interstate Technology Regulatory Council (ITRC) Technical/Regulatory Guidance document titled "Evaluating LNAPL Remedial Technologies for Achieving Project Goals" dated December 2009 (LNAPL Guidance) was followed for the identification of LNAPL remedial technologies. The purpose of the LNAPL Guidance "is to provide a framework that uses LNAPL conceptual site model (LCSM) information to identify appropriate LNAPL remedial objectives and systematically screen LNAPL remedial technologies to identify technology(ies) best suited to achieve those objectives." This process is summarized in the document included in Attachment B.

2.2.2 Groundwater Identification and Screening of Remedial Technologies

Groundwater remedial technologies and process options are screened at this point based on their technical implementability. Remedial technologies and process options that are applicable are carried forward for further evaluation. Those not technically implementable are eliminated. This process is shown schematically on Table 1. As shown on Table 1, several remedial technologies were identified for each general response action and numerous process options were identified within each technology type. Table 1 also provides a description of each process option and includes the reason for carrying forward or screening out individual process options for groundwater.

2.3 Evaluation and Selection of Technologies/Process Options

Based on the technologies that were carried forward from Section 2.2, an evaluation and selection of remedial technologies was performed in consideration of:

- LNAPL; and
- Groundwater

2.3.1 LNAPL Evaluation and Selection of Technologies/Process Options

The LNAPL Guidance was followed to evaluate and select LNAPL remedial technologies. The LNAPL Guidance contains 17 potentially applicable technologies. In addition, six additional remedial technologies are reportedly being considered for updates to the LNAPL Guidance. These 23 potentially applicable technologies were considered in this process. This process is summarized in the document included in Attachment B.

The LNAPL Guidance was discussed with the WDNR during a meeting on June 13, 2017. Based on this discussion, the following LNAPL remedial technologies warranted further consideration for the Wauleco Project Site:

- No. 4 Natural Source Zone Depletion (NSZD) – Note, looking forward, this technology is included in Alternative 3 discussed below in Section 3.0.
- No. 12 In Situ Chemical Oxidation (ISCO) – Note, looking forward, this technology is included in Alternative 2 discussed below in Section 3.0.
- No. 13 Surfactant Enhanced Subsurface Remediation (SESR) – Note, looking forward, this technology is included in Alternative 7 discussed below in Section 3.0.
- Amendment Injection - Note, this is not an ITRC listed technology. Looking forward, this technology is included in Alternative 4 discussed below in Section 3.0.

2.3.2 Groundwater Evaluation and Selection of Technologies/Process Options

After the broad screening of groundwater technologies based solely on technical implementability was performed as described in Section 2.2.2, the remedial technologies considered to be technically implementable were analyzed in greater detail to select the process options that could represent each technology type. The purpose of this task is to select a limited number of promising process options for consideration in developing groundwater alternatives. Process options are evaluated considering:

- Effectiveness
- Implementability
- Cost

Effectiveness is the primary criterion used to screen process options at this point in the process. Effectiveness focuses on:

- The potential effectiveness of the process options in handling the estimated areas and volumes of the media of concern.
- The ability of the process options in meeting the remediation goals identified in the remedial action objectives.
- The potential impacts to human health and the environment during the remedial action.
- The reliability of the process options with respect to the contaminants of concern and the site conditions.

Effectiveness is evaluated considering the relative effectiveness of a process option compared to the other process options in the same technology type. For example, the ability of the process option to meet the remedial action objective and the ability of the process option to adequately accommodate the relevant waste type and quantities compared to the other process options is critical for a process option to be retained.

Implementability focuses on the technical feasibility and availability of the technologies each process option would employ and the administrative feasibility of implementing the process option. Technical implementability considers a range of factors relevant to obtaining, installing and using a particular technology. Some remedial technologies are proven and readily available, while others are in the research and development stages. Insufficiently developed technologies are generally screened out. Site conditions must be compatible with the feasible range of a given technology's capabilities, considering for example, depth to bedrock, depth to groundwater, space requirements, ability of the technology to treat contaminants identified, etc. Administrative implementability considers a range of factors relevant to the testing; review; approval; availability of services, workers, and equipment; or permitting of a particular technology. Because technologies were screened based on their technical implementability in Section 2.2.2, this subsequent, more detailed evaluation of process options, places greater emphasis on the administrative aspects of implementability.

Cost is evaluated relative to construction (capital) costs and any long-term (operation and maintenance) costs required to operate and maintain the process option. Cost plays a limited role in the screening of process options at this stage. However, groundwater technologies that are grossly expensive but also equally or only marginally more effective than much lower cost technologies are eliminated from further consideration.

The process options are evaluated at this point based on their relative effectiveness, implementability and cost. This evaluation is documented on Table 2. Table 2 includes the evaluation of each process option carried forward from Table 1 for the above three criteria.

3.0 Development and Initial Screening of Alternatives

Based on LNAPL and groundwater technologies that were carried forward from the initial screening phase as discussed above in Section 2.0, remaining technologies were considered to assemble into alternatives.

This section discusses the development and screening of groundwater alternatives. The objective of developing alternatives is to assemble groundwater alternatives from the remaining remedial technologies carried through the initial screening. The groundwater alternatives assembled should protect human health and the environment and encompass a range of potentially appropriate remedial options.

The objective of subsequent alternative screening is to narrow the list of potential groundwater alternatives that will be evaluated in the detailed analysis and comparative analysis phase of NR 722.07(3). This subsequent screening aids in streamlining the Groundwater RAOR process while retaining the most promising groundwater alternatives for more detailed consideration.

Following is a summary of the seven groundwater alternatives developed and an overview description of each alternative:

1. **Alternative 1: On-site Pump and Treatment System; Description** – Continue the current pump and treatment system to provide a level of containment of groundwater from the Wauleco property (i.e., the majority of the mass of PCP in the plume) and reduce the groundwater flux downgradient of the site.

2. **Alternative 2: Chemical Oxidation of Portion of Residual Phase LNAPL; Description** – Continue the pump and treatment system while removing additional residual phase LNAPL near the river by chemical oxidation (chemox) to provide additional distance for natural attenuation (NA) to reduce contaminant concentrations between the eastern extent of residual phase LNAPL and the river. Discontinue the pump and treatment system when the chemox is complete.

3. **Alternative 3: Natural Source Zone Depletion (NSZD) and Natural Attenuation (NA); Description** – This alternative is a combination of natural source zone depletion (NSZD) of the residual phase LNAPL and natural attenuation of dissolved constituents in groundwater. NSZD is distinctly different than natural attenuation. The USEPA defines natural attenuation (USEPA, 1999[1]) as "a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater." ITRC (2009[2]) defines NSZD as: "a combination of processes that reduce the mass of LNAPL in the subsurface." Natural attenuation depletes contaminants in soil or groundwater, whereas, NSZD only reduces the mass of LNAPL. Therefore, NSZD is a source reduction process whereas natural attenuation is a migration control process.

   The combination of NSZD and natural attenuation can be effective in treating both the source and in migration pathways. This NSZD and natural attenuation remedy would be implemented as a pilot study, turning off the existing pump and treatment system and assessing groundwater quality under non-pumping conditions. This assessment will include evaluations of the effectiveness of NSZD for the residual phase LNAPL and natural attenuation for the dissolved phase. Prior to implementing this alternative, a Pilot Study Plan will be developed based on input from the WDNR and submitted to the WDNR. The Pilot Study Plan will present the specific assessments and groundwater monitoring that will be performed during the pilot study. While the pilot study is being implemented, the existing pump and treatment system will be maintained and periodically exercised, so that it can be restarted, if warranted.

4. **Alternative 4: Enhanced Bioremediation; Description** – Existing bioremediation of PCP would be enhanced through injection of amendments into the groundwater on the Wauleco

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[1] USEPA. 1999. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive 9200.4-17P.

[2] ITRC (Interstate Technology & Regulatory Council). 2009. Evaluating Natural Source Zone Depletion at Sites with LNAPL. LNAPL-1. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.

property and at select off-site locations. This would consist of additional electron acceptors (e.g., nitrate-N) and nutrients (e.g., phosphorous). The on-site pump and treatment system would be discontinued when the enhanced bioremediation system demonstrated declining PCP concentrations on the Wauleco property. Enhanced bioremediation injections would continue after shutdown of the pump and treatment system.

5. **Alternative 5: Permeable Treatment Walls (Property and River Walls); Description** – Implementation of treatment walls (biological or chemical) at the eastern portion of the Wauleco property boundary and at the river to reduce contaminant concentrations prior to discharge to the river. The pump and treatment system would be discontinued when the wall is complete.

6. **Alternative 6: Off-site Pump and Treatment System; Description** – Removing residual phase LNAPL near the river by a groundwater pump and treatment system is intended to reduce the volume of residual phase LNAPL near the river. Install groundwater extraction wells and associated conveyance piping/utilities to extend a pump and treatment system to off-site locations. The purpose of the off-site pump and treatment system would be to attempt to convert residual phase LNAPL to migrating LNAPL so it could be removed/recovered and to extract dissolved phase PCP from groundwater. The new groundwater extraction wells and conveyance piping/utilities would either be located within the City right-of-way or on private property (via access agreements). A new groundwater treatment system, in addition to the current groundwater treatment system, would likely be required to treat the additional quantity of extracted groundwater. Treated groundwater would either be discharged to the City's POTW system or discharged to the surface water via a WPDES Permit.

7. **Alternative 7: Off-site Horizontal Wells and Surfactant Flushing; Description** – Removing residual phase LNAPL near the river by surfactant flushing between horizontal wells is intended to reduce the volume of residual phase LNAPL near the river. Horizontal wells would be installed either in the City's right-of-way or under private property (via access agreements). A surfactant would be introduced to mobilize the residual phase LNAPL, which is currently immobile and present in an approximate 1 ft. thick zone at or above the water table. Additional horizontal wells would be pumped to capture the mobilized emulsion of LNAPL/water/surfactant. A new groundwater treatment system would be needed to treat the complex emulsified mixture. Treated groundwater would either be discharged to the City's POTW system or discharged to the surface water via a WPDES Permit. Recovered LNAPL would be disposed at a licensed facility and the recovered surfactant recycled to the system.

An initial screening of these seven alternatives was performed based on the following criteria:

1. Effectiveness: In consideration of the following:
    a. Effectiveness in protecting human health and the environment; considering both:
        i. Short-term effectiveness: Construction and implementation periods.
        ii. Long-term effectiveness: Period after the remedial action is complete
    b. Effectiveness in the reduction of toxicity, mobility or volume that alternative will achieve

2. Implementability: In consideration of the following:
   a. Technical Feasibility: The ability to construct, reliably operate and meet technology-specific regulations for process options until a remedial action is complete. Also includes operation, maintenance, replacement and monitoring of technical components of the alternative.
   b. Administrative Feasibility: Ability to obtain approvals from other offices and agencies, the availability of treatment, storage and disposal services and capacity and the requirements for, and availability of, specific equipment and technical specialists.
3. Cost: In consideration of a relative cost comparison.

This initial screening process is documented in Table 3. Table 4 illustrates the symbolic ratings of each alternative. Based on this initial screening process, Alternatives 6 and 7 will not be carried forward in the revised Groundwater RAOR to the detailed analysis and comparative analysis phase. As described in Table 3, the main reasons Alternatives 6 and 7 were screened out and not carried forward are summarized as follows:

- Alternative 6 Off-Site Pump and Treatment System – Objective of this alternative is to reduce the volume of residual phase LNAPL between the site and the river.
  - Effectiveness – This alternative would not be effective, based on the Lake Wausau drawdown that has demonstrated that there is insufficient volume of residual phase LNAPL for collection via this method (refer to Attachment A).
  - Implementability and Cost – Difficult and costly due to the off-site conditions, but the primary reason for rejection is described in Effectiveness.
- Alternative 7 Off-site Horizontal Wells and Surfactant Flushing – Objective of this alternative is to reduce the volume of residual phase LNAPL between the site and the river.
  - Effectiveness – Surfactant flushing of a thin zone of residual phase LNAPL at and possibly above the water table between horizontal wells is difficult to accomplish due to the tendency for flow of the surfactant flush to occur primarily below the water table, with the majority of the surfactant not flowing through the lower permeability zone containing the LNAPL. (Note: The zone containing the residual phase LNAPL is lower permeability because of the partial saturation of this zone with two immiscible fluids—LNAPL and water.)
  - Implementability – Requires closely spaced injection and extraction points (i.e., 50 ft. or less), so it is impractical for off-Site implementation. Use of horizontal wells may reduce disruptions at the surface, but they still require access agreements from the City or private property owners prior to installing horizontal well(s). Access to private property in this setting would be extremely difficult to secure. The presence of the sewer interceptor along the river is below the water table. Therefore, placement of a horizontal well (e.g., a barrier well to capture any surfactant emulsion before it could discharge to the river) would be very challenging administratively. Even if a horizontal well is not located under a private property, an access agreement is needed for surfactant injection that will move onto a private property. Surfactant enhanced mobilization of the residual phase LNAPL is not recommended because of the

potential to mobilize residual phase LNAPL and the potential for discharge to surface water. In addition, given the volume of residual phase LNAPL and the difficulty in treating the surfactant/mineral spirits/PCP/water emulsion, the technical practicability to achieve PCP discharge standards is questionable or at a minimum, very difficult.

— Cost – Very high cost for the volume of residual phase LNAPL potentially recovered.

4.0 List of Alternatives to Carry Forward to the Detailed and Comparative Analysis of Alternatives

Based on the initial screening of alternatives discussed above in Section 3.0, the following five groundwater alternatives will be carried forward to the detailed analysis and comparative analysis phase in the revised Groundwater RAOR:

1. Alternative 1: On-site Pump and Treatment System
2. Alternative 2: Chemical Oxidation of Portion of Residual Phase LNAPL
3. Alternative 3: Natural Source Zone Depletion and Natural Attenuation
4. Alternative 4: Enhanced Bioremediation
5. Alternative 5: Permeable Treatment Walls (Property and River Walls)

List of Enclosures

- Table 1 – Identification and Screening of Groundwater Technologies and Process Options
- Table 2 – Evaluation of Groundwater Process Options
- Table 3 – Initial Screening of Alternatives
- Table 4 – Summary of Initial Screening of Alternatives
- Attachment A – Lake Wausau Drawdown
- Attachment B – Proposed LNAPL Remedial Strategy

Tables

Table 1
Identification and Screening of Groundwater Technologies and Process Options
Wauleco, Inc.

Media	General Response Action	Remedial Technology Type	Process Option	Description	Applicability
Groundwater	Institutional controls	Deed Restrictions	Groundwater Use Restrictions	A municipal ordinance within the City that prohibits installation of new wells within the municipal water distribution system or listing on the WDNR GIS registry.	Permanently prevents use of groundwater in this area. Retain as part of potential options and GIS registry requirements if site is to be closed. City of Wausau already has an ordinance that prohibits the installation of private potable wells.
	Monitoring	Monitoring	Groundwater Monitoring	Long-term monitoring of groundwater wells to monitor degradation, dissipation, and migration of COCs in the groundwater.	Not applicable on its own, but would be a component of any remedy.
			Natural Attenuation Monitoring	Quantifying the rate of biodegradation and fate of constituents in groundwater to demonstrate that constituents will degrade before adversely affecting a receptor.	Potentially viable based on NA assessment and could be an essential component of an alternative.
	Gradient Controls	Containment	Slurry Wall	A slurry wall would be effective in reducing the pumping rate to maintain containment on the Site, but requires an extraction system to maintain gradient control.	Not viable due to the large area encompassed by the groundwater plume within the City and the number of utilities that would be present in the footprint of the slurry wall.
		Groundwater Recharge Elimination	Impermeable Surface Cap	Installation of an impermeable cap over the entire groundwater source area to prevent further recharge and migration of the plume.	Not viable. Residual phase LNAPL is present at the water table, so an impermeable surface cap would not be applicable.

Table 1
Identification and Screening of Groundwater Technologies and Process Options
Wauleco, Inc.

Media	General Response Action	Remedial Technology Type	Process Option	Description	Applicability
	Extraction and Ex-situ Treatment	Biological Treatment	Cometabolic Aerobic Biodegradation	Addition of specific compounds to feed bacteria that can cometabolize PCP into non-hazardous compounds.	No cometabolic aerobic biodegradation systems known to be effective with PCP.
			Anaerobic Biodegradation	Addition of specific compounds to enhance the anaerobic biodegradation of PCP in extracted groundwater.	Partially aerobic biological treatment shown to be more effective in existing treatment system than anaerobic biological treatment.
			Aerobic Treatment	Aerobic biotreatment of PCP in extracted groundwater.	This is the existing system's treatment method. This is technologically viable.
		Chemical Treatment	Chemical Oxidation	Addition of compounds that oxidize PCP present in extracted groundwater to non-hazardous compounds.	Potentially viable.
			Chemical Precipitation	Addition of chemicals to precipitate certain chemicals from extracted groundwater.	Not viable. Technology is most efficient for metals.
		Physical Treatment	Air Stripping	Mass transfer of VOCs from groundwater to the gaseous phase.	Not viable for PCP.
			Spray Evaporation	Dispersion of groundwater into tiny droplets with large surface area that facilitate the transfer of certain chemicals to the gaseous phase.	Not viable for PCP.
			Carbon Adsorption	Filtration of extracted groundwater through activated carbon filters which adsorb certain chemicals.	Viable treatment method, as shown by existing system polishing system.
			Discharge to POTW	Discharge of extracted groundwater to the local POTW for treatment	Not viable on its own. Historically shown not to be able to meet POTW discharge limits without pretreatment. Retained for possible treated discharge option.
			Ion Exchange	Removal of charged compounds from the groundwater.	Not viable. Non-charged chemicals are not amenable to this technology.
			Reverse Osmosis	Removal of chemicals from groundwater using microfiltration technology.	Potentially viable.

Table 1
Identification and Screening of Groundwater Technologies and Process Options
Wauleco, Inc.

Media	General Response Action	Remedial Technology Type	Process Option	Description	Applicability
	In-situ Treatment	Biological Treatment	Enhanced Biodegration	Injection of specific constituents (substrate, nutrients, oxygen, etc.) or bacteria into source area groundwater to feed bacteria that degrade PCP into non-hazardous compounds.	Potentially viable to enhance biodegradation of PCP in the dissolved phase and enhance PCP removal from LNAPL. Increasing degradation rate in groundwater would increase rate of dissolution from the free and residual phase sources. Primary limitation is due to the presence of large volumes of free and residual phase product.
		Chemical Treatment	Barrier Wall Chemical Oxidation	Injection of compounds into source area groundwater that oxidize PCP to non-hazardous compounds. Application can be areally or in a barrier wall.	Barrier wall potentially viable to treat groundwater migration away from source area as a continuous injection. Areal injection not viable due to the large volume of product present in the source area.
			Passive Treatment Wall	Installation of permeable wall in the path of groundwater flow which treats groundwater as it passes through the wall. No known material to chemically treat PCP.	Not viable for PCP.
		Physical Treatment	Air sparging/soil vapor extraction	Injection of air into groundwater to transfer volatile chemicals to the gaseous phase and then the extraction of this air through separate wells in the unsaturated zone.	Not viable for PCP. Viable for removal of mineral spirits, which is not a COC.
			Electro-kinetic Extraction	Applying voltage difference across electrodes forces movement of water, dissolved constituents and non-aqueous liquids between electrodes	Typically applicable to sites with low hydraulic conductivity soils. Not applicable to Wauleco.
			Thermal Vapor Extraction	In-situ heating of groundwater to transfer chemicals to the gaseous phase and subsequent extraction of air containing these chemicals in separate wells.	Potentially viable. Although unlikely to be cost effective due to the high PCP volatilization temperature, soils' relatively high permeability increasing flow and high energy consumption/costs.
			Vacuum Vapor Extraction	Vacuum extraction of soil gas above the water table to remove volatile constituents vented from the groundwater.	Not viable for PCP.

Table 1
Identification and Screening of Groundwater Technologies and Process Options
Wauleco, Inc.

Media	General Response Action	Remedial Technology Type	Process Option	Description	Applicability
		LNAPL Removal	Pressure pulse	Use of a water flood with pressure pulse to help force NAPL out of the soils. Used in combination with a groundwater extraction system.	Not viable based on pilot study at Wauleco.
			Surfactant Flushing	Injection and extraction of surfactants and polymers to remove product.	Potentially viable but extensive technical challenges to: • treat the surfactant/water/LNAPL emulsion prior to discharge, • install wells (horizontal). Administrative challenges for installation and operation are also significant.
			Thermal Vapor Extraction	Heated soil vapor extraction would remove product as well as dissolved phase PCP.	Potentially viable.
			Enhancing LNAPL Recovery	Product recovery while pumping groundwater to create cone of depression.	Lake Wausau drawdown demonstrates current system removed recoverable LNAPL, so this is not viable in the future.
			Chemical Oxidation	Injection of compounds into source area groundwater that oxidize product to non-hazardous compounds. This does not directly react with product. Rather it degrades constituents in groundwater increasing dissolution rate from product.	Potentially viable, however, due to volume of product, potential is low.
		Phyto-remediation	Phyto-remediation	Planting and cultivating trees to utilize groundwater flow through an area, potentially containing groundwater, with removal of COCs through treatment in rhizosphere and volatilization.	Not viable due to depth to groundwater on source area.

Notes:

(yellow box)	Process Option not carried forward
(white box)	Process Option retained
POTW	Public Owned Treatment Work
COCs	Constituents of Concern
PCP	Pentachlorophenol

Table 2
Evaluation of Groundwater Process Options
Wauleco, Inc.

Media	General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Cost
Groundwater	Institutional Controls	Deed Restrictions	Groundwater Use Restrictions	GIS registry is an effective institutional control.	The City of Wausau already has an ordinance that prohibits the installation of private potable wells.	Low to moderate cost.
	Monitoring	Monitoring	Groundwater Monitoring	Not effective on its own, but a component of any remedy.	Easy to implement for most applications.	Cost dependent on duration of remedy and complexity of required monitoring.
			Natural Attenuation Monitoring	NA is shown to be occurring and reducing PCP concentration in groundwater.	Already naturally occurring.	Low cost.
	Extraction and Ex-situ Treatment	Biological Treatment	Aerobic Treatment	(1). General for source area extraction and treatment: would be effective, but would require long term OM&M. This is the existing system and shown to be effective in containing groundwater on-site and treatment system has been effective in treating PCP.	Easy to implement. Long remediation duration likely, requiring major renovation to the old, existing system.	Moderate cost for short term operation. High capital cost for system renovation required if planned for long term OM&M. Moderate OM&M cost for long term.
		Chemical Treatment	Chemical Oxidation	See (1) in Aerobic Treatment. Treatment method not widely applied to PCP, but may be effective in meeting POTW standards.	Difficult to implement. Would require bench scale testing . Long remediation duration likely.	High capital cost, potentially lower long term OM&M cost than current system.
		Physical Treatment	Carbon Adsorption	See (1) in Aerobic Treatment. Treatment method regularly used for PCP, and would be effective in meeting POTW standards.	Moderate difficulty to implement. Would require special chemicals and treatment trains.	Moderate capital cost, high OM&M cost. Dependent on system pumping rate.
			Discharge to POTW	Not viable without pretreatment. Retained for potential discharge option.	Easy to implement.	Low cost.
			Reverse Osmosis	See (1) in Aerobic Treatment. Treatment method not widely applied to PCP, but may be effective in meeting POTW standards.	Difficult to implement. Would require bench scale testing. Long remediation duration likely.	High capital cost and moderate to high OM&M cost.

Table 2

Evaluation of Groundwater Process Options

Wauleco, Inc.

Media	General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Cost
	In-situ Treatment	Biological Treatment	Enhanced Biodegration	Natural biodegradation is shown to be occurring, so enhancement would be effective. Would require shorter term operation than extraction and treatment.	Easy to implement, but may require bench scale testing . Shorter remediation duration than current pump and treatment system.	Moderate capital cost and low to moderate OM&M cost.
		Chemical Treatment	Barrier Wall Chemical Oxidation	Systems shown to be effective with concentrations observed at Wauleco.	Difficult to implement. Is not subject to biotoxicity or heterogeneity of LNAPL distribution in source area.	Moderate to high capital costs and moderate OM&M costs for long term OM&M.
		Physical Treatment	Thermal Vapor Extraction (not carried forward)	Effectiveness considered questionable based on the quantity of groundwater requiring treatment.	Difficult to implement due to the volume of product on-site and heterogeneity of LNAPL distribution.	High to very high capital costs using utility energy. Moderate to high cost with low cost heat.
		LNAPL Removal	Surfactant Flushing	May be effective in reducing residual phase LNAPL somewhat, but limited applications for PCP sites result in limited reliability for mobilizing LNAPL and for treatment of collected surfactant/LNAPL/water emulsion. Potential for migration of emulsion to river is a serious limitation.	Difficult to implement horizontal wells and treatment system, both technically and administratively.	High to very high capital and OM&M costs.
			Thermal Vapor Extraction (not carried forward)	Effectiveness considered questionable based on the quantity of groundwater requiring treatment.	Difficult to implement due to the volume of product on site and heterogeneity of LNAPL distribution.	High to very high capital costs using utility energy. Moderate to high cost with low cost heat.
			Enhancing Product Recovery	It has been concluded that current groundwater system has recovered LNAPL to the extent practicable. The Lake Wausau drawdown results demonstrates that off-site LNAPL recovery would not be effective.	Uses existing treatment system in short term.	Moderate to high capital costs, low OM&M costs.
			Chemical Oxidation	No history of chemical oxidation for product removal on this scale, so reliability is not known. Typically used to treat dissolved phase PCP with excavation of residual phase LNAPL in smear zone prior to use. Excavation of smear zone at Wauleco is not practicable. Several years of injections would be required at a minimum.	Difficult to implement due to heterogeneity of LNAPL distribution and ability to obtain access agreements to install injection points off-site.	High to very high costs.

Notes:

(Yellow box) Process Option not carried forward

(White box) Process Option retained

POTW Public Owned Treatment Work

COCs Constituents of Concern

PCP Pentachlorophenol

Table 3
Initial Screening of Alternatives
Wauleco Project Site: Groundwater Remedial Action Options Report
Wausau, Wisconsin

INITIAL SCREENING CRITERIA EVALUATION CRITERIA	ALTERNATIVE 1 ON-SITE PUMP AND TREATMENT (P&T) SYSTEM	ALTERNATIVE 2 CHEMICAL OXIDATION OF PORTION OF RESIDUAL PHASE LNAPL	ALTERNATIVE 3 NATURAL SOURCE ZONE DEPLETION AND NATURAL ATTENUATION	ALTERNATIVE 4 ENHANCED BIOREMEDIATION (BIO)	ALTERNATIVE 5 PERMEABLE TREATMENT WALLS (PROPERTY AND RIVER WALLS)	ALTERNATIVE 6 OFF-SITE PUMP AND TREATMENT SYSTEM	ALTERNATIVE 7 OFF-SITE HORIZONTAL WELLS AND SURFACTANT FLUSHING
	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING
1. Effectiveness Evaluation							
Effectiveness in protecting human health and the environment; considering both: a. Short-term effectiveness: Construction and implementation periods. b. Long-term effectiveness: Period after the remedial action is complete	Continuation of an on-site pump and treat system at a rate to contain groundwater on the source area is effective in protecting human health and the environment in the short and long term in that the highest concentration PCP is captured and treated on-site, and off-site groundwater that discharges to the river would be protective of the environment based on the conclusion of the WDNR Water Quality Bureau[1]. This alternative would be protective in the short term and long term, as there are no receptors, other than groundwater that discharges to the river. Groundwater that discharges to the river would be protective of the environment based on the conclusion of the WDNR Water Quality Bureau[1].	Removing residual phase LNAPL near the river, by chemical oxidation (chemox), will provide additional distance for natural attenuation to reduce contaminant concentrations between the eastern extent of residual phase product and the river. In the short term there is risk that chemox could mobilize residual phase LNAPL (which is currently immobile) that could migrate and discharge to the river, thereby increasing risk to human health and the environment. Under current conditions, residual phase LNAPL is immobile, and dissolved phase constitutes that any discharge to the river would be protective based on the conclusions of the WDNR Water Quality Bureau.[(1)] Therefore, if implemented, this alternative may make conditions worse (i.e., greater risk to human health and the environment), than under current conditions. There could be short term impacts to human health, safety, and welfare during and shortly after the injection of oxidant downgradient of the Wauleco site, which is a residential area. Chemical oxidation, if implemented, could generate heat production and off-gassing in this area resulting in a vapor intrusion risk, which under current conditions, there is no potentially complete vapor intrusion pathway. In the long term this alternative would further reduce the potential for human health or environmental risk due to reducing discharge of PCP to the river. However, long term risk is currently acceptable as described in Alternative 1.	This alternative relies on various processes to degrade the residual phase LNAPL, the source of dissolved phase PCP to groundwater, and degradation of PCP in groundwater. This alternative would be protective in the short term and long term, as there are no receptors, other than groundwater that discharges to the river. Groundwater that discharges to the river would be protective of the environment based on the conclusion of the WDNR Water Quality Bureau[1]. In the short term, PCP in groundwater discharge to the river would be expected to increase over the current pump and treat remedy in the vicinity where residual phase LNAPL is present near the river, but would still be protective of the environment based on the conclusion of the WDNR Water Quality Bureau[1]. In the long term, natural source zone depletion of the residual phase LNAPL is expected to reduce the recharge of dissolved phase PCP to groundwater, with further reduction of dissolved phase PCP discharge to the river. There is no additional risk of mobilization of residual phase LNAPL in the short or long term.	Injection of amendments to enhance the current natural attenuation of PCP in groundwater would be completed on-site and off-site, shutting down the pump and treatment system when PCP concentrations begin to decline on-site. Amendment injections would continue after shutdown of the pump and treatment. This may create limited acceleration of residual phase LNAPL dissolution. There may be minor increased short term risks to human health, safety, and welfare during installation of the injection wells, and during injections; but this is considered manageable though an appropriate Health & Safety (H&S) Plan and personnel protective equipment (PPE). In the long term this alternative would further reduce the potential for human health or environmental risk due to reducing discharge of PCP to the river. However, long term risk is currently acceptable as described in Alternative 1. In the short and long term, chemical additions may mobilize some residual phase LNAPL that may not be controlled.	The treatment walls would chemically treat groundwater as it passes through the walls. However, the property area wall would not reduce the concentration of PCP within the source area faster than natural dissolution of the residual phase to groundwater. The river wall would reduce constituent concentrations in groundwater prior to discharge to the river. The remaining residual phase LNAPL is expected to continue to be immobile. However, there is a risk that chemical oxidation may mobilize some residual phase LNAPL that would need to be treated at the downgradient wall. If residual LNAPL is mobilized and not treated by the downgradient wall, it could discharge to the river, thereby increasing risk to human health and the environment. Under current conditions, residual phase LNAPL is immobile, and dissolved phase constitutes that any discharge to the river would be protective based on the conclusions of the WDNR Water Quality Bureau.[(1)] Therefore, if implemented, this alternative may make conditions worse (i.e., greater risk to human health and the environment), than under current conditions. This alternative would be protective in the short and long term for the same reasons as Alternative 1. Potential risks to the environment through mobilization of residual phase product would be controlled through close monitoring and controls in the downgradient treatment wall. However, there may be minor increased risks to human health, safety, and welfare during installation of the injection wells, and during injections; but this is considered manageable though an appropriate H&S Plan and PPE.	Installation/expansion of the pump and treat system to off-site locations to contain groundwater off-site would be no more effective in protecting human health and the environment in the short and long term than Alternative 1, as there are no receptors, other than groundwater that discharges to the river. Groundwater that discharges to the river is already protective of the environment based on the conclusion of the WDNR Water Quality Bureau[1]. No additional LNAPL would be collected from an off-site pump and treat system based on the limited volume of residual phase LNAPL present. This was demonstrated during the Lake Wausau drawdown, conducted by others, during September to November 2016 (refer to Attachment A).	Removing residual phase LNAPL near the river, by surfactant flushing between horizontal wells, is intended to reduce the volume of residual phase LNAPL near the river. In the short term there is risk that surfactants could mobilize residual phase LNAPL that could migrate and discharge to the river, thereby increasing risk to human health and the environment. Under current conditions, residual phase LNAPL is immobile, and dissolved phase constitutes that any discharge to the river would be protective based on the conclusions of the WDNR Water Quality Bureau.[(1)] Therefore, if implemented, this alternative may make conditions worse (i.e., greater risk to human health and the environment), than under current conditions. In the long term this alternative would further reduce the potential for human health or environmental risk due to reducing discharge of PCP to the river. However, long term risk is currently acceptable as described in Alternative 1.
Effectiveness in the reduction of toxicity, mobility, or volume that alternative will achieve	Toxicity reduction occurs through groundwater extraction and treatment. The pump and treatment system slowly reduces the mass/volume of residual phase LNAPL through dissolution of product into the groundwater. No mobile LNAPL is expected to be collected. The remaining residual phase LNAPL would continue to be immobile.	Chemox treatment would target approximately 9,300 gallons of residual phase product in the area 700 ft upgradient of the river for destruction. Therefore, a large mass/volume of residual phase product would be reduced. Continued natural attenuation would occur on and off the site. However, the removal of residual phase product from within 700 ft of the river would allow biodegradation to reduce PCP concentrations, without dissolution of additional PCP from residual phase product. This reduces the volume, mobility and toxicity of the residual contaminants. However, the current conditions result in groundwater discharge to the river that would be protective of the environment based on the conclusion of the WDNR Water Quality Bureau[1]. This alternative has the potential to mobilize some residual phase LNAPL, thereby increasing its mobility and potential toxicity. This would be closely monitored.	The volume, toxicity, and mobility will continue to be reduced through degradation of the residual phase LNAPL and PCP in groundwater. In the short term, some additional migration of PCP in groundwater will occur, with discharge to the river. In the short and long term the residual phase LNAPL would continue to be immobile.	The enhanced bio would treat groundwater beneath the residual phase LNAPL area, enhancing the shift of PCP from residual phase LNAPL to dissolved phase PCP in groundwater, thereby reducing the mass/volume of residual phase LNAPL. Existing PCP degradation in groundwater would be enhanced as groundwater flows towards the river, reducing the toxicity of constituents in groundwater. This alternative has the potential to mobilize some residual phase LNAPL, thereby increasing its mobility and potential toxicity. This would be closely monitored.	Treatment walls would chemically treat groundwater. However, the property area wall would not reduce the concentration of PCP within the residual phase LNAPL on-site faster than natural processes. The river wall would reduce constituent concentrations in groundwater prior to discharge to the river. The remaining residual phase LNAPL is expected to continue to be immobile. However, there is a risk that chemical oxidation may mobilize some residual phase LNAPL that would need to be treated at the downgradient wall.	Same as Alternative 1, with increased toxicity reduction and mobility of dissolved phase PCP with increased extraction off-site. Based on the results of the Lake Wausau drawdown during September to November 2016, additional mass/volume of residual phase LNAPL would not be converted to mobile phase LNAPL that could then be recovered by an off-site pump and treatment system.	The volume of residual phase LNAPL near the river will be reduced, which will reduce the mobility and discharge of PCP to the river through natural attenuation with smaller continued source of PCP to groundwater near the river. The surfactant flushing of residual phase LNAPL will increase the mobility residual phase LNAPL, which is currently immobile, that could migrate and discharge as LNAPL to the river.

Table 3
Initial Screening of Alternatives
Wauleco Project Site: Groundwater Remedial Action Options Report
Wausau, Wisconsin

INITIAL SCREENING CRITERIA EVALUATION CRITERIA	ALTERNATIVE 1 ON-SITE PUMP AND TREATMENT (P&T) SYSTEM	ALTERNATIVE 2 CHEMICAL OXIDATION OF PORTION OF RESIDUAL PHASE LNAPL	ALTERNATIVE 3 NATURAL SOURCE ZONE DEPLETION AND NATURAL ATTENUATION	ALTERNATIVE 4 ENHANCED BIOREMEDIATION (BIO)	ALTERNATIVE 5 PERMEABLE TREATMENT WALLS (PROPERTY AND RIVER WALLS)	ALTERNATIVE 6 OFF-SITE PUMP AND TREATMENT SYSTEM	ALTERNATIVE 7 OFF-SITE HORIZONTAL WELLS AND SURFACTANT FLUSHING
	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING
2. Implementability Evaluation							
a. Technical Feasibility: The ability to construct, reliably operate, and meet technology-specific regulations for process options until a remedial action is completes. Also includes operation, maintenance, replacement, and monitoring of technical components of alternative.	System relies on existing infrastructure for water treatment and discharge. Construction is either complete, or modifications are easy and reliable and can be modified further if necessary. OM&M is on-going and will provide feedback for system modifications if necessary.	The large volume of oxidant, injected on a tight spacing required to treat the residual phase LNAPL are the greatest limitations to its technical feasibility. Potential for mobilization of residual phase LNAPL, with potential for migration to the river, is difficult or impossible to predict and control. Requires construction of approximately 275 injection locations.	Demonstration of natural attenuation of LNAPL and PCP in groundwater has already been documented through routine monitoring of product and groundwater that has been conducted at Wauleco. The technology for documentation of Natural Source Depletion is readily available to Wauleco and can be implemented and monitored.	Injection technology is readily available, and theoretically can be operated and monitored, on-site and in right-of-ways (R-O-W) off-site. Requires construction of off-site injection wells (approximately 4 to 6) with several rounds of chemical injections. If these injection wells are proposed for installation in the off-site R-O-W, there are currently several utilities present in the R-O-W that may prohibit the installation. In addition, a small building to house injection equipment will be needed at injection wells.	Injection technology is readily available, and theoretically can be operated and monitored, on-site and off-site. Requires construction of approximately 22 injection locations for the property wall, and approximately 28 off-site injection locations for the river wall. There are numerous utilities in the area of the river wall which will presents constraints. In addition, injection of oxidants near the City interceptor may not be allowed by the City. There are also utilities in the area of the property wall.	Installing/extending extraction and transport systems off-site, along right-of-ways (R-O-W) is theoretically technically feasible, but practically may not be feasible based on the actual location of other off-site utilities also located in the R-O-W.	Construction of horizontal wells is theoretically feasible, but is limited by the presence of utilities. Although most utilities are expected to be shallower than the horizontal wells in the groundwater, the sewer interceptor near the river is at the same interval and would prevent placement of any horizontal wells in this area. Operational limitations are major, and include: 1). The difficulty of mobilizing a thin zone of residual phase LNAPL between widely spaced horizontal wells; 2). Treatment of PCP in solution of emulsified LNAPL, water, and surfactant; 3). Capturing 100% of the mobilized LNAPL so none of it migrates and discharges to the river; and 4). The technical infeasibility of placing a horizontal well for downgradient capture, as a barrier to migration to the river, because it would be required in the vicinity of the existing sewer interceptor.
	Green	Red	Green	Yellow	Yellow	Red	Red
b. Administrative Feasibility: Ability to obtain approvals from other offices and agencies, the availability of treatment, storage, and disposal services and capacity, and the requirements for, and availability of, specific equipment and technical specialists.	System relies on existing approvals for water treatment and discharge. System upgrade components are readily available.	Access to private property for implementation of closely spaced injection wells is a serious administrative limitation. Obtaining approval from off-site residential property owners to perform chemical injections on their property does not appear to be administratively feasible. Therefore, Alternative 2 does not appear to be administratively feasible. Potential for off-gassing also raises serious administrative feasibility concerns in this residential area.	Implementation of this alternative requires only limited off-site, right-of-way access for additional monitoring points. The specific equipment and technical specialists are limited, but available to Wauleco.	Injection of bioaugmentation fluids requires City permission for use of municipal water for injection and installation of injection wells at locations potentially in City R-O-W. Obtaining approval from the City for injection wells in City R-O-W may be challenging due to space limitations and concerns for chemical injections. If the City does not grant approval to construct these structures in their R-O-W, then this alternative is not considered to be administratively feasible as obtaining approval from off-site residential property owners does not appear to be feasible. The specific equipment and technical specialists are limited, but available to Wauleco.	River barrier chemox would require City permission for access in River Walk Park for installation and operation. Based on previous experience it is expected that the City will have significant concerns placing injection locations near utilities.	Extending extraction and transport systems off-site, along right-of-ways is expected to have limited administrative limitations. Obtaining approval from the City for work in the City R-O-W may be challenging due to space limitations. If the City does not grant approval to construct these structures in their R-O-W, then this alternative is not considered to be administratively feasible as obtaining approval from off-site residential property owners does not appear to be feasible.	Installation of horizontal wells in right-of-ways would require City permission for access. Based on previous experience it is expected that the City will have significant concerns placing horizontal wells and injection locations near utilities. Obtaining approval from the City for horizontal wells in City R-O-W may be challenging due to space limitations and concerns for chemical injections. If the City does not grant approval to construct these structures in their R-O-W, then this alternative is not considered to be administratively feasible as obtaining approval from off-site residential property owners does not appear to be administratively feasible.
	Green	Red	Green	Yellow	Red	Red	Red
3. Cost Evaluation							
Relative cost comparison	Present net worth for 30 years $5 to $10 million.	Present net worth for 30 years greater than $10 million.	Present net worth for 30 years of less than $3 million.	Present net worth for 30 years $3 to $5 million.	Present net worth for 30 years $3 to $5 million.	Present net worth for 30 years greater than $10 million when combined with Alternative 1.	Present net worth for 30 years greater than $10 million.
	Red	Red	Green	Yellow	Yellow	Red	Red

Notes:
(1) Statement from the WDNR Water Quality Bureau regarding river discharge standard: "After consultations with WDNR legal staff and wastewater managers, the Bureau of Water Quality determined that no WPDES permit is required for the diffuse, non-point discharge of groundwater containing residual PCP because the Department "do not suspect that there is potential for exceedances of water quality standards."

- Green = Alternative meets the requirement of this criterion.
- Yellow = Alternative partially meets the requirement of this criterion.
- Red = Alternative does not meet the requirement of this criterion.

Table 4
Summary of Initial Screening of Alternatives
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	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING	SYMBOLIC RATING
1. Effectiveness Evaluation							
Effectiveness in protecting human health and the environment; considering both: a. Short-term effectiveness: Construction and implementation periods. b. Long-term effectiveness: Period after the remedial action is complete	Green	Red	Green	Red	Red	Green	Red
Effectiveness in the reduction of toxicity, mobility, or volume that alternative will achieve	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
2. Implementability Evaluation							
a. Technical Feasibility:	Green	Red	Green	Yellow	Yellow	Red	Red
b. Administrative Feasibility:	Green	Red	Green	Yellow	Red	Red	Red
3. Cost Evaluation							
Relative cost comparison	Red	Red	Green	Yellow	Yellow	Red	Red

Notes:

- Green = Alternative meets the requirement of this criterion.
- Yellow = Alternative partially meets the requirement of this criterion.
- Red = Alternative does not meet the requirement of this criterion.

Attachment A

Lake Wausau Drawdown

Lake Wausau Drawdown

Lake Wausau was drawn down in the fall of 2016 for Domtar dam repair work to be completed in Rothschild. Prior to this time, Lake Wausau has been maintained at a nearly constant stage for 60+ years. Wauleco performed groundwater monitoring in select monitoring wells during this drawdown period to determine if any residual phase LNAPL was converted to mobile LNAPL during the very uniform drawdown in the groundwater elevation expected throughout the zone of residual phase LNAPL. This was expected to be an effective test to determine whether any residual phase LNAPL would be mobilized.

Drawdown was begun on September 24 and reached a maximum drawdown in the lake of approximately 4.8 ft. Refilling the lake began November 15. Groundwater and LNAPL thickness was monitored at several wells and results are included in Table A. Monitoring began on September 8, prior to beginning drawdown and then twice per week between September 24 and December 9, 2016. An additional measurement of this program was made on December 20. Table A also presents a table of head changes compared to the groundwater elevations on July 9, 2016. These values illustrate the change from a pre-drawdown level. The change in head at each well is also shown on a graph imbedded on Table A.

The drawdown of Lake Wausau over nearly an eight week period, resulted in a uniform drawdown in groundwater elevations over an extended period of time. This would be even more effective in mobilizing residual phase LNAPL than an extraction system. Therefore, it was an effective test to determine whether any residual phase LNAPL would be mobilized, to create mobile, recoverable LNAPL.

Based on the monitoring of groundwater elevations and LNAPL thicknesses over this period, the Lake Wausau drawdown has demonstrated that there is insufficient volume of residual phase LNAPL to create mobile, recoverable LNAPL. Therefore, an off-site pump and treatment system to recover LNAPL would not be effective.

TABLE A

Groundwater Measurements During Lake Wausau Drawdown
Wauleco, Inc.
Wausau, Wisconsin

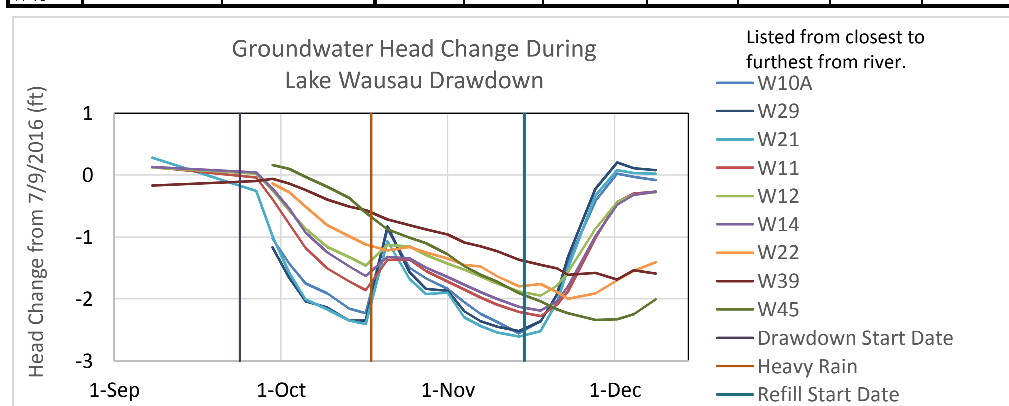
Well	Approximate Elev. Of Residual Phase Product		Groundwater Elevation																								
	Top Elev. (ft)	Bottom Elev. (ft)	7/19/2016	9/8/2016	9/24/2016	9/27/2016	9/30/2016	10/3/2016	10/6/2016	10/10/2016	10/14/2016	10/17/2016	10/21/2016	10/25/2016	10/28/2016	11/1/2016	11/4/2016	11/7/2016	11/10/2016	11/14/2016	11/18/2016	11/21/2016	11/23/2016	11/28/2016	12/2/2016	12/5/2016	12/9/2016
W10A	1161.1	1159.7	**1160.98**	-	Start Lake Wausau Drawdown	-	**1159.95**	***1159.55***	***1159.23***	***1159.07***	***1158.82***	***1158.75***	**1160.11**	***1159.48***	***1159.31***	***1159.14***	***1158.93***	***1158.74***	***1158.61***	***1158.42***	***1158.62***	***1159.04***	***1159.57***	**1160.56**	**1161.00**	**1160.95**	**1160.90**
W11	None present	None present	1160.94	1161.07		1160.9	1160.55	1160.15	1159.76	1159.43	1159.22	1159.08	1159.57	1159.57	1159.39	1159.22	1159.09	1158.96	1158.85	1158.73	1158.66	1158.85	1159.06	1159.93	1160.5	1160.64	1160.67
W12	None present	None present	1160.58	1160.7		1160.6	1160.33	1160	1159.71	1159.42	1159.25	1159.12	1159.45	1159.43	1159.29	1159.15	1159.05	1158.94	1158.83	1158.7	1158.63	1158.79	1159.01	1159.71	1160.14	1160.26	1160.3
W14	None present	None present	1159.62	1159.75		1159.66	1159.4	1159.08	1158.69	1158.37	1158.14	1157.99	1158.3	1158.27	1158.12	1157.97	1157.85	1157.73	1157.62	1157.49	1157.43	1157.58	1157.82	1158.63	1159.14	1159.3	1159.35
W21	None present	None present	1160.78	1161.06		1160.52	1159.79	1159.2	1158.77	1158.61	1158.43	1158.37	1159.71	1159.1	1158.86	1158.88	1158.48	1158.34	1158.24	1158.17	1158.26	1158.73	1159.27	1160.45	1160.86	1160.81	1160.8
W22	1160.5	1159.5	1161.68	-		-	1161.54	1161.4	1161.17	1160.87	1160.69	1160.56	**1160.46**	1160.52	**1160.43**	**1160.33**	**1160.23**	**1160.2**	**1160.05**	**1159.88**	**1159.92**	**1159.79**	**1159.68**	**1159.77**	**1159.98**	**1160.13**	**1160.27**
W29	None present	None present	1160.81	-		-	1159.64	1159.15	1158.77	1158.67	1158.46	1158.46	1159.98	1159.24	1158.97	1158.94	1158.61	1158.45	1158.36	1158.29	1158.45	1158.89	1159.49	1160.59	1161.01	1160.92	1160.89
W39	1160.3	1159.5	1162.76	1162.59		1162.66	1162.7	1162.62	1162.52	1162.36	1162.25	1162.19	1162.04	1161.95	1161.88	1161.8	1161.67	1161.61	1161.53	1161.39	1161.31	1161.25	1161.15	1161.18	1161.07	1161.22	1161.17
W45	1161	1156	1163.35	-		-	1163.51	1163.45	1163.32	1163.16	1162.98	1162.74	1162.47	1162.34	1162.25	1162.07	1161.88	1161.74	1161.63	1161.44	1161.31	1161.18	1161.12	1161.01	1161.02	1161.1	1161.34
W3A	1160.5	1159.2	1161.81							1160.95										**1159.93**							
W17	1160.5	1159.2	1162.05							1161.19										**1160.09**							
W18	None present	None present	1160.98							1159.06										1158.63							
W26	None present	None present	1160.98							1159.22										1158.65							
W40	1160	1159.6	1161.63							1160.72										1159.76[1]							

Lake Wausau Stage Notes: Oct. 4: 4.8 ft. drawdown in Lake Wausau.
Oct. 18: Large amount of rain north of Wausau resulted in 3-4 ft rise in river level.
Nov. 15: Refilling started at 2"/day, increasing to 6"/day by Nov. 19.

Bold = Groundwater elevation below top of residual phase product
Bold Italics = Groundwater elevation below bottom of residual phase product

Footnotes:
(1) Only apparent product thickness detected was at well W40 on 11/14/2016.

Well			Head Changes from July 9, 2016 Groundwater Elevations																								
W10A							-1.03	-1.43	-1.75	-1.91	-2.16	-2.23	-0.87	-1.5	-1.67	-1.84	-2.05	-2.24	-2.37	-2.56	-2.36	-1.94	-1.41	-0.42	0.02	-0.03	-0.08
W11				0.13		-0.04	-0.39	-0.79	-1.18	-1.51	-1.72	-1.86	-1.37	-1.37	-1.55	-1.72	-1.85	-1.98	-2.09	-2.21	-2.28	-2.09	-1.88	-1.01	-0.44	-0.3	-0.27
W12				0.12		0.02	-0.25	-0.58	-0.87	-1.16	-1.33	-1.46	-1.13	-1.15	-1.29	-1.43	-1.53	-1.64	-1.75	-1.88	-1.95	-1.79	-1.57	-0.87	-0.44	-0.32	-0.28
W14				0.13		0.04	-0.22	-0.54	-0.93	-1.25	-1.48	-1.63	-1.32	-1.35	-1.5	-1.65	-1.77	-1.89	-2	-2.13	-2.19	-2.04	-1.8	-0.99	-0.48	-0.32	-0.27
W21				0.28		-0.26	-0.99	-1.58	-2.01	-2.17	-2.35	-2.41	-1.07	-1.68	-1.92	-1.9	-2.3	-2.44	-2.54	-2.61	-2.52	-2.05	-1.51	-0.33	0.08	0.03	0.02
W22							-0.14	-0.28	-0.51	-0.81	-0.99	-1.12	-1.22	-1.16	-1.25	-1.35	-1.45	-1.48	-1.63	-1.8	-1.76	-1.89	-2	-1.91	-1.7	-1.55	-1.41
W29							-1.17	-1.66	-2.04	-2.14	-2.35	-2.35	-0.83	-1.57	-1.84	-1.87	-2.2	-2.36	-2.45	-2.52	-2.36	-1.92	-1.32	-0.22	0.2	0.11	0.08
W39				-0.17		-0.1	-0.06	-0.14	-0.24	-0.4	-0.51	-0.57	-0.72	-0.81	-0.88	-0.96	-1.09	-1.15	-1.23	-1.37	-1.45	-1.51	-1.61	-1.58	-1.69	-1.54	-1.59
W45							0.16	0.1	-0.03	-0.19	-0.37	-0.61	-0.88	-1.01	-1.1	-1.28	-1.47	-1.61	-1.72	-1.91	-2.04	-2.17	-2.23	-2.34	-2.33	-2.25	-2.01
W3A										-0.86										-1.88							
W17										-0.86										-1.96							
W18										-1.92										-2.35							
W26										-1.76										-2.33							
W40										-0.91										-1.87							



Prepared by: K. Quinn 3/24/2017
Checked by: T. Dushek 3/29/2017

Attachment B

Proposed LNAPL Remedial Strategy

Proposed LNAPL Remedial Strategy
Wauleco Project Site
125 Rosecrans Street, Wausau, Wisconsin
June 13, 2017

This document presents the proposed light, nonaqueous-phase liquid (LNAPL) remedial strategy for the Wauleco Project Site. Mobile phase LNAPL has been addressed to the extent practicable at the Wauleco site. There is no further expectation that active product recovery efforts continue. Rather, Wauleco and WDNR's focus has moved to the dissolved-phase component. Consequently, this document focuses on residual phase LNAPL as a source to the groundwater dissolved-phase constituents of concern (i.e., PCP). This document is based on the approach presented in the Interstate Technology Regulatory Council (ITRC) Technical/Regulatory Guidance document titled "Evaluating LNAPL Remedial Technologies for Achieving Project Goals" dated December 2009 (LNAPL Guidance) and presents a proposed remedial strategy consistent with that approach.

The purpose of the LNAPL Guidance "is to provide a framework that uses LNAPL conceptual site model (LCSM) information to identify appropriate LNAPL remedial objectives and systematically screen LNAPL remedial technologies to identify technology(ies) best suited to achieve those objectives." The LNAPL Guidance recommends four fundamental steps in developing an appropriate LNAPL remedial strategy to move LNAPL sites toward an end point. These steps are as follows:

1. Adequately characterize the site according to the complexity of the problem, including the development, use, and refinement of an LCSM.
2. Establish appropriate and achievable LNAPL remedial objectives for the site.
3. Develop an LNAPL remedial strategy designed to achieve the LNAPL remedial objectives.
4. Establish an acceptable outcome if the LNAPL remedial objectives are met (i.e., closure, NFA, release of liability, long-term monitoring, etc.).

Prior to addressing these four steps, this document summarizes background information specific to the Wauleco project site to provide necessary foundation for the development of an appropriate site-specific LNAPL remedial strategy.

Wauleco Background Information

As presented and/or discussed with the WDNR previously, relevant background information associated with the Wauleco Site includes the following:

1. There are not now, nor will there in the future, any completed exposure pathways to receptors. See, Sec. 1.6, Groundwater Remedial Action Options Report dated September 2015 (RAOR).
    a. **Direct Contact with Contaminated Soils on the Wauleco Property –** Residual soil contamination above the industrial direct contract residual contaminant level

(RCL) can be addressed by a soil performance standard per NR 720 for the direct contact pathway by capping the contaminated soil with an appropriate barrier to limit exposure. The barrier will consist of: 1) an engineering control in the form of a cover, the final configuration of which is yet to be determined (in part because future redevelopment of the Site is not yet known), will be placed, at a minimum, over the former soil mound/former dip tank area. In the interim, a cover consisting of a geotextile fabric and 6-inches of gravel has been placed over the area of the former soil mound; and 2) the existing chip-seal paving will serve as a barrier for the remainder of the Site.

b. **Use of Contaminated Groundwater on or Downgradient of the Wauleco Property –** Based on the results of a well survey with the Department of Agriculture Trade and Consumer Protection, there are no known private or public wells within the extent of PCP in groundwater. In addition, the City of Wausau Municipal Code, Chapter 19.30 regulates the construction and use of private wells. This code would not allow a new well to be installed within the limits of the groundwater plume. Furthermore, there are no public wells located south of Bridge St., which is several thousand feet north of Wauleco. There are no groundwater users between the Wauleco property and the downgradient natural discharge to the Wisconsin River. In addition, the depth to groundwater is greater than 20 ft. below the buildings downgradient of the Site. None of these buildings are large enough to expect to have a foundation or other structure that extends to groundwater. Therefore, exposure to groundwater is an incomplete pathway.

c. **Vapor Intrusion –** An assessment of potential vapor intrusion risks was conducted by TRC (June 4, 2012 letter to WDNR) that concluded there are no potentially complete vapor intrusion pathways associated with the Wauleco Site.

d. **Preferential Migration in Utility Corridors –** A May 31, 1990 Keystone Hydrogeologic Investigation Report included an assessment of utility corridors on and around the Site, including borings installed around sewers. They concluded the utility corridors were not preferential migration pathways.

e. **Sanitary Sewer Interceptor –** A City of Wausau sanitary sewer interceptor was identified as receiving PCP inflow from the groundwater. The sewer interceptor was videoed, showing very small inflows at some joints. These joints were sealed and subsequent sampling showed the sanitary sewer to not contain PCP. Therefore, this potential exposure pathway has been addressed.

f. **Groundwater Discharge to Surface Water -** Groundwater flow from the Site occurs to the east and under non-pumping conditions, discharges naturally to the Wisconsin River. Considering the concentrations and likely discharge point to be a "diffuse/non-point source" discharge, WDNR concluded that there is no potential for exceedance of surface water quality standards at the point of discharge.

With the foregoing background in mind and the focus on residual phase LNAPL as a source of PCP to groundwater, we address below the four-step process the LNAPL Guidance recommends in developing an appropriate LNAPL remedial strategy:

Step 1: Adequately Characterize the Site According to the Complexity of the Problem, Including the Development, Use, and Refinement of an LCSM

Based on the extensive investigation and remedial activities performed at the Wauleco Project Site over the past nearly three decades (e.g., more than 400 soil samples collected, more than 60 groundwater monitoring wells installed, more than 30 extraction wells installed and operated, various LIF surveys performed, etc.), a thorough LCSM has been developed. A Wauleco LCSM cross section is included as Figure 1. Additional information on the hydrogeological and LCSM for the Wauleco project site is included in Attachment 1.

As discussed in Section 4.1 of the LNAPL Guidance, ASTM identifies three tiers of data collection and analysis to develop LCSMs based on site complexity: Tier 1 – Relatively standard field and lab data, Tier 2 – Detailed vertical profiling and possible LNAPL recoverability pilot testing, and Tier 3 – Extensive data and numerical modeling. The LCSM is deemed adequate (in terms of level of detail) when the collection of additional information regarding the site/LNAPL will not enhance decision making associated with the LNAPL remedial objectives. Data collection at the Wauleco Project Site approximates Tier 2, utilizing a large number of groundwater monitoring wells and LIF points, both on and off site, and a long history of groundwater and LNAPL extraction.

As discussed in Section 4.2 of the LNAPL Guidance, LNAPL remedial objectives, remediation goals, and performance metrics are based on LNAPL concerns identified. As discussed above, because the WDNR concurs that mobile phase LNAPL has been addressed to the maximum extent practicable, and current and future receptors have been addressed, concerns are associated with the dissolved-phase component.

Site and LNAPL Conditions:

Based on the LCSM and geologic/hydrogeologic conditions described above and in Attachment 1, the Site and LNAPL conditions at the Wauleco Project Site are summarized as follows:

- Unsaturated Zone: Sand, and sand and gravel glacial outwash (C)
- Saturated Zone: Sand, and sand and gravel glacial outwash (C)
- Groundwater is Unconfined: the glacial outwash units extend from ground surface to well below the water table in most areas.
- Underlying the sand and gravel outwash is a clay deposit overlying bedrock, that limits the vertical extent of dissolved-phase constituents to the approximately 10 ft. thick saturated glacial outwash sand and gravel.

- Depth to groundwater is approximately 30 ft. bgs (well W8) west (i.e., upgradient) of the Wauleco Project Site, 25 to 28 ft. bgs on-Site, and 19 ft. bgs (well W10A) east (i.e., downgradient) of the Wauleco Project Site near the Wisconsin River. In the park north of W10A, depth to groundwater is about 10 ft. bgs.
- Natural groundwater flow is towards, and discharges to, the Wisconsin River/Lake Wausau located approximately 500 ft. to 900 ft. east of the Site.
- LNAPL is predominantly mineral spirits, with 10% inerts, and 5% PCP. Therefore, the bulk LNAPL is light (HV, HS), but contains a semi-volatile, PCP.
- PCP is the principal constituent of concern.

  Notes:
  C= Coarse soils; sand to gravel
  S= Saturated zone
  HV, HS = High volatility, high solubility, light LNAPL with significant percentage of volatile soluble constituents
  LV, LS = Low volatility, low solubility, medium or heavy LNAPL

LNAPL Concern:

For the Wauleco Project Site, the LNAPL concern is: Residual LNAPL is a source to the dissolved-phase groundwater which discharges to surface water.

Step 2: Establish Appropriate and Achievable LNAPL Remedial Objectives for the Site

As discussed in Section 4.2.1 of the LNAPL Guidance, once concerns are identified, LNAPL remedial objectives are set to address the LNAPL concerns at the site, to the extent appropriate and achievable.

LNAPL Remedial Objective:

For the Wauleco Project Site, the LNAPL remedial objective is (per LNAPL remedial objectives presented in Table 6-1 of the LNAPL Guidance): Reduce PCP concentrations in dissolved-phase from the residual phase LNAPL source to a concentration that meets surface water quality standards.

As discussed in Section 4.2.2 of the LNAPL Guidance, the LNAPL remedial objective is stated as an LNAPL remediation goal to specify the condition or end point to be achieved by the technology group to satisfy the LNAPL remedial objective.

LNAPL Remediation Goals:

For the Wauleco Project Site, the LNAPL remediation goal is (per Table 6-1 of the LNAPL Guidance that lists example LNAPL remediation goals for example LNAPL remedial objectives): Achieve dissolved-phase PCP concentration in groundwater to meet surface water quality standards.

As discussed in Section 4.2.3 of the LNAPL Guidance, for each LNAPL remediation goal, one or more performance metrics are defined. Performance metrics are measureable characteristics that relate to the remedial progress of a technology in abating the concern.

Performance Metric:

For the Wauleco Project Site, the performance metric is (per performance metric examples presented in Table 4-1 of the LNAPL Guidance): PCP dissolved-phase plume is stable. End Point: PCP dissolved-phase concentrations meet surface water quality standards.

Step 3: Develop an LNAPL Remedial Strategy Designed to Achieve the LNAPL Remedial Objectives

Many LNAPL remedial technologies exist, each with unique applicability and capability. Ideally, the degree of LNAPL remediation is commensurate with that warranted to satisfy applicable risk or non-risk-based federal and state regulations and overall project objectives. The selected LNAPL remedial technology should align with the particular LNAPL remedial objective and LNAPL remediation goal. Section 5 of the LNAPL Guidance explains the technology selection process; which consists of a two-step screening process.

Table 6-1 Screening Step 1:

As discussed in Sections 5 and 6.1.2 of the LNAPL Guidance, once the applicable remedial objective and remediation goals have been identified (Step 2), the first step of Step 3 is to screen the 17 technologies listed in the LNAPL Guidance based on their conceptual potential to achieve the remedial objectives, given the site and LNAPL conditions (Step 1). The LNAPL Guidance (refer to Section 6.1.2 of the LNAPL Guidance) provides that this screening should be accomplished by identifying the technologies listed in Table 6-1 for that remedial objective, and LNAPL remediation goal, matching the footnoted conditions. These pass the Screening Step 1. For the Wauleco Project Site, the Screening Step 1 is summarized as follows:

Step 1 Screening Table

LNAPL REMEDIAL OBJECTIVE	LNAPL REMEDIATION GOAL	TECHNOLOGY GROUP	EXAMPLE PERFORMANCE METRICS	LNAPL TECHNOLOGY AND LNAPL SITE CONDITIONS
Reduce PCP constituent concentrations in dissolved-phase from the residual LNAPL source to a concentration that meets surface water quality standards.	Achieve dissolved-phase PCP concentration in groundwater to meet surface water quality standards.	LNAPL Phase Change	PCP dissolved-phase concentrations meet surface water quality standards.	Natural Source Zone Depletion [F, C, U, S, HV, HS]

Notes:
F = Fine-grained soils; clay to silt
C= Coarse soils; sand to gravel
U= Unsaturated zone
S= Saturated zone
HV, HS = High volatility, high solubility, light LNAPL with significant percentage of volatile soluble constituents

Because only one LNAPL technology passed the Screening Step 1 process, while not required by the LNAPL Guidance, the following table summarizes why the other 16 technologies listed in the LNAPL Guidance are not applicable to achieve the remedial objectives based on the site conditions at the Wauleco Project Site.

Screening of 17 LNAPL Guidance Remedial Technologies

NO.	LNAPL TECHNOLOGY	COMMENT
1	Excavation	Not applicable as excavation depths would be too deep. Residual LNAPL is present in the smear zone, the depth to which is in the range of 20 to 30 ft bgs. In addition, various structures (e.g., utilities, private residences, roads, etc.) are also present.
2	Physical or hydraulic containment	Physical containment not viable due to the area encompassed by the residual LNAPL and the practical impossibility of placement of a physical barrier around the residual LNAPL through a residential neighborhood. Hydraulic containment of the residual phase LNAPL on Site is currently active.
3	In situ soil mixing (stabilization)	Not viable due to the area encompassed by the residual LNAPL.
4	NSZD	Carried forward, refer to Step 1 Screening Table above.
5	Air sparging/soil vapor extraction	PCP is not sufficiently volatile to be removed via air sparging/soil vapor extraction. Viable for removal of mineral spirits, which is not a COC.
6	LNAPL skimming	As stated by the WDNR on November 29, 2016, mobile phase LNAPL has been addressed to the extent practicable. As demonstrated during the Lake Wausau drawdown during the fall of 2016, residual LNAPL cannot be converted to mobile phase LNAPL in off-Site monitoring wells which would allow for recovery of mobile LNAPL. The Lake Wausau drawdown was a very effective means for demonstrating the potential to mobilize residual phase LNAPL. This demonstrates that this widespread drawdown did not mobilize residual phase LNAPL, so localized extraction well drawdown would certainly not mobilize the residual phase LNAPL.
7	Bio-slurping/ enhanced fluid recovery (EFR)	This technique relies on volatilization, vapor extraction, and aerobic degradation of petroleum constituents. Not viable for PCP because it is not sufficiently volatile and is not degraded in an aerobic environment. In addition, enhancing volatilization of mineral spirits beneath a residential area would cause concerns for vapor intrusion.
8	Dual-pump liquid extraction (DPLE)	As stated by the WDNR on November 29, 2016, mobile phase LNAPL has been addressed to the extent practicable. As demonstrated during the Lake Wausau drawdown during the fall of 2016, residual LNAPL was not converted to mobile phase LNAPL in off-Site monitoring wells where the mobile LNAPL could then be recovered by this technology.
9	Multiphase extraction (MPE/dual pump)	As stated by the WDNR on November 29, 2016, mobile phase LNAPL has been addressed to the extent practicable. As demonstrated during the Lake Wausau drawdown during the fall of 2016, residual LNAPL was not converted to mobile phase LNAPL in off-Site monitoring wells where the mobile LNAPL could then be recovered by this technology.
10	Multiphase extraction (MPE/single pump)	As stated by the WDNR on November 29, 2016, mobile phase LNAPL has been addressed to the extent practicable. As demonstrated during the Lake Wausau drawdown during the fall of 2016, residual LNAPL was not converted to mobile phase LNAPL in off-Site monitoring wells where the mobile LNAPL could then be recovered by this technology.

Screening of 17 LNAPL Guidance Remedial Technologies

NO.	LNAPL TECHNOLOGY	COMMENT
11	Water flooding	Not applicable to residual LNAPL as it is immobile. Note, this technology was used at the Wauleco Project Site in an attempt to flush LNAPL from unsaturated zone soils at the former dip tank location. In addition, an advanced Pressure Pulse Technology (PPT) was pilot tested at the Wauleco Project Site (RMT, 2006. Pressure Pulse Pilot Test), but was not successful in mobilizing LNAPL.
12	In situ chemical oxidation (ISCO)	This remedial technology evaluation as Alternative 2 in the RAOR (see RAOR for more detail) demonstrated concerns for: 1. Mobilization of LNAPL, with potential for migration to the River; 2. Limitations of access to private property for implementation; 3. The large volume and cost of oxidant required to treat the residual phase LNAPL; and 4. Potential vapor intrusion concerns with chemical oxidation in a residential area...
13	Surfactant-enhanced subsurface remediation (SESR)	Requires closely spaced injection points and extraction points (i.e., 50 ft. or less), so it is impractical for off-Site implementation. Use of horizontal wells may reduce disruptions at the surface, but they still require access agreements from the City or private property owners prior to installing horizontal well(s). The installation of horizontal wells has the potential to damage existing utilities because the precise location of utilities is not known. In addition, even if a horizontal well is not located under a private property, an access agreement is needed for surfactant that will move onto a private property. Surfactant enhanced mobilization of the residual phase LNAPL is not recommended because of the potential to mobilize residual phase LNAPL and discharge to surface water. In addition, given the volume of residual phase LNAPL and the difficulty in treating the surfactant/mineral spirits/PCP/water emulsion, it is not technically practicable to achieve PCP discharge standards.
14	Co-solvent flushing	Requires closely spaced injection points and extraction points (i.e., much less than 30 ft.), so it is impractical for off-Site implementation. Co-solvent flushing would require large quantities of solvent to flush the residual phase LNAPL and would increase the potential to mobilize residual phase LNAPL, with increased potential to discharge to surface water.
15	Steam/hot-air injection	Requires closely spaced injection points and closely spaced vapor extraction/control points (i.e., much less than 20 ft.), so it is impractical for off-Site implementation. In addition, based on the volume of groundwater flowing through the Site in the sand and gravel aquifer, energy costs would be very high, therefore, not considered a sustainable/green remediation.
16	Radio-frequency heating (RFH)	Requires closely spaced heating probes and closely spaced vapor extraction/control points (i.e., much less than 20 ft.), so it is impractical for off-Site implementation. In addition, based on the volume of groundwater flowing through the Site in the sand and gravel aquifer, energy costs would be very high, therefore, not considered a sustainable/green remediation.
17	Three and six-phase electoral resistance heating	Same as 16.

In addition to the 17 remedial technologies listed in the LNAPL Guidance, six additional remedial technologies are reportedly being considered for updates to the LNAPL Guidance. The following table summarizes why these six additional technologies are not applicable to achieve the remedial objectives based on the Site conditions at the Wauleco Project Site.

NO.	LNAPL TECHNOLOGY	COMMENT
18	In-situ smoldering	This is low temperature thermal treatment of LNAPL (typically <500 deg C for diesel). This low temperature incineration of PCP, with limited oxygen, has high risk of generating dioxins. Smoldering LNAPL beneath residential development is unlikely to be accepted by off-Site property owners. Therefore, not considered applicable.
19	Fluid recovery (LNAPL Skimming, Total Fluids, Dual Pump, Multiphase Extraction)	As stated by the WDNR on November 29, 2016, mobile phase LNAPL has been addressed to the extent practicable. As demonstrated during the Lake Wausau drawdown during the fall of 2016, residual LNAPL appeared as mobile LNAPL in monitoring wells in limited number of wells, demonstrating that there is insufficient LNAPL present to be removed by this technology.
20	Biosparging/ bioventing	Not viable for PCP as based on TRC's experience in operating the water treatment plant, PCP degrades in a small zone between anaerobic and aerobic conditions.
21	Activated carbon	Not applicable as the activated carbon is placed into excavations. As discussed above, excavations are not applicable as depths are too great.
22	Encapsulated enzymes	Use of fungal enzymes to treat crude oil. Not sufficiently well developed for application, particularly in a residential setting.
23	Thermal enhancement of biodegradation	Similar to thermal methods discussed above, this requires closely spaced heating points and vapor extraction/control points (i.e., much less than 20 ft.), so it is impractical for off-Site implementation. In addition, based on the volume of groundwater flowing through the Site in the sand and gravel aquifer, energy costs would be very high, therefore, not considered a sustainable/green remediation.

In addition to the technical applicability limitations of the technologies discussed in the two tables above, there are economic considerations that would result in many of these technologies being considered not economically viable.

Note, NSZD is consistent with the information presented in Section 4.4 of the LNAPL Guidance for remedy selection in Wisconsin which states: "If there are no receptors, the overall risk is low, and future conditions are unlikely to change, then exhaustive testing of unproven technologies may not be warranted, and the focus is shifted to other remedies, such as excavation (if practicable) or passive management alternatives (limited groundwater monitoring) if the dissolved-phase plume associated with LNAPL is not expanding or threatening potential receptors."

In addition, NSZD is consistent with information presented in WDNR's 2014 guidance (WDNR, 2014. ASSESSMENT GUIDANCE FOR SITES WITH RESIDUAL WEATHERED PRODUCT) that states: "If data from the LNAPL assessment parameters already suggest a significant proportion of the in-place, LNAPL cannot be recovered via active remediation and nearby receptors are not an issue, then no further recovery feasibility testing is warranted."

Technology Screening Step 2:

The Technology Screening Step is not applicable here because only one technology was identified as applicable and achievable during the Step 1 Screening Process; as such, no further technology screening as discussed in Sections 5, 6.2, 7 (LNAPL Technology Evaluation for the Short List) and 8 (Minimum Data Requirements and Critical Considerations for Technology Evaluation) of the LNAPL Guidance is warranted.

Summary:

In summary, based on the remedial technology screening and selection process described in the LNAPL Guidance, NSZD emerged as the LNAPL strategy designed to achieve the remedial objectives for the Wauleco Project Site.

NSZD is consistent with the following:

- Information presented in Section 4.4 of the LNAPL Guidance for remedy selection in Wisconsin.
- WDNR 2014 Guidance on Assessment Guidance for Sites with Residual Weathered Product.

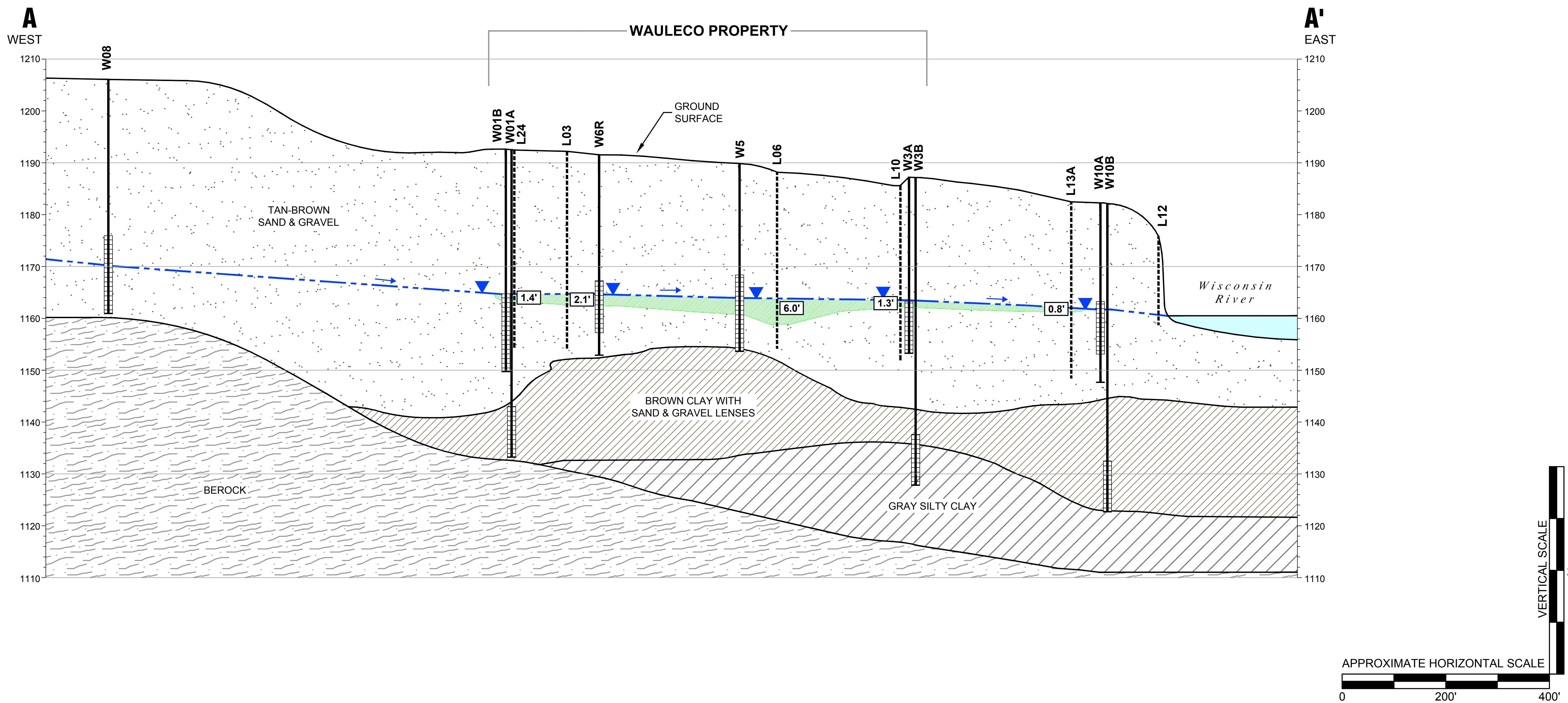
Step 4: Establish an Acceptable Outcome if the LNAPL Remedial Objectives are Met (i.e., closure, NFA, release of liability, long-term monitoring, etc.)

If the remedial objective is met through implementation of NSZD, consult with the Department regarding acceptable outcomes.

List of Attachments:

- Attachment 1 – Hydrogeological and LNAPL Conceptual Site Model Information for Wauleco Project Site
- Figure 1 – LCSM Cross Section
- Figure 2 – Areal Extent of Residual Phase LNAPL

GENERALIZED GEOLOGIC CROSS-SECTION A-A'



LEGEND

SAND & GRAVEL

BROWN CLAY

GREY CLAY

W5

WELL / BORING

WELL SCREEN

END OF BORING

L24

LASER-INDUCED FLUORESCENCE (LIF) PROBE LOCATION AND NUMBER

WATER TABLE ELEVATION (JUNE 13, 2013)

WATER TABLE FLOW DIRECTION

WATER TABLE

0.8'

ZONE OF RESIDUAL PHASE PRODUCT

RESIDUAL PHASE PRODUCT THICKNESS

NOTES

1. LIF SURVEY PERFORMED JUNE 11 THROUGH JUNE 13, 2013.
2. GENERALIZED GEOLOGIC CROSS-SECTION BASED ON 1985 EDER ASSOCIATES CROSS-SECTION.

PROJECT:
WAULECO, INC.
2013 LIF SURVEY
WAUSAU, WISCONSIN

TITLE:
LNAPL CONCEPTUAL SITE MODEL

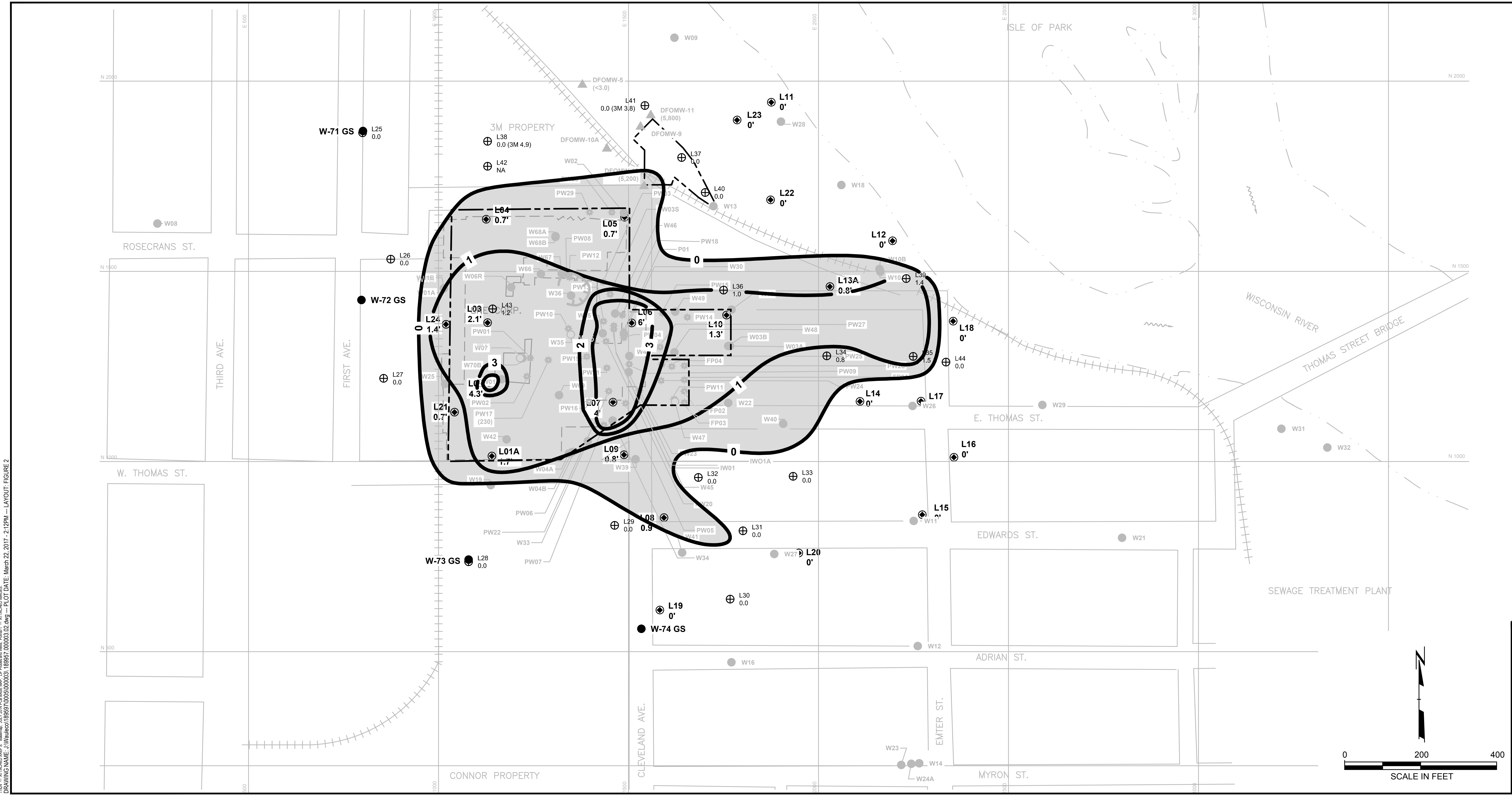
DRAWN BY:	L. STORMER	PROJ NO.:	189597.0005.000003
CHECKED BY:	K. QUINN		**FIGURE 1**
APPROVED BY:	B. IVERSON		
DATE:	MARCH 2017		

TRC

708 Heartland Trail
Suite 3000
Madison, WI 53717
Phone: 608.826.3600

FILE NO.: 189957.000003.01.dwg

DRAWING NAME: J:\Wauleco\189597\0005\000003\ 189957.000003.01.dwg --- PLOT DATE: March 22, 2017 - 11:55AM --- LAYOUT: FIGURE 1
Version: 2017-03-03



LEGEND

- W17 — MONITORING WELL LOCATION AND NUMBER
- PW12 — EXTRACTION WELL LOCATION AND NUMBER
- DFOMW-5 — 3M GROUNDWATER MONITORING WELL
- APPROXIMATE PROPERTY LINE
- FORMER BUILDING OUTLINE
- 50 — PCP ISOCONCENTRATION CONTOUR INTERVAL VARIES (DASHED WHERE INFERRED)
- L22 0' — 2013 LIF LOCATION - THICKNESS OF LIF RESPONSE
- L24 1.4' — 2015 LIF PROBE LOCATION - THICKNESS OF LIF RESPONSE
- 0 — ESTIMATED THICKNESS OF RESIDUAL PHASE PRODUCT (DASHED WHERE INFERRED)

NOTES

1. BASE MAP DEVELOPED FROM DRAWING A107250-1 OF THE SEPTEMBER 1992 SEMI-ANNUAL GROUNDWATER MONITORING REPORT BY KEYSTONE ENVIRONMENTAL, MWH DRAWING 2082658.302160101-B1, AND 3M WELLS LOCATION BASED ON 3M MAPS.
2. LASER INDUCED FLUORESCENCE (LIF) SURVEY COMPLETED JUNE 2-13, 2015 AND JUNE 11-13, 2013 BY TRC AND COLUMBIA TECHNOLOGIES, INC.
3. LIF RESULTS FROM 2003 AND 2005 WERE ALSO USED TO ESTIMATE THE THICKNESS OF RESIDUAL PHASE PRODUCT.

PROJECT:
WAULECO, INC.
2013 LIF SURVEY
WAUSAU, WISCONSIN

TITLE:
AREAL EXTENT OF RESIDUAL PHASE LNAPL

DRAWN BY:	L. STORMER	PROJ NO.:	189597.0005.000003
CHECKED BY:	K. QUINN		
APPROVED BY:	B. IVERSON		**FIGURE 2**
DATE:	MARCH 2017		

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FILE NO.: 189957.000003.02.dwg

Attachment 1
Hydrogeologic and LNAPL Conceptual Site Model Information for Wauleco Project Site

Hydrogeologic and LNAPL Conceptual Site Model:

The geologic/hydrogeologic conditions and LNAPL occurrence and behavior at the Wauleco Project Site are summarized as follows:

Hydrogeology

- Unsaturated Zone: Sand, and sand and gravel glacial outwash.
- Saturated Zone: Sand, and sand and gravel glacial outwash.
- Groundwater is Unconfined: the glacial outwash units extend from ground surface to well below the water table in most areas.
- Underlying the sand and gravel outwash is a clay deposit overlying bedrock, that limits the vertical extent of dissolved-phase constituents to the approximately 10 ft. thick saturated glacial outwash sand and gravel.
- Depth to groundwater is approximately 30 ft. bgs (well W8) west (i.e., upgradient) of the Wauleco Project Site, 25 to 28 ft. bgs on-Site, and 19 ft. bgs (well W10A) east (i.e., downgradient) of the Wauleco Project Site near the Wisconsin River. In the park north of W10A, depth to groundwater is about 10 ft. bgs.
- Natural groundwater flow is toward and discharges to the Wisconsin River/Lake Wausau located approximately 500 ft. to 900 ft. east of the Site.

LNAPL Properties

- LNAPL is predominantly mineral spirits, with 10% inerts, and 5% PCP. Therefore, the bulk LNAPL is light, but contains a semi-volatile, PCP.
- PCP is the principal constituent of concern based on its NR-140 ES (1 ug/L), and solubility in groundwater (14,000 ug/L 2016 EPA[1]).
- PCP concentration in LNAPL appears to have declined from 3.2% in 1986 (Keystone, 1986 Site Characterization Report, Sept. 1986) to <0.1% in September 2010 (based on waste LNAPL testing).
- Mineral spirits constituents are minor, secondary constituents of concern compared to PCP based on their higher NR-140 ES (i.e., Naphthalene – 100 ug/L, trimethylbenzenes, total – 480 ug/L, xylenes, total – 2,000 ug/L)
- Physical/hydraulic testing of soil and LNAPL in 1992 Keystone[2] indicate the following properties
  - Porosity – 26% to 31%

[1] 2016 EPA. Vapor Intrusion Screening Level Spreadsheet, chemical properties tab, from: https://www.epa.gov/vaporintrusion/vapor-intrusion-database

[2] 1992 Keystone. Addendum Report to Evaluation of Treatment System Alternatives for Product Removal.

- Minimum residual saturation in gas (Sog) 10% of porosity
- Minimum residual saturation in water (Sor) 14% to 17% of porosity
- Irreducible water saturation (Sm) 12% to 23% of porosity

LNAPL Distribution

- Mobile Phase LNAPL
  - The extent of mobile phase LNAPL has been reduced from an area of 302,000 ft^2 in 1997 to 4,000 ft^2 in 2013. This constitutes a 98.6% reduction in mobile phase LNAPL due to the enhanced LNAPL recovery system implemented between 1999 and 2011.
- Residual Phase LNAPL
  - The areal extent of Residual Phase LNAPL was determined via LIF (UVOST) and is presented in Figure 2.
  - Vertical distribution of residual phase LNAPL characterized by LIF, shows:
    - On-Site LIF responses:
      - A thickness of up to 6.0 ft on-Site in the vicinity of groundwater extraction wells.
      - A thickness of up to 2.1 ft. on-Site outside of the immediate influence of groundwater extraction wells.
      - On-Site mobile phase up to 40% of the reference emitter (%RE) in apparent saturated LNAPL at the water table, when saturated LNAPL existed in the 2003 LIF survey.
      - On-Site residual phase up to approximately 42% RE.
    - Off-Site LIF responses:
      - Thickness less than 1 ft.
      - Off-Site residual phase response up to 18% RE, but typically much less.

LNAPL Recovery Behavior

- Mobile phase LNAPL extraction clearly controlled by groundwater elevation, based on LNAPL recovery and groundwater elevation graphs.
- Enhanced LNAPL recovery, between January 1999 and March 2011, was effective in extracting the bulk of the 147,000 gallons of LNAPL recovered to date. Basic recovery method was LNAPL skimming with groundwater depression. Enhancements included:
  - Methods to maintain high LNAPL transmissivity:
    - Maintaining about 1 ft. of LNAPL in extraction wells, to maintain sufficient LNAPL thickness, under normal groundwater fluctuations;

        - Operating groundwater depression 100% of the time when LNAPL recovery was high, to maintain high LNAPL permeability, eliminating influx of water with even short term, small water level rises;
        - Redeveloping wells to remove fouling in LNAPL zone and to maintain groundwater production with limited well losses.
    - Focused pumping in zone of greatest LNAPL persistence, in the southeast of the Site (wells FP1 through FP4).
- Viability of off-Site LNAPL Recoverability via Large Area Drawdown Assessment
    - Lake Wausau Drawdown Study – Lake Wausau was drawn down for dam inspection/maintenance for the first time in more than 60 years, beginning on September 24, 2016 through November 15, 2016. Groundwater elevation and LNAPL thickness monitoring during this period showed:
        - 2.56 ft. (W10A) of drawdown in areas of residual phase LNAPL (more than could be achieved through remedial action pumping technologies)
        - Only one off-Site well (W40) showed a thin, 0.2 ft. accumulation of apparent mobile phase LNAPL, whereas several other wells showed no accumulation.
        - Only thin accumulations of LNAPL were observed at 5 on-Site wells (0.02 to 0.13 ft)
    - This assessment illustrates that the current residual phase LNAPL on and off the Wauleco Site has insufficient saturation to create mobile, recoverable LNAPL using existing remedial pumping/recovery technologies.

NA Assessment

- Degradation of PCP is clearly effective in the above ground bioreactor, with a low DO environment, and is optimized through the introduction of nitrogen, phosphorous, and bacteria.
- Degradation in the above ground reactor is not via reductive dechlorination and exhibits no separate PCP degradation products except for inorganic chloride.
- Concentration-Distance graphs for a flow path outside the capture zone shows a concentration decline within a zone that is within the groundwater travel distance, indicating that there is natural attenuation occurring at a rate faster than possible with adsorption or dispersion, leaving only biodegradation as the only mechanism for natural attenuation.
- Several literature examples illustrate natural attenuation of PCP does occur. One such example (Bosso, 2014[3]) summarizes more than 30 studies that describe and document biodegradation of PCP. These studies show that there are numerous bacteria that degrade PCP, many demonstrating mineralization of PCP with chloride being the only measured decay product.
- Concentration-Time graphs for several well locations, outside of the capture zone, show distinct concentration declines in shorter distances than groundwater would flow in even 10 years, indicating biodegradation must be active as well.

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[3] Boss, L. and Gennaro Cristinzio. 2014. A comprehensive overview of bacteria and fungi used for pentachlorophenol biodegradation. Rev. Environ Sci Biotechnol 13L387-427.